

THE STRESS SYSTEMS IN MUDFLOWS DURING DEPOSITION, AS REVEALED BY THE FABRIC OF SOME CARBONIFEROUS PEBBLY MUDSTONES IN SPAIN¹

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ABSTRACT

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In the Cantabrian Mountains (northern Spain) the Upper Carboniferous contains various formations with a typically syntectonic character; one of them is the Westphalian Prioro Formation which crops out in the Tejerina Syncline (province of León). This formation mainly consists of fine-grained turbidites (laminites), but intercalations of pebbly mudstones are present.

In 11 exposures the pebble fabric has been determined. In most cases the orientation of 50 pebbles was measured, in two cases this was possible only for 25 pebbles; it appears that these restricted numbers do not influence the overall picture. Another observation is that the orientation of the pebbles is not influenced by the degree of flatness, if the flatness value is 1.25 at least.

The fabrics of the pebbly mudstones are pictured in contour diagrams; it appears that various patterns can be found, but in relative frequencies which are unexpected. The explanation for this phenomenon is that the tail of the mudflow should be considered as built up by a large number of individual small tongues (which behave like separate frontal lobes), moving more or less independently.

INTRODUCTION

Pebbly mudstones form an uncommon type of deposit; the descriptive lithological term is applicable to many glacial tills, but usually is restricted to deposits which have formed by subaqueous mass-flow movements. In most cases pebbly mudstones are intercalated between marine sediments.

Although some remarks about this type of deposit were made already at the end of the 19th century, the genesis of marine pebbly mudstones remained problematic for a long time. A sedimentary origin was still denied by KAISER (1934) in a paper with the enquiring title 'Geröllton?' (= 'Pebbly mudstone?'). It lasted almost 20 years before ACKERMANN (1951) gave the right answer to KAISER's question in his paper 'Geröllton!': pebbly mudstones indeed can have a sedimentary origin.

Now it is generally accepted that most marine pebbly mudstones are the result of mass movements. Arnold HEIM (1908) was the first to mention slumping-like processes, but

his paper received little attention; ACKERMANN (1949) had more result with his idea of submarine disturbances, but especially KUENEN & MIGLIORINI (1950) gave a firm base to mass-movement theories.

CROWELL (1957) noticed that pebbly mudstones occur relatively frequently between deposits formed by the turbidity currents mentioned by KUENEN & MIGLIORINI (1950). He explained this phenomenon by a process of slumping which is due to instability as a result of coarse-grained turbidites being deposited on top of finer-grained autochthonous sediments. DOTT (1963) explained that the type of flow and/or deformation (elastic-plastic-fluid) depends on many more factors, among others the type of sediment and its porosity.

Since the work by CROWELL and DOTT various papers have dealt with specific aspects, e.g. the rare phenomenon of a grading matrix in pebbly mudstones (LINDSAY, 1966; VAN LOON, 1970; DAVIES & WALKER, 1974); this led to a growing understanding of the depositional mechanism, although not all details are yet clear (CROWELL, 1978). Generally one now assumes (see review in ALLEN 1982), that the mud with floating pebbles moves downslope as some kind of frontal lobe, followed by a longer, wider and thinner tail (Fig. 1). An analysis of the fabric in some pebbly mudstones suggests, however, that this picture is incorrect.

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Geological setting

The fabric of various pebbly mudstones has been investigated in the Prioro area (Fig. 2), part of the intramontaneous Prioro-Tejerina Basin in the southern part of the Cantabrian Mountains (province of León, Spain). This basin has been folded both syn- and postsedimentary (HELMIG, 1965; RUPKE, 1965; VAN LOON, 1972) and is filled up with Late Carboniferous deposits. The lowermost rocks belong to the Prioro Formation, which has a Westphalian age (VAN LOON, 1971) as could be proven on the basis of various fossil groups, though the frequent occurrence of washed-in fossils (VAN LOON, 1975) originally yielded many problems in biostratigraphic dating.

The presence of washed-in fossils (both marine fauna and terrestrial plants) is not surprising, because the Prioro Formation mainly consists of fine-grained turbidites (called laminites by LOMBARD, 1963), with intercalated pebbly mudstones. These pebbly mudstones have been investigated for their textural characteristics (VAN LOON, 1980). In this paper the fabric will be dealt with, since it turns out that this characteristic may reveal the movement of the mud flow just before the ultimate deposition.

EXPECTATIONS

Previous investigations (e.g. VAN LOON, 1970) made it clear that in both pebble- and matrix-supported pebbly mudstones the pebbles may show preferred orientations throughout the bed (Fig. 3), or rather a preferred orientation of the a-b plane (cf. CAILLEUX, 1952). In some specific cases this may be due to

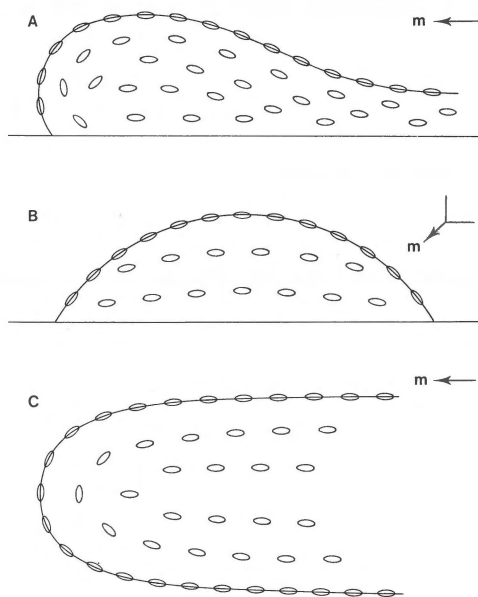


Fig. 1
Simplified model of a mudflow. A: longitudinal section; B: transverse section; C: plane view. Direction of movement (m) indicated by arrow.

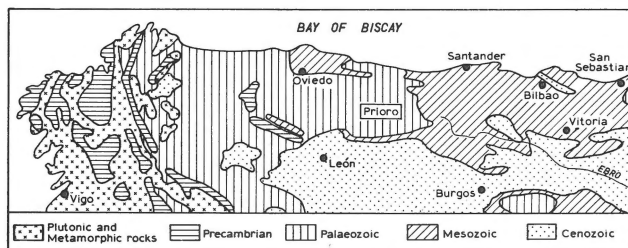


Fig. 2
Location map of the Prioro area in northern Spain.

postsedimentary movements, as shown by the occurrence of pebbly mudstones with a lamination which must be due to a process like shearing. Imbrication of the lowermost pebbles has been mentioned earlier (Photo 2 in VAN LOON, 1970) and has also been observed by others (TH. B. ROEP, Amsterdam University, pers. comm. 1980); a possible explanation for this phenomenon is that just before 'freezing' of the mudflow the transport along the substratum was comparable to pebble

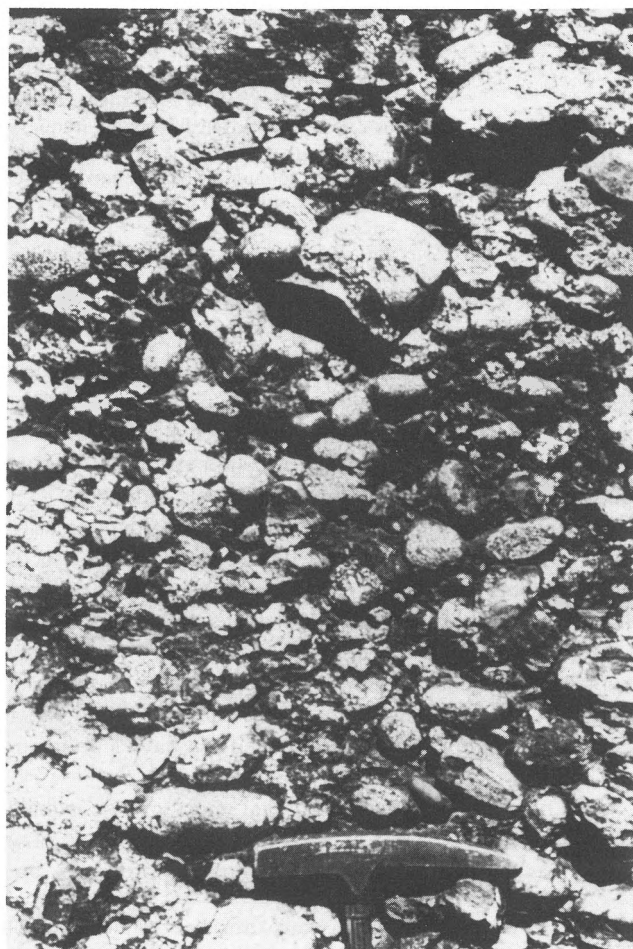


Fig. 3
Characteristic example of a densely-packed pebbly mudstone from the Prioro area. View perpendicular to bedding plane.

transport in a fluvial channel, due to a different flow regime.

Where the pebbles show a preferred orientation in the interior of a pebbly mudstone, it must be assumed that this will be according to the last significant shear stress before freezing (if, of course, no influence of later tectonic pressure is responsible). The local shear stress generally will be parallel to the direction of movement. Because of the rather sudden freezing of the mass flow, it thus can be expected that the fabric in the deposit depends on the flow lines within the mudflow.

The general picture of the flow lines during mass movements is rather well understood. In the first place it is necessary to distinguish between the frontal lobe (which has a relatively limited extent) and the tail (which is thinner but occupies a much larger surface). The frontal lobe may still have the character of a slump, but the ongoing mixing with the overlying water gives the tail much more the character of a real flow. Of course, this is a rough simplification, but it indicates how to reconstruct the possible fabrics.

A main problem, which will be dealt with later on, is the fact that in practice it is impossible to establish the fabric of an entire pebbly mudstone. One depends on the nature of the exposure, which may show a longitudinal, a transverse, or a horizontal section through the sediment, or even (more probably) something in between. Since fabric measurements in practice only are possible at (or just beneath) the exposed rock surface, this implies that it is important to know how in each ideal section the fabric will be. Such data are discussed in detail by ALLEN (1982). For several longitudinal sections this is shown in figure 4, for several transverse sections in figure 5.

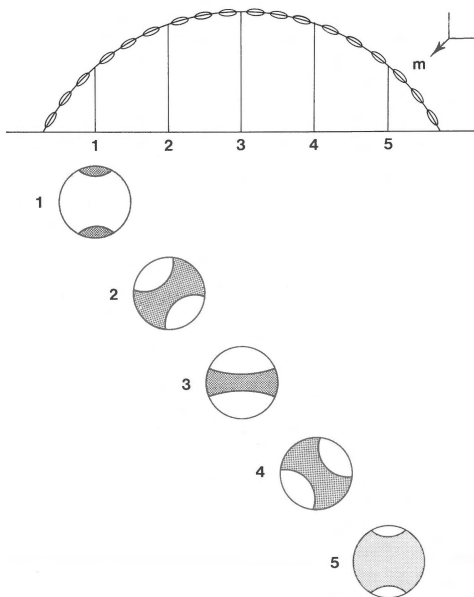


Fig. 4
Longitudinal sections through a pebbly mudstone with corresponding 'ideal' contour diagrams of the fabric.

and for several horizontal sections in figure 6.

In the field the limited dimensions of the exposures and their complicated structure (due to syn- and postsedimentary folding) usually make it impossible to establish exactly what kind of section is exposed, and sometimes even whether it is in

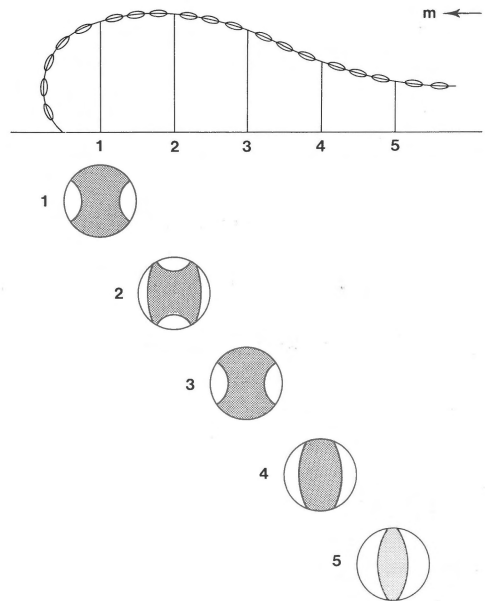


Fig. 5
Transverse sections through a pebbly mudstone with corresponding 'ideal' contour diagrams of the fabric.

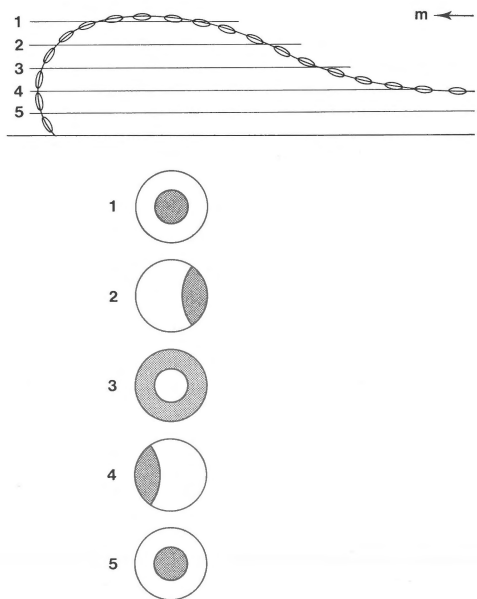


Fig. 6
Horizontal sections through a pebbly mudstone with corresponding 'ideal' contour diagrams of the fabric.

the frontal lobe or in the tail. It may be assumed, however, that there is a more or less random distribution of exposed sections; since tails cover much larger areas than frontal lobes, it therefore may be expected that measured fabrics more often point to a position in a tail than in a frontal lobe.

METHODS AND OBSERVATIONS

An inventory of the pebbly mudstones in the Prioro area has been made in detail earlier (VAN LOON, 1972). All exposures have been re-examined for the possibility of a fabric analysis; most of them appeared unsuitable for one or more of the following reasons:

- (1) too small exposure (less than some 3 m² of uninterrupted rock surface);
- (2) insufficient pebbles (less than 25; a number of 50 has been preferred);
- (3) fabric not measurable because of complete desintegration or deformation of the pebbles (due to tectonic activity);
- (4) matrix too solid to remove the pebbles within acceptable time (although some conglomerates occur which have been deposited by mass flows, only deposits with a real mud matrix have been taken into account);
- (5) unreliable fabric measurement because of insufficient flatness values of the pebbles (the average flatness value was 1.66; in each acceptable exposure at least 2/3 of the pebbles should have a flatness value of 1.50 or more);
- (6) to avoid problems of different behaviour, the pebble characteristics must be comparable (quartzite pebbles with an a-axis of 2.5-25 cm).

These restrictions resulted in only 11 pebbly mudstones (each of less than 2 m thick) which could be investigated. In 9 of them the fabric could be established on the basis of 50 pebble measurements; in 2 exposures that was possible for only 25 pebbles. In this respect it is useful to mention that a fabric picture did not change significantly in any of the 9 former cases, when compared to the first 25 data another 25 measurements were added. Thus it may be concluded that there is no serious reason to consider the two examples with only 25 pebble measurements as insufficiently reliable.

In each of the 11 localities which were selected, the 50 (or 25) pebbles were randomly selected over the entire exposure (never more than a few square metres) for fabric analysis. The apparent dip and dip direction of the a-b plane were measured, and afterwards the pebble was removed from the rock to check whether the supposed a-b plane was interpreted correctly. If this was not the case, the pebble was rejected (usually it crumbled as a result of dense nets of joints) and a next one was chosen.

Afterwards the data were plotted in a contour diagram, corrected for structural tilt. Each contour diagram represents the lower hemisphere, penetrated by the normal to the a-b

plane (being the c-axis). All values are expressed in percentages.

It has been checked whether a random selection of the pebbles is reliable; one could imagine that the most flattened pebbles are best orientated according to the local shear stress and thus give more reliable results. For that purpose in two localities (with abundant pebbles) various measurements were made, viz. for classes with flatness values of 1.0-1.5, 1.5-2.0, 2.0-2.5 and > 2.5. Rather surprisingly the contour diagrams of these separate groups showed only slight differences, which means that they all are in rather good agreement with a contour diagram for randomly selected pebbles. This implies that randomly sampled pebbles give a reliable fabric, since the degree of orientation is not (or hardly) influenced by the flatness value of the pebbles.

Another finding was that no significant differences occur between the pebble- and matrix-supported pebbly mudstones concerning the degree of preferred pebble orientation. This observation is in contradiction with findings by, e.g., MIDDLETON & HAMPTON (1976).

OBSERVATIONS AND INTERPRETATIONS

The 11 fabrics measured do not represent any of the 'ideal' situations mentioned in figures 4-6. This is not surprising, for most of them will not concern an 'ideal' horizontal, transverse or longitudinal section. In fact, most contour diagrams show neither the typically steep positions of pebbles which could be expected in a frontal lobe, nor the completely horizontal position which should prevail in a tail.

In spite of this, it is possible to distinguish between some groups of contour diagrams with comparable configurations. Such similarities might be due to comparable locations within a mudflow.

Circular patterns

Perhaps most interesting are the two examples with a more or less circular pattern in the contour diagram (Fig. 7), indicating that the pebbles have steep dips in various directions. This is a picture that must indicate a position in the front of a rather small mudflow, but one might wonder why horizontal pebbles are so scarce. It means, for instance, that it certainly does not concern an overall section through various lobes.

In the first example (Fig. 7A) one may think of a position at the frontier of two lobes within the frontal part of the flow. This explains the preference of the dipping pebbles for two opposite directions. In the other example, where the circular pattern more or less misses one segment (Fig. 7B), an interpretation is more difficult; possibly the pattern represents a (sub)horizontal section through the central part of a mudflow at the transition between the frontal lobe and the tail.

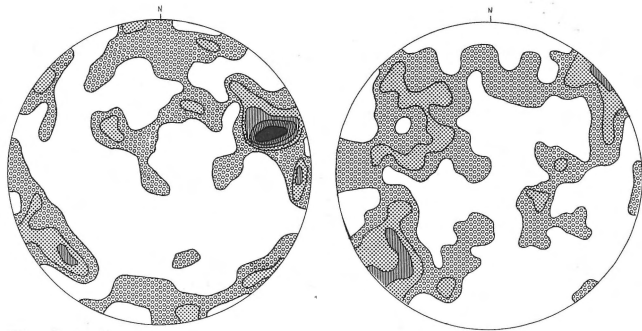


Fig. 7 A, B
Two real contour diagrams, representing a circular pattern. Areas indicate resp. <1% (white), 1-3%, 3-5%, 5-7%, 7-9% and >9% (black).

Centrated patterns

Patterns with a strong concentration in the centre, indicating a horizontal position of the pebbles, occur (Fig. 8), but are rather scarce; from the three examples which can be attributed to this group, even only one (Fig. 8A) is a clear representative. Since this fabric should be regarded as characteristic for the central parts of the tail, it should be much more common. This problem will be dealt with in the conclusions.

Linear patterns

In various sections the fabric may result in linear patterns in the contour diagram (Figs. 4-6), since such a configuration only means that the value of the dip is the prime parameter. Such finds (Fig. 9) may be the result of sampling along, for instance, a longitudinal axis of the pebbly mudstone, especially in its central part. Quite another possibility, however, is a transverse section in a part where the mudflow was relatively narrow.

It cannot be concluded from the figures whether these or other possibilities are the most likely.

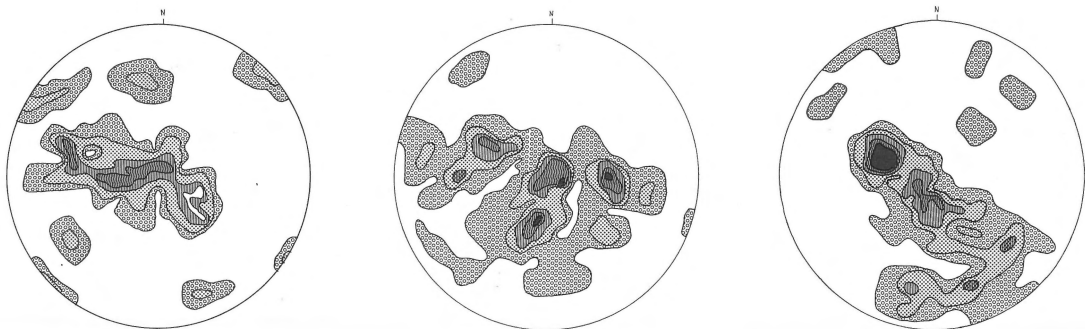


Fig. 8 A, B, C
Three real contour diagrams with centred pattern.

Curved patterns

Most contour diagrams show a picture with a considerable amount of rather horizontally lying pebbles, combined with a number of dipping specimens (Fig. 10). This situation is characteristic for the margins of the tails, although in the frontal lobe similar fabrics may occur; there, however, they are much rarer.

CONCLUSIONS

The frequency of the various fabric patterns, as found in the contour diagrams (with relatively few examples which are characteristic for the large central part of the tail), is different from what is expected. There are a few possible explanations for this discrepancy:

- (1) The measurements were carried out in non-random circumstances. There is no field evidence, however, that during sampling the tails were under-represented.
- (2) The tails in mudflows are much smaller than the frontal lobes, favouring sampling in the lobes and along the tail margins. This hypothesis seems, however, in contradiction with both field evidence and experiments.
- (3) The shear stress in the tails, responsible for the fabric, is different from what was expected.

It seems most reasonable to follow the last-mentioned explanation. Since most diagrams reveal a pattern which can be described as a mixture of frontal lobe, central tail and tail margin, we suppose that the tail (which in our opinion indeed is much larger than the frontal lobe) during mass flow is subdivided into a large number of smaller tongues, each of which partly behaves like a relatively flat frontal lobe, followed by a small tail. This explanation is the more probable, since it is well known that in other types of mass movements comparable internal subdivisions into small tongues occur; a distinct example is provided by subaerial slumping.

The numerous small tongues in the tail frequently mix up

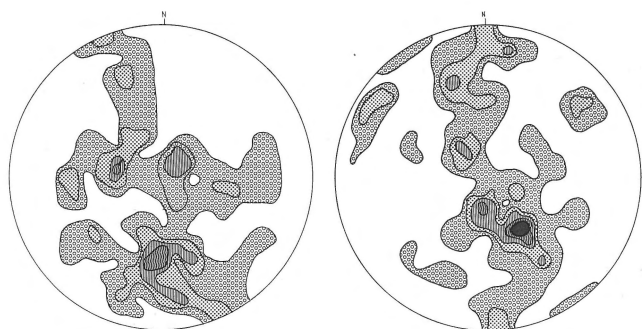


Fig. 9 A, B
Two real contour diagrams, attributable to the group with linear patterns.

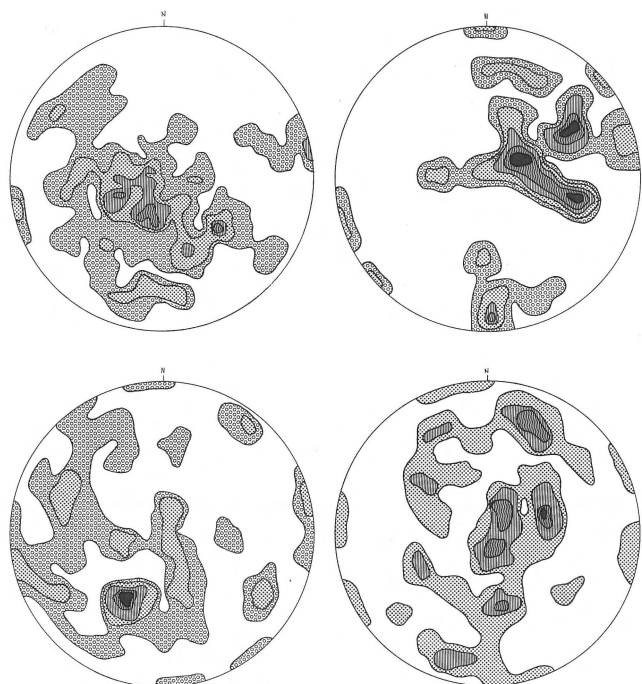


Fig. 10 A, B (above), C, D (below)
Four real contour diagrams with curved patterns.

and separate again during the flow of the mud mass; therefore there is no continuous existence of the separate tongues. Since, however, at each specific moment such separate units exist, this explains the otherwise hardly understandable fact that in one single pebbly mudstone both structureless (completely liquefied) and laminated (plastically deformed) parts can be found: in each tongue a different flow condition may prevail. This also explains why at the base of a pebbly mudstone imbricated pebbles can be found (indicative of a 'normal' transport), while higher in the same deposit floating pebbles occur embedded in a mud matrix.

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