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TURBIDITY CURRENTS AND SLIDING IN GEOSYNCLINAL BASINS OF THE ALPS[1]

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ABSTRACT

It is shown that sliding and turbidity currents have formed an important mechanism of sedimentation in several Mesozoic and Tertiary basins of the Alps. It is argued that the features developed under these conditions, if applied on a regional scale to the study of sedimentation, provide a valuable tool for paleogeographic and orogenic investigations.

INTRODUCTION

Geologists have long been aware of the existence in the Alps of sediments presumably deposited in deep-water environments. Although opinion is still divided on such matters as the depth at which radiolarites are formed, there are other less ambiguous bathyal sediments. Thus many fine-grained rocks lacking benthonic remains were evidently deposited in poorly ventilated basins well below the reach of wave action and far removed from the supply of coarse terrigenous materials. Similarly, the occurrence of graded bedding has been noted from time to time, without systematic attempts, however, to study the facies in any detail, and this structure has never been taken as an indication of deep water.

The junior author of the present paper started more detailed sedimentological studies of Alpine sediments some years ago. One of his findings has been that graded bedding appears to characterize many of the coarser deposits and that most, if not all, of these graded beds are intercalated between supposedly pelagic deep-water rocks. He has suggested tentatively (Carozzi, 1952*a*, *b*) that such sediments were emplaced by sliding and/or turbidity currents in deep basins, basing this on the ideas set forth by the senior author in conjunction with Migliorini and Natland (Kuenen, 1948, 1952; Kuenen and Migliorini, 1950; Natland and Kuenen, 1951).

Meanwhile, the senior author had studied sedimentary features of graded graywackes in the Ventura Basin of California, in Wales, and in the Southern Uplands of Scotland.

A joint visit of the present writers to some of the localities already investigated by the junior author has shown the remarkable similarity between the sedimentary features of the Alpine rocks and the graded graywackes elsewhere. The aim of the present paper is a double one. On the one hand, an attempt will be made to compare the conditions in some Alpine basins to those of the other geosynclines mentioned above and to show how these help to extend the picture already obtained of deep-water sedimentation. On the other hand, it will be indicated how important advances can be made in paleogeographic problems by the regional application of these new ideas. This, in turn, will prove of use in unraveling the structural history of the Alpine orogene.

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CHARACTERISTICS OF COARSE DEEP-WATER DEPOSITS

Formerly accumulated evidence from experiments, present deep-sea deposits, and ancient sediments, that favors attributing many occurrences of graded bedding to the action of turbidity currents, need not be repeated here. The reader is referred to the papers listed in the bibliography. Neither need it be emphasized that some occurrences of this type of bedding are the result of other agents (see especially Kuenen and Menard, 1952).

Typical series resulting from the action of turbidity currents have so far been found to show many or all of the following characteristics:

1. Interstratification of fine-grained deposits, in many cases with "pelagic" features, with coarser-grained beds.
2. Regular bedding. In the few cases where a bed pinches out, the next coarse bed re-establishes the original bottom slope.
3. Absence of wave ripple mark, channel scour, coarse or mutually opposed cross bedding, and other sedimentary features indicating small depths.
4. Absence of shallow benthos or reworked older fossils in the fine-grained beds of the series. Worm tracks are not unusual (not to be confused with flow marks).
5. Slump structures and pull-aparts.

In the coarse-grained beds of the series one finds:

6. Grading. The maximum pebble size observed up to the present is about 10 cm., but usually grading is restricted to beds with medium pebbles or smaller grain sizes. Grading is often combined with lamination, especially when the grain is of less than medium sand size (pls. 1, *A*; 2, *A*).
7. The sorting in each horizon of the graded beds is poor. This means that the sands are "dirty" and contain lutite all the way through. Hence quartz sands belong to the graywacke class.
8. The lower contacts are always sharp, the upper contacts usually so, but in some cases the beds grade up into the "pelagic" beds.
9. Load casts formed by the coarse beds sinking into the underlying "pelagic" beds.
10. Convolute bedding (pl. 2, *A*).
11. Shale inclusions, either rounded or angular, sometimes distorted.
12. Absence or insignificance of scour at the base.
13. Occasional shallow benthos or reworked older fossils.
14. Generally speaking, the beds with abnormally coarse grain for any one locality are also the thicker ones of that particular series.
15. Each bed tends to maintain its own characteristic features, such as convolute bedding, load casts, ripple mark, etc., over its entire length in an exposure.

The following features of the coarse beds can be used to find the direction of the turbidity currents and hence of the bottom slope. The slope is found to be more or less uniform over wide areas and through some thickness of the series.

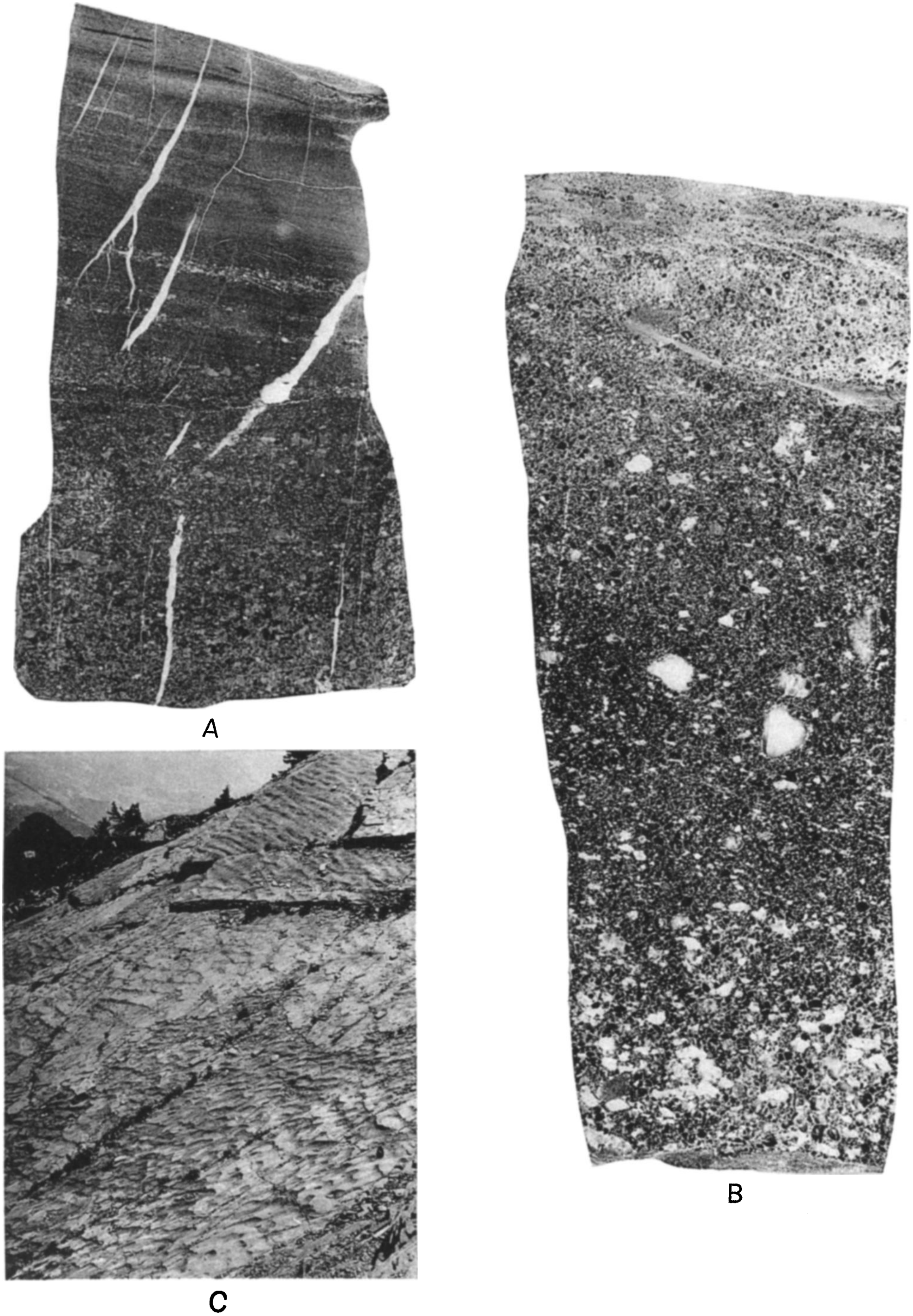
16. Flow marks, as described by Rich (pl. 2, *B*).
17. Current ripple mark (pl. 1, *C*).
18. Small-scale current bedding (pl. 2, *A*).
19. Tendency of pebbles to lie with longest axis parallel to direction of flow (Kopstein, personal communication).
20. Horizontal grading, with diminution of grain size away from the source. This happens too gradually to be observed in an exposure of normal size.

PLATE 1

A, Graded limestone breccia, Brèche Inférieure, Taninges, southeast of Geneva. Note distinct laminae; a few in the center are coarser. Bed is 19 cm. thick.

B, Graded graywacke from the Barmouth Grits, Cambrian, Wales. A few large grains scattered in center of bed. The underlying shale is just visible. Bed is 16 cm. thick.

C, Ripple mark from Brèche Inférieure, Pic Marcelly, east of Geneva. The currents came from the right.

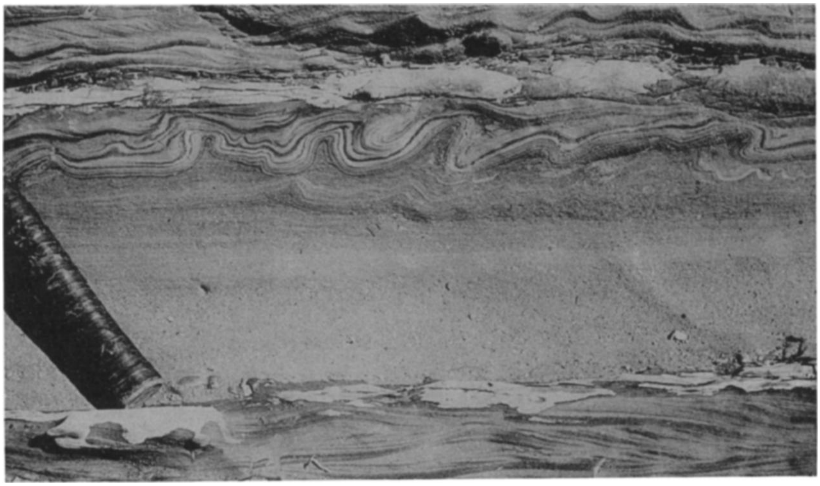


A

B

C

Rock types and surface features



A

B

C

Rocks and surface features

A final characteristic of graded series is:

21. Slide conglomerates or breccias (pl. 2, C) occur interbedded among the normal rocks. These conglomerates can be entirely isolated, or they may be present in groups with or without graded beds and "pelagic" beds between them. Although usually emplaced without marked erosion of the underlying beds, local stripping of some thin beds for laminae of the underlying deposits may occasionally be noted. There are no original voids between the pebbles as in many river conglomerates. Although imbrication is possibly present in some cases, it is certainly very inconspicuous. Cross bedding never goes right through such conglomeratic beds. They tend to have a streaky internal structure and to contain cobbles or even boulders.

It is highly significant that in all the sedimentary basins examined so far by the writers, all or practically all these features are present in so far as exposure allows a conclusion, no matter whether the coarse material is noncalcareous, calcareous, or mixed; angular or rounded; relatively fine or of large grain size. As far as ascertainable from bottom samples, deep-sea sands show the same characteristics. As the deep-water environment for these sands and for the Ventura Basin (varying from a few hundred to 2,000 meters) is certain and as the sedimentary features of the other examined series point in the same direction, the authors do not hesitate to claim for all basins under discussion a depth of accumulation beyond the reach of waves and the action of tidal currents, probably at least a few hundreds of meters.

Two aspects need emphasis, however. One is that in some basins—for instance, small bodies of water—wave action reaches only to slight depths. Hence the same sedimentary features as described above may possibly be formed, at least on a reduced scale, in much smaller depths than those of the Ventura Basin.

The other point to be borne in mind is that each ancient basin appears to be entirely or partly characterized by emphasis on some features, while other properties may be scarce or poorly developed. For example, slide conglomerates and load casts are absent in the Silurian of Aberystwyth, Wales, but flow markings occur under almost all the coarse beds, and convolute bedding is very common. In the Ventura Basin flow marks have not been observed (possibly because the base of the beds is seldom exposed), but there is a rich benthonic fauna of Foraminifera in the laminated pelagic shales. In the Cambrian of the Harlech Dome slide cobble conglomerates are absent and flow markings are rare; in some of the grit series convolute bedding is poorly developed; in others is is common, and load casts are scarce throughout. The grading in some coarse gritty sequences is indistinct, and in autochthonous deep-water shales hardly developed. In the Mesozoic breccias of the Nappe de la Brèche in the Pic Marcelly chain, near Taninges, east of Geneva, the slide material is almost entirely calcareous and at-

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PLATE 2

A, Graded graywacke sandstone lying between beds with cross bedding (supply from the left), Middle Pliocene, Santa Paula Creek, Ventura Basin, California. Depth of deposition about 1,000 meters. The top of the bed is laminated and shows convolute bedding.

B, Flow marking on lower surface of graywacke sandstone, Oligocene Flysch, Fillinges, east of Geneva. The gouging current came from the left upper side. Slab is 26 cm. long.

C, Breccia bed lying on fine-grained calcareous shale, Brèche Inférieure, Pic Marcelly, east of Geneva.

tains enormous sizes. Locally there are very distinct ripple marks (pl. 1, *C*). Convolute bedding, current bedding, and load casts are poorly represented. In the Oligocene Flysch of the Voirons chain (*nappes ultrahelvétiques*) at the quarry of the Pont de Fillinges, east of Geneva, the grading is poorly developed, and in many beds several repetitions of grading are superimposed. However, flow markings (pl. 2, *B*) and load casts are numerous (fig. 1).

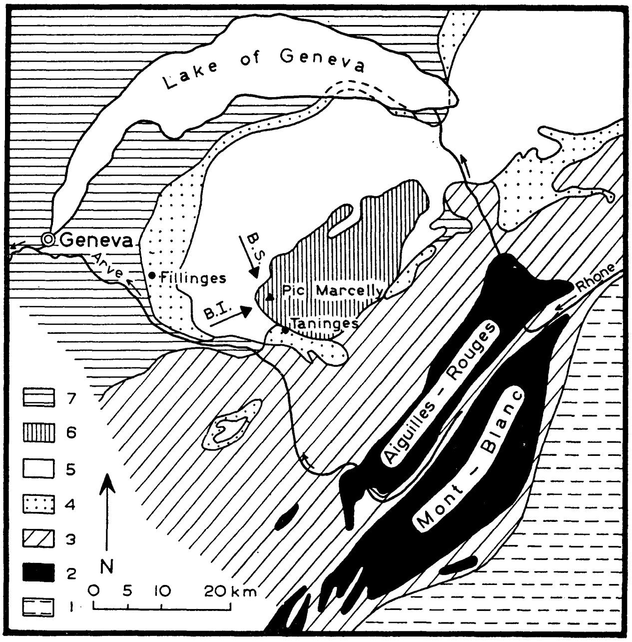

FIG. 1.—Tectonic sketch of the Haute-Savoie Alps. *1*, Nappes penniques; *2*, crystalline cores; *3*, nappes helvétiques and autochthonous chains; *4*, nappes ultra-helvétiques; *5*, Nappes des Préalpes Medianes and Niesen; *6*, Nappe de la Brèche; *7*, Molasse of the Swiss Plateau. The arrows indicate the direction of supply for the materials of the Brèche Inférieure (*B.I.*) and of the Brèche Supérieure (*B.S.*).

Many other examples could be given of various characteristics, both positive and negative, being locally predominant. The reason is to be sought in differences of depth, size, and slope of basins; in the nature and rate of supply of the source materials; and in the trigger effects which set off the slides and turbidity currents (earthquakes, overloading, wave action, turbid rivers, undercutting). As yet it is not possible to deduce these environmental properties from the observable facies. But some general relations can be tentatively suggested.

A concave profile of equilibrium is apparently established from the source out into the basin. This implies increasing steepness toward the source. As a turbidity current cannot form a graded bed until the coarser part of the load has collected at its nose, a certain distance of travel is required before the deposit can start to show grading. For these two reasons the proximal series should differ relatively from the distal series on the same slope. It should show poorer grading, insignificance of pelagic beds, more scour, coarser grain, thicker beds, less regularity, and less depth as indicated by autochthonous benthonic remains.

FLYSCH VERSUS MOLASSE

A significant comparison can be drawn up between two types of alpine deposits, the Flysch and the Molasse.

The Flysch precedes the paroxysmal phase in the Alpine type of orogeny. It is of variable age and represents the final facies to develop in each of the geosynclinal troughs (Tercier, 1947). It is characterized mainly by the nature of its component rocks and to a lesser degree by certain organisms.

In its most typical development the Flysch is represented by detrital deposits, usually of inorganic origin, showing a regular and monotonous alternation of sandstones and micaceous shales with occasional conglomeratic intercalations. Such series are always thick, and it is hard to trace lithologic subdivisions or sedimentary rhythms. They are exclusively of neritic or bathyal marine origin and appear to have been laid down in basins diversified by steep and discontinuous island chains.

The sandstones of the Flysch are micaceous, and simple or complex graded bedding is mentioned in many descriptions. The grains are generally cemented by lime, but silica also occurs. Each bed shows a remarkably constant petrographic composition, by which it may be traced over great distances.

Although the Flysch may contain series or separate beds of conglomerates or gigantic breccias, these features are by no means characteristic of the facies. They tend to appear in connection with coarse sands but do not characterize any particular horizon in the series. As with the sandstones, the petrographic composition of each conglomeratic bed varies little over great distances. The components of the breccias are in many cases formed of one single rock type (granite, gneiss, or limestone). Isolated masses of the same type met with in calcareous or noncalcareous clays are referred to as "exotic" blocks. These coarse and chaotic facies are looked upon as the product of rock slides and slumps from cliffs with poorly developed marine terraces facing deep basins.

The sandstones and micaceous shales forming the bulk of the Flysch show remarkably clear stratification due to their regular alternation. Judging from former descriptions, the exposure at Fillinges, examined in some detail by the authors, is representative of the normal type. Here it was observed that each bed tends to show certain characteristics along the whole length exposed, such as color or grain size, load casts, or small-scale current bedding, flow marks, clay pebbles, or convolute bedding. The oriented structures confirm one another as to a constant direction of supply. The grading is marked in many of the beds, the range running from coarse sand or gravel at the base to fine, muddy sand at the top. However, in many cases repetitions of grading in a single bed are observable, and lamination is usual. Ripple marks are scarce and are exclusively of the asymmetrical current type. Scour channels are absent, and coarse current bedding is highly exceptional and quite local where it does occur.

The only signs of life in Flysch beds considered to be autochthonous are the frequent Fucoides and Helminthoides of the shale beds. All the microfaunas of Foraminifera observed in the sandstones present characteristics of redeposition. In fact, the coarser the grain, the larger the size of the Foraminifera, which tend to be lacking in the shales. This evidence testifies to transport together with the sand from a different environment and also explains the poor state of preservation. On the other hand, the faunas seldom appear to be reworked from older formations and have evidently lived in the environment where the sand first accumulated.

It is hardly necessary to emphasize the complete analogy between the characteristics of the Flysch just described and those enumerated above as typical of coarse deep-water deposits. This similarity testifies to the importance of turbidity currents in forming the Flysch sandstones (Carozzi, 1952). Detailed investigations should permit the drawing of a more circumscribed picture of the conditions prevailing during the deposition of this characteristic type of Alpine sediment.

The typical Molasse, as it is developed, for instance, in the surroundings of Geneva, represents a postorogenic deposit in a foretrough fronting the Alpine chain during its emergence. These sediments are coastal, brackish water, and lacustrine. They tend to show sedimentary rhythms (Bersier, 1948), with an upward decrease in grain size in each. These start at their base with conglomeratic sandstones, passing upward through fine sands to marls at the top, often with carbonaceous lacustrine intercalations. An erosional surface covered by coarse materials marks the end of the rhythm and the onset of the next one. These sedimentary units are irregularly distributed and indistinct, the thickness varying between a few dozen centimeters and 30 meters. They are ascribed to stepwise sinking of the basin floor.

The graded rhythms of the Molasse represent considerable lengths of time (3,000–5,000 years for 5 meters). Hence they cannot be attributed to the almost instantaneous action of a single turbidity current. The Molasse deposits examined by the present authors in the neighborhood of Geneva are of an entirely different type than the Flysch. The bedding is less regular. The sandstones show hardly any grading. Some are slightly coarser toward the top, others contain more lutite toward their upper limits but not always with a decrease in maximum size of the sand. Very often, thick beds consist of a vague alternation of coarser to finer sands, or of more or less calcareous sands. In general, the upper and lower limits of the beds are not sharply marked. Very coarse current bedding is frequent and varies so much in orientation that no dominant direction of supply is ascertainable without statistical treatment. Occasional scour channels are found associated with clay pebbles.

The Molasse forms a type example of paralic deposition, continuously exposed to the action of tides, waves, currents, or flooding. In contrast with the Flysch, the facies is shallow neritic to nonmarine.

It would obviously be desirable to extend our observations over a much wider area before claiming that all typical Flysch belongs to the type of graded deep-water graywackes and all Molasse to river or shallow-water facies. But the present findings certainly strengthen the case for attributing graded graywackes to the action of turbidity currents with some submarine sliding. For the examined Molasse, known to be of shallow-water origin, has practically no structural features in common with the investigated Flysch, in spite of the almost identical petrographic bulk composition. The Flysch, on the other hand, would not seem out of place in the Ventura Basin, in which foraminiferal evidence proves great depth.

NEW LIGHT ON THE ACTION OF TURBIDITY CURRENTS

The study of graded bedding in the Alpine basins adds important information on the action of turbidity currents to that gained up to date.

The Upper Malm of the Nappe de Morcles and of the autochthonous chains in the Haute-Savoie, studied by one of us (Carozzi, 1952*b*), is formed by a monotonous series of fine-grained, dark, pyritiferous limestones, some 100–150 meters thick. The fauna consists of sponges and pelagic forms such as radiolarians, ammonites, and Calpionellidae. This deep-water series is interrupted at least nine times by coarser-grained beds varying in thickness between a few dozen centimeters and several meters. These are microconglomerates or microbreccias. The lower contact is generally clean cut, but load casts or traces of local erosion appear here and there. The great majority of the elements is less than 5 mm. in diameter and consists of broken or intact reef organisms, oölites, or pebbles of oölitic limestone. This reef and littoral material is entirely unknown in the pelagic facies above and below. The coarse beds contain only small amounts of pelagic organisms, evidently caught up from the bottom during transport, together with occasional fragments of the underlying sea floor. Some of these coarse beds are uniformly mixed, others show graded bedding or multiple grading.[2]

As they are traced out to sea as indicated by the regional paleogeography, the coarse beds disappear one by one. In the opposite direction they become coarser, thicker, and more numerous. Finally, one arrives at the southern border of the Massif des Aiguilles-Rouges to find a coral reef and associated talus slopes.

The obvious interpretation is that debris collected around this source for great lengths of time, the average approaching a million years. Then a large slide took place and the debris passed out into the deep, poorly ventilated basin to the south. Part of the material may have come to rest directly from the slide, but the majority was converted into a turbidity current which spread a graded bed over the bottom to distances of at least 10 km., as far as can now be ascertained. One or more slides may have followed the first at short intervals, or separate slides may have started at different points along the coast line simultaneously. As a result, instead of the ideal graded bed, a more complex feature with partly overlapping fans of coarse material was developed.

The principal cause of the occasional disturbances of stability of the sea floor may be sought in tectonic activity associated with Stille's Late Cimmerian phase.

The above review brings out clearly the contrast in rate of sedimentation of the pelagic limestones as against the redeposited beds. The former accumulated at the rate of about 1 cm. per 1,000 years, whereas the coarse beds were emplaced instantaneously, geologically speaking, that is, in a matter of minutes. The ratio is of the order of 1 in 10^9.

Conditions in the basin which received the deposits of the Nappe de la Brèche were entirely different (Schroeder, 1939) from those under which either the Flysch or the Malm of the Haute-Savoie collect-

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[2] The term "inverse graded bedding" used in the paper cited might be interpreted as meaning that the coarse grain is on top and grades to fine at the bottom. What was actually meant is that a single bed is composed of two or more normally graded parts on top of each other, caused by as many impulses of the supply.

ed. In the Nappe de la Brèche basin the coarse beds are represented by thick series of calcareous conglomerates and breccias, which can be followed in the field for a distance of several kilometers but in which sandstones are absent or highly inconspicuous.

Two periods of activity are represented by the lower (Dogger) and upper (Upper Jurassic) breccia series. The most remarkable property of the Brèche Inférieure is the periodic appearance of breccia beds every 8–15 meters. The blocks, formed by Liassic and Triassic limestones, may attain 8 meters in length by 2 meters in thickness in the chaotic facies (pl. 2, *C*). Grading is restricted to beds or upper parts of beds with a maximum particle size of 10 cm. Foreign elements are missing at the summits of the rhythms, where the rocks are echinoderm limestones with cherty beds and nodules. There is a constant direction in which particle size and thickness of all beds decrease (Schroeder, 1939). This direction is away from the supply and is likewise indicated by current ripple mark (pl. 1, *C*) and occasional current bedding. It coincides with a gradual thickening of the pelagic deposits.

At the front of the Nappe (Pic Marcelly) the Brèche Inférieure may attain 1,300 meters in thickness, and the size of the blocks is at its maximum. Toward the east in the Nappe the facies becomes deeper, the breccia series thins progressively (300–400 meters), and the elements seldom attain 20 cm. in diameter. Finally, the finer beds pass into gray limestones and black calcareous shales of a more pelagic nature.

Evidently, we are confronted with deposits laid down on a steep slope by numerous slides of very coarse material. Turbidity currents were developed each time and deposited graded beds on top of the slides, then passed out onto less steep slopes beyond, where only graded beds are found. Numerous minor currents were generated in between, many only reaching small distances from their source. The slides traveled for a maximum distance of 5 km.; the currents went at least three times as far.

After the first active period, a series of slates (*schistes ardoisiers*) was laid down, representing the interval Callovien-Sequanien, some 250–300 meters thick. Then came the second active period, with renewed deposition of limestone breccias.

The mechanism of emplacement for the Brèche Supérieure, which is about 200 meters thick, is similar to that of the lower series. However, the maximum size of blocks is less and does not exceed 1 meter. Lias material is of less importance, whereas Trias and green chloritic shales (Permian?) with vein rocks become conspicuous. This indicates that erosion had penetrated more deeply into the source area, which has now shifted to the north-northwest. The size of the blocks and the thickness of the formation diminish to the south-southeast, and the beds pass into fine-grained limestones with silexites and planktonic calcareous shales with Radiolaria and Calpionellidae.

PALEOGEOGRAPHIC AND STRUCTURAL IMPORTANCE OF THE PRESENT TYPE OF INVESTIGATION

Apart from its value for gaining a better insight into the action of gravity in redepositing sediments, the present type of investigation can also be used as a valuable tool in paleogeographic studies.

In the first place, a number of deposits claimed until now as shallow-water formations turn out to be of deep-water origin. This will generally result in a simplification of the geological history of the region.

A good example is furnished by the clastic beds of the Malm described above. Up to the present these had been looked upon as the result of local reworking after a strong and rapid shallowing for each coarse horizon. However, such conditions would require that each coarse bed had been preceded and followed by lithological and faunistic modifications in the pelagic sediments above and below. Actually, these are absolutely uniform, without the slightest indication of diminished depths. The only other possibility would be to assume small depths for the entire formation. But all shallow-water features are lacking, both in the fine and in the coarse beds. In the opinion of the authors the action of slides turning into turbidity currents is the only satisfactory explanation for the observed phenomena.

A similar simplification of the geological history is obtained for the Lower and Middle Cambrian of the Harlech Dome in Wales (Kuenen, *K. Akad. Wetensch. Nederlandsch. Verhandl.*, in press). These show a succession of shale and grit formations. The three principal grit formations have been looked upon as of shallow origin, the intervening and following shales as deep-water deposits. As the lowest grit is cross-bedded and not graded, the sedimentation doubtless did start in shallow water. But, instead of having to postulate two temporary unheavals to account for the other grit formations, these can be accounted for by sliding and turbidity currents on account of their grading and other deep-water features. Mr. P. Kopstein is engaged on a detailed paleogeographic study of this area.

Another example of hitherto unsuspected deep-water facies is provided by the Ordovician and Silurian succession south of Girvan in Scotland. These rocks consist of conglomerates, shales, graywackes, and limestones that have been interpreted as of shallow origin. But the conglomerates and most of the graywackes show deep-water characteristics.

One of the limestones occurs as large masses which have slid into place, and another presents graded bedding. A good case can be made for distinguishing a deep-water succession, followed by a period of shallow water and then renewed subsidence (Kuenen, in press).

A second aspect of paleogeography on which light can be thrown by the study of graded bedding is the possibility of tracing the bottom slope at the time of sedimentation. Current bedding, ripple mark, flow markings, distribution of grain size, and alignment of pebbles can be used to find the direction of the currents and hence of the slope. This, in turn, may give a clue to the shape of the sedimentary basins, the source area of materials, and the age of tectonic structures.

An instance is found in the Ventura Anticline (Kuenen, *Bull. Am. Assoc. Petroleum Geologists*, in press), which had not started to develop at the time the turbidity currents were carrying sands across its present site. The Miocene at Mugu Point in the south of the basin was supplied from the south, where water 1,000 meters in depth is now found in the Santa Monica Basin.

In the Alps the overthrusting in huge nappes during the Middle Oligocene has completely remodeled the original sedimentary basins. Each of these may have given birth to more than one tectonic element with varying amounts of displacement. In unraveling this history and fixing the time of beginning deformation, valuable evidence can be gained. Thus it can be shown that the Nappe de Morcles, described above, had not started to develop during the Malm, for the sedimentary slope appears to have run southward off the Massif des Aiguilles-Rouges. The reef facies from which the turbidity currents started has remained in place as autochthonous cover. But the distal parts of the beds deposited by these currents in the midst of the pelagic sediments have been transported about 20 km. to the northwest in the frontal hinge of the Nappe de Morcles (fig. 2).

In the Nappe de la Brèche, Schroeder (1939) had found evidence for the existence of a rising belt situated to the west of the thrust sheet in its original position. First it supplied materials from the south-southwest to form the Brèche Inférieure; then, after a period of quiescence, the supply was renewed from the northwest to deposit the Brèche Supérieure. This picture was obtained by Schroeder from the size distribution and thickness of the beds. The present studies have brought valuable support of this 90° shift in direction of supply by evidence for the action of turbidity currents, besides sliding, and by current ripple mark and current bedding confirming the deduced directions (fig. 1).

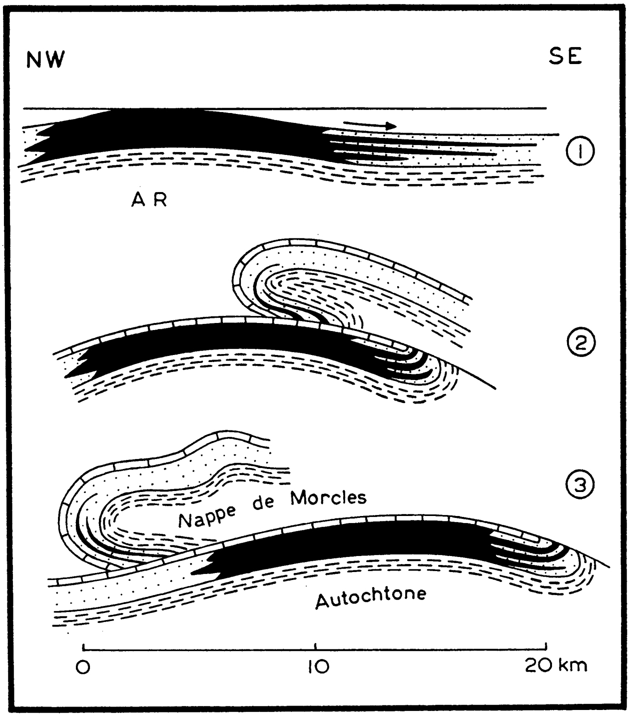

FIG. 2.—Diagram showing the tectonic effects of overthrusting on the deposits of turbidity currents in the Upper Jurassic of the Haute-Savoie. *1*, Emplacement of clastic beds derived from the coral reefs of the Aiguilles-Rouges (*A.R.*). Only three beds are shown. Reefs and clastic beds in black, pelagic deposits dotted. *2*, Initial stage in the development of the Nappe de Morcles. This must have started after emplacement of the clastic beds. *3*, Present position of the Nappe de Morcles after a displacement of about 20 km. over the Aiguilles-Rouges and its autochthonous cover.

Generally in the Alpine troughs, the slides and turbidity currents tended to be concentrated on the frontal slopes of the developing geanticlinal chains (Carozzi, 1952). Hence they were directed toward the northwest. The Nappe de la Brèche forms an exception, in that the supply came from the opposite direction, from the rear of the geanticlinal chain. Recently Tercier (1952) has arrived at a new reconstruction of the tectonic history, summarized in his section reproduced in our figure 3. The position and shape of the developing basins and geanticlinal chains renders understandable the abnormal direction of supply toward the southeast. This example may serve to emphasize the mutual benefit to structural and sedimentological studies to be obtained by close co-operation.

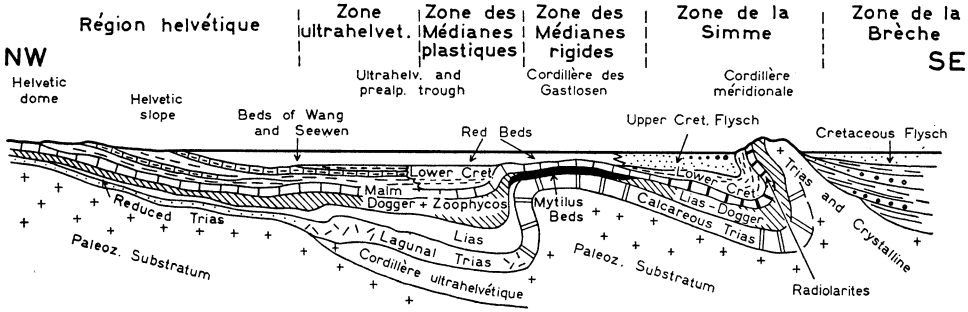

FIG. 3.—Diagram showing the paleogeographic situation in the Préalpes during the Upper Cretaceous (after Tercier, 1952, fig. 4).

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