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Sedimentology, Biostratigraphy and Mineralogy of the Lercara Formation (Triassic, Sicily) and its palaeogeographic implications

THESE

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pour obtenir le grade de Docteur ès sciences, mention Sciences de la Terre

par

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de
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ai miei genitori, Lina e Pippo, con affetto.

ABSTRACT

This thesis contributes to the resolution of one of the most controversial open questions about Sicilian geology: the age of the Lercara Formation. During the last century, it was variously attributed to the Permian, the Triassic, the Paleogene or the Miocene. A part from the question of the age, this work analyses the palaeoenvironmental context associated to the Lercara Formation deposition and the palaeogeographical evolution of the occidental part of the Tethys during the Permian and the Triassic. The study integrates sedimentological, biostratigraphic and mineralogical analyses, and proposes the reconstitution of the Sicanian basin subsidence history.

The Lercara Formation deposited at the bottom of the Sicanian basin and constitutes the oldest formation cropping out in the Siculo-Maghrebien belts chain. It outcrops in western Sicily in the Roccapalumba-Lercara and Margana-Valle Riena areas, near Palazzo Adriano where it is better known as “Fiume Sosio deposits”, and in Portella Rossa near the village of Burgio. For this study, every known outcrop has been sampled, along with a new outcrop located in Portella Rossa. This field did not permit the recognition of any stratigraphic contact with the underlying formation or the basement, nor with the overlying Mufara Formation.

The Lercara Formation's main characteristic is its high content of reworked material (ca. 95%), proved by all investigation methods, particularly biostratigraphy. This material comes from the dismantlement of Permian and Triassic (Anisian) carbonate platforms and of Lower Triassic siliciclastic platforms. It is associated to ca. 5% of upper Ladinian – Cordevolian autochthonous material. This reworking explains why the age of the Lercara Formation remained unresolved for so long.

The sedimentological study showed the presence of two members in the Lercara Formation: the Member A, constituted of clayey sandstones and the Member B, constituted of quartz-rich clays (B1). The Member B contains intercalated levels of either calcirudites/calcarenites (B2) or clayey sandstones (B3). Analysis of the microfacies and their spatial distribution revealed two distinct detritic sources. The main one was localised to the north-west of the Sicanian basin, while the second one was located to the south-west or the north-east.

The best biostratigraphic resolution was provided by palynomorphs and foraminifers, which indicated an Anisian-Cordevolian age for the Lercara Formation. More precisely, Member A was deposited during part of the Anisian-Ladinian interval and Member B during the Ladinian-Cordevolian.

Clay minerals, associated to thermal maturity indicators and to microfacies, allowed the characterisation and the differentiation of the outcrops of the Roccapalumba-Lercara, of Palazzo Adriano and of Portella Rossa areas. The Roccapalumba-Lercara sections are more proximal and underwent a higher burial loading than the Palazzo Adriano sections, which in turn are more proximal and underwent a higher burial loading than those of the Portella Rossa ones.

Sedimentological and biostratigraphic data, associated to the Sicanian basin burial history, indicate that the Lercara Formation was deposited in the Neo-Tethys. This ocean was profound enough during the Middle Permian to permit the circulation of deep and cold waters. It coexisted with the Palaeo-Tethys Ocean in the Tethys western end, in a Pangea B configuration. The Sicanian basin constituted an arm of the Neo-Tethys Ocean, which from the Ladinian was separated from the Imerese basin by the proto-Vicarese carbonate platform.

RÉSUMÉ

Cette thèse contribue à la résolution d'une problématique majeure de la géologie sicilienne : l'âge de la Formation Lercara. Pendant le siècle dernier, cette Formation a été assignée au Permien, au Trias, au Paleogène et au Miocène. En plus de l'âge, ce travail analyse le contexte paléo-environnemental dans lequel la formation s'est déposée et l'évolution paléogéographique de la portion occidentale de la Téthys pendant le Permien et le Trias. L'étude intègre des analyses sédimentologiques, biostratigraphiques et minéralogiques, et elle propose la reconstitution de l'histoire de la subsidence du bassin Sicanien.

La Formation Lercara s'est déposée dans le bassin Sicanien et constitue la plus ancienne formation sédimentaire affleurant dans la chaîne siculo-magrébine. Elle affleure dans la Sicile occidentale dans les régions de Roccapalumba-Lercara et Margana-Valle Riena, proche de Palazzo Adriano, ou elle est mieux connue comme "dépôts du Fiume Sosio", et à Portella Rossa proche du village de Burgio. Tous les affleurements connus de la Formation Lercara ont été échantillonnés, ainsi qu'un nouveau localisé à Portella Rossa. Compte tenu de sa nature lithologique et de la tectonique intense qui affecte la Sicile, l'étude de terrain n'a jamais permis de mettre en évidence ni le contact stratigraphique inférieur avec une autre formation ou avec le socle, ni celui supérieur avec la Formation Mufara.

La caractéristique fondamentale de la Formation Lercara est son contenu élevé de matériel remanié (environ 95%), mis en évidence par les différents outils utilisés, particulièrement la biostratigraphie. Ce matériel provient du démantèlement de plateformes carbonatées permienues et triasiques (Anisien) et de plateformes siliciclastiques du Trias inférieur. Il est associé à environ 5% de matériel autochtone du Ladinien supérieur-Cordevolien. Ce remaniement très important explique pourquoi l'âge de la Formation Lercara est resté non résolu pendant si longtemps.

L'étude sédimentologique a permis de distinguer deux membres dans la Formation Lercara: un Membre A constitué de grès argileux et un Membre B constitué d'argiles avec un contenu élevé en quartz. Dans le Membre B se trouvent intercalés soit des niveaux de grès argileux, soit des niveaux calciruditiques ou calcarénitiques. L'analyse des microfacies et de leur distribution spatiale a permis l'identification de deux sources d'apport détritique. La principale était probablement localisée au nord-ouest du bassin Sicanien, tandis que la seconde pouvait être localisée soit au sud-ouest, soit au nord-est.

La meilleure résolution biostratigraphique a été fournie par les palynomorphes et par les foraminifères. Ils ont permis d'assigner la Formation Lercara à l'Anisien-Cordevolien. En particulier, le Membre A s'est déposé pendant une partie de l'intervalle Anisien-Ladinien et le Membre B pendant le Ladinien-Cordevolien.

L'étude des minéraux argileux associée aux indicateurs de maturité thermique, ainsi que l'étude des microfacies, ont permis de caractériser et différencier les affleurements de la région de Roccapalumba-Lercara, de Palazzo Adriano et de Portella Rossa. En effet, les sections de Roccapalumba-Lercara sont plus proximales et ont subi une charge d'enfouissement plus élevée que les coupes de Palazzo Adriano, qui à leur tour sont plus proximales et ont subi une plus importante charge d'enfouissement que celles de Portella Rossa.

Les données sédimentologiques et biostratigraphiques associées à l'histoire de subsidence du bassin Sicanien indiquent que la Formation Lercara s'est déposée dans la Néo-Téthys. Cet océan était déjà assez profond pendant le Permien moyen pour permettre la circulation d'eaux profondes et froides. Il coexistait avec l'océan Paléo-Téthysien dans la terminaison occidentale de la Téthys dans une configuration Pangea B. Le bassin Sicanien constituait un bras de la Néo-Téthys qui à partir du Ladinien, était séparé du bassin Imerese par la plateforme carbonatée proto-Vicarese.

RIASSUNTO

La presente tesi contribuisce alla risoluzione di una delle problematiche più controverse ed ancora aperte della geologia siciliana riguardanti l'età della Formazione Lercara. Essa ha da sempre interessato i geologi perché è l'unica formazione affiorante in Sicilia a contenere una flora e una fauna permiane. Il suo studio ha dato adito negli ultimi cento anni a numerose controversie riguardo la sua età, infatti è stata assegnata al Permiano, al Trias, al Paleogene ed al Miocene. Oltre all'età, in questo studio è stato analizzato il contesto paleoambientale in cui la formazione si è deposta e la situazione geologica relativa all'evoluzione paleogeografica della porzione occidentale della Tetide durante il Permiano ed il Trias. Tutto ciò è stato realizzato grazie all'integrazione di indagini sedimentologiche, biostratigrafiche e mineralogiche, associate alla ricostruzione della storia di subsidenza del bacino Sicano.

La Formazione Lercara si è deposta nel bacino Sicano e costituisce la più antica formazione affiorante nella catena siculo-magrebide. Essa affiora nella Sicilia occidentale nelle zone di Roccapalumba-Lercara e Margana-Valle Riena, vicino Palazzo Adriano, dove è meglio conosciuta come “depositi del Fiume Sosio”, ed a Portella Rossa vicino Burgio. In campagna non sono stati riconosciuti né il contatto stratigrafico inferiore con un'altra formazione o con il basamento, né quello superiore con la soprastante Formazione Mufara. Grazie ad un accurato studio di campagna integrato dalla ricerca bibliografica sono stati campionati tutti gli affioramenti conosciuti della Formazione Lercara compreso uno nuovo localizzato a Portella Rossa vicino Burgio.

Caratteristica fondamentale della Formazione Lercara, messa in evidenza dai differenti approcci utilizzati, in special modo dallo studio biostratigrafico, è l'elevato contenuto di materiale rimaneggiamento (circa il 95%). Esso proviene dallo smantellamento di piattaforme carbonatiche permiane e triassiche (Anisico) e piattaforme silicoclastiche del Trias inferiore ed è associato a circa il 5% di materiale autoctono del Ladinico superiore-Cordevolico. L'elevato rimaneggiamento può spiegare il perché per lungo tempo la risoluzione dell'età della Formazione Lercara è rimasta in sospeso.

Le indagini sedimentologiche hanno permesso di distinguere due membri della Formazione Lercara: un Membro A costituito da arenarie argillose ed un Membro B costituito da shale con un elevato contenuto in quarzo. Nel membro B si possono trovare intercalati o livelli di arenarie argillose oppure livelli di calciruditi o calcareniti. L'analisi delle microfacies e la loro distribuzione spaziale ha permesso inoltre di identificare due direzioni principali dell'apporto terrigeno. L'area sorgente principale era probabilmente localizzata a nord-ovest del bacino Sicano, mentre la seconda poteva essere posizionata a sud-ovest od a nord-est.

La migliore risoluzione biostratigrafica è stata fornita dai palinomorfi e dai foraminiferi. Essi hanno permesso di assegnare la Formazione Lercara all'intervallo Anisico-Cordevolico. In particolare il Membro A si è depositato tra l'Anisico e il Ladinico ed il Membro B durante il Ladinico-Cordevolico.

Lo studio dei minerali argillosi associato con gli indicatori di maturità termica ha permesso di caratterizzare e discriminare gli affioramenti dell'area di Roccapalumba-Lercara, di Palazzo Adriano e di Portella Rossa. Le sezioni di Roccapalumba Lercara, infatti, si sono deposte in un'area più prossimale (questo tra l'altro è stato anche messo in evidenza dallo studio delle microfacies) ed hanno subito un

carico da seppellimento maggiore delle sezioni di Palazzo Adriano che a loro volta si sono deposte in un zona più prossimale ed hanno subito un maggiore carico da seppellimento di quelle di Portella Rossa.

I dati sedimentologici e biostratigrafici associati alla storia della subsidenza del bacino Sicano, indicano che la Formazione Lercara si è deposta nella Neo-Tetide. Tale oceano durante il Permiano medio era abbastanza profondo da permettere la circolazione di acque profonde fredde e coesisteva con l'oceano Paleo-Tetide nella terminazione occidentale della Tetide in una configurazione Pangea B. Il bacino Sicano costituiva un braccio della Neo-Tetide e a partire dal Ladinico era separato dal bacino Imerese dalla piattaforma carbonatica proto-Vicarese.

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1 INTRODUCTION AND GEOLOGICAL SETTING

1.1 INTRODUCTION AND AIMS OF STUDY

This research is focused on the Lercara Formation, in order to clarify its age, the palaeoenvironmental context in which it was deposited and the geological setting related to the palaeogeographical evolution of the westernmost part of the Tethys during the Permian and the Triassic time.

The Lercara Formation crops out in western Sicily (Italy), that is in the Roccapalumba-Lercara region, in the Margana-Valle Riena zone, near Palazzo Adriano (where it is better known as “deposits of the Fiume Sosio”) and in the Portella Rossa area (Figure 1.1). It consists of a complex siliciclastic deposit and represents the oldest known deposit in the Sicilian-Maghrebian chain deposited in the Sicanian basin. The Lercara Formation has always interested geologists because it is the only known deposit in Sicily in which a rich and varied Permian fauna can be found.

Since the beginning of the twentieth century the age of this formation has been controversial. It has been assigned to the Permian, Triassic, Paleogene and Miocene. These different interpretations are due to the geological complexity of western Sicily, affected by the Alpine deformation. During these events, the plastic Lercara Formation was completely deformed and only a few small outcrops are recognizable today in the field. Moreover, its lower stratigraphic limit or an eventual basement on which it would be deposited are unknown, as is the upper stratigraphic contact with the younger Mufara Formation.

The Mufara Formation, composed of siliciclastic sediments, was deposited in both the Sicanian and the Imerese basins, where deposition started respectively in the Julian and the late Ladinian. During the late Ladinian to Cordevolian, the Sicanian basin was characterised by deposition of the Lercara Formation. Thus, the two formations are contemporaneous during the late Ladinian-Cordevolian. The Lercara Formation can be distinguished by the presence of Permian and Early Triassic carbonate resediments which are absent in the Mufara Formation.

The determination of the age of the Lercara Formation and the understanding of the process that caused its deposition can help towards the comprehension of the palaeogeographical evolution of the westernmost termination of the Tethys Ocean during the Permian and the Triassic periods. Indeed, the time of the closing of the Palaeo-Tethys and the opening of the Neo-Tethys in this region is doubtful also because of lack of stratigraphic data.

In order to elucidate these points, a high resolution biostratigraphic, sedimentological and mineralogical study has been undertaken based on field investigations of the Lercara outcrops. Among the biostratigraphic tools used, foraminifera and palynomorphs have given the best results about the age of the Lercara Formation. Associated with others tools, such as conodonts and ostracods they provided the best indications concerning the reworking and the palaeogeographical reconstructions. The palaeodepositional environment context has been reconstructed performing sedimentological analysis of the samples, including microfacies analysis and field indications, associated with a mineralogical study to deduce the source rocks and the environmental conditions. Mineralogical analyses have been undertaken to discriminate the Lercara deposits from the coeval sections of the Mufara Formation

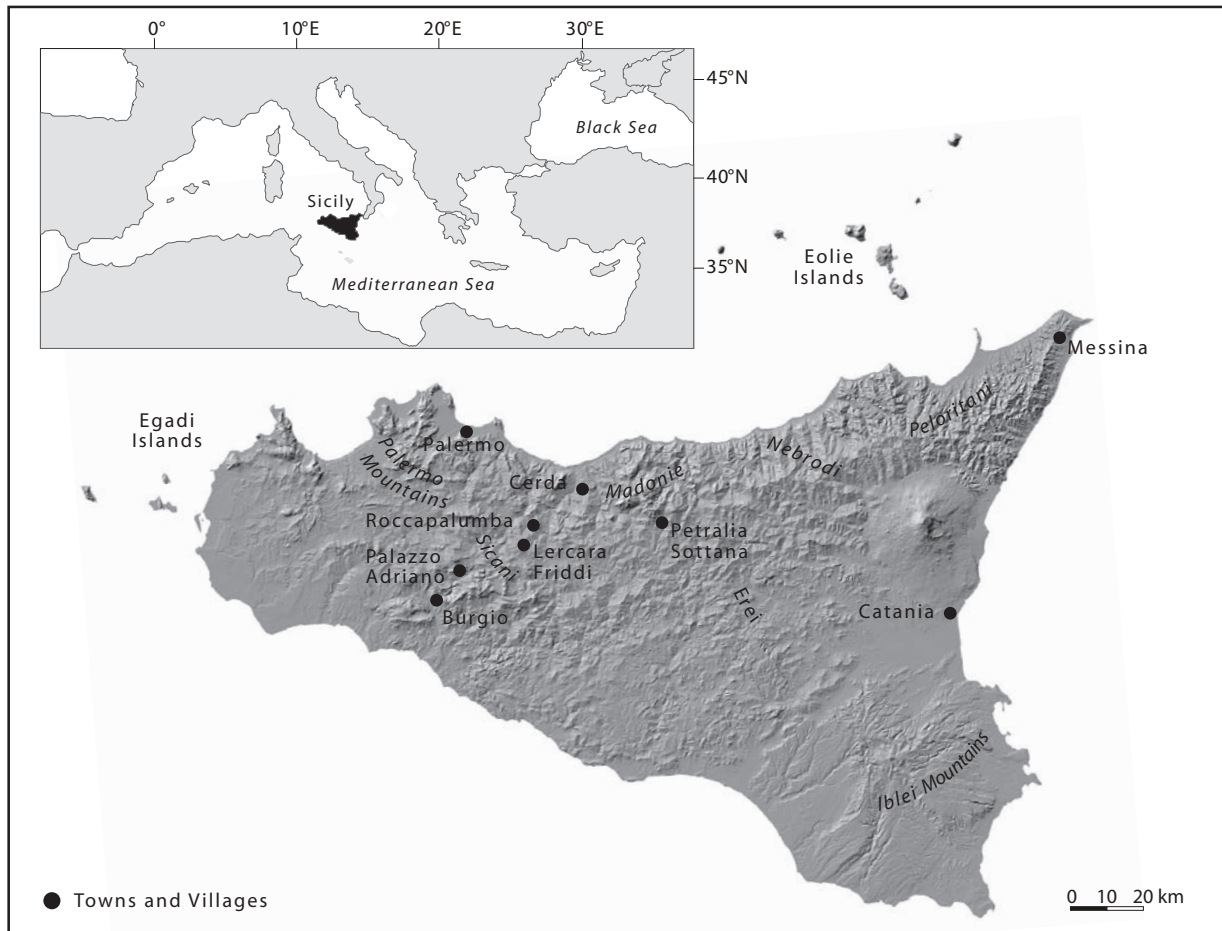


Figure 1.1 Sicily location map.

and with this in mind, sections of the Mufara Formation thus to have been late Ladinian-Cordevolian and deposited in the Imerese basin have been sampled. The *Cozzo Introna* section of the Mufara Formation deposited in the Sicanian basin has also been sampled because it overlaps the Lercara deposits.

The thermal history of the Lercara Formation and the geodynamic evolution have been evaluated, using organic and mineral parameters indicating the palaeogeographical evolution of the basin and the hydrocarbon potential.

Finally, a geodynamic history of the Sicanian basin was reconstructed, which recorded the events which occurred in the westernmost end of the Tethys.

1.2 GEOLOGICAL SETTING

Earlier authors who have dealt with the subject have used the term “Unit” in different ways and ambiguously. Sometimes it has been used for merely lithostratigraphic complex purposes, sometimes for tectonic ones and, occasionally as a tectonic-structural one (*i.e.* USS), all of which has led to notable confusion. Similar ambiguity occurs for the so-called “Domain”, which is in fact a facies-palaeodomain connected more to lithology than to the tectonic.

1.2.1 GENERALITIES

The island of Sicily is located in the central-western part of the Mediterranean Sea, along the megasuture zone between the African and European Plates. Three elements can be distinguished in the

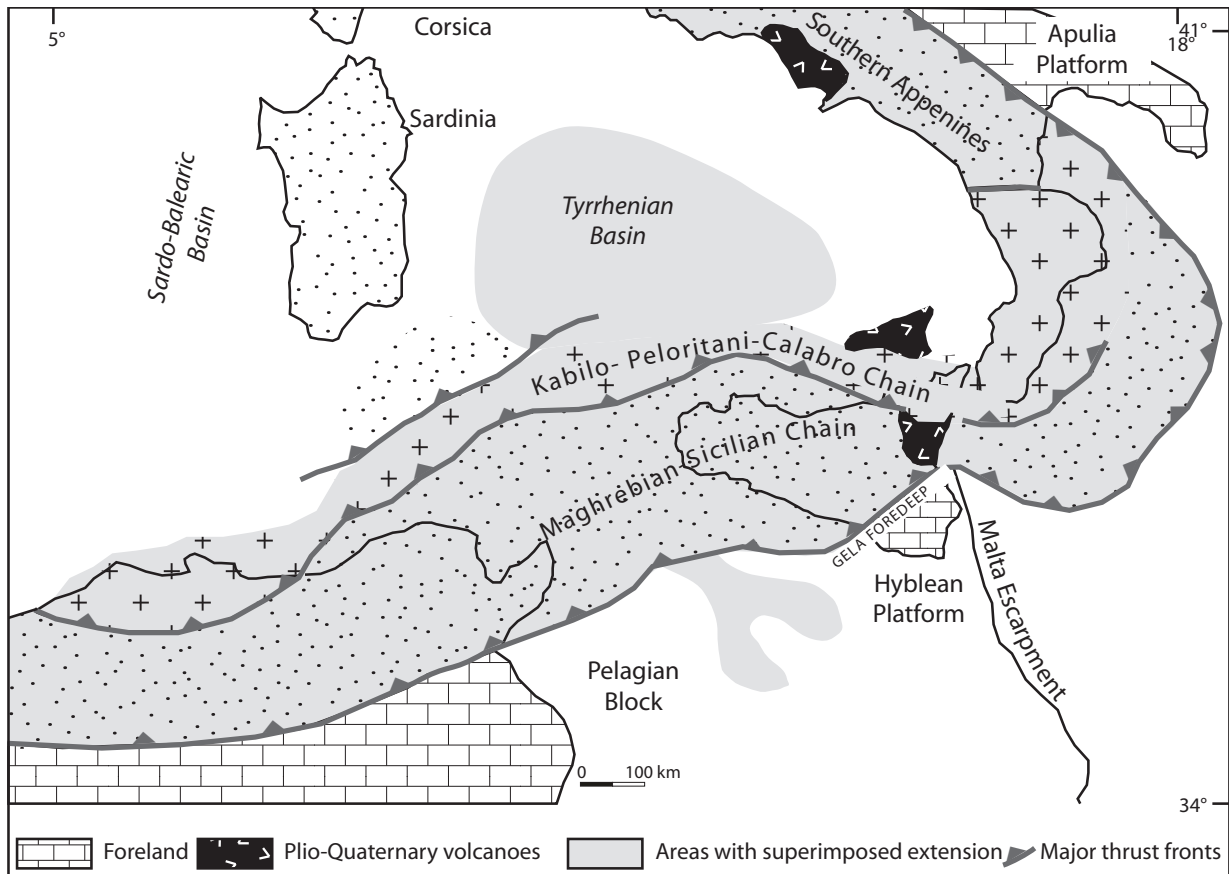


Figure 1.2 Tectonic map of the Central Mediterranean area (after Catalano *et al.*, 1995).

Sicilian collisional system (Figure 1.2) (Catalano & Montanari, 1979; Sengör *et al.*, 1984; Catalano *et al.*, 1995a):

- A foreland area (Hyblean Platform) situated in southeastern Sicily.
- A present northwestern dipping foredeep (Gela Foredeep) located along the northern margin of the foreland.
- A complex Sicilian chain consisting of the Peloritani and the Maghrebian belts, formed since the Oligo-Miocene at the time of the opening of the Balearic basin and with the collision of the Corso-Sardinian block with the African margin (Catalano & D'Argenio, 1978; Finetti *et al.*, 1996).

The Maghrebian belt, in which the Lercara Formation crops out, is located in the central-western part of Sicily and constitutes a segment of the Apennines chain. The Sicilian belt thrusts towards east-southeast and is divided into an inner tectonic element to the north and an outer tectonic element to the south (Catalano *et al.*, 1995a). Each element is formed by several imbricate units piled up with ramp-flat and duplex style that derive from the deformation of pre-existing palaeogeographic units. The classic palaeogeographical models (*e.g.*, Catalano & D'Argenio, 1978) indicate the existence during the Mesozoic of different carbonatic platforms separated from pelagic basins mentioned below. They are joined to an ancient African continental margin (Catalano & Montanari, 1979), formed during the Mesozoic extension phase and characterised by a carbonate, silico-carbonate and siliciclastic sedimentation (Catalano & D'Argenio, 1978; Catalano *et al.*, 1978).

As will be seen in section 1.3.3 (relating to the Permian to Triassic palaeogeography), different hypotheses have been advanced about the arrangement of these platforms and basins. From the present north, and southwards, the inner tectonic element includes:

- the Sicilide unit cropping out in the Nebrodi and Madonie Mountains. It derives from the deformation of the Sicilide Palaeodomain composed of Cretaceous-Tertiary silico-carbonate and

siliciclastic basinal deposits (Ogniben, 1960; Catalano *et al.*, 1978; Montanari, 1989; Catalano *et al.*, 1995a; Catalano *et al.*, 1995b);

- the Panormide unit exposed from the Madonie Mountains to the “Palermo Mountains”. It arises from the deformation of the Mesozoic-Tertiary carbonate platform and the margin series of the Panormide Palaeodomain (Giunta & Liguori, 1973; Catalano & D’Argenio, 1978; Montanari, 1989);
- the Imerese unit cropping out in the Madonie, Sicani and “Palermo Mountains”. It originates from the deformation of Mesozoic-Tertiary slope and basinal series of the Imerese Palaeodomain (Giunta & Liguori, 1973; Catalano *et al.*, 1978);

From the present north, and southwards, the outer tectonic element includes:

- the Trapanese unit exposed in north-western Sicily. It arises from the deformation of Mesozoic-Tertiary pelagic carbonate platform series of the Trapanese domain (Giunta & Liguori, 1973; Catalano & D’Argenio, 1978; Catalano *et al.*, 1995b);
- the Sicano unit cropping out in the Sicani Mountains. It derives from the deformation of Paleozoic?/ Mesozoic-Tertiary basinal deposits of the Sicano domain (Catalano & D’Argenio, 1978; Catalano *et al.*, 1978);
- the Saccense unit exposed in south-western Sicily. It originates from the deformation of Mesozoic-Tertiary pelagic carbonate platform deposits of the Saccense domain (Catalano & D’Argenio, 1978; Catalano *et al.*, 1978; Montanari, 1989);

The deformation affecting the palaeogeographic units mentioned above started in the late Oligocene/early Miocene due to the anticlockwise rotation of Corsica and Sardinia and to their collision with the African margin. In consequence the tectonic units of the Sicilian belt have undergone a clockwise rotation of 47° and 140° relative to the stable Hyblean foreland, as evidenced by palaeomagnetic data (Channell *et al.*, 1980; Montanari, 1989; Channell *et al.*, 1990; Oldow *et al.*, 1990). As result of this rotation, the palaeogeographic domains, those which are now elongated E-W, were originally oriented N-S relative to the Iblean foreland.

Terrigenous and siliciclastic Oligo-Miocene to Middle Serravallian Numidian Flysch series have been unconformably deposited over these units, and continued to be subject to distortion during the orogenesis. After the stacking of the units, the chain has undergone successive Plio-Pleistocene deformation phases, consisting of thrust fault systems, probably due to the Tyrrhenian basin opening. During this terrigenous, evaporitic phase, calcareous Upper Tortonian to Lower Pleistocene series have been unconformably deposited.

1.3 PREVIOUS WORKS

1.3.1 LERCARA FORMATION

DESCRIPTION

The Lercara Formation is the oldest known deposit in the Sicilian chain and, as yet, no type series exists and the lower stratigraphic limits or an eventual basement on which the Lercara Formation would be deposited are unknown. At the top, according to Schmidt Di Friedberg (1965) and Catalano & Montanari (1979), it would have been in stratigraphic contact with the Upper Triassic Mufara Formation or its equivalent (Montanari, 1989; Cirilli *et al.*, 1990). Montanari (1989) and Catalano *et al.* (1991) are of different opinion and suggest a tectonic contact between the two formations.

The name Lercara Formation, (which derives from the village Lercara Friddi around which the formation crops out more widely), was given to it informally by Schmidt Di Friedberg (1965). The author describes a Permian (?)–Triassic wildflysch composed at the top of micaceous sandstones containing particles of wood and at the bottom an alternation of marls, sandstones and fusulinid-rich breccias. Basaltic rocks and calcareous fossiliferous blocks are also present and, according to him, outcrops were identified near the Lercara and Cerda villages.

Deposits ascribed as the Lercara Formation were first described by Fabiani & Trevisan (1937) as varicoloured marly arenaceous wildflysch with fusulinid-bearing breccias emerging in the Lercara Roccapalumba-Vicari and Val Riena areas.

Masclé (1979) described red and green azoic clays intercalated by red microbreccia and a lens of conglomerate with Permian elements at Portella Rossa near Burgio.

Montanari & Panzanelli Fratoni (1988) reconstructed a composite succession of the Lercara Formation assigned to Ladinian?–early Carnian. It is composed of a lower Member A made up of quartz-wackes, quartzarenites, shales with intercalation of magmatic rocks and an upper Member B constituted of red-grey shales, sandstones, marly limestones and carbonates breccias comprising Palaeozoic elements.

For these authors the Lercara Formation is recognizable in the area between Roccapalumba and Lercara Friddi, near Palazzo Adriano, while the deposits of Cozzo Rasolocollo, near Cerda belong to the Mufara Formation.

According to Catalano *et al.* (1988a; 1988c; 1991) the deposits attributed to the Lercara Formation can be subdivided into three Permian Lithostratigraphic Units. The oldest, a Kungurian flysch, cropping out in the region of Lercara-Roccapalumba are made up of quartz-wackes alternating with silty shales, marls, calcarenites, microbreccias and breccias. The other two lithostratigraphic units crop out in the Sosio Valley area and are in tectonic contact. The first one, of Kubergandinian age, is composed of clays with olistoliths of micaceous sandstones, siliceous calcilutites and biogenic limestones. The second one, of Late Permian, is constituted of clays and calcarenites. Moreover, large blocks of Permian shallow-water limestones, are exposed along the Sosio Valley.

DISTRIBUTION WITHIN THE TECTONIC UNITS

The Lercara Formation has been identified at the base of the Roccapalumba Unit (Middle-Late Triassic) (Catalano & Montanari, 1979) mentioned as the “Cerda-Roccapalumba Tectonic Unit” common base by Abate *et al.* (1988), from which would be differentiated the Imerese and Sicanian Basins. This tectonic unit originates from the deformation of the intracratonic Lercara basin (Catalano & D’Argenio, 1978) where, during the Middle Triassic tensile tectonic phase, a terrigenous clastic-carbonatic sedimentation was developing. This tectonic unit can be identified near Cerda (Cozzo Rasolocollo or Cozzo Tabarani) and in the Roccapalumba-Lercara zone (Catalano & D’Argenio, 1978; Abate *et al.*, 1988).

The series of this unit is composed of Middle Triassic reddish to greenish clays, interbedded by greenish, locally micaceous, graded sandstone, diabasic vulcanites and micaceous sandstones interbedded by calcarenites, breccias, calcirudites, huge limestone blocks, in which fusulines are found. The series continues with Upper Triassic marls and greenish clays intercalated with calcilutites, calcisiltites sandstones, and occasional graded and laminated sandstones (Ta-d and Ta-c Bouma sequence) (Abate *et al.*, 1988).

In the Lercara-Roccapalumba area the Lercara deposits are part of a large antiformal structure comprising of slices of Triassic deposits and Miocene clays as documented by seismic and exploration data (Caffisch & Schmidt Di Friedberg, 1967). They tectonically cover the other Meso-Cenozoic Sicanian units and are tectonically overlaid by the Numidian Flysch.

The Lercara Formation crops out at the base of the Monte Rose Structural Stratigraphic Unit (Catalano & D’Argenio, 1978; Masclé, 1979) in the Sosio Valley, near Palazzo Adriano. This unit derives from the deformation of the most internal (northern) part of the Sicanian Domain and is thrust over the Monte Barracù and Pizzo Mondello Unit. Here the Lercara Formation has thrust itself over the late Miocene marly deposits (Catalano *et al.*, 1991).

The base of this series is composed of reddish clays, calcarenites, sandstones, quartz rich shales, with interbedded calcarenites and huge blocks of Permian limestones (Lercara Formation).

The series continues with a) clays and limestones (Carnian), b) cherty dolostones and limestones, breccias (Norian-early Liassic), c) calcarenites and resedimentated limestones (middle Lias-Malm), d) calcilutites (Late Jurassic-Early Cretaceous), e) calcilutites, megabreccias and marly calcilutites (Late Cretaceous-Eocene) f) limestones and marls (Oligocene), g) glauconitic biocalcarenes (lowermost Miocene), h) clays and sandy marls (Serravallian-Tortonian) and i) gypsiferous deposits (Messinian).

The Lercara Formation crops out at the base of the Pizzo Mondello Structural Stratigraphic Unit (Catalano & D'Argenio, 1978; Mascle, 1979), at Portella Rossa near Burgio. This unit originates from the deformation of the external side of the Sicanian Domain and is thrust over the Upper Miocene of the Monte Genuardo Unit (Mascle, 1979).

The base of the series is composed of red shales, quartz rich shales and calcarenites with Permian elements. Large Permian limestone blocks are scattered in the shales (Lercara Formation). The series continues here with a) grey marls and calcilutites (Carnian), b) dolomitized and silicified limestones, marls and breccia (Norian-early Liassic) limestones, marls, basic volcanics, radiolarites and calcilutites (middle Lias-Malm), c) Calpionellid silicified calcilutites marls and limestones (Late Jurassic-Early Cretaceous), d) marly limestones and nummulitid calcarenites, e) pelagic marls and sandy marls (Early Tertiary), f) deltaic, glauconitic biocalcarenes (Aquitania-Langhian), g) *Orbulina* marls (Serravallian-early Tortonian) and h) evaporites (Messinian) (modified after Catalano & D'Argenio, 1978).

Palaeozoic-Middle Triassic rocks may exist in the subsurface of the Hyblean foreland. Gravimetric data show evidence of the older arenaceous lithotypes that overly Upper Triassic dolomites. Equally, in the drill Vizzini 1, bored on the Hyblean Mountains, limestones, dolomites and marls were found at a depth of 5145 metres. They are attributed to the Anisian to Ladinian because of their stratigraphic position (Bianchi *et al.*, 1989).

AGE INTERPRETATION

Deposits attributed to the Lercara Formation crop out 1) in the region of Roccapalumba-Lercara, 2) in the Margana-Val Riena zone; 3) near Palazzo Adriano, where they are better known as deposits of the Fiume Sosio, 4) in Portella Rossa and 5) near Cerda.

The Lercara Formation has always interested geologists because it is the only deposit known in Sicily in which a rich and varied Permian fauna can be found. The age of this Formation has been the subject of differences of opinion since the beginning of the twentieth century and is, even today, controversial.

The first author to mention rocks that have later been assigned to the Lercara Formation was Baldacci (1886). He referred to the Permo-Carboniferous limestone blocks of the Pietra di San Benedetto near Palazzo Adriano.

Later, during the second half of the nineteenth century, Gemellaro (1887; 1888; 1889; 1892; 1893a; 1893b; 1894a; 1894b; 1898/99) made some paleontological studies of the huge limestone blocks that emerge along the Torrente San Calogero. In these blocks, known as "Permiano del Fiume Sosio" and including the outcrops of Pietra di Salomone, Rupe del Passo di Burgio and Pietra dei Saracini (otherwise called Rocca di San Benedetto), he found molluscs and brachiopods of Permian age. In his work Gemellaro (1887) also described Permian fossils which he found in rounded limestone blocks discovered near the Roccapalumba railway station along the Torto river.

Fabiani & Ruiz (1933) described some Permo-Carboniferous strophomenids found in the Pietra di Salomone and Pietra di San Calogero blocks.

In 1937 Fabiani attributed a varicoloured marly arenaceous wildflysch with fusulinid-bearing breccias emerging in the Lercara Roccapalumba-Vicari and Val Riena areas to the Permian. He dated this by an ammonite found in the marls and by fusulinids of the limestone blocks included in the marly rocks. This formation has the equivalent in some outcrops at Cozzo Rasolocollo. Near Lercara, the author also found some specimens of the brachiopod *Productus cora* attributed to the Carboniferous.

According to De Stefani (1948) the Permian fossils, isolated or in blocks, have been reworked within a Paleogene or Miocene flysch.

Castany (1956) attributed the Lercara Formation to the Carboniferous and to Early Permian, based on lithological affinities with the Carboniferous and the Permian of Djebel Tebaga of Tunisia.

In 1961 Rocco assigned deposits found at the well "Cerda" at Cozzo Rasolocollo to Late Triassic, though Fabiani (1952) had indicated they were Permian. Rocco found evidence of Permian deposits, however, at the depth of 3000 metres.

Schmidt Di Fiedberg (1965) introduced the name “Formazione Lercara” for Permian? to Upper Triassic deposits below the Mufara Formation of terrigenous nature, with basaltic intercalations and fossiliferous limestone blocks, found near Lercara and Cozzo Rasolocollo.

Caflich & Schmidt Di Fiedberg (1967), thanks to a conjoint study of seismic reflection and the wells “Lercara 1” and “Roccapalumba 1”, described a complex structure of several imbricate units composed of Triassic, Permian and a tectonic mixture of Permian and Miocene clays. Deposits of the Lercara Formation were ascribed to the Permian.

A Permian age is supported by Broquet *et al.* (1966), Mascle (1967), and Broquet (1968) for the deposits of the Lercara-Roccapalumba zone, Palazzo Adriano and for the Cozzo Rasolocollo outcrops, called “Flysch permien”. They adduced as argumentation the fusulinid microbreccia perfectly stratified in clays and Carnian deposits overlying “transgressively” the Lercara Formation.

In the same period Montanari (1968) advanced the hypothesis that the Lercara Formation was Triassic, thanks to finding Carnian fossils, among their the foraminifer *Brizalina*, with Permian fauna. The Permian fossils would have been reworked several times.

This author, after a detailed structural-stratigraphic study of the zone between Lercara, Roccapalumba, Vicari and Alia, reconstructed a composite succession of the Lercara Formation. This succession is constituted, from the bottom towards the top, of a detritic marly-calcareous unit, in which he found both Carnian and Permian fossils, of diabasic volcanic rock, of detritic limestone finely bedded with “foraminiferi di tipo carnico” and of a thick series of micaceous sandstone.

According to Ruggeri & Di Vita (1972) the Lercara Formation must be attributed to the Miocene mostly based on the planktonic foraminifers discovered in the zone of Roccapalumba and Lercara. The Permian and Triassic fossil associations would be reworked in Miocene marls.

Mascle (1979) proposed a Middle Permian age for the deposits of Lercara-Roccapalumba and Palazzo Adriano, but did not exclude the possibility that it might later be found to be of Upper Permian or Triassic age. He is the first and only author to have described a conglomerate containing a Permian fauna, intercalated in green and red Carnian clays cropping out in Portella Rossa near Burgio.

Catalano & D’argenio (1978) and Catalano & Montanari (1979) supported the hypothesis of Montanari (1968) and considered that the Permian fossils are reworked in the Carnian sediments. Moreover Catalano & D’argenio (1978) proposed that the Lercara Formation has been deposited in a basin, which was created by a transtensive tectonic phase in the Middle Triassic.

In the last fifteen years, two contrary schools of thought have emerged:

- The first one, represented by Catalano *et al.* (1988a; 1988c; 1991) and Gullo (Catalano *et al.*, 1988c, b, 1991; Gullo, 1993) supports rather a Permian age based on the finding of radiolaria, palaeopsychrospheric ostracods and conodonts. For these authors the Lercara Formation is composed of three units in tectonic contact: 1) a Kungurian (late Early Permian) Flysch Unit exposed in Lercara-Roccapalumba areas; 2) an earlier Middle Permian Olistostrome Unit and 3) a Late Permian Red Clay Unit cropping out in the Sosio Valley area. Along the Torrente San Calogero huge limestone blocks are exposed. They are the result of a synsedimentary reworking from reef complexes inside the surrounding deep-water basin.
- The second one, represented by Cirilli *et al.* (1988; 1990) and Carrillat (2001) supports a Triassic age. They found together Permian to Late Triassic palynomorphs in some samples coming from the zone near Lercara-Roccapalumba. The co-existence of these palynomorphs mean that the Lercara Formation cropping out in this zone can be attributed to the Ladinian-Early Carnian. Moreover, they allow to identify a reworking affecting the Middle Permian to Lower Triassic deposits and probably those of the Lower Permian. However, there is no evidence of palynomorphs in the samples which have come from the zone close to Pietra di Salomone.

In the section labelled “Torrente San Calogero” Catalano *et al.* (1988c; 1991) found a “nearly continuous sequence” of the above once described as Middle (Olistostrome Unit) to Late Permian (Red Clay Unit). In the same section, they found a complete Ladinian pelagic succession composed of radiolarites and tuffites, overlaid by cherty limestones; this succession bears all the index species for the conodont zone between the Fassanian and the Longobardian. This sequence is overlaid by Cordevalian to Rhaetian deep-water deposits. Scythian to Anisian deposits are lacking.

Fairly close to the Torrente San Calogero section, in the south of the Pietra dei Saraceni, a complete Changhsingian (Upper Permian) to Scythian succession, without breaks in sedimentation, have been described (Gullo & Kozur, 1993). Pelagic Lower and Upper Scythian conodonts were discovered in this series. The Lower Scythian assemblage includes pelagic and shallow water conodonts such as *Hindeodus parvus* and *Isarcicella isarcica*, and some reworked Permian conodonts. The Upper Scythian assemblage includes pelagic conodonts and radiolarians.

A recent study of Jenny-Deshusses *et al.* (2000) signals the presence of the foraminifers *Colaniella* ex gr. *parva* and *Colaniella* ex gr. *minima* in a resedimented calcarenitic block of the Pietra di Salomone. This simultaneous presence indicates a late Middle Permian (Midian) to early Late Permian (Dzhulfian) possibly Late Permian (Dorashamian). They conclude that the age of deposition of the Lercara Formation is Latest Permian, or younger.

ENVIRONMENTAL INTERPRETATION

According to Catalano *et al.* (1988a), Catalano *et al.* (1988c; 1991), Kozur (1993) and Di Stefano & Gullo (1997a) an oceanic seaway existed between the present western Sicily and the Permian Tethys, along the Gondwanian margin since the late Early Permian. The Sicanian Palaeodomain, since the Permian and during the Mesozoic and part of the Cenozoic, represented the open pelagic realm of western Sicily connected to the Circumpacific domain. In this context deep-water sequences of the Lercara Formation rich in pelagic Permian conodonts, Middle and Late Permian paleopsychrospheric ostracods and radiolaria were deposited together with carbonate blocks and breccias (Catalano *et al.*, 1991). The huge carbonate blocks of the Sosio Valley are interpreted as slope sediments from adjacent reefs or seamounts and resedimented in the surrounding broad pelagic trough (Catalano *et al.*, 1988c; Flügel *et al.*, 1991). This interpretation is confirmed by Kozur (1993) on the basis of his finding of the *Mesogondolella phosphoriensis*-*Mesogondolella siciliensis* conodont complex, characteristic of an open pelagic environment, in all samples from the blocks.

These Permian deep water conditions persisted in the Sicanian palaeodomain, during all the Triassic as attested, for instance, by the following Sosio Valley deposits: 1) Scythian claystones, reddish marls and micritic limestones (Gullo & Kozur, 1993; Kozur, 1993) including the conodonts *Clarkina* and *Gladigondolella carinata*; 2) Anisian siliceous calcilutites bearing *Neogondolella constricta* (Gullo & Kozur, 1993; Kozur, 1993); 3) Lower Ladinian radiolarites and the Upper Ladinian to Cordevalian cherty limestones (Catalano *et al.*, 1991); 4) Late Ladinian to Early Carnian pelagic cherty calcilutites rich in conodonts (*Pseudofurnishius*) (Catalano & Di Stefano, 1990) and 5) Rhaetian deep-water calcilutites also rich in conodonts: *Misikella posthernsteini* and *Zieglericonus rhaeticus* (Gullo, 1996).

Montanari & Panzanelli Fraton (1988; 1990) carried out a comparative study between the Lercara Formation and the coeval Monte Facito Formation (Scandone, 1965) cropping out in the Southern Apennines. According to them the two basins, in which are deposited the Lercara and the Monte Facito Formation (respectively Sicanian and Lagonegro Basins), were connected. The Lercara Formation was deposited in a more internal, and the Monte Facito in a more external domain.

With particular regard to the Lercara Formation, the previous authors contend that the lower Member A (quartz-wackes, quartzarenites and shales) of the Lercara Formation was deposited in a slope environment following a grain, and the upper Member B (shales, sandstones, marly sandstones and breccias) was the result of a siliciclastic turbidite deposited in a marine basin. The Permian carbonate breccias and megabreccias were canalized bodies and their angular form would suggest the vicinity of the original source area.

According to Ogniben (1960), Broquet (1968), Giunta & Liguori (1973) and Catalano & D'Argenio (1978), the Lercara Formation was deposited in an intracratonic basin during the Middle Triassic. Since the Norian, this basin has evolved into the Imerese and Sicanian basins separated by the Trapanese carbonate platform.

1.3.2 MUFARA FORMATION

DESCRIPTION

In Sicily the Mufara Formation is the youngest known deposit after the Lercara Formation, but no stratigraphic contact exists between them and there is no known stratigraphic contact with the overlying Panormide shallow carbonate platform deposits and with the Fanusi, Scillato and “Calcari con selce” Formations (Carrillat, 2001). The name “Mufara Formation”, given by Schmidt Di Friedberg (1965), derives from Monte Mufara in the eastern Madonie, where in 1960 Schmidt Di Friedberg (1960) first measured and studied this formation and temporarily gave the name “equivalente della Formazione Scillato inferiore”. The series of this formation is composed of monotonous marly deposits intercalated by relatively thin limestone levels (Carrillat, 2001). A detailed description of the Mufara Formation with an indication of earlier research is given in Carrillat (2001). However, for clarity, the salient points of this earlier research are given below.

DISTRIBUTION WITHIN THE TECTONICS UNITS

The Mufara Formation has been identified in most of the palaeodomains that constituted the Sicilian belt. It is exposed in the Trapanese and Sicanian Palaeodomains and more widely in the Panormide and Imerese Palaeodomains.

Only a few sections of the Mufara Formation, belonging to Cerda-Roccapalumba unit and to Panormide domain have been sampled for comparison with the Lercara Formation (see section 2.1 “Sampling criteria”).

The Mufara Formation overlaps tectonically the Lercara Formation deposits in the Cerda-Roccapalumba Tectonic Unit. This unit originates from the deformation of the Lercara Basin, developed during the Middle-Late Triassic and differentiated later in the Sicanian and Imerese Basins (Catalano & D’Argenio, 1978), and is composed of Middle-Late Triassic siliciclastic and carbonatic rocks. This unit crops out in the Roccapalumba and Cerda zone

The Mufara Formation is present at the base of the Monte Dipilo/Monte Mufara Tectonic unit. It results from the deformation of the carbonate platform and its margin deposits of the Panormide Domain and is thrust over the Miocene deposits of the Imerese Domain (Abate *et al.*, 1988).

The Monte Dipilo/Monte Mufara Tectonic unit is composed of: 1) clays, marls and calcilutites of the Mufara Formation (Upper Triassic); 2) dolomites and dolomitic breccias (Upper Triassic-Middle Lias); 3) stromatolitic and loferitic limestones, dolomitic limestones, algal biolithites (Upper Jurassic-Lower Cretaceous) and 4) marly clays, marls, calcarenites and calcirudites (Upper Eocene-Oligocene).

AGE INTERPRETATION

The first author to refer the Mufara Formation to the Upper Triassic deposits in Sicily () was Gemmellaro (1882). He was followed by others (*e.g.*, Fabiani & Ruiz, 1933; Fabiani & Trevisan, 1937; Castany, 1956; Broquet *et al.*, 1966; Mascle, 1967) who used the term “Carnian flysch” to describe grey marly clays, with intercalations of marls and grey limestones with occasioned silex nodules which can be found widely in north-western Sicily.

Fabiani & Trevisan (1937) and Rocco (1961) describe in, respectively, the Vicari and Cerda zones, a “Flysch antico” in which only the upper part is Carnian.

In the Monte Kumeta zone, Caflisch (1966) found some *Halobia* sp., *Daonella* sp., *Tachyceras* sp., pyritized small gastropods, radiolarian and ostracods, that suggest an Upper Triassic age.

Senowbari Daryan & Abate (1986) studied the carbonate resedimented levels intercalated in the marly clayey deposits of the Mufara Formation belonging to the Imerese domain. They identified a reef-facies constituted of Carnian calcareous sponges, a lagoon facies consisting of Ladinian (Anisian?) dasycladacean algae and Norian cayeuxian algae and Norian pisoid facies.

Martini *et al.* (1991b; 1991a) carried out a sedimentological and biostratigraphic study over different series of the Mufara Formation in the “Palermo Mountains” and in the eastern Madonie Mountains belonging to the Panormide and Imerese Domains.

Micropalaeontological analyses of foraminifers deriving from the calcarenitic and calciruditic levels revealed a Ladinian?-Carnic age, but the analyses of pollens and spores assemblage (mainly *Vallasporites ignacii*, *Patinasporites densus*, *Samaropollenites speciosus* and *Brodipora striata*), obtained from the marls, and conodonts (mainly *Paragondolella polygnathiformis*, *Paragondolella nodosa* and *Paragondolella carpathica*) extracted from the calcarenitic levels, specified a Tuvanian age (Upper Carnian) except for the topmost part.

Recently, Buratti & Carrillat (2002) published a high resolution palynostratigraphy study over 10 sections of the Mufara Formation belonging to the Panormide, Imerese, Sicano and Trapanese Tectonic Units and to Cerda-Roccapalumba Tectonic Unit.

They identified four palynological assemblages based on progressive diversification of additional taxa within the *Camerosporites secatus* phase, which allowed the attribution of the Mufara Formation to the Late Longobardian/Early Cordevalian to Late Tuvanian (Carnian).

ENVIRONMENTAL INTERPRETATION

The sedimentological and biostratigraphical study undertaken by Martini *et al.* (1991b; 1991a) indicated that the Mufara Formation is a turbiditic deposit. This proposition was supported by Di Stefano *et al.* (1998). According to Martini *et al.* (1991b; 1991a) the most marly interval is to be found from the middle or lower part of a detrital submarine fan, with an “interchannel” zone and the more calcareous part from the base of the fan in the vicinity of a lobe. The carbonatic elements of the calcarenitics and calciruditics levels would come from the adjacent platform “Panormide”. This last hypothesis is shared by Di Stefano *et al.* (1998) and Senowbari-Daryan & Abate (1986).

Bellanca *et al.* (1995) carried out a sedimentological and geochemical investigation of the Sicanian deposits of the Mufara Formation. They showed that the Julian deposits were deposited in a basin with dominantly anoxic to dysaerobic bottom waters, the lower Tuvanian deposits under dysaerobic conditions and the Middle and Upper Tuvanian cherty limestones in a deeper and more oxygenated basin.

Carrillat (2001) holds a different opinion. He integrated sedimentological and organic facies for a palaeoenvironmental reconstruction of the Mufara Formation. According to him the younger series (Ladinian/Carnian boundary and the lower Middle Carnian) were deposited on a ramp or distally steepened shelf. Instead, the upper Middle Carnian to late Carnian series are deposited on a shelf break. Additionally the resedimented carbonate debris of the Mufara deposits derived from coralline sponges and Spongiostromata patch reef found on a shelf or on a ramp. These bioconstructions were not preserved at the sites because of the low cohesive construction of microbial crust that gave rise to high debris potential.

1.3.3 PERMIAN TO TRIASSIC EAST MEDITERRANEAN PALAEOGEOGRAPHY STATE OF KNOWLEDGE

During the Late Palaeozoic and the Early Mesozoic, the island of Sicily was located in the westernmost end of the Peri-Tethys domain, turning point between the Palaeo-Tethys Ocean subduction and the Neo-Tethys Ocean opening, the former separating the Variscan domain from the Cimmerian composite terranes and the latter the Cimmerian terranes from the Gondwana (Stöckling, 1974).

Whilst a general consensus seems to exist in the literature concerning the definition of the Palaeo- and Neo-Tethys Ocean and the time of the opening of the Neo-Tethys Ocean along the eastern and central part of the Cimmerian microcontinent (*e.g.*, Dercourt *et al.*, 2000; Ziegler & Stampfli, 2001; Gaetani *et al.*, 2003), there is a general disagreement on the Tethys evolution in its westernmost terminal part. In particular, a divergence of opinion exists about the relative position of Gondwana and Laurasia at the end of Variscan Orogeny, the dating of the Neo-Tethyan rifting, its relation to the East Mediterranean and Ionian Sea and the configuration of the Cimmerian terranes.

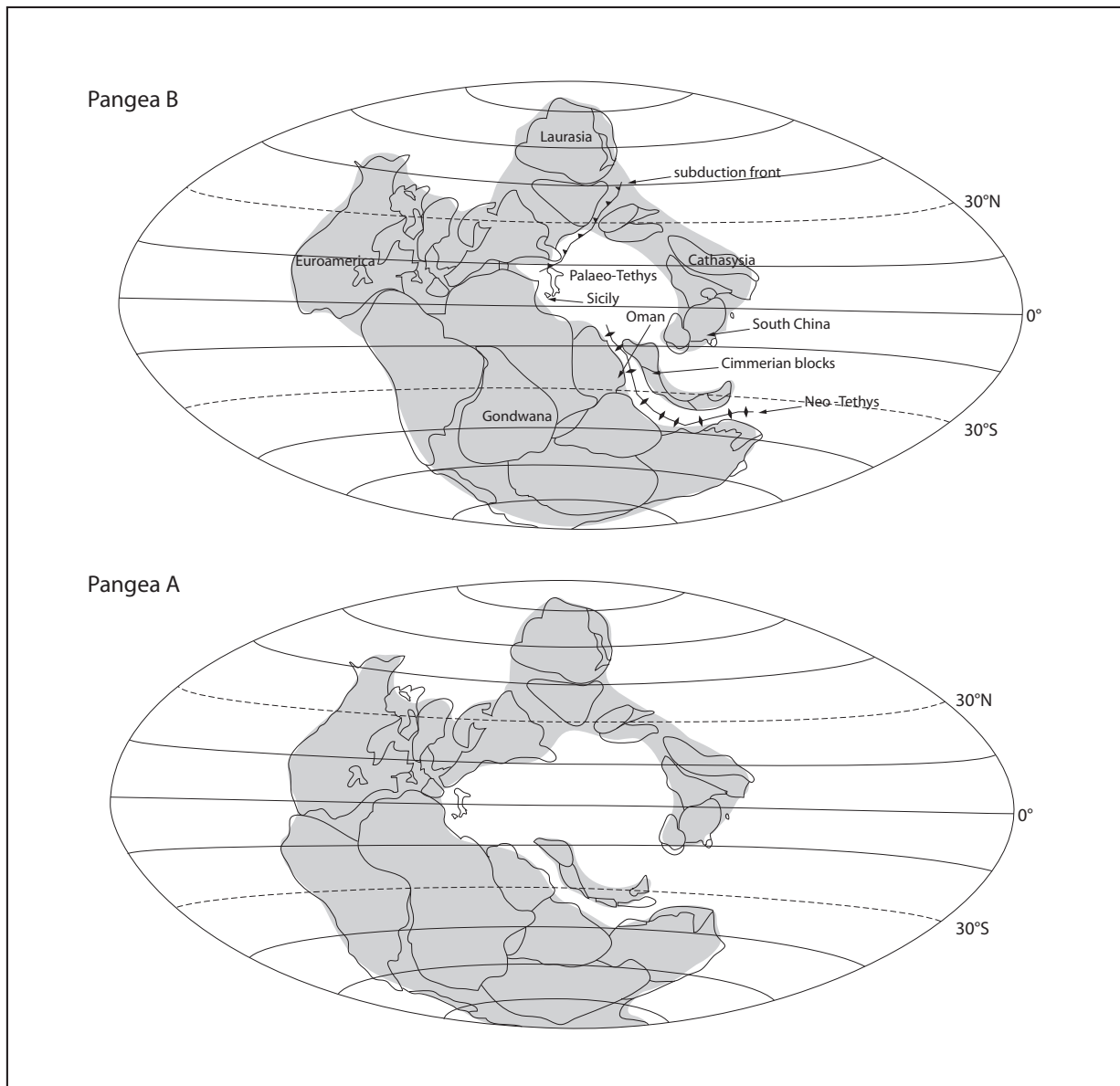


Figure 1.3 Comparison of the palaeogeographic Pangea reconstructions during the Wordian. In the Pangea B configuration Gondwana is located easter with respect to Laurasia reducing the extension of the Tethys ocean (after Bless *et al.*, 1996).

According to the majority of the authors (*e.g.*, Ziegler, 1983; Stampfli, 2000), Gondwana and Laurasia remained fixed in a Pangea A configuration from the Carboniferous to the Jurassic, implying that the Tethyan Ocean was larger. On the contrary, according to Irving (1977), Crasquin-Soleau *et al.* (2001) and Gaetani *et al.* (2003) the Laurasia was located more to west respective to Gondwana in a Pangea B configuration with a Tethys Ocean very reduced in extension (Figure 1.3).

Scandone (1975) suggested that the Central Mediterranean area had been affected by a Middle Triassic rifting that produced a deep basin on a continental crust, a prolongation of the more easterly Palaeo-Tethys Ocean and a Middle Liassic rifting that opened the Central Tethys (Figure 1.4).

The Upper Triassic seaway spread along the northern margin of the future African Plate from Greece to Sicily through Hellenids, Dinarids and Appenines (Monte Facito Formation). This pelagic basin divided in Sicily to form the Imerese and Sicanian Basins, separated by the Trapanese Platform (= old proto-Vicarese platform).

The connection between the Sicanian and Lagonegro Basins from the Middle Triassic times is also confirmed by Montanari & Panzanelli Fratonì (1988; 1990). The Lercara Formation relating to the Sicanian Basin was deposited in a more internal domain, whilst the Monte Facito Formation, pertaining to Lagonegro in a more external domain.

Sengör *et al.* (1984; 1986) and Sengör (1985) proposed an Early to Middle Triassic rift of the southern branch of the Neo-Tethys (being the northern branch situated between the Cimmerian continent and the Apulia-Anatolide-Tauride promontory) in the Eastern Mediterranean Basin which evolved into an actively spreading ridge in the Late Triassic-Early Jurassic at the same time as the opening of the Central Atlantic Ocean. During the Latest Permian to Middle Triassic the Mediterranean area, with the Apulia-Anatolide-Tauride Platforms may be related to Palaeo-Tethyan subduction (Figure 1.4).

Finetti (1982; 1985) is of a similar view and suggests, on the basis of seismic reflection data across the Sicily-Malta escarpment, that the Central Mediterranean was affected by two extensional phases from the Permo-Triassic to the Middle Jurassic. The first phase resulted, during the Middle-Upper Triassic, in a continental rifting of the Sicily-Malta platform and in the Ionian Sea, and a second one, during the Middle Jurassic, opened the Ionian Sea and the Eastern Mediterranean.

Dercourt *et al.* (1993), Dercourt *et al.* (2000), Catalano *et al.* (2001) and Gaetani *et al.* (2003) put forward the view that the eastern Mediterranean was a seaway on thinned continental crust during the Permian time, a continuation of the Palaeo-Tethys Ocean according to Catalano *et al.* (1988c; 1991). But whilst Dercourt *et al.* (2000) proposes, in respect to the Sicily the same situation as for the Eastern Mediterranean, according to Dercourt *et al.* (1993), Sicily was already the westernmost termination of the Neo-Tethys dating from the Late Murgabian (Figure 1.4).

The Neo-Tethys oceanic crust was located in the western part of the Tethyan Realm of the Norian age, situated northwards, between Moesia and Adria (Dercourt *et al.*, 2000; Gaetani *et al.*, 2003). In the Mediterranean area the continental rifting started in the Late Permian and Triassic evolving into oceanic spreading during the late Jurassic-Early Cretaceous (Dercourt *et al.*, 1993; Dercourt *et al.*, 2000; Catalano *et al.*, 2001; Gaetani *et al.*, 2003) (Figure 1.4).

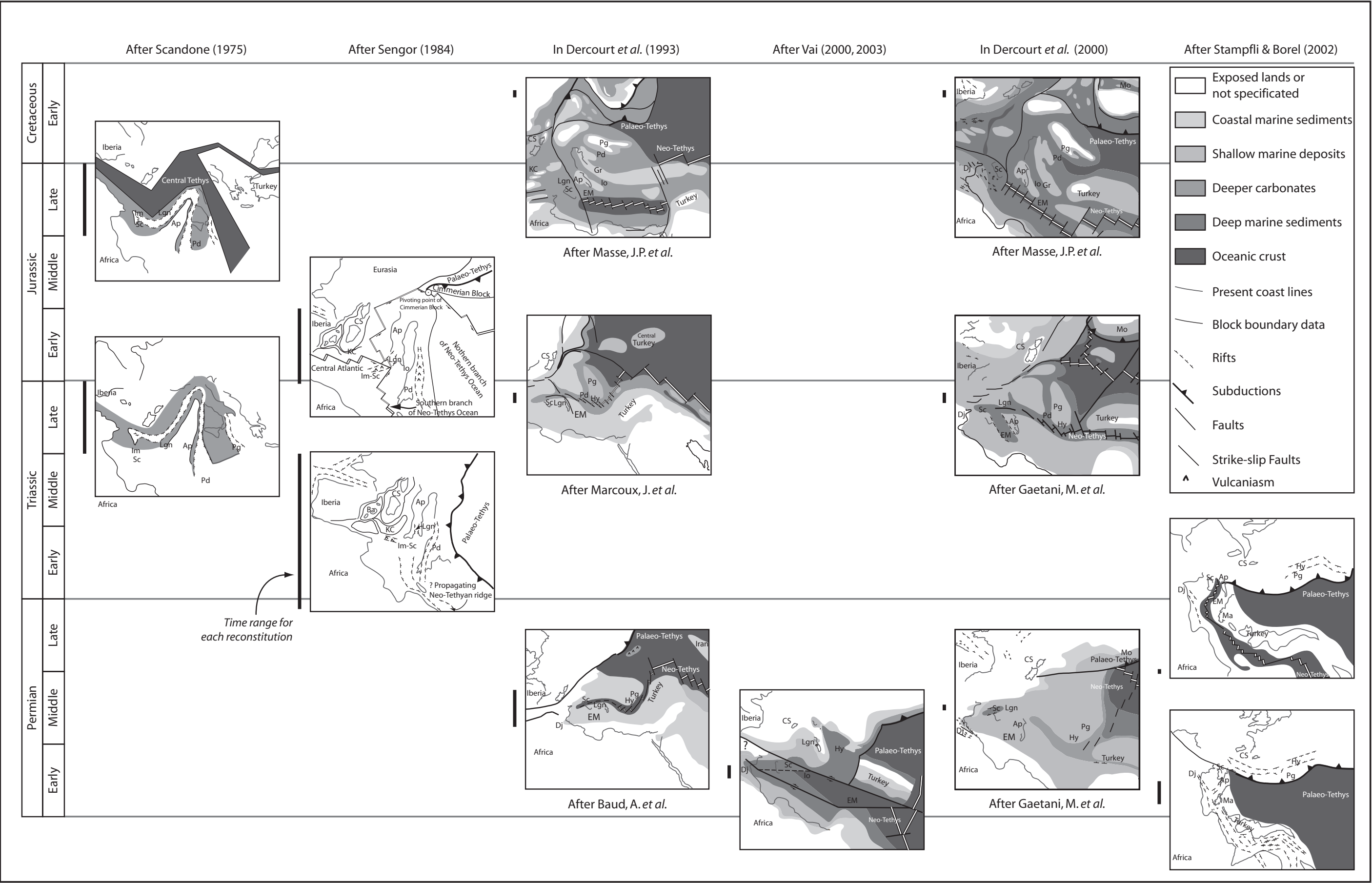
Stampfli *et al.* (2001), Ziegler & Stampfli (2001) and Stampfli & Borel (2002; 2004) have different points of view. They consider that the East Mediterranean Basin was still closed in the Early Permian because at this point in time the island of Sicily showed Kungurian basinal microfauna with Palaeo-Tethys affinity (Kozur, 1990 in Stampfli *et al.*, 2001; Ziegler & Stampfli, 2001). The rifting of the Neo-Tethyan Ocean occurred in the East Mediterranean and the Ionian Sea domain in the late Early Permian, whilst the oceanic flooding occurred in the Middle to Late Permian. The deep-water connection between the eastern part of the Neo-Tethyan Ocean and the East Mediterranean Basin is justified by the presence of similar Wordian Hallstatt-type pelagic limestones and deep-water microfauna found in Timor, Oman and Sicily (Figure 1.4).

Because of this, the Apulian microplate, considered by the authors as an African promontory, separated itself from Gondwana and constituted the easternmost Cimmerian element.

The East Mediterranean and Ionian Basins represent the western end of the Permian Neo-Tethys Ocean also according to Vai *et al.* (2000) and Vai (2003) but the seafloor spreading occurred as early as the Early Permian (Figure 1.4).

With regard more specifically to Sicily, the first palaeogeographical studies and models for the western Sicily, were carried out by Castany (1956), Ogniben (1960), Broquet *et al.* (1966), Broquet (1968; 1970) and Mascle (1970) from an autochthonistic or semiautochthonistic viewpoint. Castany (1956), in a comparative study between the Sicilian and Tunisian zones, identified, during the Permian time a Wildflisch in both Tunisian and Lercara areas (Sicanian Mountains) in conjunction, according to the author, with the Hercynian orogenesis. No Lower Triassic sediments were identified in Sicily, whereas during the Middle to Late Triassic, Sicily was submerged by the sea which deposited sediments of the Mesozoic massif.

Figure 1.4 Comparison of different palaeogeographic reconstructions for the Eastern Mediterranean area: Ap = Apulia; CS = Corso-Sardinian; Dj = Djeffara; KC = Kalabro-Calabria; EM = Eastern Mediterranean; Hy = Hydra; Im = Imerese; Io = Ionian; Lng = Lagonegro; Ma = Mani (Greece); Mo = Moesia; Pd = Pindos; Pg = Pelagonian; Sc = Sicano.



Palaeogeographic Units	Ogniben 1960, 1975	Broquet <i>et al.</i> 1966	Giunta & Liguori 1975	Catalano & D'Argenio 1978	
				Middle Triassic- Carnian	Norian-Liassic
			Internal Zone		
	Sicilide Complex			?	
	Panormide Complex	Panormide Zone	Panormide Platform	Panormide Platform	Panormide Carbonate Platform
	Imerese Complex	Scaflani Zone	Imerese Basin	Panormide	Imerese Basin
	Trapanese Complex	Vicari Zone	Intermediate Platform	Embayment Lercara Basin	Trapanese Carbonate Platform
		Campofiorito- Cammarata Zone	Trapanese Basin		Sicanian Basin
			Sicanian Basin		Saccense Carbonate Platform
	Southern Sicani Mts Complex	Southern Sicani Mts Complex	External Platform	Saccense	

Figure 1.5 Compared palaeogeographic nomenclature of Western Sicily (after Catalano & D'Argenio, 1978).

For Sicily, Ogniben (1960) proposed the following north-south palinspastic section: an internal massif (Calabride complex); a Miogeoanticline (Panormide complex); a Miogeosyncline (Basal and Mesoautoctonous Complex in Imerese facies); and a Foreland (Basal Complex in Trapanese and Hyblean facies).

The “French School” (Broquet *et al.*, 1966; Broquet, 1970; Mascle, 1970) defined the Panormide, Scaflani, Vicari, Campofiorito-Cammarata and Sciacca “zones” naming them on the basis of present geographic position. Broquet *et al.* (1966) offer the view that Sicily was an unstable platform with a differentiated sedimentation “zone”, approximately aligned along an east-west axis. During the Late Triassic, western Sicily was a zone of marine sedimentation consisting of a basin-like area of limestone deposition (Campofiorito-Cammarata zone) bordered by two less deep, but actively subsiding regions (Figure 1.5).

Catalano & D'Argenio (1978) recapitulate the palaeogeographic nomenclature of western Sicily propounded by the antecedent authors (Figure 1.5) and propose a new palaeogeographic evolution of the same area framed in the wider palaeotectonic evolution of the Tethys southern margin (Figure 1.6).

In a first palaeotectonic stage of continental rifting, identified from the Middle to Late Triassic time, the intracratonic Lercara Basin developed. It is characterised by a Middle Triassic clastic sedimentation with alkali-basaltic intercalations and Permian carbonate reworking blocks.

During the Late Triassic, margins of this basin were covered by evaporitic and carbonate sediments of the Panormide and Saccense Platforms “possibly linked along their westward prolongation” (Panormide-Saccense evaporitic carbonate embayment). During the successive tensile Latest Triassic phase, the Lercara Basin evolved in the northern Imerese Basin and in the southern Sicanian Basin, separated by the Trapanese Carbonate platform that probably originated as a result of the Panormide-Saccense embayment (Figure 1.6).

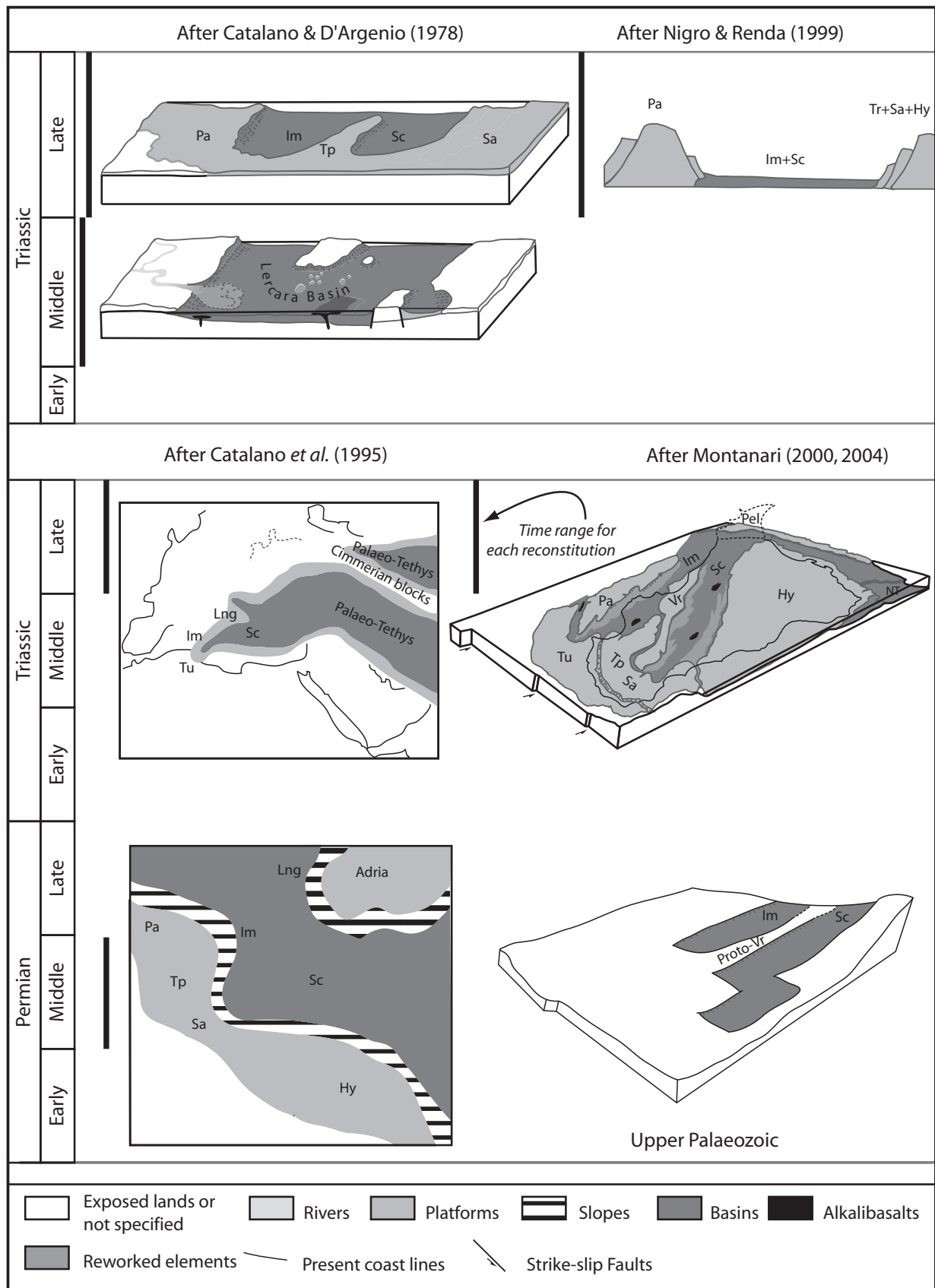


Figure 1.6 Comparison of different Permian to Triassic palaeogeographic reconstructions for Sicily: Im = Imerese; Hy = Hyblean; Lng = Lagonegro; Pa = Panormide; Pel = Peloritan; Sa = Saccense; Sc = Sicano; Tp = Trapanese; Tu = Tunisian; Vr = Vicares; NT= Neo-Tethys.

According to the authors, the Tethyan oceanic rifting developed during the successive Jurassic to Middle Cretaceous palaeotectonic stages. Western Sicily is characterised by basins separated by carbonate platform evolving in seamounts. The axis of rifting shifts northwards and the Panormide Carbonate platform becomes an epioceanic platform.

Successive Late Oligocene-Middle Pliocene compressional phase deformed basins and platforms that were overthrust to the south.

The classical palaeogeographical scheme widely accepted in the literature on the subject (*e.g.*, Ogniben, 1960; Giunta & Liguori, 1973; Catalano & D'Argenio, 1978) consists of connected platforms and basins relating to an ancient African continental margin (Catalano & Montanari, 1979) formed during the Mesozoic extension phase and characterised by a carbonate, silico-carbonate and siliciclastic sedimentation (Catalano & D'Argenio, 1978; Catalano *et al.*, 1978). This scheme has been modified by Montanari (1989), Catalano *et al.* (1995a), and Catalano & Di Maggio (1996) who produced evidence for a more internal position and consequently a geometrically more elevated location of the basinal Imerese and Sicanian Tectonic Units with regard to those at the Panormide, Trapanese and Saccense. Nigro & Renda (1999) confirmed this hypothesis and put forward the view that the Imerese Basin was the internal margin and the junction zone between the Sicanian Basin and the Panormide Carbonate Platform and the Trapanese Domain was the junction between the Sicano Basin and the Hyblean-Pelagian Domain (Figure 1.6).

Montanari (2000) only partially agreed with this new palaeogeographical interpretation. Based on field observations, he considered that the Trapanese domain was more external to the Sicanian Basin and linked to the Hyblean domain so that a "Hyblean-Trapanese" domain was possible, as already advanced by Montanari (Montanari, 1989; 1991). However, he produced evidence to show that the Imerese and Sicanian Basins presented some lithological differences, such as for example, different Cretaceous-Paleogene "Scaglia" and reworked material in both Triassic deposits: of euxinic carbonate of lagoon origin and reefal carbonate in the Sicanian Basins and only of reefal origin in the Imerese Basin. Furthermore, interposed in tectonic contact between the terranes of the two basins, some Dogger shallow water limestone interbedded to Bajocian ammonitic tuffs, cropped out. These limestones belong, according to the author, to a "Vicari" subdomain that separated the two basins since the Upper Palaeozoic and show several stratigraphical and tectonic differences from the Trapanese Domain (Figure 1.6).

According to Montanari (2000), the Vicari sequence crops out around the Vicari and Roccapalumba area and near Mistretta (Central northern Sicily) and it is composed of: 1) Triassic to Liassic loferitic limestones; 2) Dogger shallow water limestones with intercalated Bajocian tuff Fabiani & Ruiz (1933) with Ammonites and Lower, Malm *Protoglobigerines*; 3) Late Malm-Early Cretaceous shallow water limestones; 4) Upper Cretaceous and Paleogene "Scaglia"; 5) Eocene-Oligocene chalk and neritic carbonates; 6) Middle Miocene glauconiferous calcarenites and 7) Serravallian sandy marls.

Based on deep-water fauna of circumpacific affinity such as radiolaria, palaeopsychrospheric ostracods and conodonts of Permian age, found in the Lercara Formation, some authors (Catalano *et al.*, 1988b, c; Di Stefano, 1990; Catalano *et al.*, 1991; Catalano *et al.*, 1995a) suggested that a seaway existed between western Sicily and the Pacific (Panthalassa) during the Permian. This seaway persisted in the Sicanian palaeogeographical realm, where deep-water conditions existed during the Permian-Middle Triassic. From the Permian the Sicanian Basin is then considered the passive margin of the southern Tethys Ocean. This branch of the Tethys separated, during the Permian, Apulia from Gondwanian Africa (Figure 1.6).

In his synthesis concerning the pre-Triassic and Triassic deposits of Sicily and the southern Apennines, Di Stefano (1990) confirmed the classical Triassic palaeogeographic scheme composed of an alternation of carbonate platforms and basins. He admitted that there was a possible coalescence of the platforms westward, and that eastward the Sicanian and Imerese Basins could have formed a large basinal area connected to the Lagonegro Basin.

According to the lithostratigraphic scheme of Triassic deposits, the Permian rocks (Lercara Formation) existed only in the Sicanian Basin. Lower Triassic rocks have not been found in Sicily. Middle Triassic (Ladinian) are present in the Panormide and Sicanian domain. No deposits older than Lower or Upper Carnian are present in the other palaeogeographical domains.

Catalano *et al.* (1995b) however, considered that Permian basinal deposits existed also in the Imerese Basin and propose a new palaeogeographic arrangement for western Sicily. They consider that the Pre-Panormide, Panormide, Trapanese, Saccense and Hyblean domains were a unique platform developed along the Gondwana margin and that the Imerese was the inner margin of the Sicanian Basin (Catalano *et al.*, 1995a; Catalano *et al.*, 1995b).

2 SEDIMENTOLOGY

2.1 INTRODUCTION AND SAMPLING CRITERIA

A stratigraphic reconstruction and interpretation of the Lercara Formation deposits is complex, as demonstrated in previous studies (Montanari & Panzanelli Fratoni, 1990; Di Stefano & Gullo, 1997a, b):

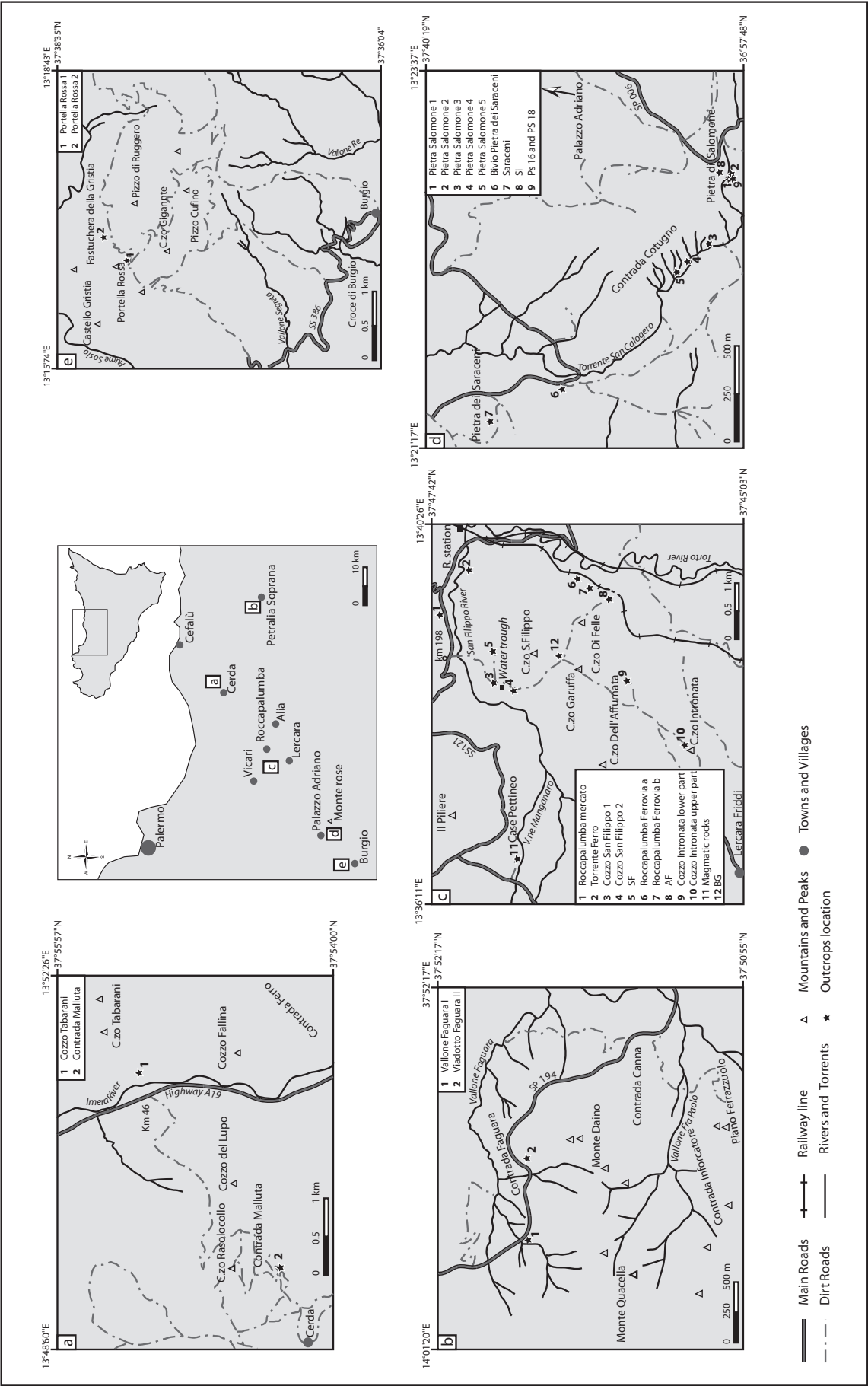
- A strong deformation linked to several tectonic phases that started in the Late Oligocene-Early Miocene has affected the incompetent plastic rocks of the Lercara Formation. At present these deposits consist of small slices tectonically intercalated between Miocene and others Triassic rocks. Field observations are confirmed by subsurface data, derived from the Roccapalumba drill cores (Lercara 1 and Roccapalumba 1) and from seismic (Caflisch & Schmidt Di Friedberg, 1967).
- The outcrops are poorly represented. Indeed only a few short discontinuous outcrops are available because of the tectonic deformation. Due to anthropogenic activity, many outcrops have disappeared. For example, the outcrop “d” described by Catalano *et al.* (1991) close to a small lake around the Roccapalumba station has been destroyed by agricultural ploughing, the huge limestone blocks of the “Valle del Sosio” have been dismantled by the palaeontologists and the unit B of Kozur (1991) destroyed by landslide.
- The lower and upper stratigraphic limits, or an eventual basement on which the Lercara Formation was deposited, have still not been found. Deposits older than the Lercara Formation are absent. In the field, the contact of the Lercara Formation with the supposedly overlying Mufara Formation or equivalents can hardly be recognized.
- A large quantity of material is reworked (about 90% of the micropaleontological content).

All known outcrops of the Lercara Formation have been sampled and where possible short sections have been reconstructed. In chaotic outcrops, scattered samples have been taken in levels or blocks that appeared interesting (Appendices 2.2 to 2.11).

The samples have been collected in order to define the age of the Lercara Formation, reconstruct the deposit environment and determine the degree of diagenesis. Samples from Permian blocks and a few from the Mufara Formation, supposedly of the same age, were taken for clay mineral analysis. In this chapter, only the Lercara Formation deposits are treated. A detailed study of the Mufara Formation deposits has been performed by Carrillat (2001). Therefore, only the description of the outcrops is given in this chapter (Appendix 2.12).

2.2 LOCATION AND FIELD OBSERVATIONS OF STUDIED OUTCROPS

The deposits of the Lercara Formation are of terrigenous origin. The most widespread lithotypes are quartz-rich shales and clayey sandstones followed by fine calcarenites to calcirudites. Scattered limestone blocks, a metre to several metres in diameter occur between Roccapalumba and Burgio.



The outcrops' coordinates, measured on the C.T.R. (Carta Tecnica Regionale) topographical maps at scale 1:10,000 edited by the *Assessorato Territorio e Ambiente* of the *Regione Siciliana*, have been expressed according to the WGS84 system. The corresponding UTM and Gauss-Boaga coordinates are indicated in Appendix 1.

The outcrops are presented from north to south (Figure 1.1). Pictures are shown in Plates 1 to 3. Detailed lithological logs of the Lercara Formation, petrographic details of each sample are given in the Appendices 2.2 to 2.11. Lithological logs of the Mufara Formation can be found in the Appendix 2.12.

Cozzo Tabarani (Mufara Formation; Imerese Domain)

Location: 37°55'21" N, 13°51'28" E, along the Imera River eastern shore, at the base of Cozzo Tabarani, in front of km 46 of highway A19 (Figure 2.1.a)

Lithological description: only the lower part of this outcrop has been sampled. It corresponds to the "*Cerda-Nicosia section*" of Carrillat (2001) interpreted by this author as the transition between the Mufara and Lercara Formations. The section consists of about 4 metres of quartz-rich shales, intercalated by decimetric layers of packstone.

Samples name number: CT 1-4

Contrada Malluta (Mufara Formation; Imerese Domain)

Location: 37°54'22" N, 13°50'22" E, west of Cerda in Contrada Malluta (Figure 2.1.a).

Lithological description: small section of about 5 metres of marly sandstones which, at the top, become finely bedded pencil quartz-rich shales. Scattered blocks of metric boundstone are found in the upper part.

Samples name number: CM 1-5

Viadotto Fagura II (Mufara Formation; Panormide Domain)

Location: 37°51'52" N, 13°02'22" E, north of Petralia Sottana along the road SP194 in Contrada Fagura before the second bridge (Figure 2.1.b).

Lithological description: small outcrop of about 5 metres of greenish marls and clayey marls intercalated by calcarenites. It corresponds to the "*Contrada Fagura section*" of Carrillat (2001). Rare bioturbations can be observed.

Samples name number: VFII 1-3.

Vallone Fagura I (Mufara Formation; Panormide Domain)

Location: 37°51'51" N, 13°01'57" E, at the north of Petralia Sottana along the road SP194 in Contrada Fagura before the first bridge (Figure 2.1.b).

Lithological description: small outcrop of about 2.5 metres of greenish marls and clayey marls intercalated by calcarenites. It corresponds to the "*Vallone Fagura section*" of Carrillat (2001). The calcarenites show parallel lamination and the greenish marls and clayey marls show a pencil cleavage.

Samples name number: VFI 1-3

Roccapalumba Mercato (Lercara Formation; Sicanian Domain)

Location: 37°37'46" N, 13°39'20" E, between the village of Roccapalumba and the railway station, at km 196 of the road SS121 on the left side (Figure 2.1.c).

Lithological description: Section of about 7 metres of mainly greyish to reddish nodular quartz-rich shale intercalated by coarse calcarenites to calcirudites. It corresponds to the "*Roccapalumba Nuovo Mercato*" of Carrillat (2001). The coarse calcarenites to calcirudites show erosional contact and a normal gradation. *Nereites* ichnofacies have been observed along this section.

Samples name number: RP 16-29

Torrente San Filippo (Lercara Formation; Sicanian Domain)

Location: 37°47'27" N, 13°39'30" E, along the Torrente San Filippo, about 500 metres south south-west of the Roccapalumba train station (Figure 2.1.c).

Lithological description: small outcrop of about 3 metres of nodular quartz-rich shales intercalated by a level of clayey sandstone.

Samples name number: TF 1-4

Cozzo San Filippo 1 (Lercara Formation; Sicanian Domain)

Location: 37°47'24" N, 13°38'34" E, south of Roccapalumba by the water trough on the dirt road, leading to Cozzo San Filippo, accessed from SS121 at km 198 (Figure 2.1.c).

Lithological description: small outcrop of about 3 metres of clayey sandstone.

Samples name number: CSF 1-4

Cozzo San Filippo 2 (Lercara Formation; Sicanian Domain)

Location: 37°47'11" N, 13°38'34" E, in the south of Roccapalumba on the dirt road, accessed from SS121 at km 198 to Cozzo San Filippo, after the water trough (Figure 2.1.c).

Lithological description: monotonous tectonically affected section of inestimable extension, because of faults and folds, of centimetric to decimetric clayey sandstones rich in fine plant detritus. The succession continues with red nodular quartz-rich shale with intercalation of centimetric coarse calcarenites. The stratigraphic relation between these two parts is not obvious in the field.

The clayey sandstones form massive decimetric thick-layers with rare clayey intercalations.

Samples name number: CSF 5-18

Roccapalumba Ferrovia (Lercara Formation; Sicanian Domain)

Location: 37°46'34" N, 13°40'04" E, along the railway line south of Roccapalumba train station and east of Cozzo di Felle (Figure 2.1.c).

Lithological description: two sections 300 metres distant from each other have been sampled. The sections are 11 and 12 metres thick.

The first section, labelled *Roccapalumba Ferrovia a*, is mainly composed of greenish to reddish quartz-rich shales intercalated by coarse calcarenites and corresponds to the "*section c*" of Catalano *et al.* (1991) in the Roccapalumba-Lercara area. In the first about 8 metres, clayey sandstones and coarse calcarenites show erosional contacts, parallel lamination and are normally graded. The last 3 meters are constituted of a sinsedimentary slump; the clayey sandstones and coarse calcarenites are less thick and are reverse graded.

The second section, labelled *Roccapalumba Ferrovia b*, is composed of greenish quartz rich shale intercalated by decimetric clayey sandstone and corresponds to “section a” of Catalano *et al.* (1991) in the Roccapalumba-Lercara area and to “*Roccapalumba Ferrovia*” of Carrillat (2001). Clayey sandstones show parallel lamination or parallel cross bedding, some including flute casts and the trace fossil *Nereites*.

Samples name number: RPFa 1-11; RPFb 1-15.

Cozzo Intronata (Mufara Formation; Sicanian Domain)

Location: Lower part 37°45'28" N, 13°37'44" E. Upper part 37°51'45" N, 13°38'08" E. Outcrops are located in the south of Roccapalumba on the dirt road accessible from route SS121 at km 198, and which goes to Cozzo San Filippo and Cozzo Intronata. The lower part is located at Cozzo Intronata and the upper part between Cozzo Intronata and Cozzo Garuffa between the dirt road and the Vallone Freddicelli (Figure 2.1.c).

Lithological description: the lower part (about 4 metres) shows alternations of finely bedded marly sandstones and marls, with a few levels of calcarenites. The upper part (about 5 metres) starts with an alternation of decimetric well-stratified limestones with intercalation of calcareous marls and continues with layers of calcirudites with intercalations of calcareous marls.

This outcrop of the Mufara Formation, not studied by Carrillat (2001), pertain to the Sicanian Domain.

Samples name number: CI 3-9

Pietra di Salomone (Lercara Formation; Sicanian Domain)

Location: 37°39'26" N, 13°22'20" E. Outcrops are located south of Palazzo Adriano, around the Pietra di Salomone on the dirt road, accessed from route SP006 at km 3.8 (Figure 2.1.d).

Lithological description: *Pietra di Salomone 1* and *2*: small sections of about 7 and 4 metres located 50 metres south of the Pietra di Salomone. They correspond respectively to the “*Olistostrome Unit*” and to the “*bedded cherts, tuffites and cherty limestones*” of the Torrente San Calogero sections described by Catalano *et al.* (1991).

The first outcrop mainly shows chaotic gray quartz-rich shales intercalated in the lower part by clayey sandstones and in the upper part by decimetric to metric blocks composed of boundstone. The second one exhibits red quartz-rich shales intercalated by centimetric bed of fine calcarenites.

Pietra di Salomone 3 to 5: 3 sections of respectively 5, 6 and 16 metres located 500 metres west of the Pietra di Salomone. They are constituted mainly of chaotic grey quartz-rich shales intercalated by centimetric clayey sandstones and some coarse calcarenites. Flute clasts and an erosional contact occur at the bottom of the clayey sandstones and coarse calcarenites levels.

Samples name number: PS 1-43

Portella Rossa (Lercara Formation; Sicanian Domain)

Location: two very similar sections have been sampled here. The first section, *Portella Rossa 1*, is located at 37°38'03" N, 13°16'51" E, and the second, *Portella Rossa 2*, at 37°38'12" N, 13°16'58" E. Outcrops are located north of Burgio on the dirt road, leaving the route SS386 near “Croce di Burgio”. Section 1 has been surveyed at the crossroad of Portella Rossa; section 2, 100 metres further to the south in “Fastuchera della Gristia” (Figure 2.1.e).

Lithological description: small sections of about 4 metres and 6 metres of nodular red quartz-rich shales with some intercalated levels of white fine calcarenites. The fine calcarenitic levels show erosional surfaces and constitute massive or laminated layers in *Portella Rossa 1* and *Portella*

Rossa 2, respectively. In the area between the two sampled sections, scattered metric limestone blocks are present.

Samples name number: PR 16-29

Isolated samples

Magmatic occurrence (*Bas*) near “Case Pettineo” have been sampled (coordinates: 37°42'02" N, 13°36'34" E) (Figure 2.1.c). It consists in decametric block of altered granodiorite (Plate 3, figure 5).

The samples *San Filippo* (SF1 and 2) and *Affumata* (AF) have been collected around Cozzo San Filippo and Cozzo di Felle in the Lercara-Roccapalumba area (coordinates: 37°47'22" N, 13°38'42" E and 37°46'17" N, 13°39'30" E, respectively) (Figure 2.1.c) and consist of quartz-rich shale.

Decimetric isolated calciruditic blocks (BG1 and 2) have been sampled at the Bivio Garuffa crossroad on the dirt road accessed from SS121 at km 198 that goes on to Cozzo San Filippo (coordinates: 37°46'39" N, 13°38'49" E) (Figure 2.1.c)

The sample *Saraceni* (Sar) has been taken from a huge carbonate block of Pietra dei Saraceni (coordinates: 37°40'12" N, 13°21'32" E) (Figure 2.1.d).

The samples *Bivio Saraceni* (BS1 and 2) have been collected at the crossroad located south-west of Palazzo Adriano, accessible by a dirt road in the direction of Pietra dei Saraceni (coordinates: 37°39'40" N, 13°21'33" E) (Figure 2.1.d). It is constituted of red quartz-rich shales.

The samples Si 123, 138, 141, 142, 145, 164 have been collected between Pietra di Salomone (coordinates: 37°39'26" N, 13°22'20" E) and the road SP006, where several large carbonate blocks crop out (Figure 2.1.d).

The samples PS 16 and 18 have been collected 50 metres west of Pietra di Salomone (coordinates, 37°39'26" N, 13°22'20" E). The sample PS 16 derives from a large carbonatic block, dipping into a quartz-rich shale matrix in which sample PS 18 was collected (Figure 2.1.d).

2.3 MICROFACIES ANALYSIS

Genetic microfacies were derived from the polarising microscopic observation of 167 thin sections and from the bulk rock mineralogy. The clasts have been classified based firstly on their origin, *i.e.* extrabasinal (older than deposition of the Lercara Formation) and intrabasinal (coeval with the Lercara Formation), and their composition.

For the siliciclastic rocks the grain size nomenclature of Folk (1980) has been used, adding where possible, an attribute in order to specify the composition of the clasts. For clast-dominated carbonate the Grabau's terminology has been used (Grabau, 1913). For the carbonate rocks, the Dunham's nomenclature (Dunham, 1962) was used.

Overall, eight microfacies labelled A to H have been identified and their characteristics are showed in Table 2.1 and illustrated in Plates 4 to 11 with their petrographic composition.

Hereafter the intrabasinal and extrabasinal components have been listed. The age assignment of some clasts is difficult, because the main components (micropaleontological like *Tubiphytes* or fragments of packstone with peloidal micritic intraclasts and porcelaneous organisms) commonly occur both in Triassic and Permian patch reefs.

2.3.1 INTRABASINAL COMPONENTS

Intrabasinal components are principally composed of rip-up clasts and carbonate fragments. They constitute less than 5% of the clasts and are absent in some levels.

RIP-UP CLASTS

Rip-up clasts, found in the microfacies A, B, D, and E have the same composition as the underlying levels made up of quartz-rich shales. They can therefore be interpreted as penecontemporaneous grains

Microfacies	Lithology	Textural maturity	Compositional maturity	Grain size	Sorting	Roundness	Intrabasinal components	Extrabasinal components	Matrix/Cement
A	Calcirudite	Mature	Immature	>2mm	Well sorted	Rounded to well rounded	Rip-up quartz-rich shales	Abundant carbonate fragments Rare clasts of clayey sandstones	Drusy mosaic
B	Coarse calcarenite	Mature	Immature	500 μm < d < 1 mm	Very well sorted	Subangular to rounded	Carbonate fragments Rip-up quartz-rich shales	Some quartz particles Abundant carbonate fragments Rare clasts of clayey sandstones Quartz and few feldspars	Early diagenetic fibrous Late diagenetic drusy mosaic
C	Coarse calcarenite	Submature	Immature	88 μm < d < 710 μm	Poorly sorted	Subrounded to rounded	Rip-up quartz rich shales Carbonate fragments	Abundant carbonate fragment Abundant quartz particles Few feldspars	Quartz/argillaceous matrix Quartz cement
D	Medium calcarenite	Submature	Immature	88 μm < d < 500 μm	Poorly sorted	Subrounded to rounded	Rip-up quartz-rich shales	Abundant carbonate fragment Abundant quartz particles Few feldspars	Quartz/argillaceous matrix Quartz cement
E	Fine calcarenites	Mature	Immature	125 μm < d < 50 μm	Well sorted	Subrounded to rounded	Carbonate fragments Rip-up quartz-rich shales	Abundant carbonate fragment Late diagenetic drusy mosaic Abundant quartz particles Few feldspars	Early diagenetic fibrous Late diagenetic drusy mosaic
F	Clayey sandstone	Immature	Immature	d < 250 μm	Poorly sorted	Subangular to rounded	-	Quartz Clay and feldspars	Argillaceous matrix
G	Quartz-rich shale	Immature	Immature	d < 62.5 μm	Poorly sorted	-	-	Clay Quartz and few feldspars	Argillaceous matrix
H	Boundstone	-	-	-	-	-	Sessile encrusting organisms Foraminifera	-	Radiaxial Bothryoidal

Table 2.1 Microfacies of the Lercara Formation.

eroded by high energy turbidity currents that affected the depositional basin (Zuffa, 1985). Information about the age of the clasts could not be obtained because of the absence of fauna.

CARBONATE FRAGMENTS

Intrabasinal carbonate components have been found in microfacies B, D and E. They are constituted of rare sessile and vagile foraminifera. These components, in addition to assigning the Lercara Formation to the Triassic, as will be seen in the chapter Biostratigraphy, can be used as environmental indicators.

Paleontological content of intraclasts

Foraminifera

Cucurbita Jablonsky, 1973 is a typical sessile reefal foraminifer (Zaninetti & Martini, 1992) commonly associated with sponge and “hydrozoan” communities (Bernecker, 1996). Specimens of *Cucurbita* have been found in cemented carbonatic fragments in some levels of the Lercara Formation and in the calcarenitic levels of Cozzo Intronata (Plate 28, Figure 5 and 6) outcrop pertain to the Mufara Formation.

Benthic vagile foraminifera *Endotebanella kocaensis* (Dager, 1978), “*Trochammina*” sp. Parker & Jones, 1859, and Duostominidae lived in carbonate platforms associated with Dasycladacean algae and calcareous sponges (Rettori, 1995; Rüffer *et al.*, 1997; Falletti & Ivanova, 2003; Fugagnoli & Posenato, 2004; Emmerich & Zamparelli, 2005).

Discussion

In Sicily, the above-mentioned Triassic Foraminifera have been reported in the Ladinian?-Carnian calcarenitic levels of the Mufara Formation deposited in the Imerese Domain. They are associated with the foraminifer *Hydrania dulloi*, sphinctozoan sponges, calcareous algae and encrusting microproblematica (Senowbari-Daryan & Abate, 1986; Martini *et al.*, 1991a, b; Carrillat, 2001). In places reefs, from which blocks, found in the Mufara Formation may have derived, are not exposed.

The finding of these same foraminifera in the Lercara Formation and in the Cozzo Intronata outcrop of the Mufara Formation implies that the Ladinian?-Carnian carbonate platform was bordered by bioconstructions that feed the Mufara Formation deposited in the Imerese Domain, and supplied fragments also in the Lercara and Mufara Formations of the Sicilian Basin.

The above-mentioned foraminifera are illustrated in the chapter 3.

2.3.2 EXTRABASINAL COMPONENTS

Extrabasinal components, posterior to the deposition of the Lercara Formation, consist of carbonate fragments, clasts of clayey sandstones, quartz and feldspars. They constitute more than 95% of the clasts and provide information about the source area.

CARBONATE FRAGMENTS

Allochthonous carbonates can be found as fragments in microfacies A to E and constitute the facies H. In facies A to E, their size is rather uniform and they are subrounded to well rounded. These calcareous clasts are constituted of wackestones, packstones or grainstones and boundstones. Mollusks, brachiopods, sponge spicules, bryozoans, foraminifera, echinoid and crinoid spines, sponges, arthropods, radiolarian, and conodonts without their original matrix can also be found.

Wackestones contain test of calcified radiolarian and sponges spicules. Packstones or grainstones are composed of peloids, micritic intraclasts, *Koivaella*, foraminifera and dasycladale

algae. Fragments of *Archaeolithoporella*, *Tubiphytes*, bryozoans, ostracods, brachiopods, echinoid spines and crinoid spines are less common. Boundstones (Plate 11) show sessile organisms such as *Archaeolithoporella*, *Tubiphytes*, inozoan sponges and bryozoans. These organisms are cemented by botryoidal syndimentary carbonate cements. Voids are filled with micritic or pelsparitic sediment or obstructed by radiaxial cement. Fragments of boundstones can be found in the facies A to E and compose the facies H. These calcareous clasts are of different ages: Early to Late Permian, Early and Middle Triassic.

Likewise, the Upper Ladinian-Lower Carnian bioconstructions, the Permian to Anisian rocks that have produced fragments found in the Lercara Formation, are not exposed.

Paleontological content of Lower to Upper Permian clasts

A diversified flora and fauna of the Early to Late Permian can be found in the fine calcarenites to calcirudites of the Lercara Formation. They are represented by bentonic vagile and sessil foraminifera, fusulinids, bryozoans, brachiopods, gastropods, ammonites, crinoids, ostracods, trilobites and dasycladacean algae. They constitute about 85% of the clasts. Smaller and larger foraminifera, ostracods and conodonts are described in the chapter on Biostratigraphy.

CYANOBACTERIA

Aphralysiaceae Vachard in Vachard *et al.*, 2001a

Archaeolithoporella hidensis is a common and widespread Permian reef builder associated with *Tubiphytes*. Such reefs have a significant relief. *Archaeolithoporella* oncolites are a crust of cyanobacteria and often form regular, crenulated laminae around specimens of *Tubiphytes*, inozoan sponges, crinoid spines or bryozoans. (Plate 12, Figures 1 to 4). *Archaeolithoporella* oncolites have been reported throughout the Permian: Middle Permian of Slovenia (Flügel *et al.*, 1984), Late Permian of the Pietra di Salomone megablock of Sicily (Flügel *et al.*, 1991), Yakhtashian to Dzhulfian of the Batain Plain, Oman (Vachard *et al.*, 2001a).

Bacinella sp. Radoicic, 1959 (Plate 12, Figure 5) is a cyanobacterial micritic biofilm that contributes to the building of reefs. Phylogenically, it seems to derive from *Archaeolithoporella* (Vachard *et al.*, 2001a). This genus has been reported since the Sakmarian in the Carnic Alps (Kochansky-Devidé, 1970), in the Kubergardian of Afghanistan (Blaise *et al.*, 1978), in the Kubergardian and Murghabian of Afghanistan (Chen & Bao, 1986), in the Artinskian of the Lercara Formation (Vachard *et al.*, 2001b). Recently it has been found in the Visean of France (Pille, in preparation).

ALGAE

Dasycladales Pascher, 1931

Mizzia sp. Schubert, 1907 (Plate 12, Figure 6) is characteristic of shallow environments with a low hydrodynamic regime and normal salinity conditions (Kirkland & Moore, 1990). This genus has been known since the Early Permian (Herak *et al.*, 1977).

PSEUDOALGAE

Chuvashovia densifolia Vachard in Vachard & Montenat, 1981 (Plate 12, Figure 7) has been reported in the Kubergardian to Murghabian of Afghanistan (Vachard *et al.*, 2001a) and in the Midian of the Batain Plain (Vachard *et al.*, 2001a).

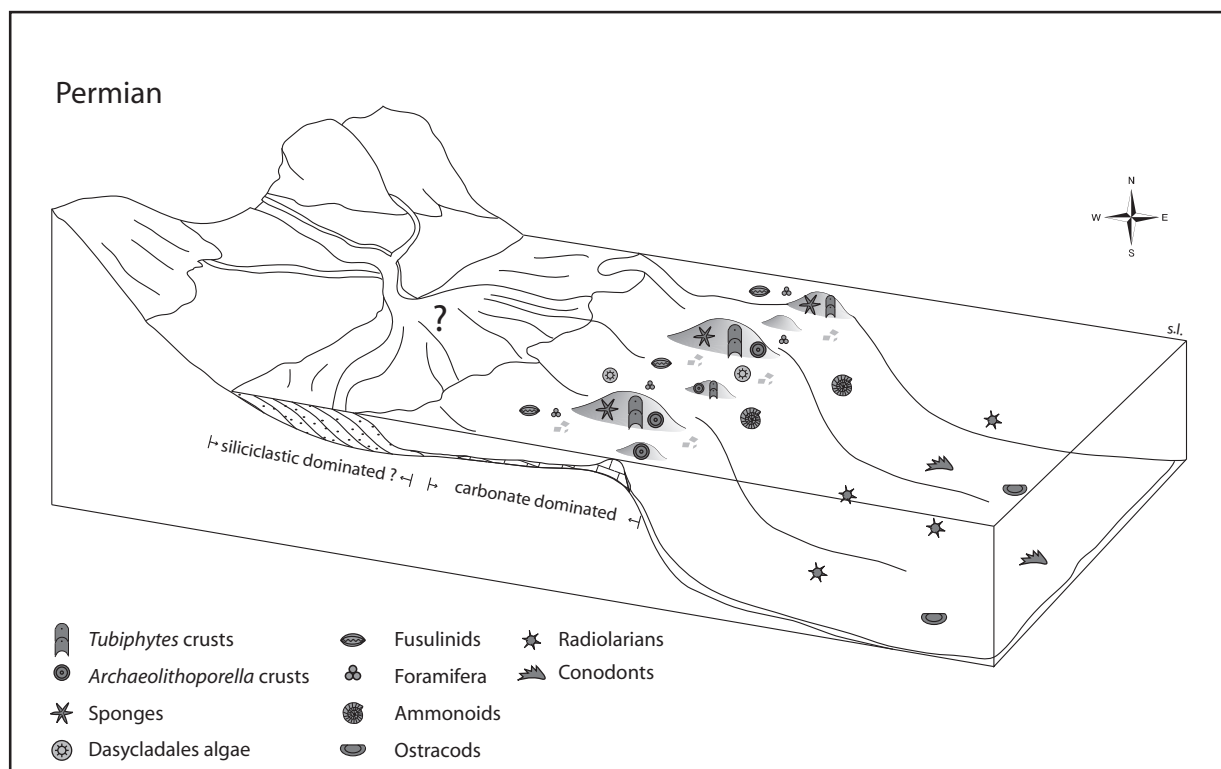


Figure 2.2 Depositional setting for the Permian.

Problematica algae

Koivaella permensis Chuvashov, 1974 (Plate 12, Figure 8). This species has been described in the Latest Carboniferous and Early Permian of the Western Urals (Chuvashov, 1974), in the Early to Late Permian of Afghanistan (Vachard, 1980), in the Middle Permian of Slovenia (Flügel *et al.*, 1984), in the Early Midian of Batain Plain, Oman (Vachard *et al.*, 2001a) and in the Lercara Formation (Vachard *et al.*, 2001b). It is often mentioned as tube-like. It occurs preferentially in intertidal environments (Vachard, 1980).

Incertae sedis

Pseudovermiporella elliotti Erk & Bilgütay, 1960 (Plate 13, Figure 1) is interpreted as a porcelanaceous foraminifer. It is known in the Bolorian of Turkey (Flügel, 1990) and in the Midian of the Batain Plain, Oman (Vachard *et al.*, 2001a).

Tubiphytes Maslov, 1956, is interpreted by Vachard in Vachard *et al.* (2001a) as a free cyanobacteria or alga developed in symbiosis with other organisms. Two species, *Tubiphytes obscurus* Maslov, 1956 (Plate 13, Figure 2) and *Tubiphytes carinthiacus* (Flügel, 1966) (Plate 13, Figure 3) have been found in the Lercara Formation. *Tubiphytes obscurus* and *Tubiphytes carinthiacus* are cosmopolitan species known from the Moscovian to the Early Cretaceous (Vachard *et al.*, 2001a) and from the Permian (Senowbari & Flügel, 1993) respectively.

Miscellaneous fossils

The other faunal components of the Lercara deposits are molluscs represented by gastropods (Plate 10) and juvenile ammonites with a goniatitic suture (Plate 13, Figure 4), brachiopods, sponge spicules

(Plates 4 and 10), bryozoans (Plate 13, Figure 5), foraminifera, echinoderms spines (Plate 6 and Plate 12, Figure 3), arthropods including trilobites (Plate 13, Figure 6) and ostracods, radiolarians composed of calcite (Plate 13, Figure 7) and conodonts (Plate 7). They are often found without their original matrix.

Radiolarians found in the quartz-rich shales are always recrystallised and not determinable.

Palaeopsychrospheric ostracods, conodonts and radiolarians point to a deep-water environment during the Permian of an area of deep deposition (see chapter 3). Thus the conodonts found during this work (see chapter 3) show that basinal conditions existed during the Rodian-Wordian (Kubergardian-Murghabian). But according to Catalano *et al.* (1991) and Gullo (1993) deep conditions of deposition existed since the Kungurian.

Discussion

Given the numerous Permian elements and the occurrence of huge blocks of Permian limestones (Pietra di Salomone, Pietra dei Saraceni, Pietra di San Calogero and other smaller blocks), the reconstitution of the palaeodepositional setting for the Permian is less difficult than for the Triassic (Figure 2.2). Pietra dei Saraceni, Pietra di San Calogero, and Pietra di Salomone are the remains of reefal limestones built by sphinctozoan sponges, bryozoans and brachiopods (Aleotti *et al.*, 1986). These blocks were interpreted as Wordian in age by Miller & Furnish (1940), Bender & Stoppel (1965) and Skinner & Wilde (1966) and to the Artinskian by Vachard *et al.* (2001b). According to Flügel *et al.* (1991) the Pietra di Salomone represents debris-flow and turbidite sediments derived from a carbonate periplatform during the Late Permian and deposited in a base-of-slope position.

In order to further constrain the reconstitution, we have compared remnants of the “Permian Sicilian platform” with other better known Permian reefs from the Early Permian of the Southern Alps (Flügel, 1981) and Ural (Chuvachov, 1983), the Middle to Upper Permian Capitan Reef Complex (Longacre, 1983; Kirkland & Moore, 1990), the nearest Middle and Upper Permian reef of the Southern Tunisia (Toomey, 1991). During the Permian small organic build-ups, mostly patch reefs, developed in Sicily. The reef biota was dominated by low-lying *Tubiphytes/Archaeolithoporella* crust reefs associated with bryozoans and calcisponge/algal reefs, encrusting foraminifera, echinoderms and brachiopods. Detailed descriptions of calcisponges of the Lercara Formation can be found in Senowbari Daryan & Di Stefano (1988) and Flügel *et al.* (1991). These build-ups were stabilized by a large amount of syndimentary carbonate cements (Plate 11) and the voids subsequently filled with micritic and pelsparitic sediments (Plate 11). No corals have been found during this work but solitary rugose corals have been reported by Montanaro-Gallitelli (1956).

These organic build-ups were located in a high-energy shallow marine environment, as testified by the high amount of early diagenetic submarine botryoidal cements (Brandner *et al.*, 1991). In lower energy environments, between the patch-reefs or in back-reefs lived smaller foraminifera, fusulinids, trilobites and dasycladales (Figure 2.2). In these environments the precipitation of carbonate cement was scarce and the space between organisms is less cemented (Kirkland & Moore, 1990).

Permian bioherms that produced carbonate fragments and blocks in the Lercara Formation existed from the Early Yakhtashian (late Early Permian) to the Lopingian (Late Permian) as documented by the microfauna (see chapter 3) to the Latest Permian (Jenny-Deshusses *et al.*, 2000). Our data are too scarce to state if a change in the composition of reef associated biota occurred and if these carbonate platform environments were continuous in time or alternated with terrigenous supply or periods of non sedimentation/erosion.

During the Rodian-Wordian, this platform was associated to a deep basin, attested by the presence of radiolarians, ostracods and conodonts.

Paleontological content of Lower and Middle Triassic clasts

Lower and Middle Triassic fossils are represented by rare sponges and vagile foraminifera. They constitute a very negligible fraction. The reader is referred to the discussion about the Triassic foraminifera in chapter 3.

Sponges

Sphinctozoan sponge *Uvanella irregularis* Ott, 1967 (Plate 13, Figure 8) is a common encrusting sponge of Ladinian and Carnian reefs (Brandner *et al.*, 1991; Bernecker, 1996). This species has been found in the Ladinian of the Western Dolomites (Brandner *et al.*, 1991), in the Carnian of the Oman Mountains (Bernecker, 1996), in the Anisian?-Ladinian of the Monte Facito Formation (Southern Apennines) (Ciarapica *et al.*, 1990b) and in the Ladinian to Carnian of the Northern calcareous Alps (Rüffer *et al.*, 1997). A single exemplar of *Uvanella irregularis* has been found (sample Rp19).

Foraminifera

Meandrospira pusilla (Ho, 1959) is a good indicator of detrital coastal facies, of meso- to infralittoral environments in the Upper Scythian-basal Anisian of all the Tethyan domain (Salaj *et al.*, 1983; Rettori, 1995).

Endotriadella wirzi (Koehn-Zaninetti, 1968) emend. Vachard *et al.*, 1994, “*Trochammina*” aff. *almtalensis* Koehn-Zaninetti, 1968, *Hoyenella* gr. *sinensis* (Ho, 1959) and *Pilamina* cf. *densa* Pantic, 1965 are associated with the development of carbonate platforms with dasycladacean algae and calcareous sponges (Rettori, 1995; Martini *et al.*, 1996; Rüffer *et al.*, 1997; Falletti & Ivanova, 2003; Fugagnoli & Posenato, 2004; Emmerich & Zamparelli, 2005).

Discussion

With regard to these foraminifera and sponges, we will see in the chapter on biostratigraphy that the presence of *Endotriadella wirzi*, “*Trochammina*” aff. *almtalensis*, *Hoyenella* gr. *sinensis*, *Pilamina* cf. *densa* and *Uvanella irregularis* suggest that one Anisian and/or Ladinian carbonate platform developed in the vicinity of the Sicanian Basin. This platform has been completely eroded during the deposition of the Lercara Formation.

Concerning the presence of *Meandrospira pusilla*, it presupposes the existence during the Early Triassic (Olenekian) of a siliciclastic platform correlatable to the Lower Triassic detrital platform of Tunisia (Kamoun *et al.*, 2001) and Lagonegro (Ciarapica *et al.*, 1990a). Therefore, Lower Triassic siliciclastic deposits, as quartz and clays, containing the foraminifer *Meandrospira pusilla*, have been reworked in the Lercara Formation.

The above mentioned foraminifera are illustrated in the chapter of biostratigraphy

QUARTZ

Quartz is the principal component of the clayey sandstones (microfacies F) and can be found in lower quantities in the facies A to E and G. Quartz grains are subangular to rounded and in the same sample can present a slightly undulated or straight extinction. Generally, a straight extinction indicates a volcanic origin while a strongly undulating one results from lattice dislocations and indicates a metamorphic origin (Basu, 1985). However, quartz extinction alone is not sufficient to indicate the source rock (Blatt & Christie, 1963), especially if sediments have undergone a strong diagenesis (Götze & Zimmerle, 2000). A slight undulation may derive in our case from the tectonic deformations that affected the Lercara deposits. This assumption is confirmed by the deformation of the carbonatic clasts, stylolites and fractures observed in thin sections.

For each sample containing quartz, cathodoluminescence (CL) characteristics have been observed in polished and uncovered thin sections. To determine the origin of the monocrystalline quartz we used a Technosyn 8200 MKII luminoscope mounted on a Leitz polarising microscope. Cathodoluminescence is a reliable characteristic to determine the provenance of detrital quartz. Thin sections have been exposed

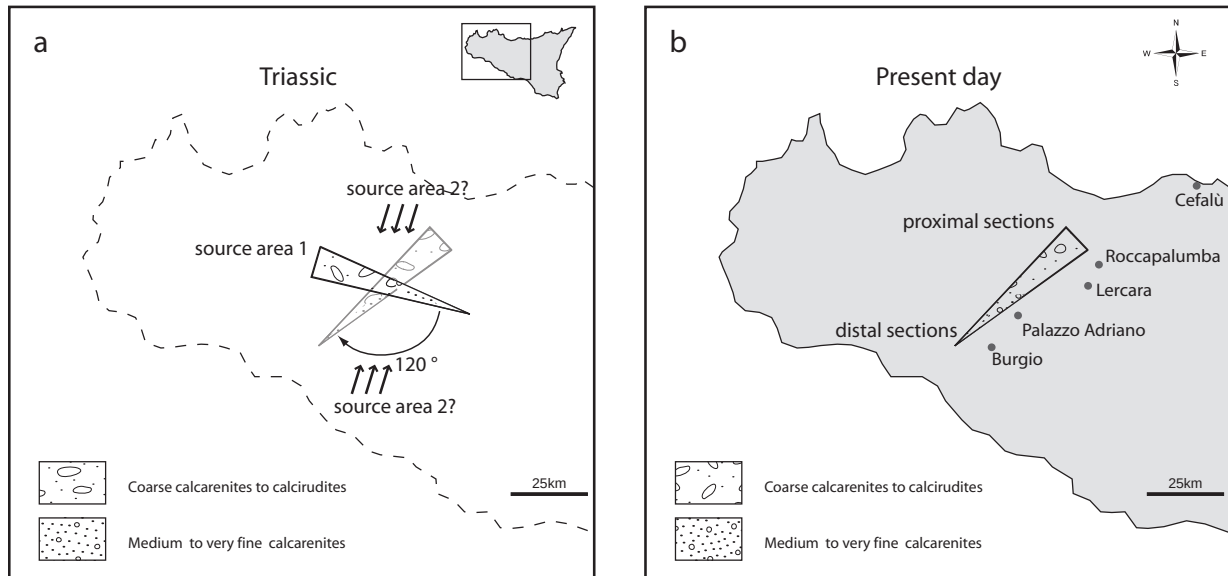


Figure 2.3 Determination of the source area directions during the Triassic (a) deduced from the granulometric distribution of the Lercara Formation deposits (b) and palaeomagnetic data of Channell *et al.* (1990).

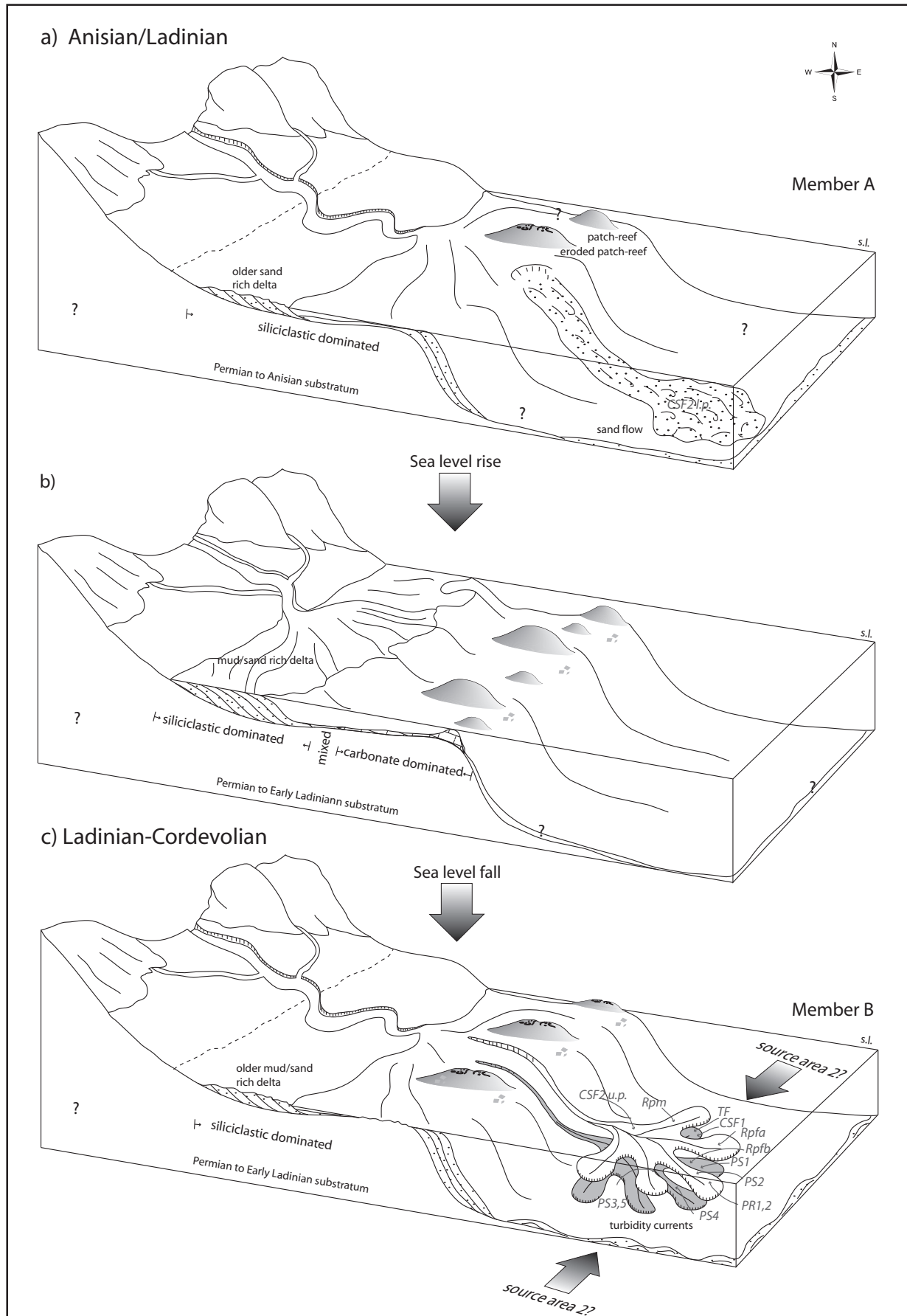
to CL light for short time to avoid an alteration of the CL colour due to long exposures (Götze & Zimmerle, 2000).

All grains of quartz observed are homogeneously non luminescent (Plate 14). Non-luminescent quartz is of authigenic origin and is generally observed as an overgrowth around older grains or as a cement between grains (Zinkernagel, 1978; Ramseyer & Mullins, 1990; Götze & Zimmerle, 2000). Except for their non-luminescence, our quartz grains do not show characteristics of authigenic precipitation because they clearly consist in clasts. Therefore, we interpret quartz as of terrigenous origin and the non-luminescence as a characteristic inherited from previous dissolution/precipitation in the sedimentary source rock.

Original quartz could derive from erosion by rivers of turbiditic sediments deposited along of the Variscan chain in Morocco and Algeria and in the south of Spain (Michard, 1976; Hoepffner *et al.*, 2006).

2.3.3 MICROFACIES INTERPRETATION

The occurrences of microfacies A to E are generally distributed in the studied sections or isolated samples according to a Northeast-Southwest direction between the Lercara-Roccapalumba and the Burgio areas (see Appendices 2.2 to 2.11). Given that the microfacies classification is principally based on the size of extrabasinal components (carbonaceous and silica-based fragments), decrease in the grain size is observed between the two areas and indicates the direction of the carbonate and siliclastic sedimentary contribution. This allows us to establish that, relative to the source areas, the outcrops of the Lercara-Roccapalumba region were deposited in a more proximal environment, those of Pietra di Salomone area in an intermediate one and those of Portella Rossa in a more distal one. The only exceptions to this spatial trend are the *Pietra di Salomone* 3 and 5 outcrops. They present a coarse granulometry despite their southwestern position and thus point to a secondary sediment source approximately perpendicular to the main sediment source. Outcrops of the Lercara Formation between the areas of Lercara-Roccapalumba and Burgio are today aligned in a Northeast-Southwest direction (Figure 2.3). Palaeomagnetic data of Channel *et al.* (1990) show that the Sicilian basin, in which the Lercara Formation was deposited, has undergone a clockwise rotation between 110° and 121° relative to the stable Hyblean foreland. Outcrops that, at the present day, are aligned in a Northeast-Southwest direction were approximately aligned in a



Northwest-Southeast direction prior to the deformation. The principal source area was thus located in the Northwest of the Lercara basin, whereas the second source area could be positioned to the Southwest or to the Northeast with respect to the Lercara Basin (Figure 2.3).

Microfacies E is texturally mature and not immature as expected, given its distal position (Table 2.1). This unexpected maturity may result from the winnowing action of bottom currents.

2.4 SEDIMENTARY INTERPRETATION

Two different lithotypes characterise the Lercara Formation: 1) massive clayey sandstones (microfacies F), here named Member A, which crop out at Cozzo San Filippo (*lower part of Cozzo San Filippo 2* section) and 2) greyish to reddish quartz-rich shales (microfacies G), named Member B, outcropping in the sections of *Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1*, upper part of *Cozzo San Filippo*, *Roccapalumba Ferrovia a* and *b*, *Pietra di Salomone 1* to 5 and *Portella Rossa 1* and 2. The thickness of the two members measured in the field is uncertain for Member A and up to 12 metres for the Member B, but is estimated to be approximately 210 and 70 metres respectively (Montanari, 2006, *pers. comm.*).

2.4.1 MEMBER A

Massive clayey sandstones (Member A) are composed of quartz, phyllosilicates and feldspars. Calcite is absent (see chapter 4). Quartz grains have the size of fine arenites. The massive banks are in sharp contact, and only sporadically show parallel laminations whilst they lack bioturbations.

Member A has the characteristics of a “*sediment-gravity flow with plastic rheology and laminar state from which deposition occurs through freezing*” (Shanmugam, 2000). More precisely the composition and thickness of the banks point to a sand flow triggered in a slope with an important topographical gradient (Bosellini *et al.*, 1989) (Figure 2.4a). The quartz grain sedimentary origin suggests that sands and clays were supplied by erosion or instability of a relict siliciclastic platform previously fed by an older deltaic system and/or erosion of fluvial deposits. Any others marine source, *e.g.*, a siliciclastic shore, can be excluded because of the absence of reworked marine organisms.

2.4.2 MEMBER B

Member B is principally constituted of nodular greenish to reddish quartz-rich shales (B1) with intercalations of reworked carbonates (B2) or clayey sandstones (B3).

Quartz-rich shales show a nodular structure due to diagenesis. They are essentially composed of phyllosilicates associated with quartz, feldspars and calcite (see chapter 4).

The reworked carbonate sediments (B2) can be subdivided into two types: B2a and B2b. The first type (B2a) consists of calcirudites (microfacies A) (*Roccapalumba Mercato* and upper part of *Cozzo San Filippo 2*, some levels of *Pietra di Salomone 3* and 5 sections), coarse to medium size calcarenites (microfacies B to D) (*Roccapalumba Mercato* and *Roccapalumba Ferrovia a* sections) and fine calcarenites (microfacies E) (*Pietra di Salomone 2* and 3, and *Portella Rossa 1* and 2 sections). These reworked sediments contain lithoclasts with Permian foraminifera associated with Triassic foraminifera.

In B2a, calcirudites to fine calcarenites are principally constituted of carbonate fragments, clasts of quartz and rip-up clasts. Carbonate fragments can undergo several sedimentary cycles of deposition/erosion/transport but they cannot be transported far away from the source area because of their chemical instability and physical weakness (Zuffa, 1985). They can be more easily destroyed if erosion and transport take place in a subaerial environment rather than in subaqueous one. Therefore, the source area of the

Figure 2.4 Sedimentary model of the Member A and B of the Lercara Formation. Sections: Rpm=*Roccapalumba mercato*; TF=*Torrente San Filippo*; CSF1=*Cozzo San Filippo 1*; CSF2 l.p.=*Cozzo San Filippo 2 lower part*; CSF2 u.p.=*Cozzo San Filippo 2 upper part*; Rpf a=*Roccapalumba ferrovia a*; Rpf b=*Roccapalumba ferrovia b*; PS1, 2, 3, 4, 5=*Pietra di Salomone 1, 2, 3, 4 and 5*; PR1, 2=*Portella Rossa 1 and 2*.

Permian and Triassic (Anisian or Ladinian) platforms must have been located in vicinity of the Lercara Basin. Furthermore, the abundance of clastics debris coming from the near platform suggests high water energy and/or intense tectonic activity.

In the field, calcirudites to fine calcarenites (B2a) appear as discontinuous beds with a small lateral extension and a sharp erosive basal contact. Locally, normal or reverse grading and parallel laminations can be noticed. Flute casts and *Nereites* ichnofossils have been observed at the base of some beds. The latter usually occur in pelagic muds between turbidites (Seilacher, 1967). *Nereites* ichnofacies of the Lercara Formation have previously been described by Kozur *et al.* (1996).

The second type (B2b) is represented by plurimetric limestone blocks (microfacies H) (*Pietra di Salomone*, *Pietra del Passo di Burgio*, *Pietra dei Saraceni* and some smaller blocks found in the *Pietra di Salomone 1* section, Si 123, 138, 141, 142, 145, 164 samples are scattered in the Portella Rossa area) which yield an exclusively Permian microfauna.

Greyish to reddish quartz-rich shales can also containing levels of clayey sandstones (B3) (microfacies F) like *Roccapalumba Ferrovia b*, *Cozzo San Filippo 1*, *Torrente Ferro* and *Pietra di Salomone 1*, 4 and 5 sections.

Levels of clayey sandstones (B3) show erosive and sharp contacts, parallel and cross bedding, bioturbation and flute clasts. They differ from clayey sandstones of the Member A by their calcite content (see chapter 4).

Member B has the characteristics of a fine mud/sand-rich grained turbidity current *sensu* Reading & Marcus (1994). According to them mud/sand-rich submarine fan systems are moderate in size, lobe-shaped and develop mainly in small, confined, tectonically active basins. Calcirudite to fine calcarenitic levels could be lobes of a turbiditic system.

Member B was fed by both siliciclastic and carbonate sediments. Quartz and clay could come from erosion of fluvial and/or deltaic deposits and by erosion of basinal sediments. The deltaic and basinal sources are the most probable because of the presence two reworked organisms: the microforaminifer *Meandropsira pusilla*, which indicates the development of a siliciclastic platform (see paragraph 2.3.2 extrabasinal components), and radiolarians. Permian to Anisian carbonate fragments come from older carbonatic platforms and ostracods and conodonts from Wordian to Roadian deep deposits. Huge blocks of the *Pietra di Salomone* area probably derived from the Permian bioherm incised by turbidity currents and transported, far into the basin, as coherent blocks sliding over argillaceous material. Similar sliding events occurred during the Holocene on the western side of the Valencia Trough, caused by significant seismic events along the passive margin (Lastras *et al.*, 2002).

As happened during the Cainozoic along the north-eastern carbonate-siliciclastic Australian shelf (Coe *et al.*, 2003), the relative sea-level rise over the older platform forced rivers to erode landward to re-establish their equilibrium profile. Siliciclastic sediments were deposited in a more internal delta (Figure 2.4b) and allowed the developments of a carbonate platform. During the relative sea-level fall, rivers were forced to incise the platform and carried sediments into the shelf-edge area (Figure 2.4c). The rapid accumulation of fine-grained sediment on the shelf-edge led to high pore pressure instability and eventually transport of sediments by turbidity currents into the basin (Bouma, 2000). Siliciclastic sediments eroded from the platform are found today in the clayey sandstones intercalated in the quartz-rich shales (B3) (Figure 2.4c green fan). Carbonate fragments produced by the dismantling of the Triassic (early Cordevolian) carbonate platform were totally dissolved by subaerial erosion which is responsible for the low content of calcite (2-11%) in B3.

As the sea level continued to fall, the Permian to Anisian/Ladinian substratum was cut by canyons feeding turbidity currents. In this case, erosion and transport of Permian carbonate was subaqueous and carbonate fragments were preserved. On the contrary, Anisian/Ladinian and lower Cordevolian carbonate fragments were probably eroded subaerially, this more aggressive erosion allowing only rare fragments to be preserved. Calcirudites to fine calcarenites levels (B2a) intercalated in the quartz-rich shales were deposited in this context (Figure 2.4 c white fan).

2.4.3 DISCUSSION

In conclusion, two different sedimentary processes have produced Members A and B: sand flows and turbidity currents. As regards the timing, the deposition occurred during the Anisian and Cordevolian

age. We will see in chapter 3 that micropaleontological data do not allow Member A to be dated with precision. However the latter crops out below the Member B (see Appendix 2.4 and description of the outcrop). Then Member A deposition took place between the Anisian and the Ladinian and the Member B between the Ladinian and the early Carnian (Cordevolian).

The two members were probably both fed by older deltaic deposits but present a different sand/clay ratio: elevated for Member A, low for Member B. This indicates that a change occurred in the supply of siliciclastic sediments in the Lercara basin between the deposition of its two members. Two scenarios are possible, both involving the erosion of a single older delta.

In the first scenario, variations of sea level or displacement of the course of the river led to the erosion of different parts of the delta: more proximal for Member A, and after, more distal for Member B.

In the second scenario, a change in the supply of the river occurred during delta formation, induced by variations in climate, relief of the source area, intensity of alteration, and tectonics or eustatic level.

Unfortunately, the absence of older deposits of the Lercara Formation or more internal deposits contemporaneous with the Lercara Formation does not permit the choice of one of the two hypotheses.

3 BIOSTRATIGRAPHY

Part of the results presented in this chapter have been published (Carcione *et al.*, 2004) or are in preparation (Crasquin-Soleau *et al.*; Carcione *et al.*). Larger Foraminifera have been determined by Dr Daniel Vachard (Villeneuve d'Ascq, Lille University), ostracods by Dr Sylvie Crasquin-Soleau (CNRS Paris), conodonts by Dr Michael Orchard (Geological survey of Canada) and acritarchs by Dr Marco Vecoli (Villeneuve d'Ascq, Lille University).

3.1 INTRODUCTION AND CHRONOSTRATIGRAPHIC SCALES

High-resolution biostratigraphic study has been carried out trying to resolve the problem of the age of the Lercara Formation. As already explained in the general introduction, different ages have been proposed and the latest investigations have opposed supporters of a Permian age and supporters of a Triassic age. In this work, all possible biostratigraphic tools have been used to try to resolve this controversy: macrofauna, foraminifera, ostracods, conodonts, radiolarians, palynomorphs and nannofossils. Several methods were unsuccessful. Ammonoids, which are good stratigraphic markers, have not been found, and only few non-determinable brachiopods and bivalvia have been observed. Nannofossils are absent and radiolarians are constituted of non-determinable recrystallised spumellarians. However, a rich fauna and flora composed of foraminifera, ostracods, conodonts and palynomorphs have been observed. Some sections of the Mufara Formation have been also studied in order to find coeval sections of the Lercara Formation.

Before the description of the microfauna and palynomorphs, the Permian and Triassic chronostratigraphic subdivisions used or mentioned in this work must be exposed. As regards the Permian, up to now no global chronostratigraphic scale has been defined, because of the absence of organisms allowing correlations between the different palaeodomains. However series and stages of the Permian system were proposed by the Subcommission on Permian Stratigraphy in 1996 and they have been adopted in this work (Jin *et al.*, 1997a; Jin *et al.*, 1997b). The proposed times scale is based on the zonation of conodonts, ammonoids and fusulinaceans. The Permian is subdivided into three series - Cisuralian (Early Permian), Guadalupian (Middle Permian) and Lopingian (Late Permian) - and the correspondent stages have been standardized in the Urals, Southwest USA and South China respectively. The basal boundary of the Permian system is defined by the First Appearance Datum (FAD) of the conodont *Streptognathodus isolatus* and the upper boundary by the FAD of the conodont *Hindeodus parvus*. The Permian time scale and chronostratigraphic chart proposed by the Subcommission on Permian Stratigraphy, is illustrated in the Figure 3.1, together with regional stages.

As far as the Triassic is concerned, a time scale, based on ammonoids and conodonts, was accepted by the Subcommission on Triassic Stratigraphy. In this work, only Lower Triassic to Carnian flora and fauna have been identified and for this reason only this interval of the Triassic period scale is represented in Figure 3.2. The basal boundary of the Triassic System is marked by the FAD of the conodont *Hindeodus parvus* (Jin *et al.*, 1997b) and the First Occurrence (FO) of the conodont

Age Ma	Series	Global Stages	Regional Stages				
			Tethys	Russian Platform	S.W. North America	China	Western Europe (Zechstein basin)
251.4 253.4	Lopingian (Late Permian)	Changhsingian	Dorashamian			Changhsingian	Zechstein
		Wuchiapingian	Dzhulfian			Wuchiapingian	
260	Guadalupian (Middle Permian)	Capitanian	Midian		Ochoan		"Thuringian"
265		Wordian	Murgabian	Tatarian	Capitanian	Maokou	
270		Rodian	Kubergandian	Ufminian	Rodian		
	Cisuralian (Early Permian)	Kungurian	Bolorian	Kungurian	Cathedralian	Chihsian	Rotliegend
280		Artinskian	Yakhtashian	Artinskian	Hessian		
283		Sakmarian	Sakmarian	Sakmarian	Lenoxian	Chuanshanian	"Saxonian"
288.6 290 292		Asselian	Asselian	Asselian	Nealian		

Figure 3.1 Permian time scale with chonostratigraphic chart proposed by the Subcommittee on Permian stratigraphy and regional stages (after Broutin *et al.*, 1990; Jin *et al.*, 1997a, 1997b & Weidlich, 2002).

Metapolygnatus communisti B was proposed to define the Carnian/Norian boundary (Krystyn & Gallet, 2002).

3.2 MICROFAUNA

3.2.1 INTRODUCTION

The microfauna of the Lercara Formation was investigated through the polarized light examination of 167 thin sections and from the scanning electron microscopy (SEM) observation of the result of material hand-picked in 61 washed samples. Foraminifera have been studied with the former method, while conodonts and ostracods have been principally observed at the SEM. For the Mufara Formation 4 thin sections have been observed and the result of 18 washed samples.

Previous biostratigraphic investigations conducted on the Lercara Formation deposits have underlined the vast quantity of Permian microfauna, and in some studies, a Permian stratigraphy was proposed. The macroinvestigations of Gemellaro (1887; 1888; 1889; 1892; 1893a; 1893b; 1894b; 1894a; 1898/99) on the huge blocks of the Palazzo Adriano area, are well-known and concern principally new molluscs and brachiopods of Permian age. In these same blocks, fusulines have been found by Skinner & Wilde (1966) and by Vachard *et al.* (2001b) of Wordian and Artinskian age respectively for which several genera and species have been instituted. In the Lercara area, Montanari (1968) discovered the Carnian foraminifera *Brizalina* associated with Permian fauna and proposed a Triassic age for the Lercara deposits. Senowbari-Daryan & Di Stefano (1988) found sphinctozoan assemblages of the Lower Permian age in some small blocks. Additional investigations conducted by Jenny-Deshusses *et al.* (2000) in the Pietra di Salomone block revealed the presence of the Latest Permian foraminifera *Colaniella* ex gr. *minima* and *Colaniella* ex gr. *parva*. A wider study concerning the Lercara outcrops of Lercara and Palazzo Adriano area was conducted by Catalano *et al.* (1988c; 1988b; 1991) and Gullo (1993). They focused their investigations on conodonts, ostracods and radiolarians. In particular, associations of conodonts testified to the presence of an upper Lower Permian to Upper

Age Ma	Series	Stages	Substages	Zechstein basin (facies)
219	Late	Carnian	Tuvalian	Keuper
223.74			Julian	
225.6			Cordevolian	
230	Middle	Ladinian	Longobardian	Muschelkalk
236.6			Fassanian	
241		Anisian	Illyrian	
242.3			Pelsonian	
242.9			Bithynian	
244.3			Aegean	
245	Early	Scythian	Spathian	Buntsandstein
246.2			Smithian	
248		Induan	Dinerian	
251.4			Griesbachian	

Figure 3.2 Triassic (Early to Carnian) time scale with chronostratigraphic chart approved by the Subcommission on Triassic stratigraphy (after Flügel, 2000).

Permian stratigraphy in the Lercara deposits. At the same time, they established new genera and species of ostracods and conodonts.

Earlier studies of the Mufara Formation concerning foraminifera and conodonts provided associations of Ladinian?-Carnian age (Carrillat, 2001 with references therein).

The micropaleontological study conducted during this thesis reveals a mixed microfauna in the Lercara Formation, characterised by abundant and diversified Permian foraminifera, ostracods and conodonts in association with less represented carboniferous and Lower to Upper Triassic foraminifera. For the Mufara Formation, it shows a monospecific association composed only of the Upper Triassic foraminifer *Cucurbita infundibuliformis*.

3.2.2 CARBONIFEROUS AND PERMIAN MICROFAUNA

A single carboniferous specimen has been observed, whereas a relatively rich Permian fauna has been found in the Lercara Formation, which consists of smaller and larger foraminifera, ostracods and conodonts.

Smaller and larger foraminifera have been found in microfacies A to E as clasts with or without their original carbonate matrix. Quartz rich shales (microfacies G) show only foraminifera belonging to the superfamily Ammodiscacea and Geinitzinacea. Geinitzinacea in the microfacies G are often associated with ostracods, conodonts and radiolarians. Foraminifera are absent in the clayey sandstones (microfacies F).

Ostracods have been observed in microfacies E and H and conodonts in microfacies C and D, but both are more common in microfacies G.

SMALLER FORAMINIFERA

Smaller foraminifera belonging to the suborder Textulariina, Fusulinina, Miliolina and some are incertae sedis. Their distribution in the samples can be found in Table 3.1

Suborder TEXTULARIINA Delage & Hérouard, 1896

Superfamily AMMODISCACEA Reuss, 1862

Family AMMODISCIDAE Reuss, 1862

Ammodiscus sp. (Plate 10) is a cosmopolitan genus known since the Carboniferous to (Loeblich & Tappan, 1987).

[illegible]

Glomospira sp. (Plate 15, Figure 1), is a cosmopolitan genus known since the Carboniferous (Loeblich & Tappan, 1987).

Suborder FUSULININA Wedekind, 1937

Superfamily EARLANDIACEA Cummings, 1955

Family CHITRALINIDAE Angiolini & Rettori, 1994

Chitralina undulata Angiolini & Rettori, 1994 (Plate 15, Figure 2) has been found in the Kubergardian to Midian of Karakorum in Pakistan (Angiolini & Rettori, 1994).

Superfamily PARATHURAMMINACEA Bykova, 1955

Several Carboniferous to Permian long ranging foraminifera, *Diplosphaerina inaequalis* Derville, 1952. (Plate 15, Figure 3) and *Eotuberitina reitlingerae* Miklukho-Maklay, 1958 (Plate 15, Figure 4) have been found.

Superfamily ARCHAEDISCACEA Cushman, 1928

Family LASIODISCIDAE Reytlinger, 1956

Lasiodiscus sp. (Plate 15, Figure 5)

Lasiodiscus irregularis Mikluklo-Maklay, 1954 (Plate 15, Figure 6) has been found in the Late Permian of Northern Caucasus (Mikluklo-Maklay, 1954) and in the Changhsingian of Northwestern Caucasus (Pronina-Nestell & Nestell, 2001).

Lasiodiscus medusa Mikluklo-Maklay, 1954 (Plate 15, Figure 7) has been signalled in the Late Permian of Northern Caucasus (Mikluklo-Maklay, 1954) and in the Changhsingian of Northwestern Caucasus (Pronina-Nestell & Nestell, 2001).

Lasiodiscus minor, Reichel, 1945 (Plate 15, Figure 8) has been found in the Late Permian of Southern Apennines (Monte Facito Formation) (Ciarapica *et al.*, 1986), Late Permian of Greece (Martini & Zaninetti, 1988), Sakmarian of Attica, Greece (Vachard *et al.*, 1993), Changhsingian of northwestern Caucasus (Pronina-Nestell & Nestell, 2001) and in the Lercara Formation (Senowbari-Daryan & Di Stefano, 1988; Vachard *et al.*, 2001b).

Lasiotrochus tatoiensis Reichel, 1945 (Plate 16, Figure 1) has been found in the Late Permian of Southern Apennines (Monte Facito Formation; Panzanelli Fratoni *et al.*, 1987).

Superfamily GEINITZINACEA Bozorgnia, 1973

Family Geinitzinidae Bozorgnia, 1973

Geinitzina sp. (Plate 16, Figure 2) known since the late Dorashamian (Vachard *et al.*, 2002).

Family PACHYPHLOIIDAE Loeblich & Tappan, 1984

Pachyphloia sp. (Plate 16, Figure 3) known since the late Sakmarian (Groves, 2000).

Superfamily PALAEOTEXTULARIACEA Galloway, 1933

Family PALAEOTEXTULARIIDAE Galloway, 1933

Climacammina sp. (Plate 16, Figure 4) known since the Carboniferous (Loeblich & Tappan, 1987).

Palaeotextularia sp. (Plate 16, Figure 5) known since the Carboniferous (Loeblich & Tappan, 1987).

Family BISERIAMMINIDAE Chernysheva, 1941

Globivalvulina sp.

Globivalvulina graeca Reichel, 1945 (Plate 16, Figure 6) has been mentioned in the Late Permian of Greece, Yugoslavia and Italy, Kubergardian and Murgabian of Afghanistan, late Murgabian and Djulfian s.l. of Iran, Artinskian?, Kubergardian? to Djulfian of Turkey (Altiner, 1981), Late Permian of Southern

Table 3.1 Repartition of Permian and Triassic foraminifer species of the Lercara and Mufara Formations per sample.

Apennines (Monte Facito Formation Ciarapica *et al.*, 1986), Sakmarian of Attica, Greece (Vachard *et al.*, 1993), and in the early Late Permian Mount Parnon, Greece (Skourtsos *et al.*, 2002).

Dagmarita sp.

Dagmarita shahrezaensis Mohat-Aghai & Vachard, 2003 (Plate 16, Figure 7) has been described in the early Late Permian (Wuchiapingian/Dzhulfian) of Central Iran (Mohat-Aghai & Vachard, 2003).

Superfamily ENDOTHYRACEA Brady, 1884

Family ENDOTHYRIDAE Brady, 1884

Endothyra sp. (Plate 16, Figure 8) known since the Carboniferous (Altiner, 1981).

Neoendothyra sp. (Plate 17, Figure 1) known in the Late Permian.

Superfamily ENDOTHYRACEA Brady, 1884

Family TETRATAXIDAE Galloway, 1933

Tetrataxis aff. *Tetrataxis conica* Ehrenberg, 1854 (Plate 17, Figure 2) has been found in the Late Permian of Southern Apennines (Monte Facito Formation) (Panzanelli Fratoni *et al.*, 1987) in the Sakmarian and Dorashamian of Attica, Greece (Vachard *et al.*, 1993) and in the early Late Permian Mount Parnon, Greece (Skourtsos *et al.*, 2002).

Suborder MILIOLINA Delage and Hérouard, 1896

Superfamily MILIOLACEA Ehrenberg, 1839 emend. Brönnimann & Zaninetti, 1971

Family HEMIGORDIOPSIDAE Nikitina, 1969

Hemigordius sp. (Plate 17, Figure 3) known since the Carboniferous (Loeblich & Tappan, 1987; Altiner *et al.*, 2003).

Superfamily ROBULOIDACEA Reiss, 1963

Family SYZRANIIDAE Vachard, 1981

Rectostipulina quadrata Jenny-Deshusses, 1985 (Plate 17, Figure 4) has been found in the Upper Permian (Dzhulfian) of Turkey (Zaninetti *et al.*, 1981), Afghanistan (Jenny-Deshusses, 1985) and Batain Plain East Oman (Vachard *et al.*, 2002). It is characteristic of confined environments (Jenny-Deshusses, 1985).

Robuloides sp. (Plate 17, Figure 5) known since the Midian (Vachard *et al.*, 2002).

Incertae sedis

Multidiscus sp. (Plate 17, Figure 6) known since the late Murgabian (Vachard *et al.*, 2002).

Ramovsia limes Kochansky-Devidé, 1973 (Plate 17, Figure 7) has been reported in the Carnic Alps (Kochansky-Devidé, 1973) and in the Dzhulfian of Iran (Jenny & Jenny-Deshusses, 1978)

Asterosphaera pulchra Reitlinger, 1962 (Plate 17, Figure 8) is a calcispherid found up to now only in the Mississippian (Early Carboniferous) (Vachard, 1977).

Discussion

In most cases, these foraminifera have been found in different samples as isolated clasts rather than associated in larger clasts. Given, in addition, that most of the smaller foraminifera encountered are long ranging - some appear since the Carboniferous, some since the Lower Permian - it is difficult to establish, using only the smaller foraminifera, which Permian intervals have been eroded and reworked in the Lercara Formation. However, *Chitralina undulata* is known only in the Middle Permian and *Ramovsia limes*, *Rectostipulina quadrata*, *Neoendothyra* sp., *Dagmarita shahrezaensis*, *Geinitzina* sp, *Lasiotrochus tatoiensis*, *Lasiodiscus medusa* and *Lasiodiscus irregularis*, are only found in the Late Permian.

SPECIES	STRATIGRAPHICAL RANGE							SAMPLES																
	Early P.			Middle P.			Late P.																	
	Early Y.	Late Y.	BOLOR	KUB.	MURG.	MID.	LOPIN.	RP19	RP27	RP29	BG1	BG2	RPFa1	RPFa2	RPFa5	RPFa6	RPFa7	PS14	PS23	PS26	PS37	PR21	PR25	PR28
<i>Reichelina</i> sp.																								
<i>Schubertella paramelonica</i>																								
<i>Schubertella silvestrii</i>																								
<i>Dunbarula? simplex</i>																								
<i>Parafusulina</i> sp.																								
<i>Minojapanella</i> sp.																								
<i>Toriyamaia (?)</i> sp.																								
<i>Mesoschubertella</i> sp.																								
<i>Neofusulinella lantenoisi</i>																								
<i>Yangchienia compressa</i>																								
<i>Rauserella staffi</i>																								
<i>Darvasites contractus</i>																								
<i>Chusenella</i> sp.																								
<i>Chalaroschwagerina (Taiyuanella?)</i>																								
aff. <i>davalensis</i>																								
<i>Levenella</i> aff. <i>evoluta</i>																								
<i>Rugososchwagerina yabei</i>																								
<i>Pamirina darvasica</i>																								
<i>Neoschwagerina</i> ex gr. <i>craticulifera</i>																								
<i>Ogbinella</i> cf. <i>saurini</i>																								

Table 3.2 Summary table of the fusulinids of the Lercara Formation, showing the reworking and the melange of different genera. P : Permian. Early Y : Early Yakhtashian/Artinskian. Late Y : Late Yakhtashian/Artinskian. BOLOR : Bolorian/Kungurian. KUB : Kurgandian/Roadian. MURG : Murgabian/Wordian. MID : Midian/Capitanian. LOPIN : Lopingian/Late Permian.

Smaller foraminifera associations found in the Lercara Formation do not show particular affinity with other associations of Palaeo- or Neo-Tethyan deposits and therefore do not permit palaeogeographical correlations with these two domains.

A peculiar reworking, difficult to explain, concerns the calcispherid *Asterosphaera pulchra*, only found up to now in the Mississippian (Early Carboniferous). This calcispherid, found in association with the reworked fusulinids, should probably be considered as a Lazarus taxon, since it survived the Visian time and developed along with the fusulinids during the Permian period.

LARGER FORAMINIFERA

Several genera and species of fusulinids have been identified in the Lercara Formation. They have been determined by the Doctor Daniel Vachard and are listed below:

- Reichelina* sp. (Plate 18, Figure 1)
- Schubertella paramelonica* Suleimanov, 1949 (Plate 18, Figure 2)
- Schubertella silvestrii* Skinner and Wilde, 1966 (Plate 18, Figure 3)
- Dunbarula? simplex* Lange, 1925 (Plate 18, Figure 4)
- Parafusulina* sp. (Plate 18, Figure 5)
- Minojapanella* sp. (Plate 18, Figure 6)
- Toriyamaia (?)* sp. (Plate 18, Figure 7)
- Mesoschubertella* sp. (Plate 18, Figure 8)
- Neofusulinella lantenoisi* Deprat, 1913 (Plate 19, Figure 1)
- Yangchienia compressa* Ozawa, 1927 (Plate 19, Figure 2)
- Rauserella staffi* Skinner and Wilde, 1966 (Plate 19, Figure 3)
- Darvasites contractus* (Schellwien, 1908) (Plate 19, Figure 4)
- Chusenella* sp. (Plate 18, Figure 6)
- Chalaroschwagerina (Taiyuanella?)* aff. *davalensis* Leven, 1967 (Plate 19, Figure 5)
- Levenella* aff. *evoluta* (Ueno, 1991) (Plate 19, Figure 6)
- Rugososchwagerina yabei* (Staff, 1909) (Plate 19, Figure 7)
- Pamirina darvasica* Leven, 1967 (Plate 19, Figure 8)
- Neoschwagerina* ex gr. *craticulifera* (Schwager 1883) (Plate 20, Figure 1)
- Ogbinella* cf. *saurini* Nguyen Duc Tien, 1970 (Plate 20, Figure 2)

The reworking and the melange of Lower to Upper Permian fusulinids genera in the Lercara Formation clearly appear on the summary Table 3.2 (e.g. sample PR21), which is based on the biostratigraphic fusulinid distributions mentioned in the literature (Lange, 1925; Skinner & Wilde, 1966; Leven, 1967; Kobayashi, 1977; Lys, 1988; Kotlyar *et al.*, 1989; Vachard & Miconnet, 1989; Ueno, 1991b, a; Leven, 1992, 1993; Ross & Ross, 1994; Ueno, 1996; Leven, 1998; Kobayashi & Ishii, 2003).

This reworking was already evidenced by the presence of Pietra di Salomone fusulinids, in the Sosio Valley (Skinner & Wilde, 1966 up dated by: Vachard, 2002). In this area, the Early Permian *Rugochusenella anachrona*, is found in the same sample with the Middle Permian *Skinnerella dainellii*, as well as with the classical Murgabian/Midian microfauna represented by *Neoschwagerina*, *Verbeekina*, *Kahlerina*, *Rauserella*, *Sosioella*, and *Rugososchwagerina*.

In addition, the presence of rare *Colaniella* in the Sosio series also indicates the reworking of the Dorashamian stage (Latest Permian) (Jenny-Deshusses *et al.*, 2000).

Finally, the presence of rare *Schubertella silvestrii* Skinner and Wilde, and of *Endoteba* sp., previously identified in the Lercara series (Vachard *et al.*, 2001b), has also suggested the reworking of some Middle Permian elements.

Palaeobiogeographically, the above-described species of fusulinids are principally known in the Mesogea (Palaeo-Tethys), as previously noted by Vachard *et al.* (2001b). The closest affinity exists with the Transcaucasia fauna (Leven, 1998), where nearly the same fusulinid association as in Sicily is found, and with those of the Monte Facito Formation of the Southern Apennines and of Central Iran (Vachard, 2006, *pers.comm.*). Some species, such as *Darvasites contractus* (Kochansky-Devidé, 1970; Kahler & Kahler, 1980; Bérczi-Makk & Kochansky-Devidé, 1981), *Pamirina darvasica* (Kahler & Kahler, 1980), *Yangchienia compressa* described as *Y. antiqua* (Kochansky-Devidé, 1958), *Neofusulinella lantenoisi* (Mikluklo-Maklay *et al.*, 1959; Kahler, 1988), *Rauserella staffi* (Skinner & Wilde, 1966) and *Neoschwagerina* ex gr. *craticulifera* (Skinner & Wilde, 1966; Panzanelli Fraton *et al.*, 1987; Vachard & Miconnet, 1989), belong to the European Permian fauna. This is the first time that the genus *Levenella* has been found in Europe. Until now this genus was exclusively known in South China and in Japan (Ueno, 1991b) and recently it was found in the American faunistic province of Guatemala (Vachard *et al.*, 2000).

The reworking and melange of fusulinids, smaller foraminifera and other Permian calcareous microorganisms are already known in Italy; they are frequent in the Sosio and Lercara areas (Sicily) and in the Monte Facito region (Southern Italy), where associations with *Dunbarula? simplex* and *Ogbinella* reported as *Boultonia* aff. *Europeea*, have been described (Pasini, 1982; Vachard & Miconnet, 1990). Our investigations have shown that the most productive periods that have been eroded and reworked are Yakhtashian-Bolorian and Murgabian-Midian.

Since the deposition of the Lercara Formation took place during the Triassic time, this study of the fusulinids of the Lercara Formation does not confirm the existence of a Permian ocean in Sicily and does not provide a precise correlation between the Wordian and Midian stages (Kozur, 1991; Henderson, 2001; Kozur *et al.*, 2001; Kozur, 2003).

OSTRACODS

Ostracods are freshwater or marine crustaceans having a chitin-calcified carapace of millimetric size. The majorities are benthic and only some are pelagic, probably during the larval stage. Ostracods are not good biostratigraphic markers, because they can have a long stratigraphic distribution, but they are good palaeoenvironmental indicators, because their morphological characters are strongly influenced by environmental parameters. Having regarding to the temperature of the water in which the ostracods live, two principal groups can be distinguished: the thermospheric or neritic forms living in the warmer shallow waters and the palaeopsychrospheric forms (Kozur, 1972) living in the cold deep waters.

The psychrospheric ostracods are panchronic, i.e. they can live during long geological periods without undergoing morphological changes and for this reason this fauna is considered as primitive.

Their carapaces are thin and brittle, smooth with long spines. Ocular tubercles are absent and hinges are primitive. The number of species is always low and the fauna is homogenous over long geographic distance.

In contrast, the neritic ostracods undergo rapid morphological changes. Their carapaces are thick with strong spines sculptures. Ocular tubercles are present and the hinges are evolved. The number of species is higher than the psychrospheric forms and the fauna exhibits a marked provincialism.

A rich and diversified ostracod fauna composed of neritic and palaeopsychrospheric forms has been recognized in the red and grey quartz-rich shales (microfacies G, Member B) of the *Portella Rossa* and *Pietra di Salomone 1* and 2 series. Seventy-two samples of the Lercara Formation were washed under water and seven of them produced ostracods, which have been observed with a scanning electronic microscope. Forty-seven species were identified and thirteen are newly described here. They belong to twenty-six genera of which three are new. The distribution is given on Table 3.3.

Ostracods from *Portella Rossa* (PR) samples are associated with conodonts of Roadian-Wordian age whereas the ostracods from *Pietra di Salomone* (PS) 1 and 2 samples are attributed to the Permian because of the similarity of the ostracod association between *Portella Rossa* and *Pietra di Salomone* sections.

Kozur described ostracods from the Torrente San Calogero section, a locality 50 m south of Pietra di Salomone, mainly from the red unit B (Kozur, 1991). However, the location of each sample is not precisely indicated.

It is important to note that the Torrente San Calogero section of Kozur corresponds to our *Pietra di Salomone 1* and 2 sections (Figure 1.1d). However, for this study the unit B of Kozur (1991) could not be sampled because of a landslide.

The very good state of preservation of the ostracod fauna, with delicate and fragile ornamentation, excludes a particle reworking of the specimens. For this reason we consider that the ostracod associations described below underwent a mass-reworking and thus represent the original assemblages.

Systematic palaeontology (Dr. Sylvie Crasquin-Soleau)

All of the studied specimens are stored in the collections of the Musée d'Histoire Naturelle de Genève – MHNG (Switzerland). Only newly erected species are described. In the descriptions the initial L represents the length and H the height of the ostracods.

Order PALAEOCOPIDA Henningsmoen, 1953

Suborder HOLLINOMORPHA Henningsmoen, 1965

Superfamily and Family inc.

Genus *Neofellerites* Kozur, 1991

Neofellerites minimus Kozur, 1991 (Plate 21, Figure 4)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Suborder BEYRICHCOPINA Scott, 1961

? **Superfamily KIRKBYACEA** Ulrich and Bassler, 1906

? **Family SCROBICULIDAE** Posner, 1951

Lethiersa gen. nov.

Derivation of name. Dedicated to Prof. Francis Lethiers, retired from Pierre et Marie Curie University, Paris, France.

Type species. *Lethiersa sinusoventralis* gen. nov. sp. nov. (Plate 21, Figures 1, 2).

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Specie \ Samples	PS12	PS22	PR16	PR17	PR19	PR20	PR22
<i>Acratia</i> cf. <i>visnyoensis</i>	•						
<i>Anahuacia lercaraensis</i> n. sp.			•		•	•	
<i>Aurigerites siciliaensis</i> n.sp.					•	•	
<i>Bairdia altiaricus</i>			•	•	•		
<i>Bairdia</i> cf. <i>austriaca</i>				•	•	•	
<i>Bairdia portellaensis</i> n.sp.	•	•	•	•	•		
<i>Bairdia</i> sp.1							•
<i>Bairdia</i> sp.2					•	•	
<i>Bairdia</i> sp.3					•		
<i>Bairdia</i> sp.6				•			
<i>Bairdiocypris</i> sp.1					•		
<i>Bassierella</i> cf. <i>tota</i>	•						
cf. <i>Baschkirina</i> n. sp.1				•			
<i>Cristanaria?</i> <i>katyae</i> n. sp.				•	•		
<i>Cyathus densistriata</i>				•			
<i>Cyathus</i> n. sp.2				•			
<i>Fabalitypris blumenstengeli</i>				•	•	•	
<i>Fabalitypris grundeli</i> n. sp.				•			•
? <i>Fabalitypris grundeli</i> n.sp.				•	•		
<i>Fabalitypris</i> sp.2				•	•	•	
<i>Fabalitypris</i> sp.3			•		•		
<i>Graphiadactyllis</i> cf. <i>deminuera</i>	•						
<i>Healdia</i> cf. <i>anterodepressa</i>					•		
" <i>Healdia</i> " cf. <i>irwinensis</i>							•
<i>Healdia</i> cf. <i>unispinosa</i>				•			
<i>Healdia</i> ?sp.3						•	
<i>Healdia</i> sp.2				•			
<i>Lethiersia salomonensis</i>		•?		•	•		
? <i>Liuzhinia antalyaensis</i>				•			
<i>Lethiersia sinusoventralis</i> n.gen. n.sp.				•	•		
<i>Marginohealdia</i> n.sp.2				•	•	•	
<i>Marginohealdia</i> sp.1				•			
<i>Marginopsis</i> cf. <i>marginella</i>					•		
<i>Neofellerites minimus</i>				•			
<i>Paraberounnella?</i> <i>laterospinosa</i>							•
<i>Portella trapezoida</i> n.gen. n.sp.				•	•	•	
<i>Praepilatina</i> cf. <i>adamczaki</i>				•	•		
<i>Pseudospinella bitauniensis</i>						•	
<i>Rectoplacera</i> cf. <i>dorsoclinata</i>			•	•			•
<i>Siciliella elongata</i> n.gen. n. sp.				•	•	•	
<i>Siciliella infernespinosa</i> n.gen. n.sp.					•		
<i>Siciliella prima</i> n.gen. n. sp.					•	•?	•
<i>Siciliella quadrata</i>				•	•		•
<i>Siciliella spinorobusta</i> n.gen. nsp.				•	•	•	
<i>Thimohealdia</i> cf. <i>vanderboogaardi</i>							•
<i>Timohealdia</i> sp.1						•	
<i>Triplacera</i> sp.1				•		•	
<i>Visnyoella parva</i>				•			

Table 3.3 Repartition of the Ostracod species per sample.

Diagnosis. A new Scrobiculidae?, a genus with small carapace, concentric large reticulations, subcentral vertical narrow sulcus and ridges along free margins, more or less expressed.

Remarks. *Lethiersa* gen. nov. is close to *Roundyella* Bradfield, 1935 and *Scrobicula* Posner, 1951. *Roundyella* has a more rectangular outline and is less high. *Scrobicula* presents a dorsal border of left valve higher than right one. The kinship with *Roundyella* and *Scrobicula* allows us to attribute *Lethiersa* gen. nov. questionably to Scrobiculidae.

Distribution. Early Carboniferous (Tournaisian) - Middle Permian (Wordian) of Germany, Italy and South China?

Species included in *Lethiersa* n. gen.:

Lethiersa sinusoventralis sp. nov. (Plate 21, Figures 1, 2)

Derivation of name. In relation to the shape of the ventral border.

Types. Holotype: one complete carapace (Plate 21, Figure 1), collection number MHNG201431; Paratype: one complete carapace (Plate 21, Figure 2), collection number MHNG201432.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of genus *Lethiersa* gen. nov. (see above) with straight to nearly concave ventral border and typical reversal of overlap in anterior part of ventral border.

Description. Small carapace, with long straight dorsal border, cardinal angles well expressed, anterior border with large radius of curvature; maximum of height located in front of the first third of length, ventral border straight to gently concave; posterior border with relatively small radius of curvature, maximum of convexity located above the upper third of height; slight overlap of left valve on right one all along free margins; reversal of the overlap on one point, on the anterior extremity of ventral border; surface reticulated; large reticulation following the carapace outline; presence of a narrow, vertical sulcus in the central part of the carapace.

Size. L=300-380µm; H= 210-250µm

Distribution. Samples PR17 and PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Lethiersa salomonensis sp. nov. (Plate 21, Figures 3, 6)

Derivation of name. From the Pietra di Salomone section where the species has been found.

Types. Holotype: one complete carapace (Plate 21, Figure 3), collection number MHNG201433; Paratype: one complete carapace (Plate 21, Figure 6), collection number MHNG201434.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of genus *Lethiersa* gen. nov., with rounded ventral border and a ridge parallel to free margins.

Description. Dorsal border straight where right valve slightly overlaps left one. Anterior border rounded with small radius of curvature and maximum of convexity located at first third of height; ventral border regularly rounded; maximum of height located a little in front of mid-length; posterior border with small radius of curvature; maximum of convexity located between first third and mid height; a thick ridge follows free margins from anterior cardinal angle to posterior one; surface regularly reticulated, with large, concentric reticulation; small vertical sulcus typical from the genus.

Remarks. *Lethiersa salomonensis* sp. nov. differs from *Lethiersa sinusoventralis* sp. nov. by the ridge parallel to free margins and the shape of anterior border (with smaller radius of curvature).

Size. L= 260-280µm; H= 185-200µm.

Distribution. Samples PR17, PR19 and PS22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 and Pietra Salomone 2 sections, Sicily, Italy.

Superfamily OEPIKELLACEA Johnson, 1957

Family APARCHITIDAE Jones, 1901

Genus *Cyathus* Roth and Skinner, 1930

Cyathus densistriata (Kozur, 1991) (Plate 21, Figure 5)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, and Torrente San Calogero section of Catalano *et al.* (1991) Sicily, Italy.

Cyathus sp. nov. 2 (Plate 21, Figure 7)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Order METACOPIDA Sylverster-Bradley, 1961

Suborder METACOPINA Sylverster-Bradley, 1961

Superfamily HEALDIACEA Harlton, 1933

Family HEALDIIDAE Harlton, 1933

Genus Healdia Roundy, 1926

Healdia cf. *anterodepressa* Blumenstengel, 1965 (Plate 21, Figure 8)

Distribution. Sample PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Healdia cf. *irwinensis* Fleming, 1985 in Foster *et al.*, 1985 (Plate 21, Figure 9)

Distribution. Sample PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

“*Healdia*” cf. *unispinosa* McLaughlin, 1952 (Plate 21, Figure 10)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Healdia? sp. 2 (Plate 21, Figure 11)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Healdia? sp. 3 (Plate 21, Figure 12)

Distribution. Sample PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus Timorhealdia Bless, 1987

Timorhealdia cf. *vanderboogaardi* Bless, 1987 (Plate 21, Figure 13)

Distribution. Sample PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Timorhealdia sp. 1 (Plate 21, Figure 14)

Distribution. Sample PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus Marginohealdia Blumenstengel, 1965

Marginohealdia sp. nov.2 (Plate 21, Figures 15, 18)

Distribution. Samples PR17, PR19 and PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Marginohealdia sp. 1 (Plate 21, Figure 17)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus Marginopsis Gründel, 1975

Marginopsis cf. *marginella* Gründel, 1975 (Plate 21, Figure 16)

Distribution. Sample PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Superfamily THLIPSURACEA Ulrich, 1894**Family QUASILLITIDAE** Coryell and Malkin, 1936**Genus Graphiadactyllis** Roth, 1929

Graphiadactyllis cf. *deminuera* Gründel, 1975 (Plate 25, Figure 18)

Distribution. Sample PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

? Family BUFINIDAE Sohn and Stover, 1961**Genus Aurigerites** Roundy, 1926

Aurigerites siciliaensis sp. nov. (Plate 22, Figures 1 to 4)

Derivation of name. From Sicily Island from where the species originate.

Types. Holotype: one complete carapace (Plate 22, Figure 1), collection number MHNG201449; paratype: one complete carapace (Plate 22, Figure 3), collection number MHNG201451.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of genus *Aurigerites* Roundy, 1926 characterised by a strong blade in postero-ventral part, a small anterior border with maximum of curvature located high and well defined cardinal angles.

Description. Subquadrangular carapace; strong overlap of left valve on right one all around the carapace; sharp cardinal angles; dorsal border straight to gently concave at right valve and slightly convex at left valve; anterior border with relatively small radius of curvature and maximum of convexity located high (above mid-height); ventral border straight at both valves, subparallel to dorsal border; posterior border almost vertical, with maximum of curvature located below mid-height; presence of a strong blade in postero-ventral part of the carapace, on each valve; the ventral part of the blade might be prolonged forward by a ventral ridge; the carapace is flattened in dorsal part; two longitudinal depressions possible in dorso-median and median part of the carapace; surface smooth.

Remarks. *Aurigerites siciliaensis* sp. nov. is close to *Aurigerites obernitzensis* Gründel, 1962 from the lowermost Carboniferous of Thuringia (Germany) (Gründel, 1962). In the latter species the anterior border is larger, the posterior blade is located lower and the overlapping is more important. Our species could be compared to *Aurigerites* sp. 1 *sensu* Gründel and Kozur (1975 in Bless, 1987) from the Early Permian of Timor Island. Here, the maximum of curvature of anterior border is located higher and the posterior blade is located further back and in a lower position.

Size (without the blade). L= 460-650µm; H= 280-420µm.

Distribution. Samples PR19 and PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Order PODOCOPIDA Sars, 1866**Suborder CYPRIDICOPINA** Jones, 1901**Superfamily BAIRDIACEA** Sars, 1888**Family BAIRDIIDAE** Sars, 1888**Genus Bairdia** McCoy, 1844

Bairdia altiarcus Chen, 1958 (Plate 22, Figures 5, 6)

Distribution. Samples PR16, PR17, PR19 and PR20 (see Table 3.3), Early to Late Permian of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy; Lungtan (Chen, 1958 and Guangxi Nikishin *et al.*, 2002), South China.

Bairdia cf. *austriaca* (Kollmann, 1963) *sensu* (Gründel & Kozur, 1975) (Plate 22, Figures 7, 8).

Distribution. Samples PR17, PR19 and PR20 (see Table 3.3), Early-Middle Permian of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy and Timor Island, Indonesia (Gründel & Kozur, 1975).

Bairdia portellaensis sp. nov. (Plate 22, Figures 9 to 12)

1982. *Cryptobairdia folgeri* (Kellett, 1934). Chen and Shi (1982), pl. 6, Figures 19-20.

1987. *Cryptobairdia folgeri* (Kellett, 1934). Shi and Chen (1987), pl. 5, Figures 21-26.

Derivation of name. From the Portella Rossa section, the *locus typicus*.

Types. Holotype: one complete carapace (Plate 22, Figure 9), collection number MHNG201457; paratype: one complete carapace (Plate 22, Figure 10), collection number MHNG201458.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of genus *Bairdia* with very regular shell, outline of left valve parallel to right valve one (except at ventral border); all dorsal parts straight.

Description. Small Bairdiidae, carapace characterized by regular outline with straight postero-dorsal, dorsal and antero-dorsal borders; anterior border with large radius of curvature and maximum of convexity located a little below mid-height; ventral border nearly straight at left valve, slightly concave at right valve; posterior border with small radius of curvature, not very tapering, extremity located below the lower third of height; slight overlap of left valve on right one, maximum on dorsal part of the shell, minimum on anterior and antero-ventral part; no lateral flattening; surface smooth.

Remarks. *Bairdia portellaensis* sp. nov. is close to *Cryptobairdia altiarcus* (Chen, 1958 in Shi & Chen, 2002) from the Early Permian of Lungtan (Chen, 1958) and Late Permian from Central Guangxi, South China (Nikishin *et al.*, 2002). The new species differs from *Cryptobairdia altiarcus* by the absence of lateral flattening at anterior and posterior borders and by its anterior border with larger radius of curvature. The small carapaces figured in Shi & Chen (2002); pl. 7, Figures 9, 10 and 12) could belong to *Bairdia portellaensis* sp. nov. The Upper Permian specimens figured by Chen & Shi (1982) and Shi & Chen (1987) and assigned to *Bairdia folgeri* Kellett, 1934, do not belong to this species but are in fact attributed here to *Bairdia portellaensis* sp. nov.

Size. L= 300-500µm; H= 200-350µm.

Distribution. Samples PR16, PR17, PR19, PR20, PS12 and PS22 (see Table 3.3), Middle-Late Permian of the Lercara Formation, Portella Rossa 1, Pietà di Salomone 1 and Pietà di Salomone 2 sections, Sicily, Italy and South China.

Bairdia sp. 1 (Plate 22, Figure 13)

Distribution. Sample PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Bairdia sp. 2 (Plate 22, Figure 14)

Distribution. Samples PR19 and PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Bairdia sp. 3 (Plate 22, Figure 15)

Distribution. Sample PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Bairdia? sp. 6 *sensu* Bless, 1987 (Plate 22, Figure 16)

Distribution. Sample PR17 (see Table 3.3), Early-Middle Permian of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy and Timor Island, Indonesia.

Genus *Fabalicypri* Cooper, 1946

Fabalicypri grundeli sp. nov. (Plate 23, Figures 1 to 3, 4?, 5?)

Derivation of name. Dedicated to Prof. Dr. Joachim Gründel who provided the foundations, together with Prof. Horst Blumenstengel, for the development of the palaeopsychrospheric ostracod knowledge.

Types. Holotype: one complete carapace (Plate 23, Figure 1), collection number MHNG201467; paratype: one complete carapace (Plate 23, Figure 2), collection number MHNG201468.

Type horizon. Sample PR17, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of genus *Fabalitypris* with symmetric carapace in lateral view and with overlapping reduced to minimum at postero-ventral border.

Description. Carapace almost symmetric in lateral view; dorsal border regularly arched; anterior and posterior border more or less equivalent for right valve, posterior border very slightly slender than the anterior one; ventral border almost straight at right valve, slightly convex at left valve; left valve overlaps right one all around the carapace; this overlap is regular and slight except at the postero-ventral border where it is quite nonexistent.

Remarks. Several specimens (Plate 23, Figures 4, 5) present almost the same characters but with an overlap at dorsal border more important which changes a some what the general outline of the carapace. They are larger (L=650-870µm; H= 360-470µm) than *Fabalitypris grundeli* sp. nov. and for this reason they are tentatively attributed to ?*Fabalitypris grundeli* sp. nov. These specimens occur in samples PR17 and PR19.

Size. L=340-490 µm; H= 180-240µm.

Distribution. Samples PR17, PR19? and PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Fabalitypris blumenstengeli sp. nov. (Plate 23, Figures 6, 9, 12)

Derivation of name. Dedicated to Prof. Dr. Horst Blumenstengel who provided the foundations, together with Prof. Joachim Gründel, for the development of the palaeopsychrospheric ostracod knowledge.

Types. Holotype: one complete carapace (Plate 22, Figure 6), collection number MHNG201472; paratype: one complete carapace (Plate 22, Figure 9), collection number MHNG201473.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of genus *Fabalitypris* with asymmetric carapace in lateral view and with posterior border tapering.

Description. Elongated carapace with dorsal border regularly arched at left valve and straight at right valve; antero-dorsal and postero-dorsal border straight at right valve, arched at left one; anterior border rounded, posterior one tapering; ventral border gently arched to straight at left valve and slightly concave at right one; overlapping all around the carapace with minimum at postero-ventral border.

Remarks. *Fabalitypris blumenstengeli* sp. nov. differs from *Fabalitypris blumenstengeli* sp. nov. by a larger radius of the curvature of the anterior border and a posterior border less slender. It is close to the specimens described as *Fabalitypris minuta* (Cooper, 1946) by Shi & Chen (1987). However, the new species is erected because the material from Late Permian of South China (Shi & Chen, 1987) does not belong to the species *Fabalitypris minuta* Cooper, 1946, originally described from Late Carboniferous of Illinois (North America).

Size. L=450-1040µm; H= 180-510µm.

Distribution. Samples PR17, PR19 and PR22 (see Table 3.3), Middle Permian (Roadian to Wordian) of Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Fabalitypris sp. 3 (Plate 22, Figure 17)

Distribution. Samples PR16 and PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus *Liuzhinia* Zheng, 1976

?*Liuzhinia antalyaensis* Crasquin-Soleau, 2004 (Plate 22, Figure 18)

Remarks. This species is particularly close to *Liuzhinia antalyaensis* (Crasquin-Soleau *et al.*, 2004) described in the first level of Induan (earliest Triassic) of Antalya Nappes (SW Turkey). The only difference is a maximum of curvature of the posterior border located somewhat higher in this species. We have only

one specimen in Sicily but, if the systematic attribution is confirmed by additional material, *Liuzhinia antalyaensis* would appear in the Middle Permian and would cross the Permian-Triassic boundary.

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus *Acratia* Delo, 1930

Acratia cf. *visnyoensis* Kozur, 1985 (Plate 23, Figures 10, 11)

Distribution. Sample PS22 (see Table 3.3), Permian? of the Lercara Formation, Pietra di Salomone 2 section (N37°39'26", E 13°22'20"), Sicily, Italy.

Superfamily BAIRDIOCYPRIDACEA Shaver, 1961

Family BAIRDIOCYPRIDIDAE Shaver, 1961

Genus *Bairdiocypris* Kegel, 1932

Bairdiocypris sp. 1 (Plate 23, Figures 7, 8)

Distribution. Sample PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus *Praepilatina* Polenova, 1970

Praepilatina cf. *adamczaki* Olempska, 1979 (Plate 23, Figure 16)

Distribution. Samples PR17 and PPR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Family RECTONARIIDAE Gründel, 1962

Genus *Rectoplacera* Blumenstengel, 1965

Rectoplacera cf. *dorsoclinata* Blumenstengel, 1965 (Plate 23, Figures 13 to 15)

Distribution. Samples PR16, PR17 and PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus *Triplacera* Gründel, 1961

Triplacera sp. 1 (Plate 23, Figures 17, 18)

Distribution. Samples PR17 and PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus *Anahuacia* Gründel, 1972

Anahuacia? *lercaraensis* sp. nov. (Plate 24, Figures 1 to 4)

Derivation of name. From the Lercara Formation, the type horizon.

Types. Holotype: one complete carapace (Plate 24, Figure 1), collection number MHNG201485; paratype: one complete carapace (Plate 24, Figure 3), collection number MHNG201487.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species questionably attributed to genus *Anahuacia* Gründel, 1972 with an elongated carapace, showing posterior spines directed towards the back and a thick ridge at postero-ventral border particularly well expressed at right valve.

Description. Carapace elongated ($0.48 < H/L < 0.53$); dorsal border straight; antero-dorsal border slightly concave; anterior border largely rounded with maximum of convexity located a little below mid-height; ventral border almost straight at left valve and concave at right one; posterior border with small radius of convexity, with maximum of curvature located at lower third of height; maximum of height located at the anterior third of length; strong spine which begins in the medio-dorsal part of the carapace and is directed towards the back; presence of a ridge parallel to anterior border, slightly behind it; presence of a thick ridge in postero-ventral part of the carapace, which begins at the bottom of posterior border and reaches the ventro-median part of the carapace; carapace flattened laterally in front and behind the anterior ridge and strongly behind the spines; surface smooth.

Remarks. *Anahuacia? lercaraensis* sp. nov. differs from *Anahuacia tlaloa* Gründel, 1962 from Early Visean of Harz (Germany) and from *Anahuacia mutisensis* Bless, 1987 from Early Permian of Timor (Indonesia) by the posterior spines directed towards the back, its more elongated carapace and the typical shape of postero-ventral part of the carapace.

This new species is questionably attributed to genus *Anahuacia*. Indeed, in comparison with others species of the genus. Here we have a very strong flattening of posterior part and overlap around the carapace. It may be a new genus.

Size. L= 655-1040µm; H= 320-530µm.

Distribution. Samples PR16, PR19 and PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus Portella gen. nov.

Derivation of name. From the Portella Rossa 1 section, the type horizon.

Type species. *Portella trapezoida* gen. nov. sp. nov. (Plate 24, Figures 5, 6, 8, 9).

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A new Rectonariidae genus with trapezoidal carapace and a small spine in dorso-median part of the carapace.

Remarks. This genus differs from the other Rectonariidae genera, and particularly from *Rectonaria* Gründel, 1962, by the trapezoidal shape of the carapace.

Distribution. Middle Permian (Roadian-Wordian) from Sicily, Italy

Portella trapezoida gen. nov. sp. nov. (Plate 24, Figures 5, 6, 8, 9)

Derivation of name. From the general shape of the carapace.

Types. Holotype: one complete carapace (Plate 24, Figure 5), collection number MHNG201489; paratype: one complete carapace (Plate 24, Figure 6), collection number MHNG201490.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species of *Portella* gen. nov. with trapezoidal carapace and small spine in dorso-posterior part of shell.

Description. Carapace trapezoidal with straight dorsal and antero-dorsal borders; anterior border with large radius of curvature (nearly vertical); ventral border nearly straight to gently concave at right valve; posterior border almost vertical; maximum of height located between mid-length and anterior third of length; left valve overlaps the right one all around the carapace; presence of a small spine in postero-dorsal part of the carapace directed towards the back; surface smooth.

Size. L= 270-420µm; H= 170-280µm.

Distribution. Samples PR17, PR19 and PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus Siciliella gen. nov.

Derivation of name. From Sicily, where the genus has been found.

Type species: *Siciliella prima* gen. nov. sp. nov. (Plate 24, Figures 7, 10 to12?).

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A new Rectonariidae genus with sub-quadrangular carapace, overlapping of left valve on right one all around the carapace; one spine on each valve; slight tapering of postero-ventral border.

Distribution. Middle Permian (Roadian to Wordian) from Sicily, Italy

Species included.

Siciliella prima gen. nov. sp. nov.

Siciliella quadrata gen. nov. sp. nov.

Siciliella infernespinosa gen. nov. sp. nov.

Siciliella elongata gen. nov. sp. nov.

Siciliella spinorobusta gen. nov. sp. nov.

Siciliella prima gen. nov. sp. nov. (Plate 24, Figures 7, 10 to 12?)

Derivation of name. From Latin “*prima*” = first. This species is the first described in relation to the new genus *Siciliella*.

Types. Holotype: one complete carapace (Plate 24, Figure 10), collection number MHNG201494; paratype: one complete carapace (Plate 24, Figure 7), collection number MHNG201493.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03”, E13°16'50”), Sicily, Italy.

Diagnosis. A species of genus *Siciliella* gen. nov. with a short dorsal border and the spine located in the dorso-median part of the carapace.

Description. Carapace sub-quadrangular with short arched dorsal border; anterior border with larger radius of curvature than posterior one; overlapping of left valve on right one all around the carapace with minimum at antero-ventral and postero-ventral borders; small spine located in dorso-median part of the carapace, directed towards the back; slight tapering of posterior border, underlined by a small furrow; H/L = 0.64-0.66.

Remarks. *Siciliella prima* gen. nov. sp. nov. differs from the other species of the genus by the specific characters.

One specimen (Plate 24, Figure 12) is questionably related to *Siciliella prima* gen. nov. sp. nov. Nevertheless, some differences are notable: maximum of height located in the anterior third of length, spine located in antero-dorso-median part of the carapace; posterior border of left valve is slender. H/L = 0.72. This specimen may belong to another new species.

Size. L = 310-510 µm; H = 200-340 µm.

Distribution. Samples PR19, PR20? and PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Siciliella quadrata gen. nov. sp. nov. (Plate 24, Figures 13 to 15)

Derivation of name. From the shape of the carapace.

Types. Holotype: one complete carapace (Plate 24, Figure 13), collection number MHNG201497; paratype: one complete carapace (Plate 24, Figure 14), collection number MHNG201498.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03”, E13°16'50”), Sicily, Italy.

Diagnosis. A species of genus *Siciliella* gen. nov. with a quadrangular carapace and a small spine located in dorso-posterior part of the carapace.

Description. Carapace sub-quadrangular with dorsal border nearly straight; dorsal and ventral border have almost the same length; curvature of anterior and posterior borders quite equivalent, maximum of curvature of posterior border located lower than at anterior border; overlapping of left valve on right one all around the carapace; small spine located in postero-dorsal part of the carapace, directed towards the back; H/L = 0.62-0.70.

Remarks. *Siciliella quadrata* gen. nov. sp. nov. differs from the other species of the genus by the specific characters.

Size. L = 340-510 µm; H = 240-350 µm.

Distribution. Samples PR10, PR17, PR19 and PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Siciliella infernespinosa gen. nov. sp. nov. (Plate 24, Figures 16 to 18)

Derivation of name. From Latin “*inferne*” and “*spinosa*” in relation to the location of the spine.

Types. Holotype: one complete carapace (Plate 24, Figure 16), collection number MHNG201500; paratype: one complete carapace (Plate 24, Figure 17), collection number MHNG201501.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03”, E13°16'50”), Sicily, Italy.

Diagnosis. A species of genus *Siciliella* gen. nov. with a quadrangular carapace and a small spine located in ventro-posterior part of the carapace.

Description. Carapace sub-quadrangular with dorsal border nearly straight; dorsal and ventral border have almost the same length; curvature of anterior and posterior borders quite equivalent, maximum of curvature of posterior border located lower than at anterior border; overlapping of left valve on right one all around the carapace; small spine located in postero-ventral part of the carapace, directed towards the back; $H/L = 0.65$.

Remarks. *Siciliella infernespinosa* gen. nov. sp. nov. differs from *Siciliella quadrata* gen. nov. sp. nov. by the position of the spine.

Size. $L=350-370\ \mu\text{m}$; $H=230-240\ \mu\text{m}$.

Distribution. Sample PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Siciliella elongata gen. nov. sp. nov. (Plate 25, Figures 1 to 6)

Derivation of name. From the shape of the carapace.

Types. Holotype: one complete carapace (Plate 25, Figure 1), collection number MHNG201503; paratype: one complete carapace (Plate 25, Figure 4), collection number MHNG201506.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section ($N37^{\circ}38'03''$, $E13^{\circ}16'50''$), Sicily, Italy.

Diagnosis. A species of genus *Siciliella* gen. nov. with an elongated quadrangular carapace and a small spine located in ventro-posterior part of the carapace.

Description. Carapace sub-quadrangular with dorsal border nearly straight; dorsal and ventral border have almost the same length; anterior border regularly arched with maximum of curvature located below mid-height; posterior border with a small radius curvature and a dorsal part almost rectilinear which makes a significant angle with dorsal border; overlapping of left valve on right one all around the carapace with minimum at antero-ventral and postero-ventral borders and at anterior part of dorsal border; small spine (sometimes difficult to observe) located in postero-ventral part of the carapace, directed towards the back; $H/L = 0.55-0.60$.

Remarks. *Siciliella elongata* gen. nov. sp. nov. differs from *Siciliella quadrata* gen. nov. sp. nov. by its more elongated carapace and by the angle between postero-dorsal and dorsal borders.

Size. $L=350-650\ \mu\text{m}$; $H=230-380\ \mu\text{m}$.

Distribution. Samples PR17, PR19 and PR20 (see Table 3.3), Middle Permian (Roadian to Wordian) of Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Siciliella spinorobusta gen. nov. sp. nov. (Plate 25, Figures 7 and 8)

Derivation of name. From the shape and the robustness of the spine.

Types. Holotype: one complete carapace (Plate 25, Figure 7), collection number MHNG201509; paratype: one complete carapace (Plate 25, Figure 8), collection number MHNG201510.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section ($N37^{\circ}38'03''$, $E13^{\circ}16'50''$), Sicily, Italy.

Diagnosis. A species of genus *Siciliella* gen. nov. with a very strong spine located in medio-posterior part of the carapace.

Description. Carapace sub-quadrangular with dorsal border nearly straight; dorsal and ventral border have almost the same length; anterior border and posterior border almost equivalent; strong overlapping of left valve on right one all around the carapace; flattening of the carapace on antero- and postero-ventral borders; strong spine located in medio-posterior part of the carapace, directed towards the back; $H/L = 0.55-0.60$.

Remarks. *Siciliella elongata* gen. nov. sp. nov. is closed from *Siciliella quadrata* gen. nov. sp. nov. but it differs from by its strong spine.

Size. $L=590-670\ \mu\text{m}$; $H=390\ \mu\text{m}$.

Distribution. Samples PR19 and PR20 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Genus *Pseudospinella* Kozur, 1991

Pseudospinella bitauniensis (Bless, 1987) (Plate 25, Figure 9)

1987. *Spinella bitauniensis* sp.n. (Bless, 1987). p. 4, Figure 3 A-K.

1991. *Pseudospinella ruggierii* gen. nov. sp. nov. (Kozur, 1991). p. 6-7, pl. 2, Figures 1-5.

Distribution. Sample PR20 (see Table 3.3), Early-Middle Permian of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy and of Timor Island, Indonesia.

? Family RECTONARIIDAE Gründel, 1962

Genus *Cristanaria* Blumenstengel, 1979

Cristanaria katyae sp. nov. (Plate 5, Figures 10 to 13)

Derivation of name. Dedicated to Prof. Catherine Marque, Université de Technologie de Compiègne.

Type. Holotype: one complete carapace (Plate 25, Figure 10), collection number MHNG201512; paratype: one complete carapace (Plate 25, Figure 11), collection number MHNG201513.

Type horizon. Sample PR19, Lercara Formation; Roadian-Wordian; Portella Rossa 1 section (N37°38'03", E13°16'50"), Sicily, Italy.

Diagnosis. A species attributed to the genus *Cristanaria* characterized by hexagonal carapace, strong anterior and ventral ridge ended in posterior spine and a large median ridge connected to previous ridge in dorso-anterior part of the carapace and to the back to the upper spine.

Description. Dorsal and ventral borders straight and parallel; anterior and posterior borders more or less equivalent, with small radius of curvature, in largest specimens the posterior border becomes angular; strong overlap of left valve on right one all around the carapace; H/L = 0.58-0.63; presence of two strong spines in the posterior part of the carapace, directed backwards, one ventral the other median; presence of a large ridge on all the median parts of the carapace; presence of a ridge parallel to anterior and ventral borders; this ridge is connected to the previous in the antero-dorsal part of the carapace and terminates at the ventral spine; the upper part of the median ridge ends in the upper spine; in the largest specimens, it seems that an additional spine exists on posterior end of dorsal border; surface smooth.

Remarks. *Cristanaria katyae* sp. nov. differs from *Cristanaria cristata* Blumenstengel, 1965 from Late Devonian of Germany by the shape of the carapace and the absence of small spine at antero-dorsal border.

Size. L=330-550µm; H= 210-390µm.

Distribution. Samples PR17 and PR19 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Family KRAUSELLIDAE Berdan, 1961

Genus *Baschkirina* Rozhdestvenskaya, 1959

cf. *Baschkirina* sp. nov. 1 *sensu* Crasquin-Soleau *et al.*, 2004 (Plate 25, Figure 14)

Distribution. Samples PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Suborder CYTHEROCOPINA Gründel, 1967

Superfamily CYTHERACEA Baird, 1850

Family BYTHOCYTHERIDAE Sars, 1926

Genus *Paraberoundella* Blumenstengel, 1965

Paraberounnella? laterospinosa Kozur, 1991 (Plate 25, Figure 15)

Distribution. Sample PR22 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Order PLATYCOPIDA Sars, 1866

Suborder PLATYCOPINA Sars, 1866

Superfamily CYTHERACEA Baird, 1850

Family CYTHERIDEIDAE Sars, 1925

Genus *Basslerella* Kellett, 1935

Basslerella cf. *tota* Chen & Bao, 1986 (Plate 25, Figure 16)

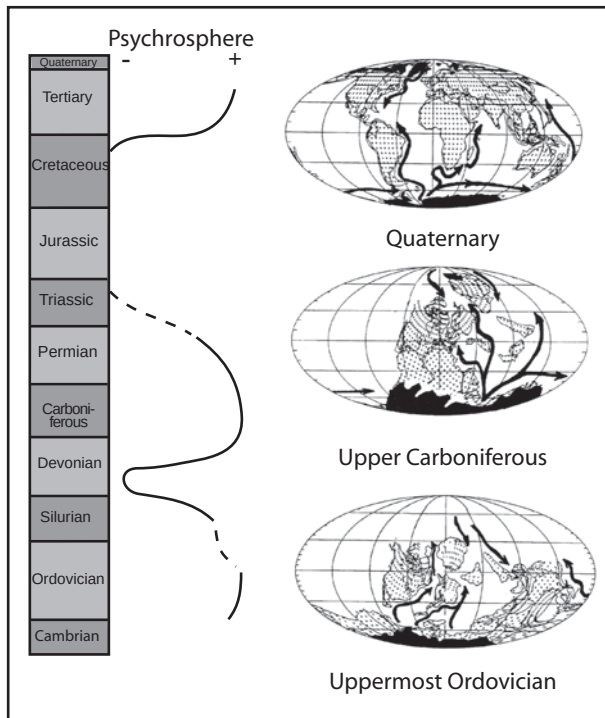


Figure 3.3 World psychrosphere during Phanerozoic based on the presence of psychrospheric ostracods. On the maps, black areas indicate icecaps and black arrows cold sea bottom currents. Modified from Lethiers (1998).

Distribution. Sample PS22 (see Table 3.3), Permian? of Lercara Formation, Pietra di Salomone 2 section, Sicily, Italy.

Family CYTHERISSINELLIDAE Schneider, 1960

Genus *Visnyonella* Kozur, 1985

Visnyoella parva Kozur, 1985 (Plate 25, Figure 17)

Distribution. Sample PR17 (see Table 3.3), Middle Permian (Roadian-Wordian) of the Lercara Formation, Portella Rossa 1 section, Sicily, Italy.

Palaeoenvironmental setting

As indicated above, the well-preserved Sicilian ostracod fauna shows delicate ornamentations. These, together with the presence of fragile conodonts, excludes a particle reworking of the specimens. Therefore, a mass reworking of the ostracods and conodonts inglobed in mass of clays is considered as being the origin of our assemblages.

The ostracod assemblages found in the Lercara Formation samples are composed of neritic and palaeopsychrospheric forms. Although Kozur (1991) evoked the transportation of the neritic forms towards the basin, we are not of the same opinion. Indeed, if the carapaces had been transported over long distances from the platform to the basin, the preservation would have been greatly altered and it would be difficult to observe delicate ornamentations as in *Neofellerites minimus* (Plate 21, Figure 4).

The palaeopsychrospheric ostracods, indicative of deep-water environments, differ from contemporary neritic forms by their thin tests and/or the presence of very well developed spines. During the Late Devonian - Dinantian interval, they were associated with bathyal facies, in low energy cold water, and probably with low oxygen content (Lethiers & Crasquin, 1987; Lethiers & Raymond, 1991). Similar fauna were described in the Early Permian of Timor (Gründel & Kozur, 1975; Bless, 1987), in the Middle Permian of Sicily (Kozur, 1991), as well as in the Early and Middle? Triassic of the Alps (Kozur, 1972) and of Roumania (Crasquin-Soleau & Gradinaru, 1996). The term “palaeopsychrospheric” was proposed by Kozur (1972) to indicate this special kind of assemblages

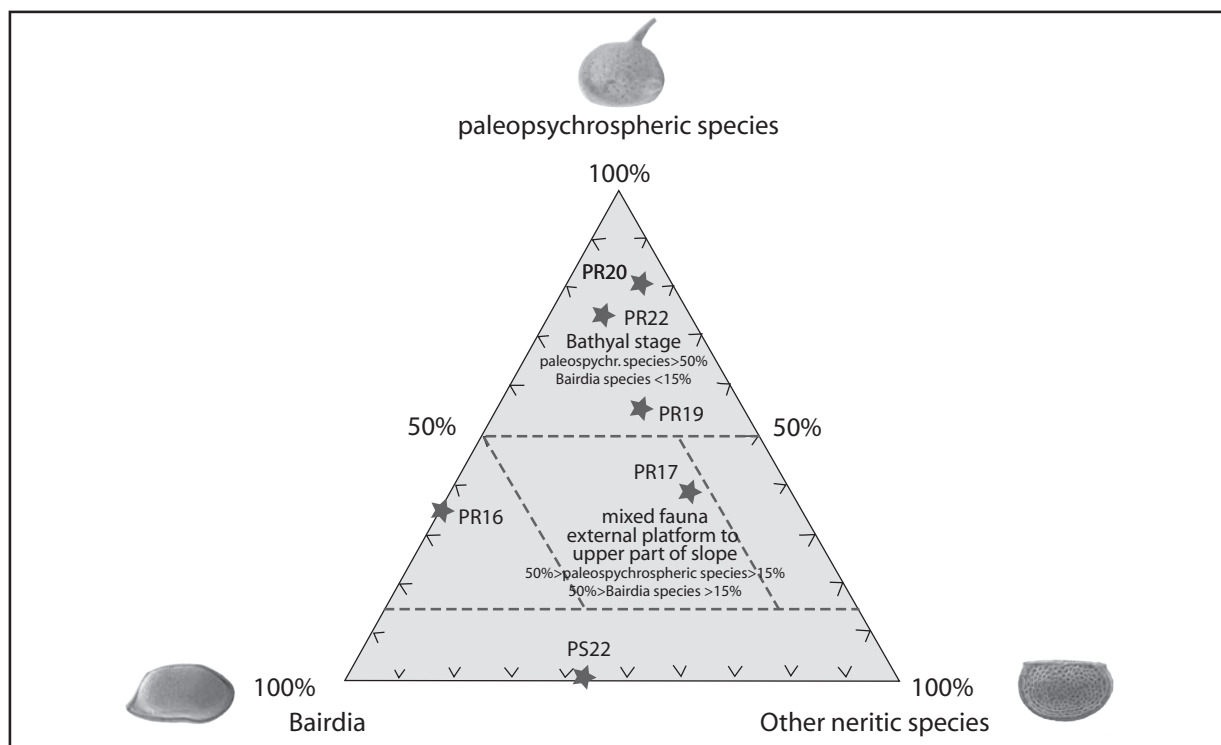


Figure 3.4 Triangular diagram showing the composition of the Lercara ostracods assemblages and the possible bathymetric location of the different samples. Model of Lethiers & Raymond (1991).

present in the whole Late Palaeozoic – Earliest Mesozoic interval. The term “palaeopsychrospheric” was chosen in order to underline the morphological analogy with the assemblage present in modern psychrosphere, occurring from Eocene to Present. The modern psychrosphere is defined as the lower cold level of the modern ocean, as opposed to the thermosphere, the less dense and warmer upper level (more than 10°C). The ocean stratification was apparently absent from Early Jurassic to Eocene. The palaeopsychrosphere existed on two occasion prior to the Quaternary: during the Late Ordovician and during the Carboniferous – Permian (Figure. 3.3) (Lethiers, 1998). The palaeopsychrospheric ostracods are found from the Late Ordovician to the Early Triassic. This fauna is restricted to deep-water environments, from 500 metres to 5000 metres deep and are linked to the global ocean circulation fed with melt waters from the Gondwana icecaps.

The neritic forms present in the Lercara Formation are typical of tropical warm water and can be split up into two palaeoecological “groups”: the Bairdiidae, which are open marine platform inhabitants, and “other neritic” species which are associated with a more shallow environment. Following the model of Lethiers and Raymond (1991), a percentage of palaeopsychrospheric ostracods higher than 50% is indicative of slope to bathyal environment.

In the *Pietra di Salomone 1* section, only one sample (PS12) provided ostracods. Therefore, Bairdiidae, the only present genus, does not have any palaeoecological significance on its own. In the *Pietra di Salomone 2* section, ostracods were found in sample PS22. They belong to five species which are 60% neritic and 40% Bairdiidae. This assemblage could indicate an open marine environment on the platform, before the slope.

Nevertheless, it is difficult to provide more precise palaeoenvironmental indications due to the small number of species. Furthermore, the reworking events affecting the series also make it impossible to estimate the bathymetry variation through time. On the other hand, we can give a fairly precise indication of the living depth of the different associations. In order to do this, the composition of our assemblages is reported in species percentage on a triangular diagram, using the Lethiers and Raymond model (1991) (Figure 3.4).

For the samples from Portella Rossa PR16 and PR17, the depositional environment could be located both on the external part of the platform and on the higher part of the slope. The bathyal stage is plausible for

sample associations PR19, PR20 and PR22, which are composed of more than 50% of palaeopsychrospheric representatives. Finally, the assemblage of sample PS22, devoid of deep representatives, seems to be significantly shallower and characteristic of the more internal part of the platform.

Palaeobiogeographic relationships

Kozur (1991) described an ostracod assemblage from the Torrente San Calogero section in Sicily. In Kozur's paper, all the material is presented as new. However, we are not in complete agreement with his generic attribution, and in addition twenty-six species out of twenty-seven described by the author seem to be endemic. Moreover, one species described as *Pseudospinella ruggierii* appears to be conspecific with *Pseudospinella bitauniensis* (Bless, 1987) from Timor Island. During our study, we retrieved only four of the species described by Kozur.

Considering the whole ostracod fauna of Western Sicily, seventy species are present: 47 from our study and 23 from Kozur's work (1991).

Seven of these were recognized outside Sicily. Three species are also present in Timor Island (Indonesia): *Pseudopinella bitauniensis* (Bless, 1987), *Bairdia* cf. *austriaca* Kollmann *sensu* Gründel and Kozur, 1975 and *Bairdia* sp. 6 *sensu* Bless (1987). They have been described in the Early Permian. They belong to palaeopsychrospheric assemblages and may have migrated from Indonesia to Sicily, in deep cold waters. This implies that in Sicily during at least the Rodian-Wordian a deep-water sedimentation connecting Timor and Sicily Islands existed.

Four neritic species are also present in other regions: *Bairdia altiarcus* Chen 1958 (whole Permian of South China) and *Bairdia portellaensis* sp. nov. (Late Permian of China); *Visnyoella parva* Kozur 1985 (Late Permian of Bükk Mountains, Hungary) and *?Liuzhinia antalyaensis* Crasquin-Soleau, 2004 (earliest Triassic of Western Taurus). The distribution over a long distance of benthic fauna can only have taken place if the palaeoenvironmental conditions remained constant all along the migration route and the plate configuration allowed a continuous migration platform to platform. We can thus venture the hypothesis that neritic faunal exchanges were possible along the Palaeo-Tethys platforms. This is possible if the Pangaea B reconstruction model (see chapter Introduction) is adopted, in which the eastern part of the Pangaea is as closed as possible as proposed in Besse *et al.* (1996) (Figure 1.3).

Some hypotheses can be advanced about the palaeogeographic relationships of the ostracods with respect to the Palaeo and the Neo-Tethys oceans, if the palaeogeographic reconstructions of Crasquin-Soleau *et al.* (2001) and Stampfli & Borel (2002) are taken into account (the reconstructions of Dercourt *et al.* 2000 are not considered because they do not extend so far eastward). For both authors, Timor Island was situated during the Permian in the Neo-Tethys, and South China in the Palaeo-Tethys. Thus, ostracods found in the Lercara Formation related to the Timor Island and China can indicate that during the Rodian-Wordian (age of the ostracods), a mix of the fauna coming from the two palaeodomains found their way into the original sediments, later reworked in the Lercara Formation.

CONODONTS

Conodonts are marine phosphatic (apatite) worm-like microfossils with dimensions of 200 to 4000 µm and are found from the Middle Cambrian to the Triassic. Conodonts are found in abundance in the outer platform sediments and become less frequent towards the basin sediments. They can be associated with radiolarians, foraminifera, ostracods and ammonites (Vrielynck, 1987). Association with ammonites and their large environmental distribution allow good correlation with ammonite zonations, making of the conodonts a good stratigraphic tool.

Conodonts are made up of a tooth-like projection, named “*cusps*” that drapes a conical basal cavity. Longitudinal and or lateral expansion named “*processes*” can also be present and can be decorated with denticles or nodes. Three groups of conodonts can be distinguished, depending on the development of the processes (Lindström, 1964). The first group or simple conodonts are characterised by the absence of processes, or by the presence of processes without denticles. The second group or compound conodonts

are characterised by processes developed longitudinally with denticles. In the last group, or platform conodonts, processes are developed longitudinally and partially laterally, forming a platform. Denticles surrounded by the platform are low or are fused in a carina.

For a long time, conodonts have been considered as the most reliable fossil for the global Permian correlations because they were regarded as more cosmopolitan than other important groups such as fusulines and ammonoids showing provincial character in different Permian domains. But recently, character of provincialism related to the temperature have been highlighted (Mei & Henderson, 2001). As far as Permian conodonts are concerned, disputes exist in the literature about their generic and specific assignment and about their stratigraphic and geographic repartition (e.g. Mei & Henderson, 2001, Henderson, 2001; Kozur & Wardlaw, 2002).

Seventy-two samples were washed under water and six were processed with a standard acetic acid dissolution (Vrielynck, 1987). Only two samples (PR17 and PR19) yielded associations of complete platform conodonts, one (PR16) supplied broken indeterminable association of simple, compound and platform conodonts, six (RP17, RPFa5, RPFa6, PS22, PR20 and PR22) provided isolated broken indeterminable platform conodonts.

Platform conodonts found in deposits of the Lercara Formation have been assigned to the *Mesogondolella siciliensis* (Kozur, 1975) group (Plate 26, Figures 1 to 6) according to the determination of the Dr. Michael Orchard of the Geological Survey of Canada (*pers. comm.*, 2005). Based on the latest correlation stage nomenclature, they can be assigned to the Rodian-Wordian (Orchard, 2005 *pers. comm.*).

Mesogondolella siciliensis (Kozur, 1975) had already been found in Lercara deposits in the Pietra di Salomone and Pietra del Passo di Burgio blocks and in the Torrente San Calogero section (Catalano *et al.*, 1991; Catalano *et al.*, 1992; Gullo, 1993).

Association of conodonts with paleopsychrospheric, *Bairdia* and others neritic species of ostracods in samples PR17 and PR19 of the Portella Rossa 1 section suggests that conodonts of the Lercara Formation come from an area situated between the upper part of slope to basin (Figure 3.4).

3.2.3 TRIASSIC FORAMINIFERA

Only a few Triassic foraminifera have been found in the Lercara Formation and only one in the Mufara Formation, belonging to suborders Textulariina, Fusulinina, Miliolina and Lagenina. They were found in the matrix or included in carbonate clasts in the microfacies B, C, and E of Member B. It is during this thesis that these Triassic foraminifera have been observed for the first time in the Lercara Formation. They are listed below and their distribution in the samples is shown in Table 3.1.

Suborder TEXTULARIINA Delage & Hérouard, 1896

Superfamily AMMODISCACEA Reuss, 1862

Family AMMODISCIDAE Reuss, 1862

Pilamina cf. *Pilamina densa* Pantic, 1965 (Plate 27, Figure 1)

Pilamina densa is found in the late Anisian to early Ladinian of the Dolomites (Premoli Silva, 1971), in the Anisian (Pelsonian to Illyrian) of Alps, Carpathian, Dinards, Balkans and Dolomites (Rettori, 1995), Pelsonian of Northern Germany and in the Middle- late Anisian of the Southern Alps (Falletti & Ivanova, 2003).

Superfamily TROCHAMMINACEA Schwager, 1877

Family TROCHSMMINIDAE Schwager, 1877

“*Trochammina*”? sp. (Plate 27, Figure 2).

“*Trochammina*” aff. “*Trochammina*” *almtalensis* Koehn-Zaninetti, 1968 (Plate 27, Figure 3)

“*Trochammina*” aff. “*Trochammina*” *almtalensis* is found in the Anisian of Carpathian, Balkans and Alps (Zaninetti, 1976) and in Middle and in the late Anisian of Southern Carpathians (Bucur *et al.*, 1997).

Suborder FUSULININA Wedekind, 1937

Superfamily ENDOTHYRACEA Brady, 1884**Family ENDOTEBIDAE** Vachard *et al.*, 1994

Endotebanella kocaensis (Dager, 1978) (Plate 27, Figure 4)

Endotebanella kocaensis is found in the late Scythian-early Anisian of Turkey, Ladinian of Malaysia, Upper Ladinian-Carnian of Sumatra (Rettori, 1995) and in the Carnian? to Norian/Raethian of Turkey (Beccaletto *et al.*, 2005). *Endotebanella* sp. has been signalled in the Ladinian?-Carnian of Sicily (Carrillat, 2001)

Endotriadella wirzi (Koehn-Zaninetti, 1968) emend. Vachard *et al.*, 1994 (Plate 27, Figures 5 to 7)

Endotriadella wirzi is found in the Anisian-Ladinian of the Southern Apennines, Alps, Carpathian, Balkans, Dinarids, Turkey and China (Rettori, 1995), in the Pelsonian of Hydra (Rettori *et al.*, 1994), in the early Carnian of Pyrenees (Fréchengues *et al.*, 1993) and in the late Ladinian-early Carnian of Tunisia (Kamoun *et al.*, 2001).

Suborder MILIOLINA Delage & Hérouard, 1896**Superfamily SORITACEA** Ehrenberg, 1839**Family PSEUDOCUCURBITIDAE** Zaninetti *et al.* 1982

Cucurbita ? sp. (Plate 27, Figure 8 and Plate 28, Figure 1)

Cucurbita cf. *Cucurbita infundibuliformis* Jablonsky, 1973 (Plate 28, Figure 2 for the specimens found in the Lercara Formation and Plate 28, Figures 5 and 6 for the specimens found in the Mufara Formation).

Cucurbita has been signalled in the Carnian of Carpathian (Jablonsky, 1973), Dianarian and Hellenids (Senowbari-Daryan, 1982), Turkey (Zaninetti *et al.*, 1982) and Alps (Senowbari-Daryan, 1987), in the Ladinian?-Carnian of Sicily (Senowbari-Daryan & Abate, 1986; Martini *et al.*, 1991a, b; Zaninetti & Martini, 1992; Carrillat, 2001) and in the Carnian of Oman (Bernecker, 1996).

Superfamily CORNUSPIRACEA Schultze, 1854**Family HOYENELLIDAE** Rettori, 1994

Hoyenella gr. *sinensis* (Ho, 1959) (Plate 28, Figure 3)

Hoyenella gr. *sinensis* is found in the Early and Middle Triassic of the Tethyan realm (Rettori, 1994).

Family MEANDROSPIRIDAE Saidova, 1981 emend. Zaninetti *et al.* 1987

Meandrospira pusilla (Ho, 1959) (Plate 28, Figure 4)

Meandrospira pusilla has been signalled in the Early Triassic (acme) of all the Tethyan Domains, in the Anisian (rare exemplars) of Hellenids, Dolomites, Carpathian and Balkans (Rettori, 1995). It has been found in the Early Triassic of the Southern Apennines (Panzanelli Fratoni *et al.*, 1987) and in Tunisia (Kamoun *et al.*, 2001).

Suborder LAGENINA Delage & Hérouard, 1896**Family DUOSTOMINIDAE** Brotzen, 1963

This family is known from the Anisian to the Late Triassic.

DISCUSSION

Like the Permian smaller foraminifera, the Triassic foraminifera were found isolated in different clasts of different samples and their original association is unknown. Moreover, these foraminifera are facies dependent and, as most of the other benthic foraminifera, their biostratigraphic resolution is limited. Consequently, they permit the attribution of the Lercara Formation to the Triassic but do not allow a precise determination of the biostratigraphic range and of the reworked material.

However, the species *Cucurbita* cf. *infundibuliformis* has been found from the Ladinian? to the late Carnian, but is considered as a Carnian foraminifer (Rettori, 2003, *pers. comm.*). Consequently, sections of the Lercara Formation containing this foraminifer cannot have been deposited before the Ladinian? or the early Carnian. Furthermore, association of Ladinian?-Carnian age, composed of *Cucurbita* sp.,

Cucurbita infundibuliformis, “*Trochammina*” sp., *Endotebanella* sp., Duostominidae with *Hydrania dulloi* have been found reworked in the late Ladinian-Carnian Mufara Formation, coming from patch reef communities located on a shelf or a ramp (Martini *et al.*, 1991b; Carrillat, 2001). If the carbonate source area for the two formations was the same, as hypothesised in this work, the Member B of the Lercara Formation, in which only a few elements of this Triassic patch reef were found, was deposited at the same time as that of the bottom of the Mufara Formation.

In the same way, *Meandrospira pusilla* lived limitedly in the Early Triassic and in the Anisian. Consequently, sediments deposited during this interval were reworked in the Lercara Formation. Moreover, Lower Triassic siliciclastic deposits with *Meandrospira pusilla* are known in the regions surrounding the Lercara basin as Tunisia (Kamoun *et al.*, 2001) and the Monte Facito Formation in the southern Apennines (Panzanelli Fratoni *et al.*, 1987; Ciarapica *et al.*, 1990a). Then, similar Lower Triassic siliciclastic platforms were probably developed in Sicily.

The biostratigraphic ranges of *Endotriadella wirzi*, *Hoyenella* gr. *sinensis*, *Pilammmina* cf. *densa* and “*Trochammina*” aff. *almtalensis* are poorly defined. *Hoyenella* gr. *sinensis* can be found in the Lower to Middle Triassic deposits, “*Trochammina*” aff. *almtalensis* in the Anisian, *Pilammmina* cf. *densa* in the Anisian to early Ladinian and *Endotriadella wirzi* in the Anisian to early Carnian. Anisian and Ladinian boundstone composed of algae, sponges, as *Uvanella irregularis*, and foraminifera are signalled in the adjacent Monte Facito Formation (Ciarapica *et al.*, 1990b; Ciarapica *et al.*, 1990c; Ciarapica & Passeri, 2000).

3.2.4 BIOSTRATIGRAPHIC INTERPRETATION OF MICROFAUNA

Detailed study of the microfauna observed in the Member B of the Lercara deposits allows to attribute Triassic (Ladinian?-Carnian) age to some sections of this member and highlights a reworking of the Carboniferous to Anisian? material, evidenced mainly by the larger foraminifera (Table 3.2).

The scarcity of Triassic foraminifera and the large quantity of Permian fauna can be explained, as in the case of the Triassic intraclasts and Permian extraclast (see chapter Sedimentology), as a subaerial and subaqueous erosion of the Triassic and Permian carbonate material, respectively. In the first case, the instability of the carbonates favoured their dissolution and they were not saved from destruction by erosion. In the second case, on the contrary subaqueous erosion preserved the carbonates better.

With regard to the palaeogeographic attribution of the Lercara Formation to the Palaeo- or to the Neo-Tethys, the Triassic fauna would not permit us to make a specific assignation to one or the other of the palaeodomains. In the same way, most of the Permian fauna does not allow us to state clearly if the reworked material was deposited in the Palaeo- or in the Neo-Tethys. This could indicate that the Lercara Formation and the Permian reworked sediments were deposited in the western part of the Tethys, where the Neo- and the Palaeo-Tethys may have coexisted at a given moment as is the case today at the southern termination of Africa where the Atlantic and Pacific oceans and fauna of the two domains mix. This assertion is supported by ostracods and fusulines.

3.3 PALYNOLOGY

3.3.1 INTRODUCTION

The Lercara Formation is principally composed of red quartz-rich shales. The red colour suggested that palynomorphs would be rare or absent because of the oxidation of the organic matter. On the contrary, the palynological study of the Lercara Formation has furnished a rich and diversified palynoflora.

Previous palynological studies have been conducted by Cirilli *et al.* (1988; 1990) and Carrillat (2001) on the Lercara and Roccapalumba outcrops of the Lercara Formation. Samples contained mixed palynoflora assemblages composed of Permian to Middle Triassic-lower Carnian palynomorphs. Based on these results, the authors assigned the Lercara Formation to the Ladinian to early Carnian. Reworked palynoflora has

Table 3.4 Repartition of Permian and Triassic palynomorph species per samples of the Lercara and Mufara Formations.

[illegible]

been assigned globally to the Permian and to the Early Triassic. Concerning the Mufara Formation, detailed palynostratigraphical investigations performed by Martini *et al.* (1991a; 1991b), Carrillat (2001), and Buratti & Carrillat (2002) furnished a Ladinian-Carnian age.

3.3.2 METHOD

Organic matter was extracted applying palynological techniques following Monteil (1985). Samples were crushed to a fraction comprised of between 200 µm and 2 mm, and approximately 35 grams per sample of this fraction was used. Inorganic matrix, which contains organic matter, was progressively attacked using diluted hydrochloric (HCl 32%) and hydrofluoric (HF 71-75 %) acids to destroy, respectively, carbonate and silicate components, followed by heavy liquid separation (ZnCl₂) to remove the heavy minerals. After each acid attack, the samples were neutralised by successive dilutions and decantings. The remainder was filtered at 11 µm in order to remove finer particles and was exposed to a second HCl attack in a bain-marie to eliminate the potential fluoride formed during the HF attack. The heating of the HCl was of a short duration so that it had an inconsequential effect on the colour of the palynomorphs. To prevent organic matter degradation the residue was not oxidised with nitric acid (HNO₃), a process generally used to remove amorphous organic matter. Slides were mounted using polyvinyl alcohol and Eukitt glue and were examined under transmitted light, using a Leitz Dialux 20.

3.3.3 RESULTS

Palynological processing has been employed on 116 samples (18 of which were of from the Mufara Formation) composed of quartz-rich shales and clayey sandstones. 87 of these, principally quartz-rich shales, have produced over 150 determinable taxa. Some samples have been processed twice but, as predictable because reworking was suspected, they did not yield the same results: the same sample provided a rich association on one occasion but on the second occasion there were no palynomorphs at all.

Palynomorphs found in the Lercara samples are poor to relatively well preserved. Most of the palynomorphs are torn, crumpled, folded or riddled by pyrite due to the activity of reducing bacteria. This, associated with the brown to dark brown colour due to the thermal diagenesis undergone makes their determination difficult. Generally, the Permian palynomorphs are better preserved than the Triassic ones, these latter often being mechanically and thermally altered.

Palynological studies carried out during this thesis provide further evidence of a mixed palynoflora characterised by abundant and diversified Permian and Lower Triassic palynomorphs, which compose between the 90 and 100 % of the entire assemblage, in association with less represented Middle and Upper Triassic taxa, as also previously recorded by other authors (Cirilli *et al.*, 1988; 1990). The palynological study of the Mufara Formation reveals the presence of a late Ladinian-Carnian palynoflora (Tuvalian for Cozzo Intronata section) which is broadly comparable with previous palynological investigations of the Mufara Formation (Cirilli *et al.*, 1990; Buratti & Carrillat, 2002). Table 3.4 listed all species of palynomorphs found in the Lercara and in the Mufara Formations, grouped in artificial categories according to the literature (*e.g.*, Potonié, 1956, 1958; Dettmann, 1963; Playford & Dettmann, 1965; Potonié, 1970). They are subdivided into Permian, Upper Permian to lower Triassic, Triassic and Permian to Triassic long-ranging palynomorphs according to the stratigraphical extension found in literature and reported in the Appendix 3. Several palynomorphs have not been determined (Plate 34, Figures 14 to 18). Only the more important Permian and Triassic forms will be discussed below.

3.3.4 REWORKED PALYNOMORPHS

EARLY PALAEOZOIC REWORKED PALYNOMORPHS

Characteristic Early Palaeozoic acritarchs have been found in some samples of the Lercara Formation and they are associated with long ranging *Micrhystridium* sp. and *Veryhachium* sp. They are listed below:

Acriora sp. cf. *A. petala* Wicander 1974 (sample PS9) (Plate 29, Figure 1)

Dictyotidium sp. (sample PS15) (Plate 29, Figure 2)

Dilatysphaera sp. (samples PS39 and PS42) (Plate 29, Figure 3)

Multiplicisphaeridium (?) sp. (sample RPFa11)

Oppilatala sp. (sample PS24) (Plate 29, Figure 4)

Polygonium sp. 1 (sample RPFa11) (Plate 29, Figure 5)

Polygonium sp. 2 (sample RPFa11) (Plate 29, Figure 6)

A more detailed determination, necessary to obtain a more accurate age, has not been possible because of the scarcity of available exemplars. However, they are not older than the Middle-Upper Silurian and not younger than the Devonian (Vecoli, 2006, *pers. comm.*).

PERMIAN REWORKED PALYNOMORPHS

Permian palynomorphs are the more abundant taxa found in the Lercara palynoflora associations, among which *Potonieisporites novicus*, *Plicatipollenites* sp., *Lueckisporites virkkiae* and different species of *Vittatina* are dominant.

Permian spores and pollen grains are listed below:

Spores

Laevigati

Leiotriletes ulutus Utting, 1994 (Plate 30, Figure 1)

Baculati

Neoraistrikia caudicea Utting, 1994 (Plate 30, Figure 2)

Zonati

Krauselisporites cf. *K. wargalensis* Balme, 1970 (Plate 30, Figure 3)

Pollen grains

Monosaccites

Cannanoropollis bilateralis (Tiwari) Lindström, 1995 (Plate 30, Figure 4)

Cordaitina sp. (Plate 30, Figure 5)

Crucisaccites variosulcatus Dyupina, 1971 (Plate 30, Figure 6)

Densipollenites sp.

Densipollenites oviformis Shwartsman in Issova *et al.*, 1976 (Plate 30, fig 7)

Florinites sp. A Utting, 1994

Florinites eremus Balme & Hennelly, 1955 (Plate 30, Figure 8)

Florinites luburae Samoilovich, 1953, (Plate 30, Figure 9)

Nuskoisporites sp. (Plate 30, Figure 10)

Nuskoisporites dulhuntyi Klaus, 1963 (Plate 30, Figure 11)

Nuskoisporites klausii Klaus, 1963 (Plate 30, Figure 12)

Parasaccites sp. (Plate 30, Figure 13)

Parasaccites distinctus Tiwari, 1965

Plicatipollenites sp.

Plicatipollenites indicus Lele, 1964 (Plate 30, Figure 14)

Plicatipollenites trigonalis Lele, 1964 (Plate 30, Figure 15)

Potonieisporites granulatus Bose & Kar, 1966 (Plate 30, Figure 16)

Potonieisporites novicus Bharadwaj, 1954 (Plate 30, Figure 17)

Vestigisporites sp. (Plate 30, Figure 18)

Wilsonites sp. (Plate 31, Figure 1)

Disaccites

Alisporites plicatus Jizba, 1962

Alisporites splendens (Leschik) Foster, 1979

Alisporites tenuicarpus Balme, 1970

Falcisporites nuthallensis Balme, 1970

Korbapollenites sp. (Plate 31, Figure 2)

Sulcatipollenites nillsonii Balme, 1970 (Plate 31, Figure 3)

Sulcatipollenites ovatus (Balme & Hennelly) Bharadwaj, 1962 (Plate 31, Figure 4)

Vesicaspora obliquus (Kara-Murza) Hart, 1965

Vesicaspora ovata (Balme & Hennelly) Hart, 1960

Vesicaspora wilsonii (Schemel) Wilson & Vekatchala, 1963 (Plate 31, Figure 5)

Disaccitriletes

Gardenasporites heisseli Klaus, 1963 (Plate 31, Figure 6)

Illinites sp.

Illinites spectabilis Klaus, 1963 (Plate 31, Figure 7)

Jugasporites delasaucei (Potonié & Klaus) Leschik, 1955 (Plate 31, Figure 8)

Limitisporites monstruosus, (Luber & Valts) Hart, 1965 (Plate 31, Figure 9)

Striatiti

Corisaccites alutas Venkatachala & Kar, 1946 (Plate 31, Figure 10)

Hamiapollenites sp.

Hamiapollenites bullaeformis (Samoilovich) Jansonius, 1962 (Plate 31, Figure 11)

Hamiapollenites erebi Utting, 1994 (Plate 31, Figure 12)

Hamaipollenites cf. *insolitus* (Bharadwaj & Salujha) Klaus, 1970 (Plate 31, Figure 13)

Hamaipollenites karrooensis Hart, 1964 (Plate 31, Figure 14)

Hamaipollenites cf. *tractiferinus* (Samoilovich, Jansonius) Hart, 1964 (Plate 31, Figure 15)

Hamiapollenites saccatus Wilson, 1962 (Plate 31, Figure 16)

Lueckisporites virkkiae Potonié & Klaus, 1954 (Plate 31, Figures 17 and 18)

Striatopodocarpites cancellatus (Balme & Hennelly) Hart, 1964

Tornopollenites toreutos Morgan, 1971 (Plate 32, Figure 1)

Vittatina sp.

Vittatina costabilis Wilson, 1962 (Plate 32, Figure 2)

Vittatina simplex Jansonius, 1962 (Plate 32, Figure 3)

Vittatina cf. *V. striata* (Luber & Valts) Samoilovich, 1953 (Plate 32, Figure 4)

Vittatina vittifera (Luber & Valts) Samoilovich, 1953 (Plate 32, Figure 5)

Weylandites striatus (Luber), Utting, 1994 (Plate 32, Figure 6)

Praecolpate

Packapites rotundus (Koloda) Utting, 1994 (Plate 32, Figure 7)

Polyplicates

Costapollenites ellipticus Tschudy & Kosanke, 1966 (Plate 32, Figure 8)

Most of the palynomorphs present such as *Corisaccites alutas*, *Falcisporites nuthallensis*, *Florinites eremus*, *Hamiapollenites* cf. *H. tractiferinus*, *Hamaipollenites karrooensis*, *Hamiapollenites saccatus*, *Nuskoisporites klausii*, *Plicatipollenites trigonalis*, *Tornopollenites toreutos*, *Vittatina* cf. *V. striata* and *Vittatina costabilis* can be found along the entire Permian; It is possible to deduce this from the stratigraphic distribution showed in the Appendix 3. It is only by autochthonous associations that we can attribute them to the Early, Middle or to the Late Permian.

On the other hand, *Potoniopsis novicus* is without doubt a typical widespread Lower Permian monosaccites pollen grain (as inferred from the literature) (Appendix 3). This pollen is found in many Lower Permian (Autunian) assemblages associated with *Hamiapollenites insolitus* and *Vittatina* spp. in Israel (Eshet & Cousminer, 1986; Eshet, 1990), with *Hamiapollenites insolitus* and *Sulcatipollenites nillsonii* in Pakistan (Balme, 1970), with *Vittatina* spp. in France and Germany (Doubinger, 1974), and with

abundant other monosaccates like *Densipollenites oviformis*, *Parasaccites* sp., *Parasaccites distinctus*, *Plicatipollenites trigonalis*, *Vestigisporites* sp. and *Wilsonites* sp., *Vesicaspora wilsonii*, *Hamiapollenites bullaeformis*, *Vittatina* spp. and *Costapollenites ellipticus* in Sardinia (Pittau Demelia et al., 2002). Other Lower Permian associations essentially composed of *Vittatina* spp. are known in Canada (Jansonius, 1962).

As regards the late Early to Middle Permian, assemblages composed of *Alisporites plicatus*, *Alisporites splendens*, *Florinites* sp. A, *Florinites luburae*, *Neoraistrikia caudicea*, *Packapites rotundus* and *Weylandites striatus* have been described in the Canadian Arctic Archipelago (Utting, 1994).

As with as *Potonieisporites novicus* for the Lower Permian, *Lueckisporites virkkiae* is considered as the characteristic marker of the Late Permian (e.g. Clarke, 1965; Balme, 1970; Visscher, 1971; Eshet, 1990). Associated with abundant *Lueckisporites virkkiae*, the less well represented *Klausipollenites schaubergeri* composed the assemblages in all Late Permian palynological domains such as Israel (Eshet & Cousminer, 1986; Eshet, 1990), even though the latter can also be found in the Early Triassic (Balme, 1970; Ottone & Garcia, 1991; Mangerud, 1994; Ouyang & Norris, 1999). These two forms are associated in the Southern Alps with *Nuskoisporites dulhuntyi*, *Illinites spectabilis*, *Jugasporites delasaucei* and *Gardenasporites heisseli* (Klaus, 1963), in England with *Nuskoisporites dulhuntyi* and *Lunatisporites noviaulensis*, in Pakistan with *Krauselisporites wargalensis* and *Densipollenites indicus* (Balme, 1970), in Ireland with *Nuskoisporites dulhuntyi* and *Jugasporites delasaucei* (Visscher, 1971), in the Zechstein Basin with *Nuskoisporites dulhuntyi*, *Lunatisporites noviaulensis*, and *Jugasporites delasaucei* (Dybova-Jachowicz, 1974) and in Gabon with *Lunatisporites noviaulensis* (Jardiné, 1974).

In conclusion, although the Permian palynomorphs are mixed, taxa reworked from the Lower, Middle and Upper Permian deposits can be reasonably identified: 1) *Potonieisporites novicus*, *Densipollenites oviformis*, *Parasaccites* sp., *Parasaccites distinctus*, *Plicatipollenites trigonalis*, *Vestigisporites* sp., *Wilsonites* sp., *Hamiapollenites insolitus*, *Vittatina* spp., *Sulcatipollenites nillsonii*, *Vesicaspora wilsonii*, *Hamiapollenites bullaeformis*, and *Costapollenites ellipticus* can be considered as reworked from the Lower Permian; 2) *Lueckisporites virkkiae*, *Klausipollenites schaubergeri*, *Nuskoisporites dulhuntyi*, *Illinites spectabilis*, *Gardenasporites heisseli*, *Gardenasporites heisseli*, *Krauselisporites wargalensis*, and *Densipollenites indicus* can be considered as reworked from the Upper Permian; 3) *Florinites* sp. A, *Florinites luburae*, *Neoraistrikia caudicea*, *Packapites rotundus* and *Weylandites striatus* can be tentatively regarded as reworked from the late Early Permian to the Middle Permian despite the scarcity of bibliographic data.

LOWER TRIASSIC REWORKED PALYNOMORPHS

Lower Triassic palynomorphs have been found in the Lercara Formation. They are relatively abundant.

Lower Triassic spores and pollen grains are listed below:

Spores

Apiculati

Anapiculatisporites decorus Ouyang & Norriss, 1999 (Plate 33, Figure 1)

Uvaesporites sp. (Plate 33, Figure 2)

Muronati

Propisporites pococki Jansonius, 1962 (Plate 33, Figure 6)

Cingulati

Krauselisporites cuspidus Balme, 1963 (Plate 33, Figures 10 and 11)

Krauselisporites septatus Balme, 1963 (Plate 33, Figure 12)

Cavatotriletes

Densoisporites nejburgii (Schultz) Balme, 1970 (Plate 33, Figure 15)

Endosporites papillatus Jansonius, 1962 (Plate 33, Figures 16 and 17)

Pollen grains**Disaccites**

Klausipollenites decipiens Jansonius, 1962 (Plate 34, Figure 5)

Klausipollenites staplinii Herbst, 1965 (Plate 34, Figure 6)

Striatiti

Ephedripites steevesii (Jansonius 1962) de Jersey 1968 (Plate 34, Figure 15)

Lunatisporites albertae Jansonius, 1962 (Plate 34, Figure 17)

Lunatisporites exagonalis Jansonius, 1962 (Plate 34, Figure 18)

Aletes

Grebespora concentrica Jansonius, 1962 (Plate 35, Figure 13)

These palynomorphs are commonly considered as Lower Triassic (see Appendix 3). Recently, Utting *et al.* (2004) have advanced the hypothesis that *Endosporites papillatus* and *Densoisporites nejburgii* were Devonian spores having a global-scale reworking.

UPPER PERMIAN TO LOWER TRIASSIC REWORKED PALYNOMORPHS

Some of the palynomorphs found in the Lercara Formation such as *Kraeuselisporites apiculatus* (Plate 32, Figure 9), *Krauselisporites spinosus* (Plate 32, Figure 10), *Densoisporites playfordii* (Plate 32, Figure 11), *Lundbludispora brevicula* (Plate 32, Figure 12), *Densipollenites indicus* (Plate 32, Figure 13), *Playfordiaspora crenulata* (Plate 32, Figure 14), *Klausipollenites schaubegeri* (Plate 32, Figure 15), *Striatoabieites richteri* (Plate 32, Figure 16) can be found in both Upper Permian and Lower Triassic.

3.3.5 TRIASSIC LONG-RANGING PALYNOMORPHS

Most of the palynomorphs found in the Lercara Formation such as *Alisporites opii*, *Lunatisporites acutus*, *Triadispora crassa*, *Verrucosisporites contactus* and *Voltziaceasporites heteromorpha*, can be extended over long Triassic stages or substages (Appendix 3) and they are present in almost all sampled sections. Therefore, the palynological content permits the definite assignment of the Lercara Formation to the Triassic.

They are listed below:

SPORES**Apiculati**

Verrucosisporites contactus Clarke, 1965 (Plate 33, Figure 3)

POLLEN GRAINS**Disaccites**

Alisporites opii (Daugherty), Jansonius, 1971

Falcisporites stabilis Balme, 1970

Platysaccus queenslandi De Jersey, 1962 (Plate 34, Figure 8)

Voltziaceasporites heteromorpha Klaus, 1964 (Plate 34, Figure 9)

Disaccitriletes

Triadispora sp.

Triadispora crassa Klaus, 1964 (Plate 34, Figure 10)

Striatiti

Lunatisporites acutus (Leschik) Scheuring, 1970 (Plate 34, Figure 16)

Lunatisporites pellucidus (Goubin) Helby ex De Jersey, 1972

Lunatisporites transversundatus (Jansonius) Fisher, 1979 (Plate 35, Figure 1)

3.3.6 AUTOCHTHONOUS PALYNOMORPHS

MIDDLE-UPPER TRIASSIC PALYNOMORPHS OF THE LERCARA FORMATION

Middle Triassic palynomorphs have been found in both the Lercara and Mufara Formations. They are poorly represented in the Lercara Formation, and constitute the entire association of the Mufara Formation.

Triassic spores and pollen grains are listed below:

Spores

Muronati

Lycopodiacidites kuepperi Klau, 1960 (Plate 33, Figures 4 and 5)

Sellaspera rugoverrucata Van der Eem, 1983 (Plate 33, Figures 7 to 9)

Cavatomonoletes

Aratrisporites fimbriatus (Klaus) Mädlar, 1964 (Plate 33, Figure 13)

Aratrisporites sp. cf. *A. spongeosus* Ottone & Garcia, 1991 (Plate 33, Figure 14)

Pollen grains

Monosaccites

Vallasporites ignacii (Leschik) Scheuring, 1970 (Plate 34, Figures 2 and 3)

Disaccites

Angustisulcites sp. (Plate 34, Figure 4)

Minutossaccus sp. (Plate 34, Figure 7)

Disaccitriletes

Triadispora obscura Scheuring, 1970 (Plate 34, Figure 11)

Triadispora stabilis Scheuring, 1970 (Plate 34, Figure 12)

Triadispora vilis Scheuring, 1970

Striatiti

Chordaesporites singulicorda ? Klaus, 1960 (Plate 34, Figure 14)

Circumpolles

Camerosporites secatus Leschik, 1956 (Plate 35, Figures 3 and 4)

Partitisporites sp. (Plate 35, Figures 6 and 7)

Patinasporites densus (Leschik) Scheuring, 1970 (Plate 35, Figure 10)

Polyplicates

Equisetosporites chinleanus (Daugherty) Scott, 1960 (Plate 35, Figure 12)

The not-reworked fraction of the Lercara Formation is composed of younger Anisian-Carnian, Ladinian-Carnian and Carnian palynomorphs. *Angustisulcites* sp., *Aratrisporites fimbriatus*, *Aratrisporites* sp. cf. *A. spongeosus*, *Chordaesporites singulicorda* ?, *Lycopodiacidites kuepperi*, *Striatoabieites aytugii*, and *Triadispora stabilis* have been found in the Anisian to Carnian assemblages (e.g. Klaus, 1960; Antonescu, 1970; Fisher, 1972a, b; Dunay & Fisher, 1978; Besems, 1983; Van der Eem, 1983; Eshet & Cousminer, 1986; Blendinger, 1988; Eshet, 1990; Mørk *et al.*, 1990; Roghi, 2004). *Camerosporites secatus*, *Partitisporites* sp., *Sellaspera rugoverrucata*, *Striatopodocarpites balmei* and *Triadispora obscura* are part of Ladinian to Carnian associations (e.g. Dolby & Balme, 1976; Dunay & Fisher, 1978; Visscher & Brugman, 1981; Brugman, 1986; Doubinger *et al.*, 1990; Eshet, 1990; Buratti & Carillat, 2002; Roghi, 2004). Finally, *Patinasporites densus*, *Vallasporites ignacii*, *Equisetosporites chinleanus* and *Triadispora vilis* are well

known components of Carnian assemblages (e.g. Scheuring, 1970; Fisher, 1972b; Dunay & Fisher, 1979; Visscher & Brugman, 1981; Van der Eem, 1983; Fisher & Dunay, 1984; Cirilli, 1995; Roghi, 2004).

As regards the geographical distribution (Appendix 3), Triassic palynomorphs found in the Lercara and in the Mufara Formations, are variously distributed in the Laurasian and Gondwanian floristic domains. Phytogeographic Triassic domains used in this work have been obtained from Visscher & Van der Zwan (1981) and Dobruskina (1987). Lower Triassic *Densoisporites nejburgii*, *Endosporites papillatus*, *Grebespora concentrica*, *Kraeuselisporites cuspidus* and *Kraeuselisporites septatus* are known in both domains, whereas *Ephedripites steevesii*, *Klausipollenites staplinii*, *Lunatisporites albertae*, *Lunatisporites exagonalis* are found only in the North of the Laurasia. Anisian to Ladinian *Aratrisporites fimbriatus*, *Aratrisporites* sp. cf. *A. spongeosus* and *Triadispora stabilis* are part of the Laurasian and Gondwanian palynoflora, and *Angustisulcites* sp., *Chordaesporites singulicorda* ?, *Lycopodiacidites kuepperi* but *Striatoabieites aytugii* is found only in the Laurasian palynoflora. Ladinian to Carnian *Camerosporites secatus*, *Duplicisporites granulatus* and *Sellasporea rugoverrucata* are common to both paleofloristic domains and *Triadispora obscura* has been found only in Laurasia. Finally, Carnian *Brodisporea striata*, *Enzonolasporites vogens*, *Ovalipollis pseudoalatus*, *Patinasporites densus*, *Praecirculina granifer* and *Vallasporites ignacii* have both been signalled in the Laurasia and Gondwana whereas *Equisetosporites chinleanus*, *Partitisporites novimundatus*, *Partitisporites quadruplicis* and *Triadispora vilis* are found only in Laurasia.

UPPER TRIASSIC PALYNOMORPHS OF THE MUFARA FORMATION

Upper Triassic palynomorphs have been found in the Mufara Formations. They constitute the entire association.

They are listed below:

Pollen grains

Monosaccites

Enzonolasporites vogens Leschik, 1955 (Plate 33, Figure 18)

Ovalipollis pseudoalatus (Thiergart) Schhrmann, 1976 (Plate 34, Figure 1)

Vallasporites ignacii (Leschik) Scheuring, 1970 (Plate 34, Figures 2 and 3)

Disaccitritetes

Triadispora obscura Scheuring, 1970

Striatiti

Brodisporea striata Clarke, 1965 (Plate 34, Figure 13)

Circumpolles

Camerosporites secatus Leschik, 1956 (Plate 35, Figures 3 and 4)

Duplicisporites granulatus Leschik, 1955 (Plate 35, Figure 5)

Partitisporites sp. (Plate 35, Figures 6 and 7)

Partitisporites novimundatus Leschik, 1955 (Plate 35, Figure 9)

Partitisporites quadruplicis Scheuring, 1970 (Plate 35, Figure 8)

Patinasporites densus (Leschik) Scheuring, 1970 (Plate 35, Figure 10)

Praecirculina granifer (Leschik) Klaus, 1960 (Plate 35, Figure 11)

Concerning the Mufara Formation, palynomorphs found in the Contrada Malluta and Cozzo Tabarani sections such as *Camerosporites secatus*, *Partitisporites novimundatus* and *Duplicisporites granulatus* yield a generic Ladinian to Carnian age (e.g., Dolby & Balme, 1976; Dunay & Fisher, 1978; Brugman, 1983; Van der Eem, 1983; Brugman, 1986). On the others hand, associations found in the Cozzo Intronata section composed of *Brodisporea striata*, *Camerosporites secatus*, *Duplicisporites granulatus*, *Enzonolasporites vogens*, *Lunatisporites acutus*, *Ovalipollis pseudoalatus*, *Partitisporites quadruplicis*, *Praecirculina granifer* and *Vallasporites ignacii* provide a Carnian age (see Appendix 3). In particular

the presence of *Brodipora striata* and *Partitisporites quadruplicis* suggested a Tuvanian age for this section (Dunay & Fisher, 1978; Visscher & Krystyn, 1978). These results are broadly comparable with previous palynological investigations of the Mufara Formation (Buratti & Carillat, 2002).

3.3.7 PALAEOGEOGRAPHICAL DISTRIBUTION

With regard to the geographical distribution of the Permian palynomorphs (Appendix 3), some taxa are widespread in several floral provinces, while others have a more restricted distribution. Phytogeographic Permian domains used in this work have been obtained from Broutin *et al.* (1990) and McAllister Rees *et al.* (2002). Lower Permian *Potonieisporites novicus*, *Vestigisporites* sp., *Hamiapollenites bullaeformis*, *Costapollenites ellipticus* and *Vittatina vittifera* are known in both Euramerican and Gondwanian floral provinces. *Vittatina vittifera* has been found also in the Urals (Angara region). *Cannanoropollis bilateralis*, *Crucisaccites variusulcatus* and *Potonieisporites granulatus* have been signalled only in the Gondwana, and *Densipollenites* only in Euramerica. Up to the present, Upper Lower Permian to Middle Permian *Florinites* sp. A, *Florinites luburae*, *Neoraistrikia caudicea*, *Packapites rotundus* and *Weylandites striatus* are found only in the Canadian Arctic archipelago (Euramerican province). *Lueckisporites virkkiae*, *Klausipollenites schaubergeri* and *Nuskoisporites dulhuntyi* are the more widespread Upper Permian palynomorphs; they are found in the Euramerican and Gondwanian provinces. *Gardenasporites heisseli* have been signalled up to now only in the Euramerica and *Krauselisporites wargalensis*, and *Densipollenites indicus* only in the Gondwana.

Triassic palynomorphs found in the Lercara and in the Mufara Formations, are variously distributed in the Laurasian and Gondwanian floristic domains. Phytogeographic Triassic domains used in this work have been obtained from Visscher & Van der Zwan (1981) and Dobruskina (1987). Lower Triassic *Densoisporites nejburgii*, *Endosporites papillatus*, *Grebespora concentrica*, *Krauselisporites cuspidus* and *Krauselisporites septatus* are known in both domains, whereas *Ephedripites steevesii*, *Klausipollenites staplinii*, *Lunatisporites albertae*, *Lunatisporites exagonalis* are found only in the North of the Laurasia. Anisian to Ladinian *Aratrisporites fimbriatus*, *Aratrisporites* sp. cf. *A. spongeosus* and *Triadispora stabilis* are part of the Laurasian and Gondwanian palynoflora, and *Angustisulcites* sp., *Chordaesporites singulicorda* ?, *Lycopodiacidites kuepperi* and *Striatoabieites aytugii* are only part of the Laurasian palynoflora. Ladinian to Carnian *Camerosporites secatus*, *Duplicisporites granulatus* and *Sellaspora rugoverrucata* are common to both paleofloristic domains and *Triadispora obscura* has been found only in Laurasia. Finally, Carnian *Brodipora striata*, *Enzonalasporites vigens*, *Ovalipollis pseudoalatus*, *Patinasporites densus*, *Praecirculina granifer* and *Vallasporites ignacii* have been signalled in the Laurasia and Gondwana whereas *Equisetosporites chinleanus*, *Partitisporites novimundatus*, *Partitisporites quadruplicis* and *Triadispora vilis* have only been found in Laurasia (Appendix 3).

DISCUSSION

The reworking of older palynomorphs into younger sediments is a common and well documented phenomena (Traverse, 1988). It would be logical to think that the reworked fraction must constitute only a small percentage of the total palynomorphs but, as we will see, this is not always the case. Muller (1959) found that in the Quaternary sediments of the Orinoco delta (South America), reworked Tertiary pollen grains eroded by Orinoco tributaries are, more abundant in levee deposits, than the autochthonous fraction. The ratio is the contrary in the shelf sediments. The reworked fraction can also constitute almost the totality of palynomorphs associations as occurs today in the Gulf of the Mexico sediments where the Paleogene taxa constitute 90% of the total association (Traverse, 1988) or in the breccias of La Fouillouse (Loire) in which, on 1000 pollen grains counted only, 2 are of the Lower Jurassic and 980 of Stephanian (Vachard, 2005, *pers. comm.*). The extreme case was documented by Owens (1972) who described Permian and Triassic deposits from Devon England in which only spores of Late Devonian to Early Carboniferous were present. The lack or the scarcity of not-reworked palynomorphs in the

sediments can lead to errors of in rock dating as in the case of the breccias of La Fouillouse, considered up to the present as Carboniferous (Pruvost *et al.*, 1950).

The abundance and the good preservation of reworked flora in younger sediments compared to the bad preservation and/or the lack of autochthonous palynomorphs, can be explained by the transportation of the former in the basin within in pebbles or shales or in large pieces of rocks that can preserve palynomorphs from oxidation (Muir, 1967; Traverse, 1988). Furthermore, enrichment in carbon during the first phase of sedimentation, small size (between 20 and 200 μm), and rapid subaqueous erosion and transport (*e.g.* turbidity currents) can preserve them from destruction (Birkenmajer & Turnau, 1962; Turnau, 1962; Muir, 1967). On the other hand, if the palynomorphs are removed subaerially and transported individually, as must be the case of the autochthonous flora, they can be destroyed through oxidation. If the Triassic sediments underwent subaerial erosion and the Permian a subaqueous erosion, as suggested in chapter on Sedimentology, the Triassic pollens can be less preserved than the Permian ones, or completely absent.

Another reason for the lack of not-reworked palynomorphs could be found in the Triassic environments. In fact during the Middle and Upper Triassic a carbonate platform developed next to the Lercara basin. This well oxygenated environment is unfavorable to the preservation of organic matter, which is degraded soon after its deposition.

During transport by wind or water currents, single palynomorphs are selectively deposited according to their aerodynamic or hydrodynamic properties. Saccate pollen grains are the more buoyant palynomorphs and can be transported for long distances (Cirilli *et al.*, 1998). This can explain why disaccites pollen grains as *Triadispora* can be found more easily in more distal Lercara deposits, whereas monosaccites *Vallasporites ignacii* and circumpolles *Camerosporites secatus* and *Partisporites* sp. have been found only in the more proximal sections.

Another problem which arose during the determination concerns the size of spores such as *Lycopodiacidites kuepperi* and *Sellasporea rugoverrucata*, which were smaller than those reported in the literature. An explication can be found in the high thermal maturity of the Lercara deposits (see chapter 5) that can cause morphological modifications such as the reduction in diameter (Marshall & Yule, 1999).

Reworked palynomorphs can yield information concerning the provenance of the detritic fraction of the Lercara deposits. In Sicily there are no known Devonian, Permian or Lower Triassic autochthonous deposits from which palynoflora could be derived. The oldest rocks are the Lower Permian blocks reworked in the Lercara Formation. The situation is similar in the Southern Apennines where only the Late Permian and Early Triassic were found reworked in the Ladinian of the Monte Facito Formation (Ciarapica *et al.*, 1990a). The nearest not-reworked Lower Permian to Early Triassic deposits known are found in Tunisia. They are represented by the Lower Permian turbiditic and lagoonal deposits (Izart *et al.*, 2003), Upper Permian carbonate platform (Toomey, 1991) and Lower Triassic siliciclastic sediments (Kamoun *et al.*, 2001). The same deposits have probably developed in Sicily and in the South of the Apennines, supplying not only Permian and Lower Triassic palynomorphs in the Lercara Formation, but also carbonate and siliciclastic sediments in the Lercara and Monte Facito Formations.

With regard to the Devonian Acritarchs, the nearest known marine Devonian deposits are in Tunisia, Libya, Algeria and Morocco (Moreau-Benoit, 1984; Loboziak & Streel, 1989; Abdesselam, 1991; Loboziak *et al.*, 1992; Rahmani-Antari & Lachkar, 2001). These Devonian deposits have emerged in Morocco and Algeria because of the Variscan orogeny during the Late Palaeozoic (Michard, 1976) and could have been eroded by rivers and transported as far as in the Lercara basin. Transport over long distances of palynomorphs is not rare because rivers can be alimented by tributaries eroding far upstream, as for instance, the Mississippi River Delta flora in which palynomorphs coming from the North Dakota can be found (Traverse, 1988).

Finally, as with fauna, Permian and Triassic palynomorph associations found in the Lercara and Mufara Formations do not show particular affinity with Palaeo- or Neo-Tethys flora.

3.4 BIOSTRATIGRAPHIC SYNTHESIS: AGE AND REWORKING FOR EACH SECTION

In the following analysis of the age of the sections, only the principal palynomorphs found are discussed. Other pollen grains and spores present in each sample are shown in the Table 3.4.

3.4.1 LERCARA FORMATION SECTIONS

ROCCAPALUMBA MERCATO.

The *Roccapalumba Mercato* outcrop represents the most proximal section and therefore yields the more reliable age for the Lercara Formation. Foraminifera *Cucurbita* cf. *C. infundibuliformis*, *Endotriadella wirzi* and “*Trochammina*”? sp. permit an attribution of this section to the Carnian. This age is confirmed by *Vallasporites ignacii*, *Camerosporites secatus*, *Partitisporites* sp., *Sellaspora rugoverrucata*, *Lycopodiacidites kuepperi*, and *Aratrisporites* sp. cf. *A. spongeosus* pollen grains. The scarcity of foraminifera and palynomorphs do not allow for greater precision.

Larger foraminifera *Levenella* aff. *evoluta* and *Yangchienia compressa* indicate that a Lower Yakhtashian and Murgabian to Midian (Middle Permian) sediments have been reworked. The presence of the foraminifera *Geinitzina* sp. and *Lasiotrochus tatoiensis* and of the palynomorphs *Gardenasporites heisseli*, *Illinites* sp., and *Lueckisporites virkkiae* show that the reworking has also concerned Upper Permian sediments.

TORRENTE FERRO

The *Torrente Ferro* section does not show any significant foraminifer. The only significant spore found is *Lycopodiacidites kuepperi* and indicates an Anisian to Carnian age. Reworking involved Early and Late Permian and Early Triassic (e.g. *Potonieisporites novicus*, *Lueckisporites virkkiae* and *Grebespora concentrica*).

COZZO SAN FILIPPO 1 AND 2

The *Cozzo San Filippo 1* section does not contain foraminifera and shows only two taxa: *Limitisporites monstrosus* of the Early Permian and *Lueckisporites virkkiae* of the Late Permian, indicating that a reworking involving at least the Lower Permian deposits took place and that the age cannot be older than the Late Permian. However, given the poverty of the palynomorphs and the age of the others sections, we think that the Late Permian also results from reworking.

The *Cozzo San Filippo 2* section contains only a few non-determinable foraminifera. The more significant palynomorph is *Lycopodiacidites kuepperi* that indicate a generic Anisian to Carnian age. Palynomorphs such as *Potonieisporites novicus*, *Limitisporites monstrosus*, *Hamiapollenites erebi*, *Densipollenites indicus*, *Nuskoisporites dulhuntyi* and *Lueckisporites virkkiae* indicate that Lower, Middle and Upper Permian sediments have been reworked.

ROCCAPALUMBA FERROVIA A AND B

As far as the *Roccapalumba Ferrovia a* section is concerned, the presence of the foraminifera *Endotabanella kocaaliensis* and *Cucurbita* ? sp. would suggest a Carnian age, whereas the spore *Lycopodiacidites kuepperi* would indicate a generic Anisian to Carnian age. The presence of other foraminifera, such as *Levenella* aff. *evoluta*, *Toriyamaia* (?) sp., *Dunbarula*? *simplex*, *Schubertella silvestrii*, *Chitralina undulate*, *Ramovsia limes* *Geinitzina* sp and *Lasiotrochus tatoiensis*, shown that lower Yakhtashian, Kubergardian, Midian and Upper Permian sediments have been reworked. The palynomorphs *Lueckisporites virkkiae*, *Grebespora concentrica* and *Lunatisporites pellucidus* demonstrate that Upper Permian and Lower Triassic deposits have been reworked. Devonian Acritarchs have also been found in this section.

With regard to the *Roccapalumba Ferrovia b* section, *Patinasporites densus* and *Lycopodiacidites kuepperi* indicate a Carnian age. *Potonieisporites novicus*, *Lueckisporites virkkiae*, *Densosporites nejbürgii* and *Grebespora concentrica* imply that Lower and Upper Permian and Lower Triassic deposits have been reworked.

PIETRA DI SALOMONE 1 TO 5

The Carnian age assigned to the *Pietra di Salomone 1* section is determined by the presence of disaccites *Triadispora vilis*. This age is in agreement with other Anisian to Carnian palynomorphs such as *Aratrisporites fimbriatus*, *Chordaesporites singulicorda* ?, *Lycopodiacidites kuepperi*, and *Triadispora obscura* (Ladinian to Carnian). In this section the reworking is more important than in the others. It concerns the Lower to Upper Permian and the Early Triassic as is attested by the presence of e.g. *Potonieisporites granulatus*, *Potonieisporites novicus*, *Vesicaspora wilsonii*, *Florinites luburae*, *Krauselisporites* cf. *K. wargalensis*, *Lueckisporites virkkiae*, *Densoisporites nejburgii*, *Grebespora concentrica* and *Krauselisporites septatus* (for more details see the Table 3.4 and Appendix 3). Devonian acritarchs have also been found in this section.

The *Pietra di Salomone 2* section does not contain palynomorphs but the foraminifer *Endotriadella wirzi* indicates an Anisian to Carnian age. Upper Permian deposits have been reworked as evidenced by the fusulinid *Reichelina* sp. and smaller foraminifera *Dagmarita shahrezaensis* and *Ramovsia limes*.

In the *Pietra di Salomone 3* section, the younger taxon is the polyaperturate pollen *Equisetosporites chinleanus* known in the Carnian. Other palynomorphs indicating a Triassic age are *Triadispora vilis* and *Lycopodiacidites kuepperi* (Anisian to Carnian). The reworking has affected the Lower and Upper Permian and Lower Triassic sediments as is attested by the presence of *Potonieisporites novicus*, *Vesicaspora wilsonii*, *Vittatina vittifera*, *Lueckisporites virkkiae*, *Endosporites papillatus* and *Lunatisporites exagonalis*. Larger foraminifera *Schubertella silvestrii*, *Dunbarula? simplex* and *Ogbinella* cf. *saurini* indicate in particular that the Midian stage has been reworked. Reworked Devonian acritarchs have also been found in this section.

As far as the *Pietra di Salomone 4* section is concerned, besides some Triassic long ranging palynomorphs such as *Triadispora* sp., *Voltziaceasporites heteromorpha* and *Lunatisporites albertae* the younger taxon is *Lycopodiacidites kuepperi* which indicates a generic Ladinian to Carnian age. As in other sections, indications of a Lower, Middle Permian, and Lower Triassic reworking are provided by *Potonieisporites novicus*, *Vesicaspora wilsonii*, *Vittatina vittifera*, *Lueckisporites virkkiae*, *Densoisporites nejburgii* and *Uvasporites* sp.

As in the *Pietra di Salomone 3* section, the age in the *Pietra di Salomone 5* section is determined by the polyaperturate pollen *Equisetosporite*. This age can be confirmed by the Anisian to Carnian taxa *Angustisulcites* sp., *Chordaesporites singulicorda* ? and *Lycopodiacidites kuepperi*. The presence of *Potonieisporites novicus*, *Vesicaspora wilsonii*, *Vittatina vittifera*, *Lueckisporites virkkiae*, *Densoisporites nejburgii*, *Ephedripites steevesii* and *Krauselisporites septatus* indicate that Lower and Upper Permian and Lower Triassic deposits have been reworked. Larger foraminifer *Ogbinella* cf. *Ogbinella saurini* imply that the Midian stage has been reworked and acritarchs show that sediments as old as Devonian have also been reworked.

PORTELLA ROSSA 1 AND 2

For the *Portella Rossa 1* section a Ladinian to Carnian age is proposed because of the presence of the foraminifera *Cucurbita* ? sp., *Endotriadella wirzi* and Duostominide. This age is confirmed by the palynomorphs *Sellaspora rugoverrucata*. A reworking involving the Lower Triassic and Anisian deposits is indicated by foraminifera and palynomorphs such as *Pilammina* cf. *Pilammina densa*, “*Trochammina*” aff. “*Trochammina*” *almtalensis*, *Hoyenella* gr. *sinensis*, *Meandrospira pusilla*, *Angustisulcites* sp., *Ephedripites steevesii*, *Klausipollenites decipiens* and *Klausipollenites staplinii*. The larger foraminifer *Levenella* aff. *Levenella evoluta* and the palynomorphs *Potonieisporites novicus* and *Vittatina vittifera* indicate that Lower Permian deposits have been reworked. Smaller foraminifera and palynomorphs *Geinitzina* sp., *Lasiotrochus tatoiensis*, *Neoendothyra* sp. and *Lueckisporites virkkiae* imply that Upper Permian sediments have also been reworked. This section also contains Rodian to Wordian conodonts.

In the *Portella Rossa 2* section a melange of Lower and Upper Permian foraminifera are present; these are *Levenella* aff. *evoluta*, *Geinitzina* sp. and *Neoendothyra* sp.

ISOLATED SAMPLES

Concerning the samples *Saraceni*, Si 123, 138, 141, 142, 145, 164 and PS 16, they come from blocks of reworked Permian and contain only a Permian fauna that cannot be determined more precisely.

Bivio Garuffa 1 and 2, reworked the Yakhtashian to Lopingian and the Yakhtashian to the Midian respectively.

San Filippo samples contain the Anisian to Carnian *Lycopodiacidites kuepperi* and they reworked the Lower to Upper Permian and Lower Triassic deposits.

Bivio dei Saraceni samples contain the Ladinian to Carnian foraminifer *Sellasporea rugoverrucata* and reworked also the Lower to Upper Permian and Lower Triassic deposits.

3.4.2 MUFARA FORMATION SECTIONS

Among the 5 sections investigated in the Mufara Formation three have provided palynomorphs and only one section provided foraminifera.

The *Cozzo Tabarani* section can be assigned to the generic Ladinian-Carnian thanks to the presence of the circumpolles *Duplicisporites granulatus*.

In the *Contrada Malluta* section, the Cordevolian to Julian age is determined by the contemporary presence of *Camerosporites secatus* and *Partitisporites novimundatus*.

Finally, a Tuvanian age is proposed for the *Cozzo Intronata* section, indicated by the presence of *Brodisporea striata*, *Camerosporites secatus*, *Duplicisporites granulatus*, *Enzonalasporites vigens*, *Lunatisporites acutus*, *Ovalipollis pseudoalatus*, *Partitisporites quadruplicis*, *Praecirculina granifer* and *Vallasporites ignacii*. Foraminifer *Cucurbita* cf. *Cucurbita infundibuliformis* compatible with a Tuvanian age, has also been found in this section.

Viadotto Faguara II and *Vallone Faguara I* sections do not provide either palynomorphs or foraminifera. Their respective assignation to the Late Ladinian to more recent and Cordevolian, necessary for the comparison between the Lercara and Mufara Formations in the chapter X-ray, was obtained from the work of Carillat (2001) and Buratti & Carillat (2002).

3.5 DISCUSSION

In conclusion, despite the scarcity or lack of stratigraphically important taxa, the Lercara Formation can be assigned to the Anisian/Ladinian to Carnian age. More precisely in Member A (lower part of *Cozzo San Filippo 2* section) the presence of *Lycopodiacidites kuepperi* as the only palynomorph, indicates an Anisian to Carnian age. In Member B (*Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1*, upper part of *Cozzo San Filippo*, *Roccapalumba Ferrovia a* and *b*, *Pietra di Salomone 1* to *5* and *Portella Rossa 1* and *2* sections), associations of foraminifera and palynomorphs indicate a Ladinian to Carnian age. Given the stratigraphic relation between the two members, (see Appendix 2.4) Member A is considered older than Member B. It is difficult to establish a more precise stratigraphic range mainly because the lower stratigraphic contact is unknown. Therefore, the Member A was deposited during an unknown time range between the Anisian and the Ladinian. Concerning the upper limit, as the overlying Mufara Formation deposited in the same basin (the Sicanian basin) as the Lercara Formation is of Julian age (Di Stefano & Gullo, 1997a), a Cordevolian age is inferred for the Lercara Formation. This age is in agreement with the age proposed by Cirilli *et al.* (1990) and Carrillat (2001) for the outcrops of the Roccapalumba-Lercara area of the Lercara Formation, but this study extends this age to every known sections of the Lercara Formation in the Pietra di Salomone and Burgio areas. Reworking has involved Devonian and Lower Permian to Lower Triassic sediments.

Among the biostratigraphic tools employed for Permian and Triassic palaeogeographic reconstructions, only ostracods and fusulinids provided results. They show that the Palaeo- and Neo-Tethys have coexisted in their westernmost termination at least during the Wordian. This situation may have existed before and after the Wordian, but the present study does not provide elements for this hypothesis.

4 X-RAY DIFFRACTION

4.1 INTRODUCTION

X-ray diffraction (XRD) analysis has been conducted for two purposes: characterization of the Lercara deposits mineralogy and investigation of the relation between the mineralogy and the age of the reworked material or of the matrix. For this second goal the relation between the age and the mineralogy was obtained from the Permian limestone blocks reworked in the Lercara Formation and from the coeval part of the Triassic Mufara Formation. Based on the results of these two source rocks, mineralogical analysis of the Lercara Formation permitted the evaluation of their respective detritic contribution using statistical methods.

4.2 METHODS

4.2.1 X-RAY DIFFRACTION

XRD analysis relies on the principle that any mineral exposed to x-rays diffracts them in the surrounding space, in particular directions and with specific intensities, characteristic of that mineral. The results of the x-ray analysis on a multi-mineral rock powder are expressed as a diffractogram with two axes: the horizontal axis indicates either the crystallographic structure inter-planar distance (d) or the diffraction angle (2θ), both being linked by Bragg's law; the vertical axis indicates the intensity of the diffracted X-ray in counts per second (CPS), which is related to the amount of a given mineral in the powder.

Two kinds of analyses were conducted to characterize the mineralogical composition of the samples:

- The whole rock analysis on randomly oriented powder to delineate the total mineralogical rock composition as a complement to the microscope observation.
- The insoluble carbonate-free oriented residue analysis of fine size fractions (2-16 μm and $< 2 \mu\text{m}$) to identify the clay minerals, which generally is not possible under the microscope. The silt-sized fraction (2-16 μm) reflects the detritic composition of the clay mineral, while the clay-sized fraction ($< 2 \mu\text{m}$) reflects the diagenetic ones, because these smaller particles are sensitive to thermobarometric changes (*e.g.* Kübler, 1964; Dunoyer de Segonzac, 1970; Merriman & Peacor, 1999).

XRD analyses of 149 samples have been carried out by the Geological Institute of the University of Neuchâtel (Dr T. Adatte).

The samples have been prepared following the procedure of Kubler (1987). About 20 g of every sample is ground coarsely (fragments between 1 and 5 mm) with a jaw crusher. For the whole rock, approximately 5 g were dried at a temperature of 60°C and then ground again with a ring grinder/agate mill to a homogenous powder with particle size $< 40 \mu\text{m}$. Eight hundred milligrams of this powder were

Mineral	(hkl)	$^{\circ}2\Theta$ $K\alpha$ Position	d Å Position
Phyllosilicates	hkl	19.9	4.46
Goethite	100	21.22	4.18
Quartz	101	26.65	3.34
K-Feldspar	002	27.51	3.24
Na-Feldspar	002	27.89	3.18
Calcite	104	29.41	3.03
Ankerite	104	30.80	2.90
Dolomite	104	30.94	2.89
Pyrite	111	33.08	2.71
Hematite	104	33.15	2.70

Table 4.1 List of minerals identified in the bulk rock analyses with relative peak position (2Θ and d) and crystallographic plane (hkl) considered.

packed mechanically at 20 bars using a hydraulic press, with insertion of a blotting paper, to obtain a disorientated preparation, and analysed by XRD. The remainder of the crushed rock was decarbonated according to the method of Kubler (1987) to allow the analysis of the mineralogy of the insoluble residue. The residue was mixed with de-ionized water (pH 7-8) and agitated. The carbonate fraction was then removed by the action of 200 ml of HCl 10% for 20 minutes or until all carbonates were dissolved. In order to separate the aggregates, ultrasonic baths were realized during 3 minute intervals. The insoluble residue was washed and centrifuged until a neutral suspension was obtained. Separation into 2-16 μm and $< 2 \mu\text{m}$ grain size was obtained by operation of successive centrifugations carried out according to methods based on Stokes's law (Rumley & Adatte, 1983). The oriented $< 2 \mu\text{m}$ fraction was XRD analysed after air-drying at room temperature and under ethylene-glycol solvated conditions to reveal the expansible minerals.

XRD analyses were conducted using a SCINTAG XRD 2000 with the following characteristics:

Goniometer theta/theta with a ray of 250 mm

Energy: 45 kV, 40 mA

Radiation $\text{CuK}\alpha 1$, $\lambda=1.54060 \text{ \AA}$

Spectral detector (Germanium crystal): PSI 1 Peltier cooled from Kevext, to eliminates the $K\beta$ and other noises

Continuous scan: $1^{\circ}/\text{min}$

Normal slits: 0.5/0.3 mm

Chopper increment: $0.03^{\circ} 2\Theta$ (whole rock) and $0.05^{\circ} 2\Theta$ (oriented plates)

$K\alpha$ 2-stripping active

Fast Fourier Noise Filter active

Background correction automatic

Noise threshold= 1.5 (whole-rock specimen) and 1.7 (oriented plates)

ESD (estimated standard deviation) multiplier= 4

Sample spin: rotating sample plate, average diameter 15 mm and 25 mm (oriented plates)

Whole-rock random powder patterns were recorded from 1° to $65^{\circ} 2\Theta$, and oriented clay specimen from 1° to $50^{\circ} 2\Theta$.

WHOLE-ROCK ANALYSIS

Mineralogy of the bulk rock provides information about the source of the sediments. Consequently, change in the composition indicates variation in the source rock or in the intensity of weathering and erosion, depending on climate and tectonic activity.

For the whole rock, X-ray diffraction analyses were executed on random oriented powder and the results was used for qualitative and semiquantitative analysis. Table 4.1 indicates the minerals identified with their relative peak positions (2θ and d) for the crystallographic plane (hkl) considered. The presence and quantity of a mineral in a preparation subjected to X-ray diffraction can be given precisely thanks to the position of the peaks on the corresponding diffractogram.

A semi-quantitative analysis of the bulk rock mineralogy has been made using a computer program developed by Rolli (1992) according to the “external standards” method described by Ferrero (1966) and Kübler (1983). This method considers that the intensity of the peaks, characteristic of each mineral, reflect the proportions of this mineral in the sample. The abundance of a mineral in a mixture is a function of the peak intensities of this mineral, of the intensity of an external pure standard and of the mass attenuation coefficient of an external pure standard. (Rolli, 1992). Rolli’s program quantifies the relative abundance of 13 minerals common in sedimentary rocks: gypsum, phyllosilicates, goethite, anhydrite, aragonite, quartz, potassic feldspars, sodic feldspars, calcite, ankerite, dolomite, halite, magnetite, hematite and pyrite. The peaks of the minerals identified in this study are presented in Table 4.1.

The program also defines an ID percentage (indeterminate components) as the difference between 100% and the cumulated percentage of all minerals already identified. These components are not recognizable because the high diffractometer accuracy of the peaks supplied from the diffractometer is not handled by the program, which uses a single standard for all the phyllosilicates. Therefore, the final percentage of the phyllosilicates component is obtained by adding together the percentage of the intensity peak at $19.9 \text{ \AA}$ ($2\theta \text{ K}\alpha$) and of the unidentified fraction (ID). This assumption is supported by the high clay content of the rocks analyzed.

In order to quantify the tectonic activity and the intensity of chemical alteration in the source area, a silicate index (SI) was calculated using the percentage of feldspars and quartz. It is based on the detrital index of Zimmermann *et al.* (1976) defined as the difference of the silicates [$SI = \text{quartz}/(\text{quartz} + \text{feldspars})$] and the carbonates indexes [$CI = \text{dolomite}/(\text{dolomite} + \text{calcite})$]. For this study, only the silicates index was considered since it was sufficient in order to define the tectonic activity and intensity of chemical alteration. Moreover, given the insignificant quantity or absence of dolomite and in some cases the high value of calcite, the CI was not applicable and condition of erosion, transport and sedimentation could not be calculated. The SI, ranging from 0 and 1, gives the proportion of quartz respective to the total content of quartz and feldspars. It points out the presence of quartz and feldspars in the source rock and provides indications about their different degree of alterability. Quartz is one of the most resistant minerals to physical and chemical alteration whereas feldspars are easily alterable. Thus, high SI reflects the period of tectonic quiescence during which erosion and transport are limited and chemical alteration processes are privileged; it can also signify that sediments derive from several sedimentary cycles.

On the other hand, a low SI value reflects intense tectonic activity, more sever and rapid erosion and transport preserving the mineral from chemical alteration, and indicates that quartz and feldspars probably derive from the first sedimentary cycle.

FINE FRACTION ANALYSIS

Clay mineral associations can provide indications about the continental morphology, climatic conditions and tectonic activities during their formation (Chamley, 1989; Weaver, 1989). They are also susceptible to thermic and mechanic changes and can give informations about the burial thermal history of sediments subject to diagenesis and very low-grade metamorphism (Merriman & Frey, 1999; Merriman & Peacor, 1999, *cum biblio*).

In order to identify clay minerals in the fine fraction, X-ray diffraction analyses were carried out on oriented carbonate free powder, since the crystallographic plane 00l was likely to furnish the best

Mineral	(hkl)	2θ K α Position	d Å Position	Fraction < 2 μ m (Type of preparation)	Fraction 2-16 μ m (Type of preparation)
Smectite	001	5.2-5.5	17-16	Glycol-solvated	
Chlorite	001	6.2	14.2	Glycol-solvated	Air -dried
Mica	001	8.85	10	Glycol-solvated	Air -dried
Mixed-layered (I/S)	001/002	9-9.7	9.04-9.8	Glycol-solvated	
Kaolinite-Chlorite	001-002	≈ 12	≈ 7	Glycol-solvated	Air -dried
Mixed-layered (I/S)	002/003	16-17	5.5-5.2	Glycol-solvated	
Mica	002	17.7	5	Glycol-solvated	Air -dried
Chlorite	003	18.7	4.72	Glycol-solvated	Air -dried
Quartz	100	20.85	4.25		Air -dried
Kaolinite	002	24.85	3.58	Glycol-solvated	Air -dried
Chlorite	004	25.10-25.20	3.56-3.55	Glycol-solvated	Air -dried
Mica	005	45	2	Air -dried	Air -dried

Table 4.2 List of clay minerals identified by the fine fraction analysis (2-16 μ m and < 2 μ m), relative peak position (2θ and d), crystallographic plane (hkl) considered and type of preparation.

diagnoses and provide more intense reflections. Detailed identification of clay minerals was done according to Moore & Reynolds (1989), taking into account the clay mineral X-ray diffraction patterns (diffractograms) characterised by the peak position, intensity, shape and breadth. The intensity of each characteristic mineral peak was measured in order to obtain semi-quantitative proportions.

Analyses of the fine fraction have concerned two fractions: the clay-sized (< 2 μ m) and the silt-sized fractions (2-16 μ m), respectively more or less affected by thermobarometric changes. Analysis of the clay-sized fraction (< 2 μ m) was made first on air-dried samples, then on ethylene glycol-solvated samples. The latter shows the behaviour of the expansible clay minerals. Analysis of the silt-sized fraction (2-16 μ m) was conducted on air-dried samples. Table 4.2 lists the clay minerals identified in these fractions with the relative peak position (2θ and d) for the associated crystallographic plane (hkl). The same table shows the type of preparation in which the intensity in CPS was measured.

Kaolinite 001 and chlorite 002 peaks are both situated at approximately 12.2 Å and superimposed peaks are not discernable on the diffractograms. In order to separate these peaks, some corrections are necessary. Determination of their contributions was obtained by deconvolution of peak 002 at 24.9 Å for the kaolinite and peak 004 at 25.2 Å for the chlorite according the following formulae:

$$K^*c = \text{Intensity (K002)} / [\text{Intensity (K002)} + \text{Intensity (C004)}] * \text{Intensity (K001/C002)};$$

$$C^*c = \text{Intensity (C004)} / [\text{Intensity (K002)} + \text{Intensity (C004)}] * \text{Intensity (K001/C002)}.$$

The relative percentage of illite and smectite in the mixed-layered illite/smectite (I/S) was estimated using the position 2θ K α of reflections of the mixed layers illite/EG-smectite 001/002 and 002/003 according to Moore & Reynolds (1989).

Semiquantitative estimation of the proportion of phyllosilicates present in the fine fraction normalised to 100% have been calculated according the following formula:

$$\text{Mineral } i \text{ Relative\%} = \text{Mineral } i \text{ Intensity} / \sum \text{Intensity (Mineral } i)$$

For the clay-sized fraction the intensity of the following peaks were considered: smectite at 16 Å, mica at 10 Å, I/S around 9, 9.7 Å (the first, I/S1, and the second, I/S2, more intense peaks), kaolinite at ≈ 12 Å

(K*c) and chlorite $\approx 12 \text{ \AA}$ (C*c). For the silt-sized fraction the peaks of the mica at $10 \text{ \AA}$ kaolinite at $\approx 12 \text{ \AA}$ (K*c) and chlorite $\approx 12 \text{ \AA}$ (C*c) were considered.

Finally, in order to discriminate the chemical nature of micas in both $< 2 \text{ \mu m}$ and $2\text{-}16 \text{ \mu m}$ fractions, the relative proportion of their basal intensity 001 ($10 \text{ \AA}$), 002 ($5 \text{ \AA}$) and 005 ($2 \text{ \AA}$) were plotted in the ternary diagram of Rey & Kübler (1983). This diagram reflects the tendency of the micas and is not equivalent to the chemical analysis. In the same way the relative proportion of the basal intensity of chlorites 001 ($14 \text{ \AA}$), 002 ($7 \text{ \AA}$) and 003 ($4.7 \text{ \AA}$) were plotted in the ternary diagram of Oinuma *et al.* (1972). This diagram permits an evaluation of the chemical analysis of chlorites considering that the pole at $14 \text{ \AA}$ represents the Mg tendency, the pole $7 \text{ \AA}$ the Fe tendency and the pole $4.7 \text{ \AA}$ the Al tendency (*e.g.* Brindley & Brown, 1980).

4.2.2 STATISTICS

Multivariate statistics of the XRD analysis of the different fraction analysed were done in the program StatisticaTM, using the Principal Components Analysis (PCA), with the aim of regrouping the samples of the Lercara Formation in categories and to discriminate between the Lercara samples and the Permian and Triassic samples (Mufara Formation).

The aim of the PCA, originally developed by Pearson (1901), is to reduce a relatively elevated number of variables to a smaller number of representative and uncorrelated ones, based on mathematical concepts such as standard deviation, covariance and eigenvalues. The two most representative new variables (highest variance: Factor 1 and Factor 2), combination of the original ones, constitute a new Cartesian system (x, y) into which the original data are projected (Bishop, 1995).

PCA was applied to the results of the mineralogical analysis performed on 149 samples. For the bulk rock analysis, percentages of phyllosilicates, quartz, K- and Na-feldspars, calcite, dolomite, hematite, ankerite and pyrite were used. For the $< 2 \text{ \mu m}$ size fraction the relative percentage of smectite (001), mica (001), mixed-layered illite/smectite (I/S1 and I/S2 001/002), kaolinite*c (001) and chlorite*c (002), and for the $2\text{-}16 \text{ \mu m}$ size fraction the percentage of mica (001), kaolinite*c (001) and chlorite*c (002) were employed. Original data have always been projected according the Factors 1 and 2, and only when their cosine square was ≥ 0.00 . Associated to the PCA of original data, variables were also projected on the plane constituted by the Factors 1 and 2. The distance of the variables to the centre is proportional to the influence of the variable in the plane Factor 1/Factor 2. Moreover, the direction indicates their influence in the plane.

4.3 ORIGIN OF CLAY AND ASSOCIATED MINERALS

Clay mineral presence in marine sediments can have a detritic or an authigenic origin, depending on if formed during or after diagenesis. Clay minerals can develop also from burial diagenesis and from very low-grade metamorphic reactions (Merriman & Peacor, 1999). This last aspect will be discussed in chapter 5. Nevertheless, it is important to distinguish between the three processes because they provide different information about climate, eustacy, diagenesis, tectonic, reworking etc. (Millot, 1970; Chamley, 1989; Weaver, 1989).

Kaolinite, chlorite, illite and smectite can have authigenic origin, forming directly in the basin of sedimentation. It is known that kaolinite, chlorite and illite can crystallise in permeable sandstones during shallow or deep burial because of fluid flow (Weaver, 1989) and smectite can be formed in marine environments because of both subaqueous alteration (halmyrolysis) and hydrolysis during the early diagenesis or weathering of volcanic ash layers (Chamley, 1989).

In any case, detritism is the most common source of clay minerals. It is highly related to the climate. Clay minerals are the result of weathering of continental rocks under particular climatic conditions and transport in marine environments. Kaolinite and smectite are minerals forming in soils. The former forms in intertropical regions, in a warm humid climate principally because of hydrolytic reactions on feldspars (Chamley, 1989). Smectite forms in subtropical and temperate regions following alternation of humid and arid periods (Millot, 1970; Chamley, 1989). When cold mean annual temperatures and low

annual precipitations are unfavourable to the formation of soils and prevent the chemical alteration of the substratum, physical weathering or low hydrolysis is favoured (Chamley, 1989). In this case, formation of illite and chlorite is advantaged. Increases in illite and chlorite production have often been observed in regions with abrupt relief and/or affected by strong tectonic activity or rapid erosion that prevents the soil formation (Gawenda, 1999). Illite and chlorite can also be derived by physical erosion of unaltered mica- or chlorite-rich rocks, as for example plutonic or metamorphic rocks (Chamley, 1989). Variation in the kaolinite/smectite ratio in marine sediments may also be due to the sedimentary segregation that depends on the distance of the source area. In fact, particles of smectite are smaller than particles of kaolinite and are transported in open quiet marine areas away from the coastal environments in which kaolinite deposits (Gibbs, 1977; Chamley, 1989).

Quartz and feldspars are of detritic origin. Quartz is more resistant to chemical and physical alteration. Therefore, feldspars are less abundant compared to quartz if the chemical alteration was strong because of climate or tectonic quiescence and if they have undergone several sedimentary cycles.

Calcite is generally considered as a neo-formed mineral in marine or lacustrine environments, due to their direct precipitation from water rich in calcium carbonate. Calcite can also have a detritic origin, as it is often the case in the Lercara Formation, if particles formed by calcite are preserved from dissolution during erosion and transport.

Accessory minerals, such as dolomite, ankerite, pyrite and hematite are minerals formed during late diagenetic processes.

4.4 WHOLE-ROCK MINERALOGY

4.4.1 LERCARA FORMATION

Lercara Formation deposits are in general characterised by a relatively high phyllosilicates and quartz content emphasised its terrigenous origin (Appendices 4.1 to 4.5). Some remarkable mineralogical variations in the bulk rock mineralogy indicated that two different lithologies characterise the Lercara Formation, as seen in chapter 2: clayey sandstones (Member A: lower part of *Cozzo San Filippo 2* section) and quartz-rich shales (Member B1). In the quartz-rich shales, calcarenites to calcirudites levels (B2a: *Roccapalumba Mercato*, upper part of *Cozzo San Filippo 2*, *Roccapalumba Ferrovia a*, *Pietra di Salomone 2* and *3*, some levels of *Pietra di Salomone 5*, and *Portella Rossa 1* and *2* sections), limestones blocks (B2b: PS14, PS16 and Saraceni samples) or clayey sandstones (B3: *Roccapalumba Ferrovia b*, *Cozzo San Filippo 1*, *Torrente Ferro* and *Pietra di Salomone 1*, *4* and *5* sections) can be intercalated.

Clayey sandstones of Member A are characterised by a high content of quartz (46 to 77%) associated with phyllosilicates (19 to 42%) and feldspars (4 to 20%). Calcite is absent and only a small amount of ankerite (less than 1.5%) has been noticed.

In the quartz-rich shales (B1) of Member B, phyllosilicates are predominant (36 to 82%) followed by quartz (13 to 43%), minor feldspars (3 to 23%) and calcite (0 to 12%). A small amount of hematite (0 to 5.53%), pyrite (0 to 3.6%), dolomite (0 to 3%) and ankerite (0 to 2.5%) are also present, linked to the late diagenetic processes.

Reworked carbonate levels constituting the portion B2a of the Member B are mainly constituted of calcite (17 to 90%, average of 38%). Contribution of phyllosilicates (5 to 53%) and quartz (2 to 45%) can be important. Minor contribution is done by feldspars (0 to 10%), dolomite (0 to 3%) and ankerite (0 to 2.8%).

Plurimetric Permian limestone blocks constituting the part B2b of the Member B are essentially composed of calcite (81 to 99.36%). Insignificant amount of phyllosilicates (1 to 12%), quartz (0 to 3%) and pyrite (0 to 4%) are also present.

Clayey sandstones (B3) intercalated in the quartz-rich shales (B1) have almost the same composition as the clayey sandstones of the Member A. They are principally composed of quartz (38 to 56%), phyllosilicates (21 to 49%), followed by subordinate feldspars (0 to 19%). Unlike of the clayey sandstones of the Member A, those of Member B contain calcite (0 to 11%) (Appendices 4.1 to 4.5).

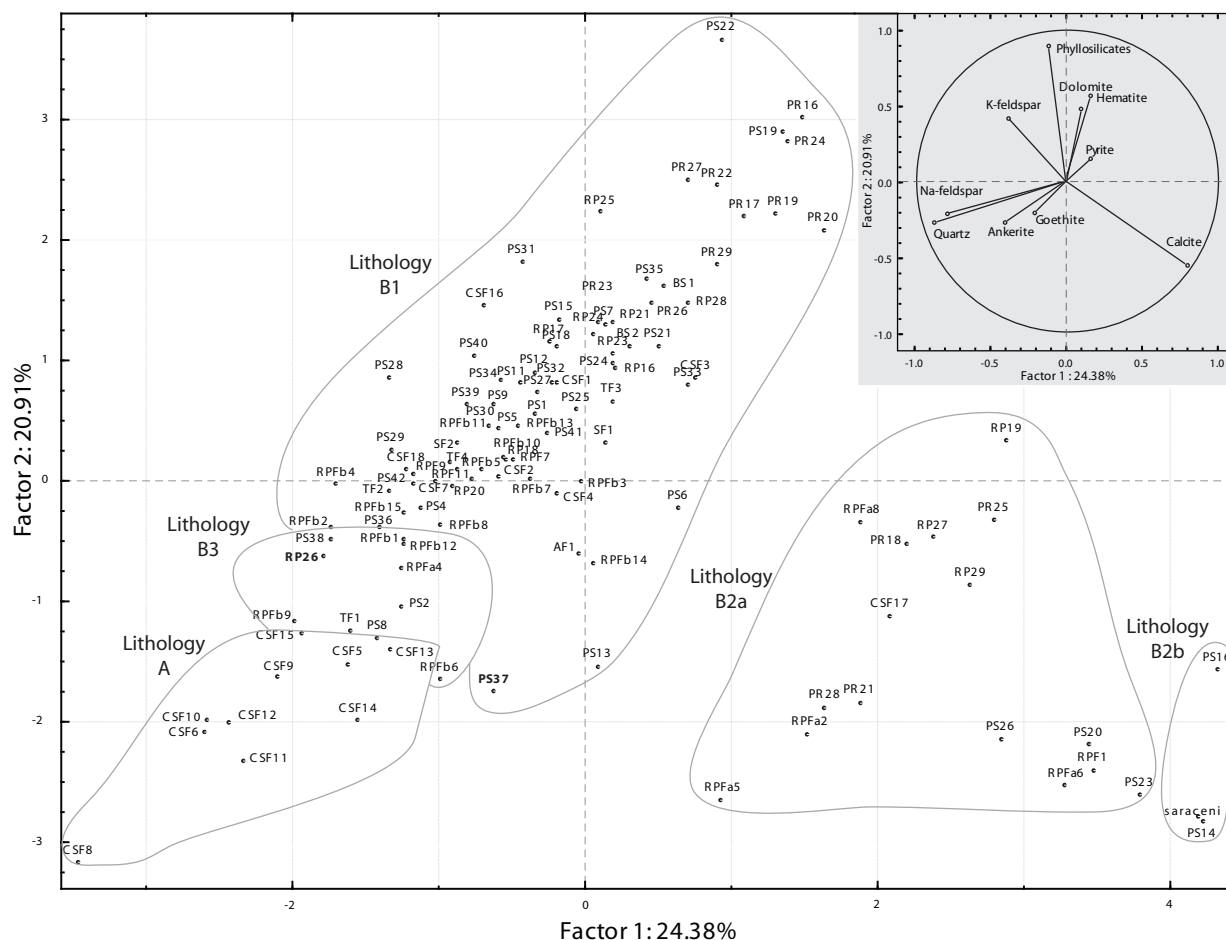


Figure 4.1 Principal components analysis of the Lercara Formation samples whole rock mineralogy showing the repartition of samples in lithological categories. Samples RP26 and PS 37 (in bold) are exceptions. Upper right insert: projection of the original variables onto the plane defined by the Factors 1 and 2. Lithology A: clayey sandstones; lithology B1: quartz-rich shales; lithology B2a: reworked carbonate levels; lithology B2b: limestone blocks; lithology B3 : clayey sandstones.

The above-mentioned repartition of the Lercara deposits in Member A and B and under levels B1, B2a, B2b and B3, is emphasised by statistical analysis (Figure 4.1). Clear-cut division of the lithologies B2a and B2b from the others exists because of their high calcite and low phyllosilicates and quartz content which are less remarkable for the other lithologies. However, a trend in the centre left part of the diagram is well marked and represents the proportion of phyllosilicates and quartz in the samples. The influence of the minerals in the diagram is shown in the upper right insert which also highlight the more important impact of calcite, quartz and phyllosilicates.

The relatively high values of the SI (0.6 to 1) of the Lercara samples (Appendix 5) could indicate either that sediments came from a source area with low tectonic activity allowing chemical alteration, or that sediments underwent several sedimentary cycles. The latter hypothesis is preferred because it is in agreement with sedimentary evidence showing that detritic siliciclastic sediments came from the erosion of older deltaic deposits (see chapter 2). An exception is found among the samples of the Member B2a with lower SI values (0.22 to 1) due to the more important contribution of carbonates and less of quartz. This can indicate periods of more intense tectonic activity when rapid erosion and transport allowed the preservation of the original detritic composition.

Mineralogical study of the bulk rock emphasises that detritic contribution is constant in the Lercara deposits, but changes occur between the deposition of the Members A and B. These changes involve a terrigenous carbonate contribution in the Member B that is minor at the beginning of the deposition (portion B3) and becomes more important at the end (portion B2), as well as an increase in phyllosilicates and a decrease in quartz (Figure 4.1).

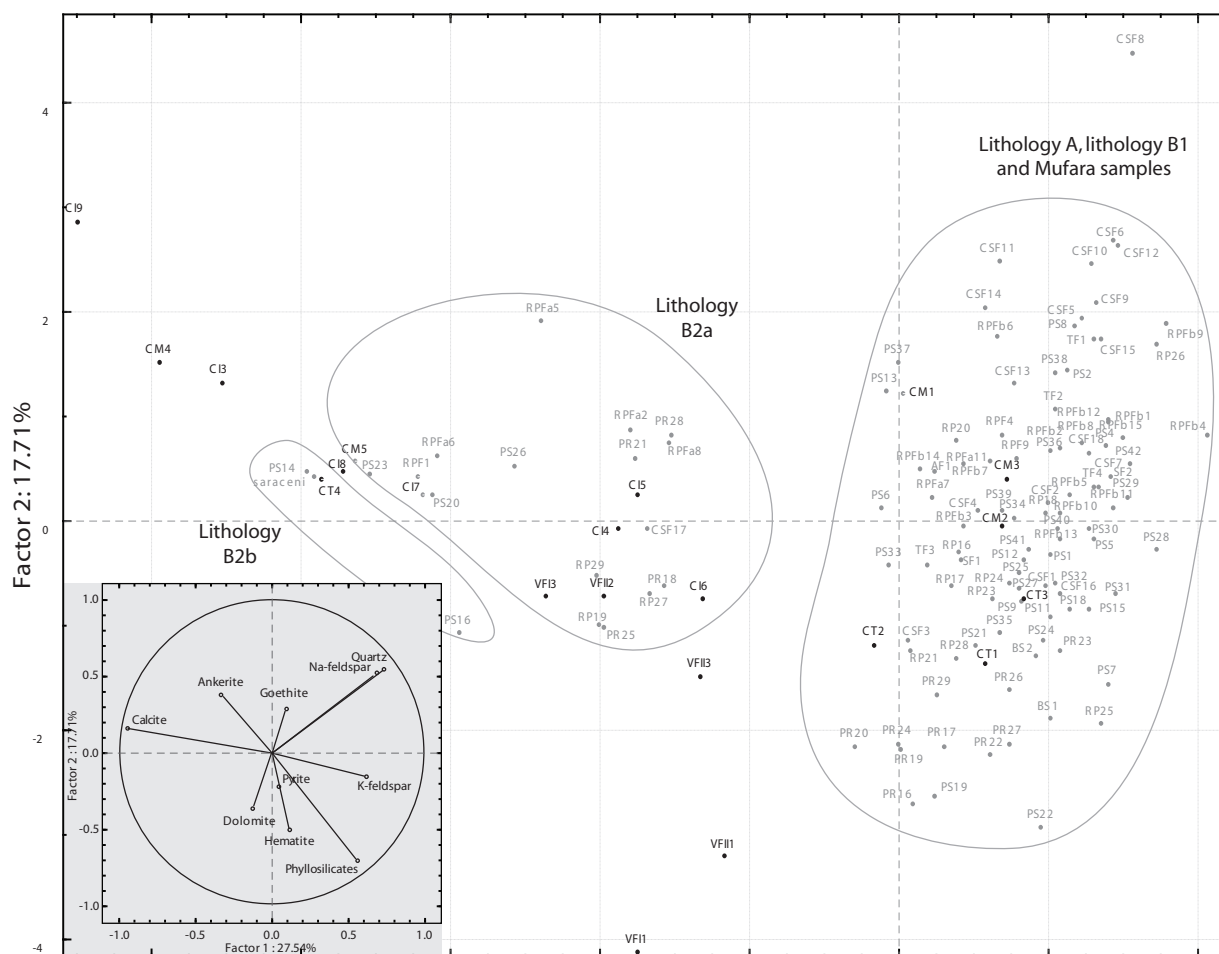


Figure 4.2 Principal components analyses of the whole rock mineralogy showing the repartition of the Mufara Formation (in black) samples with respect to the Lercara (in gray) samples. Lower left insert: projection of the original variables onto the plane defined by the Factors 1 and 2. Lithology A: clayey sandstones; lithology B1: quartz-rich shales; lithology B2a: reworked carbonate levels; lithology B2b: limestone blocks; lithology B3 : clayey sandstones.

4.4.2 MUFARA FORMATION

The Mufara Formation shows, as with the Lercara Formation, a high detritic input. Samples are composed of phyllosilicates (0 to 74%), quartz (0 to 52%), calcite (0 to 96%) and feldspars (0-10%) (Appendices 4.6 and 4.7). The highest values of calcite have been found in the reworked limestones blocks, such as in the *Contrada Malluta* section and in intercalated carbonate levels such as in the *Cozzo Intronata* and *Cozzo Tabarani* sections. However, samples of the Mufara Formation generally have a higher content of calcite than the Lercara Formation. In fact, as shown in Figure 4.2, Mufara Formation samples are plotted in the same area as the carbonate members of the Lercara Formation.

4.5 CLAY MINERALOGY RESULTS

Results of the fine fraction mineralogy will be presented following a subdivision in three groups: 1) the Permian samples that compose the portion B2b of the Member B of the Lercara Formation *i.e.* samples coming from reworked block of limestones. They provide an indication of the climatic conditions during the Permian period and have been used here to try to discriminate in the Lercara samples the detrital contribution of clays formed during the Permian; 2) Mufara samples representing the conditions during the deposition of the Lercara Formation; and 3) Lercara samples without the Permian ones, in which

detrital contribution of Devonian, Carboniferous, Permian and Triassic sediments can be found (see chapter 3).

As previously seen in chapter 3, three of the five studied sections of the Mufara Formation can potentially have the same age (Late Ladinian to Cordevolian) as the Lercara deposits. These are the sections of *Cozzo Tabarani*, *Contrada Malluta* and *Vallone Faguara I*. The *Cozzo Intronata* section is the more recent (Tuvalian) and *Viadotto Faguara II* section has an imprecise age (Late Julian to ?). Mufara Formation samples have been used to discriminate, in the Lercara samples, detrital contribution during its formation.

In this chapter, discussion principally surrounds the results derived from the clay-sized fraction, shown in Appendices 4.8 to 4.14. The silt-sized fraction data shown in Appendices 4.15 to 4.21 conform to those of the clay-sized fraction and they will be discussed only when necessary. Chemical nature of micas and chlorites in both clay- and silt sized fractions are shown in the Figures 4.3, 4.4., 4.5 and 4.6)

4.5.1 PERMIAN SAMPLES

Permian samples are principally composed of mica (50 to 70%). The second more abundant components are kaolinite (8 to 35 %) and chlorite (10 to 29%) which are present in all samples. Small amounts of smectite (I/S1 4 to 22%) are also present and only two samples (PS14 and PS16) contain interstratified I/S (8 and 24% respectively) (Appendix 4.12). Ternary intensity diagram of the harmonic series (001) of the micas show illitic to phengitic tendency in both $< 2 \mu\text{m}$ and $2\text{-}16 \mu\text{m}$ size fractions (Figure 4.3). According to the ternary diagram of the chlorites, they have an intermediate composition between ferromagnesian and the aluminium composition in both clay- and silt sized fractions (Figure 4.5).

4.5.2 MUFARA SAMPLES

Clay mineral assemblages of the *Contrada Malluta*, *Vallone Faguara I* and *Cozzo Tabarani* are dominated by mica (42 to 80%) with associated chlorite (5 to 31%), kaolinite (0 to 28%), minor interstratified I/S (I/S1 0 to 16%) and smectite (7 and 20%); this latter in only two samples (CM4 and CM5) (Appendices 4.13 and 4.14). Different mineralogical associations characterise the *Cozzo Intronata* and *Viadotto Faguara II* sections. They are dominated by kaolinite (23 to 80%) associated with minor amounts of mica (5 to 35%), chlorite (0 to 21%) and interstratified I/S (I/S1 0 to 12%). Smectite is present in two samples, CI7 and CI8 (59% and 14% respectively) (Appendix 4.13). This discrimination is clearly visible in the statistical analysis of both silt- and clay-sized fractions (Figure 4.7 and 4.8).

Micas and chlorites have the same tendency in all the Mufara sections. Micas show an illite-phengite tendency in the fraction $< 2 \mu\text{m}$ and phengite in the fraction $2\text{-}16 \mu\text{m}$ (Figure 4.3). Ternary diagram of chlorites indicate that they are ferromagnesian rich in both clay-sized and silt-sized fractions (Figure 4.5).

4.5.3 LERCARA SAMPLES

Clay mineral assemblages of most of the Lercara Formation sections, i.e. *Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1* and *2*, *Roccapalumba Ferrovia a* and *b*, *Pietra di Salomone 1*, *3*, *4* and *5*, are essentially composed of mica (14 to 100%) and chlorite (0 to 72%) with minor interstratified I/S (I/S1 0 to 32%) and kaolinite (0 to 31%). Smectite is absent or can be found in small quantities in some samples (Appendices 4.8 to 4.12). *Pietra di Salomone 2*, *Portella Rossa 1* and *2*, and some other isolated samples have a different composition, though mica is always present in relatively high quantities (14 to 81%). The particularity of these sections is the presence of smectite (1 to 69%). Chlorite is less abundant (0 to 34%), interstratified I/S (0 to 23%) and kaolinite (0 to 24%) are more or less equivalent (Appendices 4.11 and 4.12). This differentiation is shown up also by statistical analysis of the clay-sized fraction (Figure 4.7).

In the ternary intensity diagrams of micas and chlorites, Lercara samples were represented according to their sedimentological classification (Figures 4.4a and 4.6a) and according to their section relationship

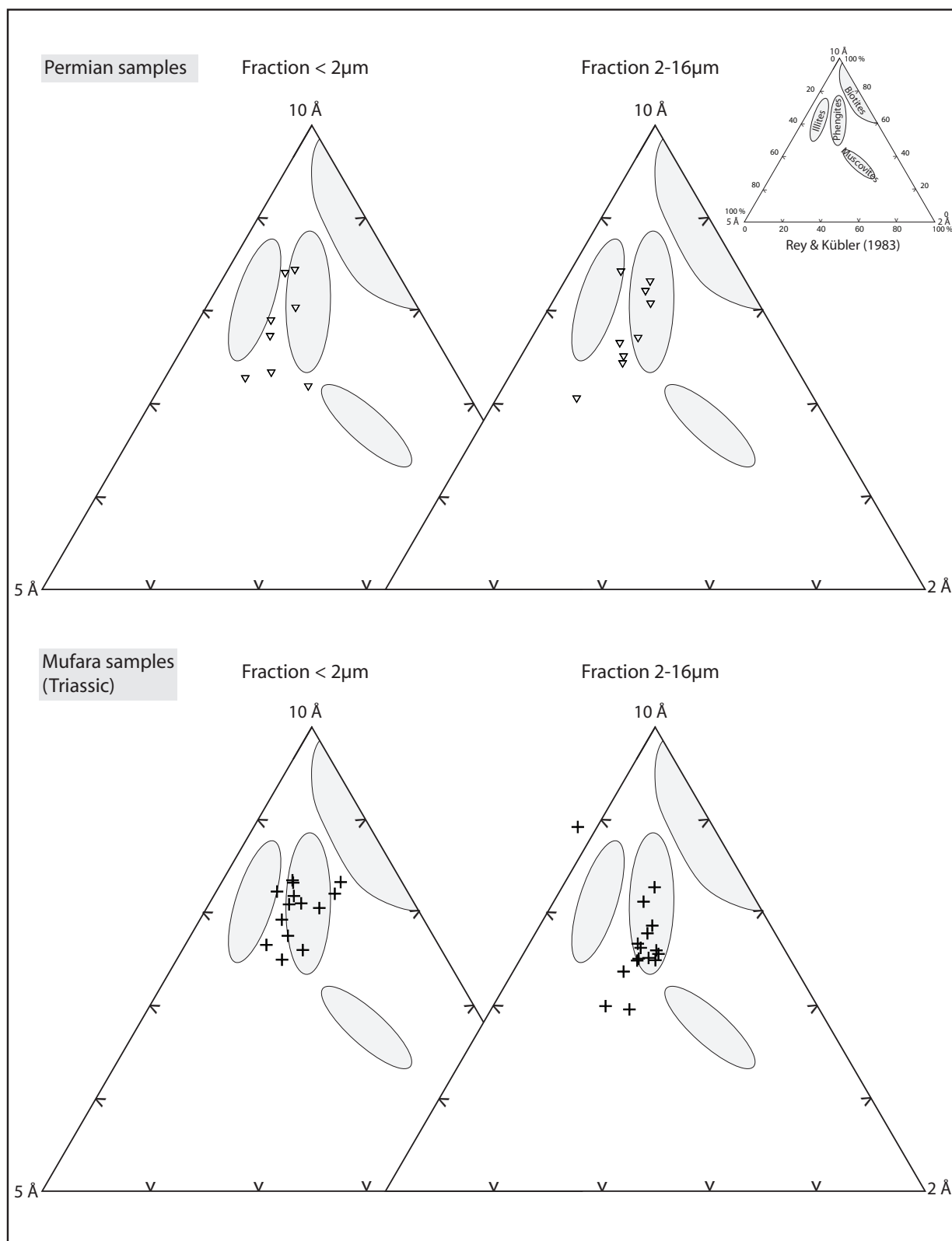


Figure 4.3 Micas discrimination of the Permian and Mufara Formation samples based on their basal reflections at 10 Å, 5 Å and 2 Å for the fractions < 2 µm and 2-16 µm.

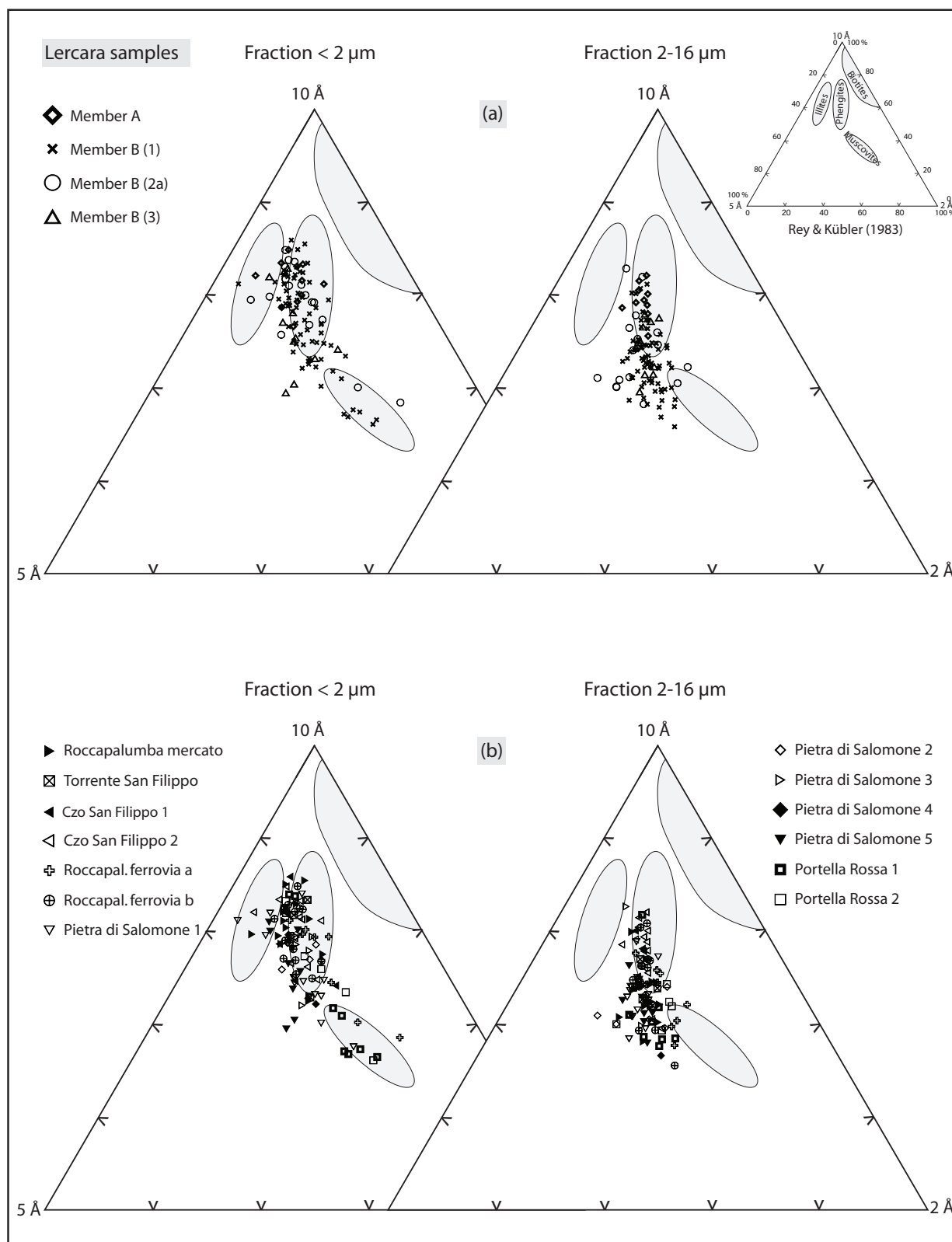


Figure 4.4 Micas discrimination of the Lercara Formation samples based on their basal reflections at 10 Å, 5 Å and 2 Å for the fractions < 2 μm and 2-16 μm. Samples are represented with symbols indicating their sedimentological classification (a) or section appartenance (b).

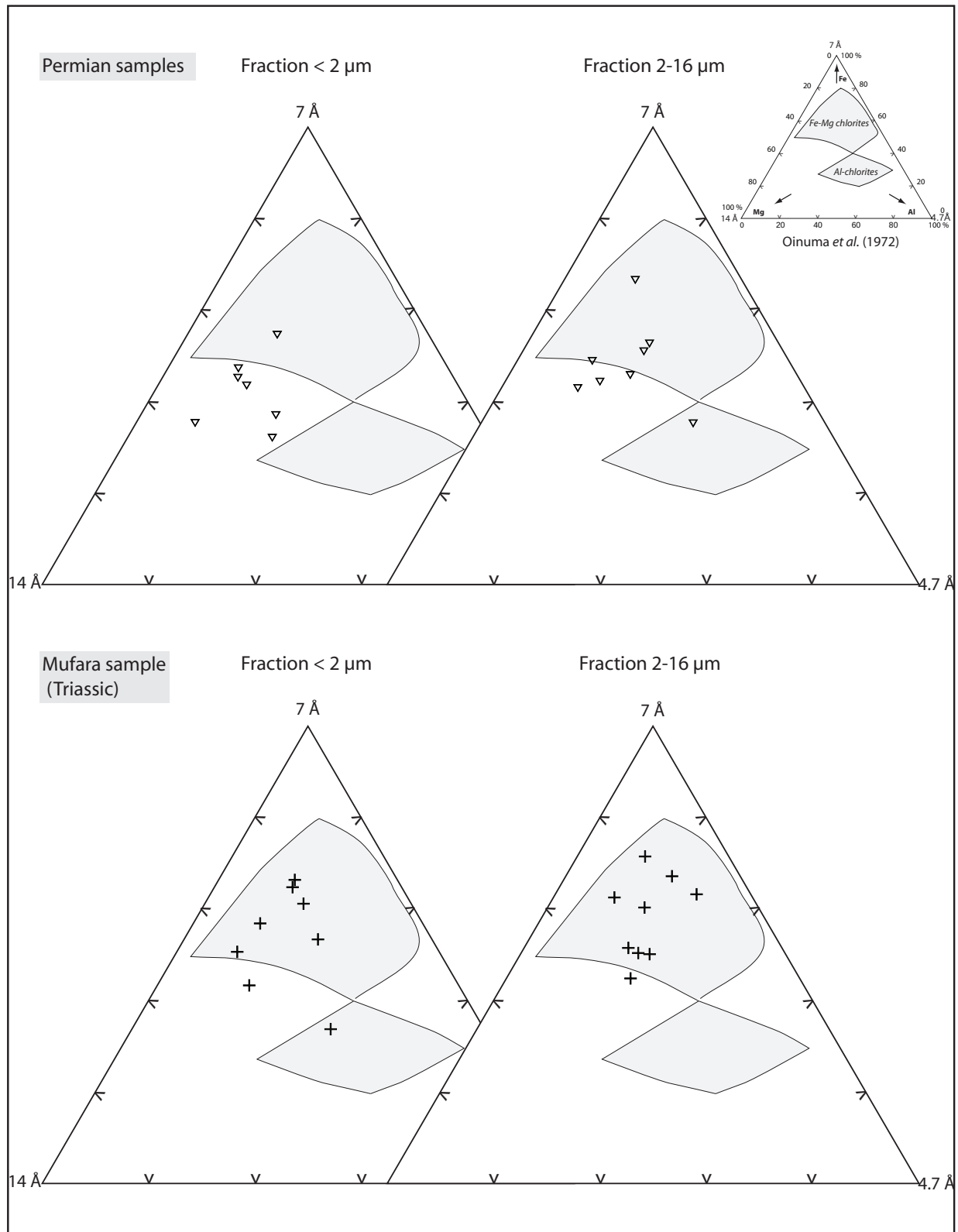


Figure 4.5 Chlorites discrimination of the Permian and Mufara Formation samples based on their basal reflections at 14 Å, 7 Å and 4.7 Å for the fractions < 2 μm and 2-16 μm.

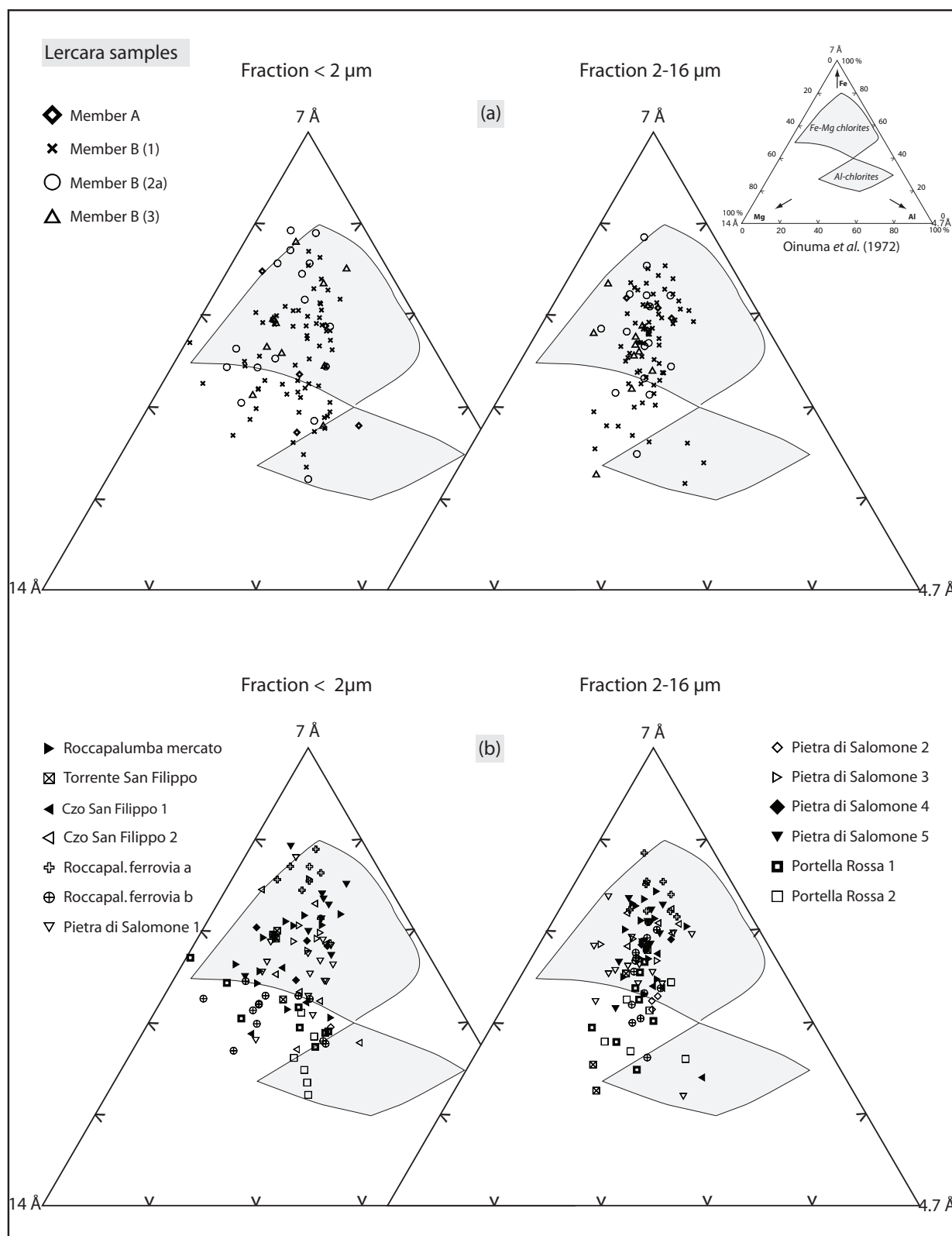


Figure 4.6 Chlorites discrimination of the Lercara Formation samples based on their basal reflections at 14 Å, 7 Å and 4.7 Å for the fractions < 2 μm and 2-16 μm . Samples are represented with symbols indicating their sedimentological classification (a) or section appartenance (b).

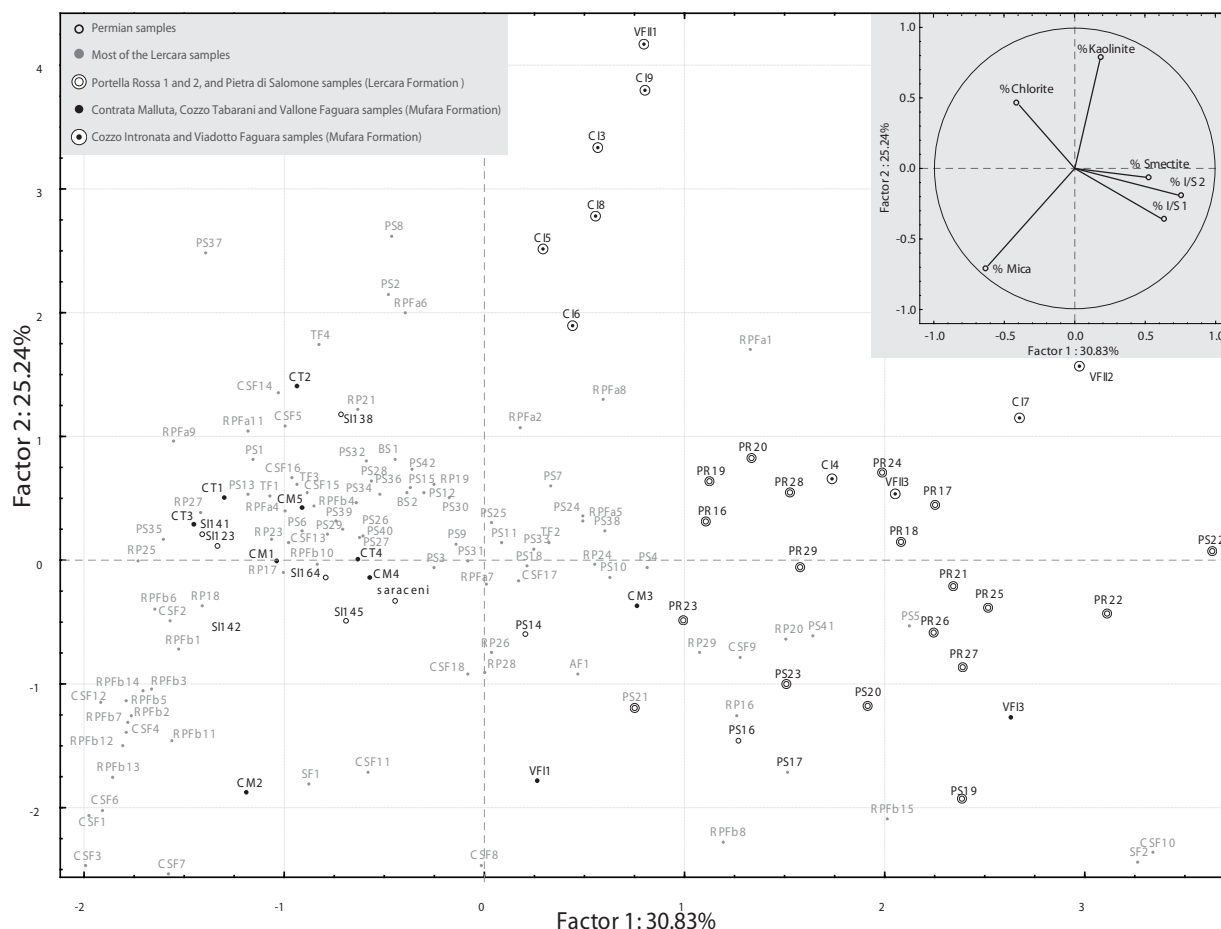


Figure 4.7 Principal Components Analysis of the clay-sized fraction mineralogy showing the repartition of the Permian, Mufara and Lercara samples. Upper right insert: projection of the original variables onto the plane defined by the Factors 1 and 2.

(Figures 4.4b and 4.6b). In the ternary diagram of micas, samples belonging to the Member A have an illite/phengite tendency in the fraction $< 2 \mu\text{m}$ and exclusively phengite in the fraction $2\text{--}16 \mu\text{m}$. Member B including parts B1, B2a and B3, show a wider distribution with an illite/phengite/muscovite tendency in the fraction $< 2 \mu\text{m}$ and phengite/muscovite in the fraction $2\text{--}16 \mu\text{m}$ (Figure 4.4a). In the ternary diagram of chlorites, sedimentological groups are principally distributed in the ferromagnesian field and only a small number in the aluminium field. Member B (B1, B2 and B3) has the same distribution in the clay- and silt-sized fractions, while Member A shows in the clay-sized, an Al-chlorite enrichment (Figure 4.6a). Samples plotted with symbols according to their section relationship, show, for the micas in the fraction $2\text{--}16 \mu\text{m}$, that sections have a phengite/muscovite tendency. In the fraction $< 2 \mu\text{m}$ Cozzo San Filippo 2, Roccapalumba Mercato and Roccapalumba ferrovia b sections have an illite/phengite tendency, the same as that in the fraction $2\text{--}16 \mu\text{m}$ (Figure 4.4b). Chlorites in the silt-sized are essentially Fe/Mg-rich in the Roccapalumba Mercato, Roccapalumba ferrovia a, Pietra di Salomone 2, 3, 4 and 5 sections, and Fe/Mg- and Al-rich in the Torrente San Filippo, Cozzo San Filippo 1 and 2, Roccapalumba ferrovia b, Pietra di Salomone 1, Portella Rossa 1 and 2 sections. These tendencies are the same in the clay-sized fraction, and only Cozzo San Filippo 1 and Portella Rossa 2 sections show aluminium enrichment (Figure 4.6b).

4.5.4 DISCUSSION

Clay mineralogy results highlight the fact that micas and chlorites are generally the more important clay components in both silt- and clay-sized fractions independent of the age of the analysed samples.

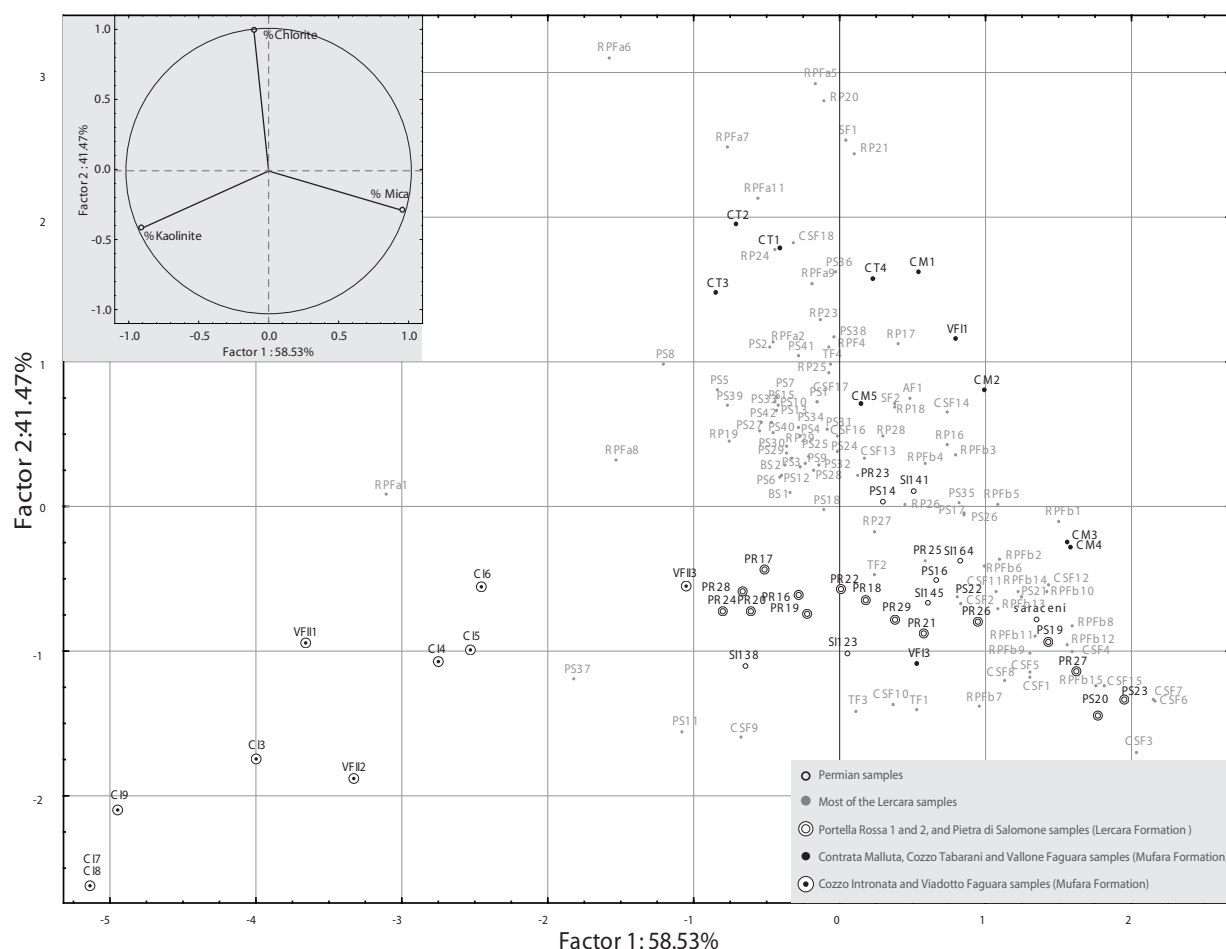


Figure 4.8 Principal Components Analysis of the silt-sized fraction mineralogy showing the repartition of the Permian, Mufara and Lercara samples. Upper right insert: projection of the original variables onto the plane defined by the Factors 1 and 2.

Interstratified I/S, kaolinite and smectite are minor constituents (Appendices 4.8 to 4.21). Exceptions to this general observation are in the Lercara Formation, the *Pietra di Salomone 2*, *Portella Rossa 1* and *2* sections and, in the Mufara Formation, the *Cozzo Intronata* and *Viadotto Faguara II* sections in which the more important components are smectite and kaolinite respectively.

As previously seen, clay minerals can have different origins and different factors can influence their repartition in the sections. In this study, for all Permian, Lercara and Mufara samples a detritic origin associated with different degrees of transformations due to burial (see chapter 5) are hypothesised. Detritic origin is supported by various evidences:

- The coexistence of illite and chlorite with kaolinite and minor smectite (typical surface derived minerals) give rise to the supposition that the former two derive from the alteration of mica- and chlorite-rich deposits composing the substratum. The tectonic activity and/or rapid erosion, already hypothesised in the chapter 2 have prevented soil formation.
- The silt- and clay-sized fractions have the same composition (Appendices 4.8 to 4.21 and Figures 4.7 and 4.8).
- For the Permian and Mufara samples, ternary diagrams of mica show a phengite tendency and phengite/muscovite for the Lercara samples (Figures 4.3 and 4.4). Phengite is a variety of muscovite typically found in rocks which have undergone high-grade metamorphism and testify to the detritic origin of micas. This is confirmed by the unaltered tendency of the micas in both silt- and clay-sized (Figures 4.3 and 4.4). No particular tendency has been observed for the Lercara samples respective to their sedimentological classification or to their section relationship.

- Ternary diagrams of chlorites show for all samples, and in both silt- and clay-sized fraction, more or less the same composition and this implies a detritic origin of chlorites (Figures 4.5 and 4.6).

The different composition of the *Cozzo Intronata* and *Viadotto Faguara II* sections of the Mufara Formation is probably due to their younger age and their formation under different climatic conditions.

Pietra di Salomone 2, *Portella Rossa 1* and *2* sections of the Lercara Formation are characterised by the abundant presence of smectite in contrast to the others Lercara sections. Three factors can be responsible for this difference: climate, sedimentary segregation and tectonic influence. Climatic variations during the deposition of these sections could encourage the formation of kaolinite and smectite to the detriment of micas and chlorite. In the same climatic conditions, the relative abundance of kaolinite and smectite can be explained by the distance to the shoreline. In effect, the *Pietra di Salomone 2*, *Portella Rossa 1* and *2* sections are deposited more distally (Figure 2.4). Finally, the high content in smectite can be due, as we will see in the chapter 5, to the minor tectonic deformation undergone by these sections that belong to the more external domains (section 1.3.1). However, smectite could also be present in the internal sections and destroyed by subsequent tectonic activity.

With regard to the provenance of detritic clay minerals in the Lercara deposits, the study of Permian and Triassic (Mufara Formation) samples failed to produce any information due to the great similarity in composition, particularly evident in the statistical analysis (Figures 4.7 and 4.8).

5 THERMAL DIAGENESIS

5.1 INTRODUCTION

The purpose of this chapter is to evaluate the thermal history of the Lercara Formation. This approach can furnish information about the palaeogeographical evolution of the basin, and about the evaluation and production of hydrocarbons.

After deposition, sediments are buried and are subject to physical and chemical changes due to the rise of temperature and pressure. These changes, undergone during the geological history, depend on palaeoclimatic conditions at the surface, on subsidence and tectonic history of the sedimentary basin, on erosion and the evolution of the thermal flux and can be quantified by some organic and mineral indicators of thermal maturity. These measurable parameters cannot be directly converted to palaeotemperatures because they depend also on other parameters as, for instance, the original rock composition, different sources of original organic matter and selective biodegradation, as well as preservation nature in the same basin (Tissot *et al.*, 1987). Changes undergone by sediments are related to a diagenetic or metamorphic stage. According to Kübler *et al.* (1979) the most common metapelitic zones are: the diagenetic zone (zones 1 to 4 of Kübler, 1970), the anchizone (zone 5 of Kübler, 1970) and the epizone (zone 6 of Kübler, 1970). The anchizone is considered as the zone of very low-grade metamorphism between the diagenesis and the low-grade metamorphism. Figure 5.1 provides a comparison of the metapelitic zones defined by Kübler (1970), Barnes *et al.* (1984) and Merriman & Peacor (1999) and of the different indicators of the thermal maturity.

5.2 METHODS

5.2.1 ORGANIC MATURATION INDICES

The organic matter subject to an increase of temperature and pressure related to subsidence and sediments compaction, undergoes some geochemical and physical changes that induce a higher degree of ordering (Tissot *et al.*, 1987). These changes are irreversible and can be expressed by optical maturation indices, such as Vitrinite Reflectance (Bostick, 1979; Tissot & Welte, 1984, *cum biblio*), Visual spore colour scales (Marshall & Yule, 1999, *cum biblio*), and Conodont Color Alteration Index (CAI) (Epstein *et al.*, 1977), and by organic geochemistry parameters, such as Tmax and H/C ratio from Rock-Eval pyrolysis (Espitalié *et al.*, 1985a, b, 1986).

Although Vitrinite Reflectance is the most reliable and exact method of quantifying the organic transformations since the procedure is standardised and applicable from the start of diagenesis, it could not be used in this work. This was because of the scarcity of vitrinite macerals in the palynofacies of

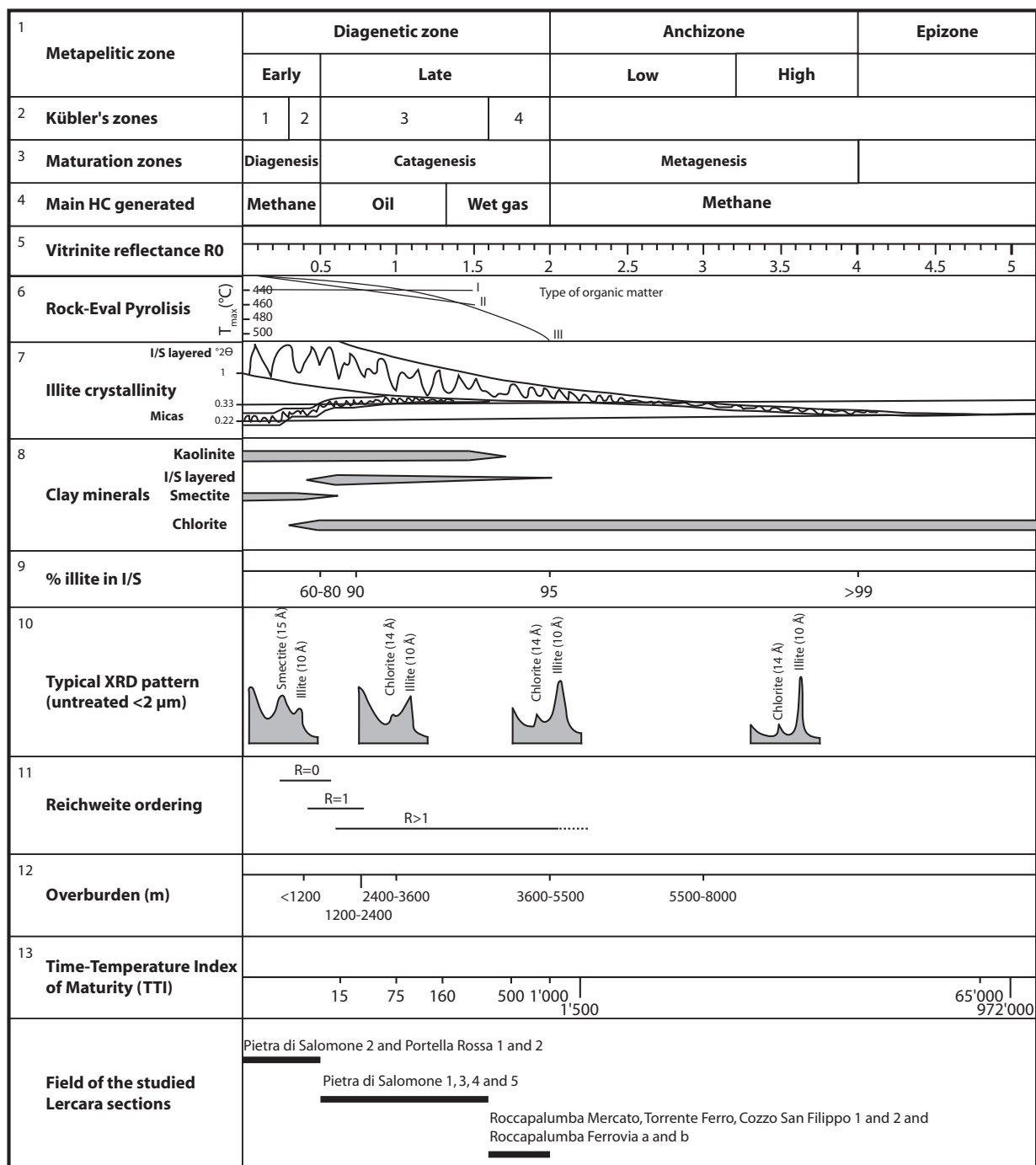


Figure 5.1 Tentative comparisons between the metapelitic zones and the organic and mineral indicators of maturity. In the last row are represented the position of the Lercara sections. From (1) Merriman & Kremp (1996); (2) Kübler 1970; (3) Barnes *et al.* (1984); (4) Tissot & Welte (1984); (5) Dow (1977); (6), Espitalié *et al.* (1985b) and Legall *et al.* (1981); (7) Kübler *et al.* (1979); (8) Kübler (1970); Kübler *et al.* (1979) and Kübler (1980); (9 and 10) Merriman & Kremp (1996); (11) Merriman & Frey (1999); (12) Harris *et al.* (1978) and Legall *et al.* (1981) and (13) Waples, 1980.

the Lercara Formation and the large quantity of reworked material that would imply the presence of several population of vitrinite (Devonian, Carboniferous, Permian, and perhaps Triassic; see chapter 3 concerning the biostratigraphy).

Indexes that characterise spores and pollens grains are very subjective. In addition, the colour of palynomorph associations also depends, apart from the effect of late diagenetic heating, on the original

nature and thickness of the particles inspected, and by syndepositional and early diagenetic processes such as the degree of oxidation and degradation, presence of reworked specimens and microbial activity (e.g., Tissot *et al.*, 1987; Batten, 2002). In the same way as the Vitrinite Reflectance, palynofacies of the Lercara Formation contain too many reworked particles that might already have recorded older diagenetic processes. Autochthonous palynomorphs are very rare and the same spore or pollen grain was almost never found in more than one sample. For this reason, even if the palynofacies show different colours (often the reworked palynomorphs are clearer than the autochthonous ones), they cannot be used to reconstruct the thermal history of the sediments.

The Conodont Color Alteration Index could not be used because the present conodonts are of Permian age; in addition they are present in three samples of only two sections.

In this study, Rock-Eval pyrolysis was therefore the only possible method to estimate organic maturation.

ROCK-EVAL PYROLYSIS

Rock-Eval pyrolysis is a low-cost and rapid physico-chemical method used to characterize the type of organic matter, to determine the petroleum potential and the thermal maturity of the rocks. This method is a pyrolysis using temperature control developed by the *Institut Français du Pétrole* and *Petrolfin* in the 1970's (Espitalié *et al.*, 1977; Espitalié *et al.*, 1985a, b, 1986; Espitalié & Bordenave, 1993).

Rock-Eval analysis was performed with an OSA apparatus at the University Pierre and Marie Curie in Paris on the 22 Lercara Formation samples containing the largest amount of organic matter. A whole rock sample of about 100 mg is initially heated under a helium atmosphere at 300°C for three minutes; the proper pyrolysis then commences when the temperature is increased to 600°C by steps of 25°C/min. Several parameters can be obtained from this method at different stages of heating and calculated after:

- S1 peak, expressed in mg HC/g of the rock, represents the free hydrocarbons, oil and gas initially present in the sample and released at 300°C during the volatilisation phase. S1 depends on the petroleum potential of the sample, the degree of evolution of the organic matter and on migration phenomena.
- S2 peak, expressed in mg HC/g of the rock, represents the hydrocarbons and oxygen containing compounds expelled from the sample during the cracking of both kerogen and heavy extractible compounds between 300°C and 600°C. S2 represents the total quantity of oil and gas that the kerogen can produce during a further evolution.
- Tmax, expressed in °C is the pyrolysis temperature recorded at the maximum of the S2 peak. It is an indicator of the level of thermal maturity of organic matter; it increases with the augmentation of the evolution of the organic matter.
- S3 peak, expressed in mg CO₂/g of the rock represents the oxygen compounds decomposed between 300°C and 390°C and the resulting CO₂. It depends on the type of organic matter and its thermal evolution. It is more important when the organic matter is of continental origin and immature.
- S4 peak, expressed in mg CO₂/g of the rock represents the organic carbon remaining in the residual fraction, derived from oxidation of the organic matter when the sample is heated under air atmosphere at 600°C during 7 minutes.
- TOC, expressed in weight % represents the total organic carbon and is the sum of the organic carbon derived from cracking (S1 and S2) and 83% of the residual organic carbon 0.83 S4. S3 is not taken into consideration because it can derive by early decomposition of siderite and because it represents only a few percent of the total carbon (5% at the most).
- HI defined as the S2/TOC ratio. There is a good correlation between HI and H/C ratio of kerogen, measured after acid treatment of the rock matrix. This correlation is valid for all types of organic matter and for all levels of thermal maturation.
- The source rock potential calculated from the S1 and the S2 peaks expressed in mg HC/g of rock.

The mineral matrix can modify the pyrolysis parameters, by reducing S2 and HI, and can also increase Tmax, adsorbing the pyrolytic hydrocarbon compounds. This effect is more important in rocks poor in

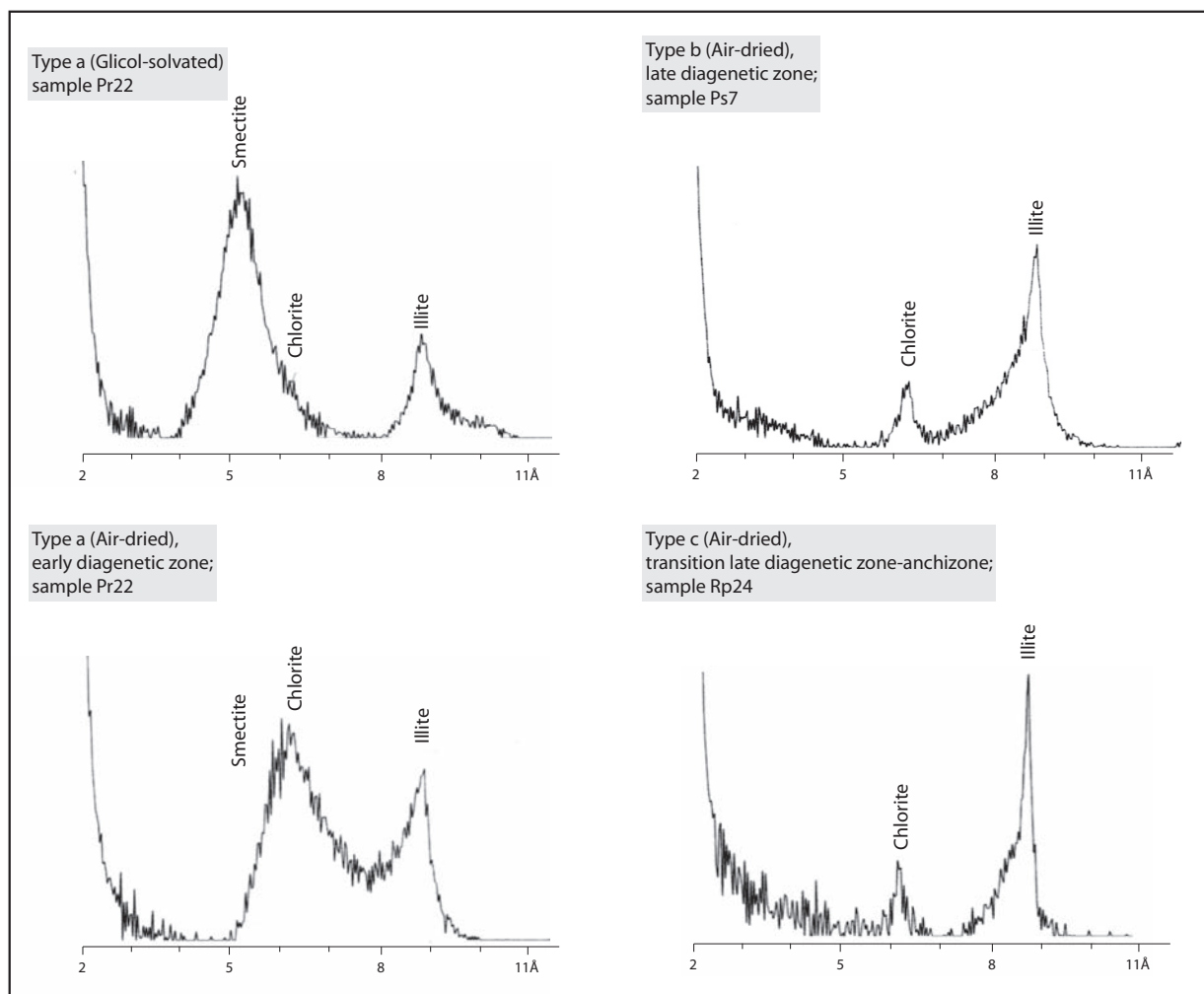


Figure 5.2 Typical X-ray patterns in air-dried conditions of analysed samples with corresponding diagenetic zones. In the type a the smectite peak is better visible in the Glicol-Solvated diffractogram.

organic matter and rich in clay minerals such as illite and montmorillonite. Kaolinite and carbonates are less active (Espitalié *et al.*, 1980; Espitalié *et al.*, 1985b). For this reason Tmax of samples poor in organic matter (TOC value lower than 0.3 or 0.5%w depending upon the authors) should not be taken in account (Peters, 1986; Lallier-Verges *et al.*, 1993). During the pyrolysis, organic matter altered by weathering, transport and sedimentation in unfavourable condition of preservation can simulate effects of the mineral matrix (Espitalié *et al.*, 1986). In addition, the Tmax has no meaning when the S2 peak is low and wide (generally S2 values lower than 0.2 mg HC/g) and when the TOC values are lower than 0.1% all parameters are considered to be insignificant (Espitalié *et al.*, 1986).

If sediments contain reworked organic matter, the quantity of organic carbon is not indicative of potentially source rocks (Espitalié *et al.*, 1986).

5.2.2 MINERALOGICAL INDICES

During sedimentary burial, clay minerals undergo some reactions related to increases in temperature and pressure equivalent to those of organic materials. These reactions are irreversible under normal diagenetic and anchizone conditions (Merriman & Frey, 1999) and can be quantified by the study of the clay minerals content, illite crystallinity and percent of illite in illite/smectite mixed layers.

CLAY MINERALS CONTENT

During diagenesis, processing of equilibration of mineral phases with environments of different salinities under increasing conditions of temperature and pressure cause the disappearance of these minerals and the appearance of new phases (Singer & Müller, 1983). Equilibrium of the new mineral phases is characteristic of the burial degree (Kübler *et al.*, 1979). The principal clay minerals involved are:

- *Smectite/illite*. Smectite is a mineral stable only in the first phases of diagenesis (zone 1 and 2 of Kübler). It gradually transforms into illite forming interstratified illite/smectite layered with an initial high proportion in smectite that progressively decreases to the complete advantage of the illite (Figure 5.1) (*e.g.*, Powers, 1959; Weaver, 1959). Subsequently, the passage from early to late diagenesis marks the transformation of 60-80% of the illite in I/S, and the passage from diagenesis to anchizone to $\approx 95\%$ of illite (Figure 5.1) (Merriman & Frey, 1999, *cum biblio*). In addition to the increasing percentage of illite, the interlayers illite/smectite present initially a random interstratification that corresponds to Reichweite ordering $R=0$. With the increase of the burial, illite and smectite show a short range ordering ($R=1$) indicating an equal number of illite and smectite interlayers (...ISISI...) and then a long range ordering ($R>1$) (Brindley & Brown, 1980). For instance, an R value of 3 corresponds to the sequence ...IIISIIIS... and a percentage of illite greater than 90% (Brindley & Brown, 1980). Concerning the distribution in the metapelitic zones, interstratified I/S with a R value of 0 corresponds to the early diagenetic zone, R value of 1 to the late early diagenetic zone to the early late diagenetic zones, and R value greater than 1, to the late diagenesis-low anchizone (Figure 5.1) (Merriman & Peacor, 1999, *cum biblio*). Finally, XRD diffractograms of untreated fraction $< 2 \mu\text{m}$ show for the smectite, chlorite and illite, typical patterns linked to metapelitic zones (Merriman & Kremp, 1996). Figure 5.2 shows examples of the types of diffractograms from the Lercara samples: a) the early diagenetic zone, b) the late diagenetic zone and c) transition between the late diagenetic zone and the anchizone of Merriman & Kremp (1996). In the anchizone, illite transforms into muscovite/phengite (Merriman & Peacor, 1999).
- *Kaolinite*. This mineral is stable in the sediments having undergone a pressure increase until it reaches the bottom of the zone 4 of Kübler (1970) (Kübler, 1980). Progressively dissolved, kaolinite may be incorporated in the interstratified I/S and then converted in illite or, more probably, involved in the formation of chlorite (Weaver, 1989) (Figure 5.1).
- *Chlorite*. Diagenetic chlorite can be formed as a by-product of the smectite to illite reaction (Weaver, 1989) but the presence of detrital chlorite in the shales makes it difficult to discriminate the contribution of diagenetic chlorite (Weaver, 1989). However, beyond the zone 4 of Kübler (1970), chlorite with mica are stable minerals.

ILLITE CRYSTALLINITY

The Illite Crystallinity (IC) or “Scherrer Width” or Kübler Index, is an indirect measurement of the amount of expandable interlayers in the illite-smectite layers that decrease with the increase of diagenesis and metamorphism. Practically, it is the measure of the full width at half maximum of the first illite diffraction peak ($10 \text{ \AA}$) on air dried samples (Kübler, 1964; Kubler & Jaboyedoff, 2000) and it can be used to detect the beginning of the late diagenetic zone up to the beginning of the epizone. The peak shape and therefore the IC values can be influenced by interferences from other phyllosilicates and by experimental and measuring conditions such as the XRD equipment utilised. In order to avoid these inaccuracies and to employ the IC values as diagenetic and metamorphic indicators, the index must be used with caution related to other mineral and organic indices as well as with the sedimentary and tectonic history of the studied region. The limits of the anchizone fixed at $0.42^\circ 2\theta$ and $0.25^\circ 2\theta$ by Kubler & Jaboyedoff (2000), correspond to $0.33^\circ 2\theta$ and $0.22^\circ 2\theta$ with the SCINTAG XDS 200, actually used at the Neuchâtel University (Goy Eggenberger, 1998). During the diagenesis, IC values are variables and do not show any

particular progression because the crystallinity measured corresponds to inherited detritic material. IC values become more regular at the beginning of the anchizone (Figure 5.1).

5.2.3 THERMAL MODELLING

Thermal history of sedimentary rocks is closely related to the rate of burial and to exhumation, and local heat flow, even if the attribution of heating to increasing burial and of cooling to erosion/uplift is not always correct. Modelling of the burial history of a sedimentary unit can determine an accurate temperature history by integrating factors that control temperatures and by enabling a calibration with thermal indicators previously exposed. If these thermal indicators cannot be evaluated or have to be verified, Lopatin's time-temperature index of maturity (TTI) can be used to reconstruct the geothermal history.

The TTI model developed by Waples (1980) could predict the thermal conditions under which hydrocarbons can be generated and preserved based on the correlation between the TTI and the Vitrinite Reflectance (R₀) (Table 5.1). This model enables the construction of a sedimentary burial curve obtained by plotting the depth of burial versus the geological age (see chapter 6), and of a temperature grid superimposed on the burial curve. This grid is constructed on the basis that the geothermal gradient and the surface temperature during the thermal history were as at the present day. The temperature grid is represented as a series of equally spaced lines every 10°C. Intersection of the isogrades with the burial curve permits the calculation of the maturity acquired by the sedimentary unit in each time interval. The TTI is then calculated by the sum of the maturities acquired in each interval according to the following formula:

$$TTI = \sum_{nmin}^{nmax} (\Delta T_n) (r_n)$$

where $r = 2$, n_{max} and n_{min} are the n -value of the highest and lowest temperature intervals encountered and ΔT for a particular interval is the age at which the sediment enters that interval minus the age at which it enters the next interval (Waples, 1980).

The geothermal gradient can vary between 10/15°C/km in thick and recent sedimentary basins, to several hundreds of °C/km in rifting or volcanic areas (Della Vedova, 2003). In the case of the Lercara Formation and Early Triassic deposits, a "normal" palaeogeothermal gradient of 30°C/km was assumed because, as we will see in the chapter 6, the Lercara Formation was deposited during a period of thermal subsidence of the basin. On the contrary, for the Permian deposits, TTI was estimated either with a gradient of 30°C/km or of 40°C/km. The latter was considered because, as we will see in chapter 6, a phase of extension affected the crust during the Permian, increasing the geothermal gradient. This gradient is unknown and 40°C/km was arbitrarily chosen in order to estimate a range of TTI between the normal condition and the warming of the crust. The surface mean temperature was estimated at 20°C considering that during the Ladinian/Carnian boundary the south-western margin of the Neo-Tethys, including Sicily, was populated with a palynoflora indicating a warm and arid climate locally modified by pluvial events (Cirilli, 1995).

5.3 RESULTS

5.3.1 ORGANIC MATURATION INDICES RESULTS

ROCK-EVAL RESULTS

Analysed samples present very low organic carbon content with a mean TOC value of 0.22% and a maximum TOC value of 0.46 (Appendix 7). These low values are usually recorded in prodeltaic and

submarine fan sediments where TOC values are generally less than 1% (Demaision & Moore, 1980). This is in agreement with the hypothesised sedimentary origin of the Lercara deposits (chapter 2).

The present source rock potential given by the quantity of free hydrocarbons (S1 peak) and heavy extractable compounds (S2) is insignificant. The S1 peak values are almost systematically more important than the S2 peak values. This may signify that there are more free hydrocarbons (S1) in the rock than heavy compound (S2), even if they are quantitatively low. This could well indicate the presence of kerogen which, when evolved, produced hydrocarbons, which have now disappeared (expulsion, migration or alteration); only residues of these were therefore analysed. As the Lercara deposits do not constitute typical source rocks facies a thermic diagenesis can be hypothesised.

With regard to the Tmax and the HI values, they are not regarded as reliable because most of the samples have a S2 lower than 0.2 and TOC lower than 0.5 (Appendix 7).

In conclusion, the Lercara Formation cannot be considered as a source rock potential.

5.3.2 MINERALOGICAL INDICES RESULTS

CLAY MINERALS CONTENT

As seen in chapter 4, clay minerals are generally composed of detritic mica and chlorite with minor interstratified I/S, kaolinite and smectite in the Permian samples and in most of Lercara and Mufara samples. However, in the *Cozzo Intronata* and *Viadotto Faguara II* sections of the Mufara Formation the most abundant constituent is kaolinite and in the *Pietra di Salomone 2*, *Portella Rossa 1* and *2* sections of the Lercara Formation the more abundant component is smectite.

- *Permian samples*: some of the Permian samples (Saraceni, Si 142, 145, 164 and PS16) contain smectite (Appendix 4.12) and kaolinite indicating that the burial effects endured was moderate and that samples underwent an early diagenesis. On the contrary, some other samples (Si 123, 138, 141 and PS14) contain no smectite (Appendix 4.12) but contain kaolinite, suggesting that samples underwent a late diagenesis (zone 3-early zone 4). Interstratified layers I/S are present only in the samples PS14 with a relative percentage of 90/10%. These samples have $R > 1$ and a X-ray diffractograms of type b (Appendix 6) compatible with the zone 3-early zone 4 of Kübler (1970).
- *Mufara samples*: the Mufara samples contain a variable amount of kaolinite and only four samples (CM4, CM5, CI6 and CI7) contain smectite (Appendices 4.13 and 4.14). This suggests that clay diagenesis due to burial was of relatively low intensity (late diagenesis). Interstratified I/S present a variable percentage of between 70-95%/30-5% indicating a diagenesis between the early diagenesis and the low anchizone. Reichweite ordering shows values of $R = 1$ and $R > 1$ and X-ray diffractograms are of type b and c (Appendix 6). These inconstant values may indicate that sediments underwent a clay diagenesis variable between the late early diagenesis and the low anchimethamorphism. However, the presence of kaolinite and the absence of smectite indicate a late diagenesis.
- *Lercara samples*: they can be subdivided in samples containing only kaolinite and samples containing kaolinite and smectite. The former samples belong to the *Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1* and *2*, *Roccapalumba Ferrovia a* and *b*, *Pietra di Salomone 1*, *3*, *4* and *5*, the latter belong to *Pietra di Salomone 2*, *Portella Rossa 1* and *2* sections, and to some other samples (Appendices 4.8 to 4.12). The presence in the first group of kaolinite and the absence of smectite suggests that they underwent a late diagenesis (zones 3 and 4). This is confirmed by the relative percentage of I/S (80-95%/20-5%), by the values of the Reichweite ordering ($R = 1$ and $R > 1$) and by the X-ray diffractograms (type b and c) (Appendix 6). In particular, they permit an additional subdivision in sections having undergone an early late diagenesis (zone 3) i.e. *Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1* and *2*, *Roccapalumba Ferrovia a* and *b* and sections underwent a late diagenesis (zone 4) i.e. *Pietra di Salomone 1*, *3*, *4* and *5* (Appendix 6). On the contrary, the presence of smectite in the second group suggests that the clay diagenesis due to burial effects was of moderate intensity (early diagenesis). This is confirmed by the relative percentage of I/S (50-70%/50-30%), by the values of the Reichweite ordering ($R = 0$ and $R = 1$) and by the X-ray diffractograms (type a).

Stage	TTI	R ₀
Onset of oil generation	15	0.65
Peak oil generation	75	1.00
End of oil generation	160	1.30
Upper TTI limit for occurrence of oil	1'000	2.0
Upper TTI limit for occurrence of wet gas	1'500	2.20
Last known occurrence of dry gas	65'000	4.80
Below dry gas liquid	972'000	>5.0

Table 5.1 Correlation of TTI with important oil generation stages and Vitrinite Reflectance (R₀) (modified from Waples, 1980).

ILLITE CRYSTALLINITY RESULTS

IC values measured in the Permian, Mufara and Lercara samples show much variation (Appendix 6), typical of the diagenetic zone, because they reflect the crystallinity of the inherited detritic material (Figure 5.1).

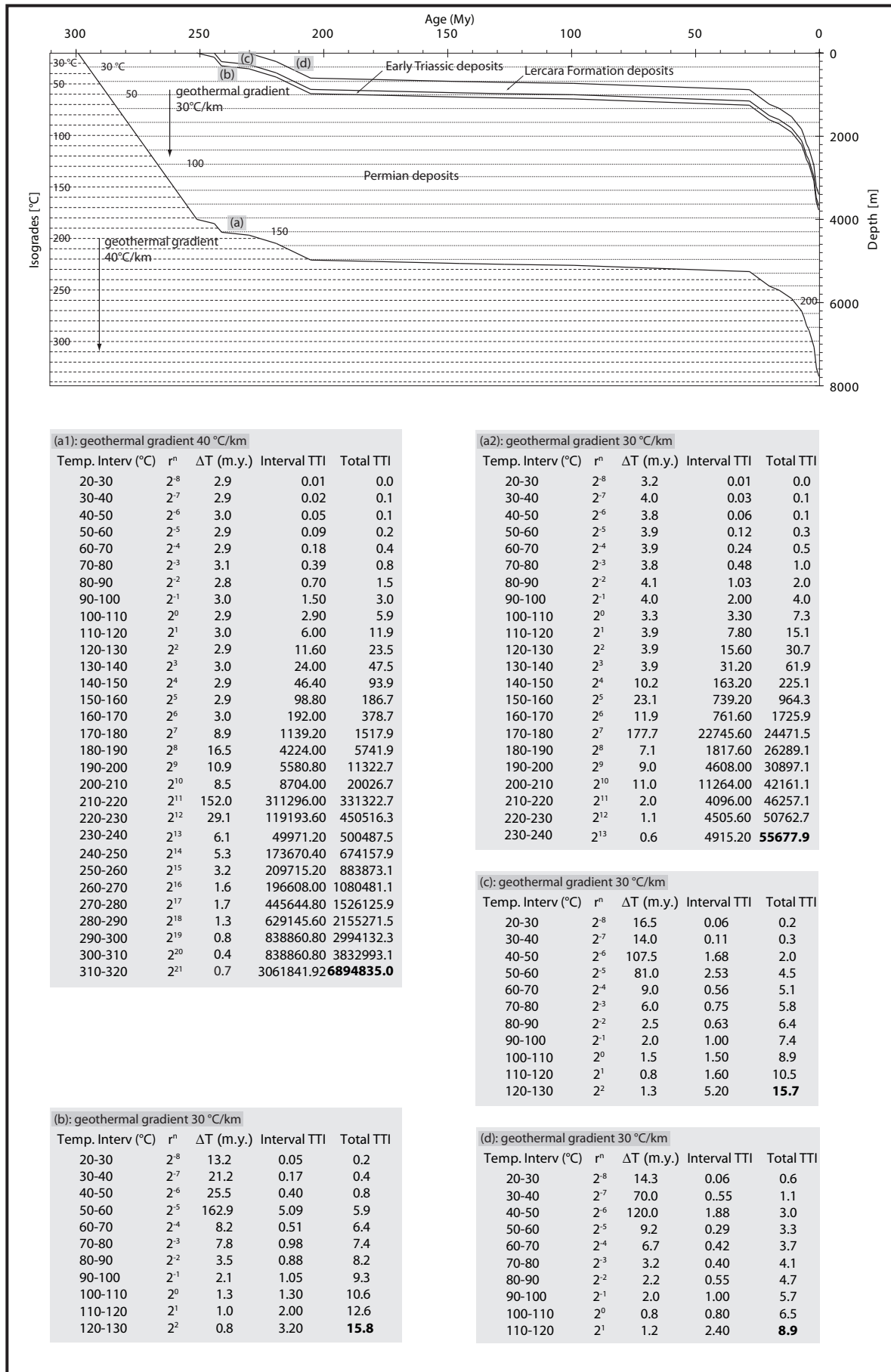
5.3.3 THERMAL MODELLING RESULTS

A burial curve has been reconstructed for the entire Sicilian Basin, at the bottom of which the Lercara Formation deposited (Figure 5.3 curves c and d). Details about its reconstruction can be found in chapter 6. Moreover, in order to reconstruct the thermal history of the sediments probably deposited before the Lercara Formation in the Sicilian Basin, which, at the present time are to be found reworked in it, the thickness of the Permian (Figure 5.3, curve a) and Early Triassic sediments (Figure 5.3, curve b) deposited in the nearby Jeffara Basin (Tunisia) have been added to the curve (see chapter 6). For the Permian, finer subdivision was not possible, because the stratigraphy was not known in detail.

Curves b, c and d indicate that the top of Permian, Early Triassic and Lercara deposits underwent a similar overburden of roughly 3600 m. According to the studies of Harris *et al.* (1978) and Legall *et al.* (1981), in the Appalachian basin in the USA and in the Michigan basin in Canada respectively, this overburden can be related to a Vitrinite Reflectance around 1 (Figure 5.1 and Table 5.1) corresponding to the zone 3 of the late diagenetic zone.

Lopatin's methods were applied to the burial curves representing the bottom of the Permian deposits (Figure 5.3, curve a), the bottom of the Early Triassic deposits (Figure 5.3, curve b) and the bottom and top of the Lercara Formation (Figure 5.3, curves c and d) in order to calculate the maximum and the minimum TTI values for each deposit. For the Permian deposits two geothermal gradients were considered (30 and 40°C/km).

Figure 5.3 Burial history and TTI computation of the potential Permian (a-b) and Early Triassic sediments (b-c) deposited before the Lercara Formation (see text for explanations).



Values obtained for the Permian deposits vary between a maximum of 6'894'835 or 55'677.9 (for a gradient of 40°C/km or 30°C/km) and a minimum of 15.8 (Figure 5.3, tables a1, a2 and b). These values correspond to a Vitrinite Reflectance of between 0.65 and >5, *i.e.*, between the oil window (zone 3 of the late diagenesis) and the last occurrence of dry gas for a gradient of 30°C or below the dry gas liquid for a gradient of 40°C/km (epizone) (Table 5.1 and Figure 5.1). Early Triassic sediments have TTI values of 15.7, 15.8 indicating that sediments are in the oil window (zone 3 of the late diagenesis). Finally, for the Lercara Formation TTI values of between 8.9 and 15.7 were obtained (Figure 5.3, tables c and d). They correspond to a Vitrinite Reflectance of around 0.65 (Figure 5.1) and indicate, corresponding to mineralogical indices, that sediments are between the early diagenesis and the oil window (Figure 5.1) without however being more precise about the sections concerned.

5.4 DISCUSSION

Data presented in this chapter indicate that, for the Lercara Formation, organic maturation indices are not adapted to the characterisation of the thermal diagenesis evolution. This is due to the poverty of organic matter contained in the Lercara samples and to the fact that the most of this organic matter is reworked.

On the contrary, mineralogical indices give the best results. As seen in chapter 4, clay minerals have a detrital origin and differences in their composition between the different sections and samples can be due to climate, sedimentary segregation burial and tectonic influence. Mineralogical indices emphasized that Permian samples did not undergo the same burial effect, but these are isolated samples reworked in the Lercara sections and is capable of different interpretations. Concerning the thermal modelling, a geothermal gradient for the Permian sediments of 40°C/km was probably overestimated because the Permian samples found in the Lercara Formation underwent an early to late diagenesis more compatible with a geothermal gradient of 30°C/km. Mufara sample composition is independent of their tectonic position and is probably related to climatic variations. The small number of studied sections, however, does not allow any reliable conclusion. Concerning the Lercara Formation, sedimentary segregation could be the reason for the composition variability, because the distal sections (*Pietra di Salomone 2* and the *Portella Rossa 1* and *2*) contain smectite whereas the more internal *Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1* and *2*, *Roccapalumba Ferrovia a* and *b*, and *Pietra di Salomone 1*, *3*, *4* and *5* do not. This difference could also result from the tectonic influence. Indeed, mineralogical indices obtained for the Lercara samples show that sections *Roccapalumba Mercato*, *Torrente Ferro*, *Cozzo San Filippo 1* and *2* and *Roccapalumba Ferrovia a* and *b* underwent more intense burial effects than those of *Pietra di Salomone 1*, *3*, *4* and *5*, while this second group then underwent a more intense burial effect than of *Pietra di Salomone 2* and the *Portella Rossa 1* and *2* sections (Figure 5.1). This is compatible with the tectonic position of the sections: more internal for the first group, intermediate for the second and more external for the third. This interpretation is supported by the thermal modelling.

In conclusion, the crossed study of clay minerals and thermal diagenesis permitted a mineralogical and thermal characterization of the Lercara deposits, but did not allow discrimination of the detrital supplies of different ages.

6 PALAEOGEOGRAPHICAL RECONSTRUCTION

As previously indicated in section 1.3.3, a general disagreement exists about the palaeogeographical evolution of the westernmost termination of the Tethys, particularly about the timing of the Palaeo-Tethys closing and of the Neo-Tethys rifting: Permian or Triassic? Palaeogeographical reconstructions in this region are complicated due to the lack of autochthonous Permian to Lower Triassic deposits and by paucity of knowledge of the stratigraphy.

The goal of this chapter is an attempt to reconstruct the regional and local palaeogeography of the westernmost termination of the Tethys, focusing on Sicily, from the Permian to the Cordevolian (early Late Triassic), integrating the stratigraphic knowledge acquired during this work and data derived from the literature. With this in mind, a geodynamic history of the Sicanian basin, which recorded the events which occurred in the westernmost termination of the Tethys, will also be proposed.

6.1 SUBSIDENCE HISTORY

Variations in the sedimentary record are essentially influenced by cyclic fluctuations of the sea level and by geodynamic mechanisms of formation and evolution of the basin. This geodynamic evolution can be indirectly found by the study of the subsidence curve. Two types of curves can be reconstructed:

- total subsidence curve, representing the burial evolution through time of the first sediments deposited at the bottom of the basin, used as levels of reference. It represents the addition of all vertical movements.
- tectonic subsidence curve, representing the burial history of the basement, *i.e.*, the evolution of the sedimentary basin. It permits the interpretation of the mechanisms that control the subsidence.

6.1.1 METHOD

Subsidence of the basement depends on the weight of sediments and water, as well as on the thermic evolution of the lithosphere. When oceanization affects the crust, initial heating is followed by cooling, leading to respective expansion and contraction of the lithosphere (Figure 6.1). Theories and methods regarding the construction and interpretation of the subsidence curves utilised in this work can be found in Loup (1992) and Borel (1997) and in references therein.

Subsidence curves have been elaborated with the EasySub program (Uriarte & Schegg, 2006, modified by Borel) in which the following parameters have been considered:

- Thickness of the lithological units. To evaluate this parameter, a good knowledge of the stratigraphic and tectonic context of the studied basin is necessary, based on field studies palinspastic restoration and literature data.
- Erosion and hiatus. Erosion is a parameter difficult to evaluate, because it requires the evaluation of both the thickness of the eroded material and the time of the erosion. Duration of the hiatus must also to be considered.

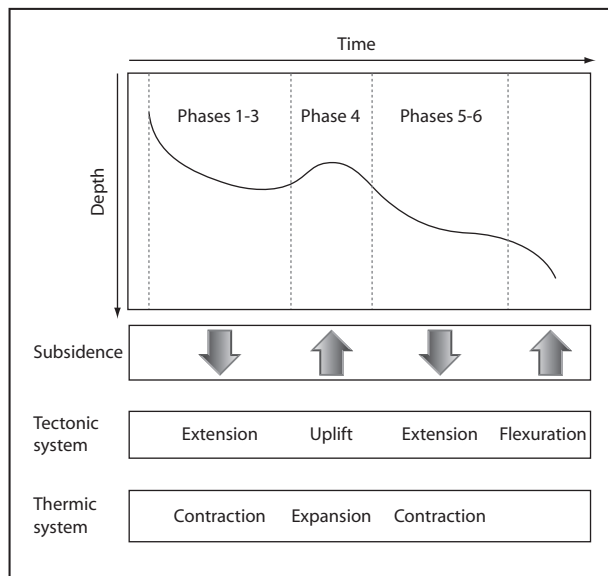


Figure 6.1 Schematic curve of subsidence of a rim basin. It illustrates the main geodynamical phases compared to the tectonic and thermic systems (after Borel, 1997).

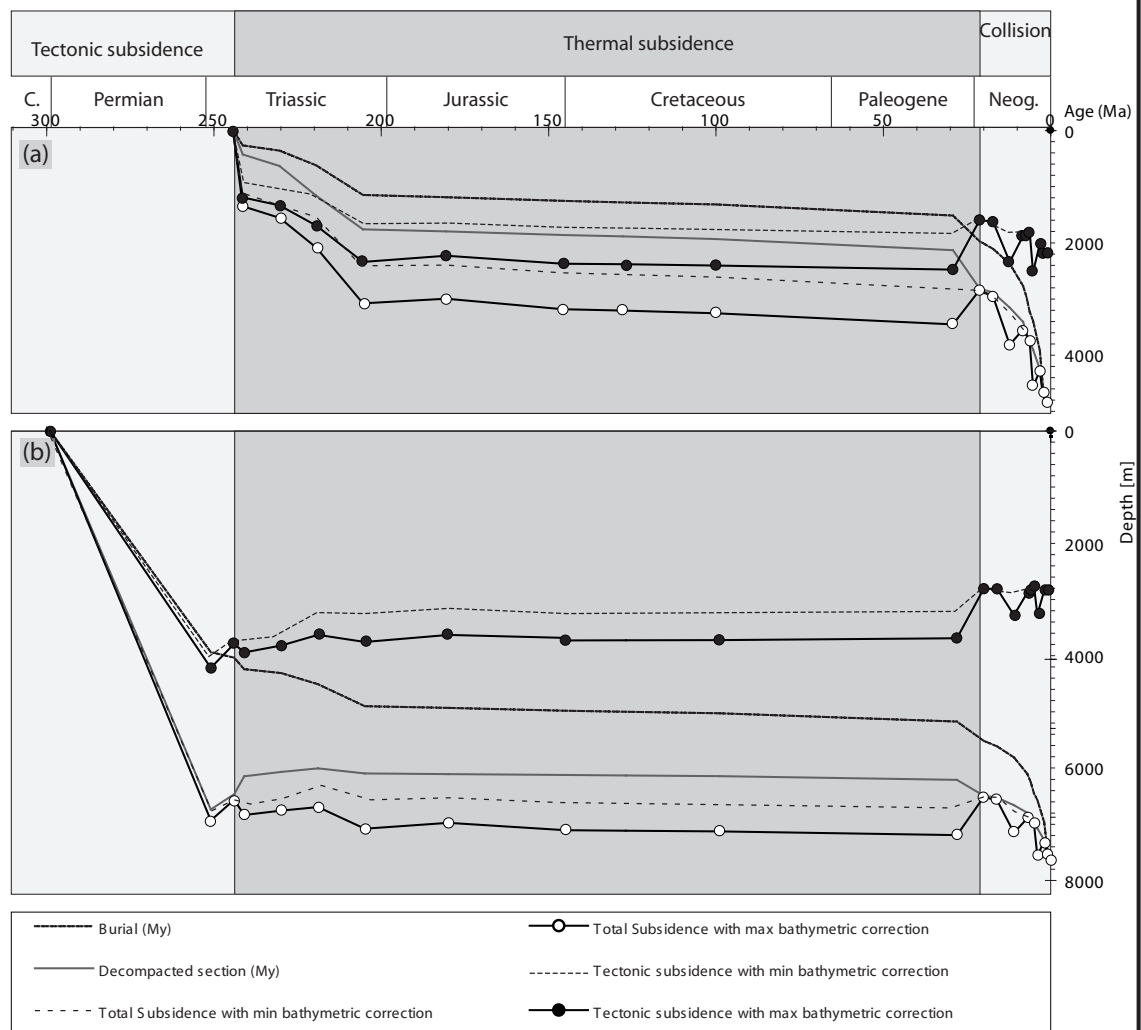
- Factor of compaction. This depends on the lithology and is calculated considering the mechanic compaction of the sedimentary levels during the burial. The Easysub program permits the choice of this factor for six lithologies, of which the values of the initial porosity are 0.41 for limestones, 0.63 for shales, 0.49 for sandstones, 0.31 for dolomite, 0.15 for evaporitic rocks and 0.45 for siltites.
- Age and bathymetry of the lithological units. It is necessary to know the age and depth of water at the top and bottom of each unit for the elaboration of the curve. The International Geological Time Scale of Gradstein *et al.* (2004) was used as the absolute age reference. Geodynamic interpretation of the subsidence curve is based on the model of the simple shear of Wernicke (1985). Six principal events can be detected on the curve: 1) crustal transtension; 2) simple shear of lithosphere; 3) pure shear and uplift of asthenosphere; 4) thermic expansion and shoulder uplift; 5) oceanization; 6) thermic subsidence (Figure 6.1).

For the construction of the subsidence curves of the Sicanian basin (Figure 6.2 a), in which the Lercara Formation was deposited, *i.e.* lithostratigraphic thicknesses, biostratigraphic ages and palaeobathymetry have been provided personally by Professor L. Montanari (University of Catania, Italy) and are shown in the Figure 6.2 c. In addition, in order to try to reconstruct the complete geodynamic evolution of the Sicanian basin, Permian and Early Triassic sediments that may have been deposited before the Lercara Formation were added to the subsidence curve (Figure 6.2 b). These deposits were extrapolated from the sedimentary succession of the Jeffara basin of Tunisia (Busson, 1967; Bishop, 1975; Newell *et al.*, 1976; Ben Ferjani *et al.*, 1990; Kamoun *et al.*, 2001; Bouaziz *et al.*, 2002). On each diagram (Figure 6.2 a and b) two pairs of curves are represented: 1) a curve of total subsidence, with a maximum and a minimum of bathymetry, 2) a curve of tectonic subsidence with a maximum and a minimum of bathymetry obtained by subtracting the sediments and water weight from the total subsidence curve. The latter curve permits the identification of the movements of the basement, allowing a geodynamic interpretation.

6.1.2 RESULTS

The Sicanian basin has continuously recorded the dynamic of its basement from the Middle Triassic to the Neogene. Its geodynamic evolution is represented by the subsidence curve of Figure 6.2 a.

Figure 6.2 Subsidence curves of the Sicanian basin comparing: (a) cropping out sedimentary successions and (b) the probable sediments deposited before the Lercara Formation (see text for explanations). Table (c) shows lithostratigraphic units deposited in the Sicanian and Jeffara basins, and their characteristics (lithology, age, erosion and bathymetry).



Formations	Lithology	Thickness (m)	Age of the Top (Ma)	Age of the Base (Ma)	Today Erosion (m)	Bathymetry Max (m)	Bathymetry Min (m)
Agrigento	limestones	200	0	1	10	0	0
Ribera	limestones	500	1	2	20	0	0
Calcareniiti Belice	sandstones	400	2	4	20	0	0
Trubi	shales	120	4	5	500	400	400
Gessoso solfifera	evaporites	200	5	6	10	0	0
Saheliane	shales	150	6	7	20	10	10
Terravecchia	sandstones	300	7	11	100	0	0
San Cipirrello	shales	200	11	16	500	100	100
Calcareniiti di Corleone	limestones	100	16	20	50	0	0
"Gratteri"	shales	350	20	28	20	0	0
Scaglia	limestones	150	28	99	1000	500	500
Hybla	shales	26	99	127	1000	500	500
"Lattimusa"	limestones	20	127	145	1000	500	500
Rosso Ammonitico	limestones	50	145	180	1000	500	500
Calcarei Nodulari	limestones	30	180	205	900	400	400
Scillato	limestones	400	205	219	1000	500	500
Mufara	shales	200	219	230	700	300	300
Lercara (Member B)	shales	70	230	241	700	500	500
Lercara (Member A)	sandstones	210	241	244	700	500	500
Early Triassic (Tunisia)	sandstones	100	244	251	100	20	20
Permian (Tunisia)	limestones	4000	251	299	200	20	20

The tectonic subsidence curve of the Sicanian basin (Figure 6.2 a) shows two principal phases: thermal subsidence and collision. The first starts from the beginning of the curve at 244 Ma ago (Middle Triassic) in correspondence with the deposition of the Member A of the Lercara Formation, and terminates about 23 Ma ago, in correspondence with the Oligocene/Miocene boundary. The movement does not necessarily commence with the deposition of the Lercara Formation, but it is the first datum for the curve. Thermal subsidence is evidenced by the low sedimentation rate, and was interrupted at 219 and 180 Ma probably by reactivation of faults. During this interval, distal facies were deposited. The second phase ranges from the Oligocene/Miocene boundary to the Quaternary and corresponds to the recording of the collision of the Corso-Sardinian block with the African margin because of the opening of the Balearic basin and the following opening of the Tyrrhenian Sea. These openings caused the deformation of the Sicilian palaeogeographic units, basins and platforms which today constitute the Sicilian-Magrebien belt (see section 1.2.1). Since the Sicanian subsidence curve does not show any important post-Middle Triassic rifting in this region, the opening of the Neo-Tethyan Ocean must have occurred before the Middle Triassic. Results obtained from this curve are in agreement with the subsidence curve obtained by Stampfli *et al.* (2001) for the Gela-1 well, located close to the Malta Escarpment.

In order to identify the possible time in which the Neo-Tethys opened in its westernmost part, an additional subsidence curve was constructed, considering the sediment that could have been deposited in the Sicanian basin before the Lercara Formation and that at the present time are reworked in it (see paragraph 6.1.1). The curve obtained (Figure 6.2 b) shows a phase of tectonic subsidence evidenced by the high sedimentation rate starting at 299 Ma, or before, and finishing at the Early-Middle Triassic boundary. This phase of extension is probably related to the Neo-Tethys opening though without being able to specify the exact time because of the lack of stratigraphic precision. A probable reactivation of the fault is present at the Early-Middle Triassic boundary.

6.2 REGIONAL PALAEOGEOGRAPHY DISCUSSION

In the westernmost part of Tethys, marine Permian and Triassic rocks are found in Sicily (Sicanian basin), in Southern Tunisia (Jeffara basin) and in the Southern Apennines (Lagonegro basin). In Sicily, as seen in the previously chapters, Lower to Upper Permian limestones, Middle Permian deep marine sediments and Lower Triassic siliciclastic sediments are reworked in the Middle to Late Triassic (Cordevolian) Lercara Formation. In the Jeffara basin, Middle and Upper Permian limestones (late Murghabian and early Dzhulfian according to Khessibi, 1985 and late Murghabian to lower Midian according to Waterhouse, 1976) as well as Lower Triassic siliciclastic deposits, are considered as autochthonous (*e.g.* Toomey, 1991; Kamoun *et al.*, 2001). In the Southern Apennines, in the Lagonegro basin, the situation is very similar to Sicily. Indeed, Middle and Upper Permian limestones and Lower Triassic siliciclastic deposits were reworked in the lower part (Anisian) of the Monte Facito Formation (Panzanelli Fratoni *et al.*, 1987; Martini *et al.*, 1989; Ciarapica *et al.*, 1990a).

Lower Permian is unknown in both Tunisia and the Southern Apennines. Although in Sicily and in the Southern Apennines **Upper Permian** to the **Lower Triassic** deposits are reworked, the three regions show the same lithologies (reefal limestones during the Late Permian and siliciclastics during the Early Triassic) and similar palaeontological associations (see chapter 3). These similarities suggest a parallel palaeoenvironmental evolution, but tectonic influence could probably lead to a different evolution of the Jeffara and of the Sicanian and Lagonegro basins, explaining why the Permian and Lower Triassic deposits are autochthonous in Tunisia and reworked in Sicily and in the Southern Apennines.

Autochthonous **Middle Triassic** siliciclastic and carbonate deposits are found in Sicily, Southern Apennines and Tunisia. In Sicily, siliciclastic sediments (Anisian/Ladinian to Cordevolian) constitute the Member A and the Member B of the Lercara Formation. Middle and Upper Triassic (Carnian) elements derived from a carbonate platform have been found during this work in the calcirudite to calcarenite levels intercalated in the Member B of the Lercara Formation (see chapter 3). They prove the existence of a Middle Triassic to Carnian carbonate platform near the Sicanian basin. The presence of a Carnian carbonate platform was already evidenced by the reworked sediments in the Mufara Formation (Carrillat, 2001, *cum biblio*). In Tunisia, proximal platform carbonate deposits

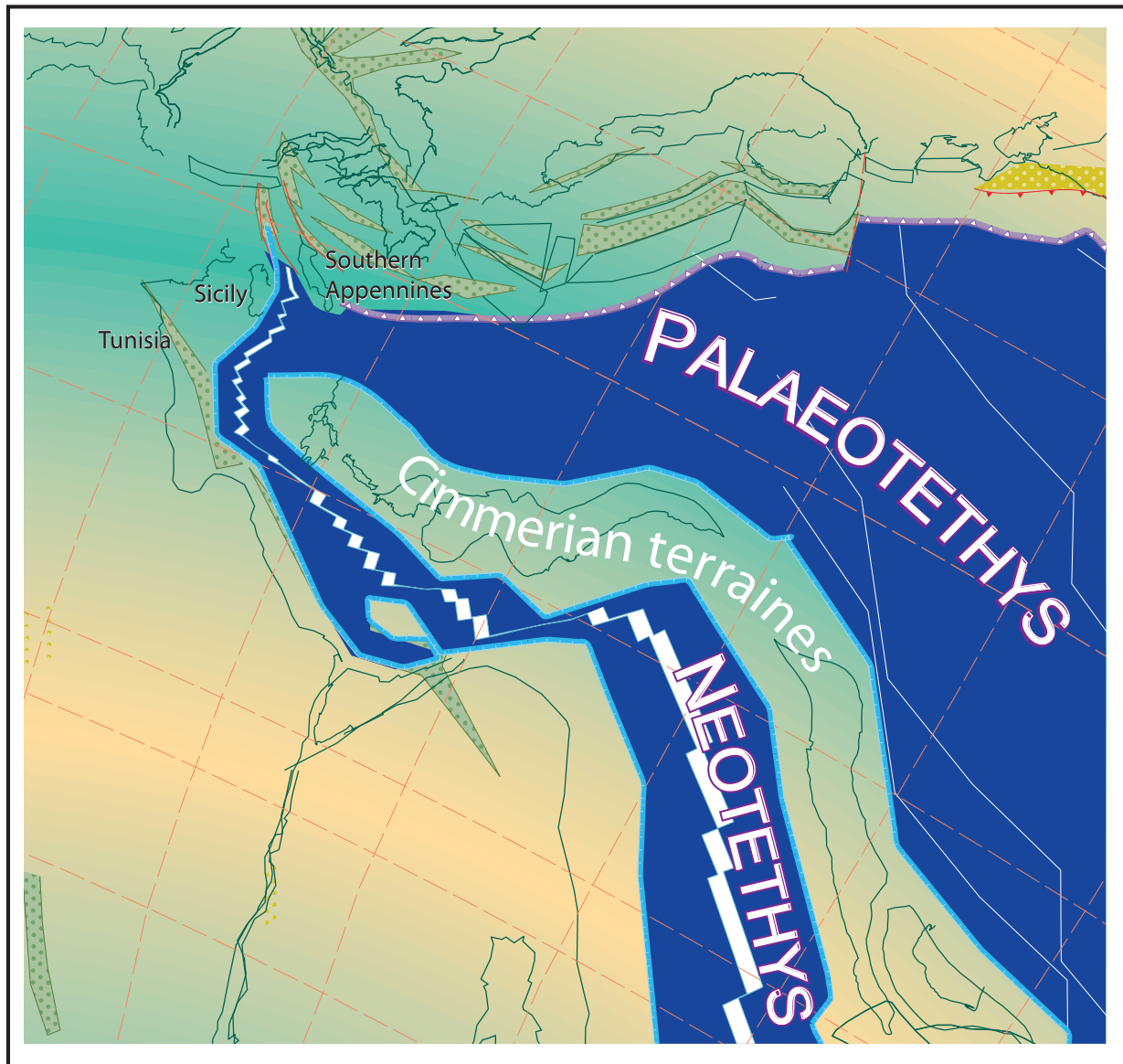
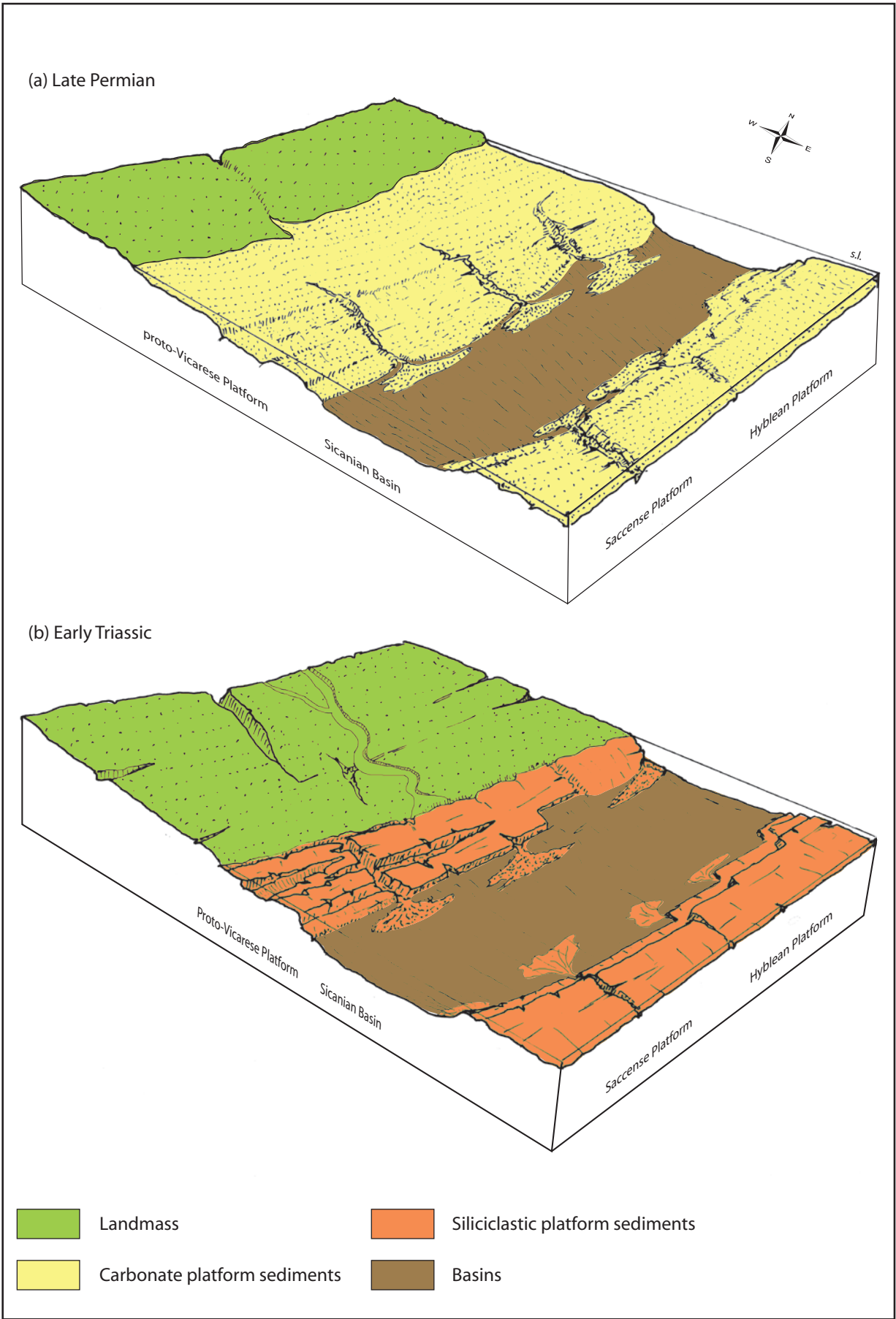


Figure 6.3 Palaeogeographical reconstruction of the westernmost termination of the Tethys during the Wordian (after Stampfli & Borel 2002).

are found in the Anisian and siliciclastic fluvio-deltaic sediments in the Ladinian (Kamoun *et al.*, 2001). Finally, Middle Triassic reefal limestones and sandstones have been described in the Monte Facito Formation (Montanari & Panzanelli Fratoni, 1990; Ciarapica & Passeri, 2000). During the Late Ladinian the Lagonegro basin deepened, with deposition of red limestones (Ammonitico Rosso type facies), marls and radiolarites (Montanari & Panzanelli Fratoni, 1990; Ciarapica & Passeri, 2000) of the Monte Facito Formation. From the **Carnian**, the three regions evolved differently. While the Jeffara basin shallowed, as proved by the Carnian carbonate platform deposits, Norian clays, evaporites and Rhaetian inter- to supratidal calcareous facies (Kamoun *et al.*, 2001), Sicanian and Lagonegro basins deepened as shown by the deposition of the “calcarei con selce” of the Scillato and the Monte Sirino Formations (Montanari & Panzanelli Fratoni, 1990). In conclusion, from a sedimentological and palaeontological point of view, these three regions evolved similarly between at least the Late Permian and the Middle Triassic and differently from the Late Triassic. The evidence suggests that the three basins that constitute the westernmost termination of the Tethyan Ocean were connected and constituted two branches of the Tethys: the Tunisian and the Sicanian-Lagonegro.



As mentioned before, subsidence curves obtained for the Sicanian basin show that it was in thermic subsidence from at least the Middle Triassic and no rifting phase affected this region after the Middle Triassic, time of the deposition of the Lercara Formation. Also, the opening of the westernmost part of the Neo-Tethys had occurred during the Permian as evidenced also by the evolution of the Jeffara basin. The latter is considered as a branch of the westernmost termination of the Neo-Tethyan basin. Indeed, Permian and Triassic sedimentary evolution and subsidence curves reconstructed for the Jeffara basin by Stampfli *et al.* (2001) show that it is an intracontinental aborted rift. The phase of rifting occurred before the Early-Late Permian boundary, before the onset of the thermal subsidence.

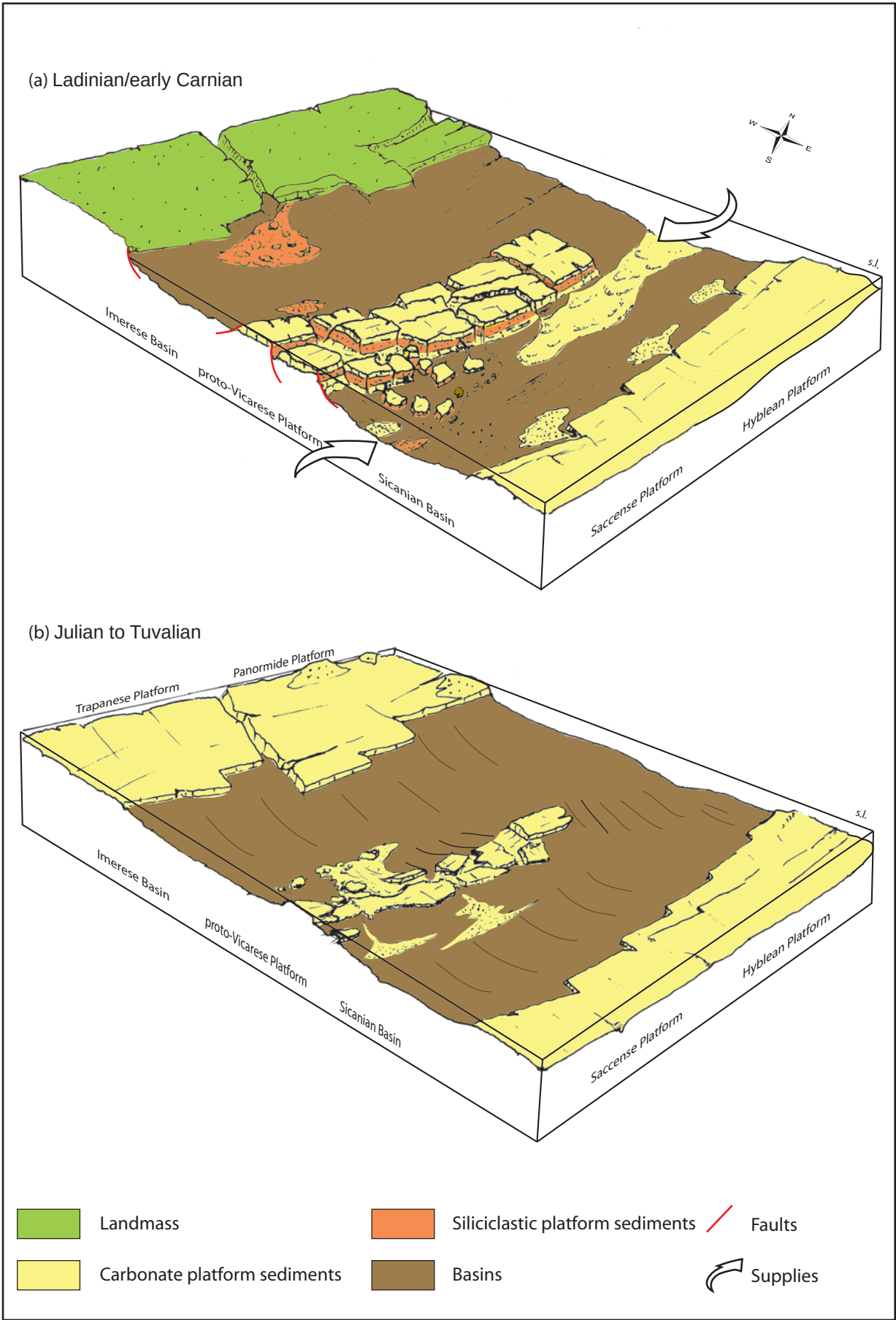
Palaeopsychrospheric Rodian-Wordian ostracods reworked in the Lercara Formation suggest that a deep-water connection existed between the Sicanian basin and Timor in which the rifting of the Neo-Tethyan Ocean was localised in the Early Permian (Crasquin-Soleau *et al.*, 2001; Stampfli & Borel, 2002) (see chapter 3). This implies a deep-water connection between the Sicanian basin and the Neo-Tethys Ocean at least from the Middle Permian and not from the Late Permian as advanced by Stampfli *et al.* (2001) based on the pelagic macro-fauna. Associated with palaeopsychrospheric Rodian-Wordian ostracods, benthic forms were also found in the same samples. Some of these ostracods, as seen in chapter 3, have been found in South China, which is a typical Palaeo-Tethys terrain (*e.g.* Crasquin-Soleau *et al.*, 2001; Stampfli & Borel, 2002). Distribution of the benthic ostracod fauna over long distances, without any morphological changes, is possible only if the palaeoenvironmental conditions remained constant all along the migration path. This implies that a Pangaea B configuration existed, in which the eastern part of the Pangaea was almost closed (as proposed in Crasquin-Soleau *et al.*, 2001) (Figure 1.3) and that a connection still existed between the Sicanian basin and the Palaeo-Tethys during the Middle Permian.

Thus, it is suggested that the Neo-Tethys was opened and was sufficiently profound to permit the circulation of deep cold water at least from the Middle Permian and that at the same time the Palaeo-Tethys was not yet completely closed, as suggested also by the mixing of the microfauna (see chapter 3) (Figure 6.3).

6.3 LOCAL PALAEOGEOGRAPHY DISCUSSION

Before the Oligo/Miocene deformation, Sicily was constituted, from the northwest to southeast, by platforms (Panormide, Trapanese, Vicarese and Saccense) separated from basins (Imerese, Sicanian and Hyblean). The older domains are the Imerese basin in which the first evidence of sedimentation are of the Late Ladinian (Carrillat, 2001); the Sicanian basin, in which the sedimentation was recorded from the Middle Triassic (Late Anisian); and the Hyblean platform in which sedimentation could have started during the Palaeozoic-Middle Triassic (Bianchi *et al.*, 1989). In other domains, platform and basin deposits are found from the Late Triassic. In the Sicanian basin, the oldest depositional unit is the Lercara Formation in which the presence of reworked Permian to Early Triassic sediments suggests that this basin is older than Middle Triassic and that it was rimmed by platforms. Indeed, sedimentation of carbonate type starts at the latest during the Early Permian (Artinskian) as proved by the larger foraminifera. This carbonate sedimentation persists along the entire Permian and is associated with deep-water sedimentation, at least from the Middle Permian. Then, at the end of the Permian, a deep-water basin, the Sicanian basin, existed and it was rimmed by carbonate platforms (Figure 6.4.a). In our reconstructions a proto-Vicarese platform, the future Vicarese platform (Montanari, 2000) was added as a possible source area of the carbonate reworked material. This platform, unknown in the field before the Carnian, can be associated with the Vicarese platform for which evidence of its existence from the Triassic/Liassic (see section 1.3.3) has been found by Montanari (2000). The existence of this platform is justified by the different sedimentary supply in the Imerese and Sicanian basins from the Late Ladinian to Early Carnian. Indeed, while in the Imerese basin the Mufara Formation was deposited without Permian to Middle

Figure 6.4 Palaeogeographic reconstruction for the Late Permian and Early Triassic time. Drawing realised by Professor L. Montanari.



Triassic resediments; in the Sicanian basin, the Lercara Formation deposited with reworking of Permian to Early Triassic sediments. At the end of the Permian, when the major regression of the Permian-Triassic boundary began, carbonate platforms were eroded, depositing sediments in the Sicanian basin.

During the Early Triassic, regression ended the carbonate sedimentation on the proto-Vicarese platform, and a siliciclastic deposition took place. This is suggested by the micropaleontological content of the reworked Lower Triassic sediments, found in the Lercara Formation. This platform corresponds to the siliciclastic platform of Tunisia and Southern Apennines (see chapter 3). During the formation of the deltaic sediments on the platform, sand flows or turbiditic deposits were deposited in the Sicanian basin (Figure 6.4b).

The Middle Triassic is characterised by siliciclastic and carbonate sedimentation. More precisely during the late Anisian-early Ladinian, the Member A of the Lercara Formation deposited in the Sicanian basin. The clayey sandstones came from the erosion of older siliciclastic sediments previously deposited on the proto-Vicarese platform. As seen in chapters 2 and 3, Middle Triassic carbonate elements found in the calcirudite to calcarenite levels of the Lercara Formation suggest that a Middle Triassic carbonate platform developed in Sicily, as they did in Tunisia and the south Apennines. Foraminifera found did not permit a more precise assignation. Sedimentological evidence (see chapter 2) suggests that during the late Ladinian siliciclastic sediments were deposited on the internal part of the proto-Vicarese platform, while in the external part carbonate sedimentation took place. During the late Ladinian-early Carnian, an extensive phase with reactivation of older faults probably affected this region, causing the opening of the Imerese basin, as suggested by some sections of the Mufara Formation (Carrillat, 2001) being deposited in the Imerese basin, deepening of the Sicanian basin and finally the dismantling of the proto-Vicarese platform. This latter released carbonate and siliciclastic sediments deposited from the Permian to the Middle Triassic in the Sicanian (deposition of the Member B of the Lercara Formation) (Figure 6.5.a). Carbonate sedimentation continued in the proto-Vicarese platform furnishing early Carnian sediment in the Lercara Formation. The supply of carbonate sediments could also be derived from the Southwest or the Northeast (see chapter 2). During the Julian to Tuvanian, the rising sea level caused the flooding of the landmass with installation of carbonate platforms (Trapanese and Panormide) and the almost total drowning of the proto-Vicarese platform. This rising sea level associated with a cessation of the tectonic activity, blocked the supply of Permian and Middle Triassic sediments in the Sicanian basin. In the Sicanian and Imerese basins, sedimentation equalised in the Imerese basin, continued the deposition of the Mufara Formation, while in the Sicanian basin it commenced. Carbonate platform syndimentary supply was more extensive on the Mufara Formation (Figure 6.5b).

Figure 6.5 Palaeogeographic reconstruction for the late Ladinian/early Carnian and Julian to Tuvanian time. Drawing realised by Professor L. Montanari.

7 CONCLUSIONS AND PERSPECTIVES

This study, focused on the Lercara deposits (western Sicily), has contributed to a better knowledge of the events which occurred in Sicily during the Permian-early Late Triassic from both a local and a regional point of view. Indeed, it has allowed the dating and the reconstruction of a depositional model for the Lercara Formation as well as its mineralogical and thermal characterization. Proceeding from these data, this work has contributed to a better knowledge of the general palaeoenvironmental setting of Permian to early Late Triassic deposits and their palaeogeographical implications. The two principal goals set at the beginning of this study - the determination of the age and the palaeogeographical reconstruction for the westernmost termination of the Tethys - have been accomplished through the integration of sedimentological, biostratigraphic and mineralogical investigations associated with the subsidence history of the Sicanian basin.

Field work permitted the sampling of all known Lercara deposits, even if the reconstruction of series was not always possible. In this case isolated samples have been taken principally for biostratigraphic aims. A new outcrop of the Lercara deposits has been localised in the Portella Rossa zone near the Burgio village. The Lercara deposits crop out only in the Sicanian basin and are overlaid by the Mufara Formation. The latter was deposited in the Imerese and in the Sicanian basins, but its deposition started during the late Ladinian in the Imerese basin, whereas in the Sicanian basin it started during the Julian.

Sedimentological and mineralogical study showed that the Lercara sediments are characterised by a strong siliciclastic input and that they are composed of clayey sandstones (Member A) and of quartz-rich shales (Member B). The latter contain intercalations of reworked carbonate or clayey sandstones. Most of the reworked clasts (about 95%) have an extrabasinal origin and are constituted of Permian to Anisian carbonate fragments and quartz. The rest (about 5%) is composed of Ladinian to Cordevolian carbonate fragments and rip-up clasts of intrabasinal origin.

Intrabasinal and extrabasinal clasts have been used as environmental indicators and permitted the reconstruction of the palaeodepositional setting for the Permian and the Triassic. Permian was characterised by small organic build-ups dominated by *Tubiphytes/Archaeolithoporella* crust reefs associated with bryozoans and calcisponge/algal reefs, encrusting foraminifera, echinoderms and brachiopods. Along with these shallow marine deposits, there was associated deep water deposition, as attested by reworked radiolarians, palaeopsychrospheric ostracods and conodonts, at least during the Rodian-Wordian. During the Early Triassic a siliciclastic platform bordered the Sicanian basin, whereas during the Anisian to the Cordevolian a carbonate platform developed widely. Both platforms were reworked in the Lercara Formation, which deposited in the Sicanian basin. Data in our possession do not permit to say whether this carbonate sedimentation was continuous or not.

Identification of eight microfacies and their spatial distribution in the studied sections allowed to establish that sections located in the Lercara-Roccapalumba area were deposited in a proximal area, whereas the sections located in the Pietra di Salomone and Burgio areas were deposited distally. In addition, two directions of the terrigenous supply have been identified. The principal source area was probably

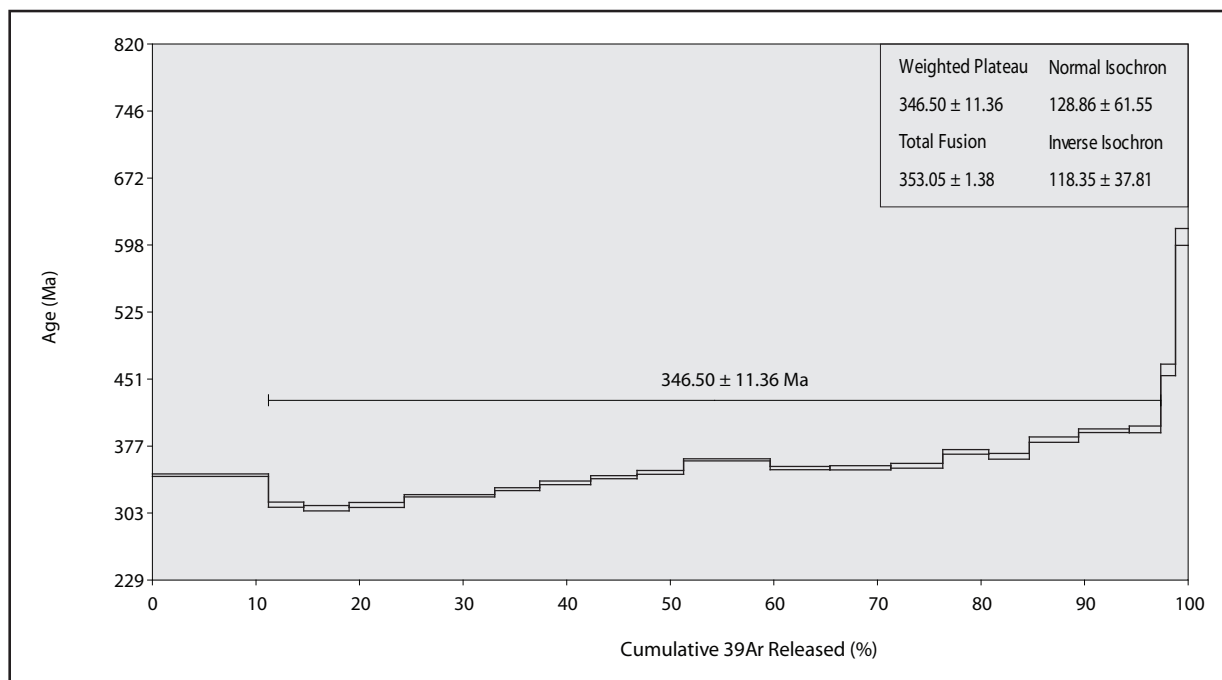


Figure 7.1 Age plateau diagram of “Case Pettineo” magmatic outcrop.

located in the Northwest of the Lercara basin, whereas the second source area could be positioned to the Southwest or to the Northeast relative to the Lercara basin.

The two members composing the Lercara Formation result from two distinct sedimentary processes. Member A results from sand flows which probably occurred during the late Anisian/early Ladinian and was fed by older deltaic deposits. Member B results from turbidity currents fed at the same time by older deltaic deposits and Permian to Anisian carbonate material.

Biostratigraphic investigations revealed that 95% of the Lercara deposits are constituted of reworked Devonian, and Permian to Anisian flora and fauna, which explain why for a long-time (about hundred years), their age was controversial. The best results concerning age were provided by foraminifera and palynomorphs and these have permitted the assignation of the Lercara Formation to the Triassic. In particular, Member A was deposited during an unknown time range within the Anisian-Ladinian interval, and Member B during the late Ladinian to Cordevolian.

Clay minerals studies emphasised the detritic origin of the sediments influenced later by burial diagenesis. Substantial compositional difference exists between the sections of *Pietra di Salomone 2*, *Portella Rossa 1* and 2 and the others. These sections contain abundant smectite respective to others sections that contain, on the contrary, micas and chlorite. This different composition can be due to both the sedimentary segregation and to the tectonic influence, as indicated by mineralogical indices of thermal maturity. Indeed, *Pietra di Salomone 2*, *Portella Rossa 1* and 2 sections are, from a sedimentological point of view, the most distal and, from a tectonic point of view, the most external. The tectonic influence is supported by thermal modelling.

Sedimentological and biostratigraphic data, in addition to the reconstruction of the subsidence history of the Sicilian basin show that during the Middle Permian the Palaeo- and the Neo-Tethys coexisted in the westernmost termination of the Tethys in a Pangea B configuration. At that time, the Neo-Tethys was already profound enough to permit the circulation of deep cold water. The Sicilian and Lagonegro basins constituted a branch of the westernmost termination of the Neo-Tethys while the Jeffara basin constituted another arm. The Sicilian basin was separated from the Ladinian, by the Imerese basin by the proto-Vicarese carbonate platform. The latter was a possible source area of the carbonate reworked material. The presence of a carbonate platform interposed between the Imerese and the Sicilian basin is justified by the different sedimentary supply in the Imerese and Sicilian basins from the Late Ladinian

to Early Carnian. Indeed, while in the Sicanian basin the Lercara Formation deposited with reworking of Permian to Early Triassic sediments, in the Imerese basin the coeval part of the Mufara Formation contains reworked synsedimentary carbonate.

Two interesting aspects could be developed in future studies about the Lercara deposits in order to complete this work: the palaeogeographical distribution of the palynoflora and the age of the magmatic intrusions.

- A more in-depth study of the palaeogeographical distribution in the palaeofloristic domains of the reworked palynomorphs would permit the identification of the source area and contribute to the palaeogeographical reconstructions. In this study, this aspect was only sketchily treated but showed that some palynomorphs are associated to particular floral provinces (*e.g.*, *Crucisaccites variosulcatus* in the Gondwana and *Densipollenites* sp. only in Euramerica) revealing that Sicily was a zone of connection between the two domains. This study could be integrated with quantitative analyses relative to temporal distribution of the palynomorphs in order to evaluate the contribution of the different source areas.
- As previously seen in the sections 1.3.1 and 2.2, magmatic rocks outcrops are scattered in the Lercara deposits. The stratigraphic contact is not clear and they were often described in relevant literature as “intercalations”. During this thesis, magmatic occurrence consisting in decametric block of altered granodiorite was sampled near Case Pettineo (Figure 1.1.c). The samples were used for $^{40}\text{Ar}/^{39}\text{Ar}$ analysis on the alkali feldspars. They provided an age plateau of $346,50 \pm 11.36$ Ma corresponding to the Devonian (Figure 7.1). This age is incompatible with the Triassic age of the Lercara Formation. Could this huge block come from the accretionary wedge of the Palaeo-Tethys suture zone situated in the east of the Sicanian basin? In order to answer this question and explain the origin of this granodiorite and other magmatic occurrences (*e.g.* that of Contrada Margana near Pettineo), a more in-depth study could be conducted.

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PLATES

Plate 1: Outcrop pictures

1. **Cozzo Tabarani:** Mufara Formation
2. **Contrada Malluta:** Upper part; Mufara Formation
3. **Viadotto di Faguara II:** Mufara Formation
4. **Vallone Faguara I:** Mufara Formation
5. **Roccapalumba Mercato:** Lercara Formation
6. **Cozzo San Filippo 1:** Lercara Formation
7. **Cozzo San Filippo 2:** Lercara Formation
8. **Roccapalumba ferrovia a:** Lercara Formation

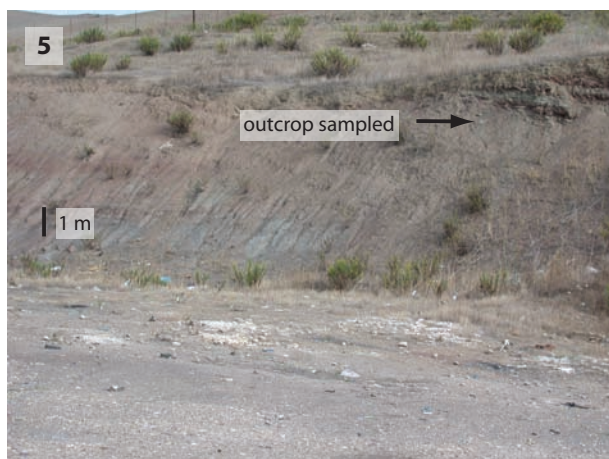


Plate 2: Outcrop pictures

1. **Roccapalumba ferrovia b:** Detail; Lercara Formation
2. **Cozzo Intronata lower part:** Mufara Formation
3. **Cozzo Intronata upper part:** Mufara Formation
4. **Pietra di Salomone 1 and 2:** Lercara Formation
5. **Pietra di Salomone 1 and samples PS16 and PS 18 :** Lercara Formation
6. **Pietra di Salomone 3, 4 and 5:** Lercara Formation
7. **Pietra di Salomone 3:** Lercara Formation
8. **Portella Rossa 1:** Lercara Formation

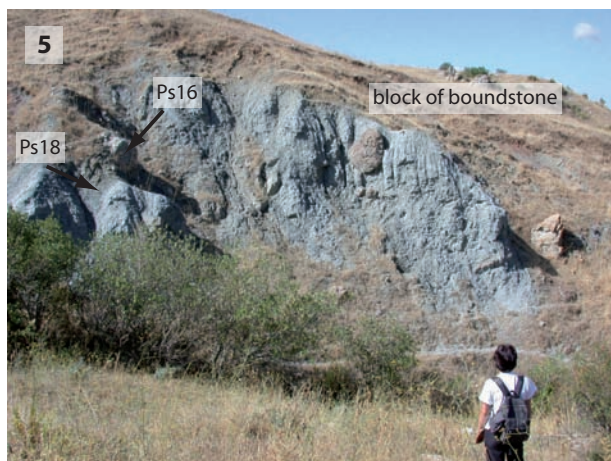


Plate 3: Outcrop pictures

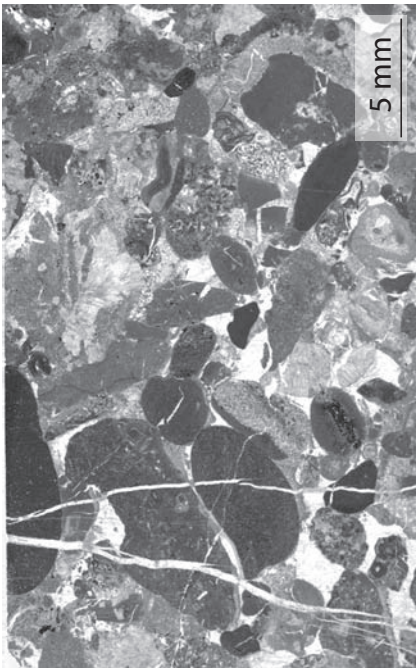
1. **Portella Rossa 2:** Lercara Formation
2. **Pietra dei Saraceni megablock:** Lercara Formation
3. **Bivio dei Saraceni:** Lercara Formation
4. **Pietra di Salomone:** Lercara Formation
5. **Magmatic occurrence of Case Pettineo:** Lercara Formation



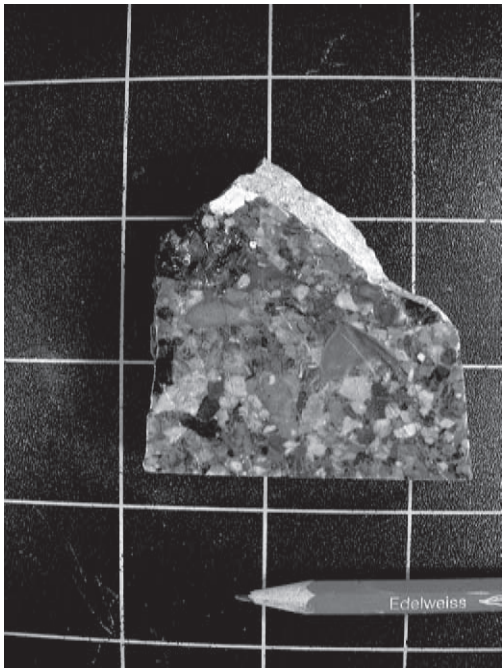
Plate 4 Microfacies.

Microfacies A: textural mature and compositional immature calcirudites

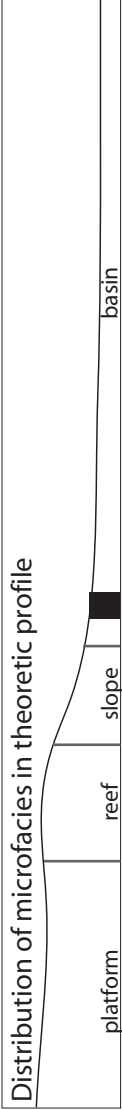
Thin-section



Macroscopic sample



Distribution of microfacies in theoretic profile



Petrographic composition

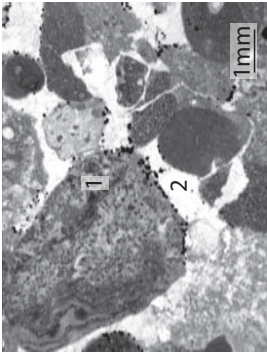
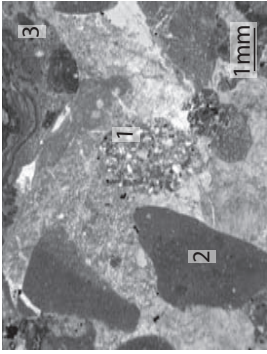
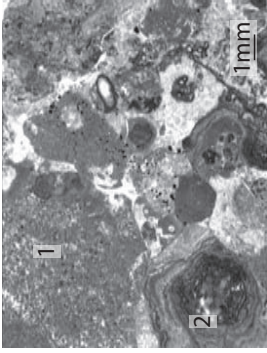
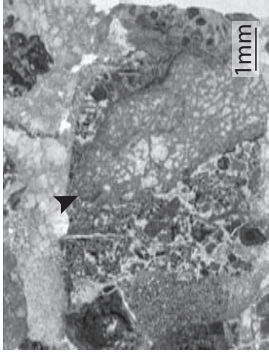
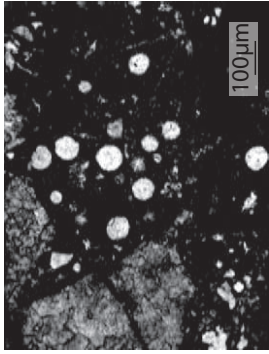
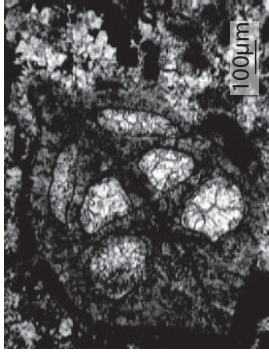
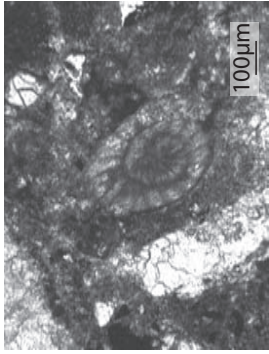
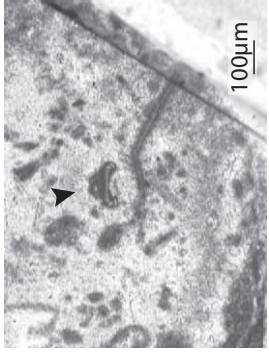
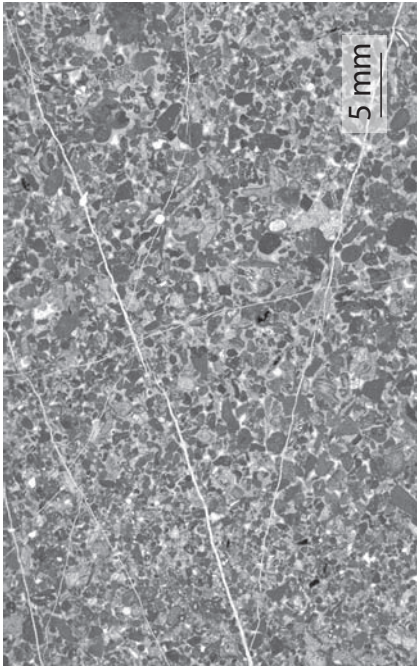
 1. Clast of grainstone 2. Drusy mosaic cement	 1. Clast of clayey sandstone 2. Rip-up clast 3. Clast of boundstone	 1. Clast packstone 2. Clast of boundstone
 <i>Tubiphytes carinthiacus</i> in a grainstone	 Clast of wackestone with radiolarian and sponge spicules	 <i>Tubiphytes obscurus</i>
 Brizoan	 <i>Schubertella paramelonica</i>	 <i>Lasiodiscus minor</i> in a clast of grainstone

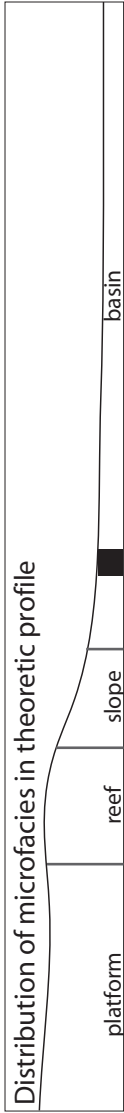
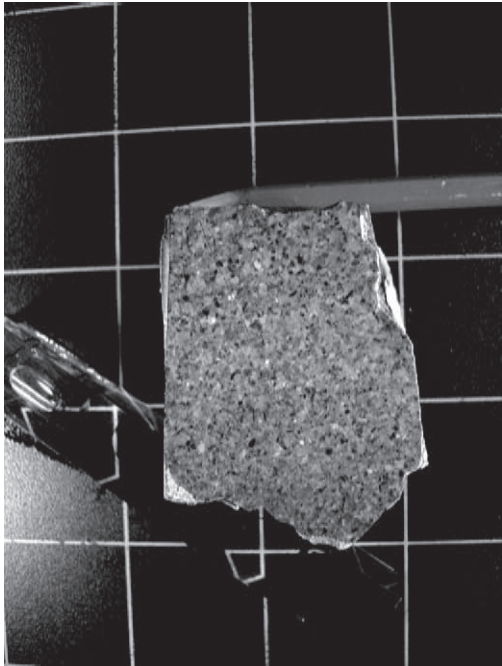
Plate 5 Microfacies.

Microfacies B: textural mature and compositional immature coarse calcarenite

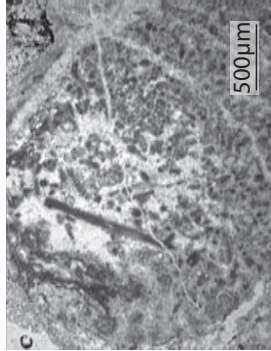
Thin-section



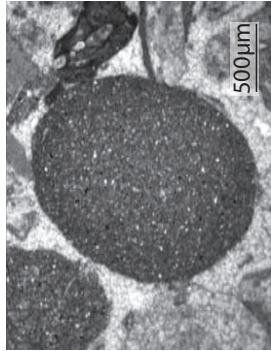
Macroscopic sample



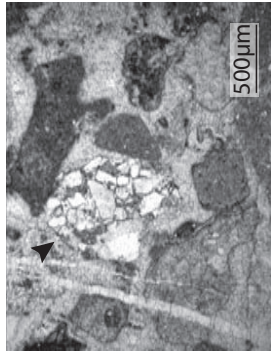
Petrographic composition



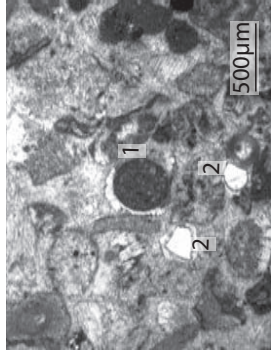
Clast of grainstone



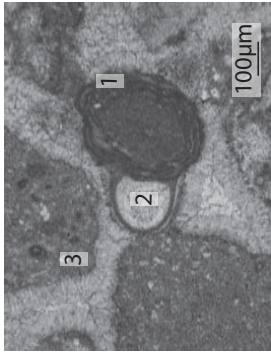
Rip-up clast



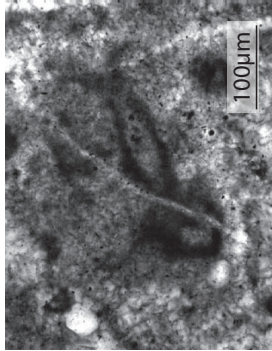
Clast of clayey sandstone



1. Brizoan
2. Fibrous cement
3. Drusy mosaic cement



1. *Tubiphytes obscurus*
2. Grains of quartz
3. *Tubiphytes cf. collosa*



Cucurbita cf. infundibuliformis



Endotriadella wirzi

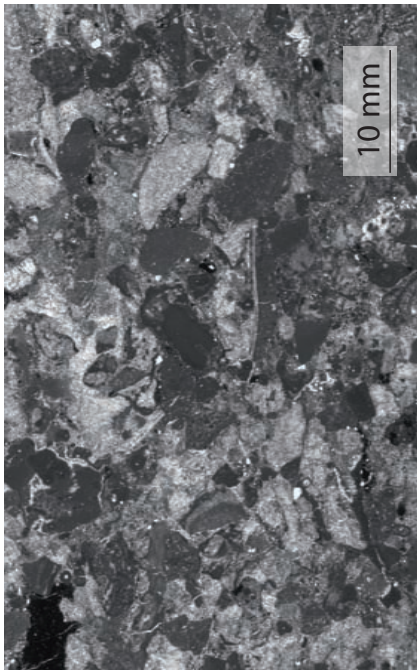


Levenella cf. evoluta

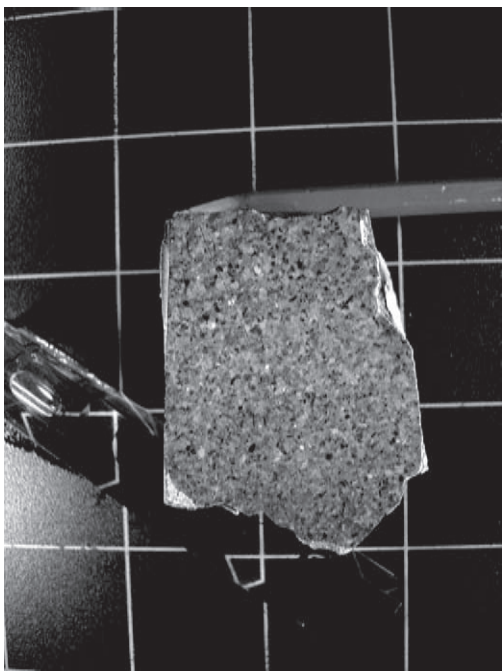
Plate 6 Microfacies.

Microfacies C: textural submature and compositional immature coarse calcarenite

Thin-section



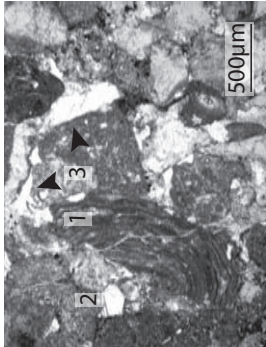
Macroscopic sample



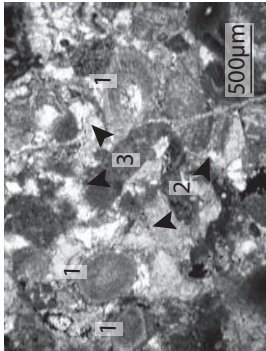
Distribution of microfacies in theoretic profile



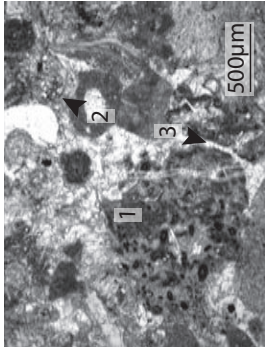
Petrographic composition



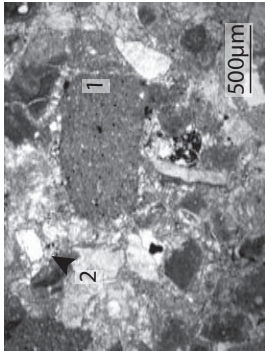
- 1. Clast of boundstone
- 2. Quartz
- 3. Quartz cement



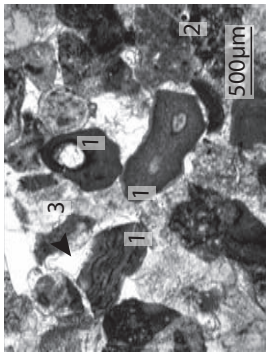
- 1. Echinoid spines
- 2. Quartz-argillaceous matrix
- 3. Quartz cement



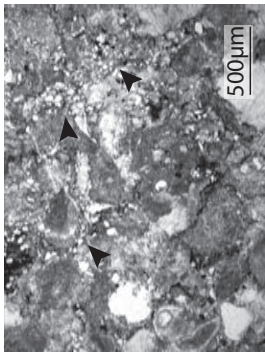
- 1. Clast of packstone
- 2. Quartz-argillaceous matrix
- 3. Quartz cement



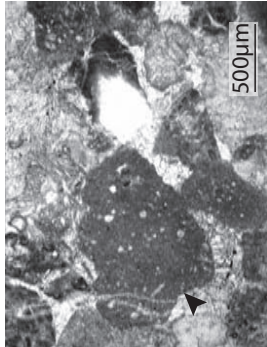
- 1. Rip-up clast
- 2. Clast of quartz



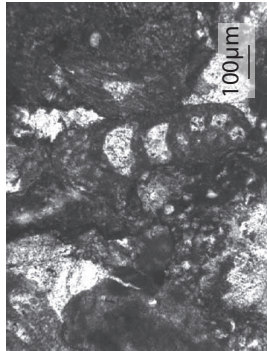
- 1. Clast of boundstone
- 2. Clast of packstone
- 3. Quartz cement



Quartz-argillaceous matrix



Clast of wackstone with radiolarians



Endotebanella kocaeliensis

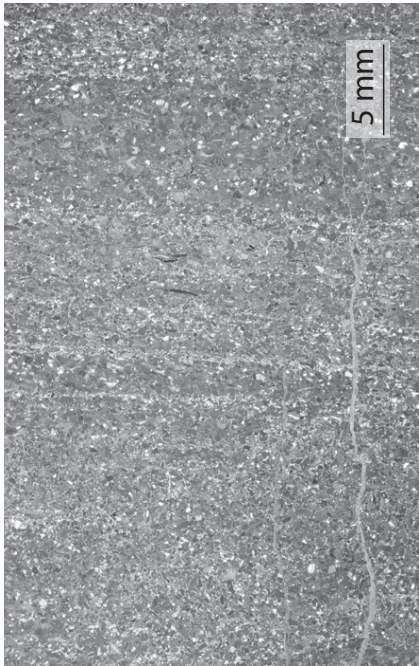


Hemigordius sp.

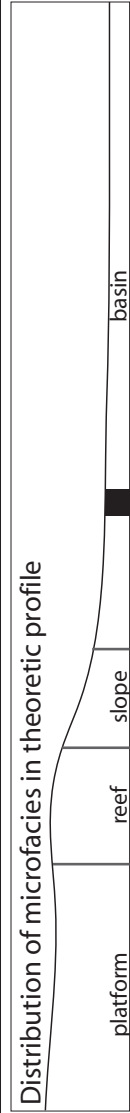
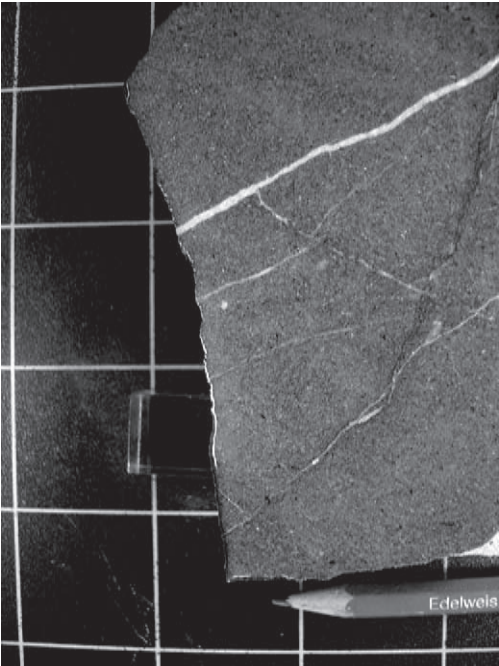
Plate 7 Microfacies.

Microfacies D: textural submature and compositional immature medium calcarenite

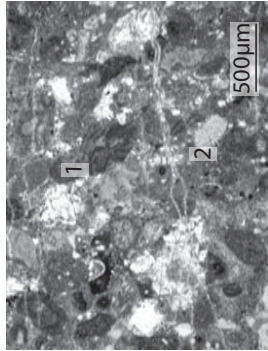
Thin-section



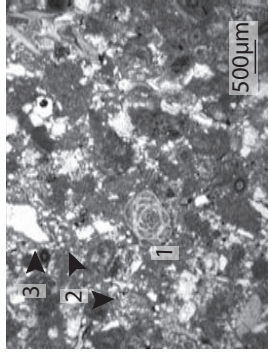
Macroscopic sample



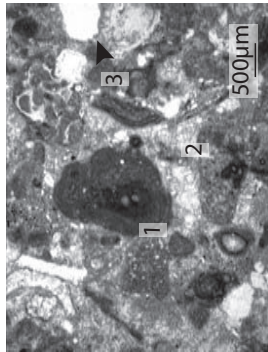
Petrographic composition



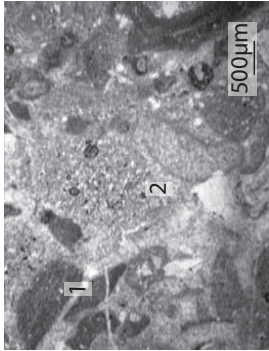
- 1. Clast of boundstone
- 2. Echinoid spine



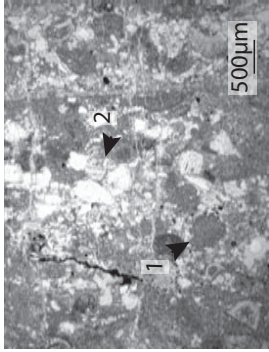
- 1. *Hemigordius* sp.
- 2. Quartz/argillaceous matrix
- 3. Quartz cement



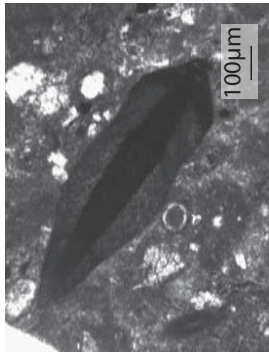
- 1. Clast of boundstone
- 2. Clast of packstone
- 3. Quartz cement



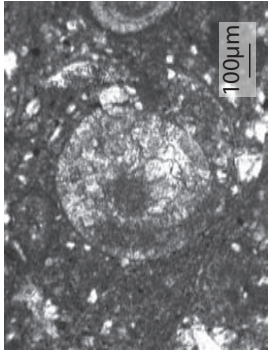
- 1. Clast of boundstone
- 2. Quartz-argillaceous matrix



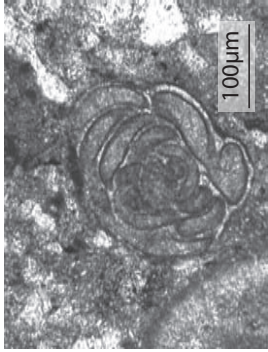
- 1. Rip-up clast
- 2. Clast of quartz



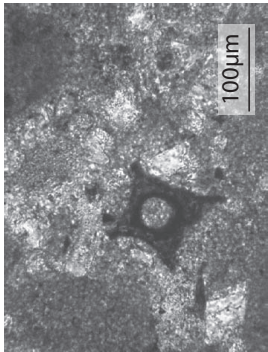
Conodont



Ammonite



Hemigordius sp.

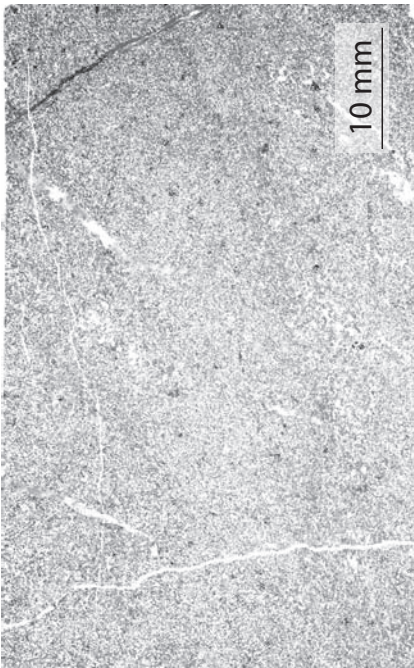


Chitralina undulata

Plate 8 Microfacies.

Microfacies E: textural mature and compositional immature fine calcarenite

Thin-section



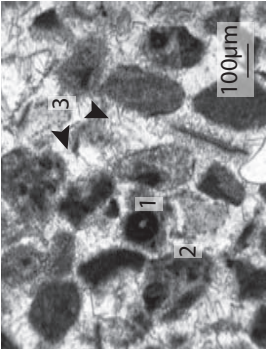
Macroscopic sample



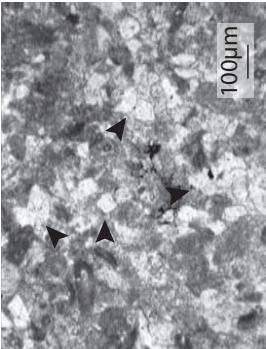
Distribution of microfacies in theoretic profile



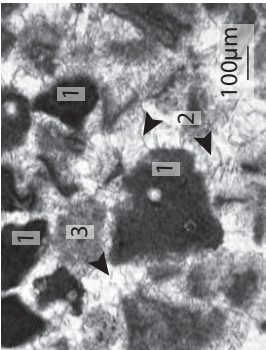
Petrographic composition



1. *Tubiphytes obscurus*
2. Clast of grainstone
3. Drusy mosaic cement

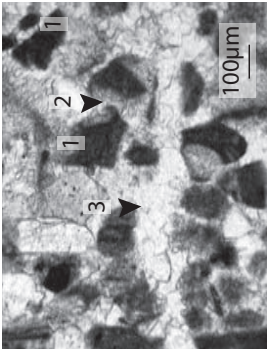


Clasts of quartz



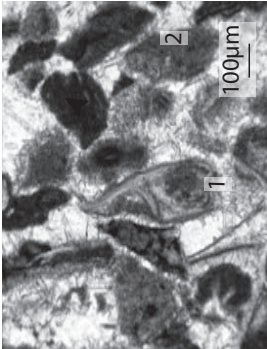
1. Clast of boundstone
2. Fibrous cement
3. Drusy mosaic cement

Endotriadella wirzi



1. Clast of boundstone
2. Fibrous cement
3. Drusy mosaic cement

Globivalvulina sp.



1. Bryozoan
2. Rip-up clast

Lasiodiscus sp.



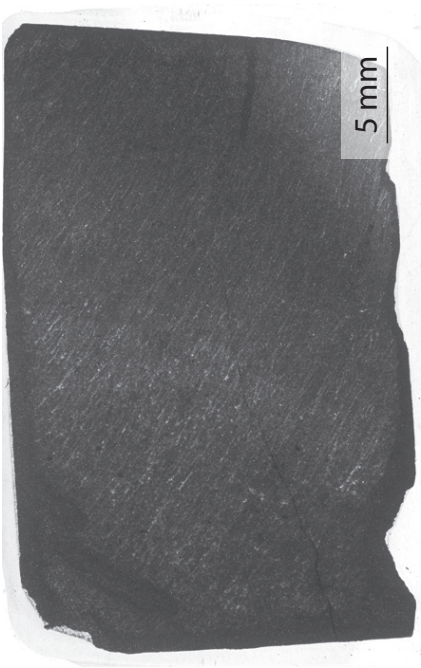
1. Clast of boundstone
2. Fibrous cement
3. Drusy mosaic cement

Dagmarita sp.

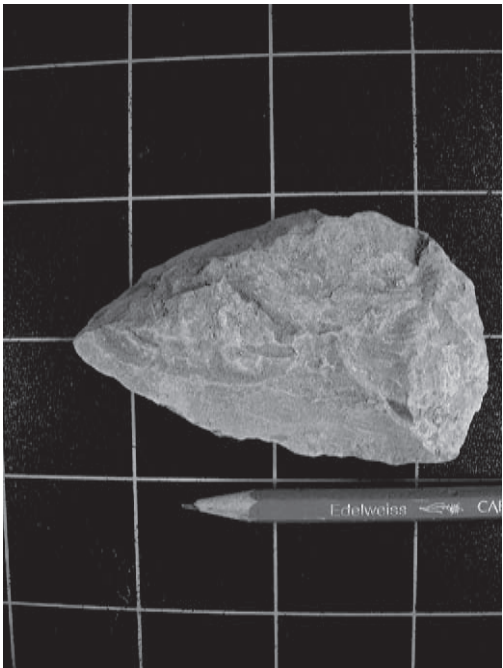
Plate 10 Microfacies.

Microfacies G: textural immature and compositional immature quartz-rich shale

Thin-section



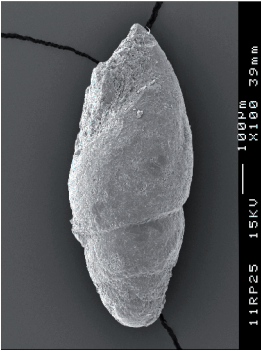
Macroscopic sample



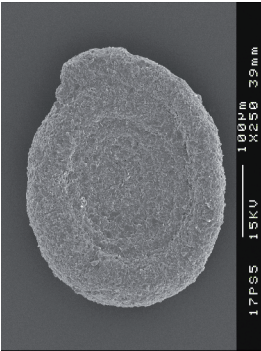
Distribution of microfacies in theoretic profile



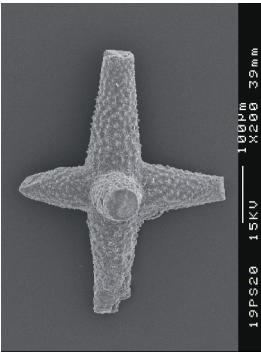
Micropaleontological content



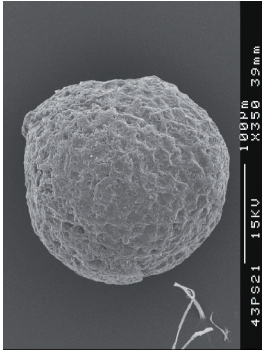
Gastropod



Amodiscus sp.



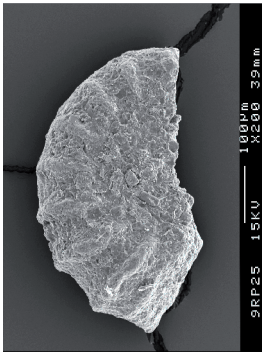
Spicule of sponge



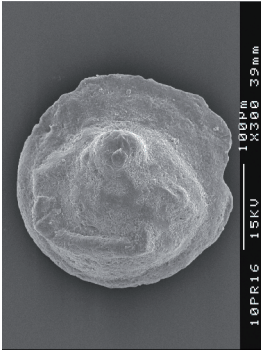
Radiolarian



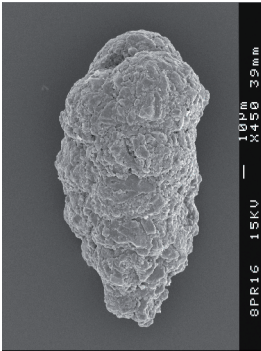
Ostracod



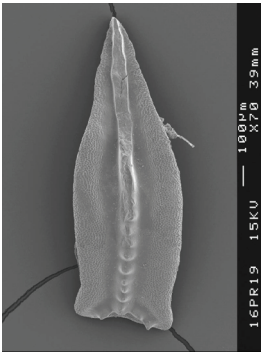
Ammonite



Inter or ambulacrum plate of
Echinodem with tubercle



Agglutinate foraminifer



Conodont

Plate 11 Microfacies.

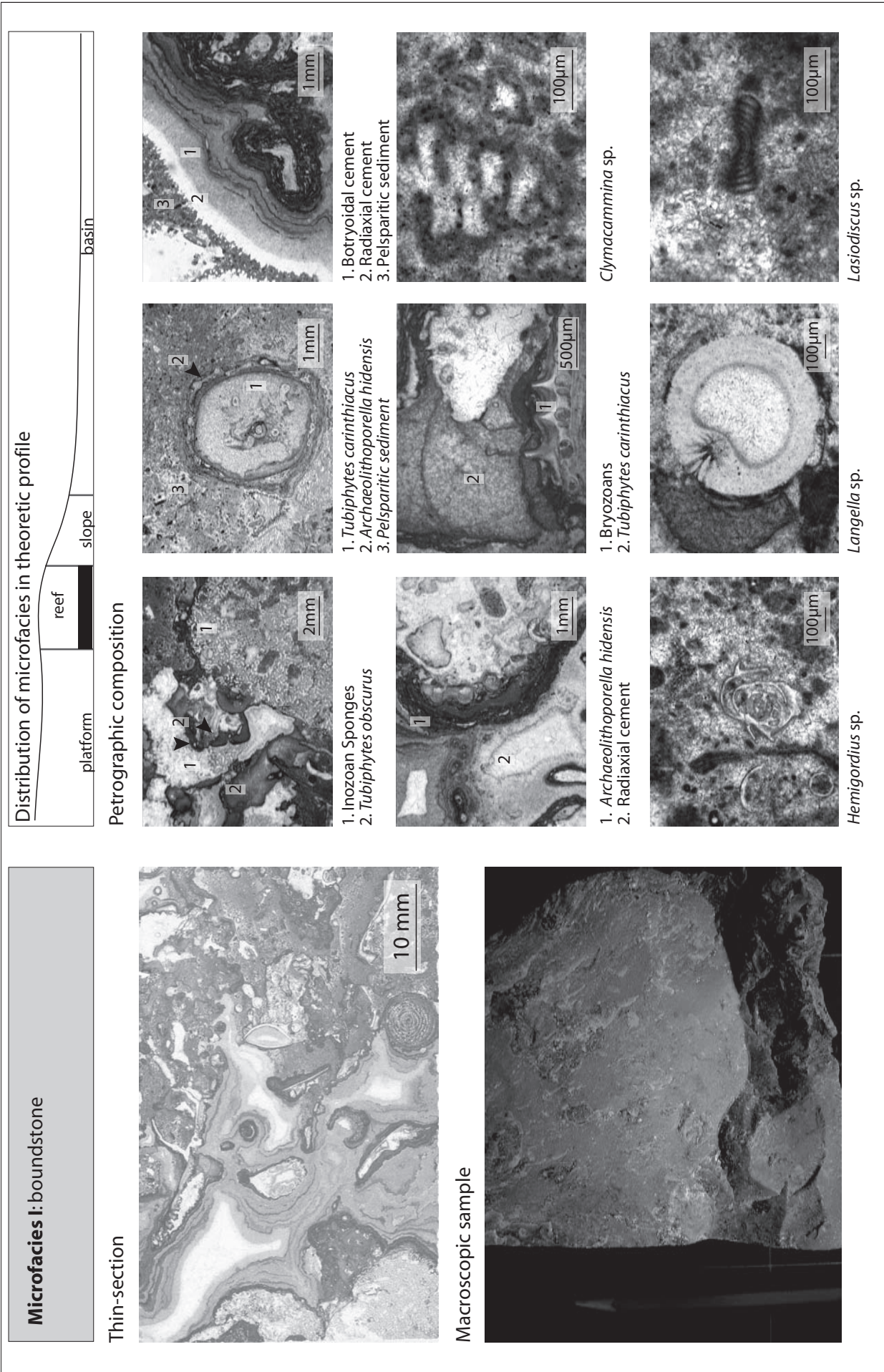


Plate 12: Paleontological content of Early to Late Permian clasts

1. *Archaeolitoporella idensis* crust around *Tubiphytes carinthiacus*, sample PS16
2. *Archaeolitoporella idensis* crust around a transversal section of inozoan sponge, sample RP19
3. *Archaeolitoporella idensis* crust around crinoid spine, sample RP19
4. *Archaeolitoporella idensis* crust around Bryozoans, sample PS14
5. *Bacinella* sp., sample RP19
6. *Mizzia* sp., transverse section, sample BG2
7. *Chuvashovia densifolia*, sample CSF17
8. *Koivaella permiensis*, longitudinal sections, sample PR21

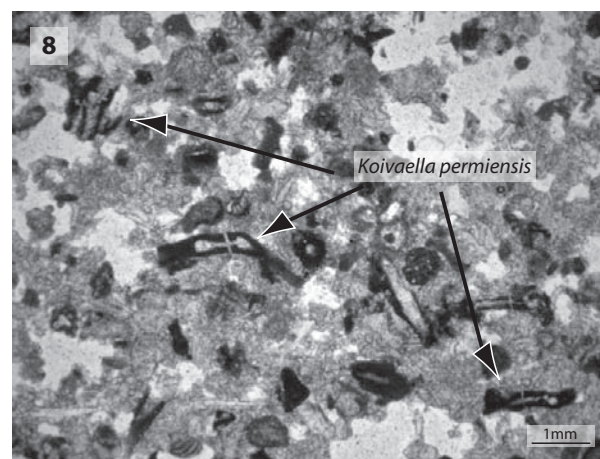
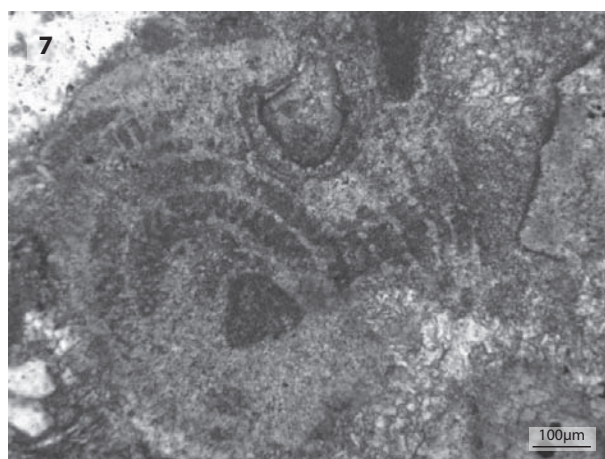
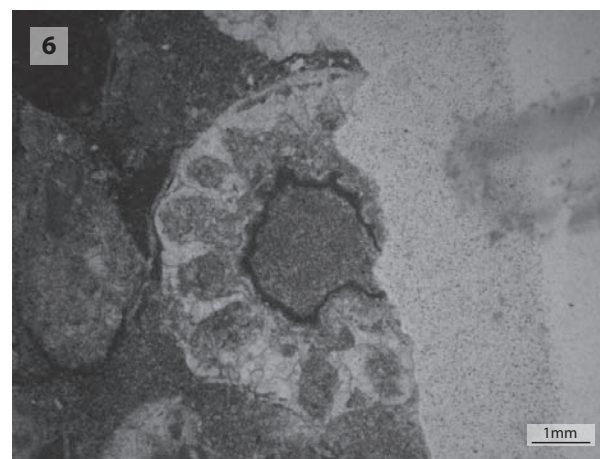
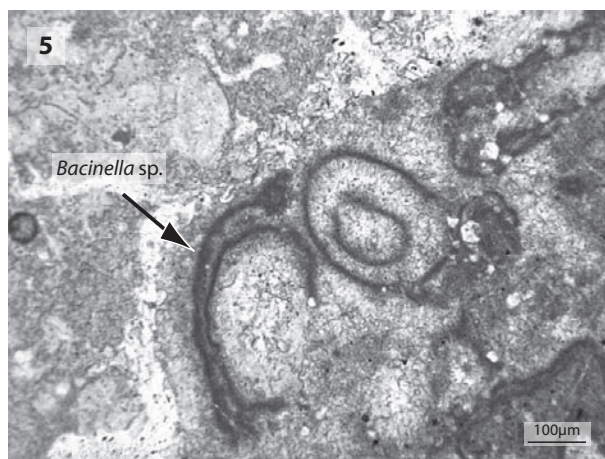
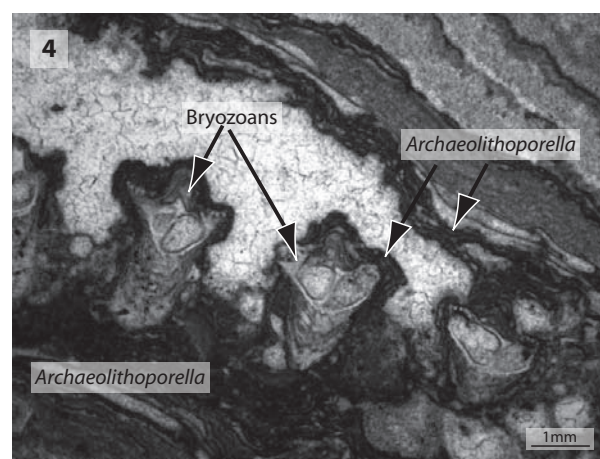
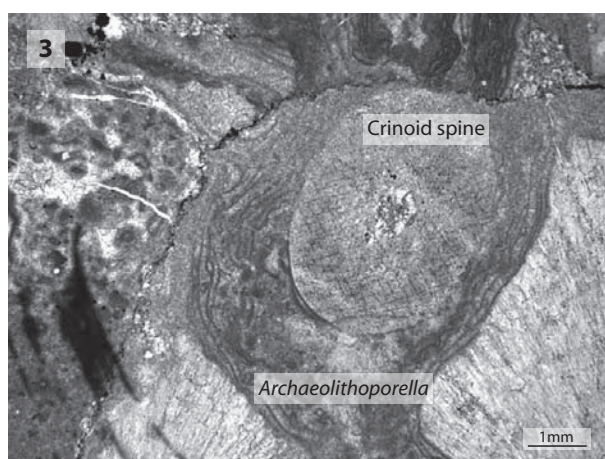
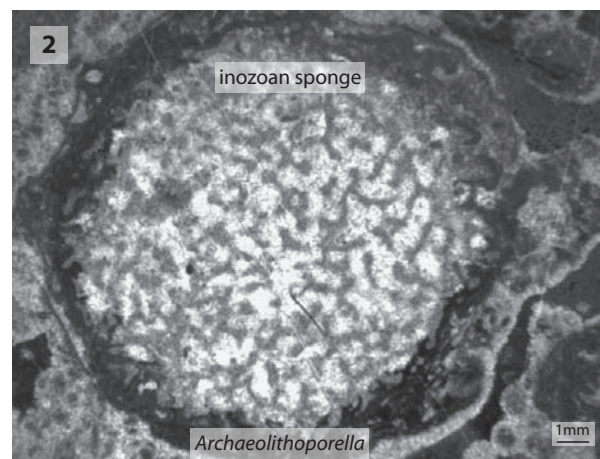
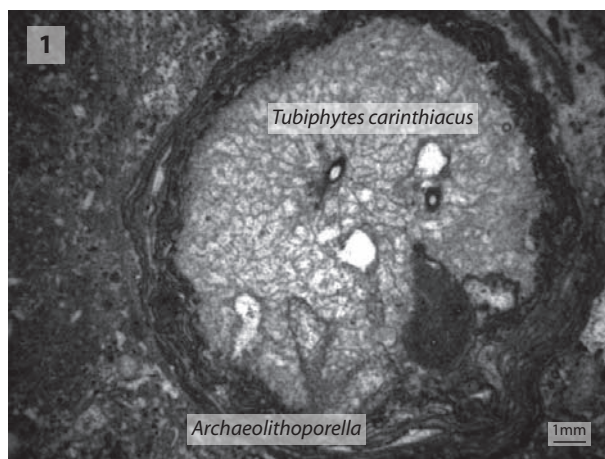


Plate 13: Paleontological content of Early to Late Permian and Middle Triassic clasts

1. *Pseudovermiporella elliotti*, sample RPFa1
2. *Tubiphytes obscurus*, sample BG1
3. *Tubiphytes carinthiacus*, sample BG1
4. Ammonite with gonitatic suture, sample RPFa5
5. Bryozoan colony, sample BG2
6. Trilobite fragment, sample RPFa3
7. Radiolarians made of calcite, sample RP19
8. *Uvanella irregularis* (Middle Triassic) , sample RP19

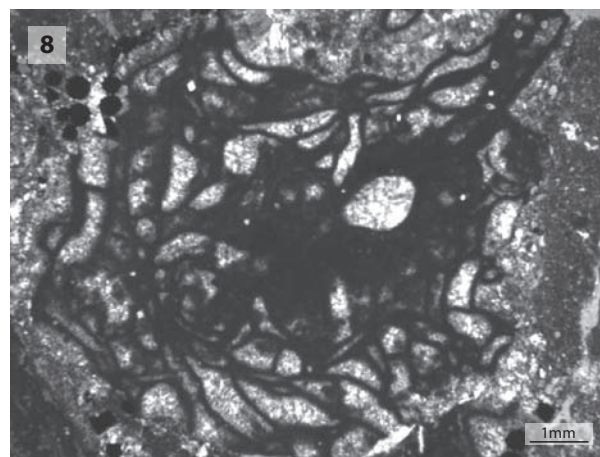
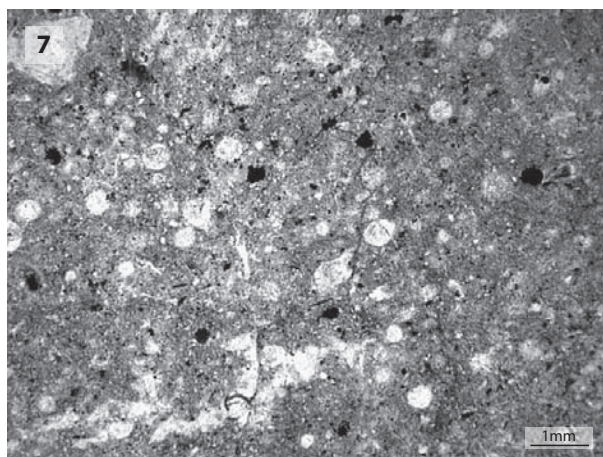
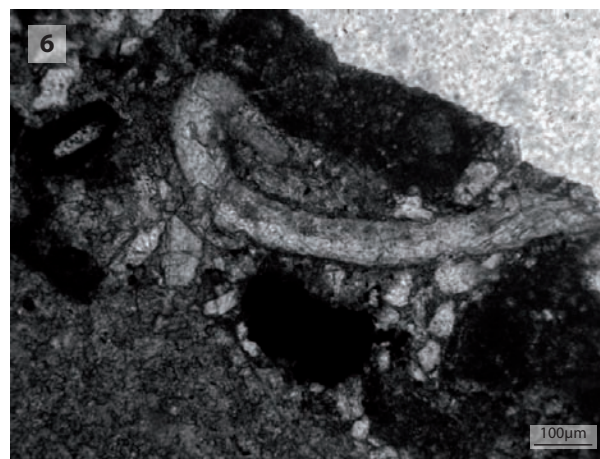
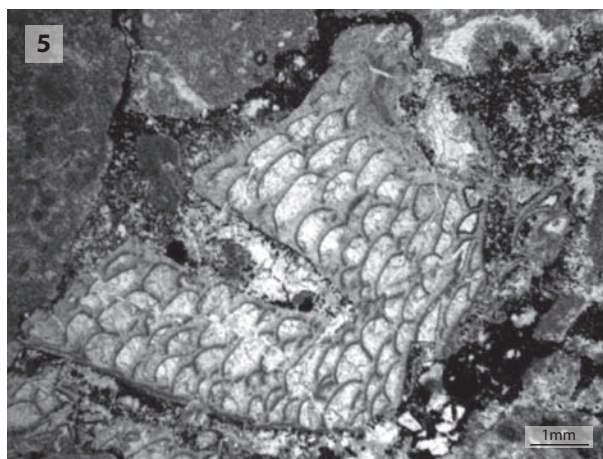
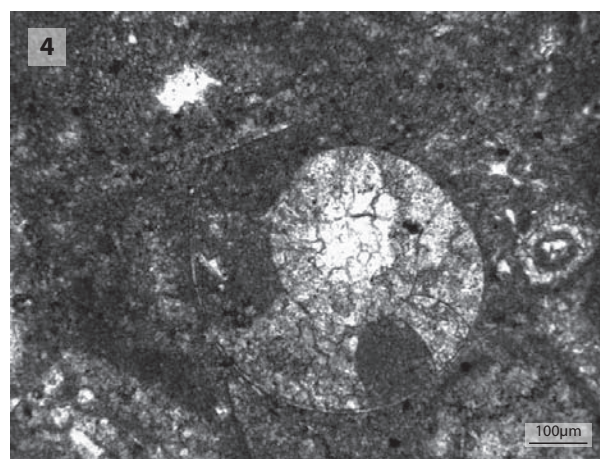
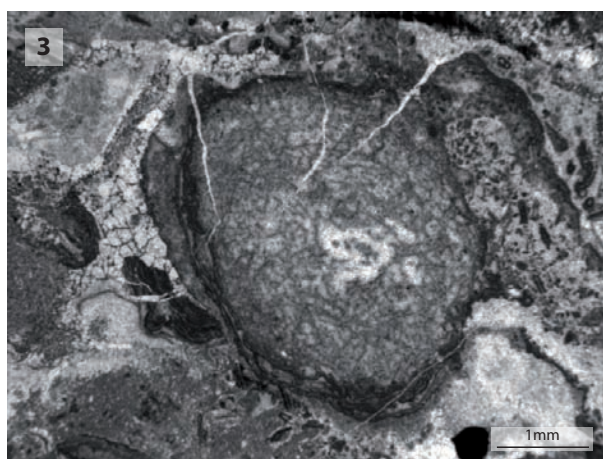
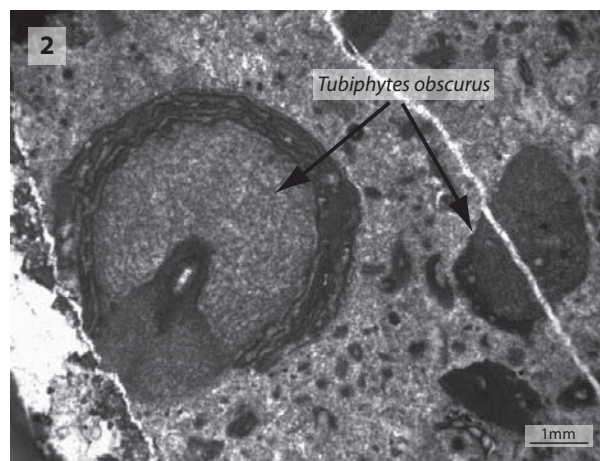
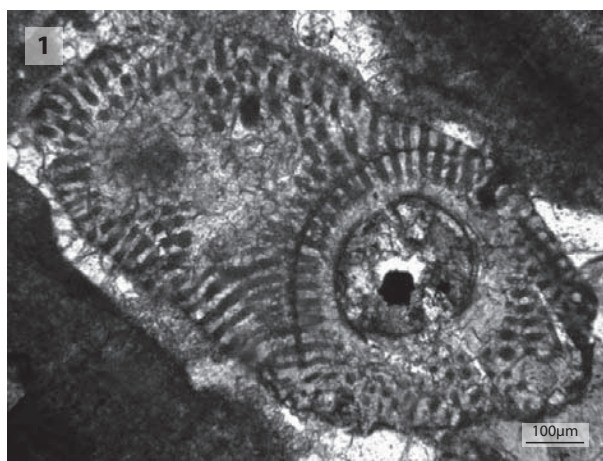


Plate 14: Cathodoluminescence pictures of quartz colour features

Recognition of quartz clasts (arrows) in plane-polarised light (left column) and presentation of their aspect in cathodoluminescence light (right column) in:

1. **Coarse calcarenites**, sample PS26
2. **Medium calcarenites**, sample RPFa5
3. **Fine calcarenites**, sample PR21
4. **Clayey sandstones**, sample CSF5

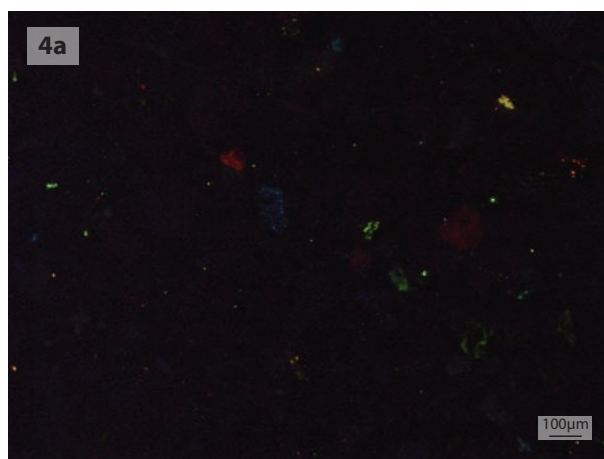
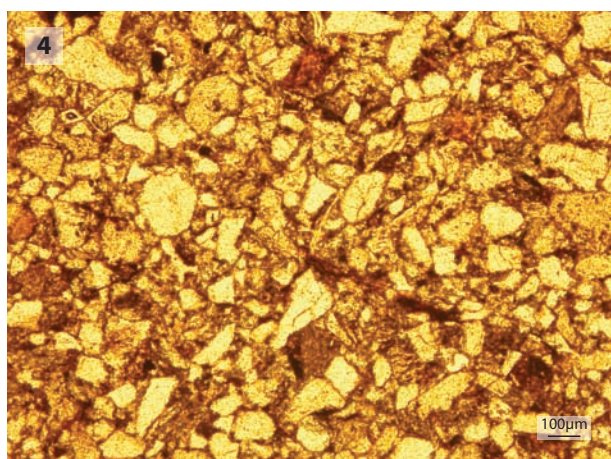
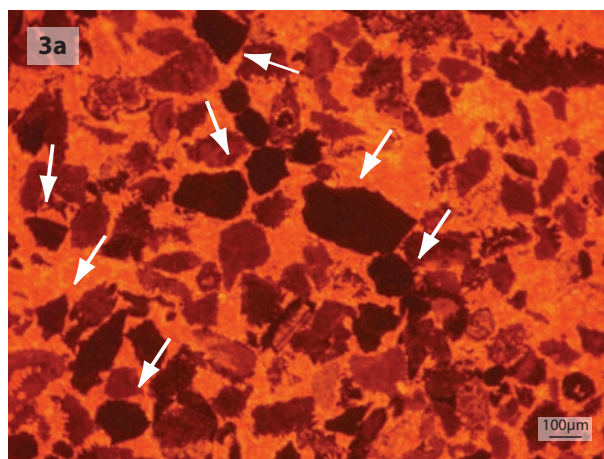
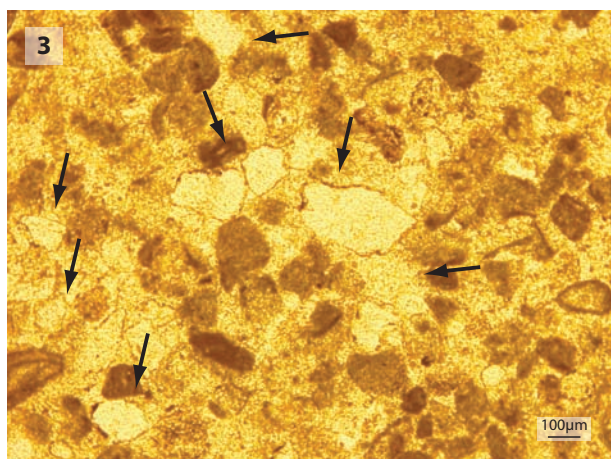
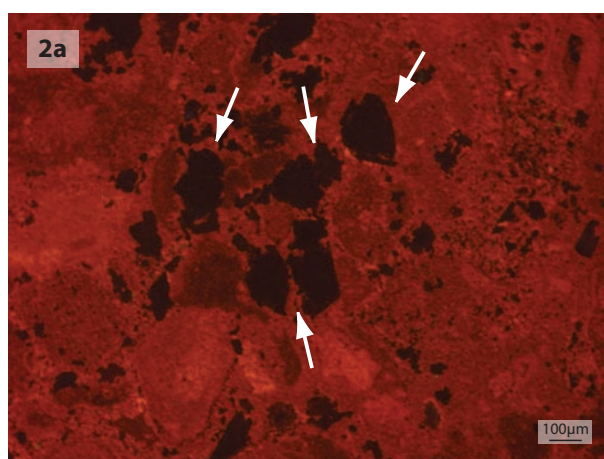
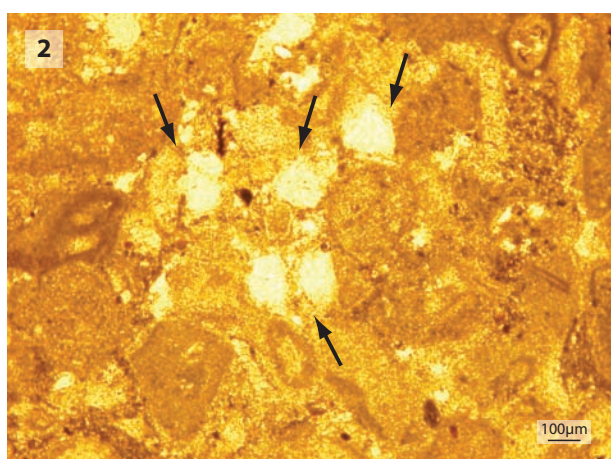
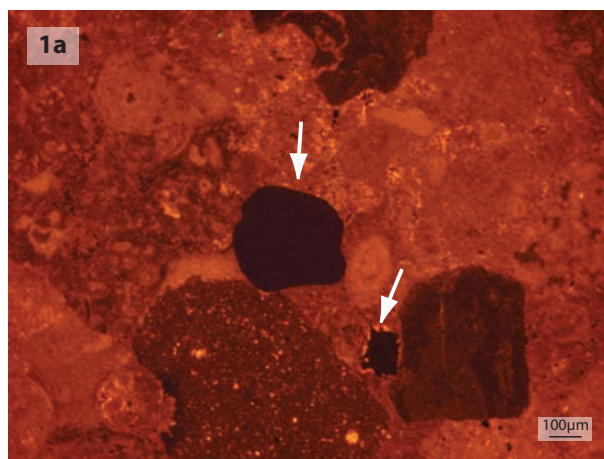
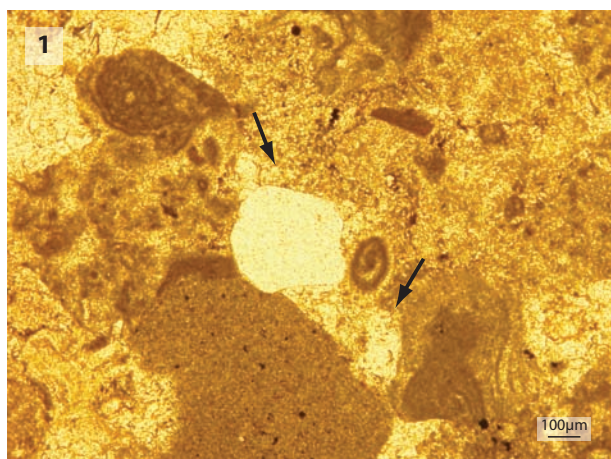


Plate 15: Permian smaller Foraminifera

1. *Glomospira* sp., oblique section, sample PR28
2. *Chitralina undulata*, transversal section, sample RPFa5
3. *Diplosphaerina inaequalis*, vertical section, sample RP19
4. *Eotuberitina reitlingerae* , vertical section, sample RP19
5. *Lasiodiscus* sp., oblique section, sample BG1
6. *Lasiodiscus irregularis*, subaxial section, sample BG2
7. *Lasiodiscus medusa*, axial section, BG1
8. *Lasiodiscus minor*, axial section, RPFa6

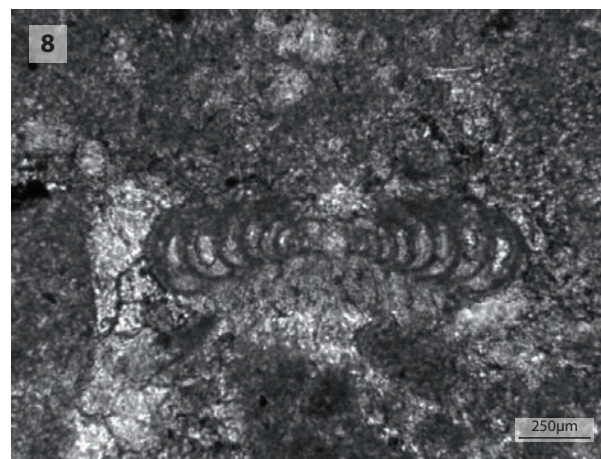
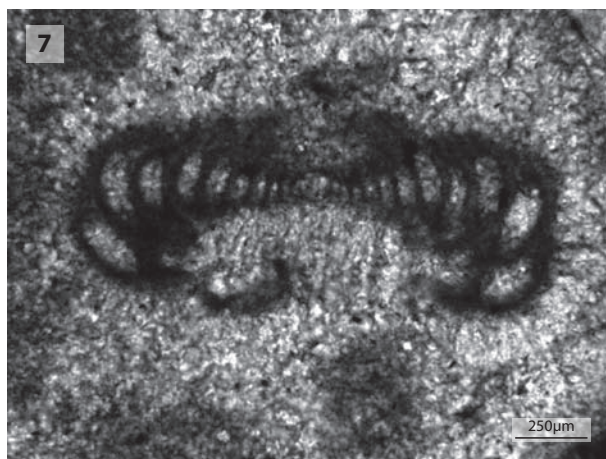
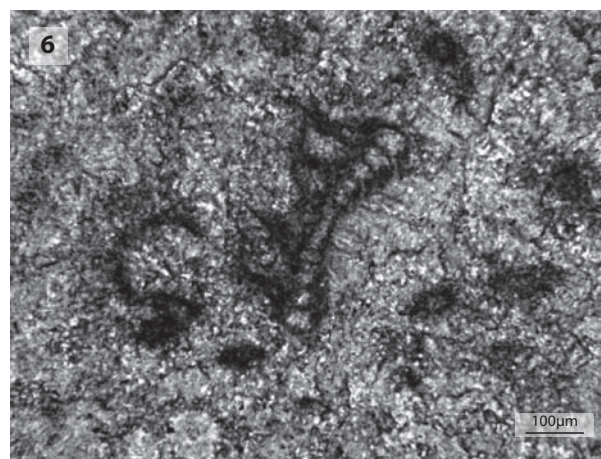
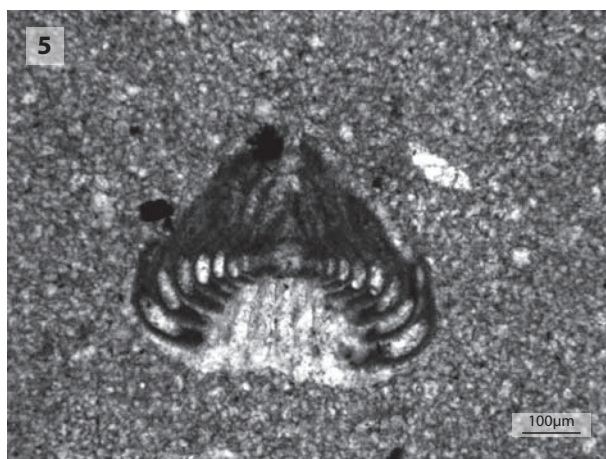
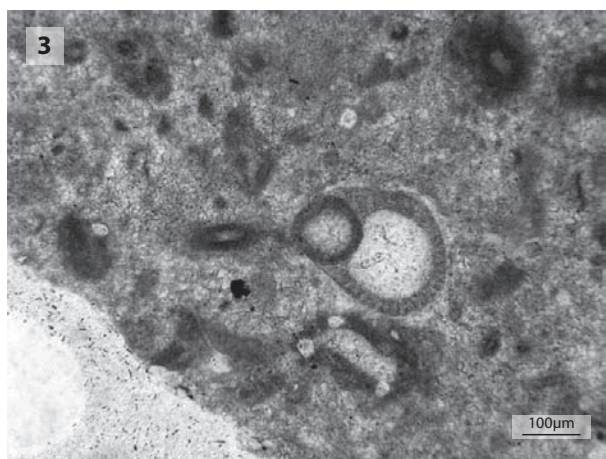
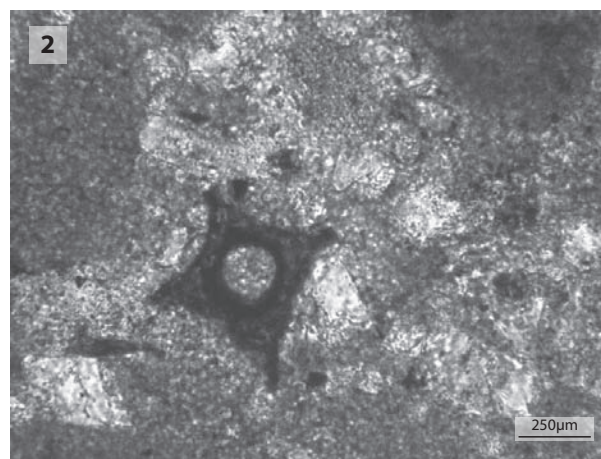
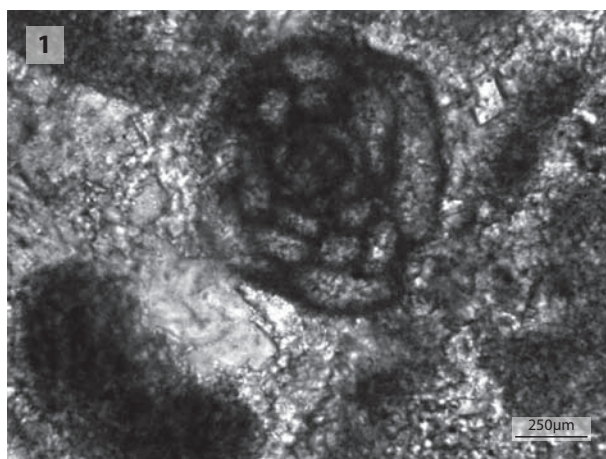


Plate 16: Permian smaller Foraminifera

1. *Lasiotrochus tatoiensis*, oblique section, sample RP19
2. *Geinitzina* sp., longitudinal section , sample RP19
3. *Pachyphloya* sp., longitudinal section, sample RP27
4. *Climacammina* sp., tangential section, sample CSF17
5. *Palaeotextularia* sp., longitudinal section, sample RPFa5
6. *Globivalvulina graeca*, tangential section, sample RP19
7. *Dagmarita shahrezaensis*, longitudinal section, sample PS23
8. *Endothyra* sp., equatorial section, sample PS23

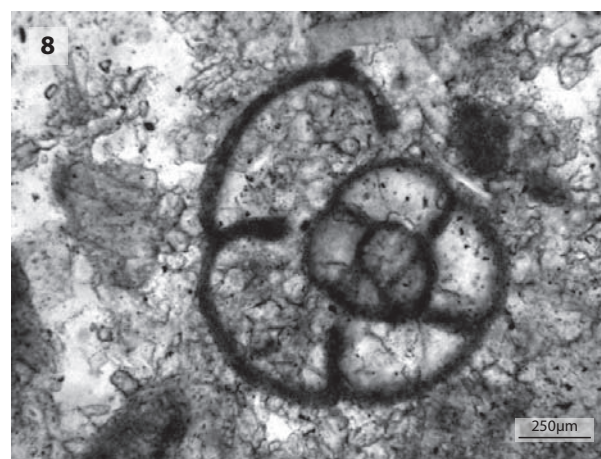
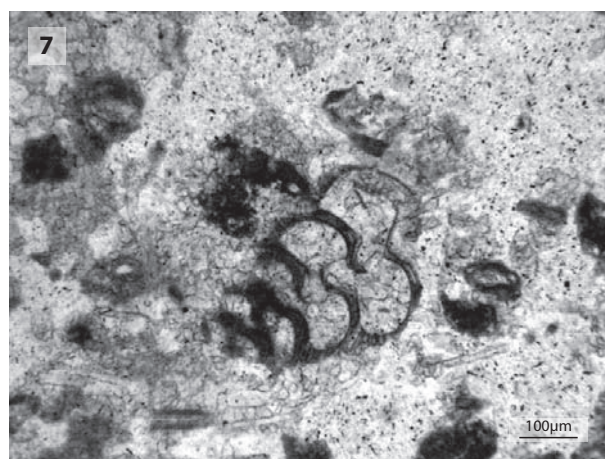
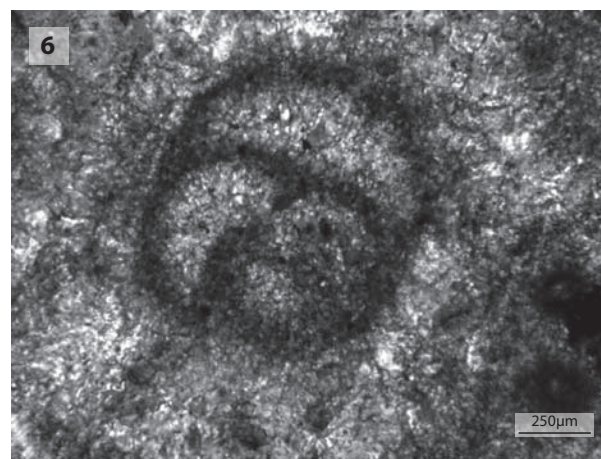
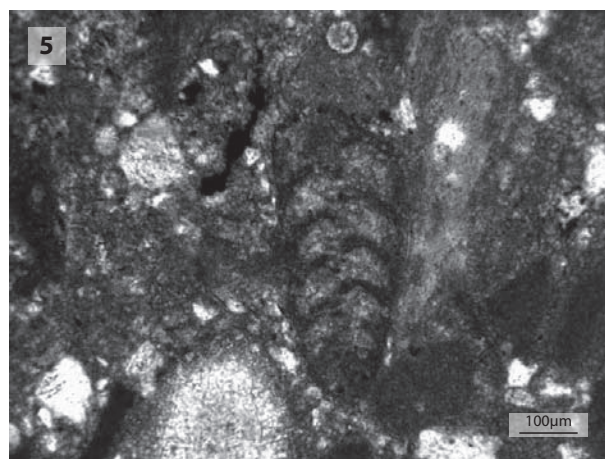
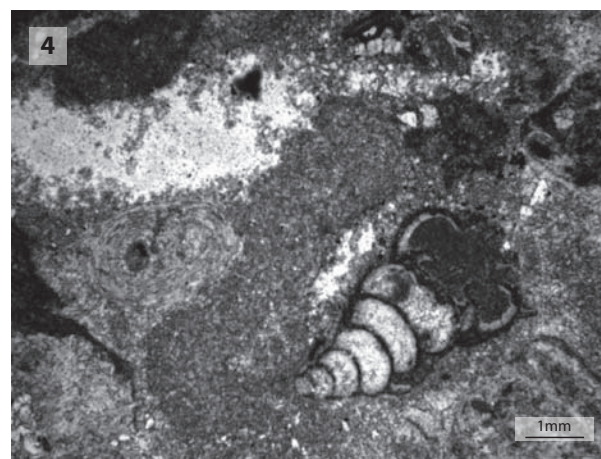
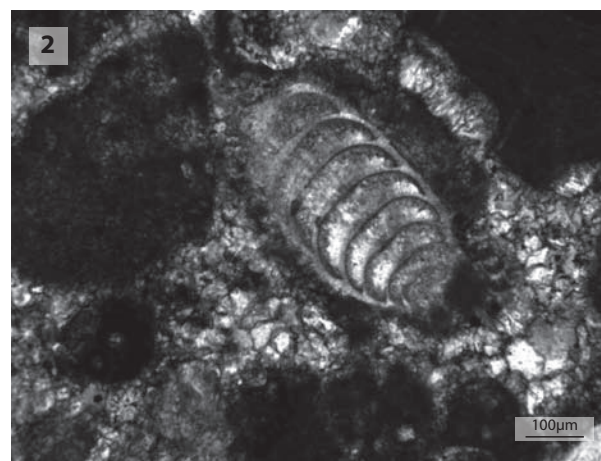
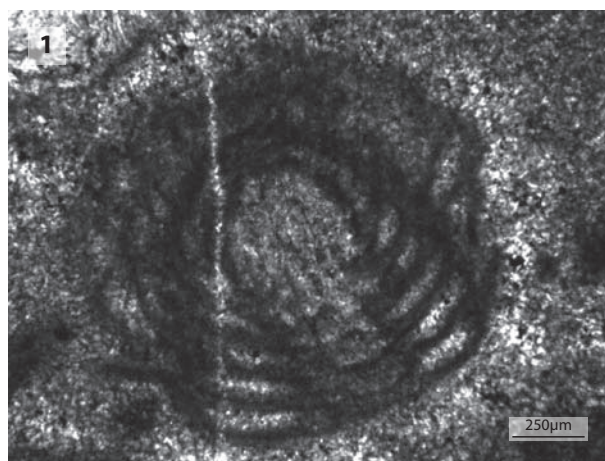


Plate 17: Carboniferous and Permian smaller Foraminifera

1. *Neoendothyra* sp., axial section, sample PR28
2. *Tetrataxis* aff. *Tetrataxis conica*, longitudinal section , sample RPFa6
3. *Hemigordius* sp., oblique section, sample RPFa6
4. *Rectostipulina quadrata*, transversal section, sample BG1
5. *Robuloides* sp., axial section, sample PS23
6. *Multidiscus* sp., axial section, sample BG2
7. *Ramovsia limes*, transversal section, sample RPFa5
8. *Asterosphaera pulchra*, transversal section (Carboniferous?), sample RP19

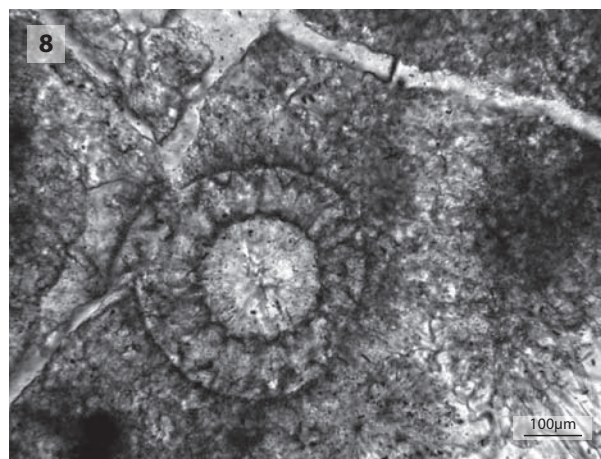
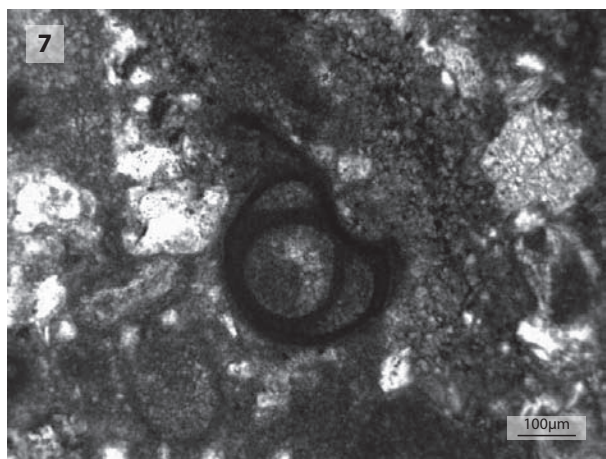
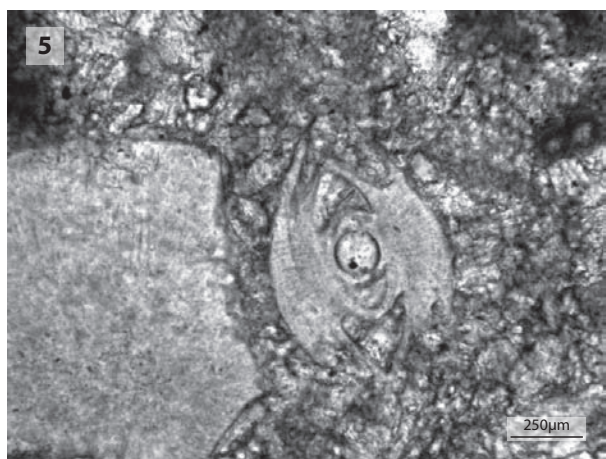
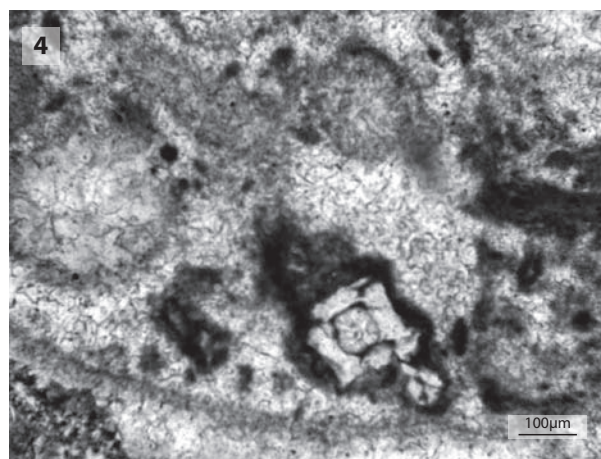
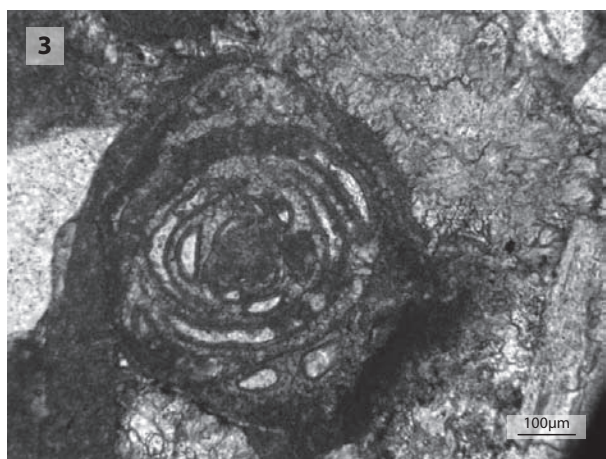
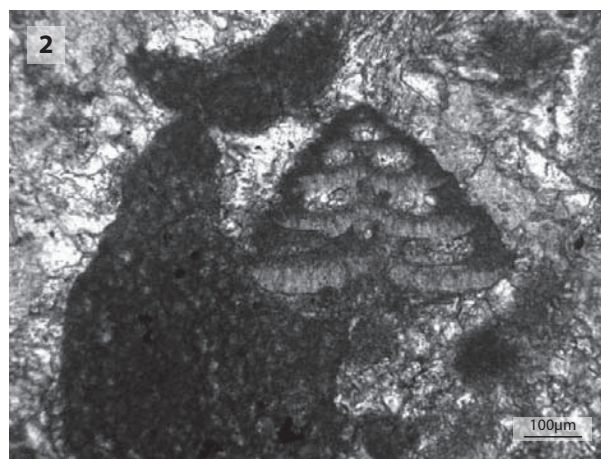
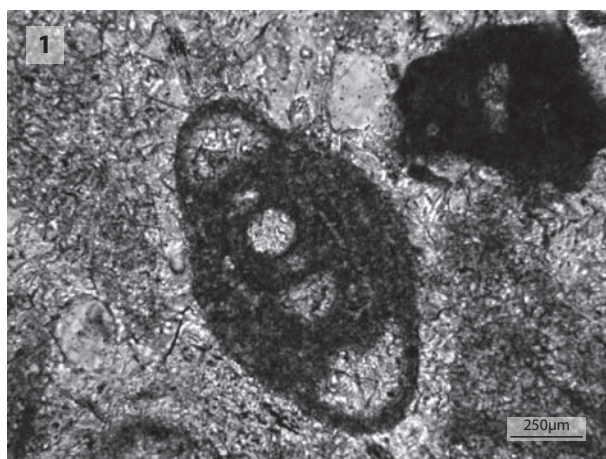


Plate 18: Larger Foraminifera

1. *Reichelina* sp., subaxial section, sample PR21
2. *Schubertella paramelonica*, equatorial section, sample RP27
3. *Schubertella silvestrii* , oblique subaxial section, sample PS26
4. *Dunbarula? simplex*, oblique subequatorial section, sample PS26
5. *Parafusulina* sp., subaxial tangential section, sample RP19
6. *Chusenella* sp., subequatorial section (1) and *Minojapanella* sp. tangential section near poles (2), sample PS26
7. *Toriyamaia* (?) sp., subaxial section, sample RPFa1
8. *Mesoschubertella* sp., equatorial section, sample RP27

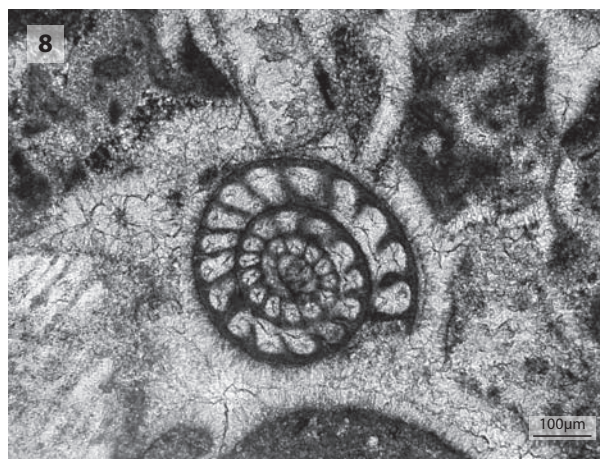
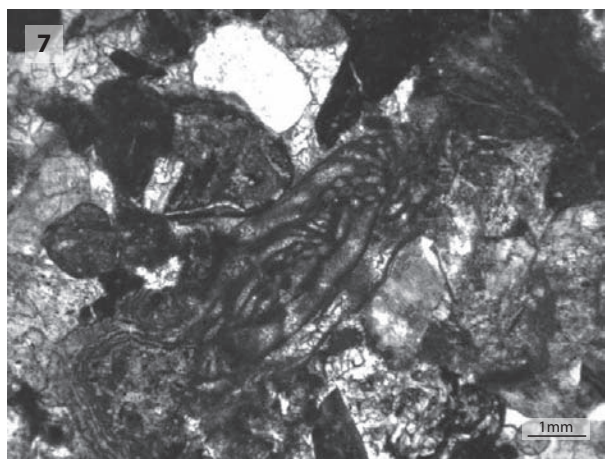
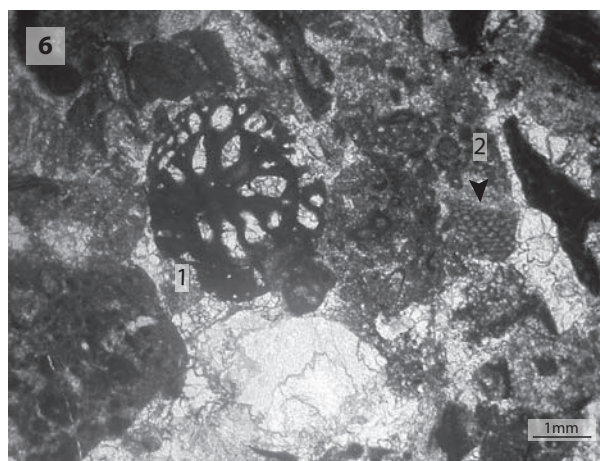
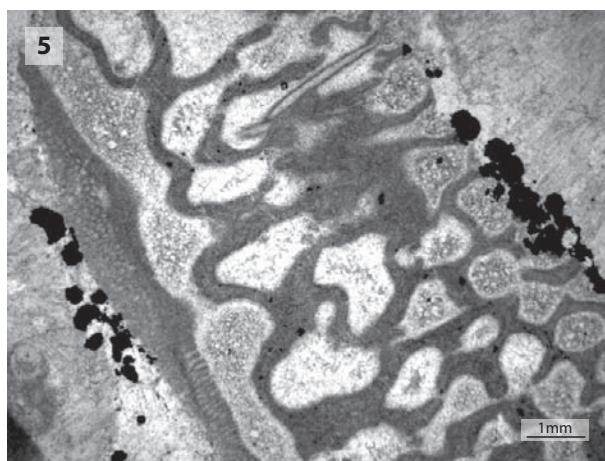
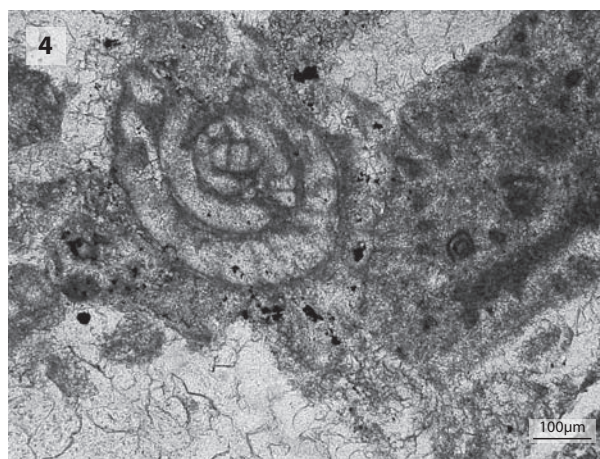
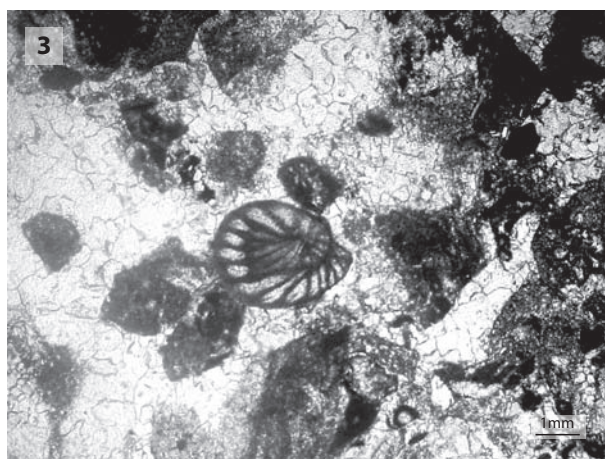
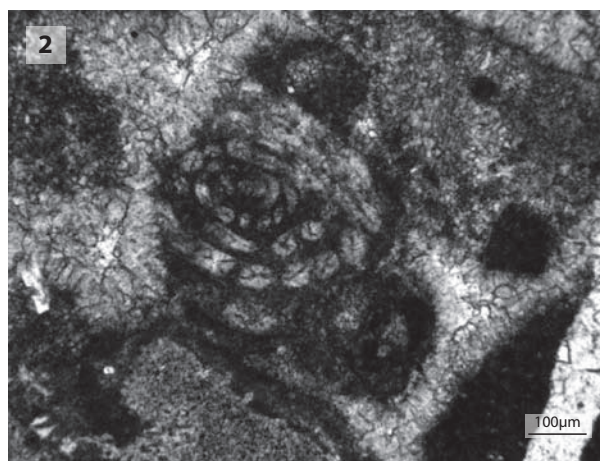
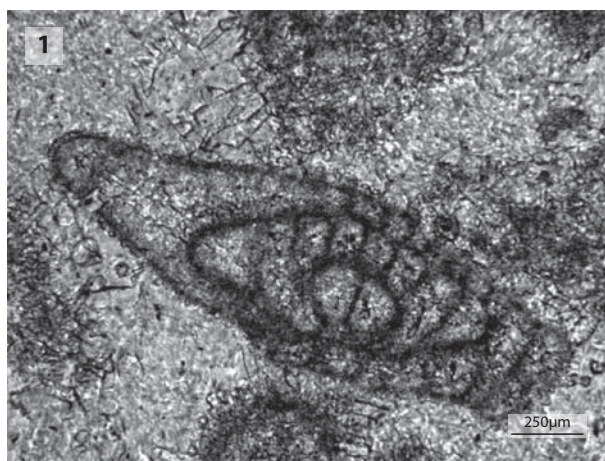


Plate 19: Larger Foraminifera

1. *Neofusulinella lantenoisi*, subaxial section, sample RPFa2
2. *Yangchienia compressa*, subaxial section, sample RP27
3. *Rauserella staffi*, subequatorial section, sample RP29
4. *Darvasites contractus*, subaxial section, sample BG1
5. *Chalaroschwagerina* (*Taiyuanella*?) aff. *davalensis*, tangential section, sample BG1
6. *Levenella* aff. *evoluta*, equatorial oblique section, sample PR21
7. *Rugososchwagerina yabei*, tangential section, sample RP19
8. *Pamirina darvasica*, axial section, RPFa2

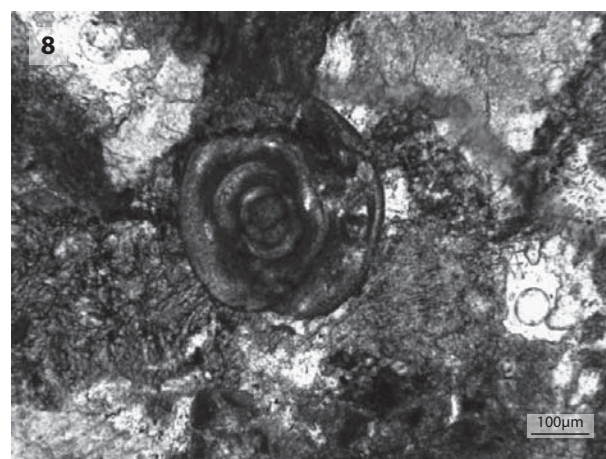
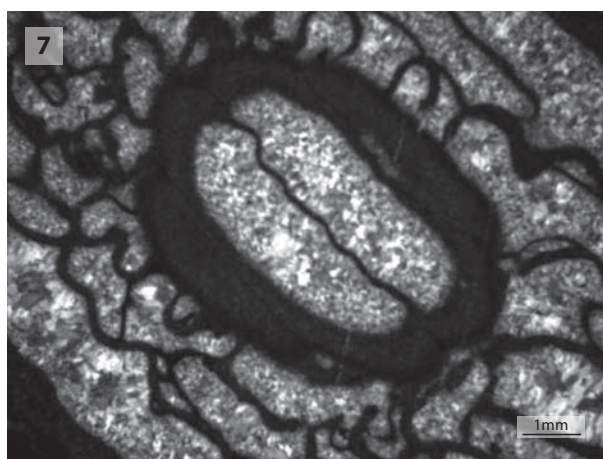
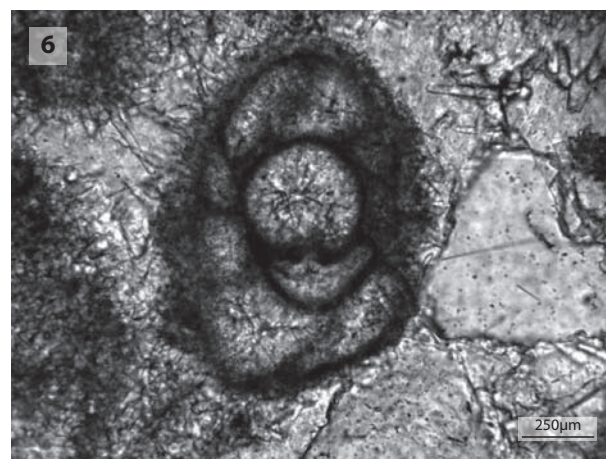
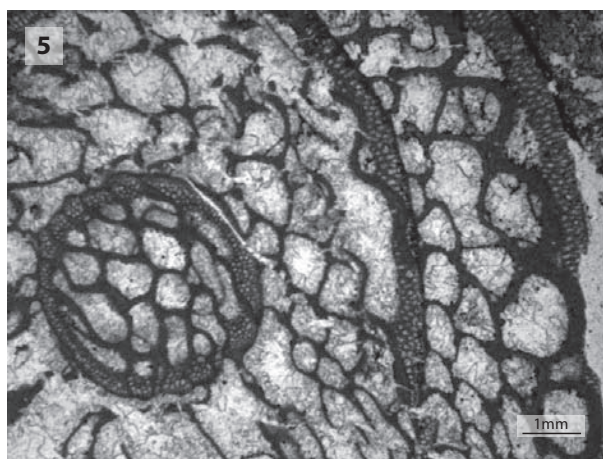
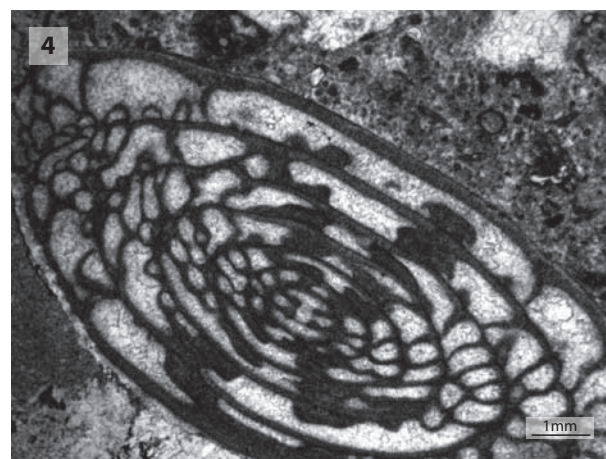
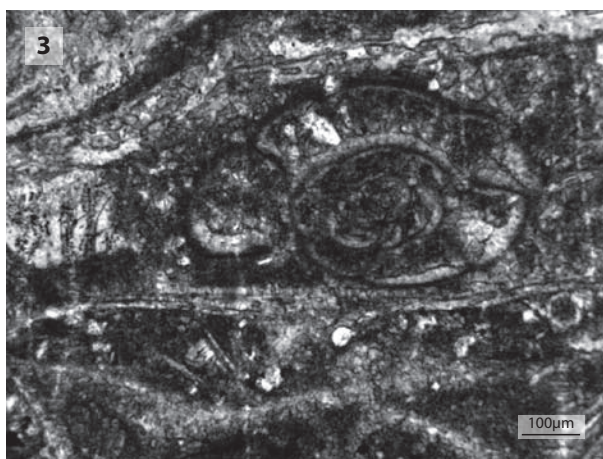
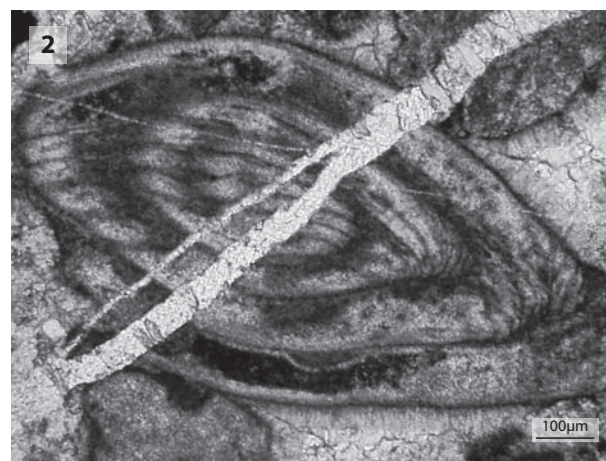
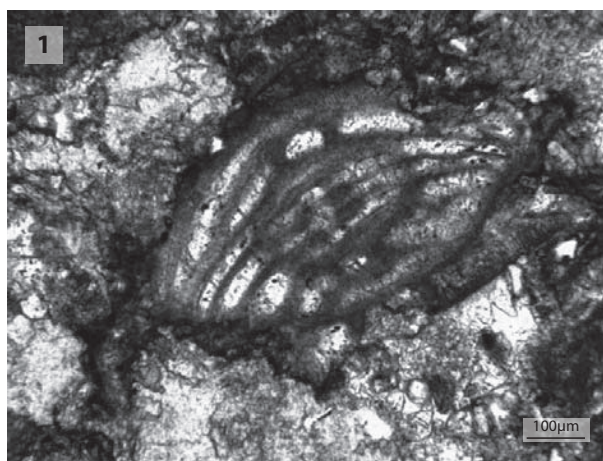


Plate 20: Larger Foraminifera

1. *Neoschwagerina* ex gr. *craticulifera*, equatorial section, sample PS14
2. *Ogbinella* cf. *saurini*, subaxial section, sample PS26

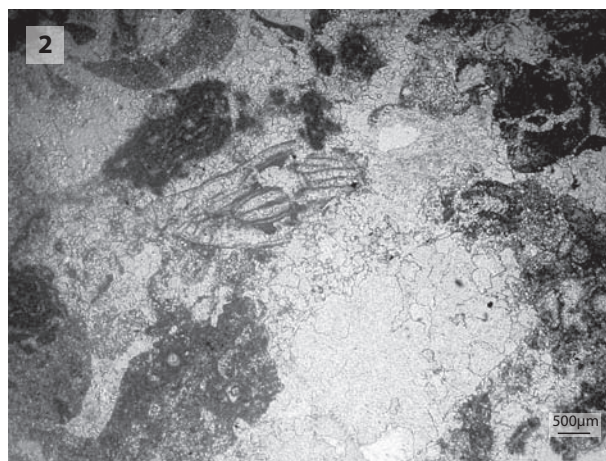


Plate 21: Ostracods

The sample from which the ostracod was extracted is indicated at the bottom left of each picture.

1. *Lethiersa sinusoventralis* gen. nov. sp. nov. Holotype; left lateral view of complete carapace
2. *Lethiersa sinusoventralis* gen. nov. sp. nov. Paratype; left lateral view of complete carapace
3. *Lethiersa salomonensis* gen. nov. sp. nov. Holotype; left lateral view of complete carapace
4. *Neofellerites minimus*, left lateral view of complete carapace
5. *Cyathus densistriata*, right lateral view of complete carapace
6. *Lethiersa salomonensis* gen. nov. sp. nov. Paratype; left lateral view of complete carapace
7. *Cyathus* sp. nov. 2, right lateral view of complete carapace
8. *Healdia* cf. *anterodepressa*, right lateral view of complete carapace
9. *Healdia* cf. *irwinensis*, right lateral view of complete carapace
10. *Healdia*" cf. *unispinosa*, right lateral view of complete carapace
11. *Healdia*? sp. 2, right lateral view of complete carapace
12. *Healdia*? sp. 3, right lateral view of complete carapace
13. *Timorhealdia* cf. *vanderboogaardi*, right lateral view of complete carapace
14. *Timorhealdia* sp. 1, right lateral view of complete carapace
15. *Marginohealdia* sp. nov. 2, right lateral view of complete carapace
16. *Marginopsis* cf. *marginella*, right lateral view of right valve
17. *Marginohealdia* sp. 1, right lateral view of right valve
18. *Marginohealdia* sp. nov. 2, right lateral view of complete carapace

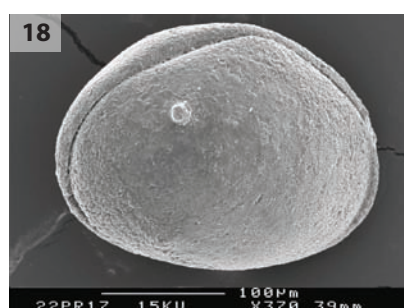
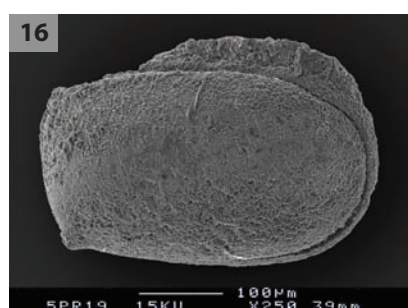
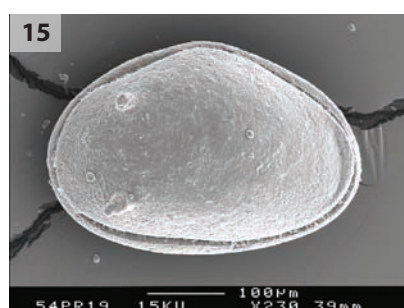
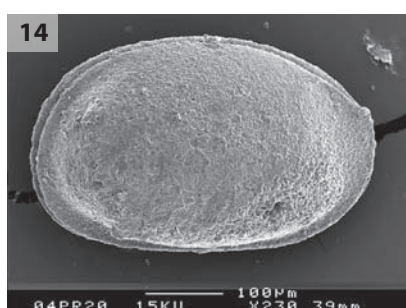
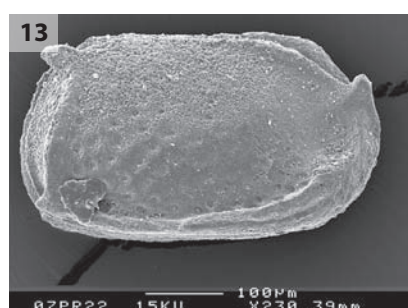
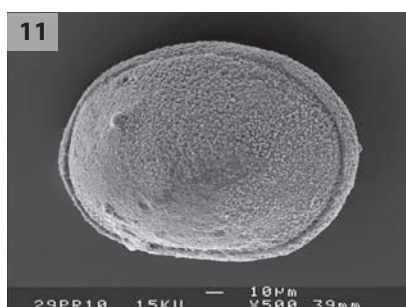
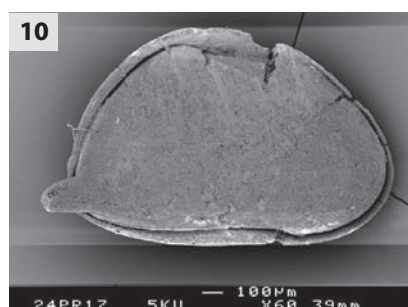
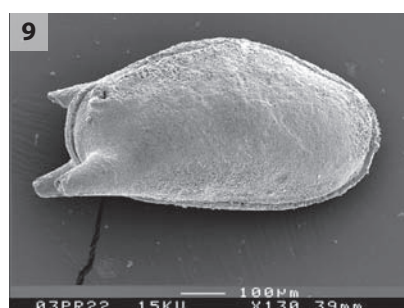
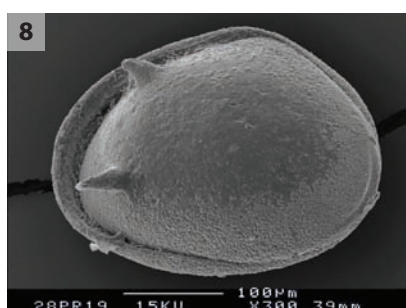
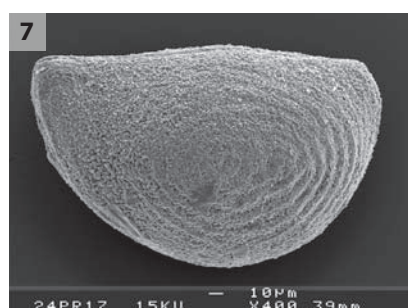
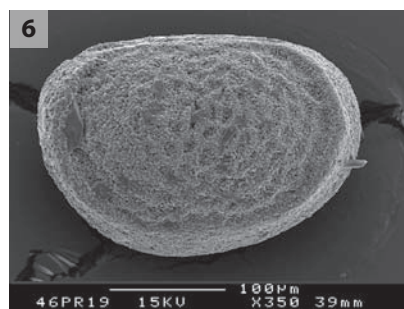
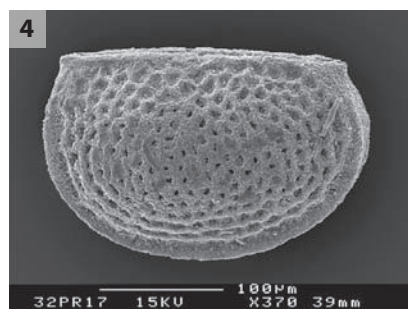
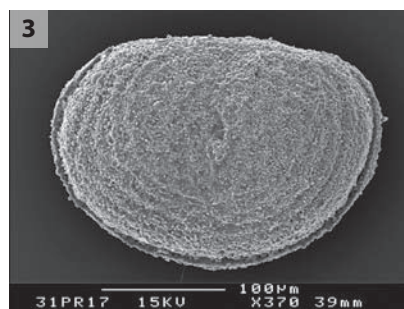
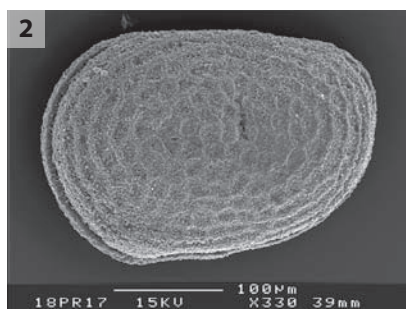
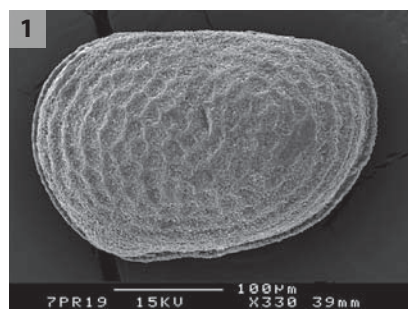


Plate 22: Ostracods

The sample from which the ostracod was extracted is indicated at the bottom left of each picture.

1. *Aurigerites siciliaensis* sp. nov. Holotype; right lateral view of complete carapace
2. *Aurigerites siciliaensis* sp. nov., right lateral view of complete carapace
3. *Aurigerites siciliaensis* sp. nov., Paratype; right lateral view of complete carapace
4. *Aurigerites siciliaensis* sp. nov., right lateral view of complete carapace
5. *Bairdia altiarucus*, right lateral view of complete carapace
6. *Bairdia altiarucus*, right lateral view of complete carapace
7. *Bairdia* cf. *austriaca*, right lateral view of complete carapace
8. *Bairdia* cf. *austriaca*, right lateral view of complete carapace
9. *Bairdia portellaensis* sp. nov., Holotype; right lateral view of complete carapace
10. *Bairdia portellaensis* sp. nov., Paratype; right lateral view of complete carapace
11. *Bairdia portellaensis* sp. nov., right lateral view of complete carapace
12. *Bairdia portellaensis* sp. nov., right lateral view of complete carapace
13. *Bairdia* sp. 1, right lateral view of complete carapace
14. *Bairdia* sp. 2, right lateral view of complete carapace
15. *Bairdia* sp. 3, right lateral view of complete carapace
16. *Bairdia?* sp. 6, right lateral view of complete carapace
17. *Fabalitypris* sp. 3, right lateral view of complete carapace
18. *?Liuzhinia antalyaensis*, right lateral view of complete carapace

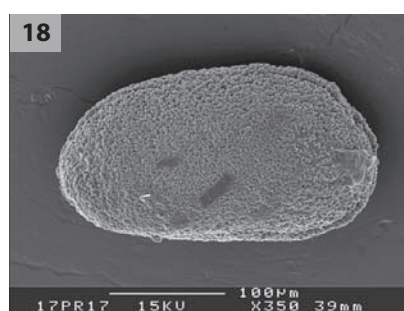
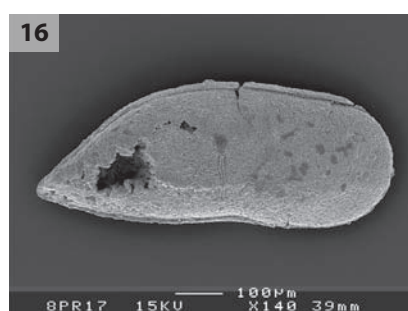
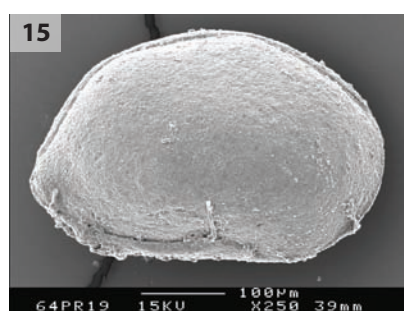
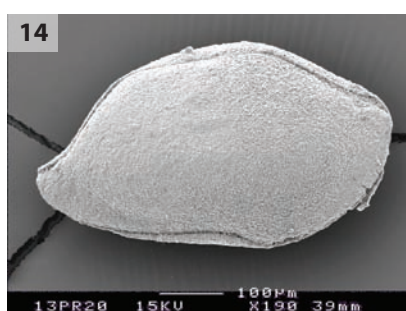
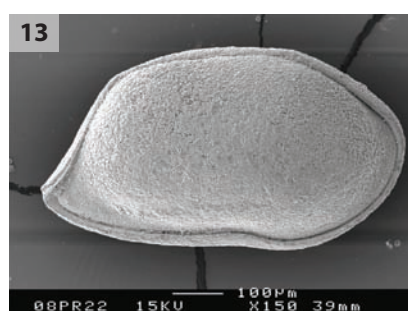
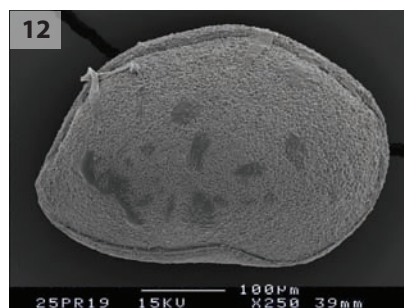
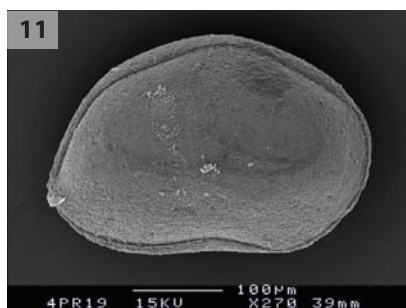
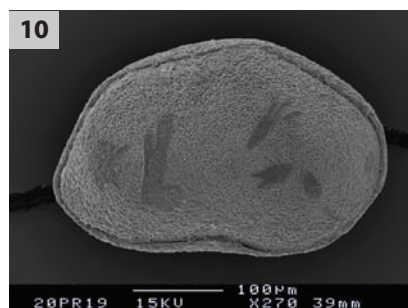
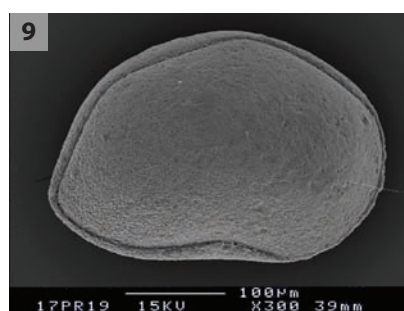
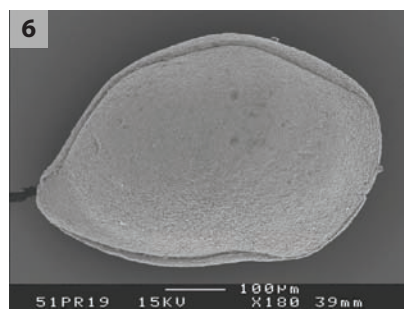
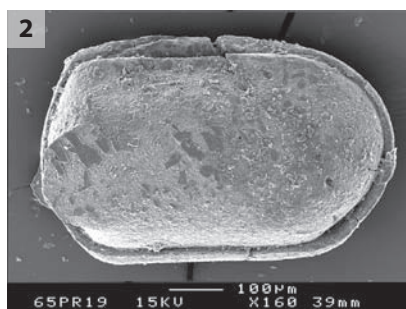
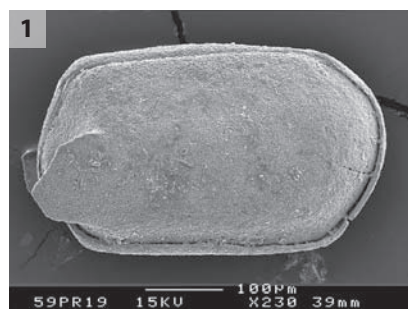


Plate 23: Ostracods

The sample from which the ostracod was extracted is indicated at the bottom left of each picture.

1. *Fabalitypris grundeli* sp. nov. Holotype; right lateral view of complete carapace
2. *Fabalitypris grundeli* sp. nov. Paratype; right lateral view of complete carapace
3. *Fabalitypris grundeli* sp. nov., right lateral view of complete carapace
4. *?Fabalitypris grundeli* sp. nov. Holotype; right lateral view of complete carapace
5. *?Fabalitypris grundeli* sp. nov. Paratype; right lateral view of complete carapace
6. *Fabalitypris blumenstengeli* sp. nov. Holotype; right lateral view of complete carapace
7. *Bairdiocypris* sp. 1, right lateral view of complete carapace
8. *Bairdiocypris* sp. 1, right lateral view of complete carapace
9. *Fabalitypris blumenstengeli* sp. nov. Paratype; right lateral view of complete carapace
10. *Acratia* cf. *visnyoensis*, left lateral view of a left valve
11. *Acratia* cf. *visnyoensis*, left lateral view of a left valve
12. *Fabalitypris blumenstengeli* sp. nov. Paratype; right lateral view of complete carapace
13. *Rectoplacera* cf. *dorsoclinata*, right lateral view of complete carapace
14. *Rectoplacera* cf. *dorsoclinata*, right lateral view of complete carapace
15. *Rectoplacera* cf. *dorsoclinata*, right lateral view of complete carapace
16. *Praepilatina* cf. *adamczaki*, right lateral view of complete carapace
17. *Triplacera* sp. 1, left lateral view of left valve
18. *Triplacera* sp. 1, right lateral view of complete carapace

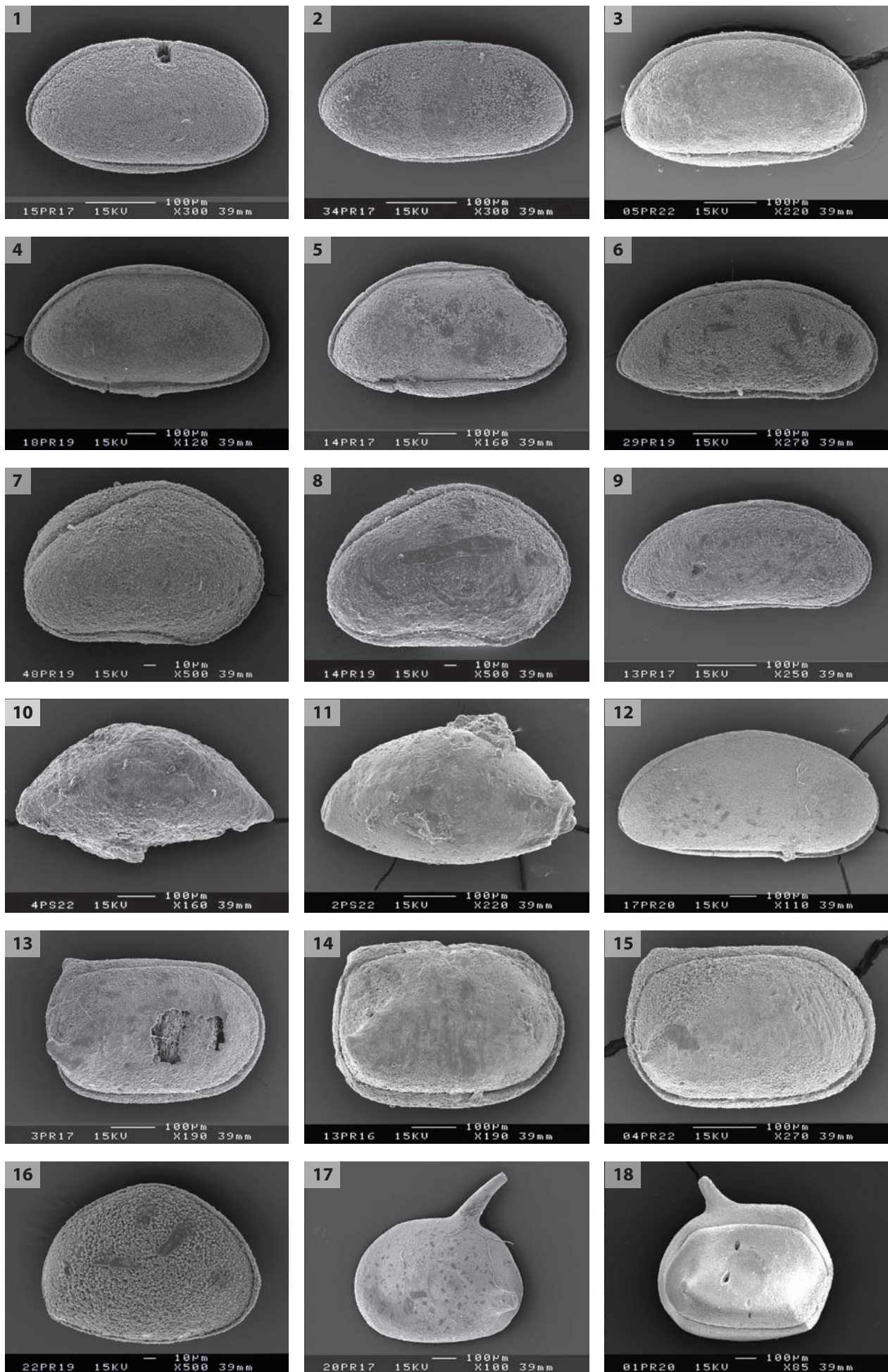


Plate 24: Ostracods

The sample from which the ostracod was extracted is indicated at the bottom left of each picture.

1. *Anahuacia lercaraensis* sp. nov. Holotype; right lateral view of complete carapace
2. *Anahuacia lercaraensis* sp. nov., right lateral view of complete carapace
3. *Anahuacia lercaraensis* sp. nov., Paratype; right lateral view of complete carapace
4. *Anahuacia lercaraensis* sp. nov., left lateral view of complete carapace
5. *Portella trapezoida* gen. nov. sp. nov. Holotype; right lateral view of complete carapace
6. *Portella trapezoida* gen. nov. sp. nov. Paratype; right lateral view of complete carapace
7. *Siciliella prima* gen. nov. sp. nov. Paratype; right lateral view of complete carapace
8. *Portella trapezoida* gen. nov. sp. nov., right lateral view of complete carapace
9. *Portella trapezoida* gen. nov. sp. nov., right lateral view of complete carapace
10. *Siciliella prima* gen. nov. sp. nov. Holotype; right lateral view of complete carapace
11. *Siciliella prima* gen. nov. sp. nov., right lateral view of complete carapace
12. ?*Siciliella prima* gen. nov. sp. nov., Right lateral view of complete carapace
13. *Siciliella quadrata* gen. nov. sp. nov. Holotype; right lateral view of complete carapace
14. *Siciliella quadrata* gen. nov. sp. nov. Paratype; right lateral view of complete carapace
15. *Siciliella quadrata* gen. nov. sp. nov., right lateral view of complete carapace
16. *Siciliella infernespinosa* gen. nov. sp. nov. Holotype; right lateral view of complete carapace
17. *Siciliella infernespinosa* gen. nov. sp. nov. Paratype; right lateral view of complete carapace
18. *Siciliella infernespinosa* gen. nov. sp. nov., right lateral view of complete carapace

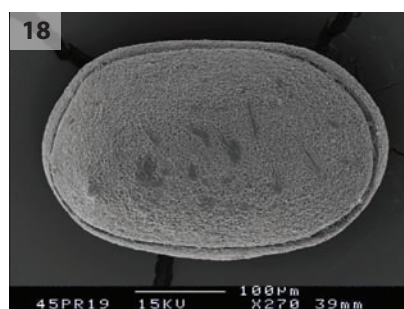
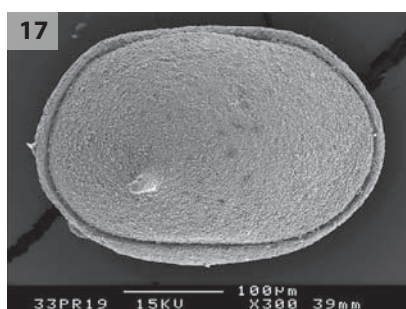
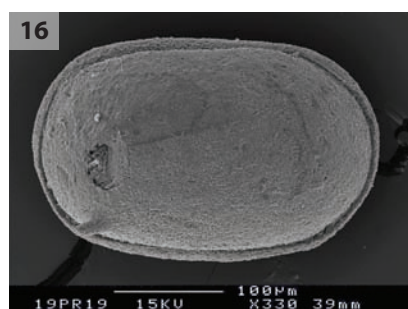
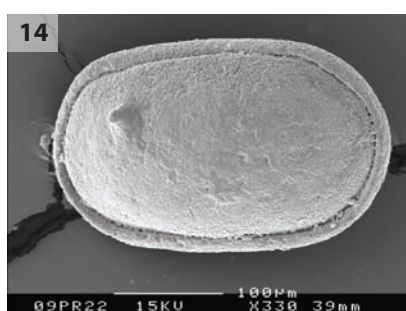
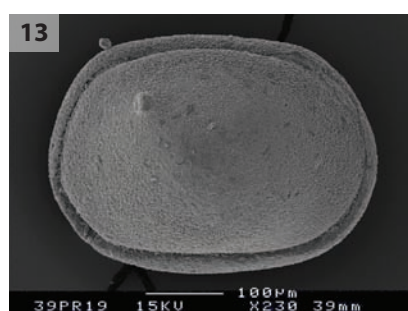
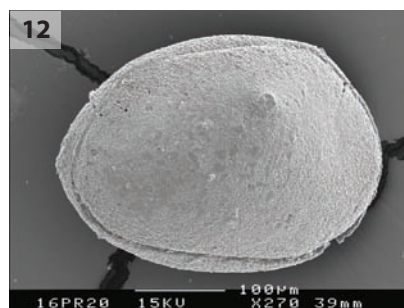
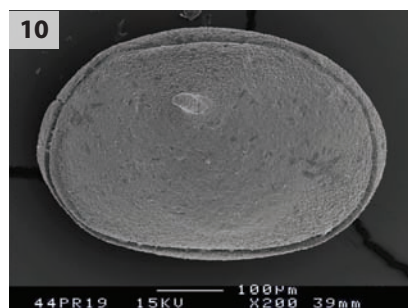
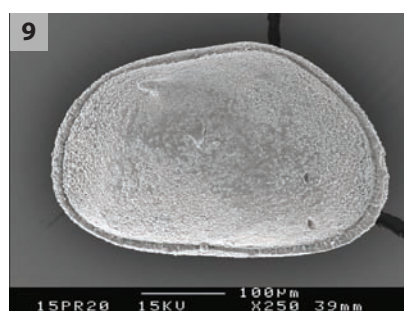
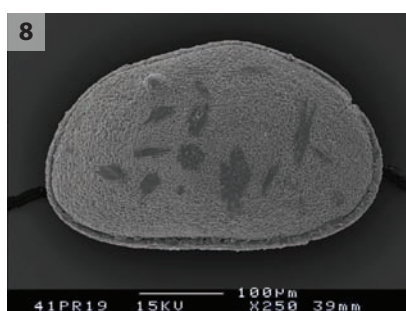
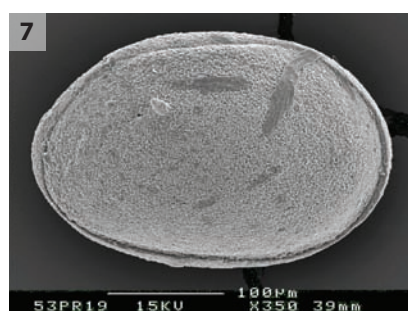
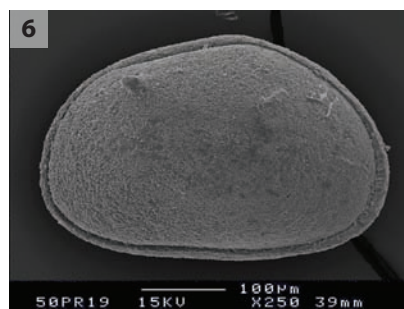
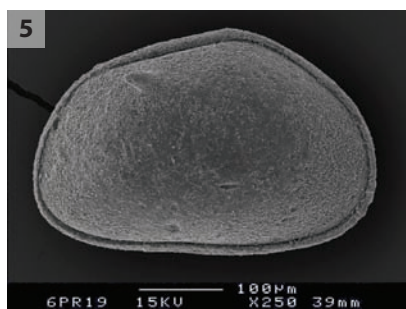
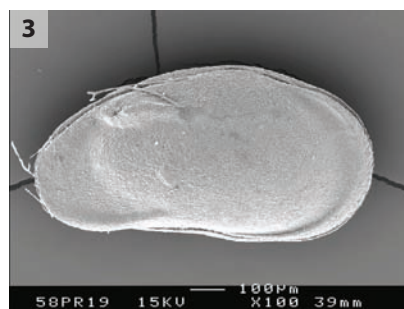
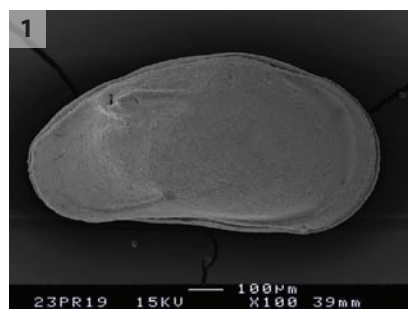


Plate 25: Ostracods

The sample from which the ostracod was extracted is indicated at the bottom left of each picture.

1. *Siciliella elongata* gen. nov. sp. nov. Holotype; right lateral view of complete carapace
2. *Siciliella elongata* gen. nov. sp. nov., right lateral view of complete carapace
3. *Siciliella elongata* gen. nov. sp. nov., right lateral view of a right valve
4. *Siciliella elongata* gen. nov. sp. nov. Paratype; right lateral view of complete carapace
5. *Siciliella elongata* gen. nov. sp. nov., left lateral view of complete carapace
6. *Siciliella elongata* gen. nov. sp. nov., right lateral view of complete carapace
7. *Siciliella spinorobusta* gen. nov. sp. nov. Holotype; right lateral view of complete carapace
8. *Siciliella spinorobusta* gen. nov. sp. nov. Paratype; right lateral view of complete carapace
9. *Pseudospinella bitauniensis*, right lateral view of complete carapace
10. *Cristanaria? katyae* sp. nov. Holotype; right lateral view of complete carapace
11. *Cristanaria? katyae* sp. nov. Paratype; right lateral view of complete carapace
12. *Cristanaria? katyae* sp. nov., right lateral view of complete carapace
13. *Cristanaria? katyae* sp. nov., right lateral view of complete carapace
14. cf. *Baschkirina* sp. nov.1, right lateral view of complete carapace
15. *Paraberounnella? laterospinosa*, right lateral view of right valve
16. *Basslerella* cf. *tota*, right lateral view of right valve
17. *Visnyoella parva*, left lateral view of a left valve
18. *Graphiadactyllis* cf. *deminuera*, right lateral view of complete carapace

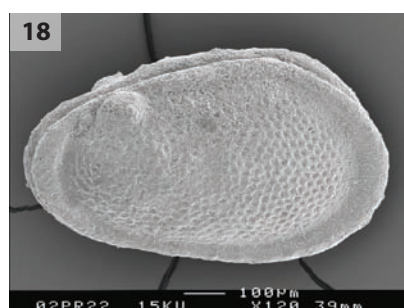
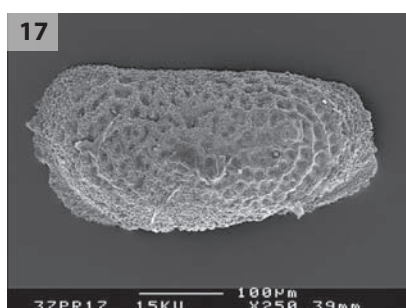
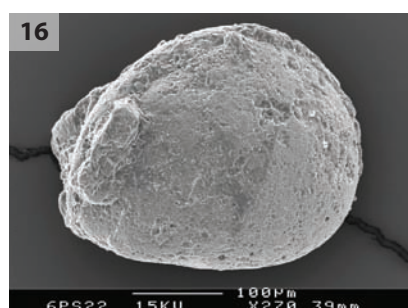
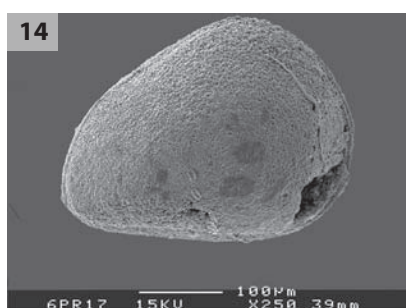
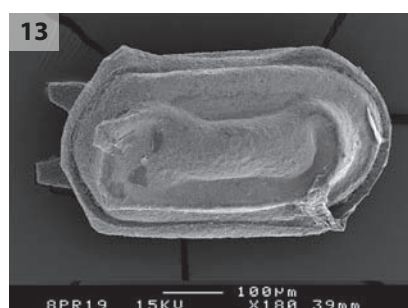
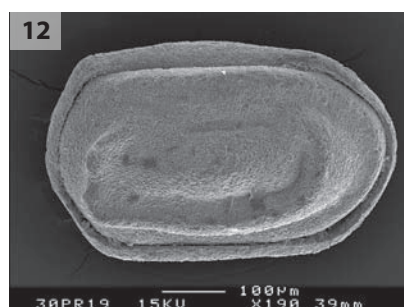
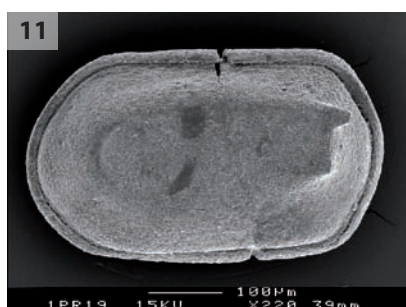
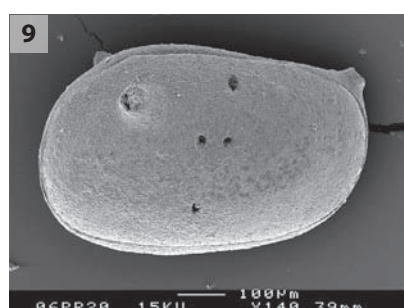
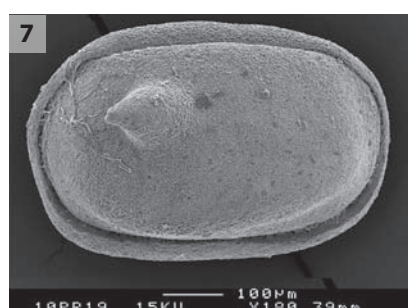
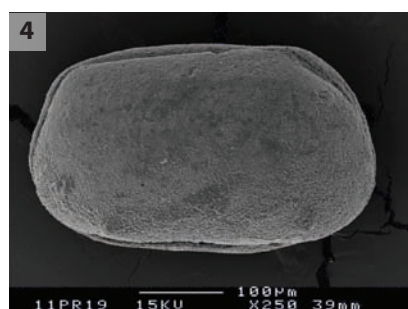
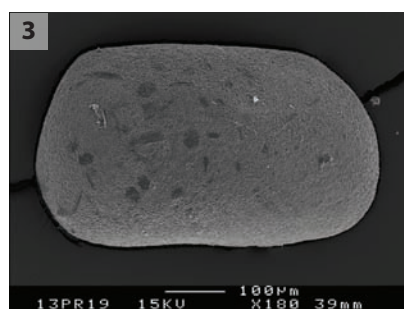
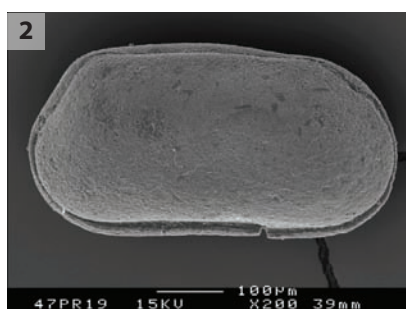
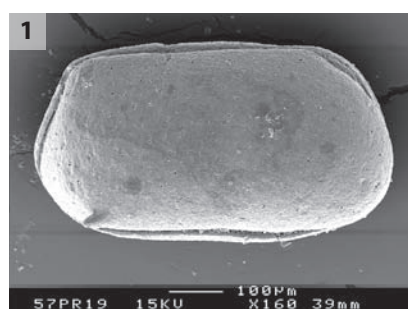


Plate 26: Conodonts

Conodonts found in the Lercara Formation, all belonging to *Mesogondolella siciliensis* (Kozur, 1975) group. For each specimen, numbered 1 to 6, three views are presented: upper (a), lower (b), and lateral (c).

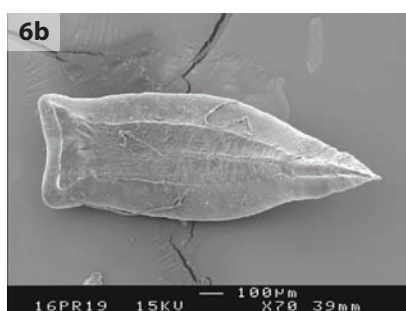
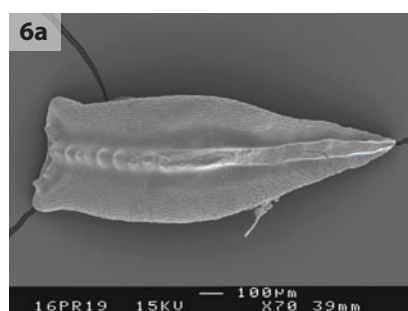
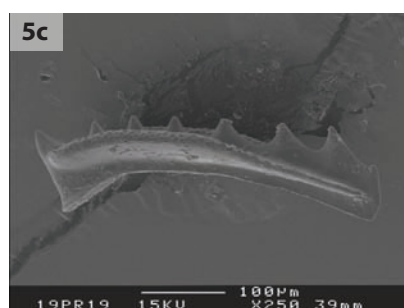
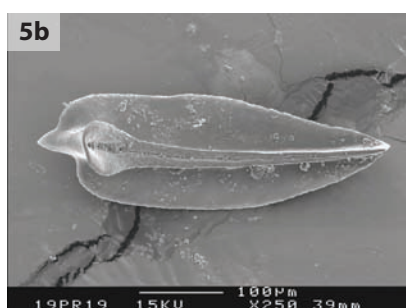
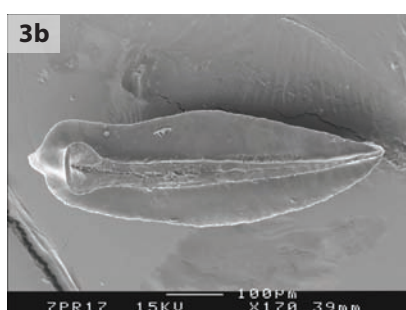
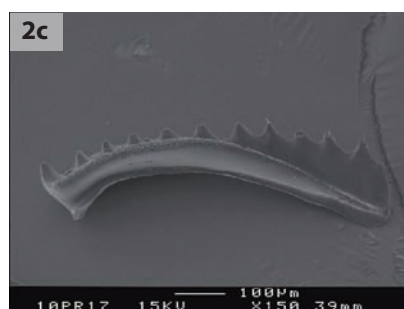
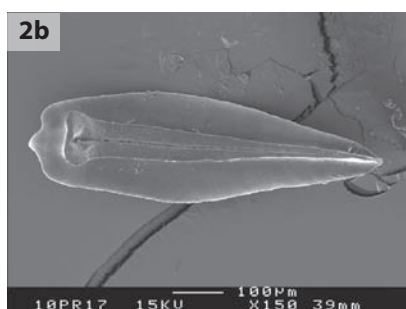
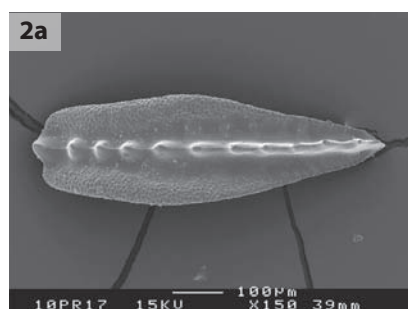
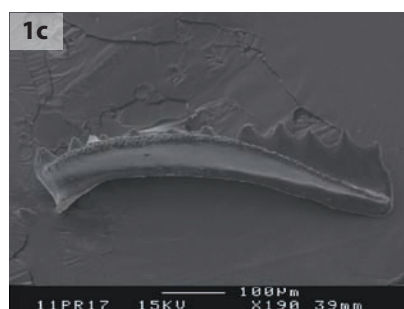
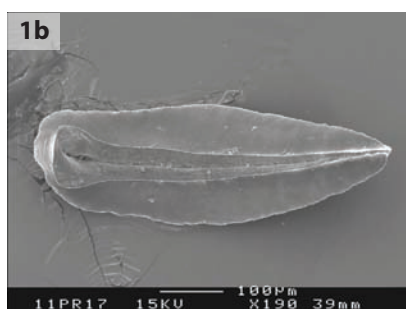
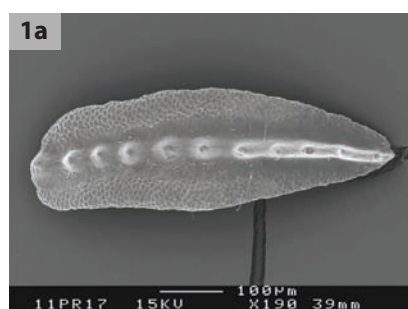


Plate 27: Triassic Foraminifera

1. *Pilamina* cf. *Pilamina densa*, oblique section, sample PR21
2. *Trochamina*? sp., transversal section , sample RP27
3. *Trochamina* aff. *Trochamina almtalensis*, longitudinal section, sample PR21
4. *Endotabanella kocaeliensis*, longitudinal section, sample RPFa2
5. *Endotriadella wirzi*, longitudinal section, sample RP29
6. *Endotriadella wirzi*, longitudinal section, sample RP27
7. *Endotriadella wirzi*, longitudinal section, sample PS23
8. *Cucurbita* ? sp., longitudinal section, sample PR21

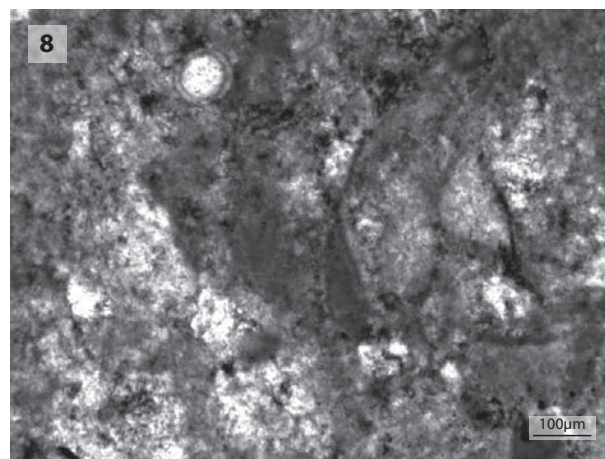
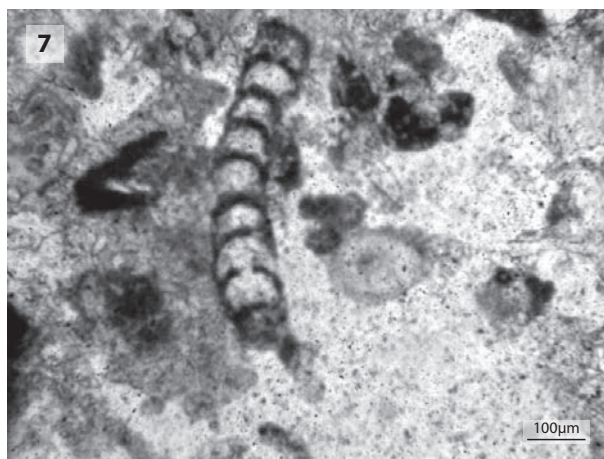
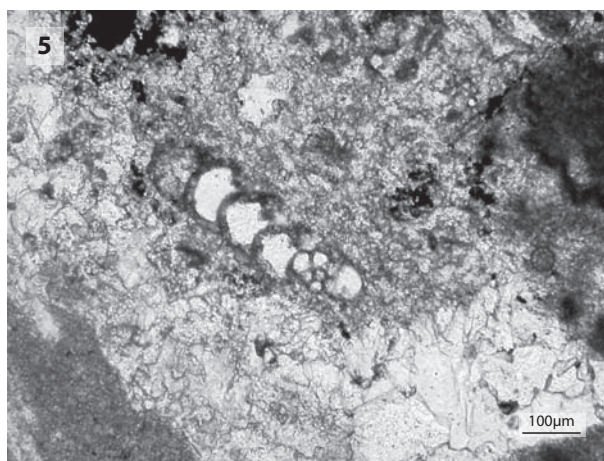
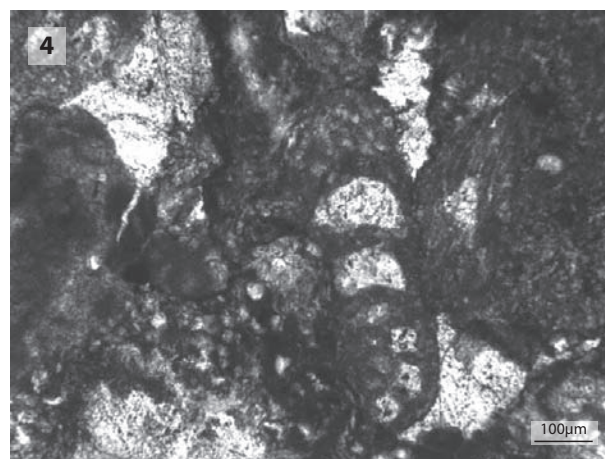
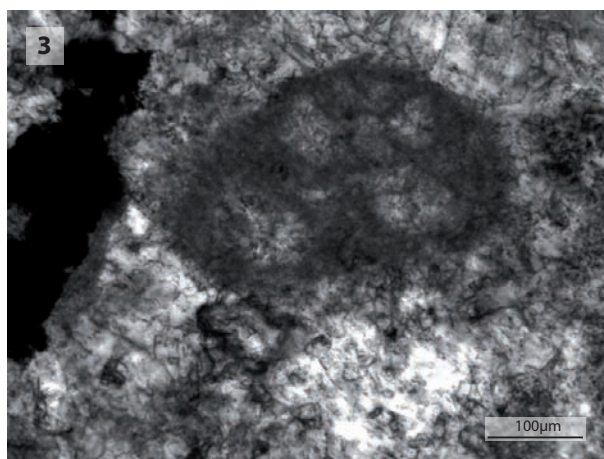
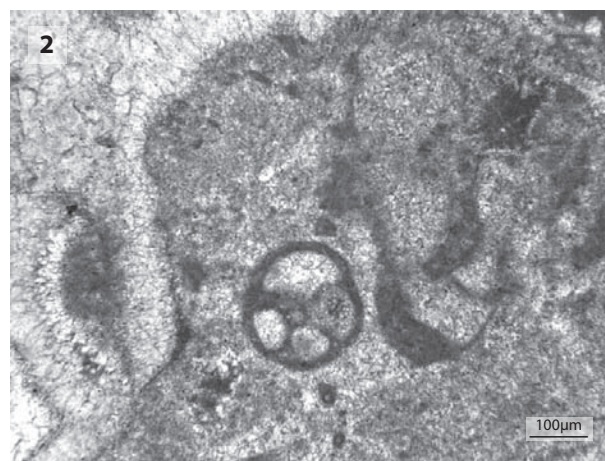
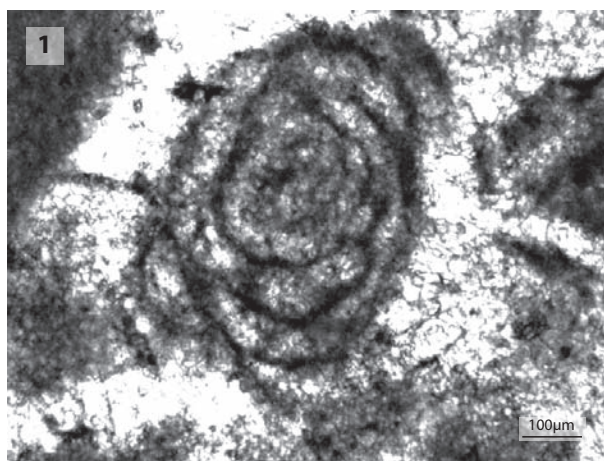


Plate 28: Triassic Foraminifera of the Lercara and the Mufara Formations

1. *Cucurbita* ? sp., longitudinal section, sample RP27
2. *Cucurbita* cf. *Cucurbita infundibuliformis*, longitudinal section , sample RP27
3. *Hoyenella* gr. *sinensis*, transversal section, sample PR21
4. *Meandrospira pusilla*, transversal section, sample PR18
5. *Cucurbita* cf. *Cucurbita infundibuliformis*, longitudinal section , sample CI9 (Mufara Formation)
6. *Cucurbita* cf. *Cucurbita infundibuliformis*, longitudinal section , sample CI9 (Mufara Formation)

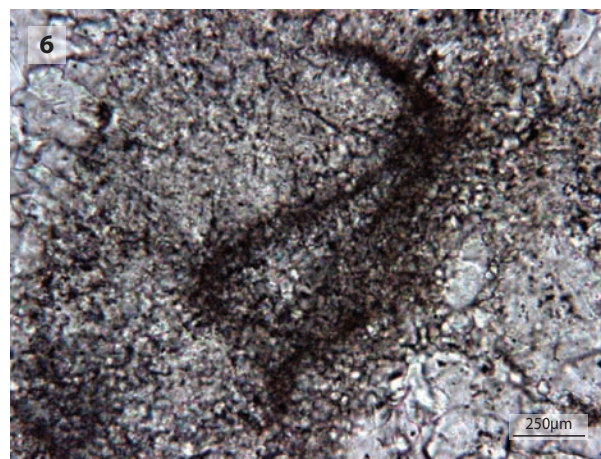
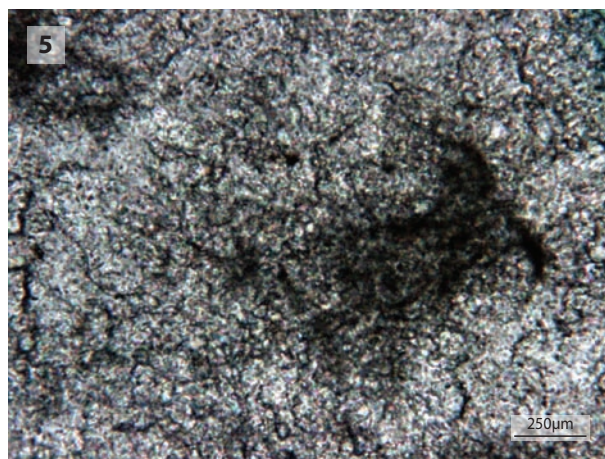
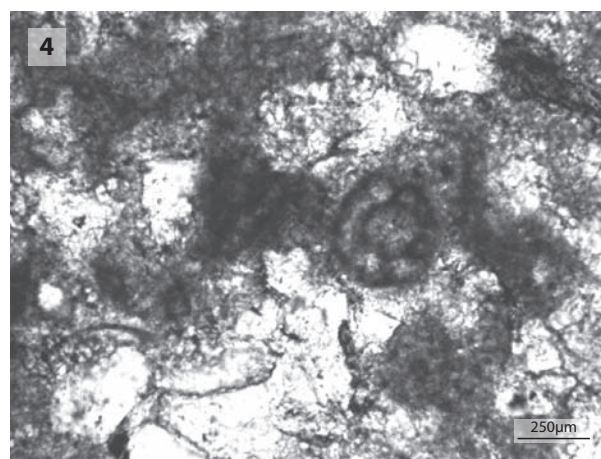
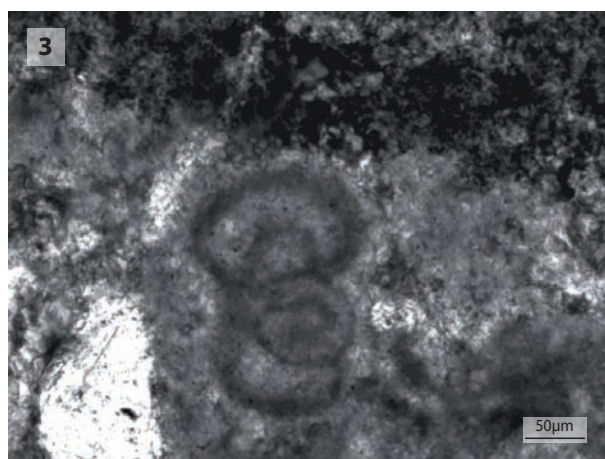
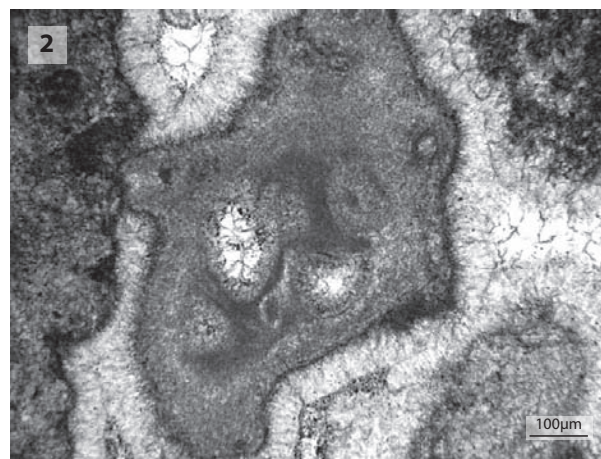
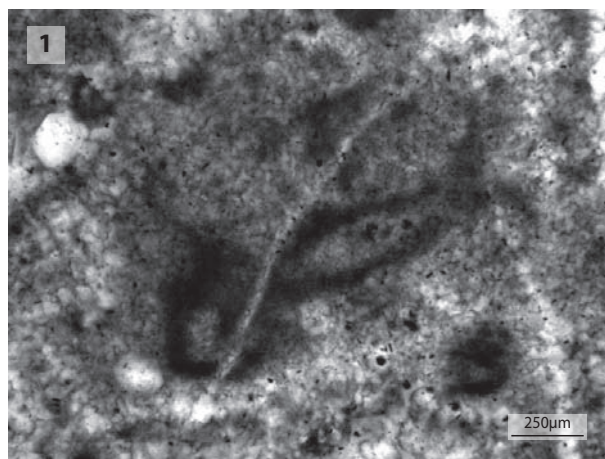


Plate 29: Acritarchs

1. *Acriora* sp. cf. *A. petala*, sample PS9
2. *Dictyotidium* sp., sample PS15
3. *Dilatisphaera* sp., sample PS42
4. *Oppilatala* sp., sample PS24
5. *Polygonium* sp. 1, sample RPFa11
6. *Polygonium* sp. 1, sample RPFa11

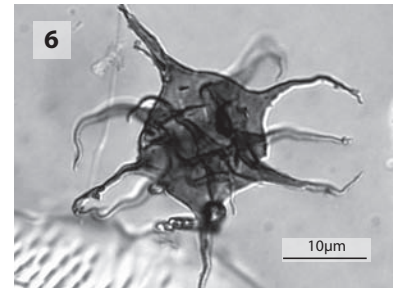
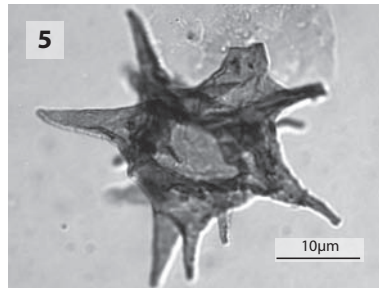
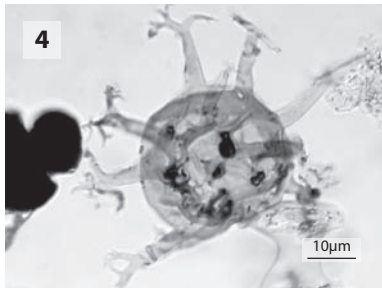
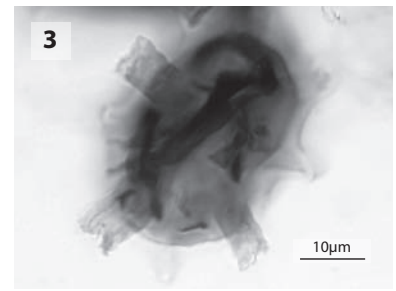
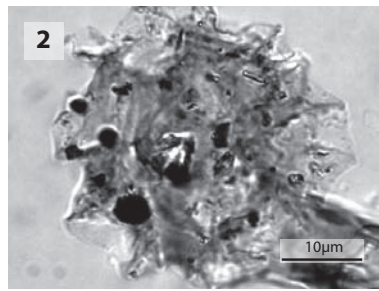
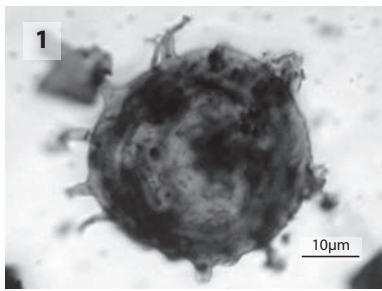


Plate 30: Permian palynomorphs

1. *Leiotriletes ulutus*, sample PS1
2. *Neoraistrikiia caudicea*, sample PS1
3. *Krauselisporites* cf. *K. wargalensis*, sample PS5
4. *Cannanoropollis bilateralis*, sample PS5
5. *Cordaitina* sp. sample PS12
6. *Crucisaccites variosulcatus*, sample PR23
7. *Densipollenites oviformis*, sample PS9
8. *Florinites eremus*, sample CSF8
9. *Florinites luburae*, sample PS5
10. *Nuskoisporites* sp., sample PS1
11. *Nuskoisporites dulhuntyi*, sample CSF7
12. *Nuskoisporites klausii*, sample PS5
13. *Parasaccites* sp., sample PS4
14. *Plicatipollenites indicus*, sample PS5
15. *Plicatipollenites trigonalis*, sample PS3
16. *Potonieisporites granulatus*, sample PS 4
17. *Potonieisporites novicus*, sample PS11
18. *Vestigisporites* sp., sample PS32

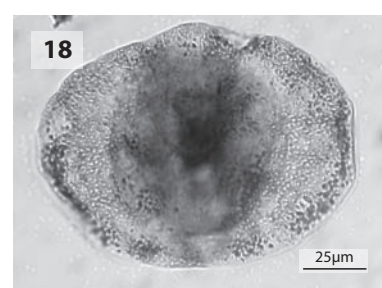
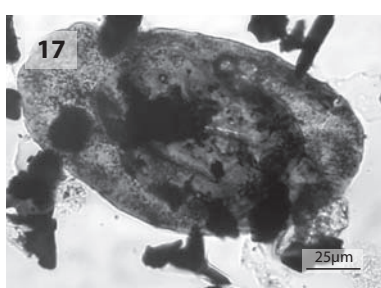
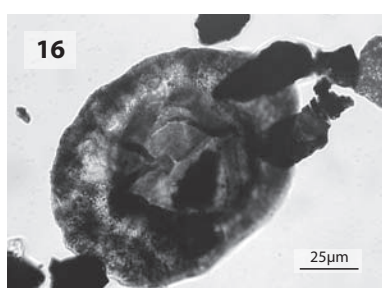
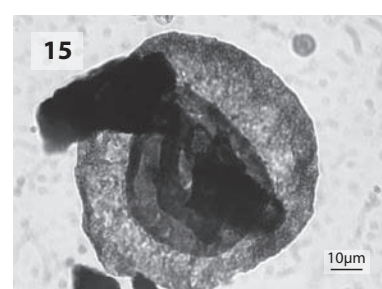
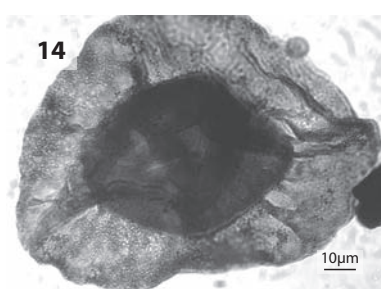
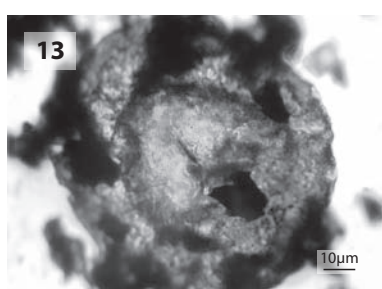
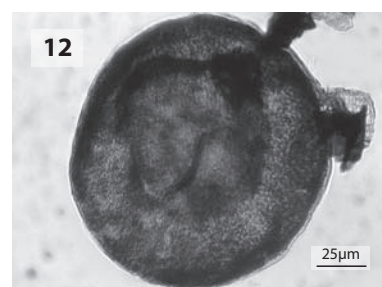
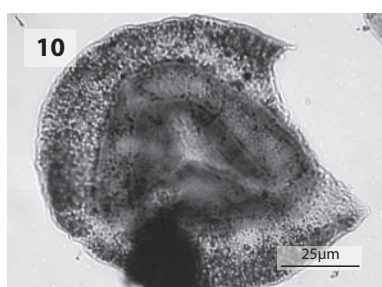
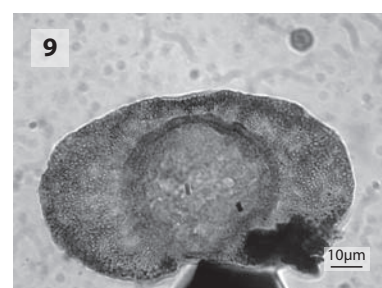
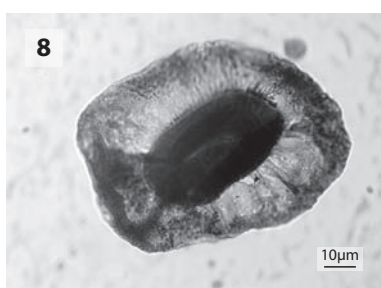
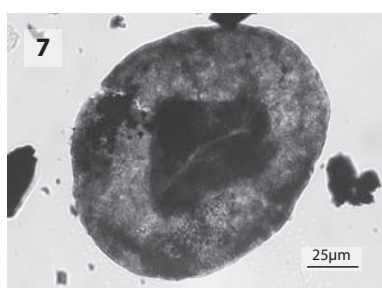
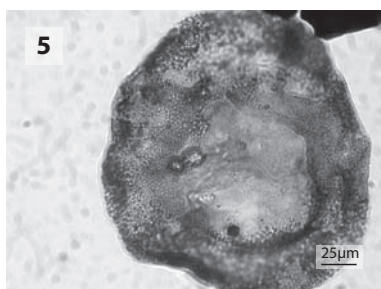
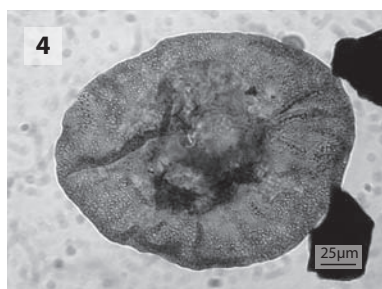
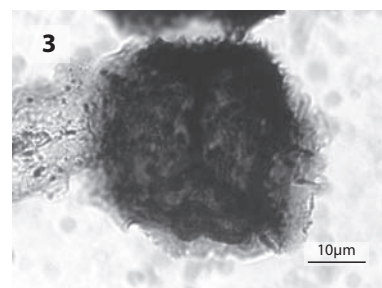
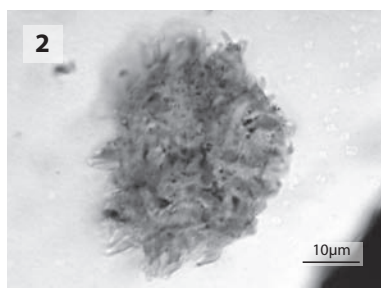
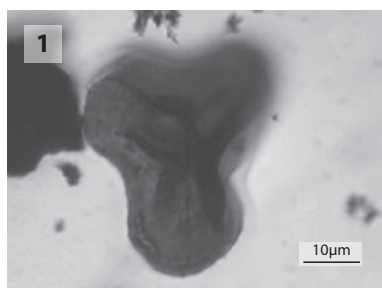


Plate 31: Permian palynomorphs

1. *Wilsonites* sp., sample PS4
2. *Korbapollenites* sp., sample PS4
3. *Sulcatipollenites nillsonii*, sample PS33
4. *Sulcatisporites ovatus*, sample PS7
5. *Vesicaspora wilsonii*, sample PS7
6. *Gardenasporites heisseli*, sample RP21
7. *Illinites spectabilis*, sample PS42
8. *Jugasporites delasaucei*, sample PR23
9. *Limitisporites monstruosus*, sample PR23
10. *Corisaccites alutas*, sample PR23
11. *Hamiapollenites bullaeformis*, sample PS29
12. *Hamiapollenites erebi*, sample CSF13
13. *Hamiapollenites* cf. *H. insolitus*, sample RP17
14. *Hamaipollenites karrooensis*, sample PS30
15. *Hamaipollenites* cf. *H. tractiferinus*, sample PS1
16. *Hamiapollenites saccatus*, sample BS2
17. *Lueckisporites virkkiae*, sample PR23
18. *Lueckisporites virkkiae*, sample RP17

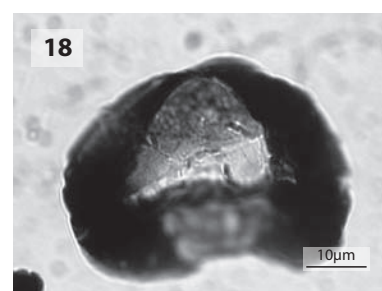
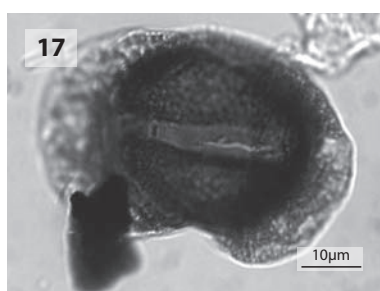
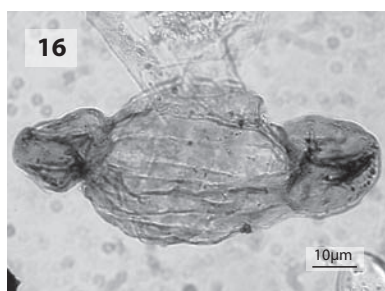
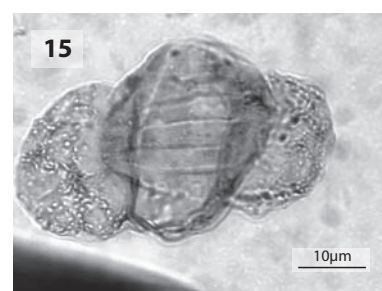
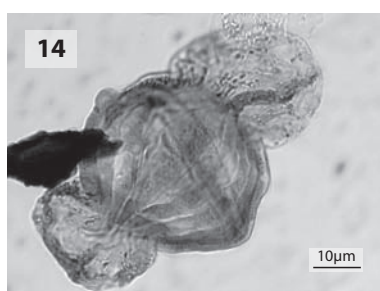
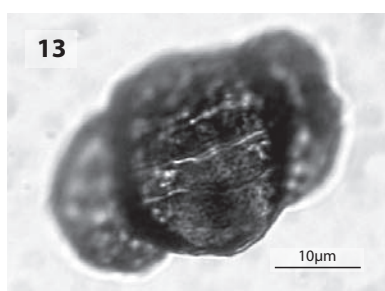
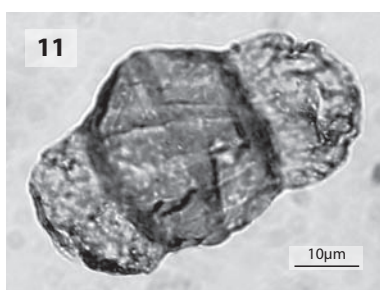
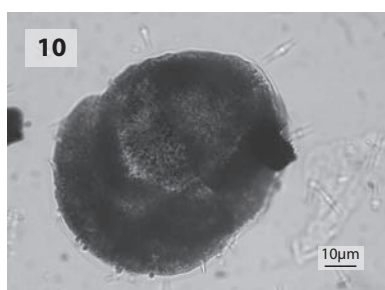
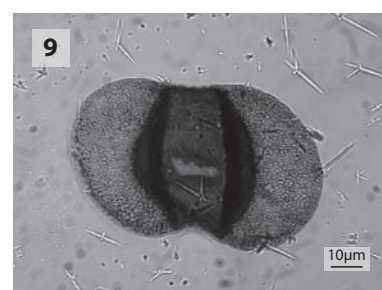
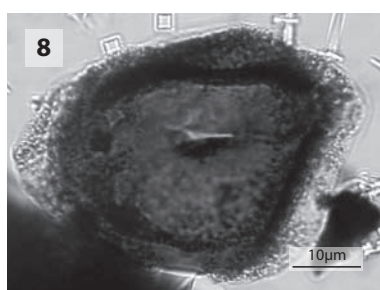
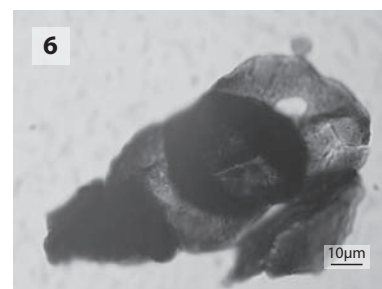
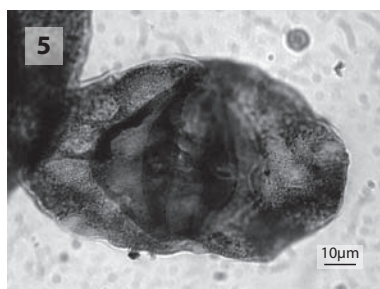
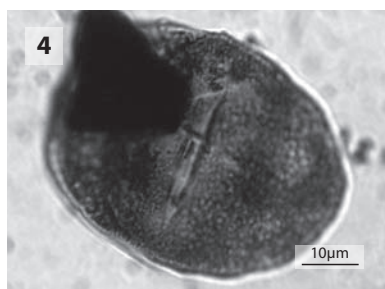
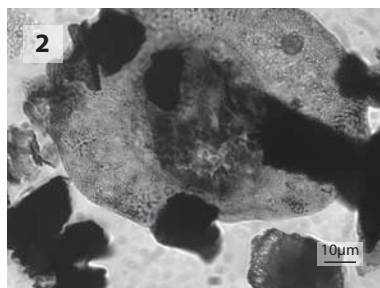
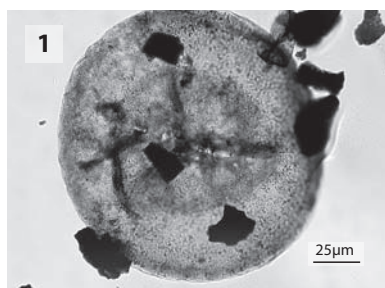


Plate 32: Permian and Upper Permian to Lower Triassic palynomorphs

1. *Tornopollenites toreutos*, sample PS1 (Permian)
2. *Vittatina costabilis*, sample PS11 (Permian)
3. *Vittatina simplex*, sample RP17 (Permian)
4. *Vittatina* cf. *V. striata*, sample RPFa7 (Permian)
5. *Vittatina vittifera*, sample PS1 (Permian)
6. *Weylandites striatus*, sample PR23 (Permian)
7. *Packapites rotundus*, sample PS3 (Permian)
8. *Costapollenites ellipticus*, sample PS3 (Permian)
9. *Kraeuselisporites apiculatus*, sample PS3 (Upper Permian to Lower Triassic)
10. *Krauselisorites spinosus*, sample PR23 (Upper Permian to Lower Triassic)
11. *Densoisorites playfordii*, sample PS28 (Upper Permian to Lower Triassic)
12. *Lundbludispora brevicula*, sample PS24 (Upper Permian to Lower Triassic)
13. *Densipollenites indicus*, sample PS29 (Upper Permian to Lower Triassic)
14. *Playfordiaspora crenulata*, sample PS13 (Upper Permian to Lower Triassic)
15. *Klausipollenites schaubergeri*, sample PS3 (Upper Permian to Lower Triassic)
16. *Striatoabieites richteri*, sample RP21 (Upper Permian to Lower Triassic)

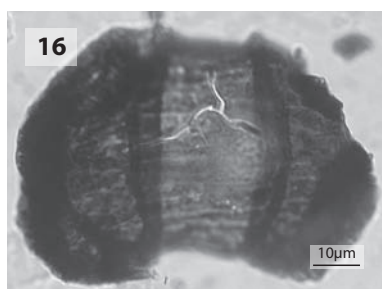
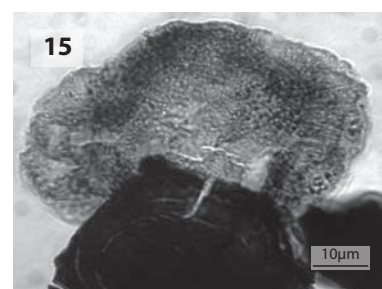
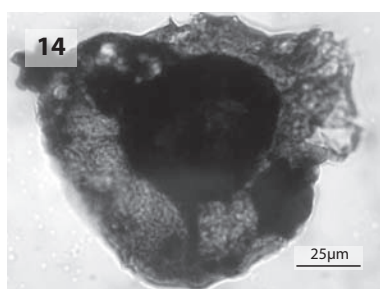
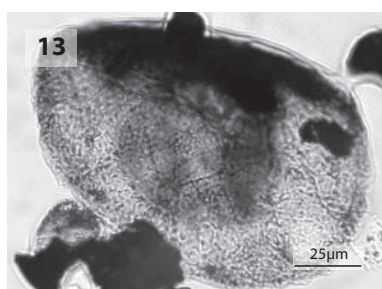
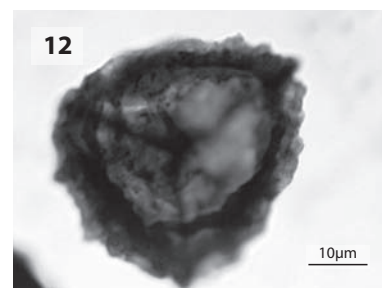
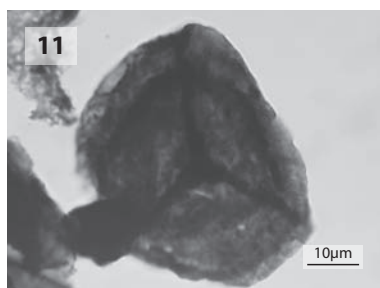
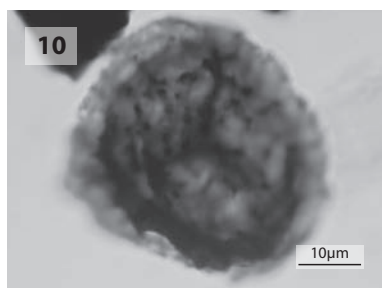
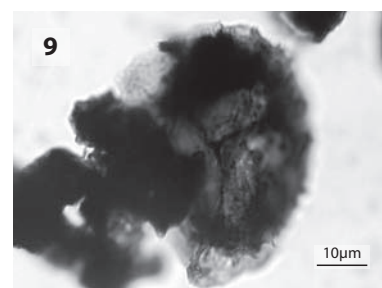
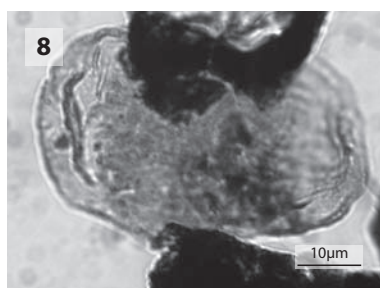
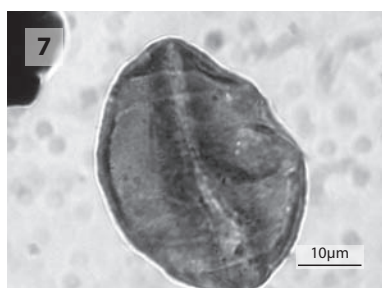
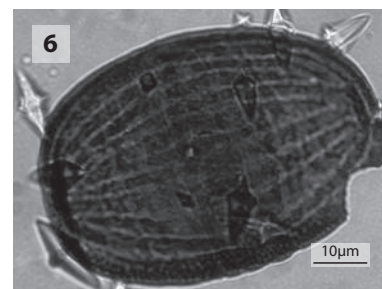
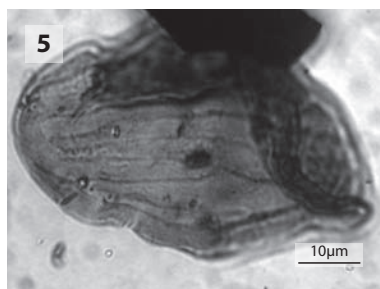
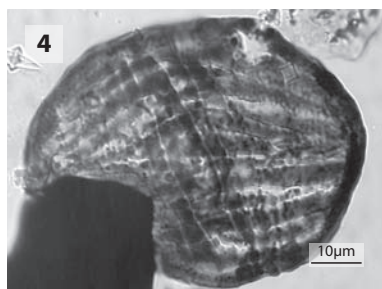
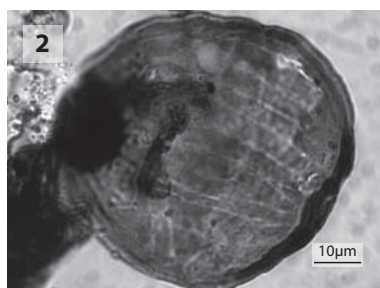


Plate 33: Triassic palynomorphs

1. *Anapiculatisporites decorus*, sample PS9 (Lercara Formation)
2. *Uvaesporites* sp., sample PS33 (Lercara Formation)
3. *Verrucosisporites contactus*, sample PS3 (Lercara Formation)
4. *Lycopodiacidites kuepperi*, sample PS4 (Lercara Formation)
5. *Lycopodiacidites kuepperi*, sample PS29 (Lercara Formation)
6. *Propisporites pococki*, sample PS1 (Lercara Formation)
7. *Sellaspora rugoverrucata*, sample PR23 (Lercara Formation)
8. *Sellaspora rugoverrucata*, sample RP28 (Lercara Formation)
9. *Sellaspora rugoverrucata*, sample BS2 (Lercara Formation)
10. *Kraeuselisporites cuspidus*, sample PS1 (Lercara Formation)
11. *Kraeuselisporites cuspidus*, sample PS1 (Lercara Formation)
12. *Krauselisporites septatus*, sample PS5 (Lercara Formation)
13. *Aratrisporites fimbriatus*, sample PR23 (Lercara Formation)
14. *Aratrisporites* sp. cf. *A. spongeosus*, sample RP17 (Lercara Formation)
15. *Densoisporites nejburgii*, sample PS5 (Lercara Formation)
16. *Endosporites papillatus*, sample PS3 (Lercara Formation)
17. *Endosporites papillatus*, sample PS4 (Lercara Formation)
18. *Enzonelasporites vigens*, sample CI6 (Mufara Formation)

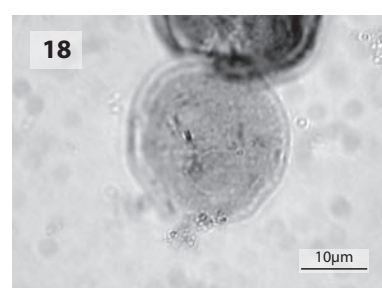
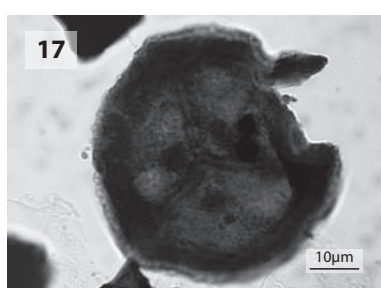
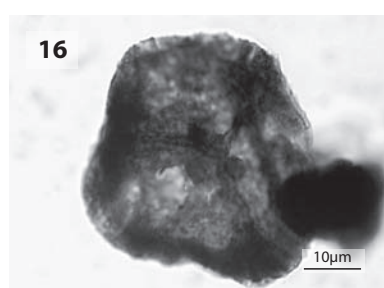
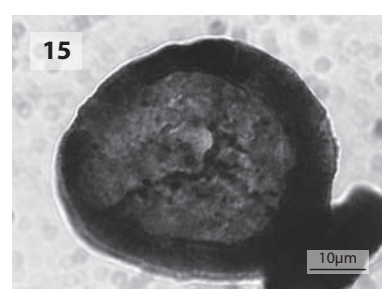
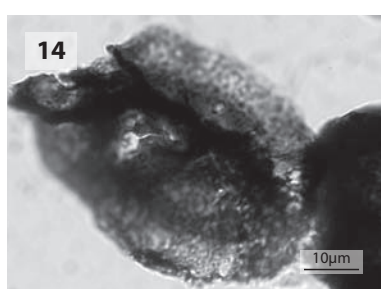
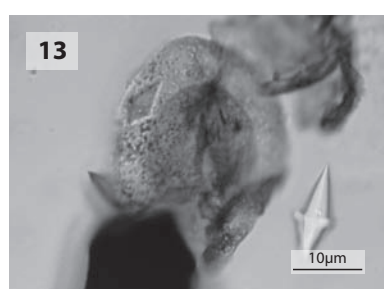
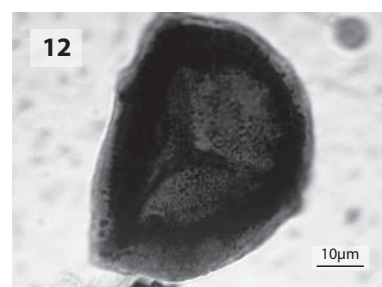
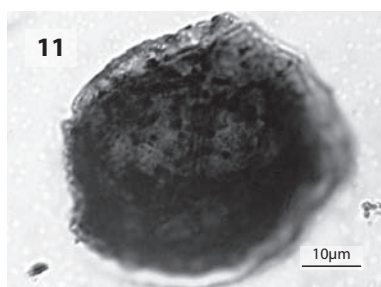
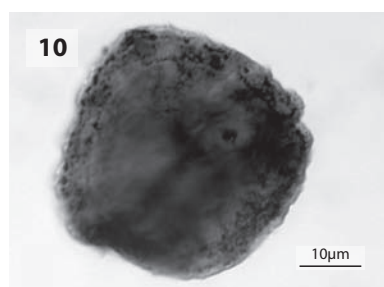
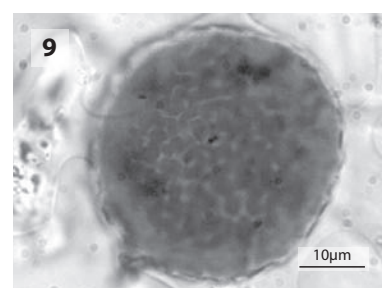
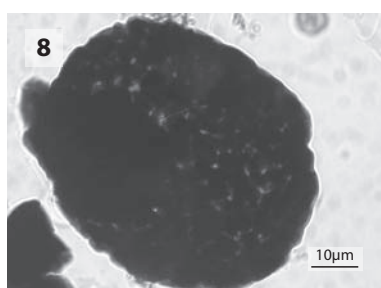
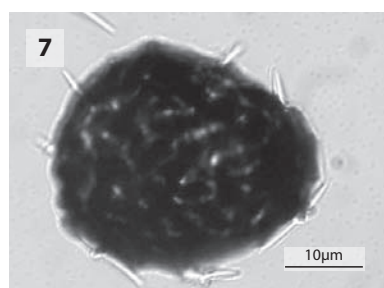
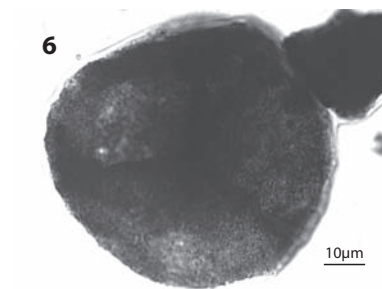
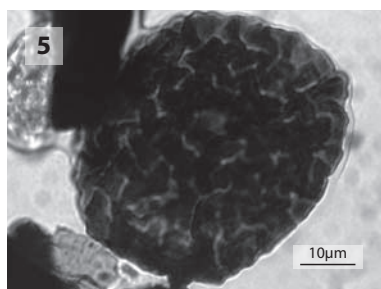
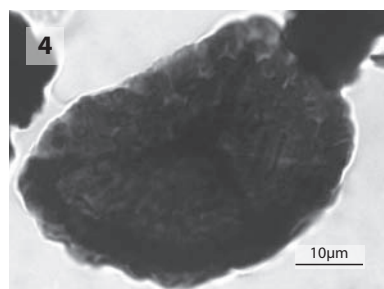
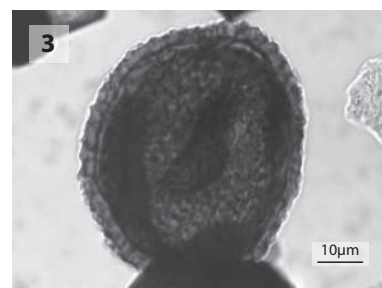
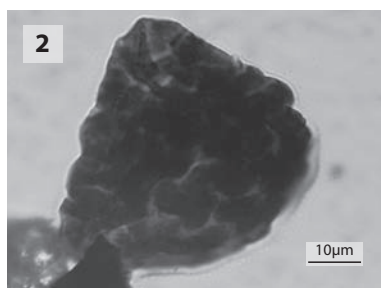
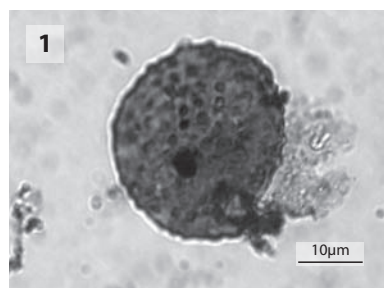


Plate 34: Triassic palynomorphs

1. *Ovalipollis pseudoalatus*, sample CI5 (Mufara Formation)
2. *Vallasporites ignacii*, sample RP20 (Lercara Formation)
3. *Vallasporites ignacii*, sample CI6 (Mufara Formation)
4. *Angustisulcites* sp., sample PR23 (Lercara Formation)
5. *Klausipollenites decipiens*, sample PS1 (Lercara Formation)
6. *Klausipollenites staplinii*, sample PR23 (Lercara Formation)
7. *Minutossaccus* sp., sample RP21 (Lercara Formation)
8. *Platysaccus queenslandi*, sample PS29 (Lercara Formation)
9. *Voltziaceasporites heteromorpha*, sample PS9 (Lercara Formation)
10. *Triadispora crassa*, sample PR23 (Lercara Formation)
11. *Triadispora obscura*, sample PS4 (Lercara Formation)
12. *Triadispora stabilis*, sample PS29 (Lercara Formation)
13. *Brodispora striata*, sample CI5 (Mufara Formation)
14. *Chordaesporites singulicorda* ?, sample PS9 (Lercara Formation)
15. *Ephedripites steevesii*, sample PR23 (Lercara Formation)
16. *Lunatisporites acutus*, sample PS33 (Lercara Formation)
17. *Lunatisporites albertae*, sample PS33 (Lercara Formation)
18. *Lunatisporites exagonalis*, sample PS7 (Lercara Formation)

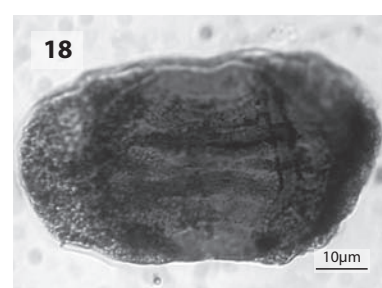
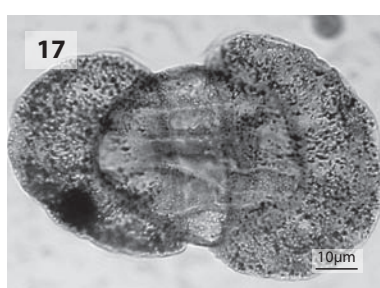
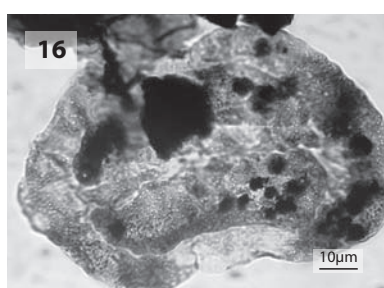
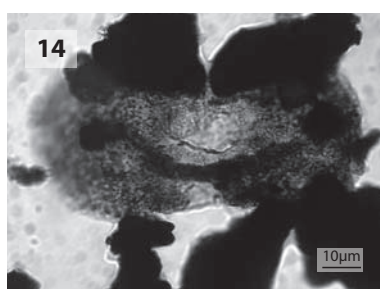
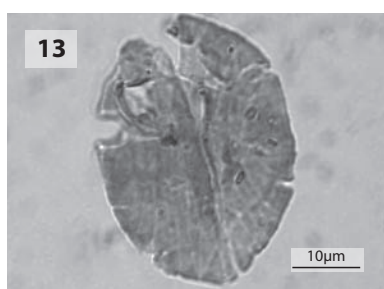
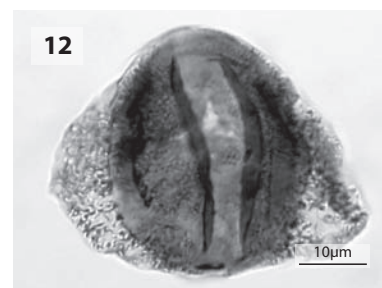
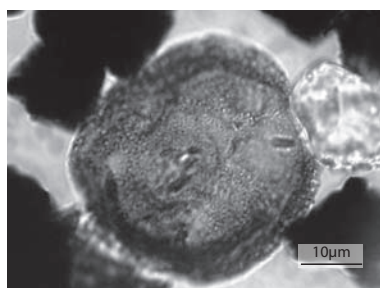
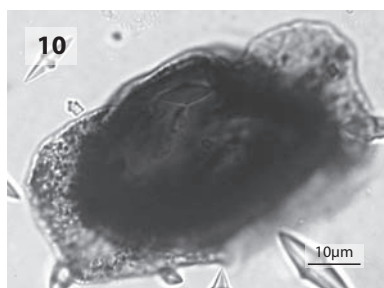
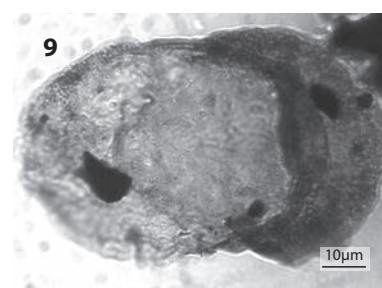
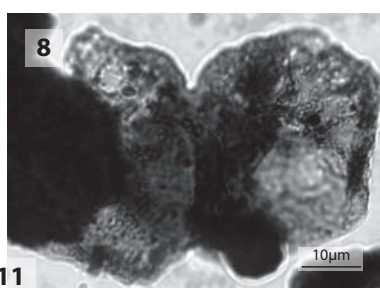
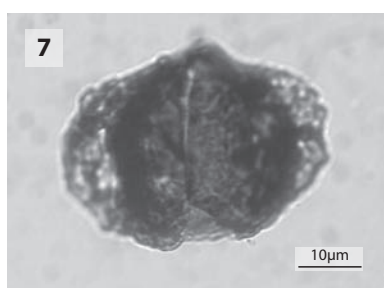
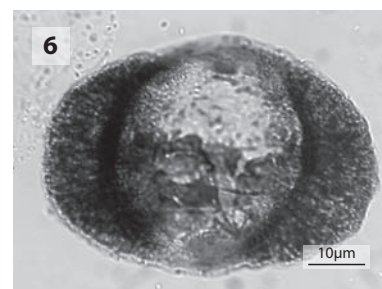
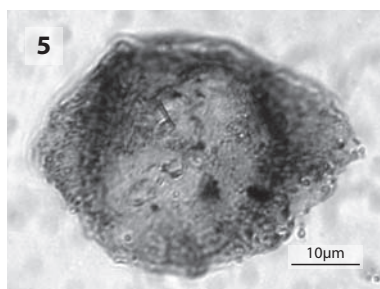
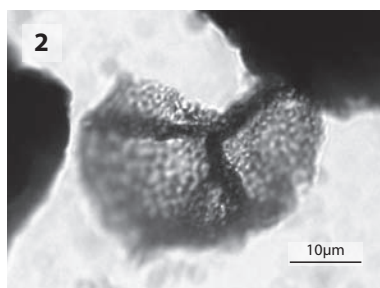
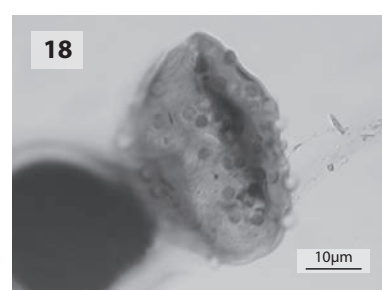
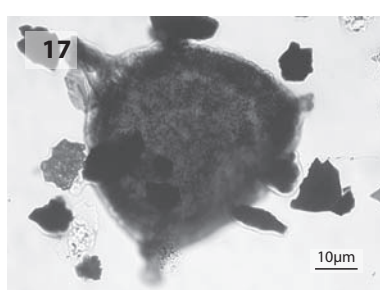
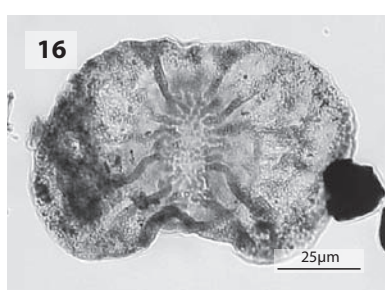
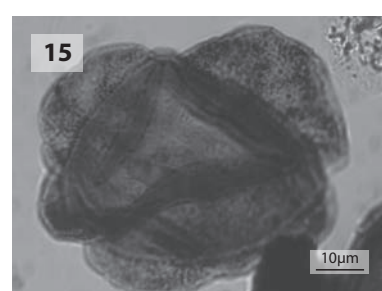
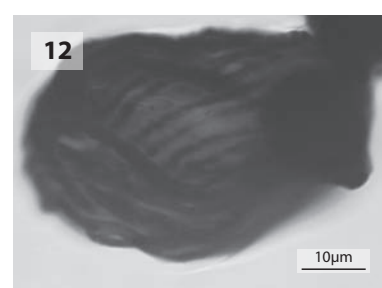
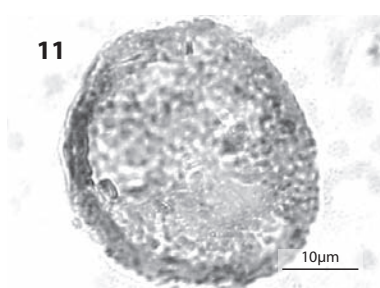
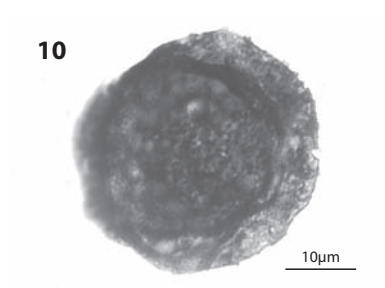
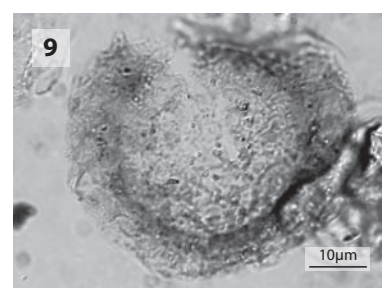
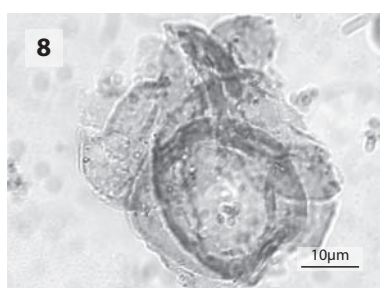
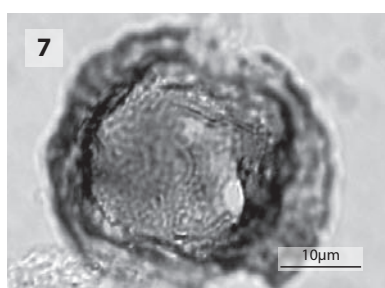
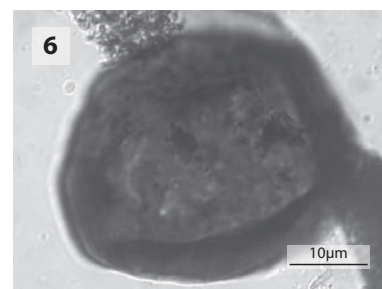
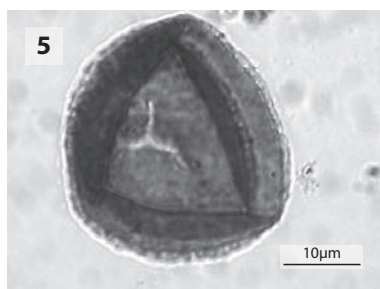
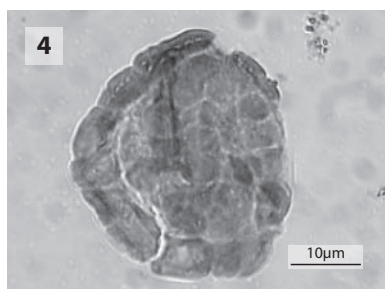
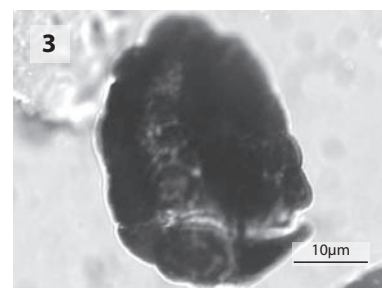
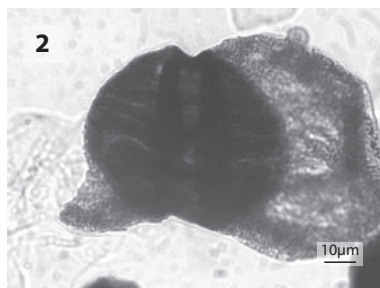
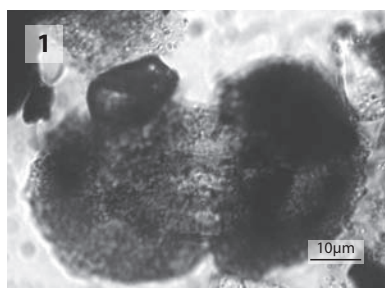


Plate 35: Triassic and indeterminate palynomorphs

1. *Lunatisporites transversundatus*, sample PS11 (Lercara Formation)
2. *Striatopodocarpites balmei*, sample BS2 (Lercara Formation)
3. *Camerosporites secatus*, sample RP18 (Lercara Formation)
4. *Camerosporites secatus*, sample CI5 (Mufara Formation)
5. *Duplicisporites granulatus*, sample CI4 (Mufara Formation)
6. *Partitisporites* sp., sample PR21 (Lercara Formation)
7. *Partitisporites* sp., sample RP17 (Lercara Formation)
8. *Partitisporites quadruplicis*, sample CI4 (Mufara Formation)
9. *Partitisporites novimundatus*, sample CM3 (Mufara Formation)
10. *Patinasporites densus*, sample CSi226 (Lercara Formation)
11. *Praecirculina granifer*, sample CI9 (Mufara Formation)
12. *Equisetosporites chinleanus*, sample PS29 (Lercara Formation)
13. *Grebespora concentrica*, sample PR23 (Lercara Formation)
14. Indeterminate, sample PR23
15. Indeterminate, sample PS4
16. Indeterminate, sample PS7
17. Indeterminate, sample PS35
18. Indeterminate, sample PS30



APPENDICES

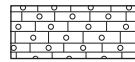
Appendix 1 Location of sampled outcrops.

Outcrops	C. T. R. 1:10,000 Topographic map:	WGS84 coordinates			Gauss-Boaga coordinates		UTM coordinates	Name of samples
		Latitude N	Longitude E	East Zone				
				North	East			
Cozzo Tabarani	N° 609070, Cozzo Tabarani	37°55'21"	13°51'28"	4,197,840	2,419,600	33SUB996198	CT 1-4	
Contrada Malluta	N° 609060, Cerdà	37°54'22"	13°50'22"	4,196,040	2,417,980	33SUB980960	CM 1-5	
Viadotto Faguara II	N° 610090, Pizzo Carbonara-Piano Battaglia	37°51'52"	13°02'22"	4,191,200	2,435,500	33SUB155191	VFI 1-3	
Vallone Faguara I	N° 610090, Pizzo Carbonara-Piano Battaglia	37°51'51"	13°01'57"	4,191,200	2,434,900	33SUB149191	VFI 1-3	
Roccapalumba mercato	N° 620040, Manganaro	37°37'46"	13°39'20"	4,184,040	2,401,644	33SUB817184	RP 16-29	
Torrente Ferro	N° 621010, Alia	37°47'27"	13°40'03"	4,183,453	2,402,680	33SUB827183	TF 1-4	
Cozzo San Filippo 1	N° 620040, Manganaro	37°47'24"	13°38'34"	4,183,391	2,400,500	33SUB805183	CSF 1-4	
Cozzo San Filippo 2	N° 620040, Manganaro	37°47'11"	13°38'34"	4,183,000	2,400,500	33SUB805183	CSF 5-18	
Roccapalumba ferrovia	N° 620040, Manganaro	37°46'34"	13°40'04"	4,181,800	2,402,680	33SUB827182	RPFa 1-11/b 1-15	
Cozzo Intronata (lower part)	N° 620040, Manganaro	37°45'28"	13°37'44"	4,179,843	2,399,215	33SUB792180	CI 3-6	
Cozzo Intronata (upper part)	N° 620040, Manganaro	37°51'45"	13°38'08"	4,191,426	2,400,000	33SUB800191	CI 7-9	
Bivio Pietra dei Saraceni	N° 620090, Palazzo Adriano	37°39'40"	13°21'33"	4,169,470	2,375,264	33SUB553685	BS 1-2	
Pietra di Salomone	N° 620090, Palazzo Adriano	37°39'26"	13°22'20"	4,169,038	2,376,423	33SUB564169	PS 1-42 and Si	
Portella Rossa 1	N° 619160, Burgio	37°38'03"	13°16'51"	4,166,618	2,368,303	33SUB348416	PR 16-23	
Portella Rossa 2	N° 619160, Burgio	37°38'12"	13°16'58"	4,166,886	2,368,491	33SUB485167	PR 24-29	
San Filippo	N° 620040, Manganaro	37°47'22"	13°38'42"	4,183,327	2,400,692	33SUB807189	SF 1-2	
Affumata	N° 620040, Manganaro	37°46'17"	13°39'30"	4,181,307	2,401,846	33SUB819181	AF	
Case Pettineo magmatic occurrence	N° 620040, Manganaro	37°47'02"	13°36'34"	4,182,760	2,397,560	33SUB771182	Bas	
Bivio Garuffa	N° 620040, Manganaro	37°46'39"	13°38'49"	4,182,000	2,400,846	33SUB155191	BG1-2	
Pietra dei Saraceni	N° 620090, Palazzo Adriano	37°40'12"	13°21'32"	4,170,471	2,375,264	33SUB553170	Saraceni	

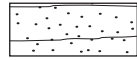
Appendix 2.1 Lithological and sedimentological legend.



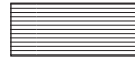
Quartz-rich shales



Packstones



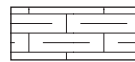
Clayey sandstones



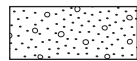
Marls



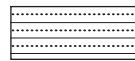
Coarse calcarenites to calcirudites



Calcareous marls



Medium to very fine calcarenites



Marly sandstones



Limestones



Sharp contact



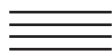
Tabular cross bedding



Erosive contact



Horizontal burrow



Parallel lamination



Flute cast



Massive banks



Slump



Normal gradation



Pencil cleavage



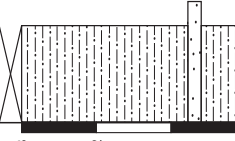
Reverse gradation



Occurrence

198

Appendix 2.3 Cozzo San Filippo 1 section.

Cozzo San Filippo 1					
Formation	Age	Scale in meters	Lithology	Field Observation	Samples
Lercara Formation	Not older than Late Permian	3 2 1 0			
Microscopic investigations					
			Thin sections	●	
			Washed samples	●	
			Palyonological processing	●	
			Conodont extraction		
Sedimentology					
			Microlacae	- - - - -	
			Rip-up clasts	- - - - -	
			Carbonate fragments		
			E. to L. Permian carb. fragments		
			E. to M. Triassic carb. fragments		
			Quartz	●	
			Clast of clayey sandstones		
			Feldspars	●	
Paleontological content of Early to Late Permian					
			<i>Archaeolithoporella idensis</i>		
			<i>Bacnella</i> sp.		
			Daykladale algae		
			<i>Milizia</i> sp.		
			<i>Chuvashovia densifolia</i>		
			<i>Koivaelia permienensis</i>		
			<i>Pseudovermiporella ellioti</i>		
			<i>Tubiphytes obscurus</i>		
			<i>Tubiphytes carinthiacus</i>		
			Sponges		
			Gastropods		
			Ammonites		
			Brachiopods		
			Spicules of sponges		
			Bryozoans		
			Echinoderm spines		
			Trilobites		
			Ostracods		
			Radiolarians		
			Conodonts		
			Foraminifera		
Foraminifera					
			(Permian and/or Triassic)		
			Autochthonous		
			Long ranging		
Palyonomorphs					
			(Permian and/or Triassic)	●	
			Autochthonous	●	
			Long ranging	●	

Appendix 2.4 Cozzo San Filippo 2 section.

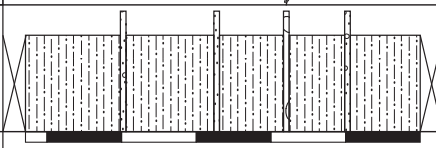
201

202

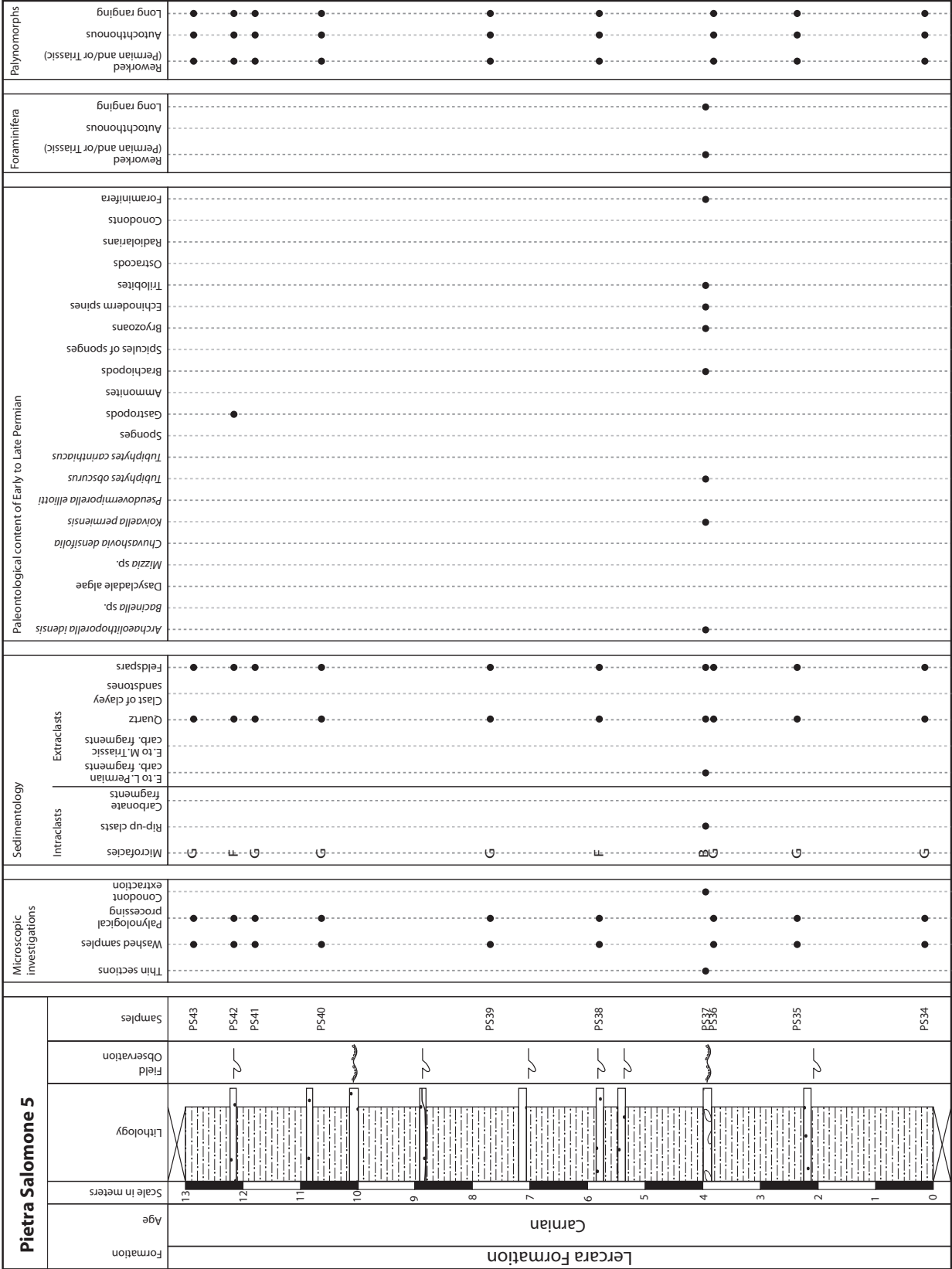
Appendix 2.7 Pietra di Salomone 1 and 2 sections.

[illegible]

4

Pietra Salomone 3						Microscopic investigations		Sedimentology		Paleontological content of Early to Late Permian																Foraminifera		Palynomorphs																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
Formation	Age	Scale in meters	Lithology	Field Observation	Samples	Thin sections	Washed samples	Palynological processing	Conodont extraction	Microfossils	Intraclasts		Extraclasts				Archaeolithoporella idensis	Bacella sp.	Daycladale algae	Mizzia sp.	Chuvashovia densifolia	Koivaelia permianensis	Pseudovermiporella ellioti	Tubiphytes obscurus	Tubiphytes carinthiacus	Sponges	Gastropods	Ammonites	Brachiopods	Spicules of sponges	Bryozoans	Echinoderm spines	Trilobites	Ostracods	Radiolarians	Conodonts	Foraminifera	Reworked (Permian and/or Triassic)	Autocochthonous	Long ranging																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
											Rip-up clasts	Carbonate fragments	E. to L. Permian	E. to M. Triassic	carb. fragments	carb. fragments																									Quartz	Clast of clayey sandstones	Feldspars																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
Lercara Formation	Carnian	5 4 3 2 1 0			PS29	●	●	●	●	●	G																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						

Appendix 2.9 Pietra di Salomone 5 section.

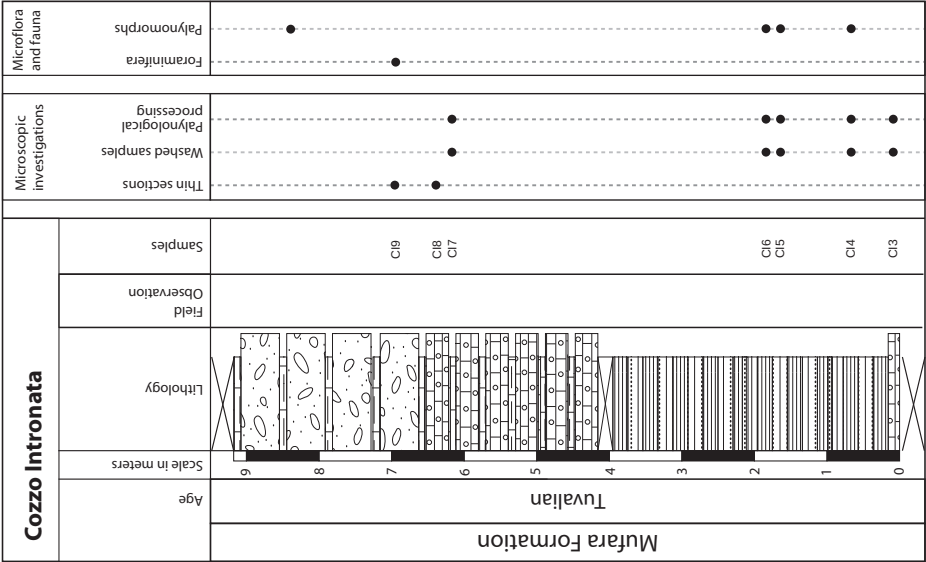
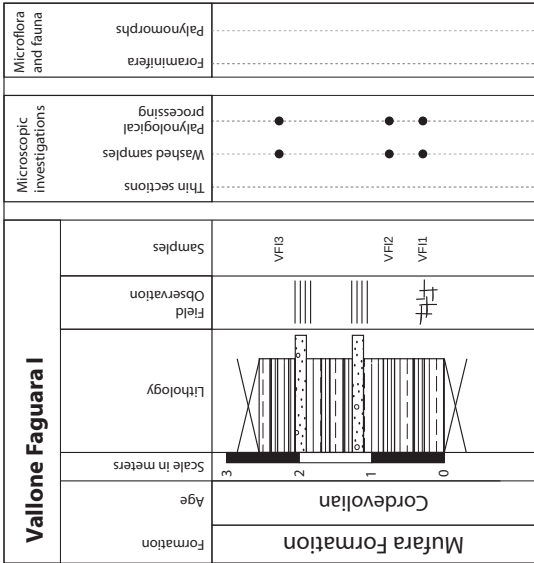
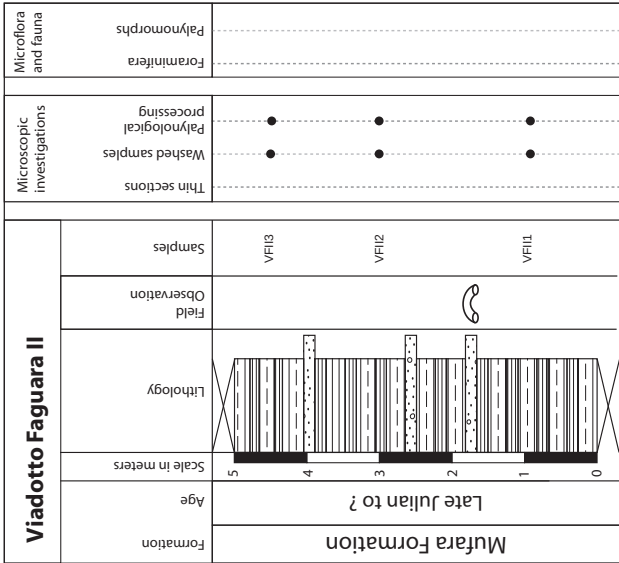
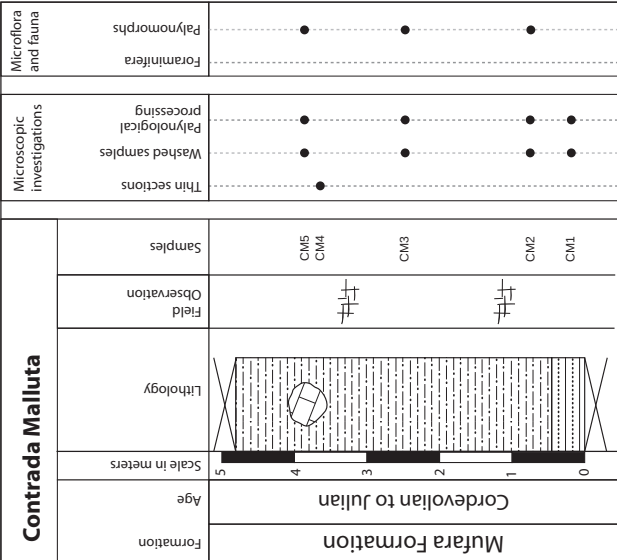
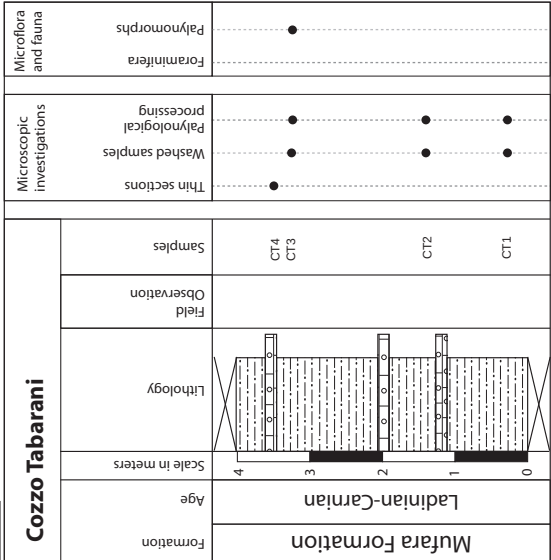


[illegible]

Appendix 2.11 Isolated samples.

[illegible]

Appendix 2.12 Mufara Formation sections.



Appendix 3 List of palynological species with their stratigraphical range and geographical distribution provided by literature.

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Alisporites opii</i> (Daugherty), Jansonius, 1971 Disaccites	Triassic System Early Triassic Late Ladinian to Rhaetian, acme Carnian to Rhaetian ● sr: Triassic long ranging	Hart, 1965 Ottone & Garcia, 1991 Cornet, 1993	Argentina Northern America
<i>Alisporites plicatus</i> Jizba, 1962 Disaccites	<i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) to Utting, 1994 <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian)) ● sr: late Early Permian to Middle Permian		Canadian Arctic Archipelago
<i>Alisporites</i> sp.- <i>Falcisporites</i> sp. Disaccites	● sr: Permian to Triassic long ranging		
<i>Alisporites splendens</i> (Leschik) Foster, 1979 Disaccites	<i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) to <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian)) ● sr: late Early Permian to Middle Permian	Utting, 1994	Canadian Arctic Archipelago
<i>Alisporites tenuicarpus</i> Balme, 1970 Disaccites	Early to Late Permian ● sr: Permian long ranging	Balme, 1970	West Pakistan
<i>Anapiculatisporites decorus</i> Ouyang & Norriss, 1999 Apiculati	Earliest Triassic (Induan) ● sr: Earliest Triassic	Ouyang & Norris, 1999	Xinjiang (NW China)
<i>Angustisulcites</i> sp. Disaccites	spp. Röt to Keuper Scythian to Anisian Assemblage A (Ladinian) and Assemblage B (Early Norian) Assemblage A (Ladinian) and Assemblage B (Carnian) plurianulatus-novimundanus (early Fassanian) to secatus-vigens (earliest Julian) phases B, (Cordevolian-Early Julian), D (Tuvalian) ● sr: Anisian to Carnian	Fisher, 1972a Fisher, 1972b Besems, 1981a Besems, 1981b Van der Eem, 1983 Buratti & Carrillat, 2002	Liverpool, England England Southern Sapin Southern Sapin Western Dolomites, Italy Sicily
<i>Aratrisporites fimbriatus</i> (Klaus) Mädler, 1964 Cavatomoletes	Early-Middle Keuper (Carnian) Early Muschelkalk to Middle Keuper Muschelkalk Julian Assemblage B (Longobardian) dominant plurianulatus-novimundanus (Early Fassanian) to vigens-densus (Cordevolian) phases Early Ladinian <i>Aratrisporites saturni</i> (Anisian, Middle Triassic) zone Ladinian to Early Hettangian, acme older than Ladinian to Early Carnian Julian ● sr: Anisian to Carnian	Klaus, 1960 Madler, 1964 Fisher, 1972a Dunay & Fisher, 1978 Besems, 1983 Van der Eem, 1983 Mørk <i>et al.</i> , 1990 Eshet, 1990 Cornet, 1993 Roghi, 2004	Australpine Alps Germany Liverpool, England Northern Alps (Austria) Southern Sapin Western Dolomites, Italy Barent Sea Subsurface Israel Northern America Julian Alps, NE Italy
<i>Aratrisporites</i> sp. cf <i>A. spongeosus</i> Ottone & Garcia, 1991 Cavatomoletes	Middle Triassic <i>saturnii</i> , <i>parvispinosus</i> Anisian Scythian to Anisian spp <i>Tigr. payfordii</i> (Smithian-Anisian) Zone spp. Assemblage A (Longobardian) sp. div. Dinerian to Rhaetian Tuvalian spp. Late Muschelkalk-Littenkohle(Ladinian) boundary spp top of the crassa-thiergatii (Late Bithynian) to vigens-densus phases (Early Cordevolian) Late Scythian-Ladinian s.l. <i>Aratrisporites saturni</i> Assemblage zone (late Late Anisian) spp. Early Longobardian to Julian spp. Dienerian to Carnian Early Triassic Early Triassic spp. Early Triassic (Scythian) spp. Ladinian Late Carnian ● sr: Anisian to Carnian	Visscher & Commissaris, 1968 Antonescu, 1970 Fisher, 1972b Dolby & Balme, 1976 Besems, 1983 Brugman, 1983 Fisher & Dunay, 1984 Düringer & Doubringer, 1985 Brugman, 1986 Doubringer <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Blendinger, 1988 Mørk <i>et al.</i> , 1990 Hankel, 1991 Ottone & Garcia, 1991 Hankel, 1993 Fréchengues <i>et al.</i> , 1993 Cirilli & Montanari, 1994	Lower Muschelkalk of Winterswijk, Netherlands Brasov, Rumanie England Western Australia Southern Sapin Chinle Fm Arizona, USA Lower Saxony (W Germany) and Wassalonne (France) Transdanubian central range, Vicentinian Alps Libya Negev, Israel SE Dolomires Barent Sea Kavee Quarry Section, Kenya Argentina Majunga Basin (Madagascar) Pyrenees Southern Albany
<i>Brodipora striata</i> Clarke, 1965 Striatiti	Keuper Tuvalian Late Carnian Carnian ● sr: Carnian	Clarke, 1965a Dunay & Fisher, 1978 Doubringer <i>et al.</i> , 1986 Fréchengues <i>et al.</i> , 1993	England Northern Alps (Austria) Libya Pyrenees
<i>Calamospora dif.</i> sp. <i>Laevigati</i>	● sr: Permian to Triassic long ranging		

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Camerosporites secatus</i> Leschik, 1956 Circumpolles	Early Triassic Late Carnian Upper part of <i>S. quadrifidus</i> Zone(?Carnian) to <i>S. speciosus</i> Zone (Carnian) Late Longobardian Cordevolian to Tuvalian Tuvalian Late Carnian Late Ladinian-Carnian Assemblage A (Longobardian) Late Fassanian to Early Norian <i>plurianulatus-novimundanus</i> (Early Fassanian) to middle <i>densus- maljawkinae</i> (Middle Julian) phases Tuvalian <i>plurianulatus-secatus</i> (Late Fassanian) to base of <i>vigens-densus</i> phases (early Cordevolian) Carnian <i>Pityosporites rutneri-Triadispora modesta</i> ((Early Carnian) to <i>Camerosporitessecatus-Circumpolles</i> (Late Carnian) Assemblage zones <i>Podosporites amicus</i> (Ladinian, Middle Triassic) to <i>Patinasporites densus</i> (Carnian) zones Ladinian to Carnian Carnian Late Fassanian Lower Norian Ladinian to Middle Carnian, acme Early to Middle Carnian Late Carnian Carnian Keuper Assemblages B, (Cordevolian-Early Julian), C (Julian-Early Tuvalian), D (Tuvalian) Julian to Middle Tuvalian ● sr: Late Longobardian to Tuvalian	Adloff & Doubinger, 1969 Fisher, 1972b Dolby & Balme, 1976 Scheuring, 1978 Dunay & Fisher, 1978 Visscher & Krystyn, 1978 Dunay & Fisher, 1979 Pittau & Del Rio, 1980 Besems, 1983 Brugman, 1983 Van der Eem, 1983 Fisher & Dunay, 1984 Brugman, 1986 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Eshet, 1990 Doubinger <i>et al.</i> , 1990 Cirilli & Eshet, 1991 Visscher & Brugman, 1981 Cornet, 1993 Cirilli & Montanari, 1994 Cirilli, 1995 Leschik, 1955 Buratti & Carrillat, 2002 Roghi, 2004	Voltzia, France England Western Australia Ticino, Switzerland Northern Alps (Austria) NW Sicily Dockum Group Texas, USA Sardagna Southern Sapin Western Dolomites, Italy Chinle Fm Arizona, USA Transdanubian central range, Vicentinian Alps Libya Negev, Israel Subsurface Israel Valencia, Spain Israel Northern America Southern Albany Southern Alps Basel, Switzerland Sicily Julian Alps, NE Italy
<i>Cannanoropolis bilateralis</i> (Tiware) Lindström, 1995 Monosaccites	Early Permian Early Permian Early Permian Early Permian ● sr: Early Permian	Kar & Bose, 1967 Utting, 1976 Utting, 1978 Lindström, 1995	Congo Lower Karroo, Zambia Lower Karroo, Zambia Antarctica
<i>Chordaesporites singulicorda</i> ? Klaus, 1960 Striatiti	Early-Middle Keuper (Carnian) Keuper Anisian ● sr: Anisian to Carnian	Klaus, 1960 Clarke, 1965a Pittau & Del Rio, 1980	Australpine Alps England Sardagna
<i>Convruccosporites</i> sp. Apiculati	Long ranging, since the Permian ● sr: Permian to Triassic long ranging		
<i>Cordaitina</i> sp. Monosaccites	sp. dif. Kungurian spp. Permian System; <i>eminens</i> , <i>spongiosa</i> , <i>ornata</i> Lower Permian System <i>L. monstruosus-V. costabilis</i> Ass. Zone (Artinskian) ● sr:Early Permian	Samoilovich, 1953 Hart, 1965 Utting, 1994	Cis Urals Canadian Arctic Archipelago
<i>Corisaccites alutas</i> Venkatachala & Kar, 1946 Striatiti	Early Permian Late Sakmarian (early Early Permian) to Murgabian (late Early Permian) Middle/Late Permian ? Kungurian Thüringian (Late Permian) Kungurian (latest Early Permian) to Kazanian (middle Late Permian) Latest Permian ● sr: Permian long ranging	Balme, 1970 Brugman, 1983 Doubinger <i>et al.</i> , 1986 Backhouse, 1991 Doubinger <i>et al.</i> 1990 Broutin <i>et al.</i> , 1990 Diéguez & Barrón, 2005	West Pakistan Libya Australia Valencia, Spain Niger Spain
<i>Costapollenites ellipticus</i> Tschudy & Kosanke, 1966 Polyplicates	Sakmarian Early Asselian ● sr: Early Permian	Jardiné, 1974 Pittau <i>et al.</i> , 2002	Gabon Sardinia, Italy
<i>Crucisaccites variolucatus</i> Dyupina, 1971 Monosaccites	sp. div. Late Asselian to Murgabian (late Early Permian) ● sr: Early Permian	Brugman, 1983	

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Crustasporites globosus</i> Leschik, 1955 Striatiti	Keuper Early Triassic Canada, rare. Late Permian Europe sp. Early Triassic (Scythian) Late Permian (Zechstein) <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) ● sr: Late Permian to Carnian	Leschik, 1955 Jansonius, 1962 Balme, 1963 Clarke, 1965b Mangerud, 1994	Basel, Switzerland Canada, Europe Western Australia England Barents sea
<i>Cycadopites</i> dif. sp. Monocolpates	Long ranging, since the Permian Common in the Late Permian and Early Triassic Jansonius (dispensa) ● sr: Permian to Triassic long ranging		
<i>Cyclogranisporites</i> sp. Apiculati	● sr: Permian to Triassic long ranging		
<i>Cyclogranitrites</i> sp. Apiculati	Long ranging (since Permian) ● sr: Permian to Triassic long ranging		
<i>Densipollenites</i> sp. Monosaccites	Permian long ranging ● sr: Permian long ranging		
<i>Densipollenites indicus</i> Bharadwaj, 1962	late Late Permian <i>E. papillatus</i> - <i>Krauselisporites</i> spp. Assemblage zone, Scythian (Early Triassic) Kungurian (latest Early Permian) to Kazanian (middle Late Permian) ● sr: Late Permian to Early Triassic	Balme, 1970 Eshet & Cousminer, 1986 Brouin <i>et al.</i> , 1990	West Pakistan Negev, Israel Niger
<i>Densipollenites oviformis</i> Shwartsman in Issova <i>et al.</i> , 1976 Monosaccites	Early Asselian ● sr: Early Permian	Pittau <i>et al.</i> , 2002	Sardinia, Italy
<i>Densoisporites nejburgii</i> (Schultz) Balme, 1970 Cavatotrites	Scythian to Anisian Dinerian to Aegean nejburgii-heteromorphus (Spathian) to conmilvinus-crassa phases (Early Aegean) abundant to dominant in the nejburgii-heteromorphus to heteromorphus-conmilvinus phases (Spathian) Late Scythian-Anisian s.l. <i>V. heteromorpha</i> - <i>A. grauvogeli</i> (Early Anisian) to <i>Latosaccus latus</i> (early late Anisian) Assemblage zones Dienerian to Early Anisian or older Late <i>Endosporites papillatus</i> (Late Scythian, Early Triassic) to <i>Aratrisporites saturni</i> (Anisian, Middle Triassic) zones Spathian to lower Lower Anisian Early Triassic (Scythian) <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) Devonian ● sr: Scythian to Anisian; Devonian?	Fisher, 1972b Brugman, 1983 Brugman, 1986 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Mørk <i>et al.</i> , 1990 Eshet, 1990 Visscher & Brugman, 1981 Hankel, 1993 Mangerud, 1994 Utting <i>et al.</i> , 2004	England Transdanubian central range, Vicentinian Alps Libya Negev, Israel Barent Sea Subsurface Israel Majunga Basin (Madagascar) Barents sea
<i>Densoisporites playfordii</i> (Balme) Dettmann, 1963 Cavatotrites	Late Permian to Early Triassic <i>K. septatus</i> (Griensbachian-Smithian) Zone <i>Playfordiaspora crenulata</i> (Latest Chidruan-?Early Djulfian) to <i>Lunatisporites pellucidus</i> (?!Griensbachian to Middle Dinarian) zones Late Muschelkalk-Littenkohle(Ladinian) boundary Late Scythian <i>E. papillatus</i> - <i>Krauselisporites</i> spp. Assemblage zone, Scythian (Early Triassic) Dienerian <i>Endosporites papillatus</i> (Scythian, Early Triassic) zone Early Triassic Early Triassic (Scythian) <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) Devonian ● sr: Late Permian to Early Triassic; Devonian?	Balme, 1970 Dolby & Balme, 1976 Foster, 1982 Düringer & Doubinger, 1985 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Mørk <i>et al.</i> , 1990 Eshet, 1990 Hankel, 1991 Hankel, 1993 Mangerud, 1994 Utting <i>et al.</i> , 2004	West Pakistan Western Australia Bowen Basin, Queensland, Australia Lower Saxony (W Germany) and Wassalonne (France) Libya Negev, Israel Barent Sea Subsurface Israel Kavee Quarry Section, Kenya Majunga Basin (Madagascar) Barents sea

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Duplicisporites granulatus</i> Leschik, 1955 Circumpolles	Keuper Early-Middle Keuper (Carnian) Early Triassic Keuper Late Carnian Late Longobardian Cordevolian to Tuvalian Tuvalian Late Ladinian to Carnian Assemblage A (Ladinian) and Assemblage B (Carnian) Fassanian to Early Norian Carnian <i>Camerosporitessecatus-Circumpolles</i> (Late Carnian) Assemblage zone plurianulatus-novimundanus (Early Fassanian) to middle densus- maljawkinae(Middle Julian) phases <i>Podosporites amicus</i> (Ladinian, Middle Triassic) to <i>Patinasporites densus</i> (Carnian) zones Ladinian to Carnian Ladinian Ladinian to Early Norian, acme Carnian Late Carnian Carnian Assemblages A (Late Ladinian-Early Carnian), C (Julian- Early Tuvalian), D (Tuvalian) ● sr: Ladinian to Norian	Leschik, 1955 Klaus, 1960 Adloff & Doubinger, 1969 Scheuring, 1970 Fisher, 1972b Scheuring, 1978 Dunay & Fisher, 1978 Visscher & Krystyn, 1978 Pittau & Del Rio, 1980 Besems, 1981b Brugman, 1983 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Van der Eem, 1983 Eshet, 1990 Doubinger <i>et al.</i> 1990 Fréchengues <i>et al.</i> , 1993 Cornet, 1993 Cirilli & Montanari, 1994 Cirilli, 1995 Buratti & Carrillat, 2002	Basel, Switzerland Australpine Alps Votzia, France Solothurner, Jura England Ticino, Switzerland Northern Alps (Austria) NW Sicily Sardegna Southern Sapin Libya Negev, Israel Western Dolomites, Italy Subsurface Israel Valencia, Spain Pyrenees Northern America Southern Albany Southern Alps Sicily
<i>Endosporites papillatus</i> Jansonius, 1962 Cavatritiletes	Early Triassic nejburgii-heteromorphus to heteromorphus-conmilvinus phases (Spathian) Late Scythian-Anisian s.l. <i>E. papillatus-Krausellisporites</i> spp. Scythian (Early Triassic) to <i>V. heteromorpha -A. grauvogeli</i> Assemblage zones Early Anisian Dienerian to Smithian <i>Endosporites papillatus</i> (Scythian, Early Triassic) zone Late Scythian to Anisian Induan (Griesbachian to Nammalian) <i>Tympanicysta stochiana- L. obsoleta</i> Assemblage zone (Griesbachian) Devonian ● sr: Early Triassic; Devonian?	Jansonius, 1962 Brugman, 1986 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Mørk <i>et al.</i> , 1990 Eshet, 1990 Kilani-Mazraoui <i>et al.</i> , 1990 Visscher & Brugman, 1981 Mangerud, 1994 Utting <i>et al.</i> , 2004	Western Canada Transdanubian central range, Vicentinian Alps Libya Negev, Israel Barent Sea Subsurface Israel Southern Tunisia Barents sea
<i>Enzonasporites vigens</i> Leschik, 1955 Monosaccites	Keuper Keuper Middle Keuper Keuper Late Carnian Upper part of <i>S. quadrifidus</i> Zone(Early Carnian) to <i>M.</i> <i>crenulatus</i> Zone (Carnian-?Norian) Cordevolian to Tuvalian Tuvalian Late Carnian Late Ladinian to Carnian Assemblage B (Longobardian) very scarce presence sp. div. Late Longobardian to middle Rhaetian secatus-vigens (Late Longobardian) to middle densus- maljawkinae(Middle Julian) phases Tuvalian Late Muschelkalk-Littenkohle(Ladinian) boundary secatus-vigens (Late Longobardian) to base of vigens- densus phases (Early Cordevolian) Late Longobardian to ? Tuvalian <i>Podosporites amicus</i> (Ladinian) to <i>Patinasporites densus</i> (Carnian) zones Carnian sp. Div. Cordevolian to Lower Raethian Late Ladinian to Rhaetian, acme Carnian Late Carnian Carnian Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), C (Julian-Early Tuvalian), D (Tuvalian) Julian to Tuvalian ● sr: Late Longobardian to Norian?	Leschik, 1955 Clarke, 1965a Schulz, 1967 Scheuring, 1970 Fisher, 1972b Dolby & Balme, 1976 Dunay & Fisher, 1978 Visscher & Krystyn, 1978 Dunay & Fisher, 1979 Pittau & Del Rio, 1980 Besems, 1983 Brugman, 1983 Van der Eem, 1983 Fisher & Dunay, 1984 Düringer & Doubinger, 1985 Brugman, 1986 Blendinger, 1988 Eshet, 1990 Cirilli & Eshet, 1991 Visscher & Brugman, 1981 Cornet, 1993 Cirilli & Montanari, 1994 Cirilli, 1995 Buratti & Carrillat, 2002 Roghi, 2004	Basel, Switzerland England Central Germany Solothurner, Jura England Western Australia Northern Alps (Austria) NW Sicily Dockum Group Texas, USA Sardegna Southern Sapin Western Dolomites, Italy Chinle Fm Arizona, USA Lower Saxony (W Germany) and Wassalonne (France) Transdanubian central range, Vicentinian Alps SE Dolomires Subsurface Israel Israel Northern America Southern Albany Southern Alps Sicily Julian Alps, NE Italy

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Ephedripites steevesii</i> (Jansonius 1962) de Jersey 1968	Early Triassic <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian)	Jansonius, 1962 Mangerud, 1994	Barents sea
Striatiti	<i>Tympanicysta stochiana</i> - <i>Striatoabeites richteri</i> Zone (Griensbachian) ● sr: Early Triassic	Utting, 1994	Canadian Arctic Archipelago
<i>Equisetosporites chinleanus</i> (Daugherty) Scott, 1960 Polyplicates	Late Carnian Tuvalian ● sr: Carnian	Dunay & Fisher, 1979 Fisher & Dunay, 1984	Dockum Group Texas, USA Chinle Fm Arizona, USA
<i>Falcisporites nuthallensis</i> Balme, 1970	Early to Late Permian <i>H. insolitus</i> - <i>P. novicus</i> Assemblage zone (zone A2 Doubling, 1974), Autunian (Early Permian) ● sr: Permian long ranging	Balme, 1970 Eshet & Cousminer, 1986	West Pakistan Negev, Israel
<i>Falcisporites stabilis</i> Balme, 1970 Disaccites	Uppermost Permian to Middle Triassic Carnian Early Triassic Late Carnian ● sr: Latest Permian to Triassic long ranging	Balme, 1970 Cirilli & Eshet, 1991 Hankel, 1991 Cirilli & Montanari, 1994	West Pakistan Israel Kavee Quarry Section, Kenya Southern Albany
<i>Florinites</i> sp. A Utting, 1994 Monosaccites	<i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian) ● sr: Middle Permian	Utting, 1994	Canadian Arctic Archipelago
<i>Florinites eremus</i> Balme & Hennelly, 1955	Early Permian ? <i>Florinites eremus</i> Stage 2 and 3, Early Permian (Asselian)	Foster, 1975 Gilby & Foster, 1988	Queensland, Australia South Australia
Monosaccites	Kungurian (latest Early Permian) to Kazanian (middle Late Permian) ● sr: Permian long ranging	Broutin et al, 1990	Niger
<i>Florinites luburae</i> Samoilovich, 1953 Monosaccites	Kungurian Since ? Asselian <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Scutasporites</i> sp. cf <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) <i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) Artinskian ● sr: late Early Permian to Middle Permian	Samoilovich, 1953 Backhouse, 1991 Mangerud, 1994 Utting, 1994 Dunn, 2001	Cis Urals Australia Barents sea Canadian Arctic Archipelago Kazakhstan
<i>Gardenasporites heisseli</i> Klaus, 1963 Disaccitritetess	Late Permian Late Permian ● sr: Late Permian	Klaus, 1963 Clapham, 1970	Southern Alps W Oklahoma
<i>Grebespora concentrica</i> Jansonius, 1962 Aletes	Early Triassic Early Triassic <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zones (● sr: Early Triassic)	Jansonius, 1962 Hankel, 1991 Mangerud, 1994	Canada Kavee Quarry Section, Kenya Barents sea
<i>Hamiapollenites</i> sp. Striatiti	<i>Hamiapollenites</i> s p. div. <i>Late Sakmarian</i> (early Early Permian) to <i>Middle Murgabian</i> (late Early Permian) ● sr: Permian long ranging	Brugman, 1983	
<i>Hamiapollenites bullaeformis</i> (Samoilovich) Jansonius, 1962	Lower Permian System spp. <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian)	Hart, 1965 Mangerud, 1994	Barents sea
Striatiti	<i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) to <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian)) Artinskian Early Asselian ● sr: Early Permian	Utting, 1994 Dunn, 2001 Pittau et al. , 2002	Canadian Arctic Archipelago Kazakhstan Sardinia, Italy
<i>Hamiapollenites erebi</i> Utting, 1994 Striatiti	<i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian)) ● sr: Wordian (Middle Permian)	Utting, 1994	Canadian Arctic Archipelago
<i>H. cf Hamiapollenites insolitus</i> (Bharadwaj & Salujha) Klaus, 1970	Early Permian <i>H. insolitus</i> - <i>P. novicus</i> Assemblage zone (zone A2 Doubling, 1974), Autunian (Early Permian) ● sr: Early Permian	Balme, 1970 Eshet & Cousminer, 1986	West Pakistan Negev, Israel
<i>Hamaipollenites karrooensis</i> Hart, 1964 Striatiti	Permian System Late Permian Sakmarian to earliest Late Permian Early Permian Kungurian (latest early Permian) to Kazanian (middle Late Permian) ● sr: Permian long ranging	Hart, 1965 Clapham, 1970 Jardiné, 1974 Utting, 1976 Broutin et al. , 1990	W Oklahoma Gabon Lower Karroo, Zambia Niger
<i>Hamiapollenites saccatus</i> Wilson, 1962 Striatiti	Late Permian Permian System Kungurian (latest Early Permian) to Kazanian (middle Late Permian) ● sr: Permian long ranging	Wilson, 1963 Hart, 1965 Broutin et al. , 1990	Oklahoma Niger
<i>H. cf Hamiapollenites tractiferinus</i> (Samoilovich, Jansonius) Hart, 1964 Striatiti	Upper Permian System Late Permian <i>L. monstruosus</i> - <i>V. costabilis</i> Ass. Zone (Artinskian) to <i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) Artinskian Early Asselian ● sr: Permian long ranging	Hart, 1965 Clapham, 1970 Utting, 1994 Dunn, 2001 Pittau et al. , 2002	W Oklahoma Canadian Arctic Archipelago Kazakhstan Sardinia, Italy

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<i>Illinites</i> sp. Disaccitriteless	sp. div. Late Permian ● sr: Late Permian	Klaus, 1963	Southern Alps
<i>Illinites spectabilis</i> Klaus, 1963 Disaccitriteless	Late Permian ● sr: Late Permian	Klaus, 1963	Southern Alps
<i>Inaperturopollenites nebulosus</i> Balme, 1970 Inaperturato	Late Permian Early Triassic (Scythian) <i>Scutasporites</i> sp. cf <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) to <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian)) ● sr: Mdile Permian to Early Triassic long ranging	Balme, 1970 Hankel, 1993 Mangerud, 1994 Utting, 1994	West Pakistan Majunga Basin (Madagascar) Barents sea Canadian Arctic Archipelago
<i>Jugasporites delasaucei</i> (Potonié & Klaus) Leschik, 1955 Disaccitriteless	Late Permian Late Permian Permian System Late Permian Late Permian (Thuringian) Late Zechestein Early Thuringian Upper Permian Late Permian Latest Permian ● sr: Late Permian	Klaus, 1963 Klaus, 1964 Hart, 1965 Visscher, 1971 Clement-Westerhof, 1974 Dybova-Jachowicz, 1974 Visscher <i>et al.</i> , 1974 Visscher & Brugman, 1981 Warrington & Scrivener, 1990 Diéguez & Barrón, 2005	Southern Alps Ireland Vicentinian Alps (N Italy) Poland "Saxonian" deposits of Germany and France Devon, England Spain
<i>Klausipollenites decipiens</i> Jansonius, 1962 Disaccites	Early Triassic, infrequent ● sr: Early Triassic	Jansonius, 1962	W Canada
<i>Klausipollenites schaubergeri</i> (Potonié & Klaus) Jansonius 1962 Disaccites	Late Permian Late Permian Late Permian (Zechestein) Late Permian Late Permian to Early Triassic Late Permian Late Permian Late Zechestein Early Thuringian earliest Late Permian to Late Permian Middle/Late Permian <i>Protohaploxypinus</i> spp.- <i>L. virkkiae</i> Assemblage zone Thuringian (Late Permian) <i>Lueckisporites virkkiae</i> (Thuringian, Late Permian) zone Late Permian Late Permian Early Triassic Upper Permian <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zones (Griensbachian) Earliest Triassic (Induan) Latest Permian ● sr: Late Permian to Early Triassic	Klaus, 1963 Klaus, 1964 Clarke, 1965b Visscher, 1966 Balme, 1970 Clapham, 1970 Visscher, 1971 Dybova-Jachowicz, 1974 Visscher <i>et al.</i> , 1974 Jardiné, 1974 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Eshet, 1990 Kilani-Mazraoui <i>et al.</i> , 1990 Warrington & Scrivener, 1990 Ottone & Garcia, 1991 Visscher & Brugman, 1981 Mangerud, 1994 Ouyang & Norriss, 1999 Diéguez & Barrón, 2005	Southern Alps England Austrian Alps and Netherlands West Pakistan W Oklahoma Ireland Poland "Saxonian" deposits of Germany and France Gabon Libya Negev, Israel Subsurface Israel Southern Tunisia Devon, England Argentina Barents sea Xinjiang (NW China) Spain
<i>Klausipollenites staplinii</i> Herbst, 1965 Disaccites	<i>Tympanicysta stochiana</i> - <i>Striatoabielites richteri</i> Zone (Early Triassic (Griensbachian)) <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zones (Griensbachian) ● sr: Early Triassic	Utting, 1994 Mangerud, 1994	Canadian Arctic Archipelago Barents sea
<i>Korbapollenites</i> sp. Disaccites	sp. div. Late Sakmarian ● sr: Early Permian	Brugman, 1983	
<i>Krauselisporites</i> sp. Cingulati	spp. <i>E. papillatus</i> - <i>Krauselisporites</i> spp. Assemblage zone, Scythian (Early Triassic) ● sr: Permian to Triassic long ranging	Eshet & Cousminer, 1986	Negev, Israel
<i>Krauselisporites apiculatus</i> Jansonius, 1962 Cingulati	Early Triassic Canada, Permian Australia Late Scythian <i>Endosporites papillatus</i> (Scythian, Early Triassic) zone Dienerian to Smithian <i>Scutasporites</i> sp. cf <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) to <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) ● sr: Late Permian to Early Triassic	Jansonius, 1962 Doubinger <i>et al.</i> , 1986 Eshet, 1990 Mørk <i>et al.</i> , 1990 Mangerud, 1994	Western Canada, Australia Libya Subsurface Israel Barent Sea Barents sea

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<i>Kraeuselisporites cuspidus</i> Balme, 1963 Cingulati	Early Triassic (Scythian) Anisian Late Permian to Early Triassic <i>L. pellucidus</i> (?Griensbachian to Middle Dinarian) zone <i>Endosporites papillatus</i> (Scythian, Early Triassic) zone Early Triassic Early Triassic (Scythian) ● sr: Early Triassic	Balme, 1963 Antonescu, 1970 Balme, 1970 Foster, 1982 Eshet, 1990 Hankel, 1991 Hankel, 1993	Western Australia Brasov, Rumanie West Pakistan Bowen Basin, Queensland, Australia Subsurface Israel Kavee Quarry Section, Kenya Majunga Basin (Madagascar)
<i>Krauselisporites septatus</i> Balme, 1963 Cingulati	Early Triassic (Scythian) Anisian <i>K. septatus</i> (Griensbachian-Smithian) Zone <i>L. pellucidus</i> (?Griensbachian to Middle Dinarian) zone <i>Endosporites papillatus</i> (Scythian, Early Triassic) zone Early Triassic Early Triassic (Scythian) <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zones (Griensbachian) ● sr: Early Triassic	Balme, 1963 Antonescu, 1970 Dolby & Balme, 1976 Foster, 1982 Eshet, 1990 Hankel, 1991 Hankel, 1993 Mangerud, 1994	Western Australia Brasov, Rumanie Western Australia Bowen Basin, Queensland, Australia Subsurface Israel Kavee Quarry Section, Kenya Majunga Basin (Madagascar) Barents sea
<i>Krauselisporites spinosus</i> Jansonius, 1962 Cingulati	Early Triassic Early Triassic <i>Scutasporites</i> sp. cf <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatirian) to <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) ● sr: Late Permian to Early Triassic	Jansonius, 1962 Hankel, 1991 Mangerud, 1994	Western Canada Kavee Quarry Section, Kenya Barents sea
<i>Krauselisporites</i> cf <i>K. wargalensis</i> Balme, 1970 Cingulati	Late Permian ● sr: Late Permian	Klaus, 1970	West Pakistan
<i>Leiotriletes ulutus</i> Utting, 1994 <i>Laevigate</i>	<i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) ● sr: late Early Permian to Middle Permian	Utting, 1994	Canadian Arctic Archipelago
<i>Limitisporites monstruosus</i> (Luber & Valts) hart, 1965 Disaccitriletes	Permian System Artinskian <i>L. monstruosus</i> - <i>V. costabilis</i> Ass. Zone (Artinskian) ● sr: Early Permian	Hart, 1965 Dunn, 2001 Utting, 1994	Kazakhstan Canadian Arctic Archipelago
<i>Limutalasporites fossulatus</i> (Balme) Helby & Foster, 1979 Cavate	Late Permian to ? Middle Triassic Early Triassic Early Triassic (Scythian) ● sr: Late Permian to Early Triassic	Balme, 1970 Hankel, 1991 Hankel, 1993	West Pakistan Kavee Quarry Section, Kenya Majunga Basin (Madagascar)
<i>Lueckisporites</i> sp. Striatiti	A3 (Early Permian, Artinskian-Early Kungurian) Zone sp. div. Late Kubergandian to Dorashamian Late Permian spp. <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zones (Griensbachian) ● sr: Permian long ranging	Doubinger, 1974 Brugman, 1983 Kilani-Mazraoui et al. , 1990 Mangerud, 1994	Autunian, France Southern Tunisia Barents sea
<i>Lueckisporites singhii</i> Balme, 1970 Striatiti	Early to Late Permian top of the secatus-vigens (Late Longobardian) to base of vigens-densus phases (Early Cordevolian) Late Longobardian to Cordevolian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) Latest Permian <i>Tympanicysta stochiana</i> - <i>Striatoabieites richteri</i> Zone (Early Triassic (Griensbachian)) ● sr: Permian to Triassic long ranging	Balme, 1970 Brugman, 1986 Blendinger, 1988 Broutin et al. , 1990 Kilani-Mazraoui et al. , 1990 Utting, 1994	West Pakistan Transdanubian central range, Vicentinian Alps SE Dolomires Niger Southern Tunisia Canadian Arctic Archipelago

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Lueckisporites virkkiae</i> Potonié & Klaus, 1954 Striatiti	Late Permian Late Permian Late Permian (Zechstein) Permian System Late Permian Late Permian Late Permian Late Permian Late Permian (Thuringian) Late Zechstein earliest Late Permian to Late Permian Early Thuringian Upper Permian Middle/Late Permian <i>Prothaploxypinus</i> spp.- <i>L. virkkiae</i> Assemblage zone Thuringian (Late Permian) Middle Murghabian to Dorashamian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) Thüringian (Late Permian) <i>Lueckisporites virkkiae</i> (Thuringian, Late Permian) zones Late Permian Late Permian <i>Dypetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Tympanicysta strochiana</i> - <i>L. obsoleta</i> Assemblage zones (Griensbachian) Earliest Triassic (Induan) Latest Permian ● sr: Late Permian	Klaus, 1963 Wilson, 1963 Clarke, 1965b Hart, 1965 Visscher, 1966 Balme, 1970 Clapham, 1970 Visscher, 1971 Clement-Westerhof, 1974 Dybova-Jachowicz, 1974 Jardiné, 1974 Visscher <i>et al.</i> , 1974 Visscher & Brugman, 1981 Doubinger <i>et al.</i> , 1986 Eshe & Cousminer, 1986 Brugman, 1983 Broutin <i>et al.</i> , 1990 Doubinger <i>et al.</i> , 1990 Eshet, 1990 Kilani-Mazraoui <i>et al.</i> , 1990 Warrington & Scrivener, 1990 Mangerud, 1994 Ouyang & Norriss, 1999 Diéguez & Barrón, 2005	Southern Alps Oklahoma England Austrian Alps and Netherlands West Pakistan W Oklahoma Ireland Vicentinian Alps (N Italy) Poland Gabon "Saxonian" deposits of Germany and France Libya Negev, Israel Niger Valencia, Spain Subsurface Israel Southern Tunisia Devon, England Barents sea Xinjiang (NW China) Spain
<i>Lunatisporites acutus</i> (Leschik) Scheuring, 1970 Striatiti	Keuper <i>K. septatus</i> (Griensbachian-Smithian) Zone to <i>S.speciosus</i> (Carnian) Zone Cordevolian to Tuvalian Late Longobardian Tuvalian <i>L. pellucidus</i> (?Griensbachian to Middle Dinarian) zone top of the thiergartii-vicentinense (Late Illyrian) to base of the densus-majlawkinae (Middle Julian) phases Late Muschelkalk-Littenkohle(Ladinian) boundary Late Scythian-Late Carnian <i>Patinasporites densus</i> (Carnian) zone Carnian Early Triassic Ladinian to Middle Rhaetian, acme Early to Middle Carnian Ladinian Late Carnian Ladinian Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), C (Julian-Early Tuvalian), D (Tuvalian) Julian ● sr: Triassic long ranging	Scheuring, 1970 Dolby & Balme, 1976 Dunay & Fisher, 1978 Scheuring, 1978 Visscher & Krystyn, 1978 Foster, 1982 Van der Eem, 1983 Düringer & Doubinger, 1985 Doubinger <i>et al.</i> , 1986 Eshet, 1990 Cirilli & Eshet, 1991 Hankel, 1991 Cornet, 1993 Fréchengues <i>et al.</i> , 1993 Cirilli & Montanari, 1994 Cirilli, 1995 Buratti & Carrillat, 2002 Roghi, 2004	Solothurner, Jura Western Australia Northern Alps (Austria) Ticino, Switzerland NW Sicily Bowen Basin, Queensland, Australia Western Dolomites, Italy Lower Saxony (W Germany) and Wassalonne (France) Libya Subsurface Israel Israel Kavee Quarry Section, Kenya Northern America Pyrenees Southern Albany Southern Alps Sicily Julian Alps, NE Italy
<i>Lunatisporites albertae</i> Jansonius, 1962 Striatiti	Early Triassic common ● sr: Early Triassic	Jansonius, 1962	Canada
<i>Lunatisporites exagonalis</i> Jansonius, 1962 Striatiti	Early Triassic common Early Triassic System ● sr: Early Triassic	Jansonius, 1962 Hart, 1965	Canada

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Lunatisporites noviaulensis</i> (Leschik) Scheuring, 1970	<i>T. cf. T. noviaulensis</i> Early Triassic (Scythian) <i>Tympanicysta stoschiana</i> - <i>Striatoabieites richteri</i> Zone (Early Triassic (Griensbachian))	Balme, 1963 Utting, 1994	Western Australia Canadian Arctic Archipelago
Striatiti	Early Triassic Canada abundant, Late Permian England Late Permian (Zechstein) Permian System late Late Permian to early Early Triassic Late Zechstein earliest Late Permian to Late Permian Late Longobardian <i>P. microcorpus</i> (?Early Djulfian to ?Griensbachian) to <i>L. pellucidus</i> (?Griensbachian to Middle Dinarian) zones nejburgii-heteromorphus phase (Early Spathian) to base of vigens-densus phase (Cordevolian), abundant to dominant in the conmilvinus-crassa (Aegean) to base of the thiergartii-vicentinense phases (Base of the Pelsonian) <i>E. papillatus</i> - <i>Krauselisporites</i> spp. Scythian (Early Triassic) to <i>V. heteromorpha</i> - <i>A. grauvogeli</i> Assemblage zones Early Anisian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) <i>Endosporites papillatus</i> (Scythian, Early Triassic) zone Late Permian Early to middle Ladinian Early Triassic Early Triassic (Scythian) <i>Scutasporites</i> sp. cf. <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatirian) to <i>Tympanicysta stroschiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) Ladinian Assemblages B, (Cordevolian-Early Julian), C (Julian-Early Tuvalian), D (Tuvalian) ● sr: Late Permian to Triassic long ranging	Jansonius, 1962 Clarke, 1965b Hart, 1965 Balme, 1970 Dybova-Jachowicz, 1974 Jardiné, 1974 Scheuring, 1978 Foster, 1982 Eshet & Cousminer, 1986 Brugman, 1986 Brouin <i>et al.</i> , 1990 Eshet, 1990 Kilani-Mazraoui <i>et al.</i> , 1990 Mørk <i>et al.</i> , 1990 Hankel, 1991 Hankel, 1993 Mangerud, 1994 Cirilli, 1995 Buratti & Carrillat, 2002	Canada, England England West Pakistan Poland Gabon Ticino, Switzerland Bowen Basin, Queensland, Australia Transdanubian central range, Vicentinian Alps Negev, Israel Niger Subsurface Israel Southern Tunisia Barent Sea Kavee Quarry Section, Kenya Majunga Basin (Madagascar) Barents sea Southern Alps Sicily
<i>Lunatisporites pellucidus</i> (Goubin) Helby ex De Jersey, 1972	Early to early Middle Triassic <i>K. septatus</i> (Griensbachian-Smithian) Zone <i>V. heteromorpha</i> - <i>A. grauvogeli</i> (Early Anisian) to <i>Latosaccus latus</i> (early late Anisian) Assemblage zones <i>Aratrisporites saturni</i> (Anisian, Middle Triassic) zone Dienerian to Smithian Early Triassic Early Triassic (Scythian) <i>Tympanicysta stroschiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) ● sr: Early to Middle Triassic	Balme, 1970 Dolby & Balme, 1976 Eshet & Cousminer, 1986 Eshet, 1990 Mørk <i>et al.</i> , 1990 Hankel, 1991 Hankel, 1993 Mangerud, 1994	West Pakistan Western Australia Negev, Israel Subsurface Israel Barent Sea Kavee Quarry Section, Kenya Majunga Basin (Madagascar) Barents sea
<i>Lunatisporites transversundatus</i> (Jansonius) Fisher, 1979	Early Triassic common Early to Middle Triassic <i>V. heteromorpha</i> - <i>A. grauvogeli</i> (Early Anisian) to <i>Latosaccus latus</i> (early late Anisian) Assemblage zones <i>Podosporites amicus</i> (Ladinian) zone <i>Tympanicysta stoschiana</i> - <i>Striatoabieites richteri</i> Zone (Early Triassic (Griensbachian)) ● sr: Early to Middle Triassic	Jansonius, 1962 Balme, 1970 Eshet & Cousminer, 1986 Eshet, 1990 Utting, 1994	Canada West Pakistan Negev, Israel Subsurface Israel Canadian Arctic Archipelago
<i>Lundbladispora brevicula</i> Balme, 1963 Cavate	Early Triassic (Scythian) Early to Middle Triassic <i>K. septatus</i> (Griensbachian-Smithian) Zone Latest Permian ● sr: Latest Permian to Middle Triassic	Balme, 1963 Balme, 1970 Dolby & Balme, 1976 Kilani-Mazraoui <i>et al.</i> , 1990	Western Australia West Pakistan Western Australia Southern Tunisia
<i>Lycopodiacidites kuepperi</i> Klau, 1960 Murornate	Early-Middle Keuper (Carnian) Anisian Julian Early Longobardian to Early Julian Julian to Early Tuvalian ● sr: Anisian to Carnian	Klaus, 1960 Antonescu, 1970 Dunay & Fisher, 1978 Blendinger, 1988 Roghi, 2004	Australpine Alps Brasov, Rumanie Northern Alps (Austria) SE Dolomires Julian Alps, NE Italy
<i>Minutossaccus</i> sp. Disaccites	spp. Tuvalian spp. Top of vicentinense-scheuringii (Early Fassinian) to base of the vigens-densus (Early Cordevolian) phases Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), D (Tuvalian) ● sr: Middle to Late Triassic	Visscher & Krystyn, 1978 Brugman, 1986 Buratti & Carrillat, 2002	NW Sicily Transdanubian central range, Vicentinian Alps Sicily
<i>Neoraistrikia caudicea</i> Utting, 1994 Trilete, Baculate	<i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) ● sr: late Early Permian to Middle Permian	Utting, 1994	Canadian Arctic Archipelago

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Nuskoisporites</i> sp. Monosaccites	Sakmarian Autunian spp. <i>H. insolitus</i> - <i>P. novicus</i> Assemblage zone (zone A2 Doubinger, 1974), Autunian (Early Permian spp. <i>Dypetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Scutasporites</i> sp. cf <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) ● sr: Permian long ranging	Jardiné, 1974 Visscher <i>et al.</i> , 1974 Eshet & Cousminer, 1986 Mangerud, 1994	Gabon "Saxonian" deposits of Germany and France Negev, Israel Barents sea
<i>Nuskoisporites dultuntyi</i> Klaus, 1963 Monosaccites	Late Permian Late Permian (Zechstein) Permian System Late Permian Late Permian Late Permian (Thuringian) Thüringian (Late Permian) <i>Potonisporites novicus</i> (Autunian, Early Permian) zone Upper Permian Latest Permian Late Zechstein ● sr: Late Permian	Klaus, 1963 Clarke, 1965b Hart, 1965 Visscher, 1966 Visscher, 1971 Clement-Westerhof, 1974 Doubinger <i>et al.</i> , 1990 Eshet, 1990 Visscher & Brugman, 1981 Diéguez & Barrón, 2005 Dybova-Jachowicz, 1974	Southern Alps England Austrian Alps and Netherlands Ireland Vicentinian Alps (N Italy) Valencia, Spain Subsurface Israel Spain Poland
<i>Nuskoisporites klausii</i> Klaus, 1963 Monosaccites	Late Permian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) Latest Permian ● sr: latest Early Permian to Latest Permian	Klaus, 1963 Brouin <i>et al.</i> , 1990 Diéguez & Barrón, 2005	Southern Alps Niger Spain
<i>Ovalipollis pseudoalatus</i> (Thiergart) Schirmann, 1976 Monosaccites	Tuvalian Late Ladinian-Carnian Assemblage A (Ladinian) and Assemblage B (Early Norian) Assemblage A (Ladinian) and Assemblage B (Carnian) Assemblage A (Longobardian) Assemblage B (Longobardian) dominant plurianulatus-novimundanus (Early Fasnian) to middle densus- maljawkinae(Middle Julian) phases Carnian Ladinian to Carnian Fasnian to Raethian Ladinian to Norian Late Carnian Ladinian ● sr: Ladinian to Norian	Visscher & Krystyn, 1978 Pittau & Del Rio, 1980 Besems, 1981a Besems, 1981b Besems, 1983 Besems, 1983 Van der Eem, 1983 Doubinger <i>et al.</i> , 1986 Mørk <i>et al.</i> , 1990 Visscher & Brugman, 1981 Fréchengues <i>et al.</i> , 1993 Cirilli & Montanari, 1994 Cirilli, 1995	NW Sicily Sarbegna Southern Sapin Southern Sapin Southern Sapin Southern Sapin Western Dolomites, Italy Libya Barent Sea Pyrenees Southern Albany Southern Alps
<i>Packapites rotundus</i> (Koloda) Utting, 1994 Praecolpate	<i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) to Utting, 1994 <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian)) ● sr: late Early Permian to Middle Permian	 Utting, 1994	Canadian Arctic Archipelago
<i>Parasaccites</i> sp. Monosaccites	Early Asselian ● sr: Permian long ranging	Pittau <i>et al.</i> , 2002	Sardinia, Italy
<i>Parasaccites distinctus</i> Tiwari, 1965 Monosaccites	Late Permian Early Asselian ● sr: Permian long ranging	Balme & Playford 1968 Pittau <i>et al.</i> , 2002	Antarctica Sardinia, Italy
<i>Patinasporites densus</i> (Leschik) Scheuring, 1970 Circumpolles	Keuper Keuper Late Carnian Tuvalian Late Carnian Assemblage B (Early Norian) Assemblage B (Carnian) Assemblage B (Longobardian) very scarce presence middle vigens-densus (Middle Cordevolian) to middle densus- maljawkinae(Middle Julian) phases Tuvalian Carnian <i>Camerosporitessecatus</i> - <i>Circumpolles</i> (Late Carnian) Assemblage zone Cordevolian to ? Tuvalian Carnian Cordevolian to Lower Norian Carnian to Rhaetian, acme Carnian to Rhaetian Late Carnian Carnian Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), C (Julian-Early Tuvalian) and D (Tuvalian) Julian ● sr: Carnian to Rhaethian	Leschik, 1955 Scheuring, 1970 Fisher, 1972b Visscher & Krystyn, 1978 Dunay & Fisher, 1979 Besems, 1981a Besems, 1981b Besems, 1983 Van der Eem, 1983 Fisher & Dunay, 1984 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Blendinger, 1988 Cirilli & Eshet, 1991 Visscher & Brugman, 1981 Cornet, 1993 Cirilli & Montanari, 1994 Cirilli, 1995 Buratti & Carrillat, 2002 Roghi, 2004	Basel, Switzerland Solothurner, Jura England NW Sicily Dockum Group Texas, USA Southern Sapin Southern Sapin Southern Sapin Western Dolomites, Italy Chinle Fm Arizona, USA Libya Negev, Israel SE Dolomites Israel Northern America Southern Albany Sicily Julian Alps, NE Italy
<i>Partisporites</i> sp. Circumpolles	sp. Assemblage A (Ladinian) and Assemblage B (Carnian) sp.Div. Late Fasnian to Lower Norian ● sr: Ladinian to Carnian	Besems, 1981b Visscher & Brugman, 1981	Southern Sapin

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Partitisporites novimundatus</i> Leschik, 1955 Circumpolles	Keuper Early-Middle Keuper (Carnian) plurianulatus-novimundanus (Early Fassanian) to middle densus- maljawkinae (Middle Julian) phases plurianulatus-novimundatus (Middle Fassanian) to base of vigens-densus phases (Early Cordevolian) Cordevolian to Tuvallian Carnian Assemblages B, (Cordevolian-Early Julian), C (Julian-Early Tuvallian) abundant to dominant at the base of vigens-densus phases (Early Cordevolian) ● sr: Ladinian to Carnian	Leschik, 1955 Klaus, 1960 Van der Eem, 1983 Brugman, 1986 Blendinger, 1988 Cirilli, 1995 Buratti & Carrillat, 2002	Basel, Switzerland Australpine Alps Western Dolomites, Italy Transdanubian central range, Vicentinian Alps SE Dolomites Southern Alps Sicily
<i>Partitisporites quadruplicis</i> Scheuring, 1970 Circumpolles	Keuper Tuvallian Late Cordevolian to Tuvallian Early to Middle densus- maljawkinae (Early to Middle Julian) phases Julian to ? Tuvallian Late Cordevolian to Tuvallian Norian Assemblage D (Tuvallian) ● sr: Cordevolian to Norian	Scheuring, 1970 Visscher & Krystyn, 1978 Brugman, 1983 Van der Eem, 1983 Blendinger, 1988 Visscher & Brugman, 1981 Fréchengues <i>et al.</i> , 1993 Buratti & Carrillat, 2002	Solothurner, Jura NW Sicily Western Dolomites, Italy SE Dolomites Pyrenees Sicily
<i>Platysaccus papilionis</i> Potonié & Klaus, 1954 Disaccites	● sr: Permian to Triassic long ranging		
<i>Platysaccus queenslandi</i> de Jersey, 1962 Disaccites	late Early Triassic <i>V. heteromorpha</i> - <i>A. grauvogeli</i> (Early Anisian) to <i>Latosaccus latus</i> (early late Anisian) Assemblage zones <i>Aratrisporites saturni</i> (Anisian, Middle Triassic) zone Early Triassic ● sr: Early Triassic to Anisian	Balme, 1970 Eshet & Cousminer, 1986 Eshet, 1990 Ottone & Garcia, 1991	West Pakistan Negev, Israel Subsurface Israel Argentina
<i>Playfordiaspora crenulata</i> (Wilson) Foster, 1979 Synonymus of <i>Guthoerisporites</i> <i>cancellus</i> , Playford & Dettmann, 1965	<i>Pl. crenulata</i> (Latest Chidruan-?Early Djulfian) to <i>P.</i> <i>microcorpus</i> (?Early Djulfian to ?Griensbachian) zones ● sr: Late Permian to Early Triassic	Foster, 1982	Bowen Basin, Queensland, Australia
<i>Plicatipollenites</i> sp. Monosaccites	<i>Plicatipollenites</i> "complex" Carboniferous to early Dorashamian (late Late Permian) <i>densus</i> , <i>gondwanensis</i> , <i>malabarensis</i> , stage 2 and 3, Early Permian (Asselian) Since ?Asselian <i>gondwanensis</i> Kungurian (latest Early Permian) to Kazanian (middle Late Permian) ● sr: Permian long ranging	Brugman, 1983 Gilby & Foster, 1988 Backhouse, 1991 Broutin <i>et al.</i> , 1990	South Australia Australia Niger
<i>Plicatipollenites indicus</i> Lele, 1964 Monosaccites	Early Permian Early to Late Permian Early Permian Early Permian <i>Potoniesporites novicus</i> (Autunian, Early Permian) to <i>Lueckisporites virkiae</i> (Thuringian, Late Permian) zones Early Permian ● sr: Permian long ranging	Kar & Bose, 1967 Balme, 1970 Utting, 1976 Utting, 1978 Eshet, 1990 Lindström, 1995	Congo West Pakistan Lower Karroo, Zambia Lower Karroo, Zambia Subsurface Israel Antarctica
<i>Plicatipollenites trigonalis</i> Lele, 1964 Monosaccites	Early Permian <i>Playfordiaspora crenulata</i> (Latest Chidruan-?Early Djulfian) to <i>Protohaploxylinus microcorpus</i> (Late Djulfian- Dorashamian) zones Early Asselian ● sr: Permian long ranging	Utting, 1976 Foster, 1982 Pittau <i>et al.</i> , 2002	Lower Karroo, Zambia Bowen Basin, Queensland, Australia Sardinia, Italy
<i>Potoniesporites granulosus</i> Bose & Kar, 1966 Monosaccites	Earliest Sakmarian Early Permian ● sr: Early Permian	Jardiné, 1974 Utting, 1978	Gabon Lower Karroo, Zambia
<i>Potoniesporites novicus</i> Bharadwaj, 1954 Monosaccites	Early to early Late Permian A2 (Autunian) and A3 (Early Permian, Artinskian-Early Kungurian) Zones Sakmarian to latest Early Permian Autunian sp. dif Carboniferous to Abadehian (early Late Permian) spp. <i>H. insolitus</i> - <i>P. novicus</i> Assemblage zone (zone A2 Doubling, 1974), Autunian (Early Permian spp. stage 2 and 3, Early Permian (Asselian) ? Asselian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) <i>Potoniesporites novicus</i> (Autunian, Early Permian) zone Artinskian Early Asselian ● sr: Early Permian	Balme, 1970 Doubling, 1974 Jardiné, 1974 Visscher <i>et al.</i> , 1974 Brugman, 1983 Eshet & Cousminer, 1986 Gilby & Foster, 1988 Backhouse, 1991 Broutin <i>et al.</i> , 1990 Eshet, 1990 Dunn, 2001 Pittau <i>et al.</i> , 2002	West Pakistan Autunian, France Gabon "Saxonian" deposits of Germany and France Negev, Israel South Australia Australia Niger Subsurface Israel Kazakhstan Sardinia, Italy

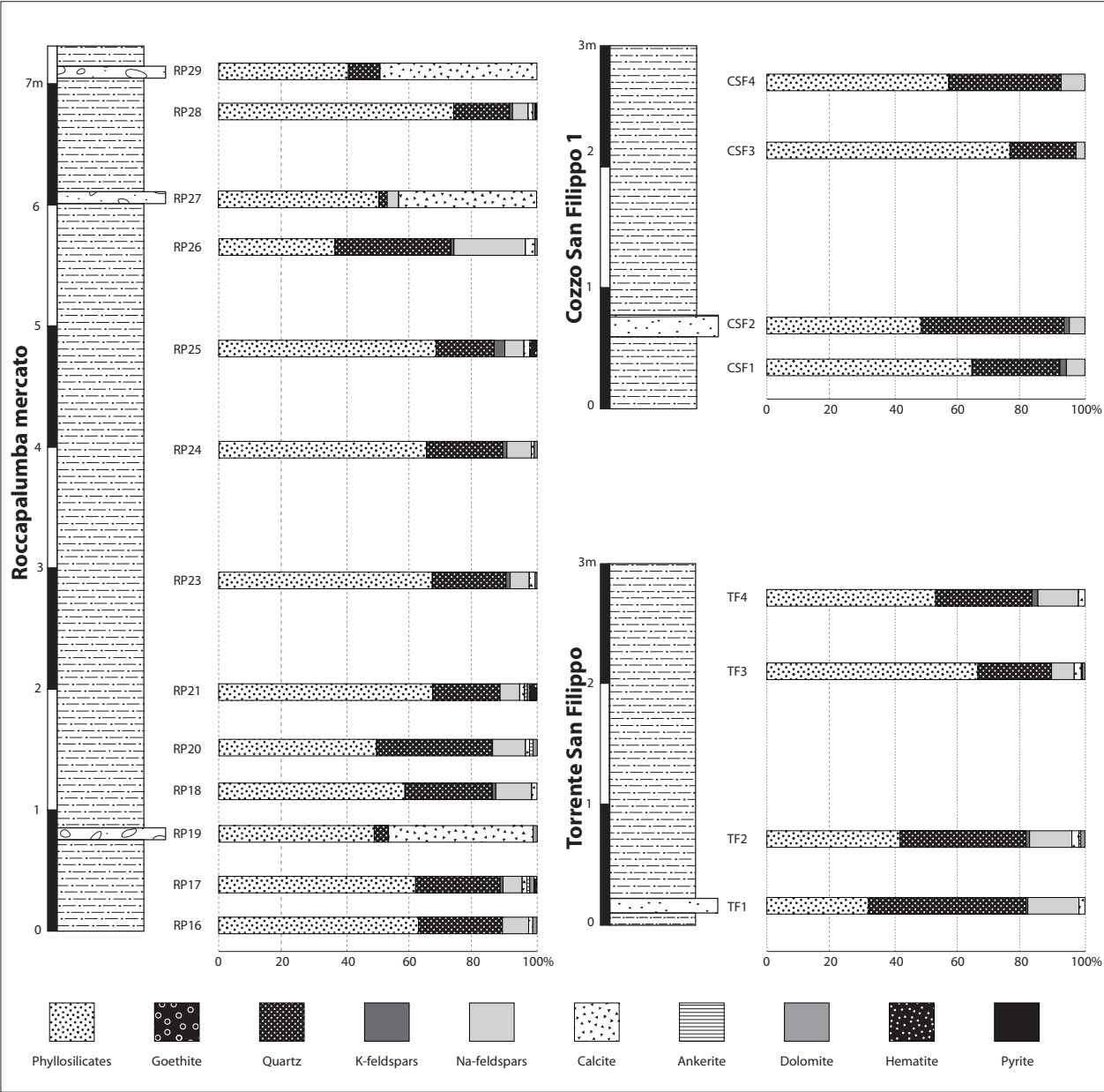
Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Praecirculina granifer</i> (Leschik) Klaus, 1960 Circumpolles	Early-Middle Keuper (Carnian) Late Ladinian-Carnian Pelsonian to Norian Carnian Middle Pelsonian to Tuvallian Ladinian to Early Norian, acme Carnian Ladinian to Norian ● sr: Carnian to Norian	Klaus, 1960 Pittau & Del Rio, 1980 Brugman, 1983 Doubinger <i>et al.</i> , 1986 Visscher & Brugman, 1981 Cornet, 1993 Fréchengues <i>et al.</i> , 1993	Australpine Alps Sardegna Libya Northern America Pyrenees
<i>Propisporites pococki</i> Jansonius, 1962 Muronate	Early Triassic Dienerian <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) ● sr: Early Triassic	Jansonius, 1962 Mørk <i>et al.</i> , 1990 Mangerud, 1994	Canada Barent Sea Barents sea
<i>Prothaploxypinus</i> dif. sp. Striatiti	● sr: Permian to Triassic long ranging		
<i>Punctatisporites</i> sp. <i>Laevigate</i>	● sr: Permian to Triassic long ranging		
<i>Sellasporea rugoverrucata</i> Van der Eem, 1983 Muronate	middle Anisian plurianulatus-novimundanus (Early Fassanian) to top vigens-densus(Late Cordevolian) phases plurianulatus-secatus (Late Fassanian) to base of vigens-densus phases (Early Cordevolian) Early Longobardian to Cordevolian <i>Aratrisporites satumi</i> (Anisian, Middle Triassic) to <i>Patinasporites densus</i> (Carnian) zones Ladinian Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), D (Tuvallian) Julian ● sr: Ladinian to Carnian	Taugourdeau-Lantz, 1983 Van der Eem, 1983 Brugman, 1986 Blendinger, 1988 Eshet, 1990 Cirilli, 1995 Buratti & Carrillat, 2002 Roghi, 2004	Languedoc (France) Western Dolomites, Italy Transdanubian central range, Vicentinian Alps SE Dolomires Subsurface Israel Sicily Julian Alps, NE Italy
<i>Striatoabielites</i> dif. sp. Striatiti	● sr: Permian to Triassic long ranging		
<i>Striatoabielites aytugii</i> (Visscher) Scheuring, 1970 Striatiti	Late Bunter Anisian Keuper Röt to Keuper Scythian to Anisian Julian Assemblage A (Ladinian) Middle Anisian to Early Early Carnian top of the thiergartii-vicentinense (Late Illyrian) to base of the densus-maljawkinae (Middle Julian) phases Late Muschelkalk-Littenkohle(Ladinian) boundary Anisian s.l. Ladinian-Early Carnian Ladinian to Carnian older than Ladinian to Middle Carnian, acme Early to Middle Carnian Ladinian Ladinian Assamblage B, (Cordevolian-Early Julian) ● sr: Anisian to Carnian	Visscher, 1966 Antonescu, 1970 Scheuring, 1970 Fisher, 1972a Fisher, 1972b Dunay & Fisher, 1978 Besems, 1981b Taugourdeau-Lantz, 1983 Van der Eem, 1983 Düringer & Doubinger, 1985 Doubinger <i>et al.</i> , 1986 Doubinger <i>et al.</i> , 1990 Mørk <i>et al.</i> , 1990 Cornet, 1993 Fréchengues <i>et al.</i> , 1993 Cirilli, 1995 Buratti & Carrillat, 2002	Netherlands Brasov, Rumanie Solothurner, Jura Liverpool, England England Northern Alps (Austria) Southern Sapin Languedoc (France) Western Dolomites, Italy Lower Saxony (W Germany) and Wassalonne (France) Libya Valencia, Spain Barent Sea Northern America Pyrenees Southern Alps Sicily
<i>Striatoabielites richteri</i> (Klaus) Hart, 1964 Striatiti	Early Triassic Canada, common, Late Permian Europe common Late Permian Late Permian (Zechstein) Permian System <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zone (Griensbachian) <i>Tympanicysta stochiana</i> - <i>Striatoabielites richteri</i> Zone (Griensbachian) ● sr: Late Permian to Early Triassic	Jansonius, 1962 Klaus, 1963 Clarke, 1965b Hart, 1965 Mangerud, 1994 Utting, 1994	Canada, Europe Southern Alps England Barents sea Canadian Arctic Archipelago
<i>Striatoabielites striatus</i> (Luber and Valtz) Hart, 1964 Striatiti	Lower Triassic System <i>Al. plicatus</i> - <i>J. compactus</i> Ass. Zone (Kungurian to Rodian) to <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian) ● sr: Middle Permian to Early Triassic	Hart, 1965 Utting, 1994	Canadian Arctic Archipelago
<i>Striatopodocarpites</i> sp. Striatiti	● sr: Permian to Triassic long ranging		
<i>Striatopodocarpites balmei</i> Sukh Dev, 1961 Striatiti	Triassic System conmilvinus-crassa (Aegean) to base of vigens-densus phases (Cordevolian), abundant to dominant at the base of seatus dimorphus phase (Early Longobardian) ● sr: Longobardian to Carnian	Hart, 1965 Brugman, 1986	Transdanubian central range, Vicentinian Alps

Species	Ages according to the Authors • Stratigraphical range (sr)	Authors	Geographical distribution
<i>Striatopodocarpites cancellatus</i> (Balme & Hennelly) Hart, 1964 Striatiti	Late Permian (Zechstein) Permian System Early to Late Permian Early Permian Early Permian Early Permian Since Aktanstanian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) • sr: Permian long ranging	Clarke, 1965b Hart, 1965 Balme, 1970 Foster, 1975 Utting, 1976 Utting, 1978 Backhouse, 1991 Broutin <i>et al.</i> , 1990	England West Pakistan Queensland, Australia Lower Karroo, Zambia Lower Karroo, Zambia Australia Niger
<i>Sulcatipollenites nillsonii</i> Balme, 1970 Disaccites	Early Permian • sr: Early Permian	Balme, 1970	West Pakistan
<i>Sulcatiporites ovatus</i> (Balme & Hennelly) Bharadwaj, 1962 Disaccites	Early to Late Permian Late Permian • sr: Permian long ranging	Balme, 1970 Kilani-Mazraoui <i>et al.</i> , 1990	West Pakistan Southern Tunisia
<i>Todisporites</i> sp. Laevigate	• sr: Permian to Triassic long ranging		
<i>Tornopollenites toreutos</i> Morgan, 1971 Striatiti	Sakmarian to earliest Late Permian Late Artinskian to Kubergardian Middle/Late Permian • sr: Permian long ranging	Jardiné, 1974 Brugman, 1983 Doubinger <i>et al.</i> , 1986	Gabon Libya
<i>Triadispora</i> sp. Disaccitriletes	<i>T. plicata, staplini, falcata</i> , sp. Early Triassic sp. div. Anisian to Norian <i>Triadispora</i> "complex", top of the thiergartii-vicentinense (Late Illyrian) to base of the densus-majlawkinae (Middle Julian) phases spp. late Muschelkalk-Littenkohle(Ladinian) boundary <i>Latosaccus latus</i> (early late Anisian) to <i>Echinisporites illacoides- Podosporites amicus</i> (Ladinian) Assemblage zones spp. Early Longobardian to ?Tuvalian Late Smithian to Carnian spp. Carnian sp. Div. Anisian to Early Tuvalian Norian spp. Late Carnian Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), D (Tuvalian) Late Julian • sr: Triassic long ranging	Adloff & Doubinger, 1969 Brugman, 1983 Van der Eem, 1983 Düringer & Doubinger, 1985 Eshet & Cousminer, 1986 Blendinger, 1988 Mørk <i>et al.</i> , 1990 Cirilli & Eshet, 1991 Visscher & Brugman, 1981 Fréchengues <i>et al.</i> , 1993 Cirilli & Montanari, 1994 Buratti & Carrillat, 2002 Roghi, 2004	Voltzia, France Western Dolomites, Italy Lower Saxony (W Germany) and Wassalonne (France) Negev, Israel SE Dolomires Barent Sea Israel Pyrenees Southern Albany Sicily Julian Alps, NE Italy
<i>Triadispora crassa</i> Klaus, 1964 Disaccitriletes	Late Buntsandstein (Early Triassic) Late Bunter Middle Triassic Anisian Röt to Keuper Scythian to Ladinian Late Anisian Assemblage A (Ladinian) and Assemblage B (Early Norian) Assemblage A (Ladinian) and Assemblage B (Carnian) Assemblage A (Longobardian) Middle Anisian to early Early Carnian Tuvalian top of heteromorphus-connilvinus (Late Spathian) to base of vigens-densus phases (Early Cordevolian); Ladinian-Early Carnian <i>Klausii Aratrisporites saturni</i> (Anisian, Middle Triassic) to <i>Podosporites amicus</i> (Ladinian, Middle Triassic) zones Ladinian Ladinian abundant to dominant at crassa-thiergartii phase (Late Aegean to Buthynian) and in to the top of thiergartii-vicentinense (Pelsonian) to vigens-densus phases (Early Cordevolina) • sr: Triassic long ranging	Klaus, 1964 Visscher, 1966 Visscher & Commissaris, 1968 Antonescu, 1970 Fisher, 1972a Fisher, 1972b Pittau & Del Rio, 1980 Besems, 1981a Besems, 1981b Besems, 1983 Taugourdeau-Lantz, 1983 Fisher & Dunay, 1984 Brugman, 1986 Doubinger <i>et al.</i> , 1990 Eshet, 1990 Fréchengues <i>et al.</i> , 1993 Cirilli, 1995	Netherlands Lower Muschelkalk of Winterswijk, Netherlands Brasov, Rumanie Liverpool, England England Sardagna Southern Sabin Southern Sabin Southern Sabin Languedoc (France) Chinle Fm Arizona, USA Transdanubian central range, Vicentinian Alps Valencia, Spain Subsurface Israel Pyrenees Southern Alps
<i>Triadispora obscura</i> Scheuring, 1970 Disaccitriletes	Keuper Cordevolian to Julian middle Anisian to early Early Carnian Ladinian to Carnian Norian • sr: Ladinian to Norian	Scheuring, 1970 Dunay & Fisher, 1978 Taugourdeau-Lantz, 1983 Mørk <i>et al.</i> , 1990 Fréchengues <i>et al.</i> , 1993	Solothurner, Jura Northern Alps (Austria) Languedoc (France) Barent Sea Pyrenees
<i>Triadispora stabilis</i> Scheuring, 1970 Disaccitriletes	Keuper Late Longobardian <i>Patinasporites densus</i> (Carnian) zone Pelsonian- Fassanian, predominant in the Fassanian • sr: Anisian to Carnian	Scheuring, 1970 Scheuring, 1978 Eshet, 1990 Goczan & Oravec-Scheffer, 1993	Solothurner, Jura Ticino, Switzerland Subsurface Israel Transdanubian Central Range

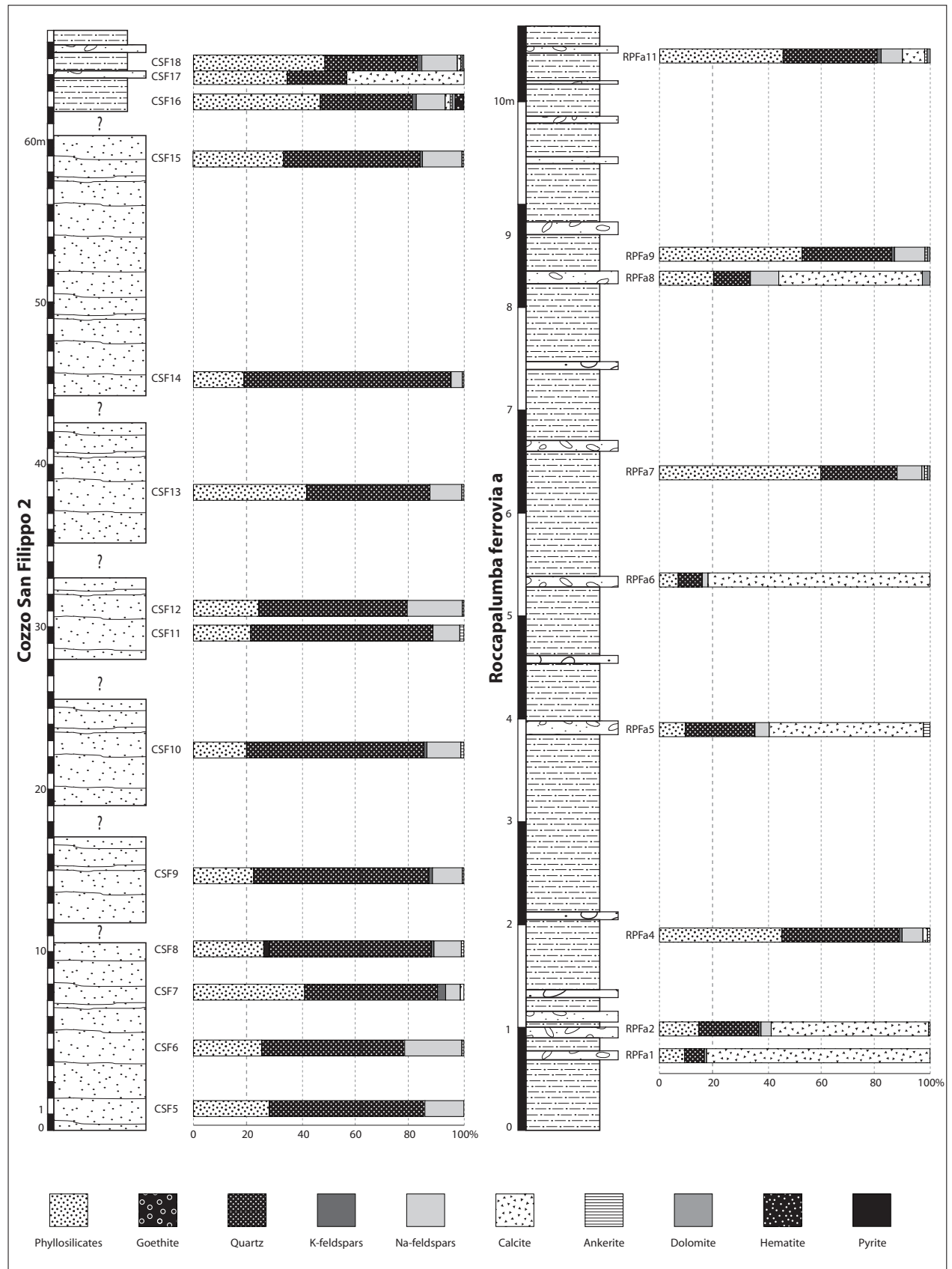
Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Triadispota vilis</i> Scheuring, 1970 Disaccitriteless, Leschik, 1956	Keuper ● sr: Carnian	Scheuring, 1970	Solothurner, Jura
<i>Uvaesporites</i> sp. Apiculati	<i>Tigrisp. payfordii</i> Zone (Smithian-Anisian) Early Triassic (Scythian) ● sr: Early Triassic	Dolby & Balme, 1976 Hankel, 1993	Western Australia Majunga Basin (Madagascar)
<i>Vallasporites ignacii</i> (Leschik) Scheuring, 1970 Monosaccites	Keuper Keuper Late Carnian Cordevolian to Tuvalian Tuvalian Late Carnian Cordavolian to Middle Rhaetian vigens-densus (Cordevolian) to middle densus- majawkinae (Middle Julian) phases Tuvalian base of vigens-densus phases (Early Cordevolian) Late Carnian Cordevolian to ? Tuvalian Cordevolian to Lower Norian Carnian to Rhaetian, acme Carnian to Early Rhaetian Late Carnian Carnian Assemblages A (Late Ladinian-Early Carnian), B, (Cordevolian-Early Julian), C (Julian-Early Tuvalian), D (Tuvalian) Julian to Early Tuvalian ● sr: Carnian to Rhaethian	Leschik, 1955 Scheuring, 1970 Fisher, 1972b Dunay & Fisher, 1978 Visscher & Krystyn, 1978 Dunay & Fisher, 1979 Brugman, 1983 Van der Eem, 1983 Fisher & Dunay, 1984 Brugman, 1986 Doubinger <i>et al.</i> , 1986 Blendinger, 1988 Visscher & Brugman, 1981 Cornet, 1993 Cirilli & Montanari, 1994 Cirilli, 1995 Buratti & Carrillat, 2002 Roghi, 2004	Basel, Switzerland Solothurner, Jura England Northern Alps (Austria) NW Sicily Dockum Group Texas, USA Western Dolomites, Italy Chinle Fm Arizona, USA Transdanubian central range, Vicentinian Alps Libya SE Dolomires Northern America Southern Albany Southern Alps Sicily Julian Alps, NE Italy
<i>Verrucosporites</i> sp. Apiculati	● sr: Permian to Triassic long ranging		
<i>Verrucosporites contactus</i> Clarke, 1965 Apiculati	Keuper Early Triassic ● sr: Early Triassic to Carnian	Clarke, 1965a Adloff & Doubinger, 1969	England Votzia, France
<i>Vesicaspora obliquus</i> (Kara-Murza) Hart, 1965 Disaccites	Permian System ● sr: Permian long ranging	Hart, 1965	
<i>Vesicaspora ovata</i> (Balme & Hennelly) Hart, 1960 Disaccites	Permian System Late Permian Early Permian ● sr: Permian long ranging	Hart, 1965 Clapham, 1970 Utting, 1976	W Oklahoma Lower Karroo, Zambia
According to Balme & Hennelly, 1968 it is synonym of <i>Sulcatissporites ovatus</i> Late Permian			
<i>Vesicaspora schemeli</i> Klaus, 1963 Disaccites	Early Permian Kungurian (latest Early Permian) to Kazanian (middle Late Permian) <i>Dyupetalum</i> sp.-H. <i>bullaeformis</i> (?Kungurian-Uffimian) to <i>Tympanicysta stochiana</i> - L. <i>obsoleta</i> Assemblage zones (Griensbachian) ● sr: Permian to Early Triassic long ranging	Utting, 1978 Brouin <i>et al.</i> , 1990 Mangerud, 1994	Lower Karroo, Zambia Niger Barents sea
<i>Vesicaspora wilsonii</i> (Schemel) Wilson & Vekatchala, 1963 Disaccites	Carboniferous System A2 (Autunian) Zone Autunian Early Asselian ● sr: Carboniferous to Early Permian	Hart, 1965 Doubinger, 1974 Visscher <i>et al.</i> , 1974 Pittau <i>et al.</i> , 2002	Autunian, France "Saxonian" deposits of Germany and France Sardinia, Italy
<i>Vestigisporites</i> sp. Monosaccites	Permian System Sakmarian Early Asselian ● sr: Early Permian	Hart, 1965 Jardiné, 1974 Pittau <i>et al.</i> , 2002	Gabon Sardinia, Italy
<i>Vitreisporites pallidus</i> (Reissinger) Nilsson, 1958 Disaccites	Late Permian-Early Crataceous <i>Al. plicatus</i> -J. <i>compactus</i> Ass. Zone (Kungurian to Rodian) ● sr: Permian to Triassic long ranging	Balme, 1963 Utting, 1994	Australia Canadian Arctic Archipelago
<i>Vittatina</i> sp. Striatiti	Sakmarian to earliest Late Permian <i>Vittatina</i> "complex" Carboniferous to Early Dorashamian (late Permian) spp. <i>H. insolitus</i> -P. <i>novicus</i> Assemblage zone (zone A2 Doubinger, 1974), Autunian (Early Permian spp. <i>Potoniesporites novicus</i> (Autunian, Early Permian) zone L. <i>monstruosus</i> -V. <i>costabilis</i> Ass. Zone (Artinskian) to <i>Al. plicatus</i> -J. <i>compactus</i> Ass. Zone (Kungurian to Rodian) ● sr: Permian long ranging	Jardiné, 1974 Brugman, 1983 Eshet & Cousminer, 1986 Eshet, 1990 Utting, 1994	Gabon Negev, Israel Subsurface Israel Canadian Arctic Archipelago

Species	Ages according to the Authors ● Stratigraphical range (sr)	Authors	Geographical distribution
<i>Vittatina costabilis</i> Wilson, 1962 Striatiti	Late Permian Late Permian Permian System Late Permian A3 (Early Permian, Artinskian-Early Kungurian) Zone Kungurian (latest Early Permian) to Kazanian (middle Late Permian) <i>Potoniesporites novicus</i> (Autunian, Early Permian) zone <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Tympanicysta stochiana</i> - <i>L. obsoleta</i> Assemblage zones (Griensbachian) <i>L. monstruosus</i> - <i>V. costabilis</i> Ass. Zone (Artinskian) Artinskian ● sr: Permian long ranging	Klaus, 1963 Wilson, 1963 Hart, 1965 Clapham, 1970 Doubinger, 1974 Broutin <i>et al.</i> , 1990 Eshet, 1990 Mangerud, 1994 Utting, 1994 Dunn, 2001	Southern Alps Oklahoma W Oklahoma Autunian, France Niger Subsurface Israel Barents sea Canadian Arctic Archipelago Kazakhstan
<i>Vittatina minima</i> Jansonius, 1962 Striatiti	Early Triassic and Permian Canada, common Permian System <i>L. monstruosus</i> - <i>V. costabilis</i> Ass. Zone (Artinskian) ● sr: Permian to Early Triassic long ranging	Jansonius, 1962 Hart, 1965 Utting, 1994	Canada Canadian Arctic Archipelago
<i>Vittatina simplex</i> Jansonius, 1962 Striatiti	Permian System Late Permian spp. <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Scutasporites</i> sp. cf. <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) Artinskian ● sr: Permian long ranging	Hart, 1965 Clapham, 1970 Mangerud, 1994 Dunn, 2001	 W Oklahoma Barents sea Kazakhstan
<i>Vittatina</i> cf. <i>V. striata</i> (Luber & Valts) Samoilovich, 1953 Striatiti	Permian System spp. <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Scutasporites</i> sp. cf. <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) ● sr: Permian long ranging	Hart, 1965 Mangerud, 1994	 Barents sea
<i>Vittatina vittifera</i> (Luber & Valts) Samoilovich, 1953 Striatiti	Kungurian Permian System <i>L. monstruosus</i> - <i>V. costabilis</i> Ass. Zone (Artinskian) to <i>A. thorsteinssonii</i> - <i>S. nanuki</i> A ss. Zone (Wordian) spp. <i>Dyupetalum</i> sp.- <i>H. bullaeformis</i> (?Kungurian-Uffimian) to <i>Scutasporites</i> sp. cf. <i>S. unicus</i> Concurrente range Zone (Kazanian-?Tatryan) Artinskian ● sr: Early Permian	Samoilovich, 1953 Hart, 1965 Utting, 1994 Mangerud, 1994 Dunn, 2001	Cis Urals Canadian Arctic Archipelago Barents sea Kazakhstan
<i>Voltziaceasporites heteromorpha</i> Klaus, 1964 Disaccites	Late Buntsandstein (Early Triassic) Late Bunter, common. In Muschelkalk and Keuper present Middle Triassic Early Triassic Anisian Röt to Keuper Tuvanian nejburgii-heteromorphus (Spathian) to base of secatus-dimorphus phases (Early Longobardian) abundant to dominant at the top of heteromorphus-conmilvinus (late Spathian) to conmilvinus-crassa phases (early Aegean) Anisian s.l. <i>V. heteromorpha</i> - <i>A. grauvogeli</i> (Early Anisian) to <i>Latosaccus latus</i> (early late Anisian) Assemblage zones <i>Aratrisporites saturni</i> (Anisian, Middle Triassic) zone Anisian Early Ladinian Late Spathian to lower Lower Anisian Ladinian Earliest Triassic (Induan) Assemblage D (Tuvanian) ● sr: Triassic long ranging	Klaus, 1964 Visscher, 1966 Visscher & Commissaris, 1968 Adloff & Doubinger, 1969 Antonescu, 1970 Fisher, 1972a Fisher & Dunay, 1984 Brugman, 1986 Doubinger <i>et al.</i> , 1986 Eshet & Cousminer, 1986 Eshet, 1990 Kilani-Mazraoui <i>et al.</i> , 1990 Mørk & al., 1990 Visscher & Brugman, 1981 Fréchengues <i>et al.</i> , 1993 Ouyang & Norris, 1999 Buratti & Carrillat, 2002	Netherlands Lower Muschelkalk of Winterswijk, Netherlands Votzia, France Brasov, Rumanie Liverpool, England Chinle Fm Arizona, USA Transdanubian central range, Vicentinian Alps Libya Negev, Israel Subsurface Israel Southern Tunisia Barent Sea Pyrenees Xinjiang (NW China) Sicily
<i>Weylandites striatus</i> (Luber), Utting, 1994 Striatiti	<i>L. monstruosus</i> - <i>V. costabilis</i> Ass. Zone (Artinskian) to <i>A. thorsteinssonii</i> - <i>S. nanuki</i> Ass. Zone (Wordian) ● sr: late Early Permian to Middle Permian	Utting, 1994	Canadian Arctic Archipelago
<i>Wilsonites</i> sp. Monosaccites	<i>vesicatus</i> A2 (Autunian) Zone early Asselian ● sr: Early Permian	Doubinger, 1974 Pittau <i>et al.</i> , 2002	Autunian, France Sardinia, Italy

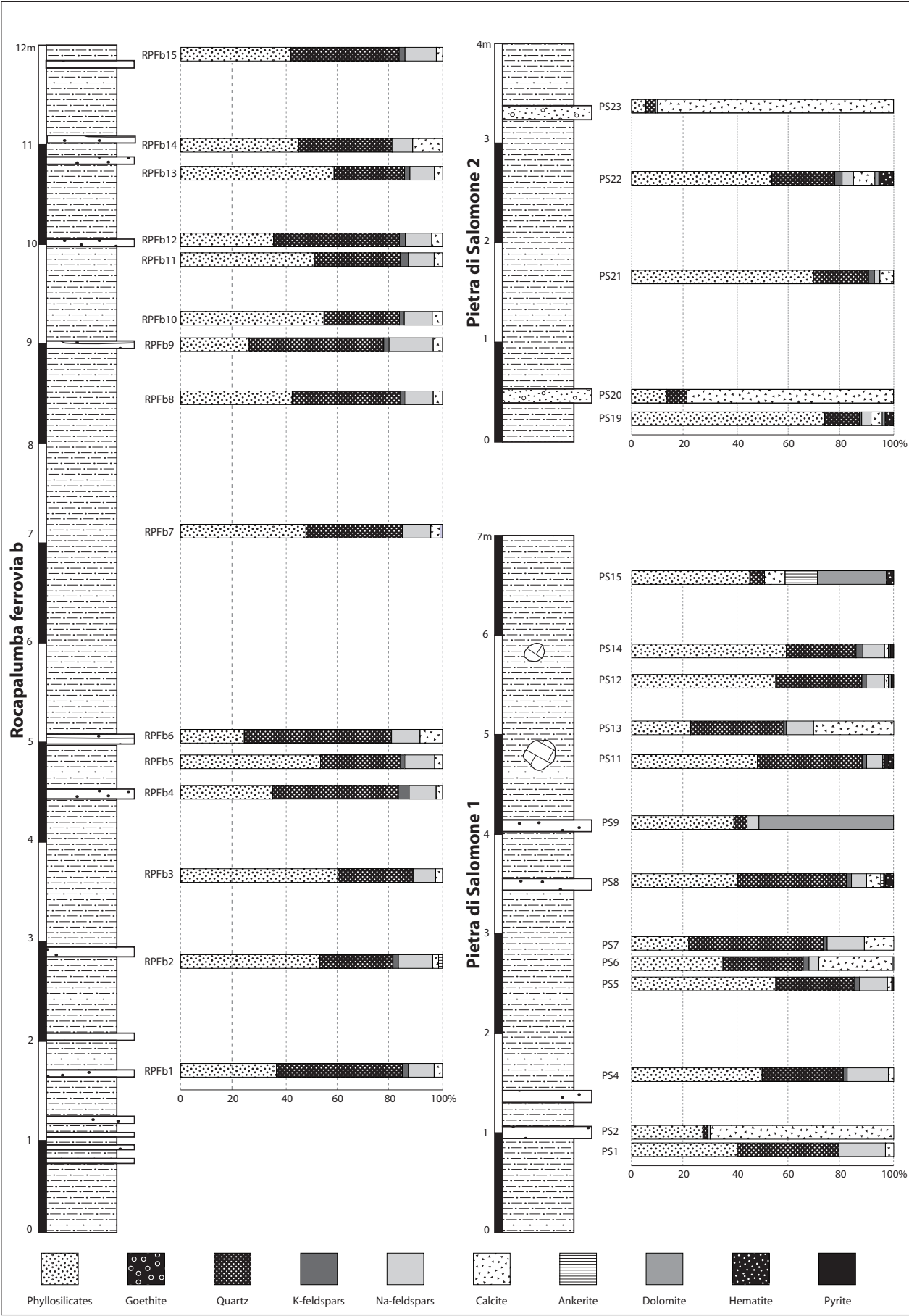
Appendix 4.1 Bulk rock (%) mineralogy of the Lercara Formation samples.



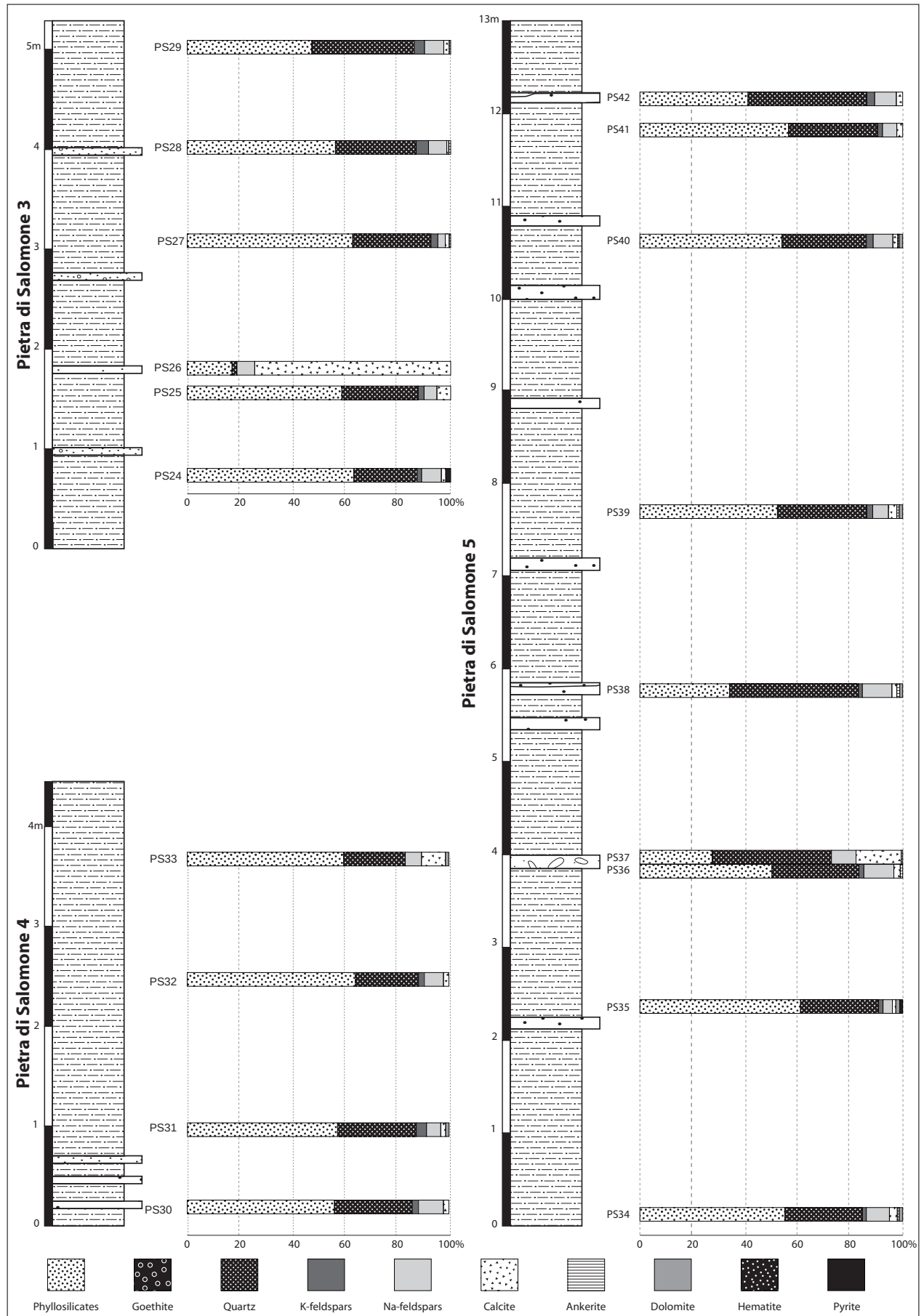
Appendix 4.2 Bulk rock (%) mineralogy of the Lercara Formation samples.



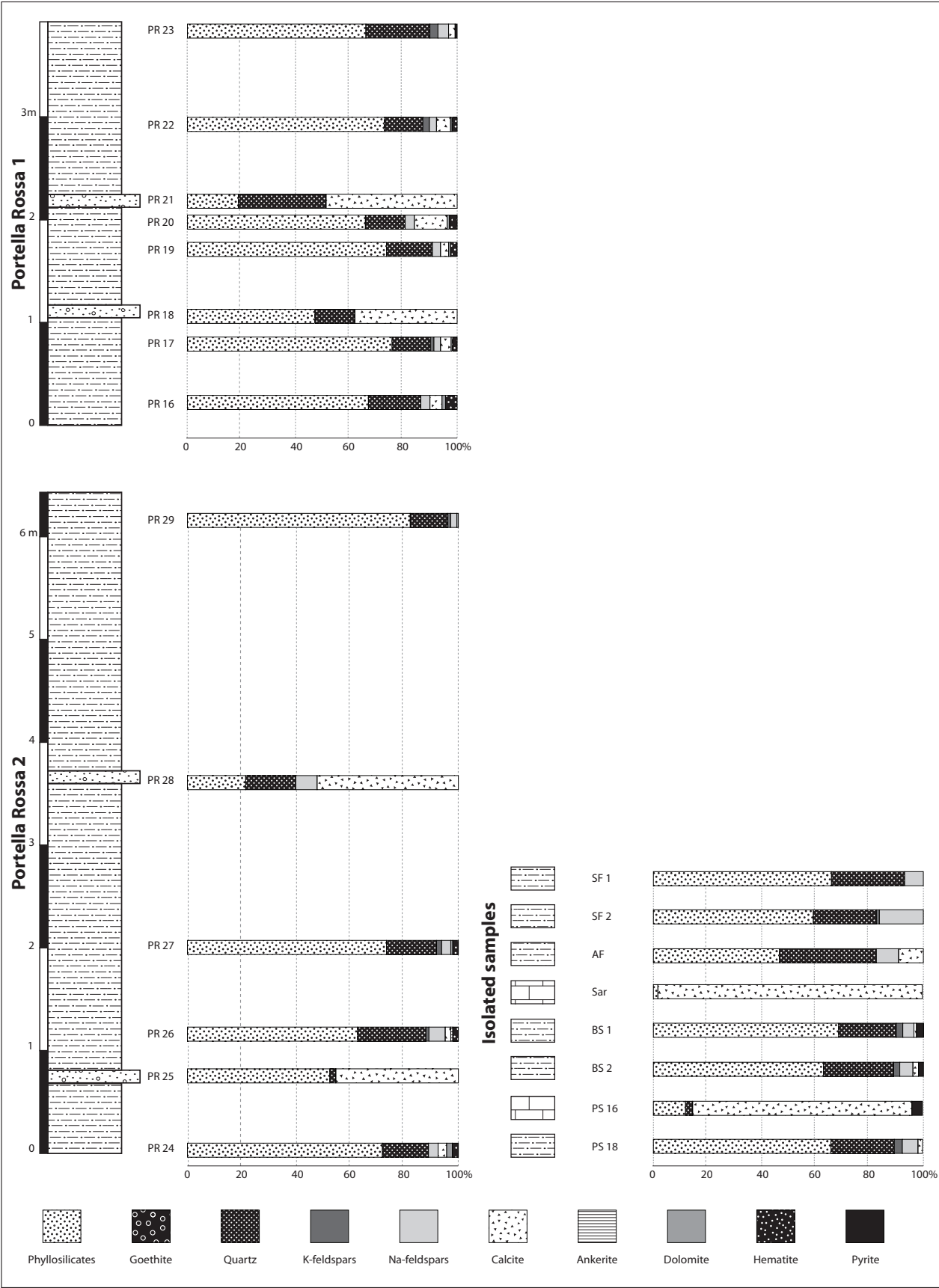
Appendix 4.3 Bulk rock (%) mineralogy of the Lercara Formation samples.



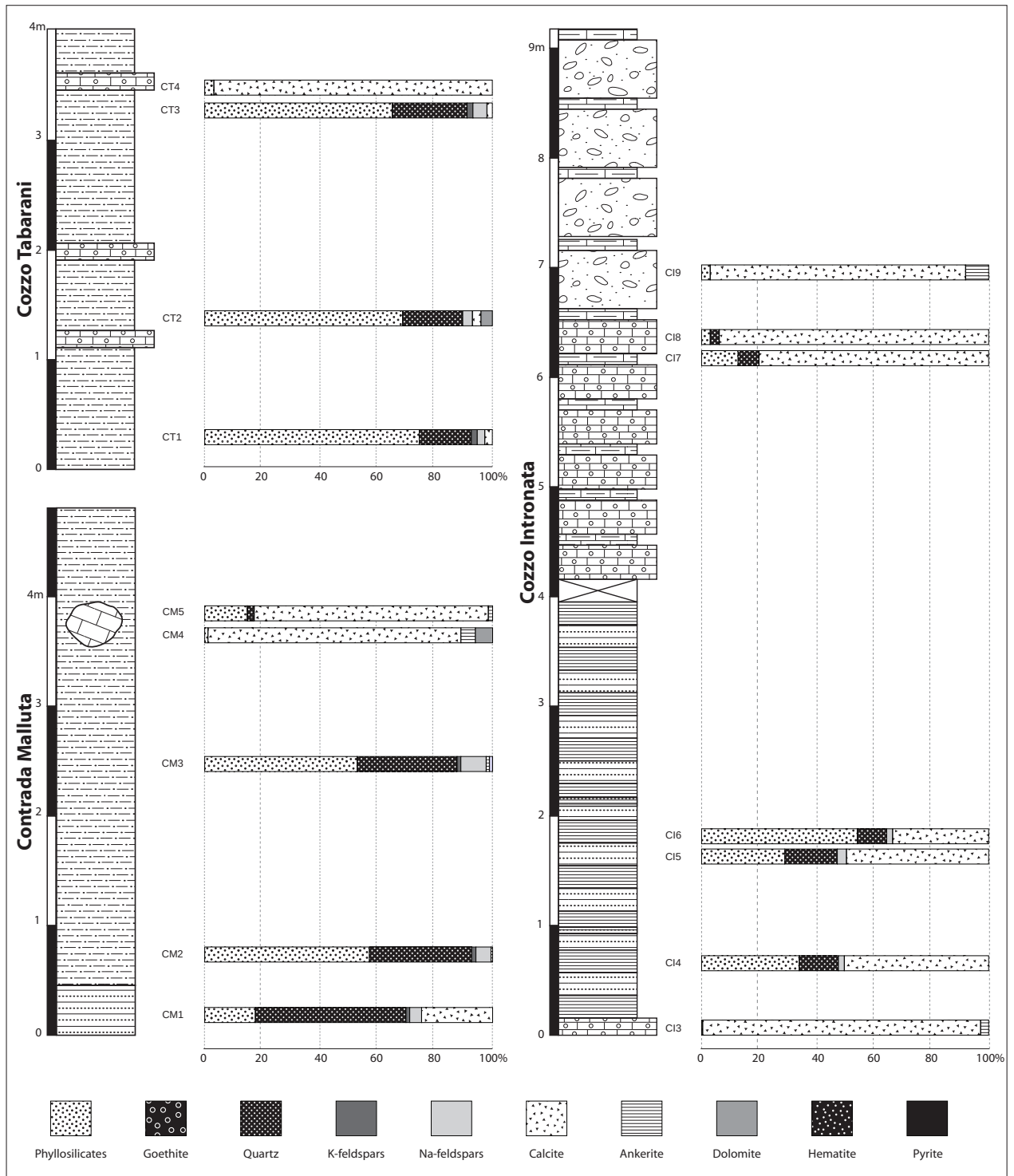
Appendix 4.4 Bulk rock (%) mineralogy of the Lercara Formation samples.



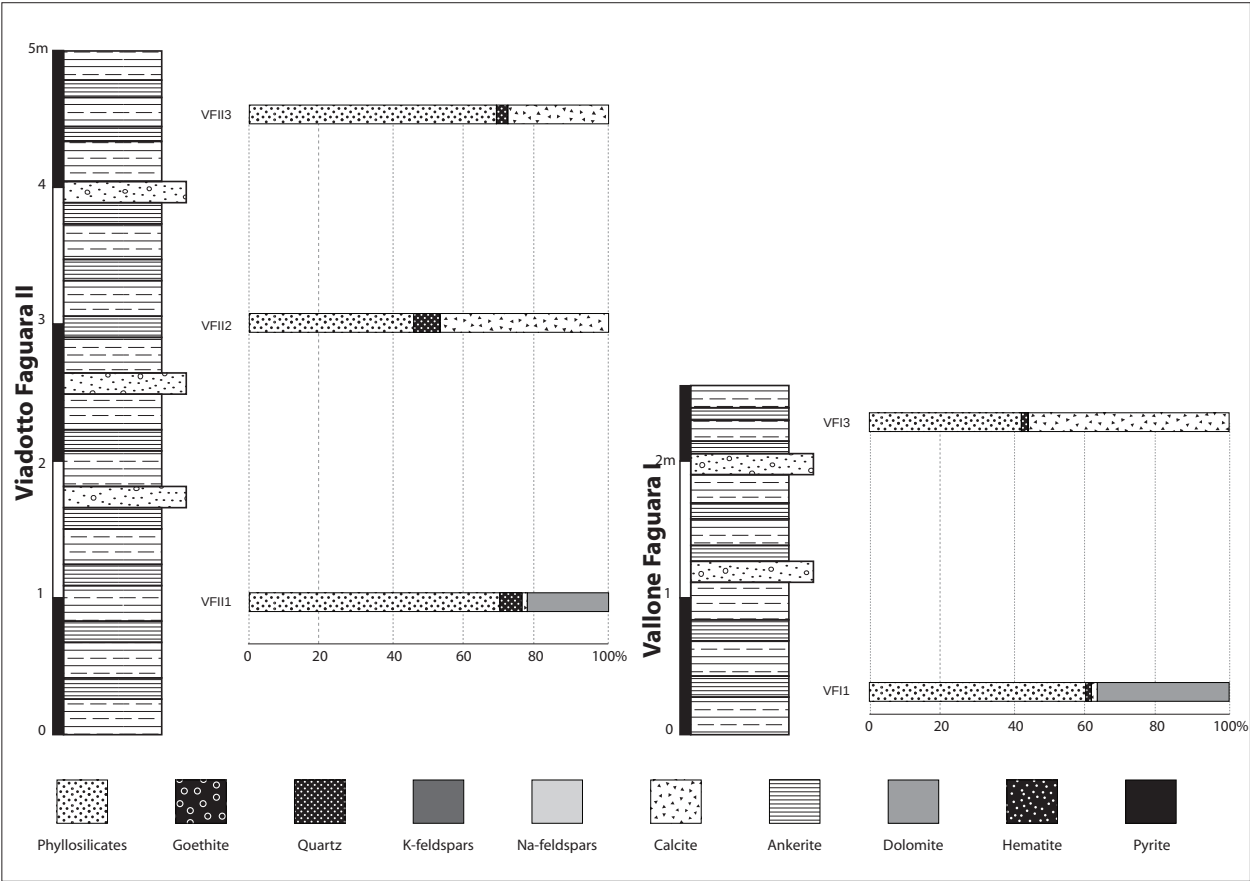
Appendix 4.5 Bulk rock (%) mineralogy of the Lercara Formation samples.



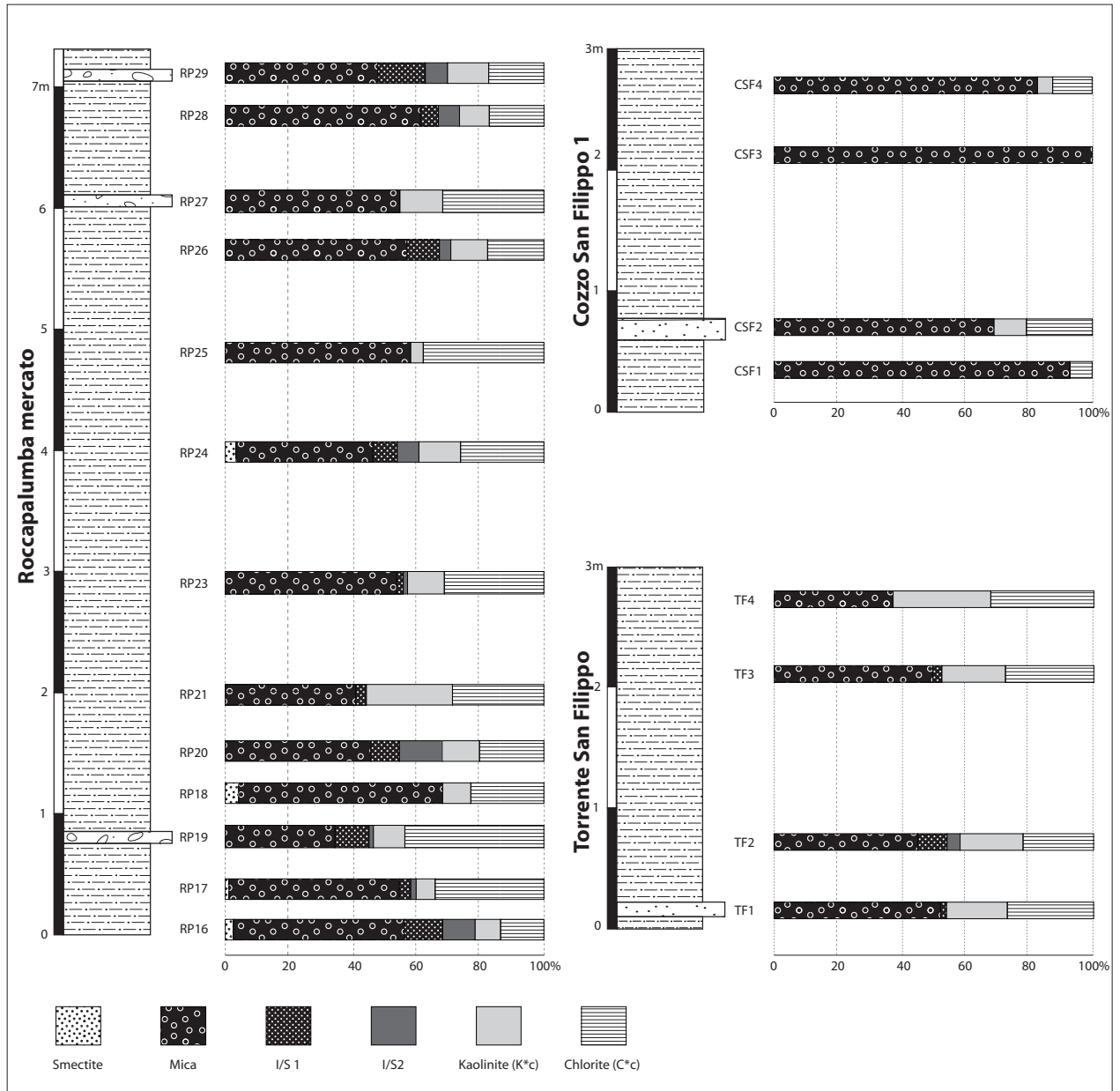
Appendix 4.6 Bulk rock (%) mineralogy of the Mufara Formation samples.



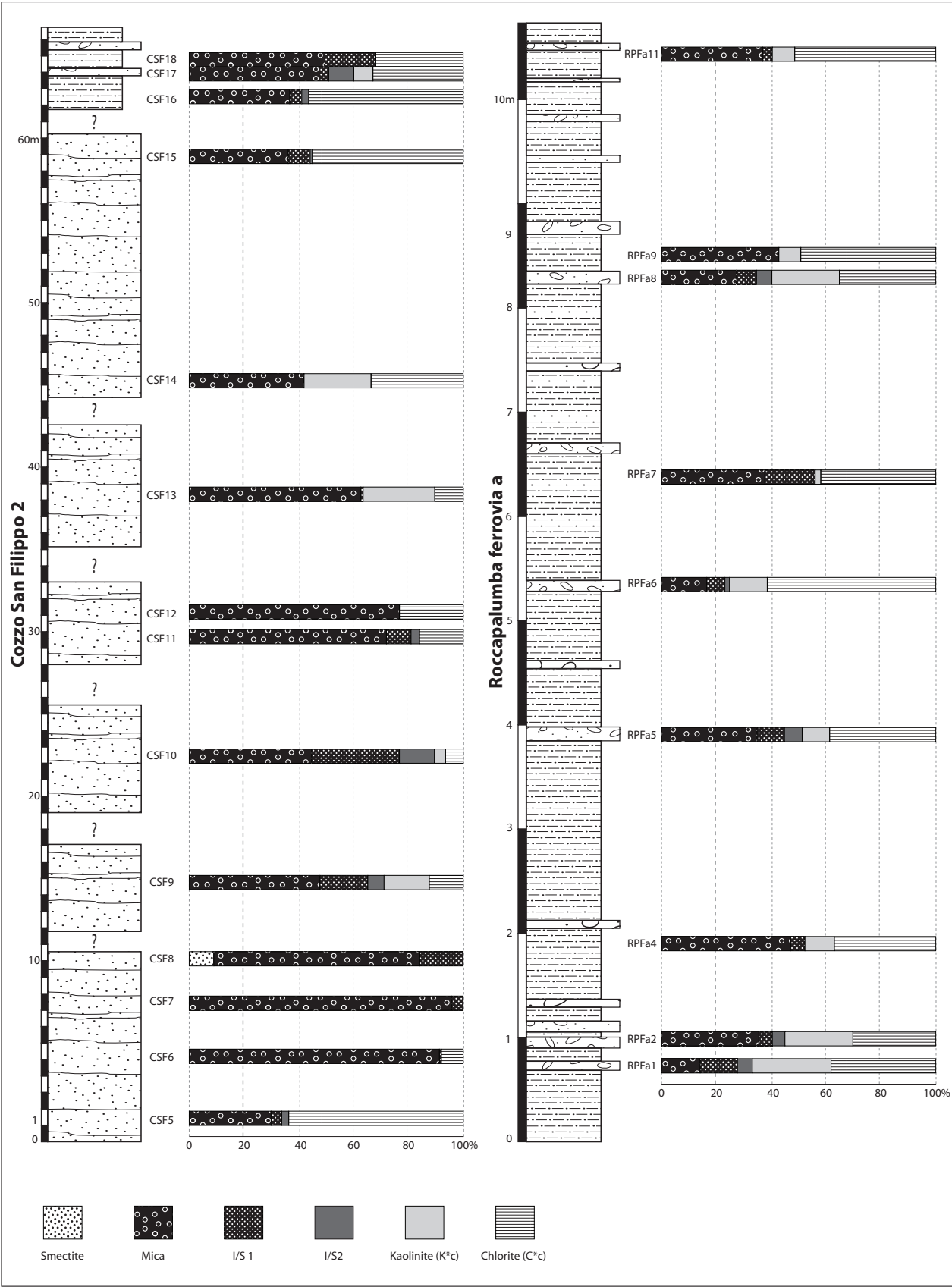
Appendix 4.7 Bulk rock (%) mineralogy of the Mufara Formation samples.



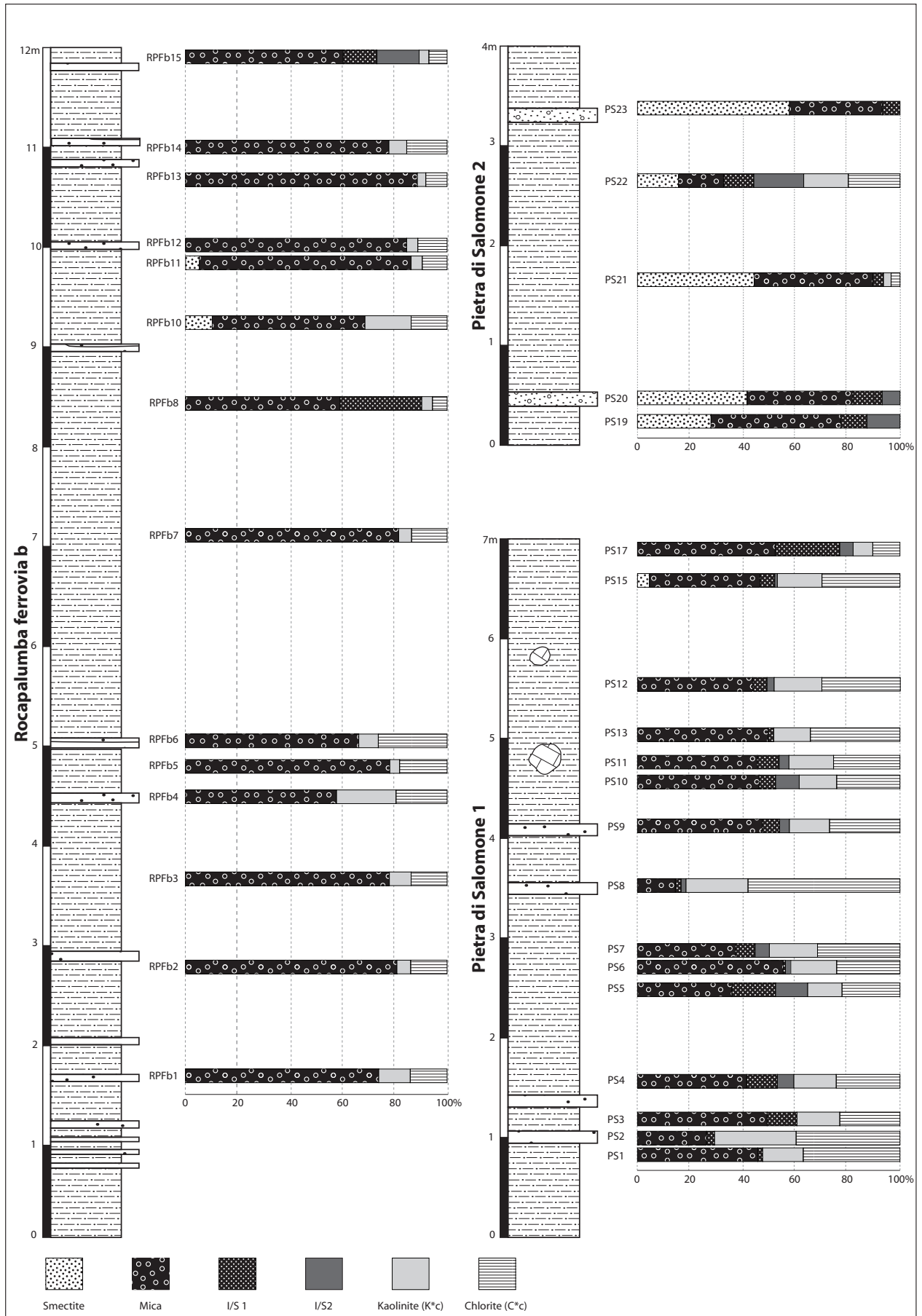
Appendix 4.8 Fraction < 2 µm clay mineralogy (%) of the Lercara Formation samples.



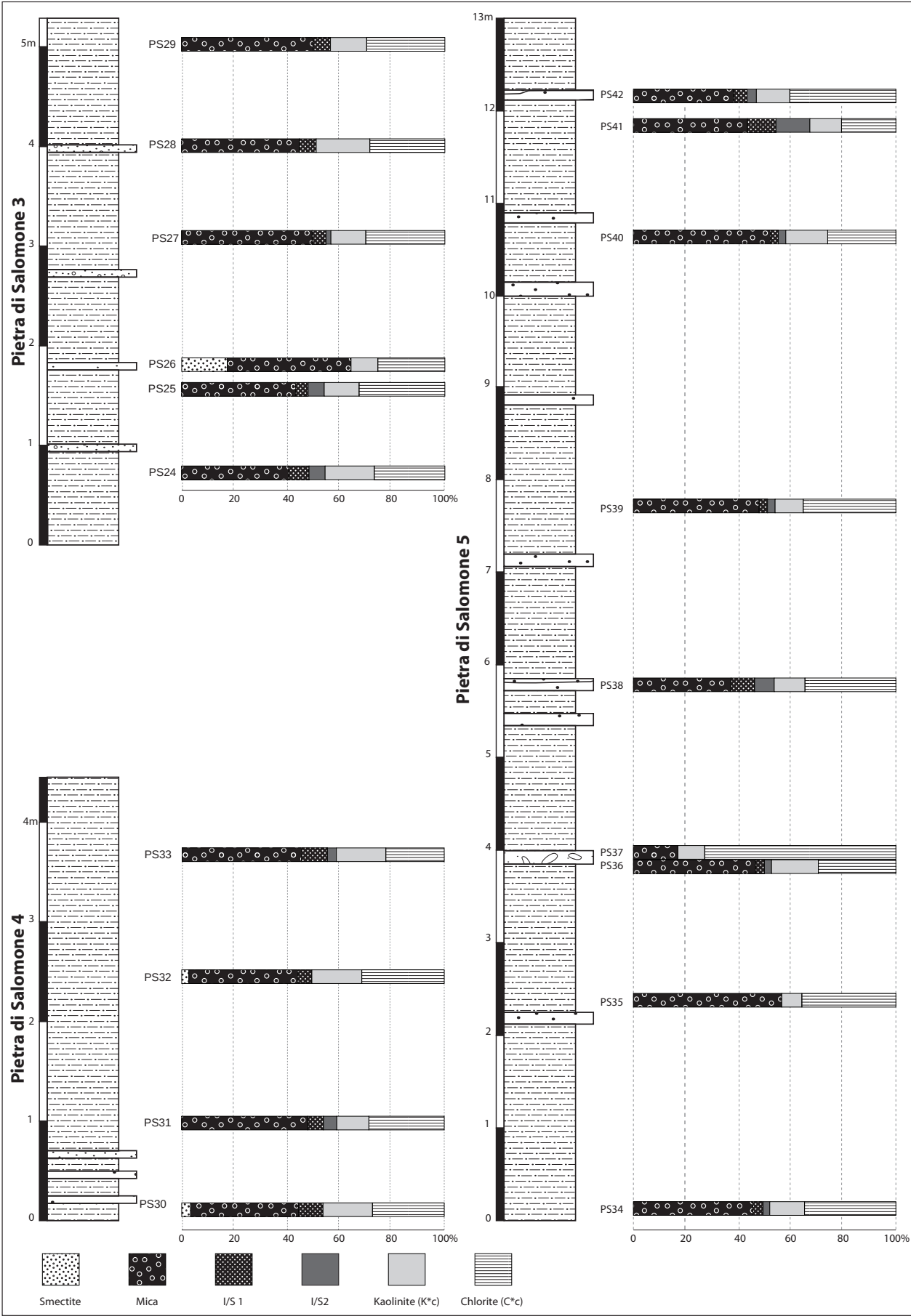
Appendix 4.9 Fraction < 2 µm clay mineralogy (%) of the Lercara Formation samples.



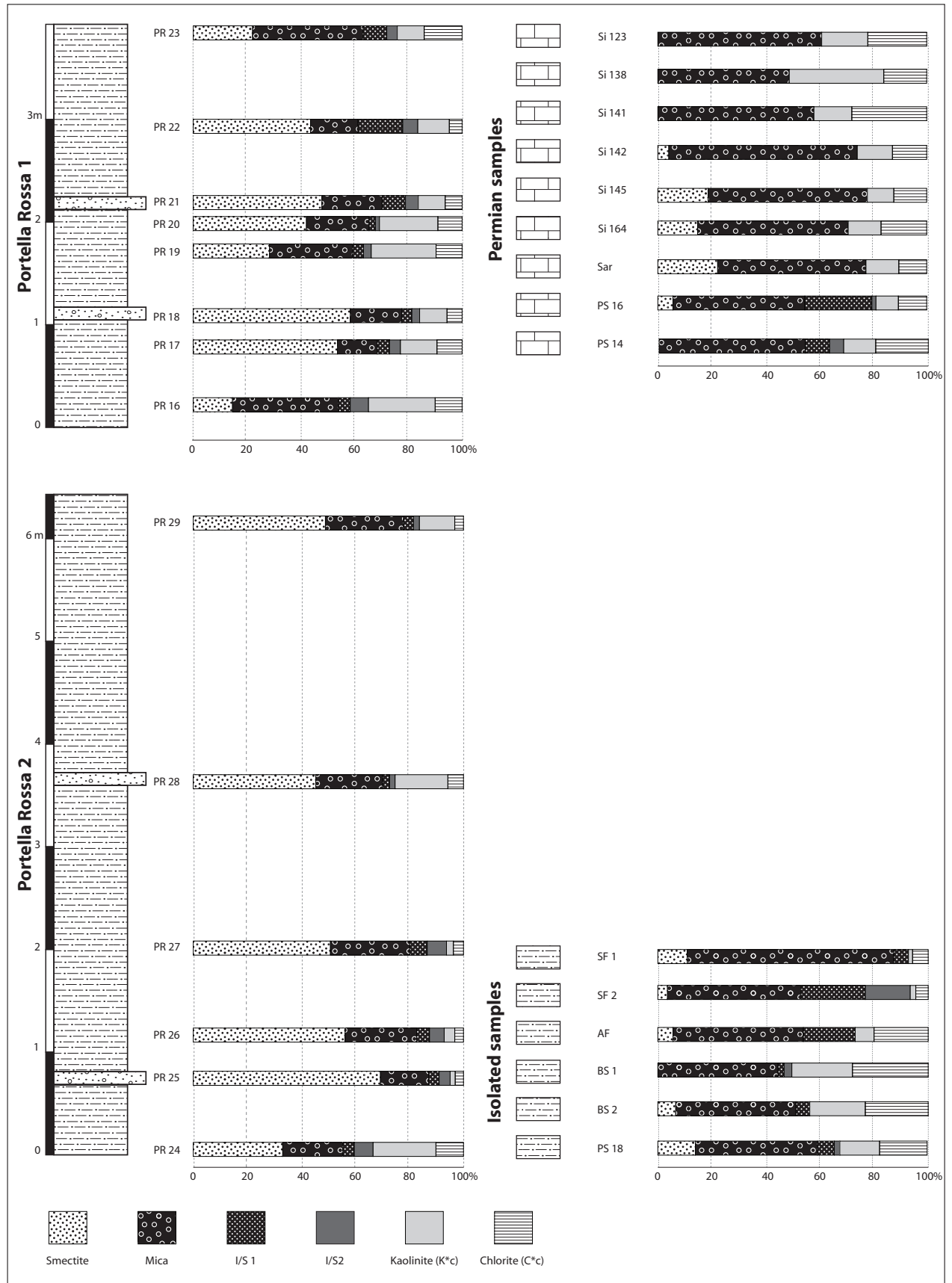
Appendix 4.10 Fraction < 2 µm clay mineralogy (%) of the Lercara Formation samples.



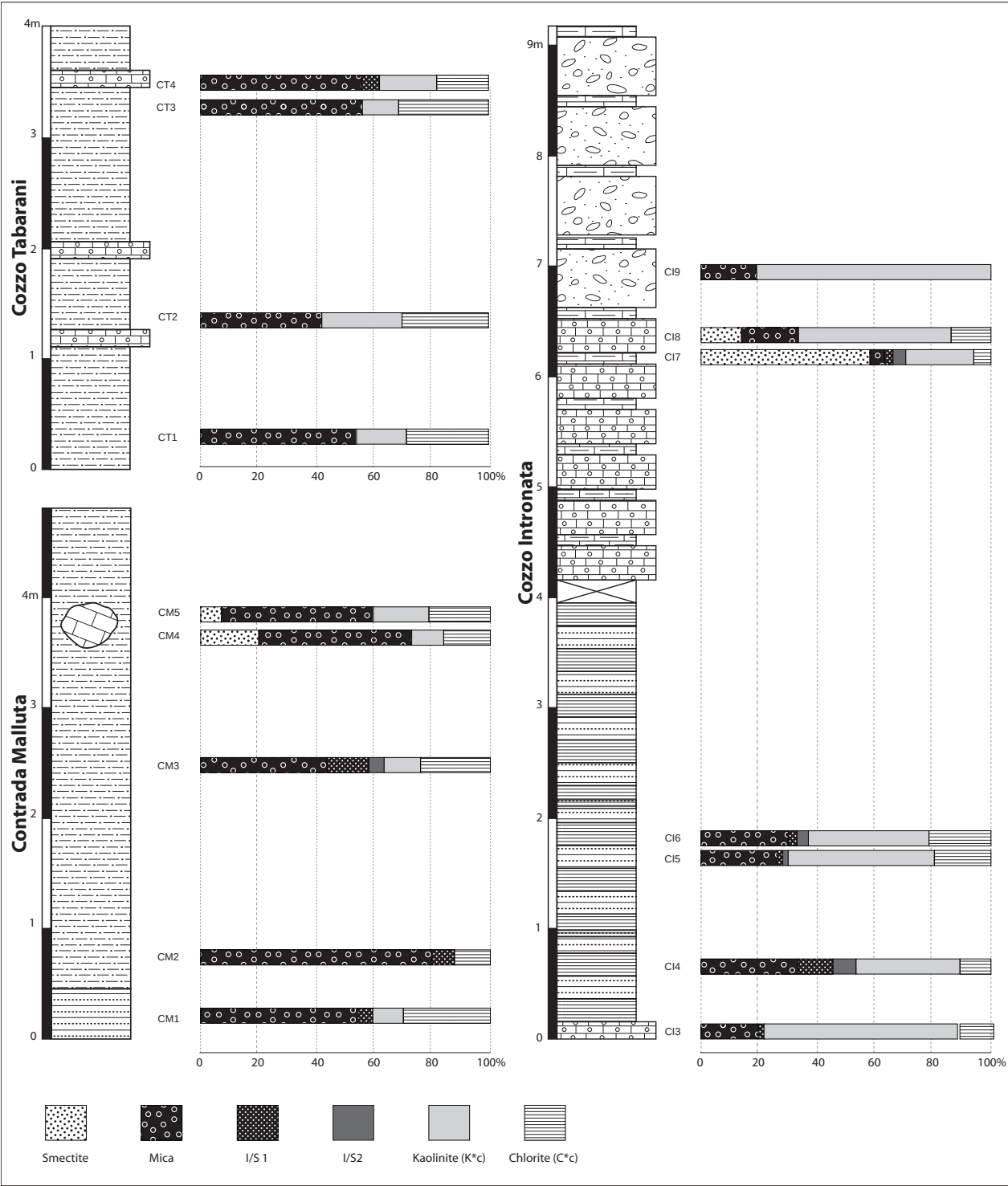
Appendix 4.11 Fraction < 2 µm clay mineralogy (%) of the Lercara Formation samples.



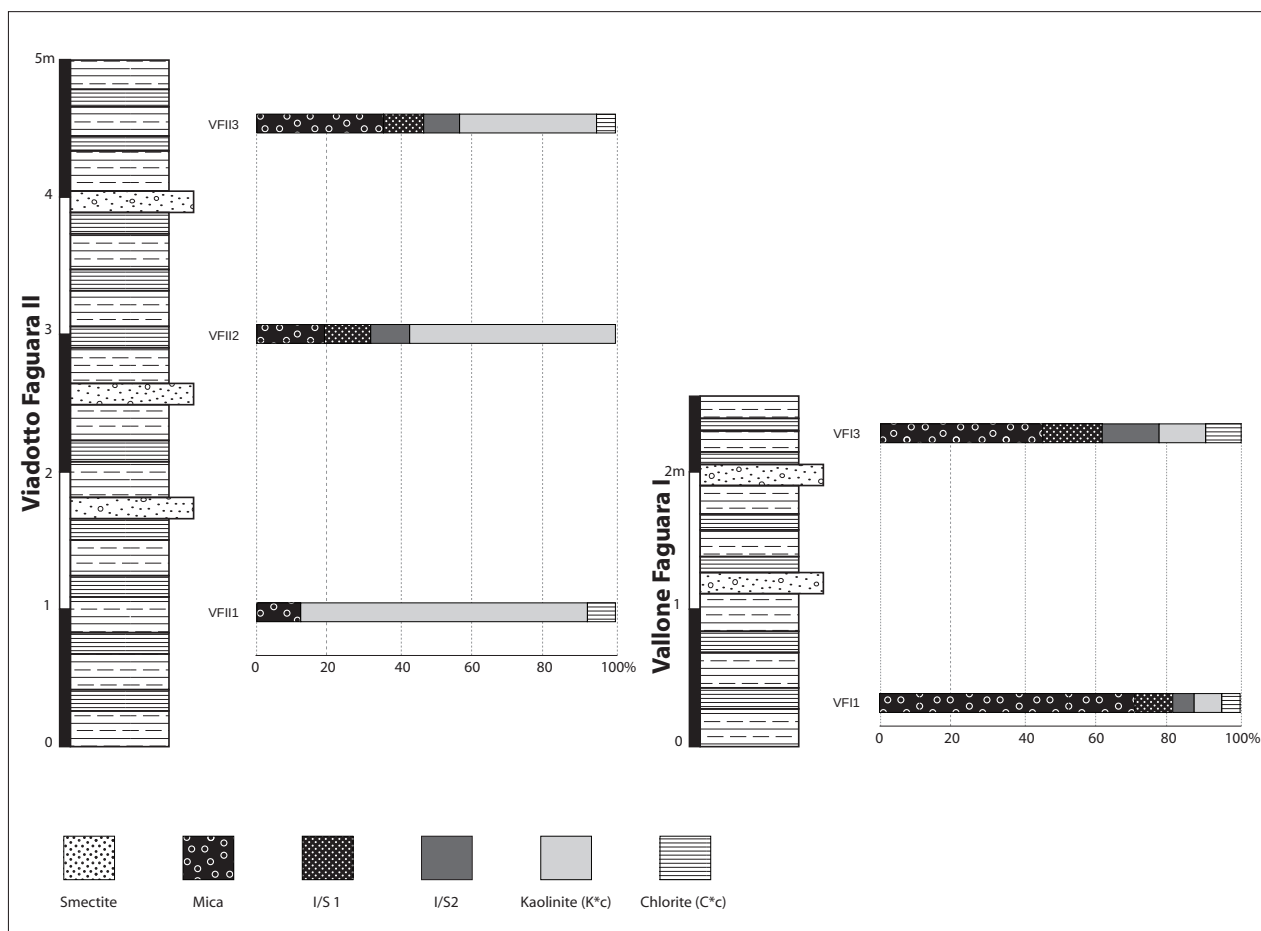
Appendix 4.12 Fraction < 2 µm clay mineralogy (%) of the Lercara Formation and of the Permian samples.



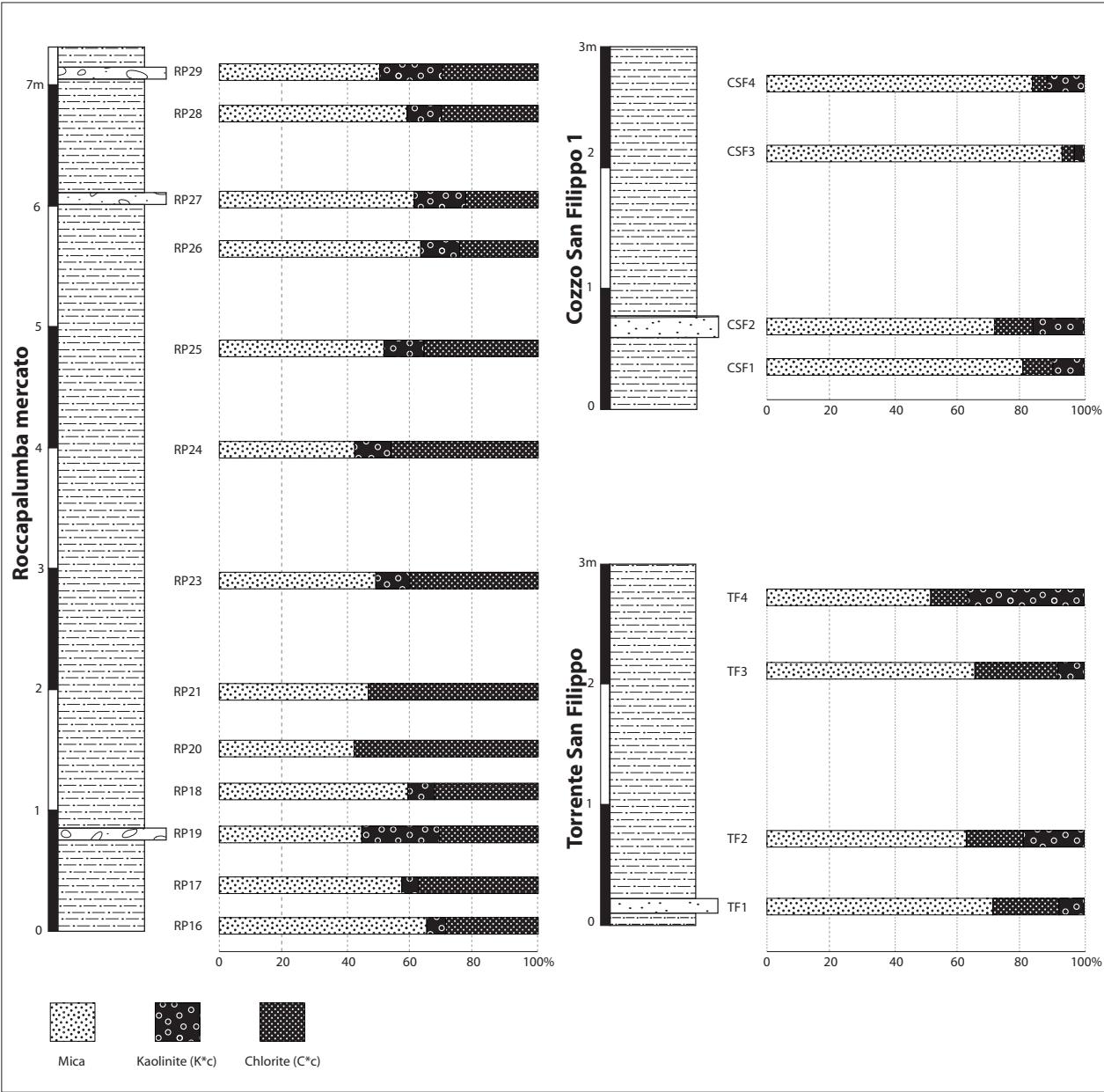
Appendix 4.13 Fraction < 2 µm clay mineralogy (%) of the Mufara Formation samples.



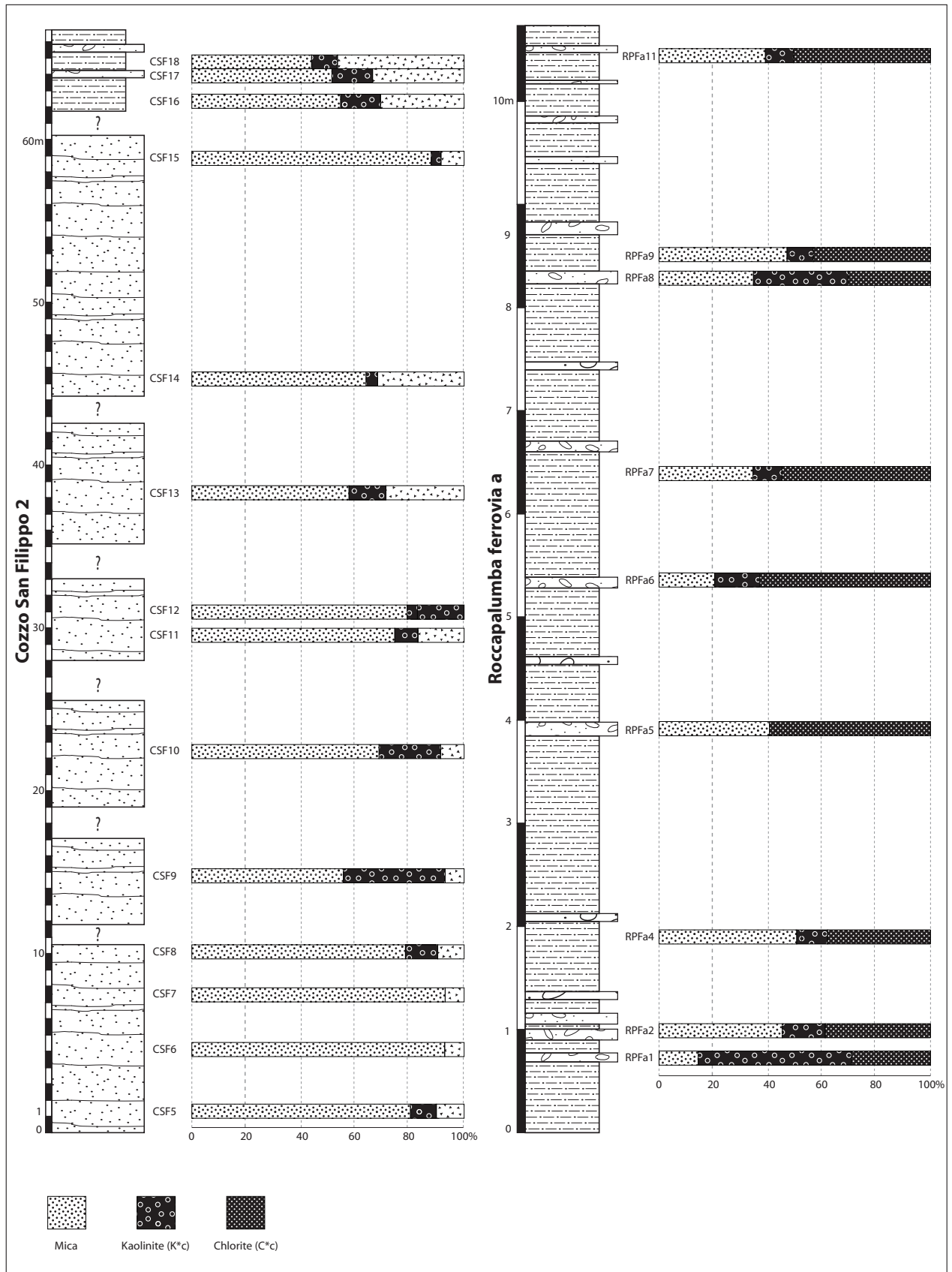
Appendix 4.14 Fraction < 2 µm clay mineralogy (%) of the Mufara Formation samples.



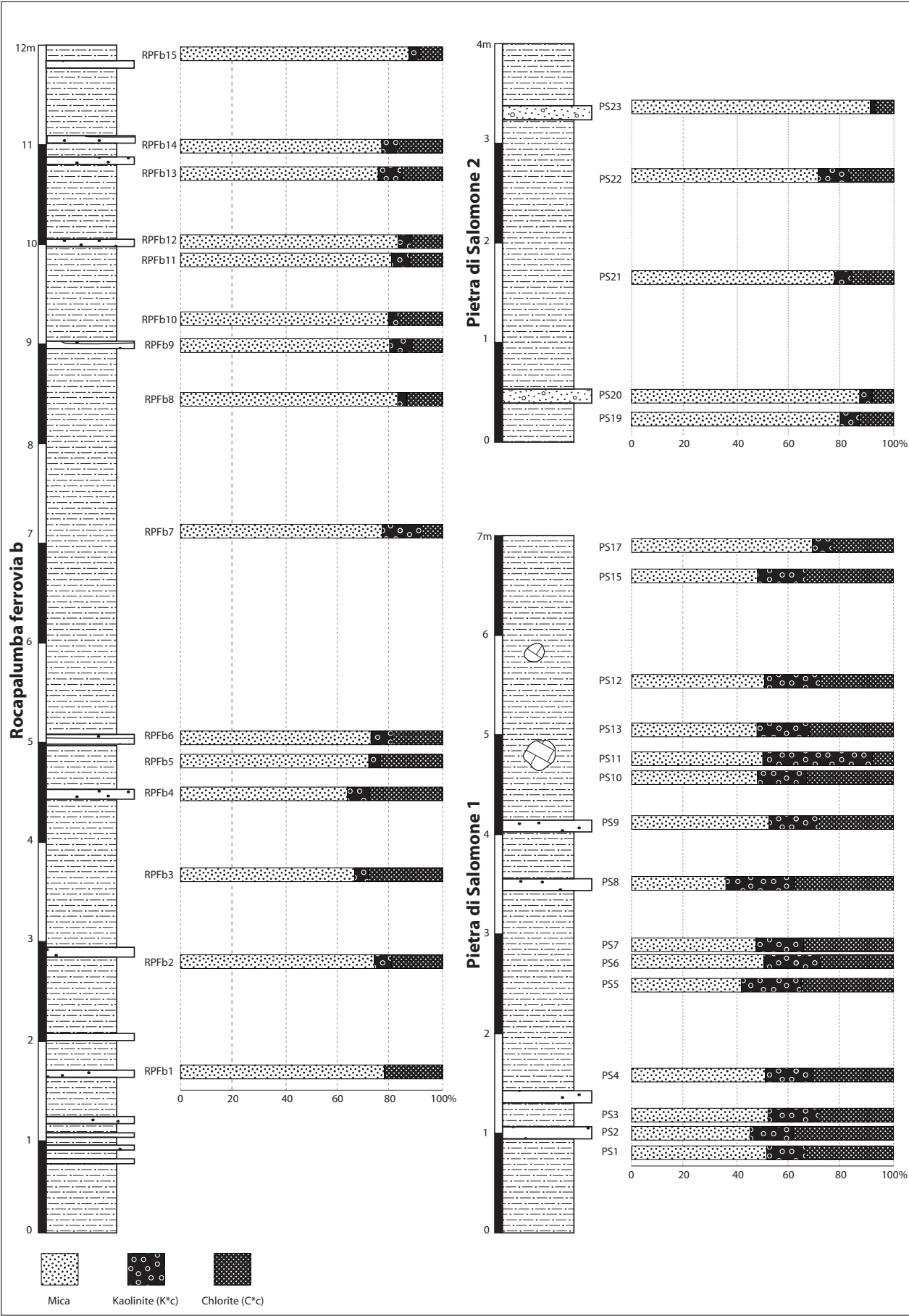
Appendix 4.15 Fraction 2-16 μm clay mineralogy (%) of the Lercara Formation samples.



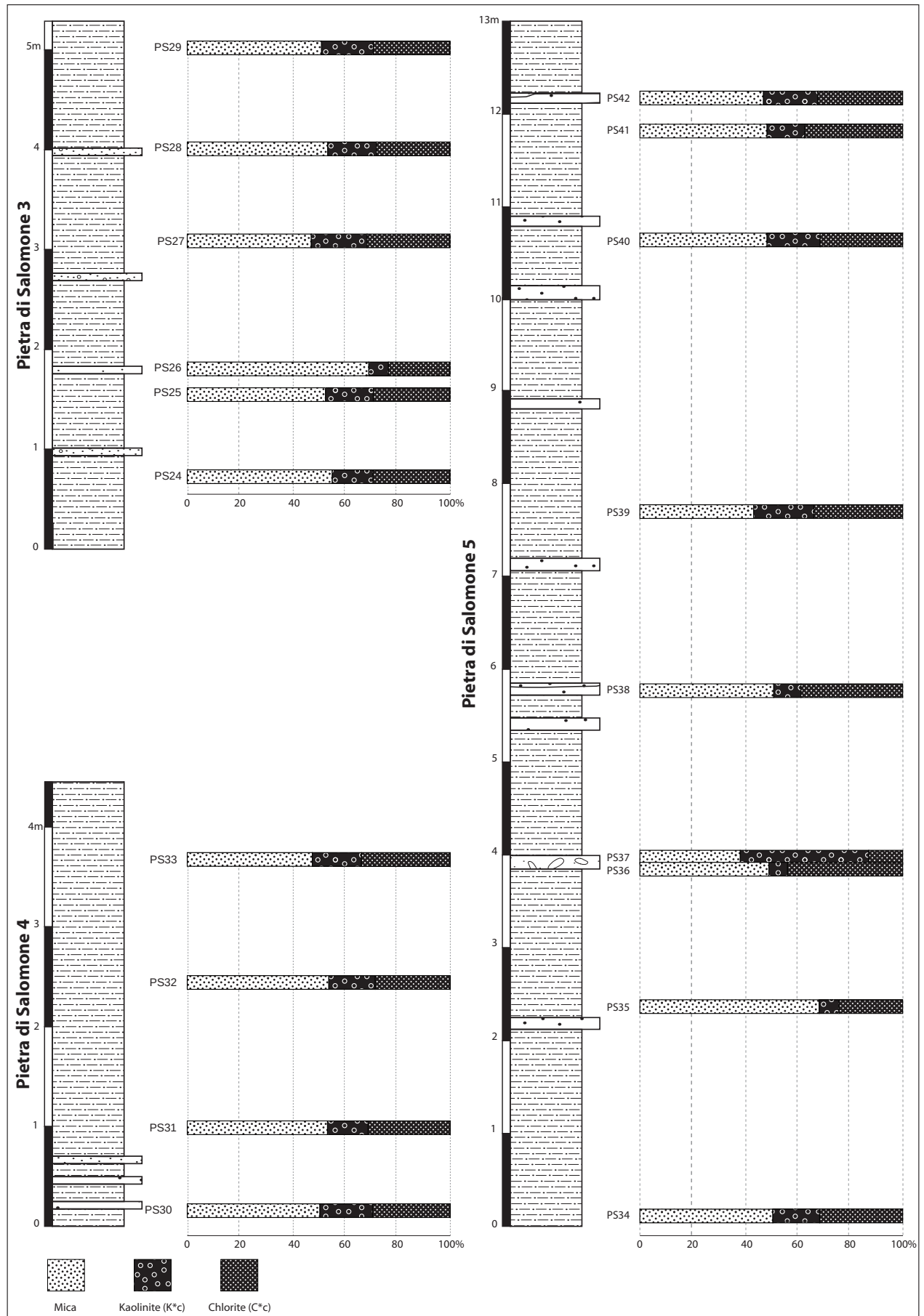
Appendix 4.16 Fraction 2-16 μm clay mineralogy (%) of the Lercara Formation samples.



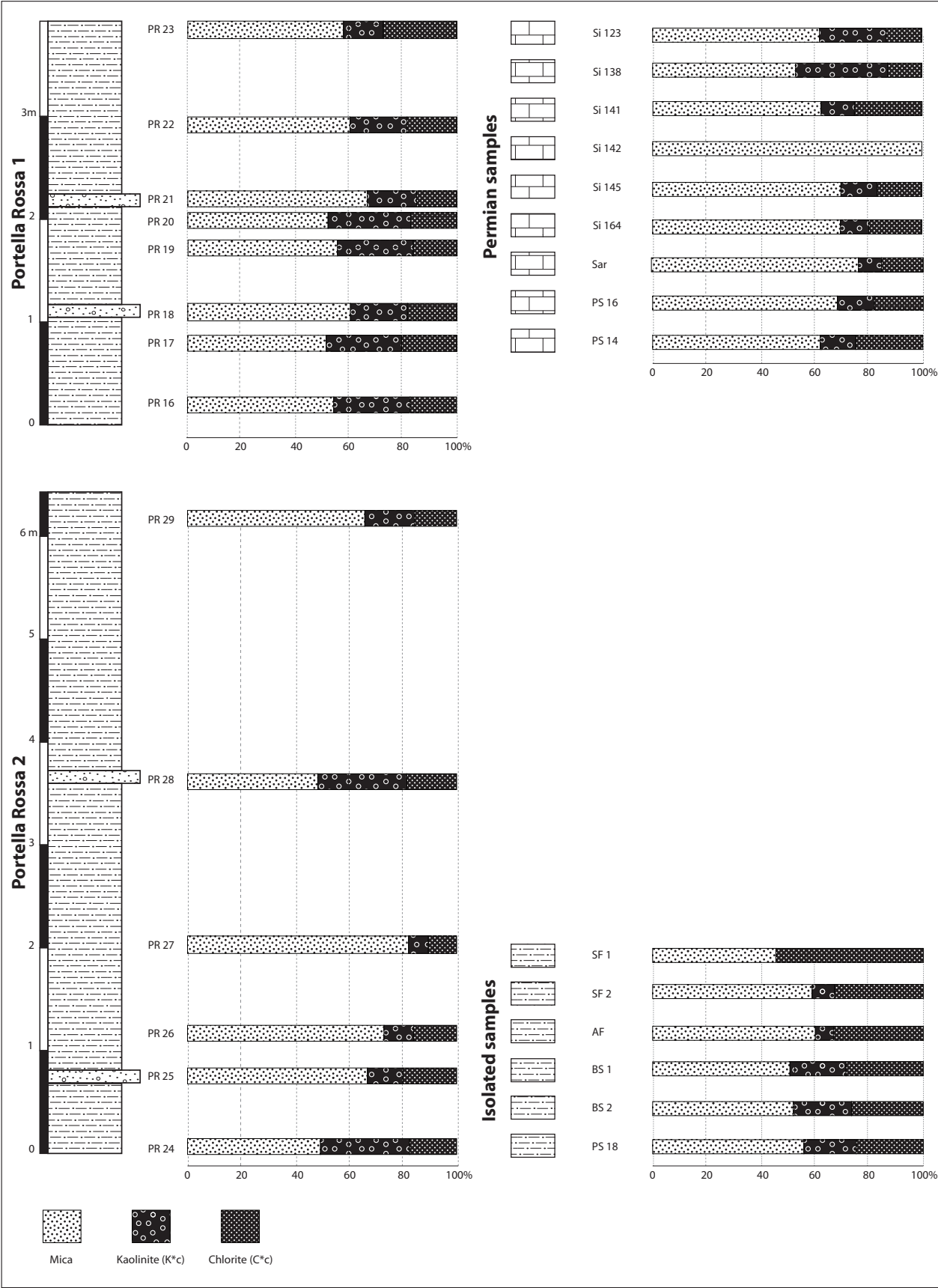
Appendix 4.17 Fraction 2-16 µm clay mineralogy (%) of the Lercara Formation samples.



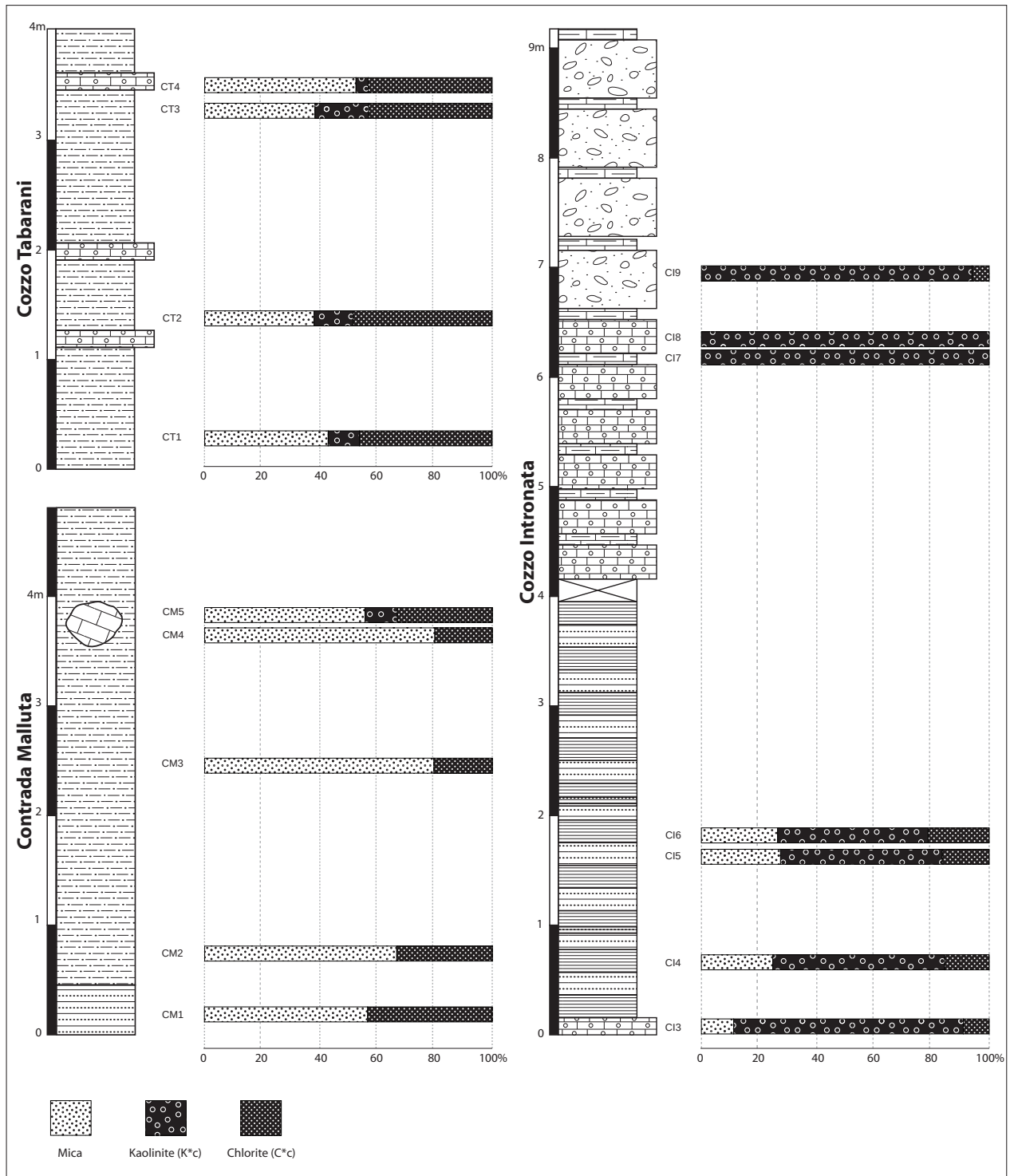
Appendix 4.18 Fraction 2-16 μm clay mineralogy (%) of the Lercara Formation samples.



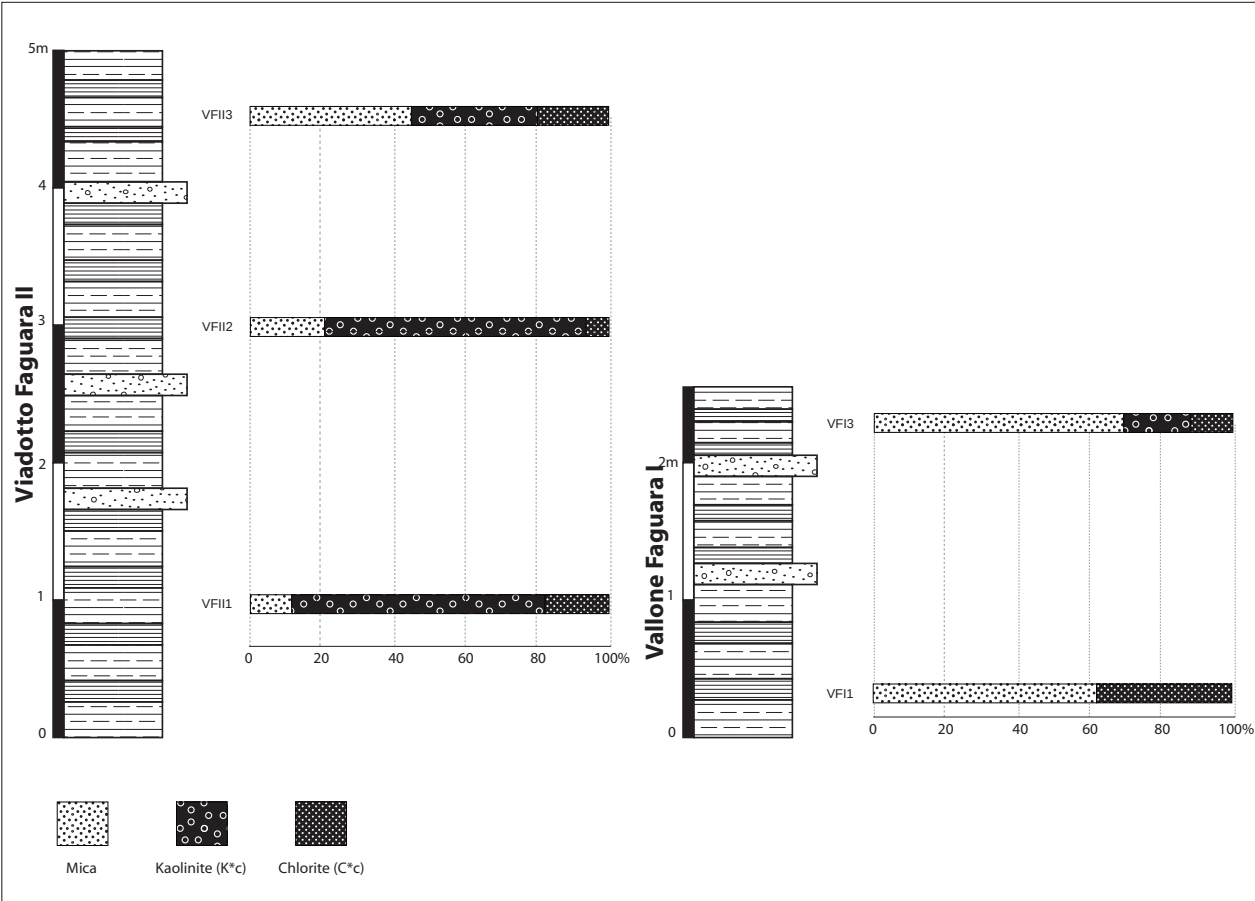
Appendix 4.19 Fraction 2-16 μm clay mineralogy (%) of the Lercara Formation and of the Permian samples.



Appendix 4.20 Fraction 2-16 μm clay mineralogy (%) of the Mufara Formation samples.



Appendix 4.21 Fraction 2-16 µm clay mineralogy (%) of the Mufara Formation samples.



Appendix 5 Silicate Index of the Lercara Formation samples.

Member	samples	IS	Member	samples	IS	Member	samples	IS
Member A	CSF15	0.76		PR24	0.83		RPfb12	0.79
	CSF14	0.95		PR23	0.77		RPfb9	0.73
	CSF13	0.79		PR22	0.74		RPfb6	0.84
	CSF12	0.73		PR20	0.81		RPfb4	0.77
	CSF11	0.87		PR19	0.86		RPfb1	0.80
	CSF10	0.83		PR17	0.79		PS9	0.84
	CSF9	0.84		PR16	0.85		PS8	0.77
	CSF8	0.85		BG3	0.74		PS2	0.69
	CSF7	0.85		BG1	0.70		PS42	0.80
	CSF6	0.72					PS38	0.79
	CSF5	0.80						
Member B lithology B1			Member B					
	RP28	0.76	lithology B2a	RP29	1.00			
	RP26	0.61		RP27	0.43			
	RP25	0.65		RP19	1.00			
	RP24	0.73		RPfa8	0.57			
	RP23	0.76		RPfa6	0.81			
	RP21	0.77		RPfa5	0.83			
	RP20	0.78		RPfa2	0.82			
	RP18	0.69		RPfa1	0.90			
	RP17	0.79		CSF17	1.00			
	RP16	0.76		PS23	0.85			
	TF4	0.68		PS20	1.00			
	TF3	0.76		PS37	0.83			
	TF2	0.73		PS26	0.22			
	CSF16	0.82		PR28	0.70			
	CSF15	0.88	Member B					
	CSF13	0.78	lithology B2b	PS16	1.00			
	RPfa11	0.79		PS14	0.00			
	RPfa9	0.73		saraceni	0.00			
	RPfa7	0.76						
	RPfa4	0.83	Member B					
	RPfb15	0.75	lithology B3	TF1	0.75			
	RPfb14	0.82		CSF14	0.87			

Appendix 6 Percentage of illite (%) and smectite (%Sm) in the interlayered I/S, Reichweite ordering (R), Illite crystallinity (IC) and X-ray patterns (XRD) for all the studied samples.

Sections	samples	%I	%Sm	R	CI	XRD	Sections	samples	%I	%Sm	R	CI	XRD	Sections	samples	%I	%Sm	R	CI	XRD
Lercara samples																				
	RPFa9							RPFa9	0	0	/	0.96	c		PS22	70	30	0	0.25	a
	RPFa8							RPFa8	0	0	/	0.46	c		PS21	50	50	0	0.87	a
	RPFa7							RPFa7	95	5	>1	0.27	c		PS20	50	50	0	2.78	a
	RPFa6							RPFa6	95	5	>1	0.16	c		PS19	60	40	0	1.49	a
	RPFa5							RPFa5	90	10	>1	0.17	c	Pietra Salomone 3	PS29	85	15	1	0.75	b
	RPFa4							RPFa4	90	10	>1	0.6	c		PS28	85	15	1	1.06	b
	RPFa2							RPFa2	90	10	>1	0.74	c		PS27	85	15	1	1.04	b
	RPFa1							RPFa1	95	5	>1	0.9	c		PS26	0	0	/	0.42	b
	RPFa15							RPFa15	0	0	/	0.28	c		PS25	85	15	1	0.86	c
	RPFa14							RPFa14	0	0	/	0.47	c		PS24	90	10	>1	0.57	b
	RPFa13							RPFa13	0	0	/	0.17	c	Pietra Salomone 4	PS33	85	15	1	0.6	b
	RPFa12							RPFa12	0	0	/	0.17	c		PS32	90	10	>1	0.57	b
	RPFa11							RPFa11	0	0	/	0.45	c		PS31	85	15	1	0.58	c
	RPFa10							RPFa10	0	0	/	0.21	c		PS30	85	15	1	0.68	b
	RPFa8							RPFa8	95	5	>1	0.22	c	Pietra Salomone 5	PS42	90	10	>1	0.68	b
	RPFa7							RPFa7	0	0	/	0.62	c		PS41	90	10	>1	0.25	b
	RPFa6							RPFa6	0	0	/	0.21	c		PS40	85	15	1	0.79	c
	RPFa5							RPFa5	0	0	/	0.38	c		PS39	90	10	>1	0.96	b
	RPFa3							RPFa3	0	0	/	1	c		PS38	90	10	>1	0.91	b
	RPFa2							RPFa2	0	0	/	0.6	c		PS37	0	0	/	0.9	b
	RPFa1							RPFa1	0	0	/	0.15	c		PS36	80	20	1	0.83	b
	PS15							PS15	90	10	>1	0.33	c		PS35	0	0	/	0.8	b
	PS13							PS13	85	15	1	0.73	b	Portella Rossa 1	PR23	70	30	0	1.11	a
	PS12							PS12	85	15	1	0.86	b		PR22	60	40	0	1.06	a
	PS11							PS11	85	15	1	0.93	b		PR21	50	50	0	0.33	a
	PS10							PS10	90	10	>1	0.47	c		PR20	60	40	0	1.15	a
	PS9							PS9	90	10	>1	1.04	b		PR19	60	40	0	0.8	a
	PS8							PS8	90	10	>1	0.86	b		PR18	50	50	0	0.13	a
	PS7							PS7	80	20	1	0.53	b		PR17	50	50	0	0.86	a
	PS6							PS6	85	15	1	0.7	b		PR16	60	40	0	0.27	a
	PS5							PS5	90	10	>1	0.85	b	Portella Rossa 2	PR29	50	50	0	2.9	a
	PS4							PS4	85	15	1	0.25	b		PR28	50	50	0	0.43	a
	PS3							PS3	90	10	>1	0.71	b		PR27	50	50	0	0.72	a
	PS2							PS2	90	10	>1	0.38	b		PR26	50	50	0	0.6	a
	PS1							PS1	90	10	>1	0.5	b		PR25	50	50	0	1.89	a
	PS23							PS23	50	50	0	0.4	a		PR24	50	50	0	0.85	a
	PS22							PS22	70	30	0	0.25	a		PS21	50	50	0	0.87	a
	PS21							PS21	50	50	0	0.46	c		PS20	50	50	0	2.78	a
	PS20							PS20	50	50	0	0.27	a		PS19	60	40	0	1.49	a
	PS19							PS19	60	40	0	0.16	c		PS18	85	15	1	0.75	b
	PS18							PS18	85	15	1	0.6	c		PS17	85	15	1	0.42	b
	PS17							PS17	85	15	1	0.45	c		PS16	90	10	>1	0.58	c
	PS16							PS16	90	10	>1	0.34	b		PS15	90	10	>1	0.24	b
	PS15							PS15	90	10	>1	0.21	c		PS14	90	10	>1	0.17	b
	PS14							PS14	90	10	>1	0.15	c		PS13	85	15	1	0.11	a
	PS13							PS13	85	15	1	0.11	a		PS12	85	15	1	0.08	b
	PS12							PS12	85	15	1	0.08	b		PS11	85	15	1	0.06	c
	PS11							PS11	85	15	1	0.06	c		PS10	85	15	1	0.05	c
	PS10							PS10	85	15	1	0.05	c		PS9	85	15	1	0.04	c
	PS9							PS9	85	15	1	0.04	c		PS8	85	15	1	0.03	c
	PS8							PS8	85	15	1	0.03	c		PS7	85	15	1	0.02	c
	PS7							PS7	85	15	1	0.02	c		PS6	85	15	1	0.01	c
	PS6							PS6	85	15	1	0.01	c		PS5	85	15	1	0.01	c
	PS5							PS5	85	15	1	0.01	c		PS4	85	15	1	0.01	c
	PS4							PS4	85	15	1	0.01	c		PS3	85	15	1	0.01	c
	PS3							PS3	85	15	1	0.01	c		PS2	85	15	1	0.01	c
	PS2							PS2	85	15	1	0.01	c		PS1	85	15	1	0.01	c
	PS1							PS1	85	15	1	0.01	c		PS0	85	15	1	0.01	c
	PS0							PS0	85	15	1	0.01	c		PS-1	85	15	1	0.01	c
	PS-1							PS-1	85	15	1	0.01	c		PS-2	85	15	1	0.01	c
	PS-2							PS-2	85	15	1	0.01	c		PS-3	85	15	1	0.01	c
	PS-3							PS-3	85	15	1	0.01	c		PS-4	85	15	1	0.01	c
	PS-4							PS-4	85	15	1	0.01	c		PS-5	85	15	1	0.01	c
	PS-5							PS-5	85	15	1	0.01	c		PS-6	85	15	1	0.01	c
	PS-6							PS-6	85	15	1	0.01	c		PS-7	85	15	1	0.01	c
	PS-7							PS-7	85	15	1	0.01	c		PS-8	85	15	1	0.01	c
	PS-8							PS-8	85	15	1	0.01	c		PS-9	85	15	1	0.01	c
	PS-9							PS-9	85	15	1	0.01	c		PS-10	85	15	1	0.01	c
	PS-10							PS-10	85	15	1	0.01	c		PS-11	85	15	1	0.01	c
	PS-11							PS-11	85	15	1	0.01	c		PS-12	85	15	1	0.01	c
	PS-12							PS-12	85	15	1	0.01	c		PS-13	85	15	1	0.01	c
	PS-13							PS-13	85	15	1	0.01	c		PS-14	85	15	1	0.01	c
	PS-14							PS-14	85	15	1	0.01	c		PS-15	85	15	1	0.01	c
	PS-15							PS-15	85	15	1	0.01	c		PS-16	85	15	1	0.01	c
	PS-16							PS-16	85	15	1	0.01	c		PS-17	85	15	1	0.01	c
	PS-17							PS-17	85	15	1	0.01	c		PS-18	85	15	1	0.01	c
	PS-18							PS-18	85	15	1	0.01	c		PS-19	85	15	1	0.01	c
	PS-19							PS-19	85	15	1	0.01	c		PS-20	85	15	1	0.01	c
	PS-20							PS-20	85	15	1	0.01	c		PS-21	85	15	1	0.01	c
	PS-21							PS-21	85	15	1	0.01	c		PS-22	85	15	1	0.01	c
	PS-22							PS-22	85	15	1	0.01	c		PS-23	85	15	1	0.01	c
	PS-23							PS-23	85	15	1	0.01	c		PS-24	85	15	1	0.01	c
	PS-24							PS-24	85	15	1	0.01	c		PS-25	85	15	1	0.01	c
	PS-25							PS-25	85	15	1	0.01	c		PS-26	85	15	1	0.01	c
	PS-26							PS-26	85	15	1	0.01	c		PS-27	85	15	1	0.01	c
	PS-27							PS-27	85	15	1	0.01	c		PS-28	85	15	1	0.01	c
	PS-28							PS-28	85	15	1	0.01	c		PS-29	85	15	1	0.01	c
	PS-29							PS-29	85	15	1	0.01	c		PS-30	85	15	1	0.01	c
	PS-30							PS-30	85	15	1	0.01	c		PS-31	85	15	1	0.01	c
	PS-31							PS-31	85	15	1	0.01	c		PS-32	85	15	1	0.01	c
	PS-32							PS-32	85	15	1	0.01	c		PS-33	85	15	1	0.01	c
	PS-33							PS-33	85	15	1	0.01	c		PS-34	85	15</			

Appendix 7 Rock-Eval parameters.

Sections	samples	Tmax (°C)	S1 (mg/g)	S2 (mg/g)	TOC (%)	HI (HC/gCOT)
Roccapalumba mercato	RP18	364	0.32	0.19	0.19	100
Torrente San Filippo	TF1	361	0.54	0.39	0.29	134
Cozzo San Filippo 1			0.13	0	0.14	
Cozzo San Filippo 2	CSF16	361	0.5	0.21	0.32	65
	CSF16 bis		0.51	0.18	0.31	58
	CSF13		0.06	0	0	
	CSF12		0.14	0.01	0.46	
Roccapalumba Ferrovia a	RPFa9		0.17	0.01	0.18	
	RPFa7	424	0.15	0.07	0.25	28
	RPFa7bis	349	0.25	0.17	0.24	70
Roccapalumba Ferrovia b	RPFb11		0.1	0	0.19	
	RPFb5		0.08	0.02	0.15	
Pietra Salomone 1	PS9	369	0.22	0.31	0.41	75
	PS3	363	0.13	0.2	0.28	71
Pietra Salomone 2	PS22	356	0.16	0.12	0.02	
Pietra Salomone 3	PS27	350	0.36	0.28	0.33	84
	PS25	348	0.25	0.21	0.26	80
	PS24	366	0.12	0.16	0.24	66
Portella Rossa 1	PR23	347	0.19	0.19	0.16	118
	PR23bis	346	0.24	0.23	0.14	164
Isolated Samples	BS1	346	0.64	0.06	0.19	