GEOLOGICA ULTRAIECTINA

Mededelingen van
het Geologisch Instituut der Rijksuniversiteit
te Utrecht

No. 12

SEDIMENTARY STRUCTURES AND FACIES INTERPRETATION OF SOME MOLASSE DEPOSITS

Sense- Schwarzwasser area, Canton Bern, Switzerland

W. J. M. VAN DER LINDEN

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Sense- Schwarzwasser area, Canton Bern, Switzerland

W. J. M. VAN DER LINDEN

1963

BOEK- EN OFFSETDRUKKERIJ DE WERELD - EINDHOVEN

PROMOTOR: PROF. DR. D. J. DOEGLAS

This memoir contains a doctoral thesis defended before the Senate of the State University at Utrecht on October 14th, 1963.

Ce mémoire a fait l'objet d'une thèse de doctorat en Sciences à l'Université d'Etat d'Utrecht le 14 octobre 1963.

Diese Schrift ist eine Doktorarbeit, verteidigt vor dem Senat der Reichsuniversität Utrecht am 14. Oktober 1963.

CONTENTS

SUMMARY

Burdigalian sand- and siltstones, belonging to the Upper Marine Molasse, have been studied in the Swiss "Mittelland", to get an insight into the relationships between primary sedimentary structures, their genesis and facies. To obtain information on the conditions, prevailing during the deposition of sand and silt in the investigated area, a synopsis is given from the paleogeography and paleoclimate. This synopsis together with the estimation of the paleocurrent pattern and the petrographic characteristics is given in chapter I.

In chapters II, III and IV, the observed structures have been analysed. In these chapters the textural properties of the sediments have also been given and their mode of formation is discussed.

Four main structural types have been distinguished:

Giant ripples of fluviatile origin (chapter II).

Mega flaser structures, belonging to deposits formed in the deeper part of the shallow marine zone (chapter III, § 1).

Giant ripples, belonging to offshore bars (chapter III, § 2).

Parallel bedded structures, belonging to lagoons and/or bays, cut off from the main basin by formerly built offshore bars (chapter IV, § 1).

The gullies described in chapter IV, § 2 are the channels in the coastal area, through which the feeding rivers discharged their material into the basin.

In relation with the tectonic movement of the basin floor, the sequence of the formation of the different structural types has been discussed (chapter V). In this chapter we also come to the conclusion that the Sense-Schwarzwasser area during the Burdigalian (Miocene) can be characterized as the coastal zone of a shallow marine inland sea (the peri-Alpine depression). Rivers supplied the material, from which part accumulated as talus fans and giant ripples, whereas the finer material was dumped in the sea and reworked towards the coast forming a wave built terrace.

The cyclic sedimentation pattern is more or less similar to that of the cyclothems of the Carboniferous.

SAMENVATTING

Dit onderzoek beoogt de relatie weer te geven tussen een aantal sedimentaire structuren, hun ontstaanswijze en het afzettingsmilieu. Tot dit doel werden molasse sedimenten bestudeerd, welke behoren tot het Burdigalien, bovenste mariene Molasse, stroomgebied van Sense en Schwarzwasser in het Zwitserse "Mittelland". Gegevens over de omstandigheden tijdens sedimentatie werden verkregen uit de litteratuur. Een overzicht van de paleogeografie en het paleoklimaat is gegeven in hoofdstuk I. In ditzelfde hoofdstuk is aandacht besteed aan het paleo-stroompatroon en aan de petrografische kenmerken der afzettingen.

In hoofdstukken II, III en IV zijn de waargenomen sedimentaire structuurtypen geanalyseerd, de textuurkenmerken der afzettingen behandeld en zijn eveneens beschouwingen gewijd aan de ontstaanswijzen.

Vier hoofd-structuurtypen zijn onderscheiden:

Reuze ribbels, zandbanken van fluviatiele origine (hoofdstuk II).

Mega flaserstructuren, welke behoren tot afzettingen, ontstaan in het diepere gedeelte der paralische zone (hoofdstuk III, § 1).

Reuze ribbels, buiten de kust gevormde zandbanken (hoofdstuk III, § 2).

Parallel gelaagde structuren, behorende tot lagunes en/of baaien, aan de zeezijde begrensd door eerder gevormde zandbanken (hoofdstuk IV, § 1).

Geulen zoals beschreven in hoofdstuk IV, § 2 zijn toevoerkanalen waardoor terrestrisch materiaal naar het kustgebied werd getransporteerd.

In samenhang met de daling van het bekken is in hoofdstuk V de opeenvolging der verschillende stuctuurtypen besproken. In dit hoofdstuk komen we tot de conclusie dat het Sense-Schwarzwasser-gebied tijdens het Burdigalien (Mioceen) kan worden beschouwd als de kustzone van een ondiepe binnenzee (de peri-Alpine depressie). Het sediment werd aangevoerd door rivieren. Het grove materiaal werd afgezet als puinwaaiers en zandbanken, terwijl het fijne materiaal in zee werd gebracht, waar het door golfwerking werd opgeworpen tot een accumulatieterras.

Het cyclische sedimentatiepatroon vertoont grote overeenkomsten met cyclothemen uit het Carboon.

INTRODUCTION

Primary sedimentary structures provide important data for the determination of depositional environments and may be of great help in analysing the geological history of various deposits. Although this statement seems to be generally accepted, the knowledge about primary structures and their genesis is rather limited.

The most suitable place to analyse sedimentary structures, together with their depositional environment, appears to be found in recent sedimentation areas. However, several sections, vertical as well as horizontal through a sediment body are needed to determine the geometric outline of the structural framework. For unconsolidated sediments special sampling techniques, such as lacquer peels and impregnation methods enable us to study the undisturbed material. Furthermore, the exact circumstances governing the deposition of sediments are often beyond observation, because of several factors: waterdepth, visibility, etc.

Another approach to the analysis of the relationship between sedimentary structures and their mode of formation lies in the field of experiments in current channels and wave tanks, in which the formation and behaviour of sediment bodies can be studied under various conditions. This method too has its limitations: The work of Nature, being rather complex, is not so easily duplicated. No such experiments can be carried out on sufficiently true scale, because of the many varied scale factors. For instance, when the behaviour of sand in a current is studied on scale, the sand grains cannot be replaced by clay particles. Both methods, the study of recent sediments and experiments on the behaviour of sediments in air and water, even though having their restrictions, have provided useful information on the influence of wind, current and wave action on detritus. In ancient, mostly consolidated sediments, the greatest problem is to gather sufficient data to determine the formation circumstances. Useful data may be obtained from fossils, and also from structures known from experimentation or from those present in recent sediments. However, many of the structures in ancient sediments have not been previously desribed or are not yet recognised. The latter may be due to influences as compaction and diagenesis, which obscured some features. On the other hand, additional and new characteristics may be imposed on former recognisable structures.

To get a better insight in the relationships between primary sedimentary structures, their genesis and environment, we studied shallow marine, brackish and fluviatile deposits of Tertiary age in the Swiss Molasse region.

In 1959, Professor Doeglas, when visiting one of his students who was involved in taking graphic logs of Tertiary Molasse deposits in Switzerland, thought it worthwhile to give the sediments, which showed interesting but rather complex structures, more attention.

In 1960, we started our investigations with a reconnaisance of Devonian quartzites in the Koblenz area, W. Germany. The structures in these quartzites have been thoroughly analysed by Niehoff (1958). The Devonian deposits at first sight greatly resembled the sediments studied later on in the Swiss Molasse region and gave an opportunity to become somewhat familiar with large scale sedimentary structures and with the problems involved in their analysis.

As for the sub-Alpine Molasse region, most authors do not hesitate to interpret the environment in which sediments accumulated as delta, lagoon, bay, or in general as shallow marine to brackish fluviatile. These environments are situated more or less close to the shore line on both the land- and seaward sides. The characterization is fairly easily derived from the paleogeographical position of the sedimentation basin, the so called "Peri-Alpine depression" (cf. chapter I § 2). In these Molasse sediments one could expect therefore to find the same structures which are known to occur in various recent shallow marine or brackish fluviatile environments. However, as has already been remarked, the knowledge of some of these structures and their genesis is rather poor. Cores taken from such deposits reveal only minor features, whereas structures of larger dimensions may be overlooked.

To obtain satisfactory results from the investigations carried out in the Burdigalian sand- and siltstones in the area indicated on the map (Fig. 1), we started making an inventory of all sedimentary structures present. Some 5 structural types could be distinguished. Namely:

1. Giant ripples, represented in plate I and photographs 1, 2, 3, and 6. Ellipsoidal troughs related to giant ripples are represented in photos 4 and 5.
2. Mega flaser structures, represented in fig. 15 and photo 7.
3. Offshore bars, represented in fig. 15 and photo 8.
4. Parallel bedded series, represented in plate II and III and in photos 9, 10 and 11.
5. Gullies represented in fig. 17 and in the upper left hand corner of plate II.

Analyses of the different structural types, discussions on their origin and their mutual coherence are given in chapters II, III and IV.

As a great many of the structures are roughly speaking inclined bedding structures, different sections through these structures reveal necessarily different appearances. The relationship between these appearances was but slowly unraveled. The making of drawings on scale, though being a time consuming procedure, forced one to careful observation and was very helpful in detecting the

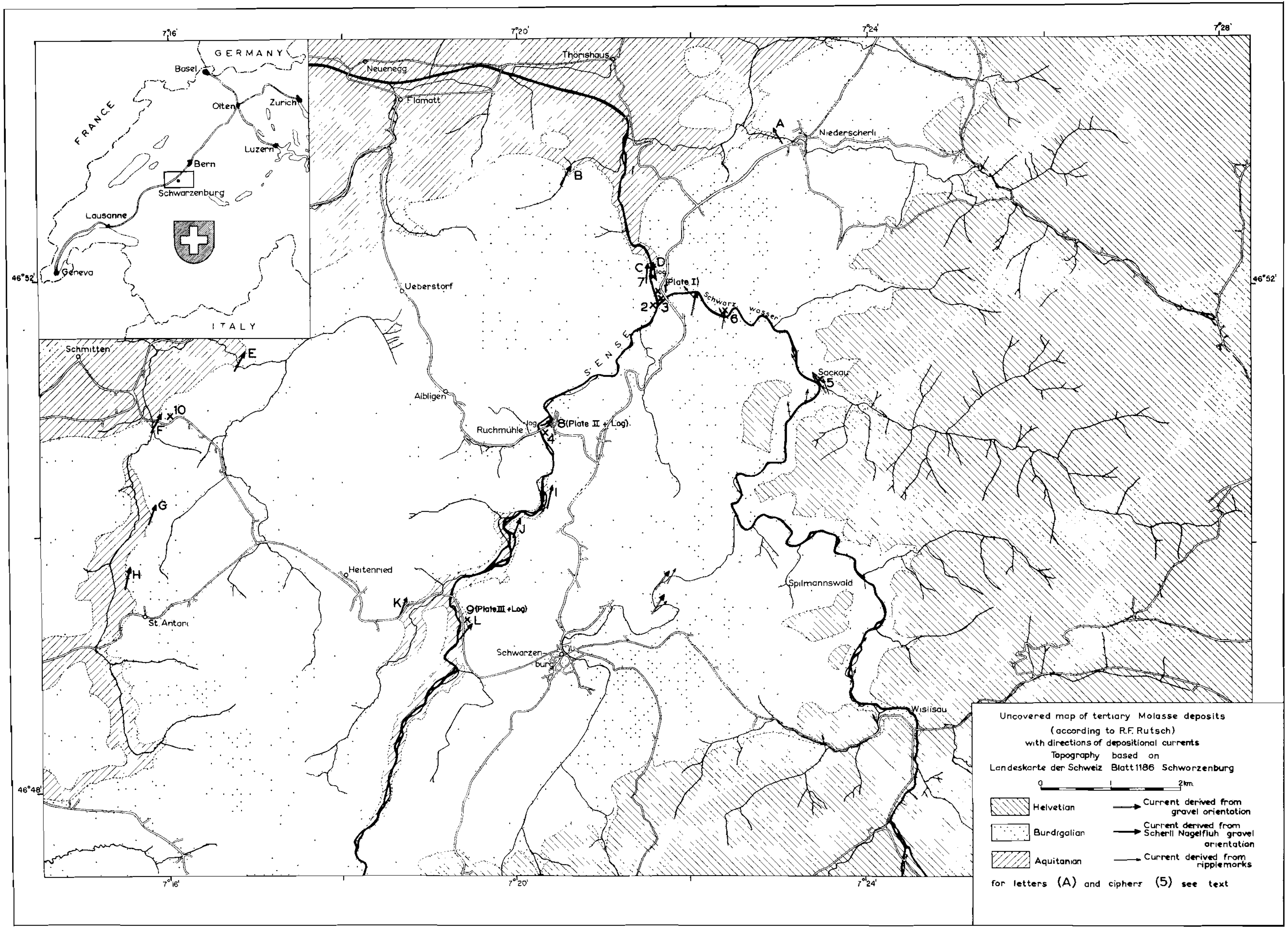
GERMANY
FRANCE
ITALY
Basel
Olten
Zurich
Luzern
Bern
Schwarzenburg
Lausanne
Geneva
Neuenegg
Flamatt
Thörishaus
Niederscherli
Ueberstorf
Aibligen
Ruchmühle
Schmitten
St. Antoni
Heitenried
Schwarzen-burg
Spilmannswald
Sackau
Wislisau
SENSE
Schwarz wasser
7 (Plate I)
8 (Plate II + Log).
9 (Plate III + Log)
7°16'
7°20'
7°24'
7°28'
46°52'
46°48'
Uncovered map of tertiary Molasse deposits
(according to R.F. Rutsch)
with directions of depositional currents
Topography based on
Landeskarte der Schweiz Blatt 1186 Schworzenburg
0 1 2 km.
Helvetian
Burdrgalian
Aquitanian
Current derived from gravel orientotion
Current derived from Scherli Nagelfluh gravel orientation
Current derived from ripplemorks
for letters (A) and ciphers (5) see text

Fig. 1

relationships mentioned.

Drawings of the different sections have been put together into three-dimensional diagrams. In this way a fairly good understanding of the structural framework of the sand- and siltstones has been obtained.

An estimation of the direction of the depositional currents, derived from the orientation of long axes of pebbles intercalated in the sediments, made it possible to put the different structures into the right position with respect to these currents (chapter I, § 3).

Apart from undeterminable plant remains, the deposits contain no fossils. Information about the conditions, prevailing during the accumulation of the sediments has therefore been required from other sources: Textural, chiefly grainsize analyses (chapter I, § 4) and the study of the literature chapter I, § 1 and § 2). Articles and works on the paleogeography and paleoclimate of the Miocene and Burdigalian in central Europe have been consulted together with those works dealing with the geology of neighbouring areas.

Fieldwork was carried out during the summers of 1960, 1961 and 1962. Also detailed graphic logs were made in which the structural and textural properties as observed in the field have been plotted (cf. Bouma and Nota, 1961).

CHAPTER I. GENERAL

§ 1. *Geology and Stratigraphy*

The geological mapping of the region, indicated on the map, fig. 1, was carried out for the greater part by Rutsch (1927-1949) and by Frasson (1942-1945) for the S W part. The map gives only the Tertiary formations. Quaternary deposits have been omitted.

A weak E - W folding moulded the Tertiary deposits in anticlines and synclines. In the region studied, we find the Albligen syncline in the N and the Schwarzenburg anticline in the S, both running in a W S W - E N E direction. The dip of the fold axes is towards the E. On the flanks of these tectonic structures dips seldom exceed 5° (Rutsch, 1958).

Especially W of the Schwarzwasser, the Tertiary is covered by glacial deposits. Rhone glacier in the W and Aare glacier in the E left spurs of their spreading over the area during the Würm glacial epoch, mostly in the form of glacial debris such as moraines.

Although the area is largely covered by Quaternary deposits, the rivers cutting through, provide fine exposures of the Tertiary.

We confined our investigations to the Burdigalian. Its position in the stratigraphic column is given in the following table, together with the subdivision of the Molasse, as used for the sub-Alpine region (cf. Rutsch, 1947, and Frasson, 1947).

Some authors (e.g. Crausaz, 1959) place the Aquitanian in the Oligocene, the Miocene then starts with the marine transgression of the Upper marine Molasse. Through this transgression the fresh water conditions prevailing in the Swiss Molasse region during the Aquitanian, changed into brackish to marine conditions.

A further subdivision of the Burdigalian for this region was not possible because fossils are absent and key horizonts are absent apart from the lower and upper boundary. The lower and upper boundaries are distinguished by differences in lithology. The lower contact with the underlying Aquitanian marls and sandstones is characterized by the "Scherli-Nagelfluh" the Burdigalian basal-conglomerate, ranging in thickness from 50 cm in the S towards some 8 m in the N (Scherlibach).

The upper boundary is formed by the "Ulmiz-Nagelfluh", the basal conglomerate of the Helvetian. The total thickness of the Burdigalian in the Sense-Schwarzwasser area is 370 m.

§ 2. *The depositional environment*

In this paragraph several data are collected to estimate the conditions prevailing during the deposition of the Burdigalian sands and silts in the Sense-Schwarzwasser area. Together with the analyses of the structural and textural properties of

MIOCENE	SARMATIAN		Upper fresh water
	VINDOBONIAN	TORTONIAN	Molasse
		HELVETIAN	Upper marine
	BURDIGALIAN		Molasse
	AQUITANIAN		Lower fresh water
OLIGOCENE	STAMPIAN	CHATTIAN	Molasse
		RUPELIAN	Lower marine Molasse
	LATTORFIAN = SANNOISIAN		

the deposits (chapters II, III and IV) they may lead to a correct interpretation of the genesis of the deposits.

A. Biofacies

The Burdigalian in the studied area is next to sterile in fossil content and does not much support facies interpretation. Authigenic glauconite abundant in the sandstones might be proof in itself of the marine character of the deposits (cf. chapter I, § 4 B).

Rutsch (1947) is of the opinion that pure marine conditions reached the Sense-Gürbe region not until the middle-Helvetian. For the Burdigalian he concludes to limnic and/or brackish conditions.

Frasson (1947) argues for a marine environment for the Burdigalian, on account of the sudden appearance of authigenic glauconite and the occurrence of ***Rotalia sp.***, a representative for shallow marine conditions (after Cushman, 1922).

Crausaz (1959) and Dorthe (1962) studied the geology of the Freiburger area. Crausaz' area of investigation is bounded to the East by the Sense-Schwarzwasser area. The Dorthe area lies some 20 km to the S W! In Burdigalian deposits they found some bivalves: ***Tapes*** and ***Mactra***. They also found ***Solea antiqua*** and a tooth of ***Odontaspis cuspidata*** (Agassiz).

The textural and structural characteristics of the Freiburg, Burdigalian sediments are, as far as can be derived from their photographs and descriptions, strikingly similar to those found in the Sense-Schwarzwasser area. On account of the, be it, poor fossil content Crausaz and Dorthe conclude to brackish to marine conditions (régime saumâtre).

B. Paleogeography

The Burdigalian transgression invaded a longitudinal basin, known as the peri-Alpine depression, connected with basins in the S and in the E. The depression had a width of some 50 - 70 kilometres (Schwab, 1960 fig. 7, p. 40) and a length of some 1000 kilometres. The paleogeography is given in fig. 2 after Kummel (1961).

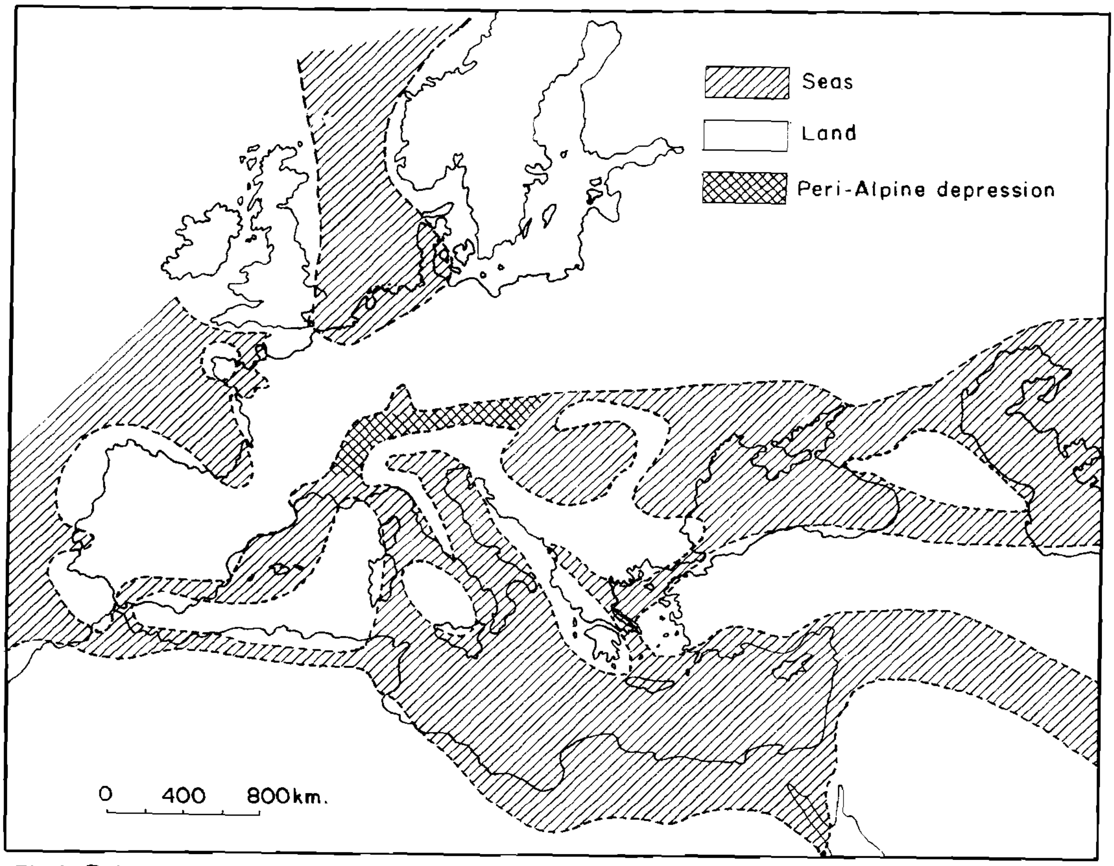

Fig. 2 Paleogeographic map of Europe for the Miocene (after B. Kummel, adapted from L. I. Wills, S. von Bubnoff and R. Brinkmann).

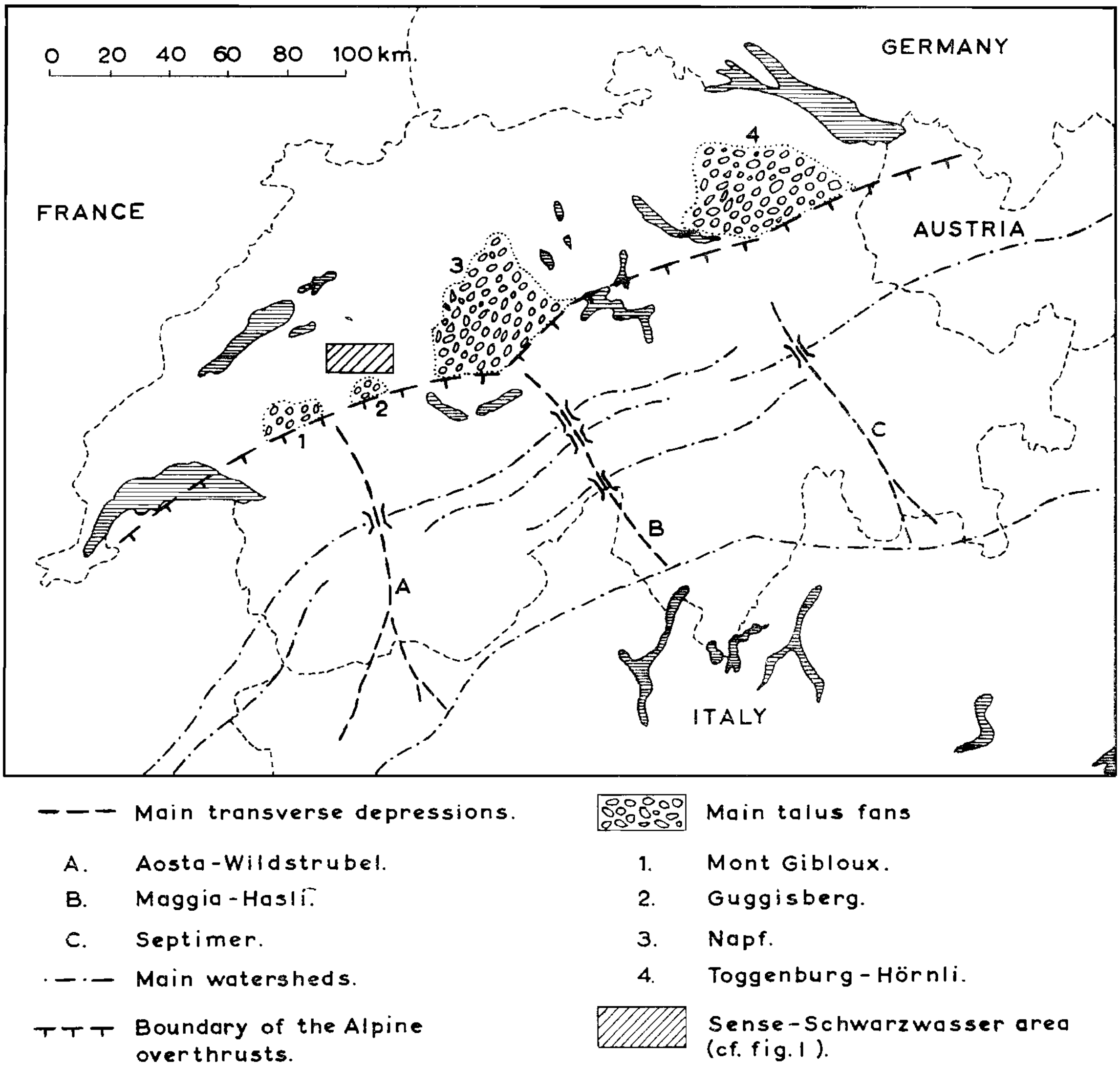

Fig. 3 Drainage pattern in the Swiss Alps during the lower Miocene (adapted from R. Staub 1934 and E. Baumberger 1931).

It is very unlikely that tidal movements played an important part in the complex Miocene European - African system of basins and straits, without broad open connections to the ocean and with a great many obstacles in the form of large islands. In to-day's Mediterranean the tidal range has a maximum of only 30 cm.

The sediments dumped into the peri-Alpine depression were supplied by river systems carrying the products of the erosive forces from the rising Alpine backland.

It should be borne in mind that the uplift of the Western Alps, unlike the Eastern Alps, caused an outstanding relief already in early Miocene (Staub, 1934).

According to Staub (1934), the drainage pattern of the Swiss Alps during the lower Miocene, was connected with a number of transverse depressions. These depressions developed in relatively short time during and after the upheaval of the Alps (Upper Oligocene). Fig. 3 adapted from Staub and Baumberger is a schematic map of the Miocene drainage pattern. Three valley systems cutting the main watersheds of the Alpine system almost at right angles occurred from W to E.

The importance of the main drainage system can be derived from the enormous Miocene talus fans dumped in front of the depressions. From W to E we find the Freiburg talus fans, Mont Gibloux and Guggisberg in front of the Aosta-Wildstrubel depression (early Rhone); the Napf talus fans in front of the Maggia-Hasli depression (early Aare); the Toggenburg fans in front of the Septimer depression (early Rhine). The fans consist of conglomerates and boulders and reach a thickness of several hundreds of metres.

The accumulation of the Napf and Toggenburger fans started with the beginning of the Burdigalian, whereas the Freiburger fans, covered for the greater part by overthrust nappes (Préalps), accumulated duing the Helvetian. Proof for the existence of the mentioned transverse depressions during Oligocene is found in the talus fans of the Mont Pelerin (early Rhone?), of Fuchsegg (early Rhone), of Thun (early Rhone and/or early Rhine), of the Rigi (early Rhine and/or early Aare), of the Speer (early Rhine).

Only the axes of the three main drainage basins have been plotted in fig. 3. Staub, in one of his plates gives extended river systems, catchment areas and tributaries. In his opinion, to-day's river Sense might originally have been one of the main tributaries of the early Rhone.

C. Climate

As for the climatic conditions prevailing during the deposition of Burdigalian sediments in the studied area, clues are found in Schwarzbach (1961) who collected data from several authors.

1. Temperature

During the Tertiary the temperature gradually decreased from rather high to to-day's values. Evidence is found in a great many plant and animal remains, which point to subtropic conditions in regions now situated in the Moderates. Some facts may be mentioned, which give almost direct clues for the conditions during the Burdigalian in the studied area.

Coral reefs are found at the borders of the Helvetian sea (Thethys zone) from Morocco, via Catalonia towards southern France and towards the near East. Although it is very likely that the Helvetian sea communicated with the rather warm Indian ocean, this one fact cannot be responsible for the high water temperatures coral growth requires. (Not less than 20°; favourable 25° to 30°, Kuenen, 1950).

A comparison with N America (Durham, 1950) and calculations based on plant remains found at Oeningen, Bodensee (Hantke, 1954) gives a mean annual temperature for the Swiss Miocene of 16° to 18°. This is some 8 degrees higher than to-day's values.

2. Humidity

The middle European Tertiary as a whole is thought to be rather humid (Browncoal in Germany; Eocene, Oligocene and Miocene) though some fluctuations have occurred depending on place and time, giving rise to deposition under arid conditions (Gypsum and Rocksalt in Spain, Germany, Italy and Austria; Eocene, Miocene, Pliocene).

In the sub-Alpine Molasse (near St. Gallen. N.E. Switzerland) the boundary between Burdigalian and Helvetian is characterized by coalbands (Baumberger, 1931). In the Sense-Schwarzwasser area plant debris is abundant in the sand- and siltstones. At the base of giant ripple units (cf. chapter II) we found a substantial peace of washed-in peat, some 20 centimetres in thickness and a few metres in diameter. These facts suggest rather humid conditions with abundant plantgrowth.

Summarizing the above mentioned data we find that the Burdigalian sediments of the Sense-Schwarzwasser area were deposited in a brackish to marine longitudinal inland sea at the foot of the rising Alps with already outstanding relief under humid, warm, (subtropical?) climatic conditions. The sediments were supplied by a river (early Rhone), having its catchment area in the young Alpine backland.

§ 3. *Current directions*

To obtain information about the directions of the depositional currents, if possible independant of the sedimentary structures described in chapters II and III, the greater part of the data were acquired from the orientation of interbedded gravel.

The orientation of long axes of pebbles was therefore measured with the compass. For the measurements only oblong forms were used with a ratio of longest axis to shortest axis greater than 2. The orientations were measured in such manner that only angles between 0° and 180° were obtained. Per exposure 200 pebble orientations were measured. In a few cases where pebbles could be loosened only with the greatest difficulty, only 150 or but a hundred orientations were measured. The results per exposure were collected in groups, with intervals of 10 degrees. The total of each group is plotted as a segment in a circle diagram, together with an opposing segment of equal dimensions, representing the same values plus 180°. The length of each segment represents the total of each group.

Mostly one can distinguish in such a diagram two maxima at right angles to each other. In our opinion this may be explained as follows:

A pebble is transported in a stream rolling (round its longest axis), shifting (partly turning round its shortest axis) or jumping (partly turning round its longest or shortest axis). Rolling keeps the pebble with its longest axis perpendicular to the current during transport, whereas a jumping or shifting pebble may have any orientation. When the current velocity decreases and loses transporting power, the pebbles are deposited. At that moment the current, still loaded with finer particles, has enough power left to direct some of the pebbles deposited, now with their longest axes parallel to the current. Other pebbles deposited on the slope of a streambank may roll down and become in this way orientated with their longest axes parallel to the current. Thus, if the pebbles did not effect eacht other's position one could indeed expect two maxima perpendicular to each other.

For the estimation of the exact current direction,

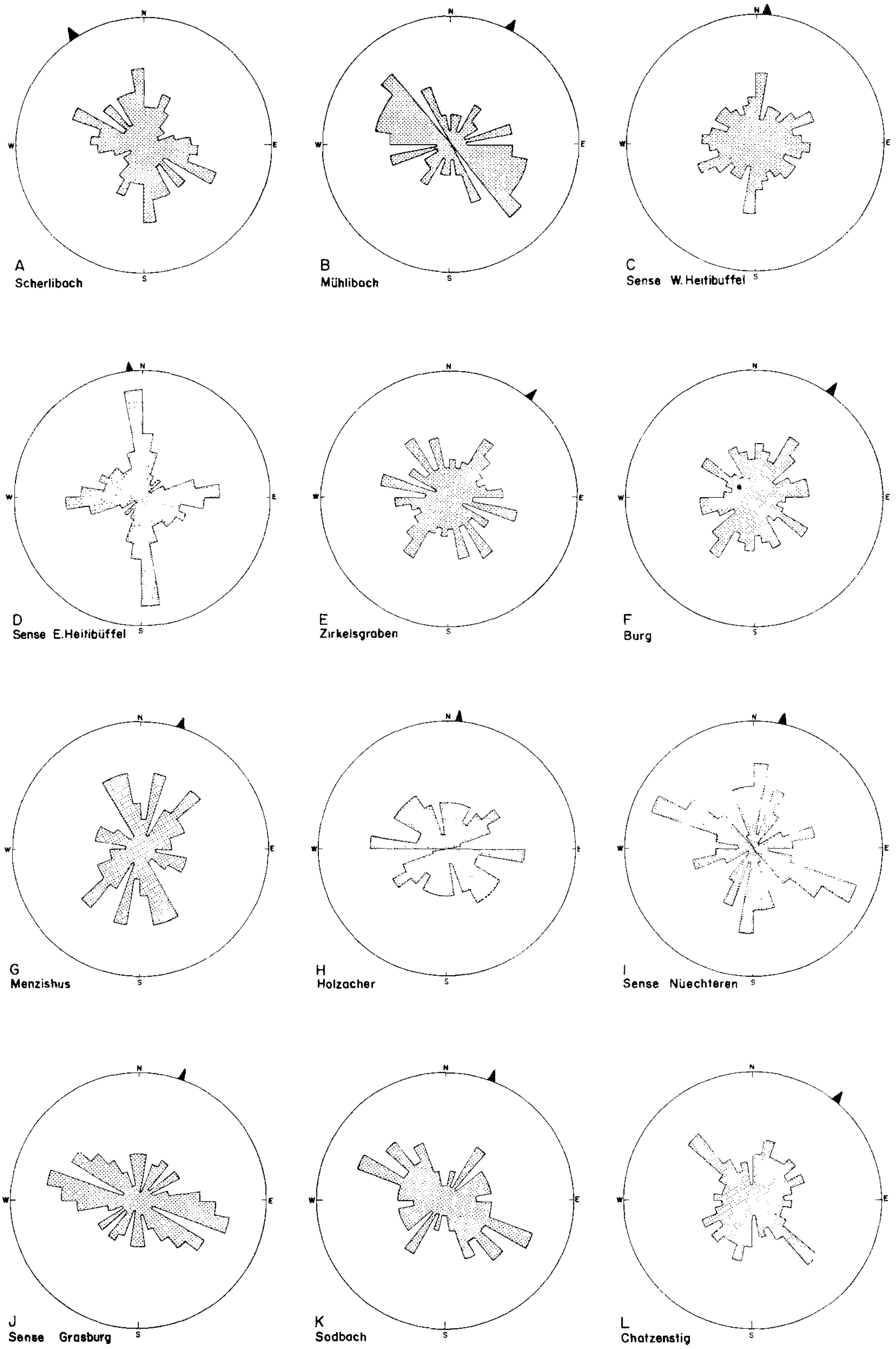

Fig. 4 Orientation diagrams of long axes of "Scherli Nagelfluh" - pebbles

photo 1

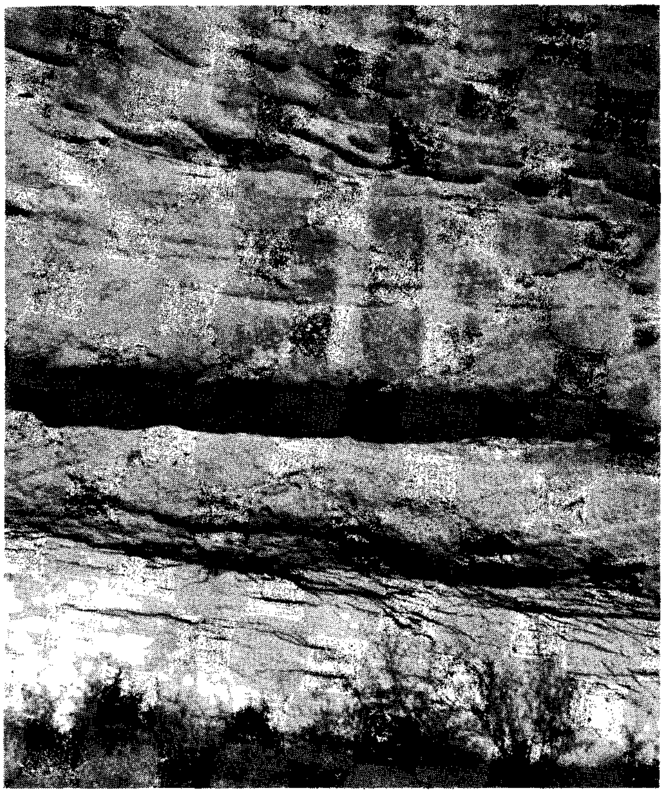

photo 2

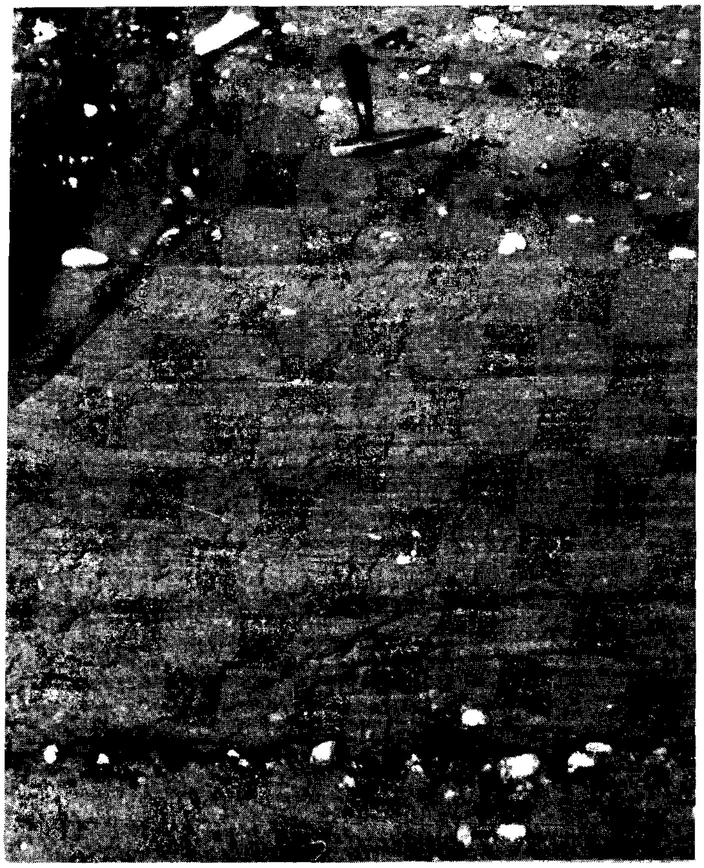

photo 3

photo 1
Giant ripples. Vertical section, parallel to the current of deposition. E-bank of the river Sense. Fig. 1, loc. 1 (cf. plate I).

photo 2
Giant ripples. Vertical section, parallel to the current of deposition. E-bank of the river Sense. Fig. 1, loc. 1 (cf. plate I).

photo 3
Giant ripples. Horizontal section. NW-bank of the river Sense. Fig. 1, loc. 2.

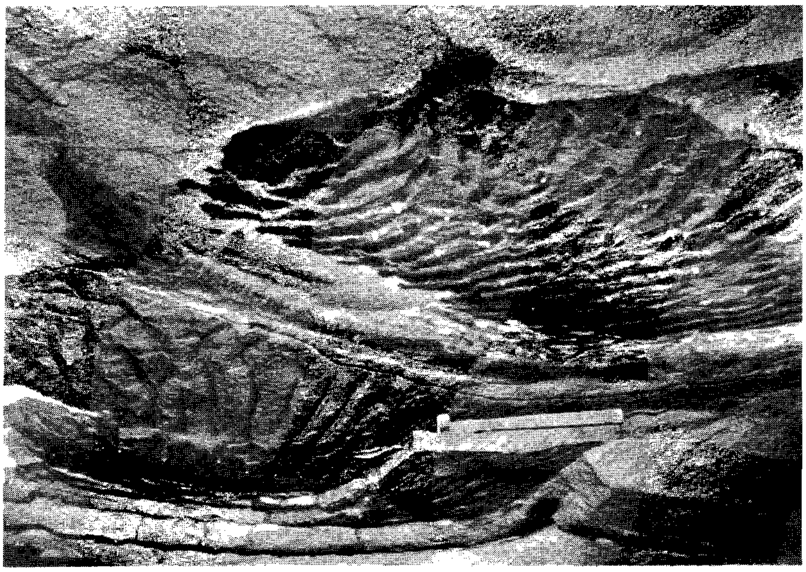

photo 4

photo 4
Ellipsoidal troughs belonging to the lower fore-set and bottom-set part of giant ripples. Ceiling of the Ruchmühle quarry. Fig. 1, loc. 4.

photo 5
Ellipsoidal trough belonging to the lower fore-set and bottom-set part of giant ripples. Ceiling of the Ruchmühle quarry. Fig. 1, loc. 4.

photo 5

photo 6

photo 6
Lower fore-set and bottom-set part of a giant ripple unit. E-bank of the river Sense. Fig. 1, loc. 7 (cf. fig. 12).

based on such a diagram, one has to make a choice out of four possibilities. Other phenomena as the imbrication of the pebbles or inclined bedding of the deposit in which the pebbles are interbedded may be helpful.

In general, the problem is more complicated, for the bottomfriction and the mutual influences of the pebbles confuse the picture.

The current directions, the arrows plotted on the map (fig. 1), have not been corrected for magnetic deviation (3°30′ W 1963) and neither for tilt. The dip of the strata seldom exceeds 3°. Especially the bottom series of the Burdigalian in the studied area, are rich in pebble. They belong to the "Scherli-Nagelfluh" or its offshoots, the basal conglomerate of the Burdigalian. The orientations from these pebbles afford a general view of the current directions in the Sense-Schwarzwasser area within a rather well outlined zone. Since the best exposures of giant ripples, described in chapter II are situated in the same bottom series of the Burdigalian, these current directions give an important indication for the position of the giant ripples and are therefore distinguished from the directions obtained in stratigraphic higher strata. The orientation diagrams of the "Scherli-Nagelfluh" pebbles are collected in fig. 4.

The arrows on the circumference of the diagrams in fig. 4 give the flow direction of the depositional currents. The choice whether this is perpendicular to the average orientation of long axes of pebbles or parcllel to this orientation depended on other information, such as imbrication of the pebbles or structural properties of the deposit in which the pebbles are interbeddedd, e.g. inclined bedding and ripple marks. The full drawn arrows on the map (fig. 1) represent the current directions obtained from fig. 4.

The mean current direction for the Burdigalian basal series in the area is 15°. Deviations between 327° (fig. 1, location A) and 40° (fig. 1, location L) occur.

The current directions derived from gravel orientations and from ripple marks in levels of which the proper stratigraphic position in the Burdigalian is unknown, are given so as to show that the general S - N trend of supply in the area was preserved during the Burdigalian. The directions obtained from these gravel orientations are plotted on the map (fig. 1) as arrows with open shafts, the directions obtained from ripple marks as small arrows.

The mean S - N direction is in agreement with the concept of Staub (cf. this chapter § 2).

As for the determination of current directions on ripple marks, this is allowed only if the ripples belong to a ripple field of which the pattern of the crest lines can be established. Therefore apart from vertical sections, exposing the dip of the ripple fore-sets, a good-sized part of the ripple surface should be open to observation. Otherwise the direction obtained is not reliable (Wurster, personal communication). To avoid errors several measurements per exposure were taken. The small arrows on the maps (fig. 1) represent the mean values from at least some 5 or 6 determinations. In all these localities part of the ripple surface could be observed.

§ 4. *Petrography*

A. Size frequency distribution.

Analyses were carried out to determine the grain size distribution of the various deposits and to have a check on the field estimations. In the field we made a distinction between siltstone and sandstone. From the siltstone-samples were analysed:

Ln 303	Sackau, fig. 1, location 5
Ln 307	Schwarzwasser, fig. 1, location 6
Ln 324 a	,, ,, ,,
Ln 314 a	Ruchmühle, fig. 1, location 4
Ln 321 a	Sense, fig. 1, location 7 (cf. fig. 12)
Ln 351	Sodbachstrasse, fig. 1, location 9 (cf. fig. 19)
Ln 364	Ruchmühle, fig. 1, location 8 (cf. fig. 18)
Ln 365 a	,, ,, ,, ,,
Ln 368	,, ,, ,, ,,
Ln 375 a	,, ,, ,, ,,

From the sandstone-samples were analysed:

Ln 302	Sackau, fig. 1, location 5
Ln 306 a	Schwarzwasser, fig. 1, location 6
Ln 306 b	,, ,, ,,
Ln 324 b	,, ,, ,,
Ln 314 b	Ruchmühle, fig. 1, location 4
Ln 321 b	Sense, fig. 1, location 7 (cf. fig. 12)
Ln 338	Sodbachstrasse, fig. 1, location 9 (cf. fig. 19)
Ln 349	,, ,, ,, ,,
Ln 350	,, ,, ,, ,,
Ln 354	,, ,, ,, ,,
Ln 363	Ruchmühle, fig. 1, location 8 (cf. fig. 18)
Ln 365 b	,, ,, ,, ,,
Ln 375 b	,, ,, ,, ,,

The samples were pestled carefully in a mortar to loosen the grains. To remove organic material they were treated with a 30 % H_2O_2 solution. Furthermore the samples have been boiled in a 30 % HCl solution to remove the carbonate cement and ironoxide films.

The particles coarser than 50 microns were sieved, and in this way the distribution of the sample over the following size groups was obtained:

> 2000 microns	210 - 300 microns
1000 - 2000 microns	150 - 210 ,,
850 - 1000 ,,	105 - 150 ,,
600 - 850 ,,	75 - 105 ,,
420 - 600 ,,	50 - 75 ,,
300 - 420 ,,	< 50 ,,

The particles smaller than 50 microns were suspended in water in a 1000 cc cylinder with added peptizer (0.1 mole Na-oxalate + 0.02 mole Na-carbonate per litre H_2O) and shaken to ensure complete dispersion and production of a homogeneous suspension. With a pipette, at measured time intervals and at given depths, 20 ml fractions of the suspension were withdrawn. After drying and weighing the distribution over the following size groups was obtained:

50 - 32 microns	16 - 8 microns
32 - 16 „	< 8 „

The results of both sieve and pipette analyses were plotted on arithmetic propability paper as used by Doeglas (1941).

In fig. 5 all sieve-pipette analyses have been plotted together, the lower group representing the siltstone samples, the upper group representing the sandstone samples. It is obvious from this diagram that the field estimations siltstone and sandstone are not correct. Better names are silty sandstone and medium sandstone respectively. With a dashed line the mean values of the two groups are presented.

A comparison of these values with curves given by Doeglas for various deposits (1952) show great similarities to river deposits. Especially the upper group is poorly sorted and has a long tail of coarse material.

The medium sand group seems to have been deposited by a river, practically without differentiation by the current (high water deposits). The silty sand group with smaller maximum grain size may be seen as differentiated from the upper group (low water deposits).

Of course some further differentiation and also some mixing of originally differentiated material took place near the shore, owing to waves and currents, prevailing in this zone of the basin in which the rivers dumped their load, but the fluviatile character of the sediments was preserved. The preservation of the fluviatile character in the basin can be understood if we accept a high rate of supply, thus preventing repeated mixing and reworking of sediment.

B. Mineralogy.

To obtain a general idea about the mineralogical composition thin sections of some ten samples were studied.

The sediments consist mainly of quartz and feldspar cemented by calcite. Among the minor constituents we find mica, chlorite and glauconite. Glauconite fills the interstices and is present also as separate grains with a rather fresh unweathered appearance. An analysis of the heavy mineral content of 16 samples gave the following mean composition:

47 % Garnet
32 % Epidote
10 % Zircon
4 % Staurolite
2 % Tourmaline
5 % Rest

The rate between translucent minerals and opaque minerals is 32 : 68.

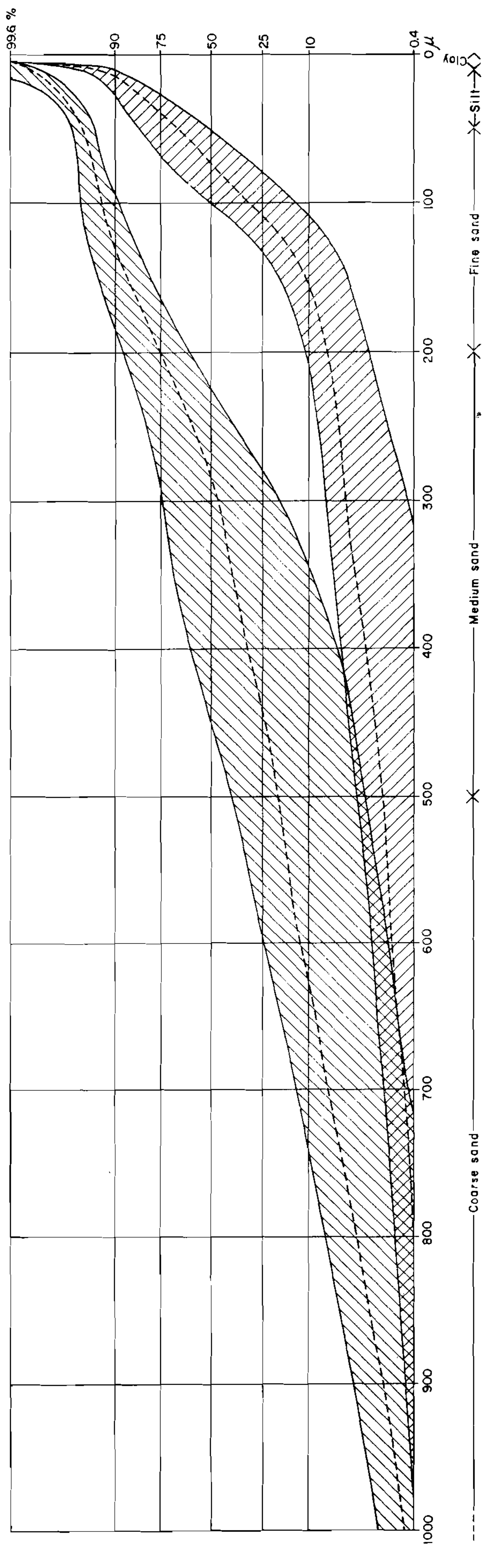

Fig.5 Size frequency distribution.
Compilation of Burdigalian sand- and siltstones

Frasson (1947) analysed pebbles of the Scherli-Nagelfluh conglomerate. They consist mainly of quartzites, white, green and red granites, pointing to East Alpine origin (Unter Ost Alpin, Bernina and Err Kristallin).

C. Roundness.

Under the microscope, 5 medium sandstone samples and 5 silty sandstone samples divided over the various deposits, were compared for roundness of the grains with a chart prepared by Powers (1953).

Roundness is defined in the following formula:

$$P = \frac{\Sigma r_i / R}{N} \quad \text{(Krumbein, 1940)}$$

P (rho) stands for roundness

r_i the individual radii of the corners of the grain

R the radius of the maximum inscribed circle

N the number of corners

Powers distinguished six roundness grades:

very angular	P = 0.10
angular	P = 0.20
subangular	P = 0.30
subrounded	P = 0.40
rounded	P = 0.60
well rounded	P = 0.85

The mean values for the Sense-Schwarzwasser Budigalian samples as compared with Powers' grades are:

20 %	very angular	11 %	subrounded
37 %	angular	2 %	rounded
30 %	subangular		

Granular variations could not be detected.

CHAPTER II. STEEP ASYMMETRIC TRANSVERSAL GIANT RIPPLES

The structures described in this chapter can be observed in many exposures in the Sense-Schwarzwasser area (fig. 1). They are common throughout the whole Burdigalian series in this area from bottom to top.

The exposures, on which the analysis of the structural pattern is based are found near the Schwarzwasser mouth (fig. 1, locations 1, 2, 3, 6 and 7) and near Ruchmühle (fig. 1, locations 4 and 8).

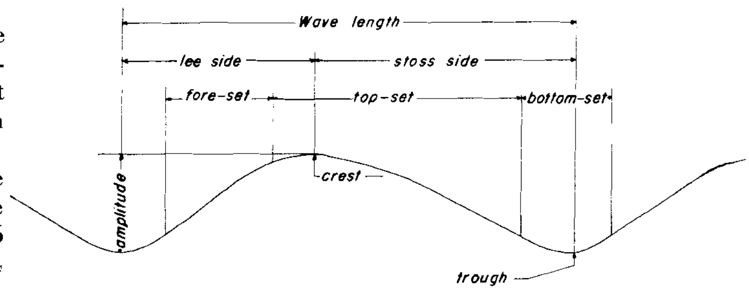

Fig. 6 Ripple nomenclature

§ 1. *Nomenclature*

For a good understanding of ripples and their formation it is necessary to give some names and definitions. As far as they correspond to the "Geological Nomenclature" of the Royal Geological and Mining Society of the Netherlands (1959), this is indicated in brackets.

Ripples: A more or less rhytmic pattern of ridges of sediment formed by wind or water movement on the bedding plane of a rock (2466 p.p. modified).

Ripple crest: The line connecting the higher parts of one ripple ridge.

Ripple trough: The line connecting the lower parts of one ripple ridge.

Wave length of ripples: The transverse horizontal distance between corresponding points on two successive ripples (2466 p.p. modified) *.

Amplitude of ripples: The vertical distance between ripple crest and adjacent ripple trough (2466 p.p. modified) *.

Ripple index: The ratio of amplitude to wave length (2466 p.p. modified).

Bottom-set beds: The deposits covering the lee ward foot of a ripple and the lower stoss side of the adjacent downstream ripple (1218 p.p. modified).

Fore-set beds: The deposits formed on the lee slope of a ripple (1219 p.p. modified).

Top-set beds: The deposits formed on top of the fore-set beds, covering the greater part of the stoss side of a ripple (1220 p.p. modified).

Bottom-set beds and chiefly fore-set beds form the ripple body and its inner structures, as will be described in the next paragraph. The top-set beds are only thin layers (with a thickness of one grain) and are the remnants of foregoing processes of erosion and transport: Every moment they are refashioned by these processes. Read also next paragraph, page ....

* Horizontal and vertical refer to the original bedding plane. Horizontal is parallel, vertical is perpendicular to this plane.

§ 2. *Ripple formation. Inner structures. Ripple wandering*

By the force of an air or water current, sediment particles are loosened from the bottom, transported over some distance in the current and over the bottom and deposited downstream. Under certain conditions this deposition occurs according to a regular pattern, which we call ripples. Successive ripples of more or less equal dimensions form a ripple field.

Much has been written on the subject of ripple formation, but fig. 7 (Reineck, 1961) fairly well illustrates the general subject.

Fig. 7a gives the current pattern, observed during current velocities from 25 to 60 cm/sec. (Bagnold, 1941; Muller, 1941; Reineck, 1961). Ground vortices are rotating on the lee side of the ripples. There is a quiet water zone (still water zone) between the vortices and the ripple lee sides.

In fig. 7b the sediment movement is illustrated. In section 1 the formation of the fore-set beds is observed, which is caused by the following processes:

a. Shearing (black arrows in the lee slope)
b. Sediment rain (white arrows over the lee slope)
c. Sedimentation of fine grains in the still water zone
d. Back transport by the vortices

The destruction of the ripple body, caused by erosion and transport is seen, in sections 2 and 3.

As for the sedimentation processes, governing the formation of the fore-set beds, the most active ones are sediment rain and shearing. The shearing may be continuous or in successive stages. In the latter case, just over the crest on the top-lee side a heap of sediment is deposited (sediment rain and material rolled over the stoss side and dumped over the crest). After reaching a certain critical value, the weight of this heap causes it to move downward, thereby covering the lee side of the ripple with one fore-set lamina.

Removal of sediment material from the stoss side and formation of fore-set beds on the lee side, causes the ripple body as a whole to wander downstream.

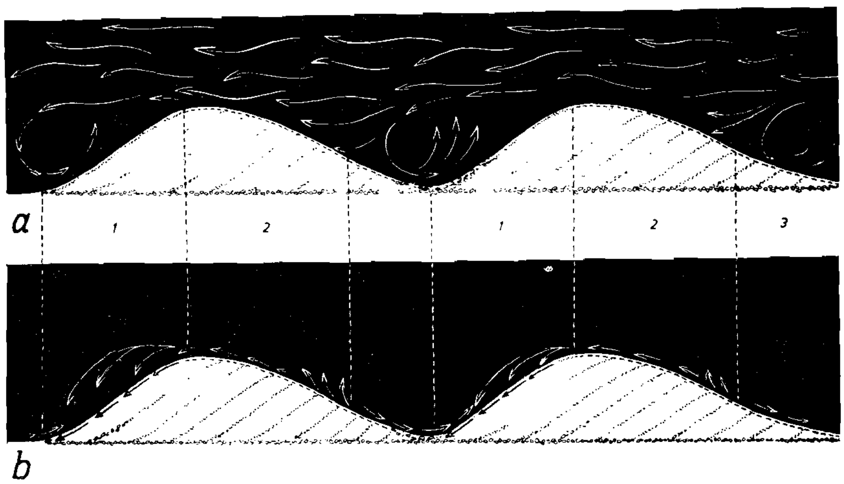

Fig. 7 Current pattern and sediment movement on wandering current ripples (Afer H.E.Reineck '61)

In this description the current velocity is thought to be constant. When variations occur the ripple features become irregular. For instance a temporary increase of the current velocity causes a temporary increase of the erosive forces in the ripple trough and on the stoss side (cf. § 4 and § 6).

The amount of sediment supply is responsible for the levels in which the ripples are wandering. In areas without sediment supply every ripple is wandering in the same level as its preceding one, thereby destroying every trace of formerly built ripples. This is illustrated in fig. 8a. The movement of the ripples is given in successive stages. The amount of the material deposited on the lee side during a certain period is equal to the amount removed from the stoss side in the same time. Shape and volume of the ripple body are thus constant during the movement.

The solid line 1 represents a set of 2 ripples, A and B at a certain position, while wandering downstream. In 11 successive stages the upstream ripple (B), is thought to have wandered over one wave length, thus taking the place of A at position 1. The intermediate stages of ripple B are given with dashed lines (2, 3, ...10). The remnants of the fore-set beds formed during this movement are given with solid lines.

In areas with sediment supply every ripple is wandering in a higher level than the preceding one, as if it were riding on the lower stoss side of a downstream ripple, thus eroding only the upper parts of foregoing ripples. This is illustrated in fig. 8b.

Far from being complete, an attempt was made in this section, to give a general idea of ripple formation and ripple wandering. The processes described are valuable for current ripples (ripples formed in an air or water current), but are, with a few modifications, also of value for oscillation or wave ripples. Oscillation of a water body causes to and fro motions at its bottom, which may be interpreted as momentary current movements. Oscillation or wave formed ripples generally show other forms and structures than current ripples. It is beyond the scope of this chapter to give further details.

§ 3. *Classification*

In 1955 Hülsemann gave the following useful classifications for the various ripples:

1) After their form in cross-section:
   a) Symmetric
   b) Asymmetric
2) After their position with respect to the current direction:
   a) Longitudinal
   b) Transversal

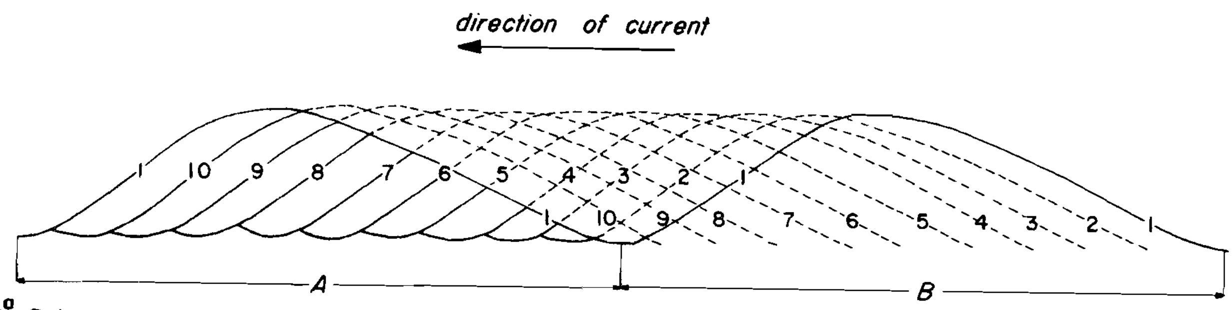

Fig.8[a] Scheme of wandering ripples in areas without sediment supply

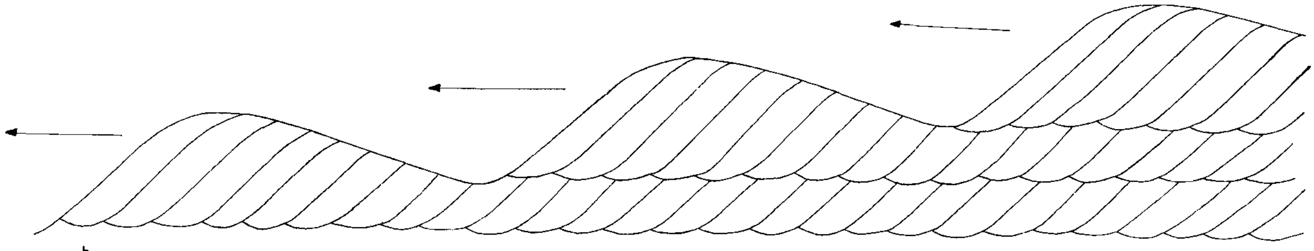

Fig.8[b] Scheme of wandering ripples in areas with sediment supply

3) After their wave length (λ):
a) Ripple marks ($\lambda < 0.2$ à 0.3 m.)
b) Mega ripples (0.2 à 0.3 m. $< \lambda <$ 3 à 4 m.)
c) Giant ripples ($\lambda > 4$ m.)

Some ripples have rather steep lee ward sides and are therefore distinguished as steep ripples. Hülsemann states that the form of these steep ripples is restricted to mega ripples. They show the following characteristics:

Lee ward dip $> 15°$
wave length > 2 m.
Ripple index > 0.05

However, apart from the size the form is a common, if not normal, feature for both ripple marks and giant ripples. According to the given classifications, the ripples, described in this chapter, are defined as steep, asymmetric, transversal giant ripples (cf. § 4). Furtheron, they are in short referred to as giant ripples.

§ 4. *Geometry of the observed giant ripples*

The eastern bank of the river Sense, immediately north of the mouth of the Schwarzwasser (fig. 1, location 1) reveals the giant ripples in vertical sections parallel and oblique to current directions (plate I, photos 1 and 2). Several layers can be distinguished. Some layers show bottom- and fore-set beds with rather steep dips, others show trough-shaped structures and transitions of these into bottom- and fore-set beds. The different structural appearance of the distinguished layers are due to different intersections of the profile with the current directions belonging to the individual layers. The bottom- and fore-set beds occur in vertical sections through a giant ripple more or less parallel to the depositional current, the trough-shaped structures and their transitions occur in vertical sections through a giant ripple cutting the depositional current at an oblique angle.

Until further notice we confine our attention to the giant ripple layers with bottom- and fore-set beds. In one layer a number of units can be distinguished which are enfolded by thin bands notable in plate and photos. These thin bands corres-

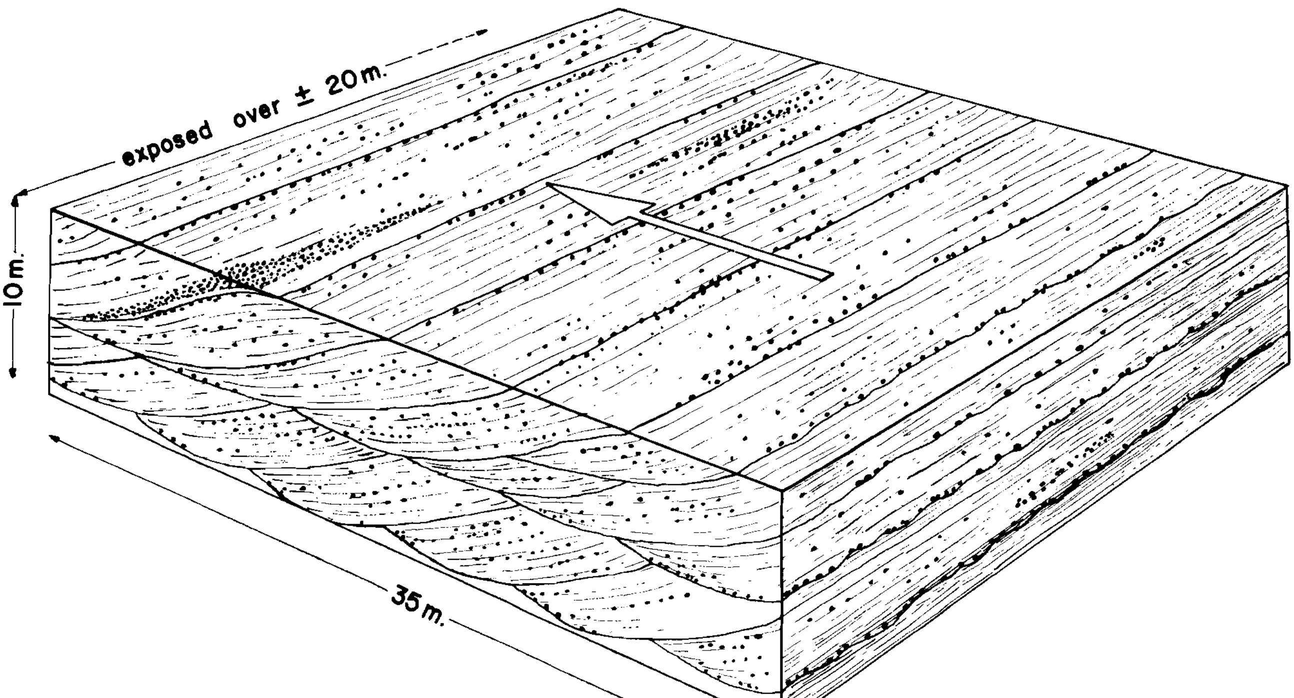

Fig.9 Geometric pattern of giant ripples

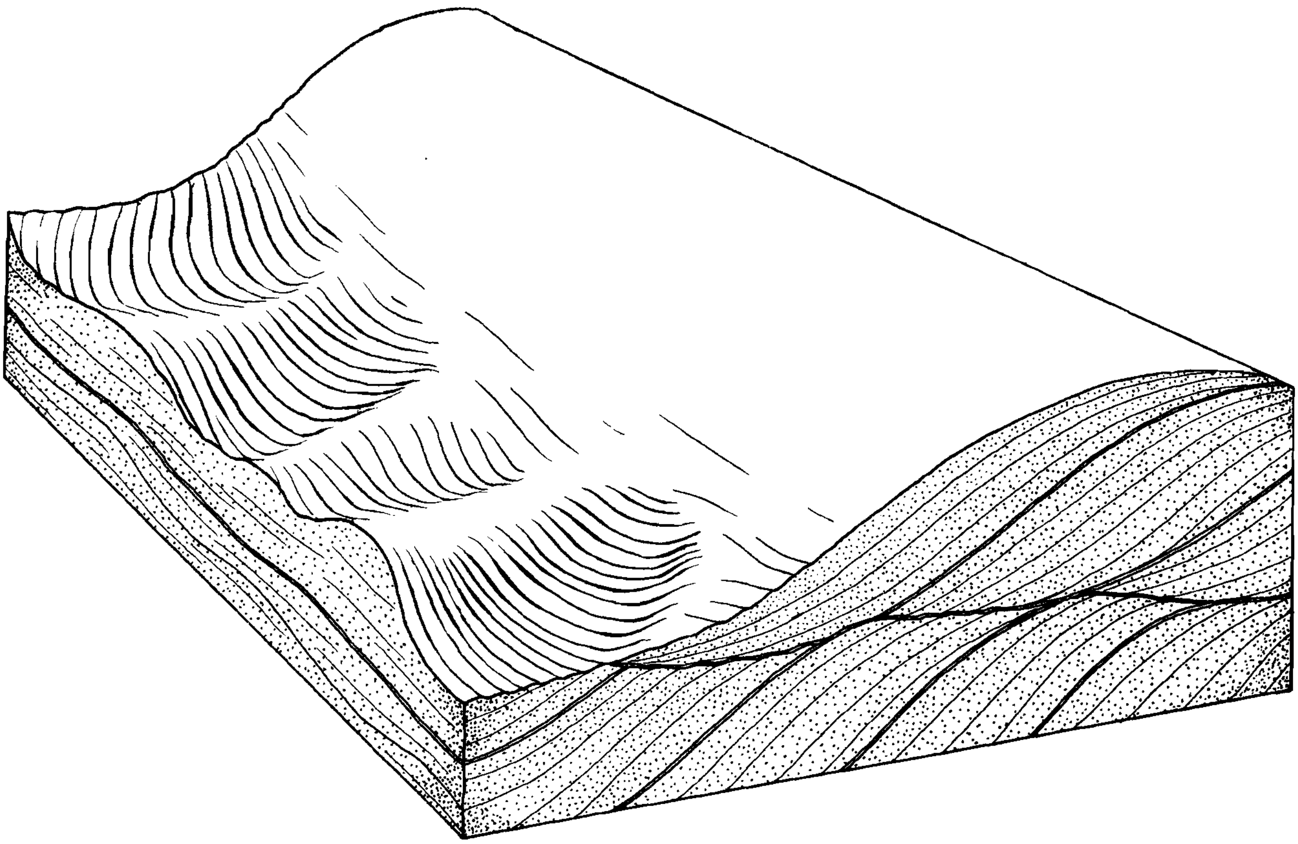

Fig. 10 Reconstruction of the front of a giant ripple

pond to laminae of silty material, whereas the bulk of each unit consists of medium to coarse sand. Each unit in its turn is built up of a number of laminae. Some of these laminae have the sigmoidal form of fully preserved fore-set beds. The height of one ripple layer amounts to 6 metres in the thickest parts, which leads to an estimated ripple amplitude of at least 6 metres. The dip of the fore-set beds shows maxima of 37°.

About 250 metres to the S S W, the riverbed exposes a horizontal section through these giant ripples (fig. 1, location 2 and photo 3). The intersections of the horizontal plane with the upper parts of the fore-sets (near the ripple crest) were observed to be almost straight and parallel, whereas the intersections of this plane with the lower parts of the fore-sets (near the ripple trough) or with the bottom-sets were undulating. This is confirmed by a vertical section, perpendicular to the depositional current, at the northern bank of the Schwarzwasser at its mouth (fig. 1, location 3) and by a great many exposures which gave views from above or from below on uncovered parts of ripple units (e.g. fig. 1, locations 4 and 6).

Figure 9 gives a geometric pattern of the ripple features, based on the above mentioned observations.

A reconstruction of the front of a ripple unit is given in fig. 10. We see that the ripple, in the lower part of the lee slope is dividing itself into a number of more or less regular troughs. The form of these troughs is ellipsoidal, with a width varying between 0.5 m and 10 m and a length between 1 m and 20 m. They are situated on the lower part of the giant ripple; lower fore-set and bottom-set. Very often, also on the lower downstream part of the ripple, a ripple mark pattern is superimposed. Their crests run at right angles to the current direction. The concave troughs cause deviations of the current, giving rise to a smoothly curving design of the crest line of the ripple marks.

The base of each unit (the dark heavy lines of fig. 9), including the above mentioned troughs, has an erosive character. The formation of fore-set laminae is interrupted, at more or less regular intervals, by a break in the sedimentation processes. Every unit, especially in the lower fore-set and bottom-set part, cuts the underlying strata.

A fine example of the erosive force of the ripple bases with their troughs could be observed near Ruchmühle (fig. 1, location 4). Here parallel bedded, hard sandstones, with a perfect parallel cleavage, are quarried for garden stones and front stones. These sandstones are underlying a set of giant ripples. Where the parallel bedded layers are removed by quarrying, a remarkable pattern could be observed on the ceiling of the quarry (photos 4 and 5).

Near Sackau, Schwarzwasser (fig. 1, location 5) a field of the ellipsoidal troughs could be studied. Here the Schwarzwasser has eroded a set of giant ripples, almost to the bottom, leaving the troughs, at low water level of the Schwarzwasser, exposed for observation (fig. 11). In the diagram of fig. 11 the orientation of the long axes of the troughs has

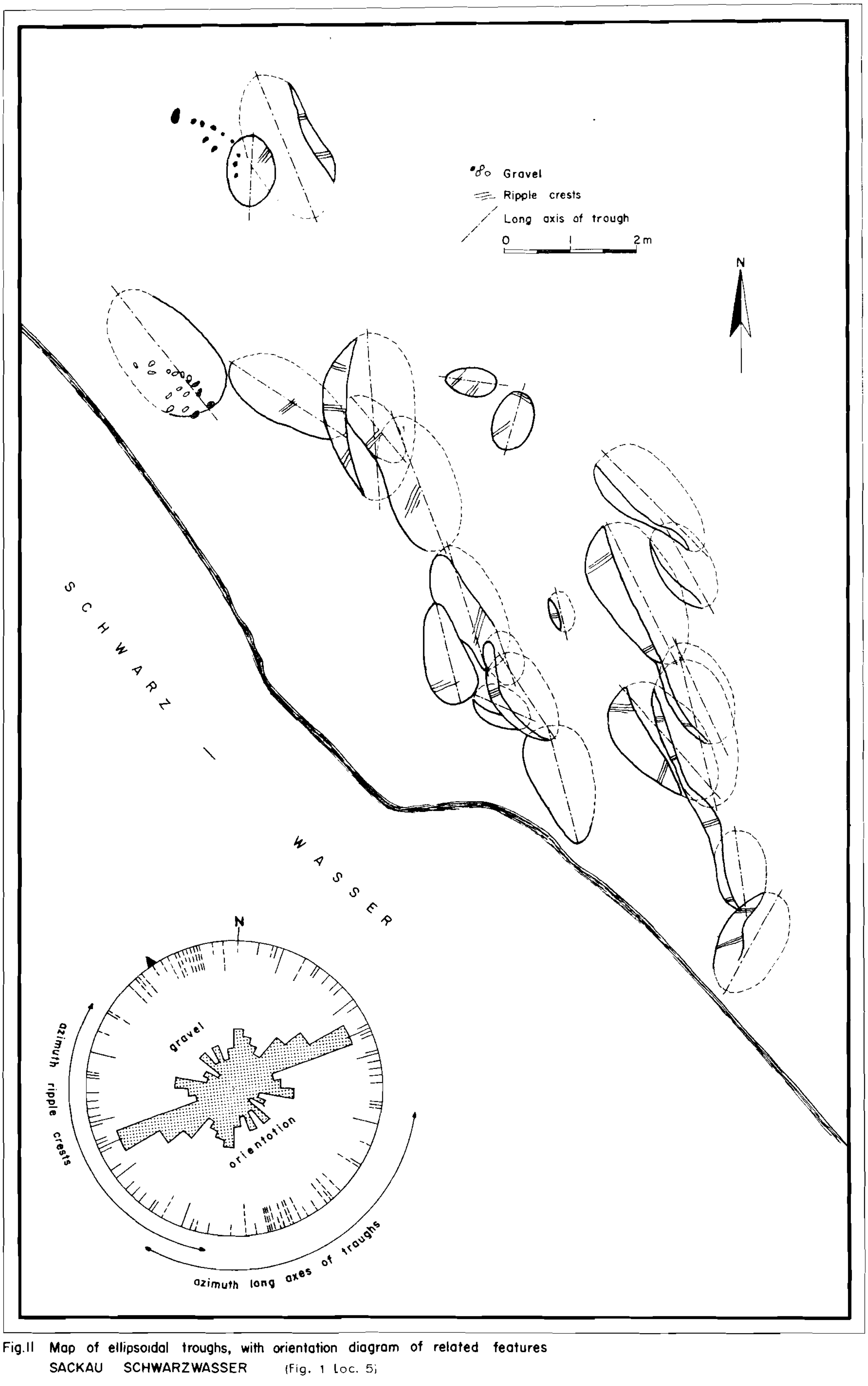

Fig. 11 Map of ellipsoidal troughs, with orientation diagram of related features
SACKAU SCHWARZWASSER (Fig. 1 Loc. 5)

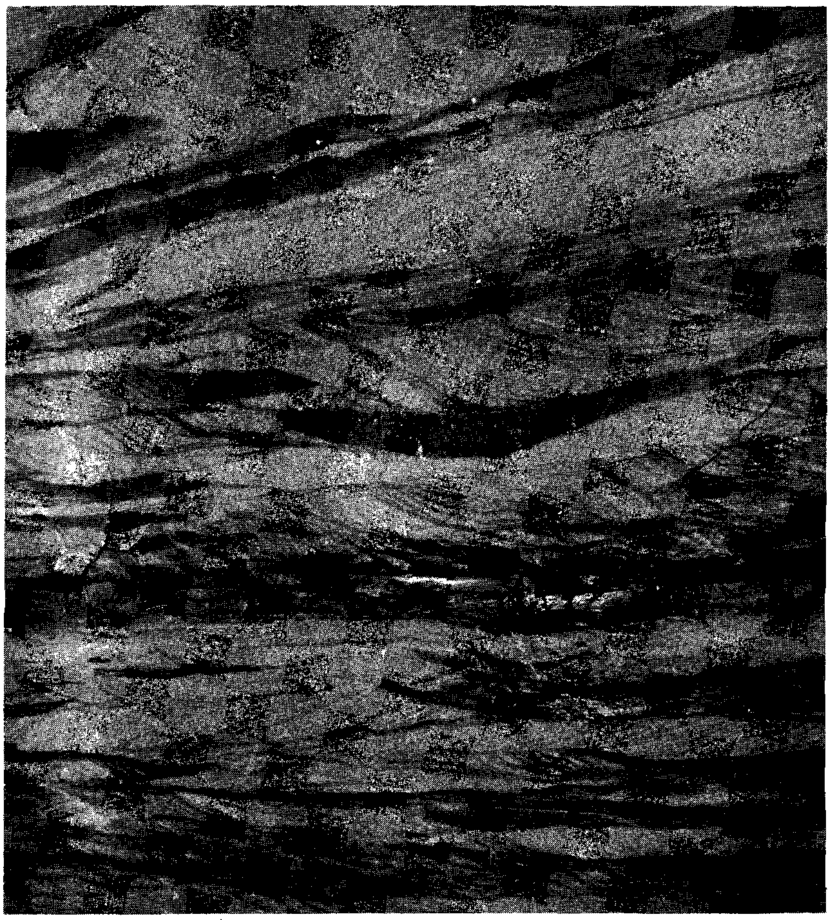

photo 7

photo 7
Mega flaser structures. Ruchmühle quarry, old entrance. Fig. 1, loc. 4 (cf. fig. 15).

photo 8
Offshore bar. Ruchmühle quarry, old entrance. Fig. 1, loc. 4 (cf. fig. 15).

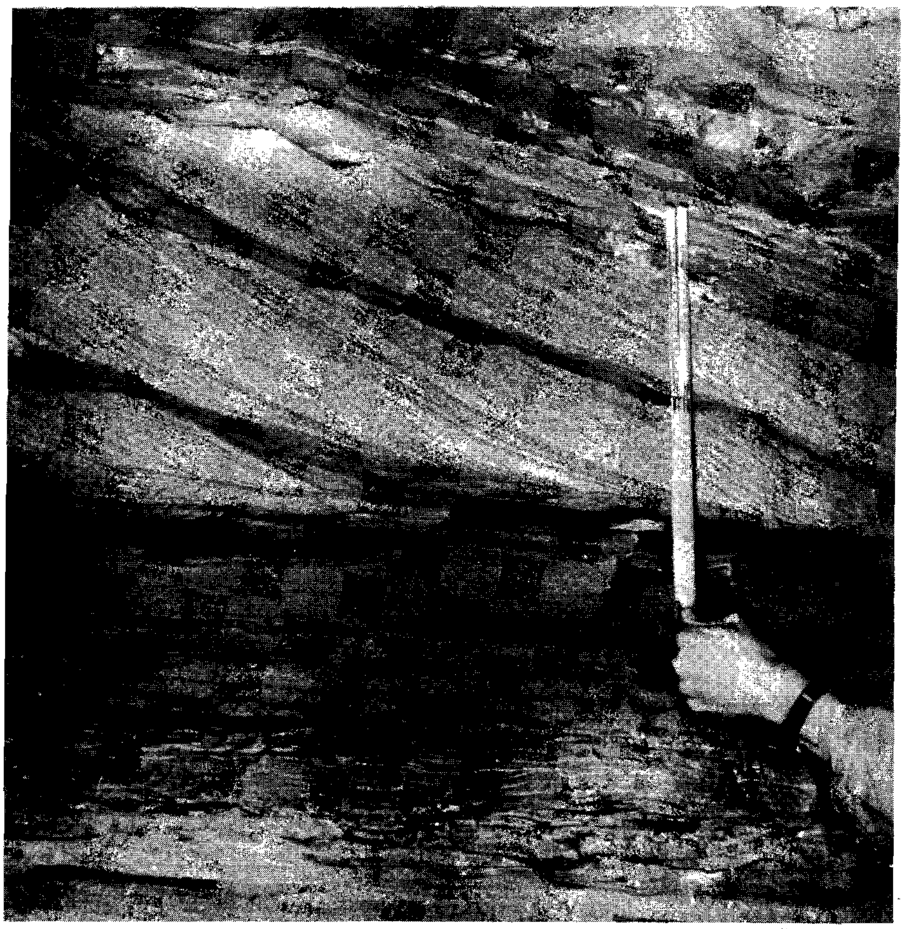

photo 8

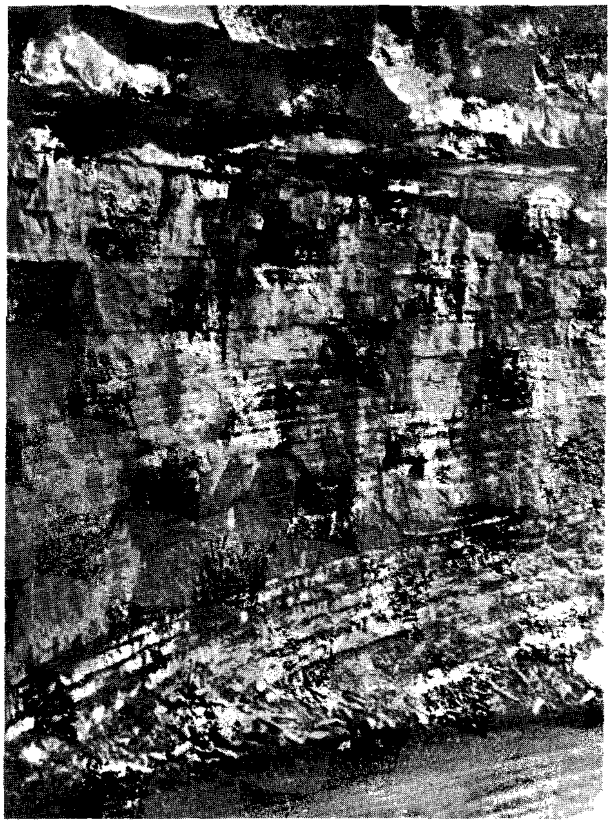

photo 9

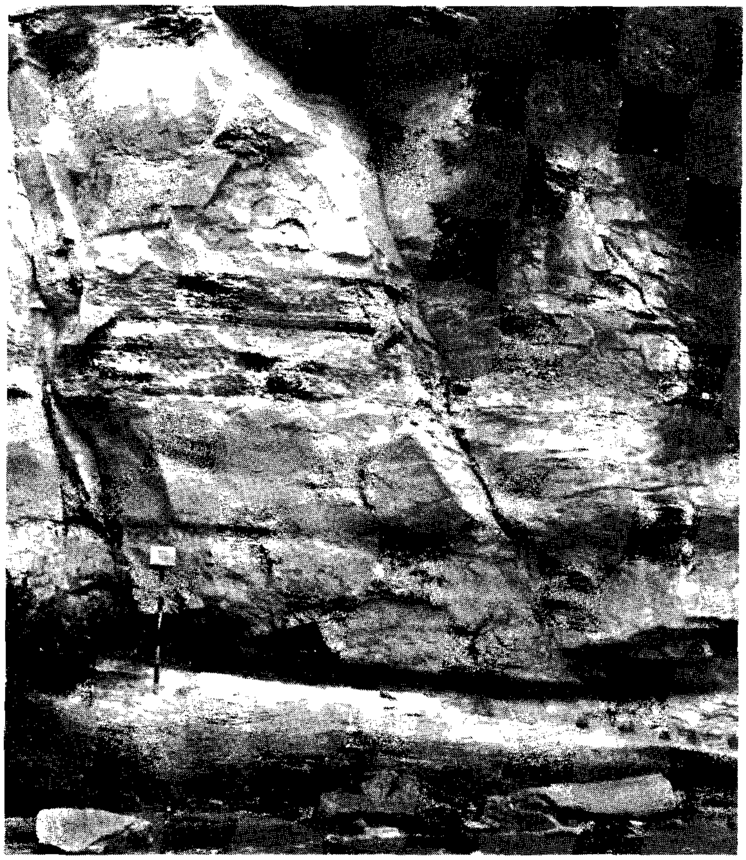

photo 10

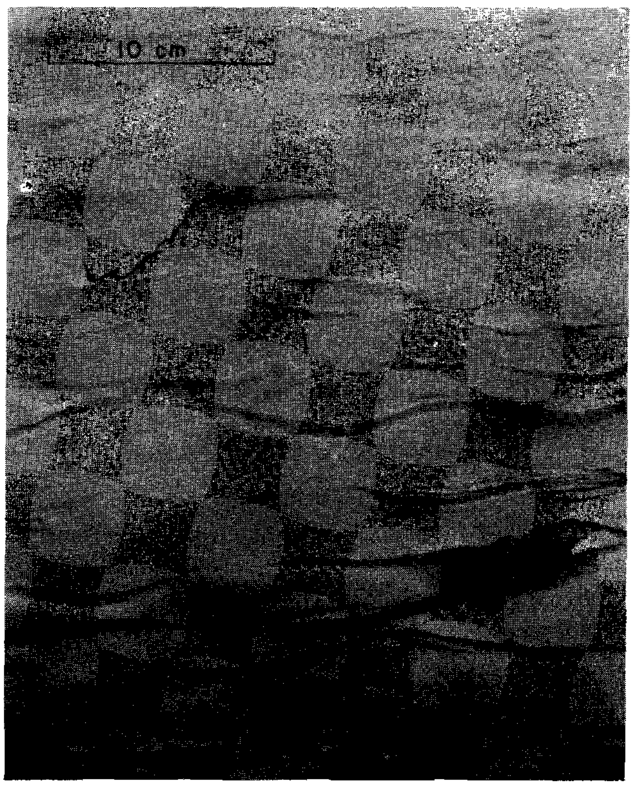

photo 11

photo 9
Parallel bedded series. Ruchmühle road exposure. Fig. 1, loc. 8 (cf. plate II and fig. 18).
photo 10
Ripple mark horizon. Sackau. Fig. 1, loc. 8.
photo 11
Ripple mark features. Detail of photo 10. Sackau. Fig. 1, loc. 8.

been plotted, together with the orientation of the ripple marks in the troughs, both in relation to the depositional current, derived from orientation of long axes of pebbles. In a great many of the studied giant ripples, gravel is interbedded in the structure. The erosional forces scouring the troughs in front of the ripple wash out all material finer than gravel, leaving a pebble layer covering the bottom of the trough (lag gravel). It is evident from fig. 11 that the prevailing orientation of the long axes of the troughs is parallel to the depositional current, whereas the crests of the superimposed ripple marks run at right angles with this current.

After the current has scoured the bottom in front of a ripple with or without forming ellipsoidal troughs, sedimentation starts again with deposition of silty material embedding the lag gravel. With increasing current velocity coarser material is supplied and the ripple body wanders downstream with bottom- and fore-set beds until the next break in the sedimentation. This process causes an inclined, laminated structure. Lamination is due to an alternating deposition of coarse and medium sand, dependant on fluctuations in current velocities and/or water-depths. The troughs are filled by these deposits, which give them in sections perpendicular to the depositional current the normal features of a scour and fill structure, with a concave bottom and a flat top.

In one exposure at the Schwarzwasser (fig. 1 location 6) the more or less parallel bedded deposits belonging to the bottom-sets of giant ripples were disturbed by mud slumps. Here clay layers of some 10 to 20 cms were deposited in the bottom-set area. A dip of one degree or even less was then sufficient for this soft material to slide downslope over a few centimetres and produce rumpled clay balls.

Until so far nothing has been said about the dip of the stoss side and about the wave length of the ripples. If the dip of the stoss side is known, the wave length can easily be calculated from the ripple amplitude. However, top-set beds which could help estimating the angle of dip of the stoss side, are not present.

Studies on recent ripples of this kind, where the upstream dip could be measured, inform us that these dips seldom exceed 7°. If this also applies to the ripples with fore-set dips of 37° and amplitudes of 6 metres, as described in this chapter, then the minimum wave length of these ripples can be estimated as 57 metres.

The structural pattern of the troughs has a great resemblance with that of the ripples described by Niehoff (1958) for the Koblenz quartzites. He considers his so-called "spoon forms" (Löffelformen) as fore-sets of giant ripples. In our opinion it is very likely that they are the same troughs as described in this chapter, thus the transitions of fore-sets of giant ripples in the bottom-set area.

The picture given by Niehoff shows that he considers the structures as Festoon-cross-bedding (Frazier and Osanik, 1961; Wurster, 1958).

Most likely Niehoff missed the complete picture of the giant ripple pattern because in the Koblenz area only few complete ripples are preserved and horizontal sections through the ripple body seem not to be observed.

§ 5. *Textural and structural properties*

In fig. 12 a graphic representation is given of the structural and textural properties of a giant ripple. A suitable exposure for making this graph was found at the eastern bank of the Sense (fig. 1, location 7, photo 6). The graph includes all field observations in a vertical section through the lower fore-set and bottom-set parts of giant ripples.

The mode of representation initiated by Doeglas (1959) is the same as developed by Bouma (1962); see also Bouma and Nota (1961). At the moment the method is used for a program, that deals with the representation of sediments in various known environments, by the department of Sedimentology of the State University of Utrecht. Some improvements were made. For instance: The use of the symbols has been reduced and as far as possible been replaced by words, to make the graphs more readable. However, this replacement of symbols by words, could not be carried out consistently, because otherwise the advantage of having the characteristics of a deposit at a glance, would be lost. It seems best to describe the structural and textural properties of this giant ripple deposit with the help of the graph. Symbols and use of the graph will be explained at the same time.

1st column: thickness.
A vertical section of 200 cm. through a giant ripple has been surveyed in the lower fore-set and bottom-set region (photo 6).

2nd column: stratigraphy.
The deposit belongs to the Burdigalian, the lower part of the Miocene.

3rd column: rock type.
In this graph only two rock types occur; sandstone, the most abundant type, and siltstone.

4th column: bedding plane properties.
This column is divided into two subcolumns. Under "Type", the sharpness of contact between two layers is given, together with the dip of the layers, as observed in section. In this case, as the profile runs approximately N - S, N corresponds to the left hand side, S to the right hand side of the column. The contacts in this graph are rather sharp (— —) to sharp (—·—). (In general one may say, the nearer the boundary line gets to a full-drawn line, the sharper the contact.)
In the second subcolumn "Structures", the properties observed on the bedding plane are plotted. In this case only current ripple marks could be observed.

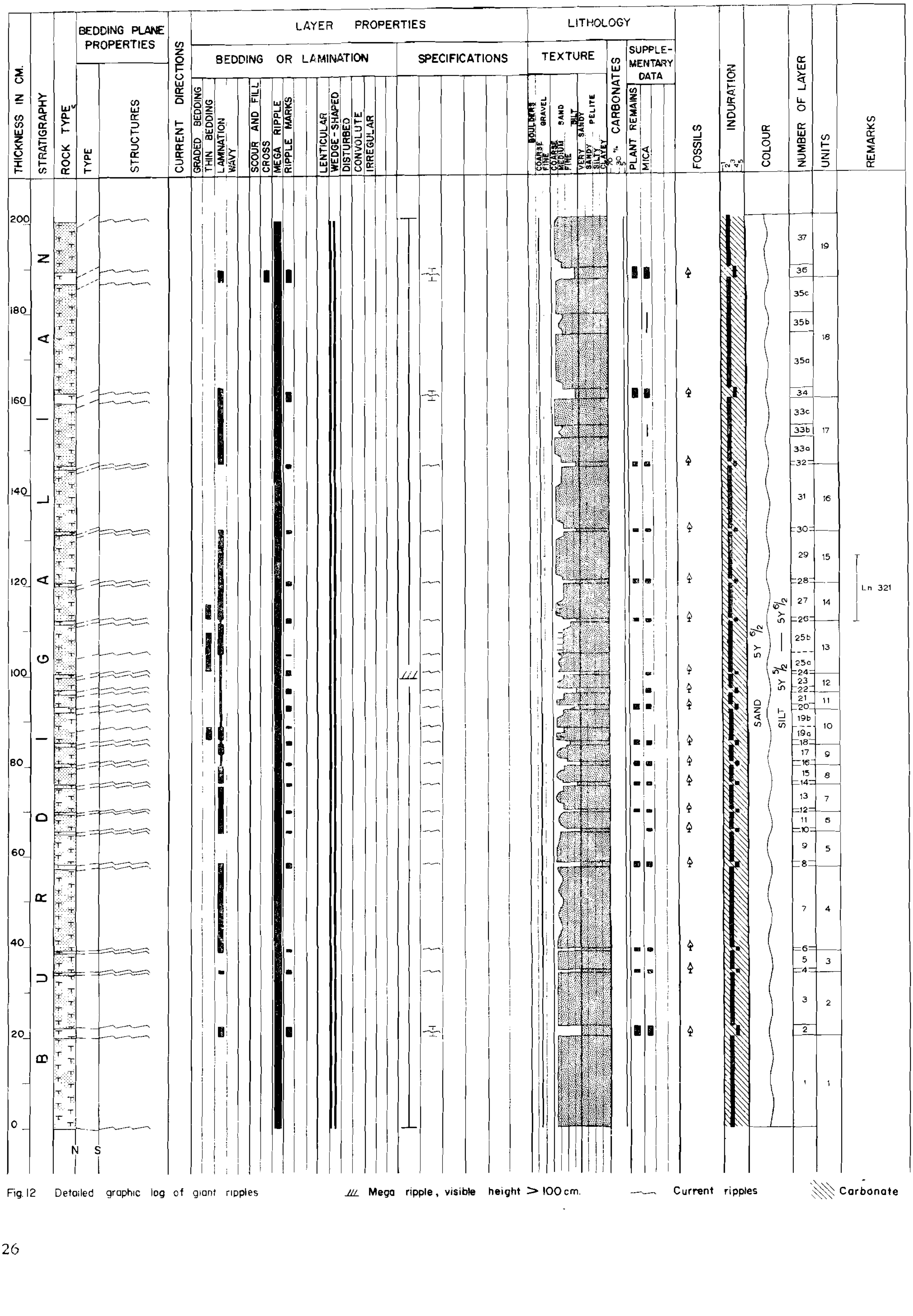

Fig. 12 Detailed graphic log of giant ripples — /// Mega ripple, visible height > 100 cm. — Current ripples — Carbonate

5th column: current directions.

As not enough of the bedding planes was exposed, current directions could not be deduced from the observed current ripples.

6th column: layer properties.

This column is divided into two subcolumns, "Bedding or lamination" and "Specifications". The first subcolumn gives the layer properties and their vertical distribution in general. The observed properties are plotted under the different heads with vertical lines; their lengths corresponding to the traject over which each property occurs, their thickness corresponding to the clearness and/or abundancy of each property.

Under "Wedge shaped", one observes two vertical lines; one in the left hand side and one in the middle of the column. The line in the left hand side means that the deposit as a whole is wedge shaped, the line in the middle indicates that the different layers are wedge shaped.

The second subcolumn gives if necessary or possible a specification of the observed properties. In this case the mega ripple is further defined as having a visible height of more than 100 cm. The ripple marks have been identified as current ripple marks.

7th column: lithology.

This column is divided into three subcolumns, "Texture", "Carbonates" and "Supplementary data". The first, "Texture", gives the grain size of the various layers. As can be seen in the graph the giant ripple is built of coarse sandstone layers alternating with siltstone layers (cf. chapter I, § 4 A).

As the deposit is scattered with coarse gravel, this is indicated with a separate line in the column of coarse gravel.

The second subcolumn gives the carbonate content. The carbonate content is roughly estimated with the help of a 10 % HCl solution. In the present case this method gave some 10 % for the whole section.

Grain size and carbonate content have been checked in the laboratory. The grain size analyses were plotted on arithmetic propability paper. The results divided over the size groups, coarse sand, medium sand, fine sand, silt and clay are listed below (cf. chapter 1, § 4 A).

For the sandstone:
(without gravel)

39 %	coarse sand	(2000 - 500 microns)
48 %	medium sand	(500 - 200 microns)
9 %	fine sand	(200 - 50 microns)
4 %	silt	(50 - 10 microns)

For the stilstone:

10 %	medium sand	(500 - 200 microns)
40 %	fine sand	(200 - 50 microns)
42 %	silt	(50 - 10 microns)
8 %	clay	($<$ 10 microns)

As can easily be recognized from the column texture, a great deal of the sandstone layers show positive and negative grading together with lamination and/or thin bedding. For such combined features Mac Gillavry introduced the term "laminated grading" (personal communication). Per lamina the grain size starts with medium sand at the base, increases up to coarse sand and decreases again to medium sand.

The carbonate content, measured by the Scheibler apparatus gave 13 % $CaCO_3$ for the sandstone, and 17 % $CaCO_3$ for the siltstone.

The last subcolumn is used for the plotting of other lithological characteristics, which cannot be shown under "Texture" or "Carbonates". In this case plant remains and mica; both restricted to the siltstone layers.

8th column: fossils.

Apart from washed-in plant debris, as plant stems, peat, silicified wood and some questionable wormtracks, the whole Burdigalian series in the area is sterile. The condition of the plant remains was such, that they could not be determined.

9th column: induration.

In this column both the hardness and the composition of the cement are plotted. The cement is $CaCO_3$, which is shown by oblique hatching. The sandstone layers have a hardness 2 (grains can be detached with the fingernail), the siltstone layers have a hardness 3 (grains can be detached with a knife). The greater hardness of the siltstones corresponds to a higher carbonate content as was found in the laboratory.

10th column: colour.

The colour of the fresh rock is given according to the letter-cipher code of the Munsell Rock Color Chart. Over the length of the column a subdivision has been made to distinguish the coarser from the finer material. The sandstone has code 5 y 6/2 (yellowish gray to light olive gray), the siltstone shows a darker hue: 5 y 5/2 - 5 y 6/2 (light olive gray).

11th column: number of layer.

For possible references from text to graph, each layer has its own number. This also facilitates to distinguish the different layers in the field.

12th column: units.

This column is used for the combination of different layers into distinguished units. These units may be; cycles, sequences or other depositional types. In this case a unit consists of two layers; one siltstone layer at the base and one sandstone layer at the top. Reasons for this grouping are given in the next paragraph.

Note: A unit as used in the graph does not correspond to a giant ripple unit (cf. § 4).

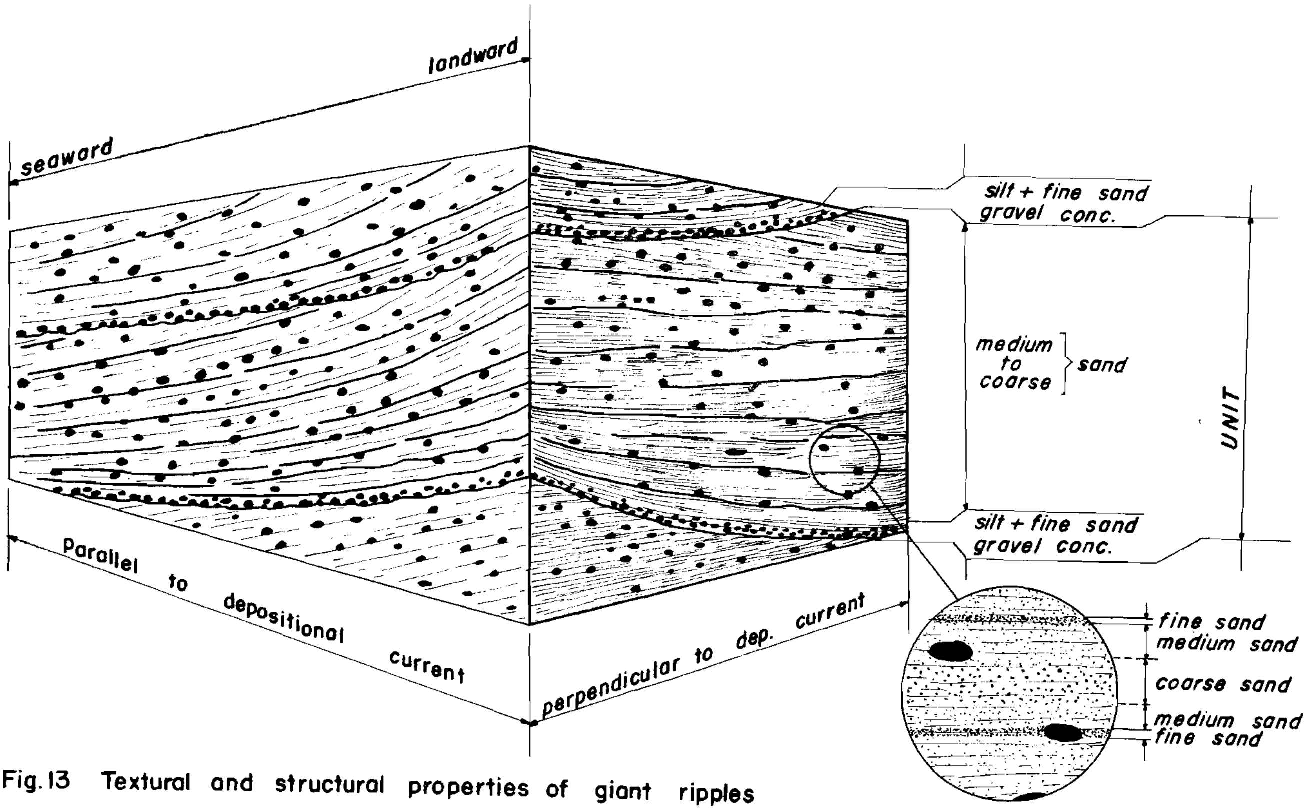

Fig. 13 Textural and structural properties of giant ripples

§ 6. *Analysis of the character of deposition*

A striking feature of the giant ripples is the uniformity of the units. This suggests a periodicity in the deposition, of which the character may be detected by close observation of the textural and structural properties of each unit. This will be done at the hand of fig. 13. Point by point the characteristics of the units are described and short remarks are made referring to current velocities and deposition.

1°. The boundary lines between successive units are of an erosive character, especially in the lower fore-set and bottom-set region where the earlier mentioned troughs occur. The scour at the base of the ripple unit in underlying deposits is evident. High current velocity and no deposition.

2°. The pebbles which are scattered through the whole ripple body, are very often concentrated in the troughs. They are a residual deposit after erosion (lag gravel) and are embedded in silt and fine sand, whereas little or no medium nor coarse sand is present. This means a sudden lowering of the current velocity and the beginning of renewed deposition and ripple wandering.

3°. Mostly a current ripple pattern is superimposed on the giant ripple, also in the region of the ellipsoidal troughs, restricted to the siltstone.

4°. The troughs are filled with sediment, thereby smoothing the surface, disturbed by the scour of the ripple base. Deposition of medium and coarse sand and some pebbles.

5°. The grain size distribution per bed, as is indicated in the inset of fig. 13, is from bottom to top as follows (cf. fig. 12):
At the base a few centimetres silt and fine sand. (In a few exposures reaching a thickness of some 10 to 20 centimetres).
The grain size increases gradually upward into fine, medium and coarse sand, and decreases again to medium sand in the upper part of the unit. Positive and negative grading reflecting to an increase and decrease of the current velocity.

6°. The sandstone is laminated and/or thin bedded. Fluctuations in the current velocity.

7°. The inclination of the fore-sets is towards the deeper part of the Molasse basin. Current direction towards the sea.

In fig. 14 a curve is given based on the current velocities derived from the grain size distributions of a giant ripple unit (after Hjullström, 1939). On the vertical axis the current velocities are plotted on a logarithmic scale. The horizontal or time axis is not drawn on scale, because no data are available to estimate the time necessary for the deposition of a bed of a certain thickness. The factor time is varying of course with grain size and supply. Therefore the curve has only a schematic trend; some parts of the diagram may have to be compressed, others may have to be stretched in horizontal sense.

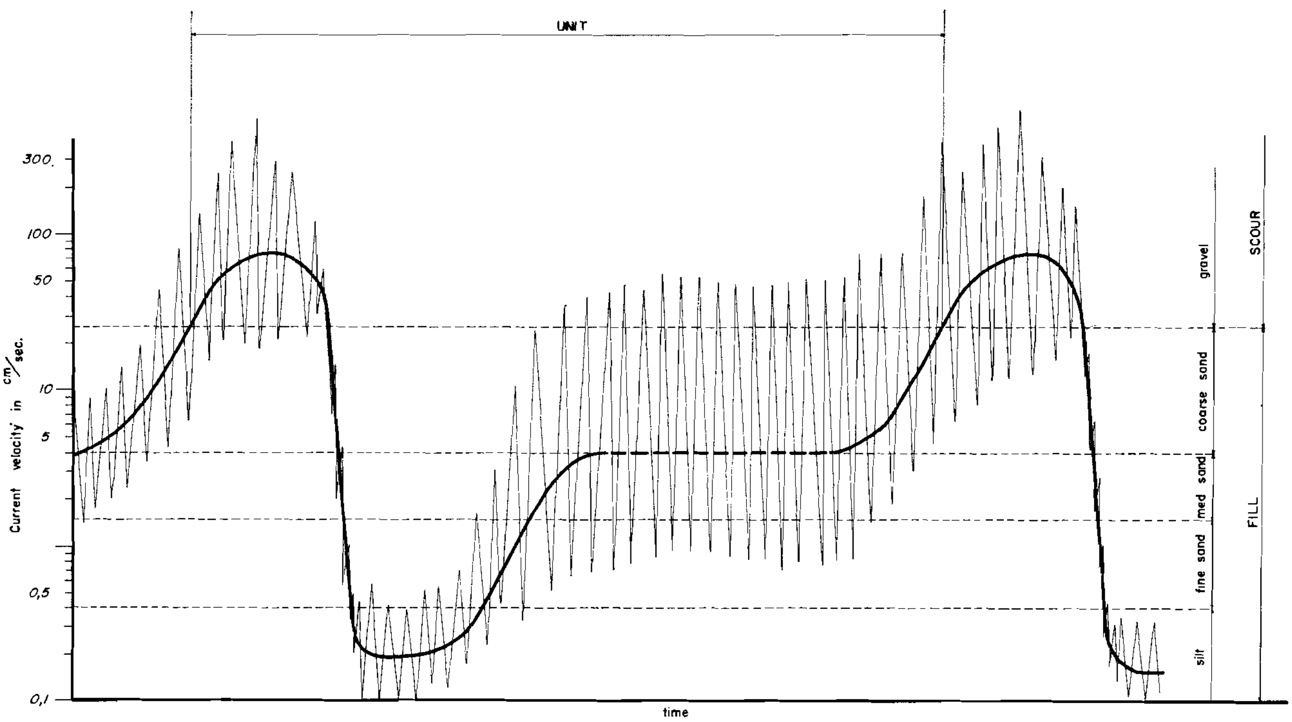

Fig. 14 Sedimentation — time relationship for a giant ripple unit

The mean current velocities are represented by a thick line, whereas the thin line gives a more realistic picture of smaller current variations which are implicated by the lamination and thin bedding.

The peak of maximum velocity was responsible for the scour of the trough and the washing out of all material finer than gravel. A sudden decrease in the current velocity prevented the deposition of medium and coarse sand in the troughs and caused the deposition of silt and fine sand: The lag gravel is bedded in silt and fine sand only.

The current velocities causing silt and fine sand deposition were favourable for the formation of ripple marks.

An increase in the current velocity supplied more and coarser material, fine, medium and coarse sand and some pebbles. The bulk of the unit was formed with fore- and bottom-set beds (cf. § 2).

A further increase in the current velocity ended this sedimentation cycle, a new trough was formed and a new cycle began.

The most likely causes for the suspected periodicity are tides or seasons.

In our opinion the character of the variations in the current velocity is more likely relevant to seasonal changes, causing variations in the quantity of water passing through a river, than to hourly variations in the discharge of a tidal channel. Moreover many authors point to the limited extent of the Molasse basin, with no or only small entrances to ocean basins, which makes it unlikely that tidal influences would be of importance. The question, whether the high current velocities due to wet seasons, occurred once (monsoon) or twice a year cannot be answered. Our knowledge about the paleoclimate is not sufficient to permit such an answer (cf. chapter I, § 2 C).

A discussion on the position of the giant ripples in respect of the other sedimentary structures in the area and a discussion on the environment in which they occur is given in chapter V.

To get an impression about the amount of sediment deposited during the formation of one giant ripple unit, we made a few calculations.

The area of one ripple unit as observed in a vertical section parallel to the current direction is at least 25 m^2. Horizontal, perpendicular to the current of deposition, the ripple layers have an extension of at least 750 m. Per unit thus 750 $\times$ 25 = 18,750 m^3 of sediment was deposited.

Units of overlying layers may have been formed in the same time interval (cf. fig. 8b), so the total discharge of sediments may be multiplied by 2 or even 3 (plate I shows two giant ripple layers overlying each other). A total of some 50,000 or even a 100,000 m^3 per year is not abnormal for sedimentation areas fed by rivers: The annual discharge of the Kander in lake Thun amounts to 373,427 m^3 of sediment. Every year the river Reuss adds some 150,000 m^3 of material to its delta in lake Luzern (Collet, 1925).

CHAPTER III.
THE RUCHMÜHLE QUARRY STRUCTURES

In a quarry near Ruchmühle (fig. 1, location 4) a N - S profile is exposed at the old entrance of the quarry (fig. 15 and photos 7 and 8). In a vertical sense the profile shows several layers in which two structural types can be distinguished.

1°. Mega flaser structure, layers A, C and H.
2°. Giant ripples differing in many aspects from those described in chapter II, layers E and G.

Different structural properties are revealed in layers B, D and F. Layers D and F and perhaps also layer B may be seen as downstream transitions of giant ripples (type 2, cf. § 2).

The geometry of both mega flaser structure and giant ripples is described in § 1 and § 2 respectively. The genesis of the structures is discussed in § 3.

§ 1. *Mega flaser structure*

"Flaser" structure and also "lens" structure are patchy, lenticular bedded deposits of alternating coarser and finer material. Inclined bedding, most distinct in the coarser material reveals the character of ripple structures. If lenses of finer material are embedded in coarser material one speaks of flaser structure (fig. 15, layers A, C and H and photo 7), in the other case when lenses of coarser material are embedded in finer material one speaks of lens structure (Reineck, 1960).

Häntzschel (1936), van Straaten (1954) and Reineck (1958) describe the occurrence of these structures in recent sediments from the tidal flats and within the shallow marine range of the North Sea. Niehoff (1958) among others, describes the occurrence in ancient sediments. A discussion on their origin is given by the Reineck (1960).

The origin of flaser structure and lens structure is due to alternating rapid and slow water movements with their respective deposition of coarser and finer material. The water movement may be current action or wave motion *.

During a certain period, under influence of currents and/or waves coarse material, e.g., sand, is deposited as ripples with their inclined bedding. After some time the water moves more slowly or becomes almost stagnant; now fine material, e.g. silt or clay, is deposited and covers the underlying ripples. Again the water movement becomes rapid; the underlyinng deposits may be partly eroded and a new layer of sandy material with inclined bedding is deposited. Thus the alternately rapid and slow water movement gives rise to a typical patchy deposit.

* Waves propagating against a shore become asymmetric, if the water depth becomes less than half the wave length. Ripples formed under influence of such asymmetric waves, so called "half stationary wave ripples" (Reineck, 1961; Zenkovitch, 1962) show similar characteristics as current ripples.

Both flaser and lens structures are abundant in basins with tidal influences (Reineck, 1960, 1961; van Straaten, 1954). The tidal currents transport debris as sand ripples, whereas during slack water, clay and silt is deposited. The inclination of the fore-sets is unidirectional when the deposit is formed under influence of one tidal movement only (ebb or flood). When both ebb and flood currents have their influence on the deposit, the dip of the fore-sets in a vertical profile shows two opposing directions.

Apart from tidal environments, there are other regions where flaser and lens structures may occur, if only the factors controlling the genesis of the structures are present. The structures are known also in lakes, in shallow marine basins without tidal influences and in rivers (Reineck, 1960). The action of variable winds on waves, differences in river discharge caused by seasonal variations in downpour, shifting of currents and the like may provide the necessary factors for formation.

The descrptions given by the various authors for lens and flaser structures are restricted to ripple structures of ripple mark proportions, As the dimensions of the stuctures in the quarry Ruchmühle belong to mega ripples (0.2 à 0.3 m $< \lambda <$ 3 à 4 m cf. chapter II, § 3), the name "mega flaser structure" is suggested for these deposits.

In fig. 15 layers A, C and H show mega flaser structure. Part of layers A, B and C approximately 230 - 340 cm from the left hand side of fig. 15 is represented in photo 7. Layer A is not complete in the profile because quarrying undermined the section in this spot and the lower part of layer A collapsed into the quarry. This part in connection with underlying deposits could be observed elsewhere in the quarry.

Special attention is drawn to some characteristics of the mega flaser layers of fig. 15.

First of all it should be mentioned that the greater part of the ripple fore-sets is dipping to the S, though opposing dips occur too.

Secondly, layer H lies unconformable upon layer G.

The same goes for layer A. The boundary between A and the underlying parallel bedded quarry stone is formed by a pebble horizon with a thicknes of only one pebble. This horizon is the erosion rest (lag gravel) of a set of giant ripples and is the continuation of giant ripple bases with their troughs, exposed on the ceiling of the quarry (cf. chapter II, § 4 and photos 4 and 5). The pebble horizon has been traced over a distance of 200 m, perpendicular to the mean orientation of the longest axes of the pebbles. The orientation diagrams

Fig. 15 Ruchmühle Quarry

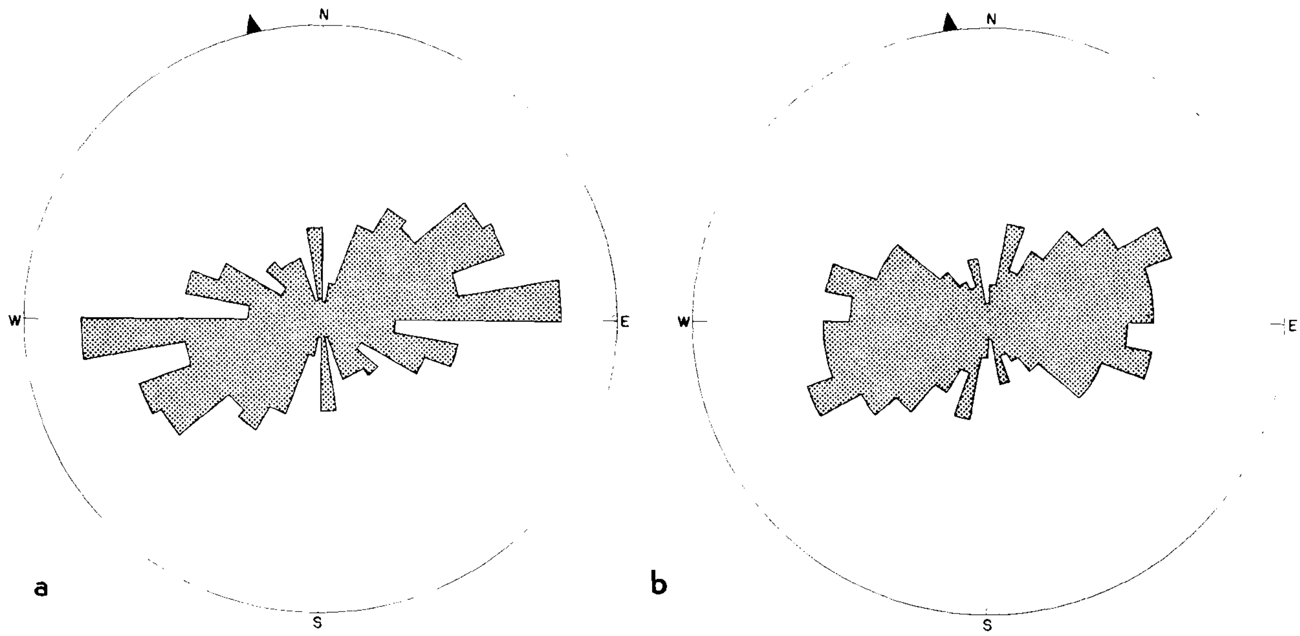

Fig. 16 Orientation diagrams of long axes of pebbles.
Base level of section A, Ruchmühle quarry (c.f. fig.15)

plotted in fig. 16a and b were estimated at two localities lying some 100 m apart. The pebble horizon is situated 3 m underneath the base of layer D.

The grain size analyses of samples of layer C give the following results: (sieve-pipette)

The coarser material

36 %	coarse sand	2000 - 500	microns
46 %	medium sand	500 - 200	microns
14 %	fine sand	200 - 50	microns
4 %	silt	50 - 10	microns

The finer material

3 %	coarse sand	2000 - 500	microns
8 %	medium sand	500 - 200	microns
70 %	fine sand	200 - 50	microns
14 %	silt	50 - 10	microns
5 %	clay	< 10	microns

The size frequency distributions point to fluviatile origin (cf. chapter I, § 4).

Mention should also be made of the dips of the boundary of layers A and C, of the upper boundary of layer H, or layer B and of a great many of the flaser streaks in layers A, the lower part of C and H. These dips are all strikingly parallel, at an angle of some 4° or 5° with the subhorizontal boundaries of layers C and D, of layers D and F (p.p.), of layers G and H and also with the mentioned pebble horizon.

§ 2. *Giant ripples*

In layers E and G of fig. 15 giant ripple units are shown. They differ in many aspects from the giant ripples discussed in chapter II.

1°. The dip of the fore-set beds is towards the S.

2°. Troughs have not been observed at the ripple bases comparable with those described in chapter II. Some slight depressions that hardly affect the underlying layers, are evidence of the weak erosive force of the waves or currents responsible for the deposition.

3°. In one ripple unit one can distinguish a 3 to 4 cm parallel laminated, fine sandy to silty bottom bed overrun by fore-sets of predominantly medium and material. The inclination of the silty bottom beds is unconformable with the inclination of under- and overlying fore-set beds.

The giant ripples as described in this chapter are thought to belong to spits or offshore bars. A photograph and descriptions by Thompson (1937) of spits and bars in California show strikingly similar characteristics. The idea is supported chiefly by the landward dip of the fore-sets and the lack of strong erosive forces at the bottom. Offshore bars are indeed formed under relative quiet conditions by currents or waves propagating towards the coast. If the water movement becomes to turbulent, e.g. by storms, formerly built bars will be destroyed and every trace of them may then be swept away.

§ 3. *Analysis of fig. 15*

Anticipating on chapter V in this section the mutual coherence of mega flaser structures and offshore bars in relation to their genesis is discussed. Attention is drawn to the following observations (fig. 15).

1°. The fore-set beds of layer E pass into the horizontal laminated beds of the upper part of layer D. The lower part of layer D, layer F and perhaps layer B also are thought to be lateral transitions of northward lying giant ripples. The lower 10 cm of layers D and F show wavy lamination.

2°. The mega flaser structure becomes more sandy towards the top.

3°. Streaks with ripple marks are common in the upper zone of C.

4°. The inclination of the flaser streaks in C becomes smaller in the upper zone and more and more parallel with the subhorizontal layer D.

The first observation suggests that, enclosed between the offshore bars and the coast, a bay or lagoon existed in which horizontal parallel bedded deposits accumulated (layers D and F and possibly layer B).

The other observations revealing a vertical transition of layer C into layer D shows that the conditions under which the mega flaser structures developed passed upward into bay or lagoon conditions. In other words the flaser structures developed in deeper water thus farther offshore than the bay or lagoon deposits and probably also on the seaward side of the offshore bars.

The formation of layers C, D, E, F and G is thought to have taken place, chronologically as follows:

Starting with a profle of disequilibrium, representing a marine transgression (the boundary line B C), the formation began with the deposition of material relatively rich in silt content in the shallow offshore zone of a marine basin. (The peri-Alpine depression). The material was supplied in great amounts by rivers. The destruction of formerly built delta deposits by the transgressing sea supplied also large quantities of sediment. (Proof for such destruction is found where layer A lies immediately upon a gravel layer, remnant of a formerly built set of delta giant ripples. cf. § 1). As the accretion continued, the grain size of the material supplied in this part of the basin increased, because the water depth decreased; the finer material being restricted to the deeper parts of the basin only.

Owing to combined wave action and deposition the originally rather steep basin floor (boundary line B C) grew more and more towards a horizontal floor profile (boundary line C D, cf. § 1). Thus layer C with its mega flaser structure and also layer A may be considered as wave-built terrace deposits. The predominant inclination of the fore-sets in layer C towards the S (coast) shows that they are formed under influence of waves propagating towards the coast. The opposing directions of fore-set dips towards the sea may have been caused by rip currents. Somewhere offshore the first bar(s) formed on the wave-built terrace and wandered coastward (cf. chapter II, § 2) thereby barring a bay or lagoon from somewhat rougher conditions prevailing in open sea.

In the bay or lagoon wavy- (ripple mark) and parallel-bedded deposits accumulated. The lower part of layer D (fig. 15, left hand side) shows such deposits. They are overrun by a coastward wandering bar which moved the lagoon or bay also towards the coast. The transition of inclined bedded offshore bar deposits into parallel bedded bay or lagoon deposits can be observed where layer E passes into layer D. Thus layers D, E, F and G formed, E and G representing offshore bars, D and F representing bay or lagoon sediments. Some minor unconformities between layers E and F and between layers F and G reflect minor fluctuations in sea level.

Corresponding to layers A and C, lying in a deeper part of the basin than layers D up to and including F, is layer H with flaser streaks dipping to the N again: The boundary line G H represents a new transgression of the sea, probably because of subsidence of the basin.

Layers A up to H, thus represent the filling of a descended basin, with reworked land derived material.

It seems likely to accept rather sudden subsidences of the basin, as layer A lies immediately upon demolished (delta) giant ripples and both layers A and H show disconformities with underlying deposits. The gradual vertical transitions of flaser structures into offshore bars and bay or lagoon sediments suggest rather quiet tectonic activities while the basin was filled.

The process as described above, resembles very much the development of the Carboniferous cyclothemes (Wanless, 1932).

CHAPTER IV.
OTHER STRUCTURES OBSERVED

In this chapter parallel bedded series and gullies are described to complete the inventory of all sedimentary structures observed in the Sense-Schwarzwasser area. They are dealt with separately because they are common in various milieus and give on their own no further information for the determination of the depositional environment of the Burdigalian in the area.

The parallel bedded series point to relatively quiet conditions, whereas the dimensions of the observed gullies reveal fairly strong erosive forces, which disturbed the profile of equilibrium.

§ 1. *Parallel bedded series*

In the group of parallel bedded structures we distinguished two types, those with and those without wavy patterns. Several transitions exist between the two types and a sharp distinction cannot be made. Some at first sight, homogeneous, parallel bedded series of alternating sand- and siltstones, show after grinding of vertical sections especially in the siltstones wavy lamination due to ripple formation.

The ripple mark horizons occur in various thicknesses. Sometimes they are restricted to one or a few ripple mark layers, sometimes they range in thickness from scores of centimetres up to some metres and are built up of several tens of ripple mark layers.

Mostly the thin ripple mark horizons are embedded in parallel laminated or thin bedded series. Representatives of such horizons are present in the Ruchmühle road exposure in sections 5.20 - 10.00 m, 10.75 - 12.90 m and 14.25 - 18.25 m. (Plate II, fig. 18 and photo 9) and in the Sodbach road exposure in section 13.00 - 19.00 m (Plate III, and fig. 19).

The thick ripple horizons are mostly embedded in mega and/or giant ripple layers. Representatives of this group are found near Sackau (fig. 1, location 5, photos 10 and 11).

To start with the last group, these ripple mark horizons persist horizontally over many hundreds of metres, whilst their thicknesses remain constant. The composition is rather homogeneous. Variations in competency are due to accumulations of plant debris in the ripple mark troughs. Wind, loaded with sandparticles, eroded the softer parts of the deposits, giving rise to the pattern as shown on photo 10. A fresh fracture gives only vague structures owing to the homogeneous composition of the material. Only after polishing of sawed surfaces do the features become visible.

Whether the ripple marks originated from wave or current action could not be determined (cf. chapter III, § 1).

Sieve-pipette analyses gave the following mean composition:

2 %	medium sand	500 - 200 microns
48 %	fine sand	200 - 50 microns
37 %	silt	50 - 10 microns
13 %	clay	< 10 microns

As stated above, the horizons are intercalated in medium to coarse sand layers, showing inclined bedding of undefined character (mega or giant ripple?). The upper contacts of the ripple mark horizons with these sandstones are rather sharp, the lower contacts are gradual and show transitions into the underlying sandstones. The extensive uniform appearance in horizontal sense, points to deposition in an area with uniform conditions prevailing over fair distances. In the coastal zone, such conditions may be expected in lagoons or bays, in the shallow littoral zone, on beaches and also in lakes.

Dorthe (1962) who observed the ripple mark horizons in the Fribourg area, simply calls them "rides de plage" (beach ripples), a statement which in our opinion may be correct, but is not fully justified.

The thin ripple horizons (plate II and III) are as stated above embedded in parallel laminated or thin bedded series. The latter consist of alternating medium, fine sand and silt layers.

A detailed observation of section 10.75 - 12.90 m (fig. 18) reveals sharp upper contacts and gradual lower contacts of the ripple mark horizons.

The lamination and thin bedding of the sandstones are rather distinct in the Ruchmühle sections; they are vague or absent in the Sodbach section.

The section 12.90 m up to 18.25 m of fig. 18 corresponds to the Ruchmühle quarry profile (fig. 15). The section lies some 200 m N of the quarry and starts with flaser structures (layer nr. 7) lying immediately upon a pebble horizon (layer nr. 6). This horizon has been mentioned already in chapter III, § 1 and § 3 (lag gravel).

The parallel bedded series from 14.25 m up to 18.25 m (layer nr. 8) corresponds to the bay or lagoon sediments as exposed in the Ruchmühle quarry. The section is overrun at 18.25 m by giant ripples (layer nr. 9) of fluviatile origin. The top of the giant ripple deposits is formed by a new gravel horizon (layer nr. 10, see also § 3).

The numbers in brackets refer to the layers of the graph fig. 18. An argument for the parallel bedded series having been formed in shallow marine water is given in the next paragraph.

§ 2. *Gullies*

The best exposure of a gully was found N W from Nidermuren (fig. 1, location 10). Fig. 17 presents the W - E profile on the N side of the road. The exposure has been hammered for safety pur-

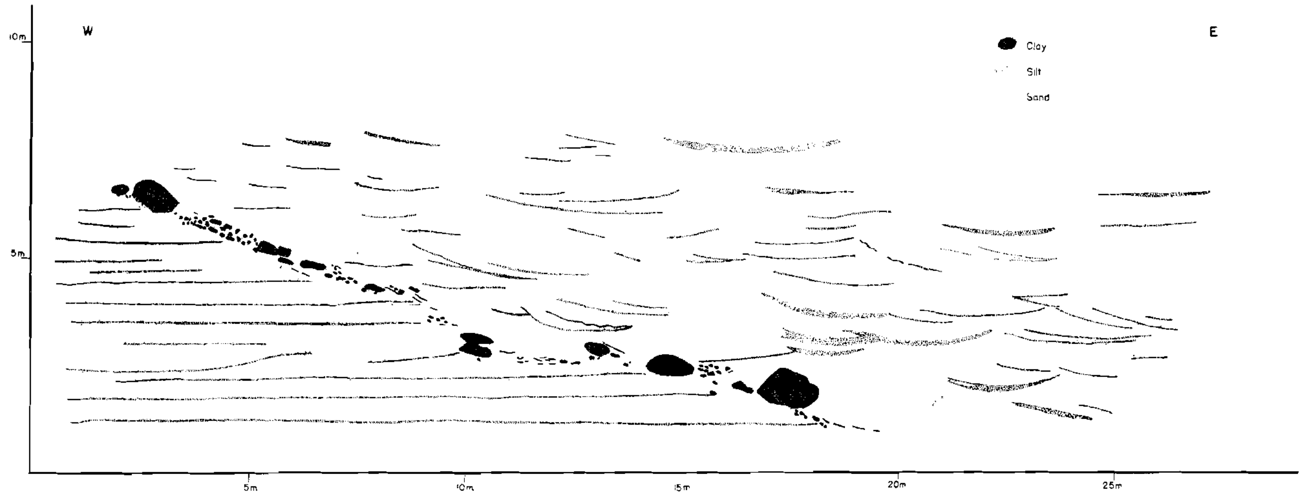

Fig. 17 Gully cutting, parallel bedded series (Fig. 1 loc 10)

poses, to avoid the falling of rock debris. This obscures the structures and prevents a detailed examination. The section reveals only the western bank of a gully, cutting through parallel bedded sandstones, comparable with those from the Sodbach road exposure (cf. plate III, 11.00 - 19.00 m). The depth of the gully is at least 6 metres. The gully base is marked by clay pebbles and clay boulders.

The sediment filling the gully shows irregular giant ripple structures, cut perpendicular to the depositional current (cf. the vertical sections on the right hand side of fig. 9 and on the left hand side of fig. 10).

This shows the relationship between the gullies and the giant ripples as described in chapter II. This reveals also the position of the giant ripples in respect to the other structures and leads to some important conclusions.

The gully is due to the scour of a river branch in its lower course (delta region), having shifted its bedding and cut a new channel, which was filled with sediment showing giant ripple structures. The occurrence of the gully demonstrates that the area in which the river discharged itself must have been a very shallow basin, perhaps even land, otherwise such deep channels could ot have been formed. This leads also to the conclusion that the parallel bedded sandstones of fig. 17 and certainly the layer(s) of which the clay boulders have been derived have been deposited in a shallow part of the basin.

The same feature of giant ripples, cutting parallel bedded series is shown in the Ruchmühle road exposure (the upper left hand part of plate II, 18.30 m). The profile cuts the giant ripple deposits almost parallel to the current of deposition. The incision of the base of the giant ripple series, the gully, is therefore rather flat in this direction.

N.B. Dorthe (1962) gives a great many photos and drawings of gullies which he compares with gullies occurring in the Rhine-Meuse estuary (Haringvliet excavation, The Netherlands). However, the greater part of his "chenaux" (channels, gullies) are simply troughs of giant ripples. Of course they represent a sort of scour and fill structure, but these "gullies" are in no way comparable with gullies as described in this paragraph.

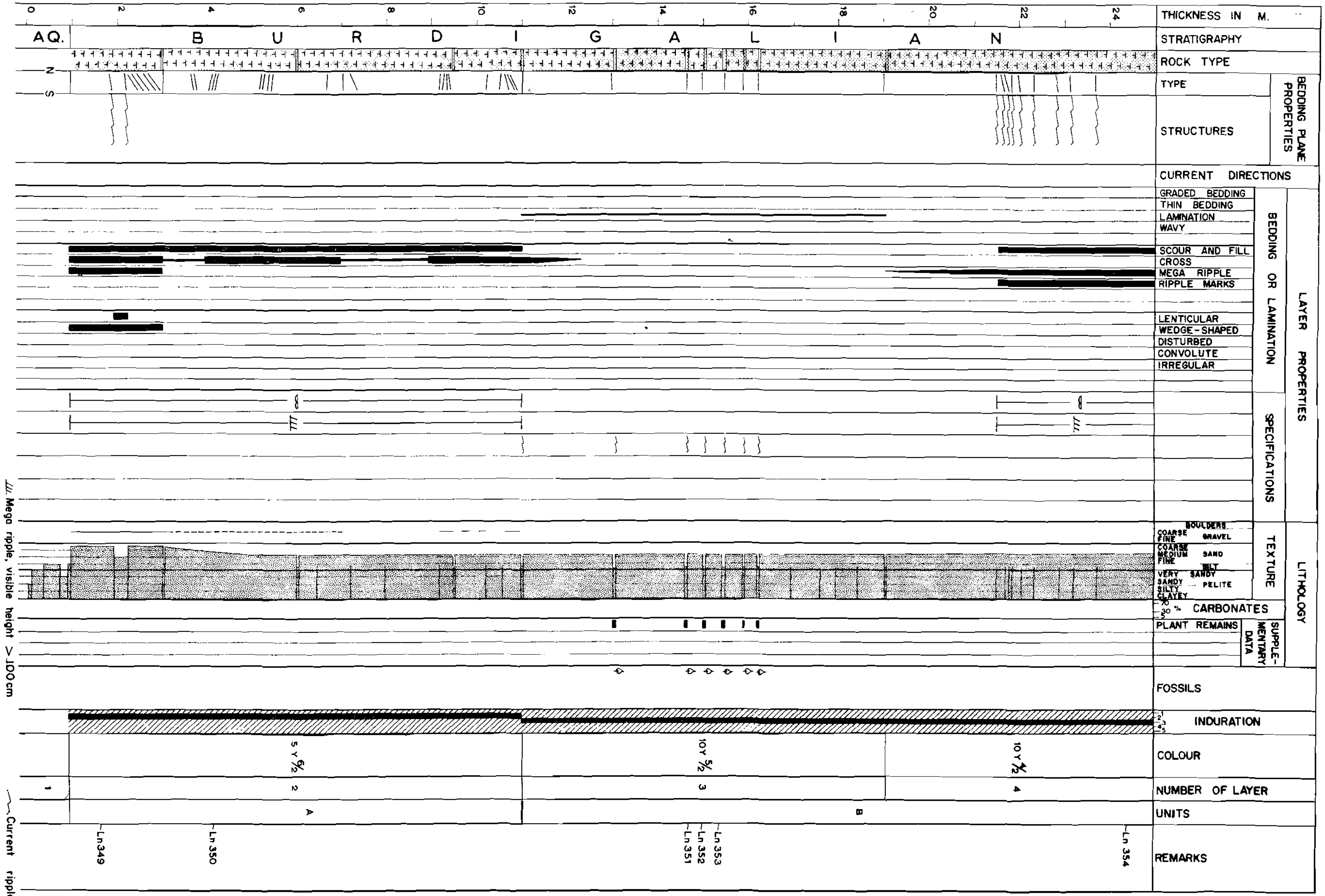

Fig 19 Detailed graphic log of the Sadbach road exposure (c.f. plate III)

Mega ripple, visible height >100 cm
Scour and fill structure, channel, washout; width 1–5 m.
Carbonate
Current ripples

as prevailed in the tertiary Molasse region. The delta deposits of the Swiss Molasse are not comparable with a great many well-known delta systems such as Mississippi, Fraser, Orinoco and Rhone. (c.f. Barrel, 1912; Fisk, 1954, 1961; Johnston, 1922; Mc Kee, 1939; Russell and Russell, 1939; Shepard, 1960 a; v. Straaten, 1957). Important factors, governing the sedimentation circumstances and causing great differences with the mentioned recent deltas, are climate and orogenesis. The observed structures especially the giant ripples may therefore seem to be unique in regard to what we know from recent delta environments.

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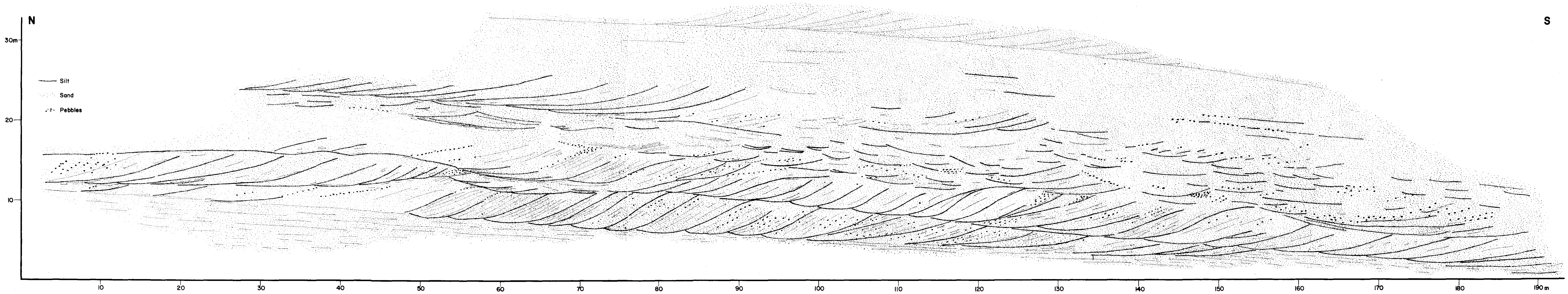

Plate I. N–S profile, on the eastern bank of the Sense river   0 1 2 3 4 5 10 Scale in meters

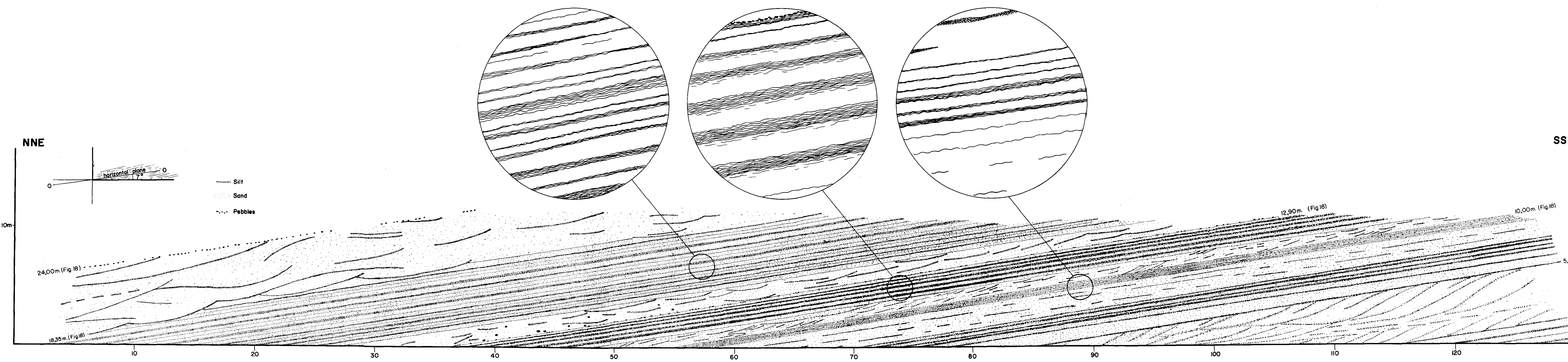

Plate II. NNE – SSW profile, road near Quarry Ruchmühle   0 1 2 3 4 5 10 Scale in meters

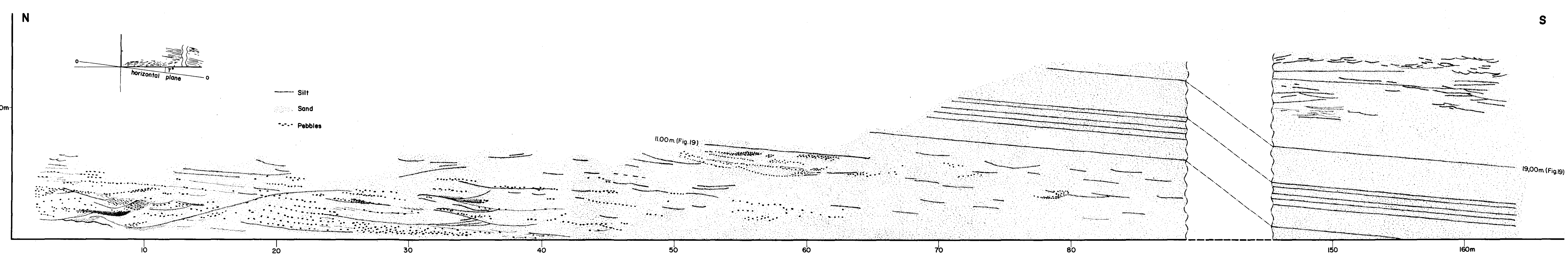

Plate III. N – S profile, road Schwarzenburg to Sense bridge   0 1 2 3 4 5 10 Scale in meters