On Some Sedimentological Problems of the Swiss Flysch Series

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With 4 figures in the text

In the summer of 1960, the present author had the opportunity to examine some of the flysch series in the Swiss Alps. Due to the shortness of his visit to Switzerland the observations are admittedly incomplete. No comprehensive study or full solutions to the problems investigated are attempted in the following report. The purpose of this paper is to bring out into consideration some problems connected with the sedimentation of flysch deposits.

Outlines of the paleogeography of the North Helvetic Flysch

These flysch deposits were laid down in most northern parts of the shrinking Alpine geosyncline and build up the youngest series (uppermost Eocene – lowest Oligocene) of the Helvetic zone.

The beginning of the flysch formation is marked by the appearance of **Taveyannaz sandstones** over the Globigerina shales. In places (Brückner 1952) one can observe a rapid but continuous passage between these two units. It is indicated by the occurrence of a few sandstone beds in the Globigerina shales. This passage zone is covered by the complex of the Taveyannaz sandstones proper (similar relationship was seen by the writer at Dürrenberg, Canton Bern).

Petrography of the Taveyannaz sandstones is well known, mainly due the investigations of de Quervain (1928) and Vuagnat (1952). The sandstones in question consist predominantly of volcanic debris i. e. fragments of spilites, andesites, basalts, dacites and minerals derived from these rocks. These volcanic constituents may form up to 90% of the rock. The origin of volcanic materials has not yet been solved. None of the known tectonic elements in the Alps contains rocks to which these fragments would exactly fit. According to de Quervain (1928) the volcanic debris were derived from a source situated somewhere to the south. An alternative origin however from the north, namely from an area outside the Alpine belt was not excluded in his paper. De Quervain suggested also that the clastics were transported by currents along the axis of the geosynclinal trough.

Measurements of current indicators such as flute casts, prod-marks, cross-stratification etc., carried out by the present writer seem to confirm to some degree the conclusion already reached by de Quervain (1928)[1].

[1]) The methods of currents reading are to be found in the papers listed in the references.

Westernmost exposures of the Taveyannaz sandstones in Switzerland reveal flute- and drag-casts pointing to NNE and NE as a direction of flow (Fig. 1a). The trend of these current structures is slightly oblique to the long axis of the trough, which in the area discussed runs approximately from SW to NE. Farther east, the exposures show predominantly longitudinal transport, which can be traced over the whole belt up to the area of Richetlipass in the canton of Glarus (Fig. 1 b–f, Fig. 2).

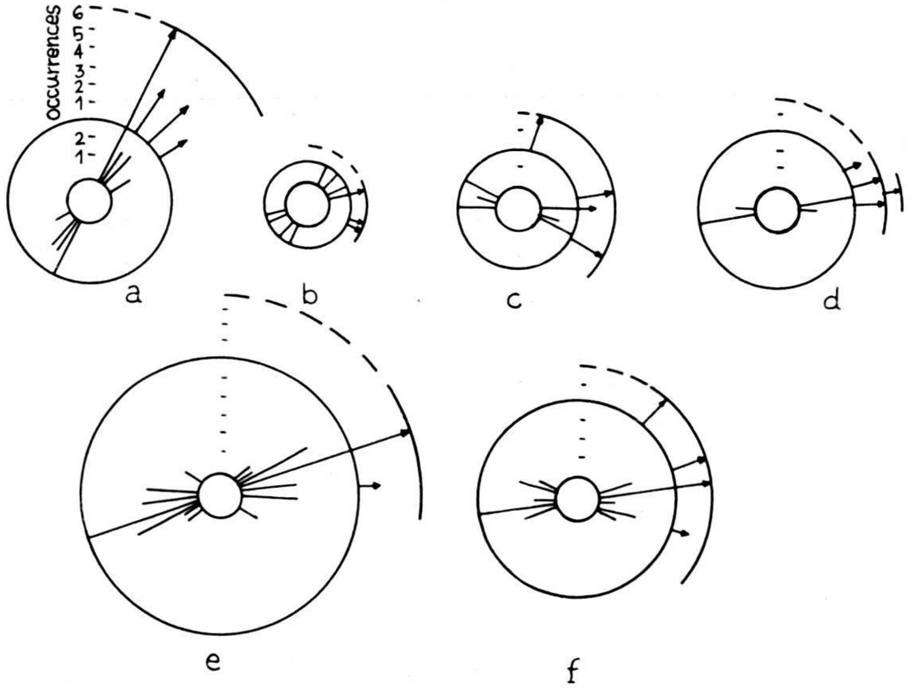

Fig. 1. Current-rose diagrams, Taveyannaz sandstones. a = Alpe Taveyannaz, b = Dürrenberg-Bundalp, c = Burg, d = Muttsee, e = SW Nüschenstock, f = Richetlipass. Directions of the drag casts are indicated in the inner ring. Those of the flute casts and impact casts are indicated in the second, and those of diagonal stratification in the third ring.

In the area of Alpe Taveyannaz (Western Switzerland) the current structures are indicative of a southern source for clastics. It may be suggested that the bulk of clastics was first delivered to the area situated somewhere west of Alpe Taveyannaz and then distributed in eastern direction parallel to the long axis of the trough. This conclusion seems to be confirmed by the occurence of coarse conglomerates in the Taveyannaz complex exposed in France. We are referring to the so-called "Dauphiné"type of Taveyannaz sandstones as distinguished by DE QUERVAIN (1928)[2]).

Marked facies changes within the Taveyannaz sandstones occur along the trend of the geosynclinal trough i. e. as we pass from the western frontier of Switzerland to the east. In Western Switzerland the predominant facies type is the "Kiental" type as distinguished by DE QUERVAIN (1928). It consists of thick, ill-bedded, massive, structureless sandstones (homogeneous in the meaning of DŻUŁYŃSKI & RADOMSKI 1955) with an insignificant amount of shaly intercalations.

[2]) The relationship with the similar Champsaur and Annot sandstones of the French Alps will not be discussed in this paper.

The thickness of sandstones in the Kiental type ranges from 2–20 m. Grains and rock fragments larger than the average grain-size are randomly scattered in the matrix. The fragments of volcanic rocks may measure up to 10 cm in diameter. Sharp-edged shale fragments are common and in places mud balls are to be found. Volumetrically insignificant pebbly mudstones (the average diameters of grains and fragments are confined within the range of 0,5–5 cm) are characterized by a conspicuous amount of silty matrix.

Farther east the Kiental type grades into the "Glarus" type (see DE QUERVAIN 1928). In its typical development the Glarus type is exposed on the slopes of Nüschenstock (Canton Glarus) and presents the appearance of a flysch series. The sandstones are usually thin-bedded (20–30 cm) and exhibit generally graded bedding. Their bottom surfaces show numerous scour and tool markings (in the meaning of DŻUŁYŃSKI & SANDERS 1959) i.e. flute casts, prod-, drag-casts etc. The alternating shales are somewhat thinner than the sandstones (10–15 cm).

The Kiental and Glarus types have transitional relationships and the rocks exposed on the summit of Burg (Canton Uri) and in a small fold north of Muttsee (Canton Glarus) are supposed to present a transitional link between them.

In the first locality the sandstones are thick-bedded, structureless and contain rare fragments of siltstones having diameters up to 10 cm. Some of these fragments are rounded, other sharp-edged. Graded bedding is generally absent. Shales play here a subordinate rôle and are confined to thin intercalations measuring few cm in thickness. In places even these thin shale layers are absent.

The sandstones cropping out in the area of Muttsee (north of Scheidseeli, P. 2500 m) are almost everywhere graded, the discontinuous type of graded bedding (KSIĄŻKIEWICZ 1954) with the silt part missing at the top being the most common. Their thickness ranges from 0,5 to 2–3 m. Medium-bedded sandstones show often multiple graded bedding, whereas the thick ones are commonly structureless. Here again the shales are very thin and in places lacking. A layer of silty shales with exotic pebbles and boulders (which may reach a diameter up to several dm) already noted by DE QUERVAIN (1928) and STYGER (1961) apparently deposited by a submarine mud-flow or a slump was observed by the present author on a field-trip with F. FREY in the northern adjacent area of Muttsee.

The rocks supposed to be transitional between the Kiental and Glarus type of Taveyannaz sandstones have also been observed in the upper part of the Kiental valley. The sandstones are thick-bedded (maximal thickness up to 8–10 m) and intercalated with thin layers of shales. In the Dürrenschafberg the upper part of the discussed sandstones, which rests upon a thick intercalation of Dachschiefer becomes more like typical flysch. The sandstones are thinner, their thickness seldom exceeds 1 m, they are usually graded and the proportions of sandstones to shales are about 3:1.

On the basis of sedimentological data exclusively we arrive at the following paleogeographical reconstruction as shown on Figure 2.

The interpretation of facies and their characteristic features leads to the conclusion that the original distribution of tectonic units in which these facies occur was different from that indicated by their present position.

If the facies belts are restored to their presumed original distribution, it appears that the Taveyannaz sandstones which now are found farthest north in the Kiental valley belong to the southermost part of the sedimentary basin. Evidences of a supply from the south are to be found in some sandy intercalations within the shales and mudstones. We are referring to the cross-stratification in these sandy intercalations showing foreset-laminae dipping north.

Consequently the transitional types of the rocks exposed near Muttsee should be placed south of the typical flysch series from Nüschenstock. This would imply that during the alpine thrusting more southern parts of the Flysch series were moved farther north than the more external ones. STYGER (1961) considers this as very probable.

Conditions controlling the sedimentation of Taveyannaz sandstones and the mechanism of transportation of clastics have not been adequately studied. According to DE QUERVAIN (1928) the Taveyannaz complex should be considered as a near-shore and shelf deposit; BRÜCKNER (1952) considered the North Helvetic Flysch as a delta sediment. In the light of modern interpretation of the sedimentary pro-

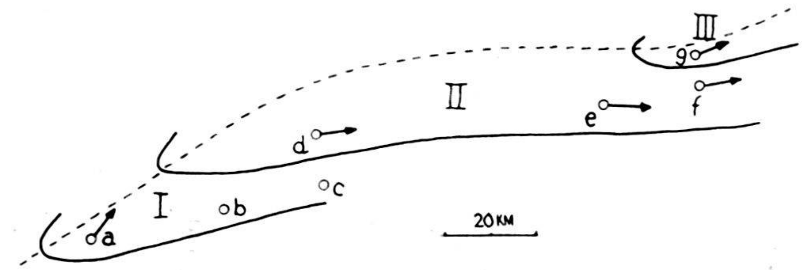

Fig. 2. Facies distribution in the Taveyannaz sandstones basin, and current directions. a = Alpe Taveyannaz, b = Varnerkumme, c = Kiental, d = Dürrenberg–Bundalp, e = Burg, f = Muttsee, g = Nüschenstock. I Kiental type, II transitional types, III Glarus type.

cesses in flysch basins this view may face criticism. A striking characteristic feature of the Taveyannaz sandstones like the other flysch deposits is the absence of structures suggestive of shallow-water environment as for instance planar type of cross-stratification, tidal channels etc. The Glarus sandstones present an appearance of typical flysch rocks which are supposed to be turbidity currents deposits laid down in relatively deep-water environment (see KUENEN & MIGLIORINI 1950, NATLAND & KUENEN 1951, KSIĄŻKIEWICZ 1954 and others).

Doubts may arise with regard to the Kiental type and partly to some other transitional types discussed. Nevertheless these rocks besides the absence of features suggestive of shallow-water environment show many similarities to the flysch deposits i.e. non-uniform grain-size, sharp-edged shale fragments embedded in a sandy matrix, large scale slump structures etc. They are also closely associated with the typical flysch sediments.

In the light of the turbidity current hypothesis the following distribution of facies may be assumed (Fig. 2).

While turbidity currents having partly a character of submarine avalanches were rapidly accumulating large quantities of clastics at the base of the slope, the deposition of shales was in such places impeded. The resulting deposits are thus devoid of conspicuous intercalations of shales, and consist of thick bedded, structureless, poorly sorted sandstones (DŻUŁYŃSKI & RADOMSKI 1955, DŻUŁYŃSKI, KSIĄŻKIEWICZ, KUENEN 1959) (e.g. Kiental type, Fig. 2 zone I).

Further on, towards the center of the basin, shale layers and thus also limits between deposits of particular turbidity currents, become more distinct. Graded bedding is developed better; it is frequently not complete, the uppermost grades (silt) are lacking (transition rocks between Kiental and Glarus type, Fig. 2 zone II).

In the more central part of the basin, which turbidity currents reached after they had travelled over a long distance, "typical flysch» has been developed. Sand layers are rather not very thick, graded bedding is distinct and the shale layers occur between sandstones (e.g. Glarus type, Fig. 2 zone III). In this zone laminated and finely cross-bedded sandstones become more frequent.

In the basin of Taveyannaz sandstones the flysch facies still more distant from the source areas have not been developed. It should be expected that in the next zone (IV) the rôle of fine grained laminated and cross-bedded sandstones would increase.

In the last zone (V) only the finest material i.e. silt and clay would have been deposited (e.g. sediments of the type of Globigerina shales of the Helvetic zone). In this zone deposits were probably mostly pelagic, and resulted by undisturbed downfall of suspension carried by surface currents.

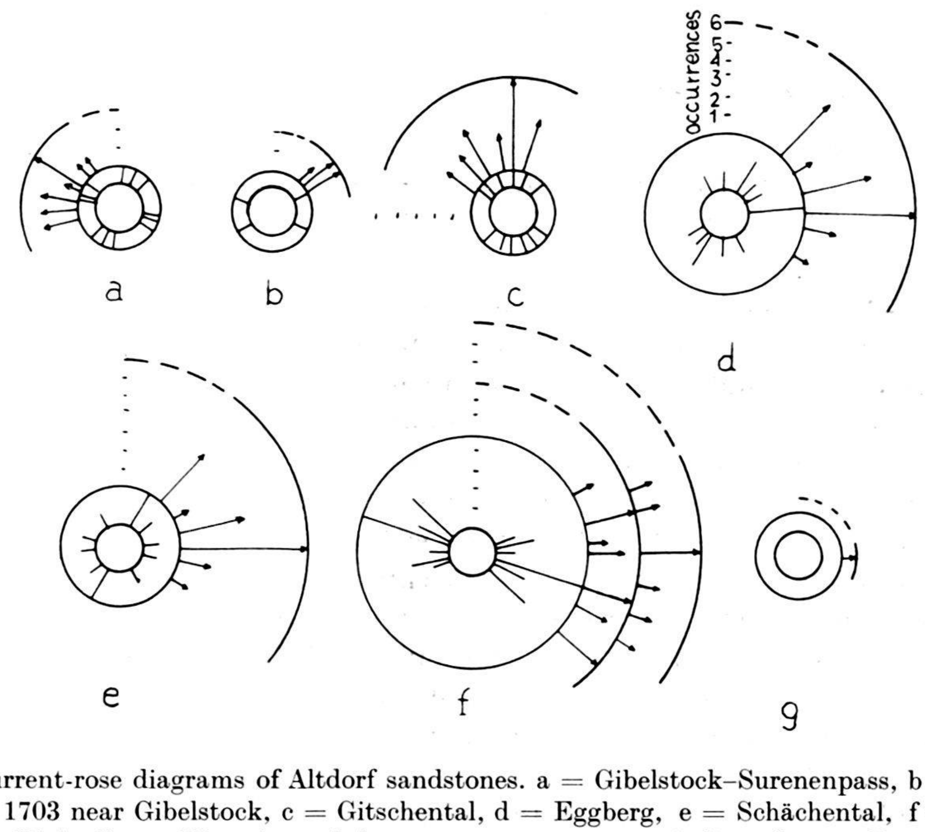

Fig. 3. Current-rose diagrams of Altdorf sandstones. a = Gibelstock–Surenenpass, b = Klippes east of P. 1703 near Gibelstock, c = Gitschental, d = Eggberg, e = Schächental, f = Linthal, g = Richetlipass. Directions of the current structures are indicated as on Figure 1.

This is only the most general pattern of facies distribution and of the position of flysch in a basin where clastics are being deposited by turbidity currents. It should not be expected that this pattern would be completly realized in any area. The differences would vary according to local conditions.

The next member of the North Helvetic Flysch are the **Altdorf sandstones.** They differ from the Taveyannaz sandstones by their grey colour and the scarcity resp. lack of volcanic material. As this series is very intensely tectonically disturbed, and its stratigraphy is not definitely established, no detailed sedimentological analysis is possible. The investigation has been limited therefore to the statement that this series is developed in a flysch facies and to the reconstruction of general directions of transport.

In the Gitschental area (near Altdorf, Canton Uri) and in a quarry nearby directions of transport oscillating from towards NW to towards NE were found, the prevailing direction being towards the north (Fig. 3c). The measurements have been taken partly in tectonically inverted layers. However, directions obtained from measurements in inverted and normal layers roughly agree.

East of the meridian of the Gitschental the direction of transport is towards NE or E, i.e. generally parallel to the axis of the basin (Fig. 3d–g).

West of Gitschental the directions towards NW distinctly prevail, this is seen in fig. 3a–b.

The zone where directions of transport are transversal to the axis of the basin is very narrow. It is limited to the Gitschental area. It may be assumed that the clastics were furnished to the basin through a narrow area, perhaps through the outlet of a submarine canyon (see Gorsline & Emery 1959, Menard 1960), and spread from there fan-like eastward and westward (Fig. 4).

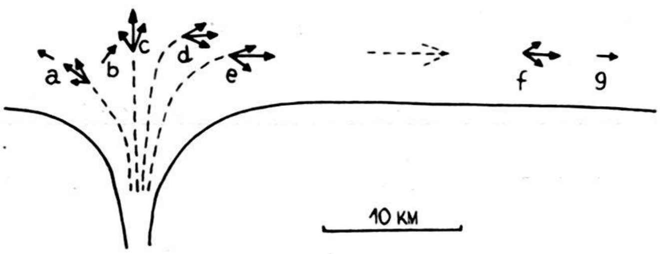

Fig. 4. Distribution of current structures in the Altdorf sandstones. Localities indicated as on Figure 3.

Some remarks about the interpretation of paleocurrent pattern

These data contribute to the question of longitudinal filling advanced by Kuenen (1957). It has been observed in various flysch series that the prevailing direction of transport of clastics was usually parallel to the longer axis of the trough. According to Kuenen, the clastics have been derived from areas longitudinally closing the basin, probably from deltas or rivers.

On the other hand, instances of significant lateral filling have been recently found in the Carpathians (Książkiewicz 1958, Dżułyński, Książkiewicz, Kuenen 1959, Dżułyński & Ślączka 1959) and in the Alps (Hsu 1960). The latter author reconstructed on data established by himself and by Crowell (1955) the Gurnigel and Schlieren Flysch basins; he placed these basins south and north of the hypothetical Habkern massif. Hence the author suggests a transversal supply of the material in both series. TRÜMPY (1960) took exception to this view on account of regional tectonics. According to the above mentioned author the both sedimentary regions were situated on the southern side of the Habkern massif. The depositional site of the Gurnigel Flysch was originally situated nearer to the shore and this would explain the predominance of transversal supply from the north.

On the other hand the Schlieren Flysch was laid down farther from the shore and occupied more central position in the sedimentary basin. It may be assumed that the turbidity currents arriving from the lateral slope were turning into longitudinal direction i.e. towards NE (similar observations were made by KSIĄŻKIEWICZ 1956, and BIRKENMAJER 1958 in the Carpathians).

Casual observations made by the present writer are in agreement with the above interpretation.

In the lowest members of the Schlieren Flysch (basaler Schlierenflysch SCHAUB 1951) with which the writer is more familiar, besides the directions towards NE (shown by HSU 1960) there are also directions towards SE. The glimpses of evidence tend to the inference that this supply, transverse to the main direction of transport, appears also in higher units of the Schlieren Flysch.

Assuming that the Schlieren Flysch was originally accumulated in more central portions of the trough, one can suppose that strong currents, while crossing the flat bottom, could maintain their transverse direction obtained on lateral slopes, whereas other (weaker) currents were turning into longitudinal direction. It should be noted that crossing of currents coming from different directions have been observed in the Carpathians (DŻUŁYŃSKI & ŚLĄCZKA 1959, MARSCHALKO & RADOMSKI 1960). With regard to the Schlieren Flysch, however, this question remains open until more data are obtained.

There appears to be several ways of distributing clastics by turbidity currents in sedimentary basins. One is represented by the longitudinal filling in the meaning of KUENEN (1957). As an example of this may be cited the case of the Central Carpathian Flysch[3]) and to some degree the Taveyannaz sandstones.

Transversal filling represents another type of distribution. The clastics are delivered from lateral slopes and one can imagine two particular cases of such a distribution; from one point i.e. from an outlet of a submarine canyon, or from several points along the lateral slope of the trough. The former case is probably represented by the Altdorf sandstones or by the Pasierbiec sandstones (Carpathians; see DŻUŁYŃSKI, KSIĄŻKIEWICZ, KUENEN 1959), the later by the Krosno beds in the Carpathians (DŻUŁYŃSKI & ŚLĄCZKA 1959) or Gurnigel Flysch (CROWELL 1955, HSU 1960).

Dealing with various flysch formations we meet with portions of an original basin or even with small relics of the original bottom area; therefore it is conceivable that the conditions which permit the preservation of transversal filling (usually confined to a relatively narrow zone at the base of lateral slopes) are not common. From this one can see the necessity of application of a "paleogeographic

[3]) With some modifications respective to KUENEN's original interpretation, see MARSCHALKO & RADOMSKI (1960).

view" (Dżułyński, Książkiewicz, Kuenen 1959) in interpreting the paleocurrent pattern.

Molasse and Flysch

The last problem discussed in this paper is the relationship between the terms molasse and flysch. Emphasis should be put on the fact that in modern usages these words are not necessarily comparable.

Under the term of flysch we understand at present a particular type of facies or a formation (Tercier 1947, Vassoevič 1948) deposited in rather deep trough by means of turbidity currents (Kuenen & Migliorini 1950, Książkiewicz 1954, Khvorova 1959).

On the other hand the term molasse (used in a broad sense) implies a relationship between the deposits formed in a fore-deep and the orogene (Bertrand 1897, van Waterschoot van der Gracht 1931, Kay 1942, King 1937, Tercier 1947). In this meaning molasse is a postorogenic (or more precisely "late synorogenic or epiorogenic", Trümpy 1960) formation comprising differing facies, marine, brackish and non-marine (e.g. Swiss Molasse).

In cases when the bottom of a "molasse basin" reached a considerable depth one can imagine conditions favouring turbidity currents and other types of gravity mass-movements which would lead to the deposition of flysch rocks within the molasse. This seems to be the case with the Grisiger marls which consist of marls interbedded with sandstones showing some features characteristic of a flysch deposit. The bottom surfaces of sandstones are sharply defined and there is often a transition between sandstones and the overlying marls.

The flysch-like complex of Grisiger marls is overlain along a sharp contact surface by a series of Horwer sandstones displaying a different appearance. These sandstones show large scale torrential type of cross-bedding and their top surfaces often exhibit numerous ripples. Conglomerate beds which are to be found in the next member overlying the Horwer sandstones have irregular, erosional bottom surfaces. There is a good reason to suppose that these sandstones were laid down in a very shallow water above the wave base. One can not identify the Horwer sandstones with the flysch although these sandstones also alternate with shales.

ACKNOWLEDGEMENTS

The author wishes to thank Prof. A. Gansser and Prof. R. Trümpy for the use of the facilities of the Geological Institute, Eidgenössische Technische Hochschule, Zürich. He is also greatly indebted to Prof. M. Książkiewicz, Prof. R. Trümpy and F. Frey for reading the manuscript and to Prof. W. Leupold, Prof. H. Schaub, Dr. H. Laubscher, R. Frei, F. Frey, R. Herb for their help in his field studies.

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Kraków, January 1961

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