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GRADING OF MATRIX AND PEBBLE CHARACTERISTICS IN SYNTECTONIC PEBBLY MUDSTONES AND ASSOCIATED CONGLOMERATES, WITH EXAMPLES FROM THE CARBONIFEROUS OF NORTHERN SPAIN

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ABSTRACT

Pebbly mudstones are known from many syntectonic sediments. Since particles of clay size can only be deposited in very quiet water, in which pebbles cannot be transported, the occurrence of pebbles and a clayey matrix proves that such sediments must have been transported by mass movement. If the matrix of the pebble-containing sediment consists of sand grains, the sediment could have been deposited grain after grain. But here too it may have been transported by mass movement, which can sometimes be proved if the matrix grades from sand to silt or even clay size.

Three examples from the Upper Carboniferous of the Cantabrian Mountains (N. Spain) are described. Attention has been paid to the characteristics of the pebbles, from which the mechanism of deposition can be reconstructed.

INTRODUCTION

During recent decades many investigations on pebbly mudstones have been published (e.g. Ackermann, 1949, 1951; Crowell, 1957; Dott, 1963), all of which led the authors to conclude that these sediments must have been transported by mass movement.

In the same sequences in which pebbly mudstones occur, conglomerates are also sometimes found. Although the criteria that pebbles floating in a sandstone matrix indicate a marine environment and that pebbles touching one another in a sandstone matrix indicate a fluviatile environment, have already been abandoned, the possibility of a transport by mass movement of these conglomerates has not or rarely been envisaged. With this possibility in mind, the author investigated some graded sediments of the Upper Carboniferous Yuso Group (Westphalian) in a region in the southern part of the Cantabrian Mountains in the northwestern part of the province of León (Spain).

Attention was paid to the shapes of the pebbles. The roundness and flatness of pebbles from 2 to 20 cm were measured according to Cailleux (1952) (Fig. 1). In the description, boulders, cobbles, and pebbles will all be designated as "pebbles". For practical reasons the symmetry of the pebbles rather than the asymmetry, as proposed by Cailleux, was measured. It proved to be hardly impossible to hold a little pebble at the part BC (Fig. 1) for measuring the part AC.

Graded sediments containing pebbles were found in two areas. Example 1 is from the vicinity of Prioro, a village in the centre of one of the two basins, containing Yuso deposits, partly lying south of the Léon line, which forms a fundamental zone of weakness (Rupke, 1965) (Fig. 2). The sediments have a Westphalian age, probably uppermost Westphalian B or lowermost Westphalian C, as demonstrated by the occurrence of the fusulinid *Schubertella subkingi* Putrya (van Ginkel, 1965) and the leaves of *Linopteris obliqua* Bunbury. The second example is from the Curavacas conglomerate in the surroundings of Portilla de la Reina (Fig. 2). This Curavacas conglomerate follows upon an unconformity marking the Sudetic folding phase, locally known as the Curavacas phase (Kanis, 1956). These sediments could not be dated due to absence of

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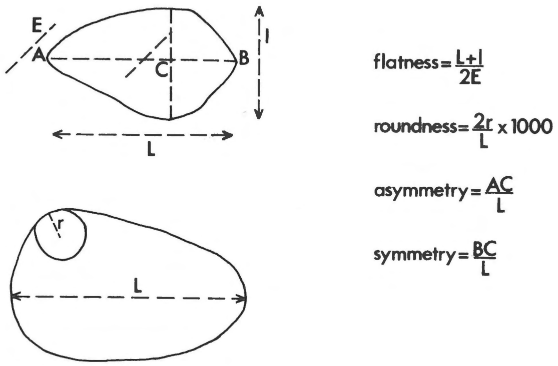


Fig. 1
Pebble characteristics (after Cailleux, 1952).

fossils. The third example is again from the vicinity of Prioro, from about the same stratigraphic level as example 1. Possibly, these sediments can be correlated with the Curavacas conglomerate of Portilla de la Reina. It is known that the influence of the Curavacas phase, which is strong in the eastern part of the Cantabrian Mountains (K a n i s, 1956; K o o p m a n s, 1962; v a n V e e n, 1965; S a v a g e, 1967), diminishes further to the W, until it disappears totally (S j e r p, 1966; E v e r s, 1967). The Prioro region may be considered as intermediate.

STRATIGRAPHY

The stratigraphy in the two investigated areas is distinctly different, and the areas will therefore be treated separately.

A. *The Prioro Region.*

Figure 3 shows a simplified stratigraphic column. The investigated part of the Yuso Group starts with almost exclusively structureless mudstones, but some sandstones and pebbly mudstones also occur. Because of the sharp and flat lower bedding planes, the laterally unchanging character, and the occasional grading, sometimes followed by a parallel lamination, these sandstones can be considered as turbidites, mainly a- and ab-turbidites (B o u m a, 1962). Although there are very few fossils in this sequence, the occurence of the tender leaves of *Linopteris obliqua* Bunbury indicates an environment not very far removed from the coast, which is in accordance with the presence of ab-turbidites and pebbly mudstones. The fauna (some brachiopods, gastropods, pelecypods, and fusulinids) indicate a shallow marine environment, but all these fossils are reworked. Sedimentological indications for a shallow environment are not present.

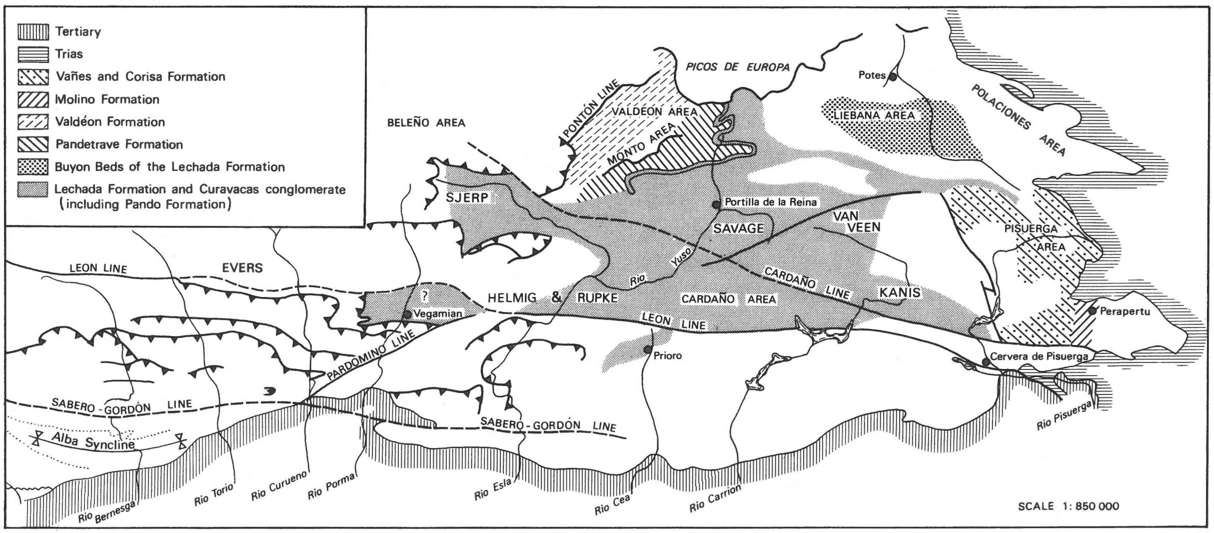


Fig. 2
Distribution of Formations of the Yuso Group (modified after Boschma & van Staalduinen, 1968), with names of previous authors.

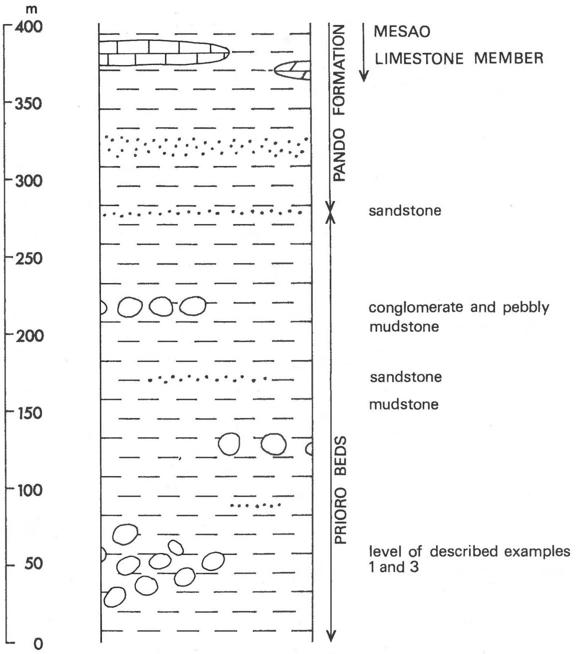


Fig. 3
Simplified stratigraphic column of the Prioro region. The name "Prioro Beds" has been maintained according to Van Ginkel (1965).

B. *The Portilla de la Reina Region.*

Fig. 4 shows the stratigraphic column made by Savage (1967), who investigated this region. Both the Ruesga Group (Namurien) and the Yuso Group (Westphalian) are almost totally built up of mass-transported mudstones and conglomerates. Fossils have not been found, probably because the environment was unfavourable due to the very rapid sedimentation.

REVIEW OF THE LITERATURE

Since the sequence in the surroundings of Prioro can probably be correlated with the Curavacas conglomerate near Portilla, it may be useful to compare the sequences in these two areas with those more to the E.

Arranged roughly from E to W (Fig. 2), previous authors offer the following descriptions.

A. Kanis (1956) introduced the Curavacas tectonic phase in his study of the Sierra del Brezo area (Palencia). About the Curavacas conglomerate he says (p. 405-406):

"... one can observe:
1. poor sorting,
2. size distribution varying from fine-grained to boulders of 50 cm in diameter, but a diameter of 5-15 cm being most common,
3. incomplete rounding of the orthoquartzite boulders.
4. a sand matrix, through which the boulders do not touch each other.

Considering these characteristics, we must consider this to be a fluviatile, orogenic conglomerate (cf. Pettijon, 1949, p. 209). The presence of shales with plant remains intercalated in the conglomerate also proves the terrestrial character of this formation."

B. Koopmans (1957), in a study on the area of the Valsurvio Dome (León and Palencia), mentions (p. 161):
"... the conglomerates ... show evidences of having been formed by mudflows. The rock is composed of dispersed pebbles in a mudstone matrix. The quartzite pebbles and cobbles, well rounded, are 8-20 cm

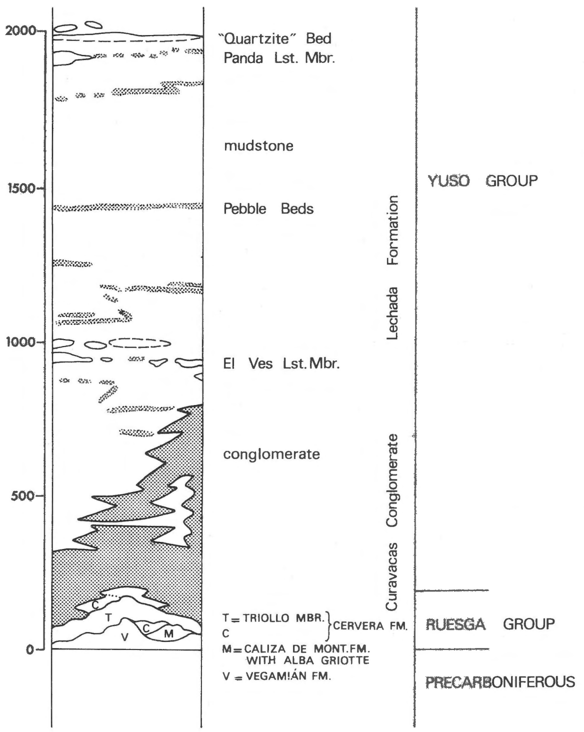


Fig. 4
Generalized lithostratigraphic column of the Portilla region (after Savage, 1966).

large and have an elongate shape. They show a preferred orientation of their longest axes in the current direction. The pebbles do not touch each other. Higher in the sequence, the amount of quartzite pebbles decreases, whereas the amount of limestone fragments increases. These limestone fragments are subangular and tabular in shape and vary in size from 5-30 cm. They show an imbricate arrangement which agrees with the flow direction found from the orientation of the pebbles. The packing is more compact, the pebbles and fragments often touch each other and are badly sorted. The matrix becomes more sandy."

Koopmans concludes (p. 178):
"The characteristics of the conglomerates point to a fluviatile origin. . . . Southwards, . . . they grade laterally into a thick sequence of shales, mudstones, pebbly mudstones and thin conglomerate beds. . . . These conditions can occur on a seacoast, near steep cliffs. The occurrence of crinoid fragments gives an indication of a marine environment."

C. van Veen (1965) studied the Cardaño area (León and Palencia), in which the Curavacas Mountain lies. He says (p. 68):
"The Curavacas conglomerate in the present area consists of a thick sequence of rather well rounded but badly sorted pebbles, cobbles and boulders of quartzites. The highly argillaceous sandy matrix (graywacke type) is often very abundantly represented. Lateral and vertical variations are characteristics of this formation."

D. Savage (1967), in his study on the Portilla de la Reina region, states (p. 197):
"Lenses of greywacke and even shale may occur completely enclosed within the conglomerates, while similar masses may widen out to tongues of the Lechada Formation. It is in fact remarkable how little variation there is to be seen in the lithology of the Curavacas conglomerate throughout its extent despite the rapid changes of thickness.

There is now no question but that these rocks in the western part of the basin have been deposited by a high density mud flow mechanism as demonstrated so clearly by exposures of some isolated lenses."

According to these authors, the character of the Curavacas conglomerate seems to change from fluviatile in the E to deposition by high density flow mechanisms in a marine environment in the W near Portilla de la Reina.

DESCRIPTION OF THE GRADED UNITS

A. *Description of example 1.*

This unit crops out (near a house) some hundreds of meters N of Prioro, in the wall of an irrigation channel. Fossils have not been found here, but the lithology is in accordance with the Westphalian sediments of dated beds in the surroundings.

The sequence here starts with tectonically strongly disturbed mud stones with a few sandstone layers, most probably to be considered as turbidites for the reasons described above. Then follows a 7 to 20 m thick conglomerate. Because of the erosive base, changing thickness and rapid wedging out, this conglomerate, being a disturbed mixture of real conglomerates and pebbly mudstones, must be considered as a channel fill. Other mudstone beds follow, with some conglomerates and pebbly mudstones which become rarer toward the top of the sequence. One of the first ones of these clonglomerates is the graded unit we will describe here. It can be divided into three parts lacking sharp boundaries:

a. The lowermost part consists of 80 cm of pebbles in a non-graded matrix of coarse sandstone;
b. The middle part measures 90 cm, the matrix grading from coarse sandstone into fine sandstone;
c. The uppermost part consists of 80 cm in which the matrix grades from fine sandstone into mudstone.

a. This lowermost part lies with a distinctly erosive base upon a pebbly mudstone in which the pebbles disappear toward the top. The non-graded matrix of part a (all the material between the pebbles is here considered as matrix) consists mainly of angular quartz grains up to ± 1200 mu, but some silt and clay are also present. In some places quartz grains are more concentrated, and form quartzitic patches.

The pebbles of grey quartzite touch each other, and have their longest axes parallel to the bedding plane. The maximum length of the longest axis here is 21.0 cm, but for most of the pebbles this value is 4 to 8 cm. Neither the average pebble size nor the maximum size diminish toward the top. Almost all the pebbles are subrounded to rounded, but a few are angular and subangular.

b. In the middle part the grain size of the matrix grades from coarse sandstone to fine sandstone, but some clay and silt are present. Upward the pebbles become less closely packed, until at the top of this part they even do not touch each other. They still lie with their longest axes in the bedding plane. The maximum as well as the average pebble size diminish towards the top, the maximum from 20 to 7 cm, the average from about 7 to about 5 cm. The pebbles range from angular to well rounded, most of them being rounded.

c. In the upper part the matrix grades from very fine sandstone to a mudstone consisting of silt with some clay, although it also contains very fine sand grains.

In the first 35 cm of this upper part the pebbles show no grading, the uppermost pebble still having a longest axis of 6 cm, but the pebbles begin to become scarcer. In contrast to parts a and b, the longest axes are no longer parallel to the bedding plane but have random directions. The pebbles are subangular to rounded; only a few are angular.

The next 45 cm consists of structureless mudstone without pebbles. Another, non-graded, pebbly mudstone follows upon this upper part.

All these pebbles consist of white and grey quartzites with grey weathering colours. Because of this weathering they are often very strongly crumbled, which makes it difficult to isolate them for measuring. They are most probably derived from the Ordovician Barrios quartzite, as indicated by the frequent presence of the mineral phengite (O e l e, 1964), and from the Devonian quartzites.

In order to find out, whether the characteristics of the pebbles (flatness, roundness, and symmetry) are dependent on the location of the pebble in the grading unit, these characteristics were measured for 25 pebbles each, from parts a, b, and c. The characteristics are shown in Tables 1, 2, and 3. Flatness was calculated to 1 decimal place, symmetry to 2 decimal places, and roundness without decimals. This appeared to be sufficient.

B. *Description of example 2.*

This unit (photo 1), located some hundreds of metres north of Portilla de la Reina along the road to the Puerto de San Glorio, forms part of the Curavacas conglomerate, which is very thick here. The unit can be divided into four parts:

a. About 800 cm conglomerate with a sandstone lens;

TABLE 1
Characteristics of 25 pebbles in part a of example 1.

Nr.	L in mm	l in mm	E in mm	r in mm	BC in mm	Flatness	Symmetry	Roundness
1.	155	118	100	30	68	1,6	0,44	387
2.	121	95	71	28	45	1,5	0,37	462
3.	111	99	70	30	40	1,5	0,36	540
4.	110	85	67	20	48	1,4	0,43	363
5.	106	95	51	27	45	1,9	0,42	509
6.	87	56	38	18	31	1,8	0,35	413
7.	79	60	40	20	35	1,7	0,44	506
8.	77	50	36	14	22	1,9	0,28	363
9.	70	64	45	18	28	1,4	0,40	514
10.	69	48	35	10	31	1,7	0,44	898
11.	61	45	35	15	30	1,5	0,49	491
12.	60	55	35	18	28	1,6	0,46	600
13.	59	52	35	20	26	1,6	0,44	677
14.	58	48	38	18	25	1,3	0,41	620
15.	57	30	26	5	25	1,6	0,43	175
16.	55	40	26	10	22	1,8	0,40	363
17.	52	51	41	12	8	1,3	0,15	461
18.	45	32	22	10	15	1,6	0,33	444
19.	44	34	24	10	12	1,6	0,27	454
20.	43	35	29	10	15	1,5	0,34	465
21.	41	36	29	12	13	1,3	0,31	585
22.	24	21	19	7	9	1,1	0,37	583
23.	39	31	28	10	13	1,4	0,33	512
24.	24	17	15	4	11	1,3	0,45	333
25.	22	18	10	7	11	2,0	0,50	636

TABLE 2
Characteristics of 25 pebbles in part b of example 1.

Nr.	L in mm	l in mm	E in mm	r in mm	BC in mm	Flatness	Symmetry	Roundness
1.	155	110	70	45	75	1,8	0,48	580
2.	140	99	55	35	70	2,1	0,50	500
3.	92	62	59	15	36	1,3	0,39	326
4.	90	78	54	17	34	1,5	0,37	377
5.	90	58	35	37	33	2,1	0,36	822
6.	70	39	25	10	27	2,1	0,38	285
7.	66	56	37	25	30	1,6	0,45	757
8.	66	45	33	12	24	1,6	0,36	363
9.	66	40	36	12	29	1,4	0,43	363
10.	61	54	42	15	22	1,3	0,36	491
11.	59	38	26	15	27	1,4	0,45	508
12.	57	48	37	15	12	1,4	0,42	526
13.	48	42	31	12	19	1,4	0,39	500
14.	43	29	19	12	20	1,6	0,46	558
15.	42	38	23	15	17	1,7	0,40	716
16.	42	29	20	12	20	1,7	0,47	571
17.	40	34	24	15	17	1,5	0,42	750
18.	40	34	24	14	16	1,5	0,40	700
19.	36	24	16	10	16	1,8	0,44	555
20.	33	27	20	12	14	1,5	0,42	727
21.	33	25	16	10	15	1,8	0,45	606
22.	32	20	17	5	9	1,5	0,28	311
23.	28	24	22	7	13	1,1	0,46	500
24.	27	18	18	3	11	1,2	0,40	555
25.	23	23	11	11	11	2,1	0,47	956

TABLE 3
Characteristics of 25 pebbles in part c of example 1.

Nr.	L in mm	l in mm	E in mm	r in mm	BC in mm	Flatness	Symmetry	Roundness
1.	80	55	33	24	37	2,0	0,46	600
2.	73	40	35	15	18	1,6	0,24	410
3.	71	47	38	20	22	1,5	0,30	563
4.	66	51	40	22	28	1,4	0,42	666
5.	64	36	35	15	29	1,4	0,45	468
6.	62	50	36	18	22	1,5	0,35	580
7.	58	47	31	12	27	1,6	0,46	413
8.	58	31	30	8	25	1,4	0,41	274
9.	52	36	25	13	23	1,7	0,44	500
10.	46	37	26	16	22	1,9	0,47	695
11.	45	37	17	13	21	1,5	0,46	577
12.	44	33	24	15	22	1,6	0,50	681
13.	43	36	31	17	15	1,2	0,34	790
14.	42	25	20	4	19	1,6	0,45	190
15.	39	39	29	12	18	1,1	0,46	615
16.	39	27	19	10	19	1,6	0,48	510
17.	37	29	21	11	17	1,5	0,45	594
18.	35	28	21	11	14	1,5	0,40	628
19.	35	26	23	9	14	1,3	0,40	514
20.	32	27	22	3	13	1,3	0,40	187
21.	31	27	19	11	12	1,5	0,38	709
22.	30	25	19	5	12	1,4	0,40	333
23.	30	18	13	7	13	1,8	0,43	466
24.	27	17	14	6	9	1,5	0,33	444
25.	26	18	14	6	12	1,5	0,46	461

b. About 110 cm pebbly mudstone with pebbles that touch each other;
c. About 350 cm pebbly mudstone with floating pebbles, becoming scarcer towards the top;
d. The uppermost part consisting of about 360 cm mudstone without pebbles.

a. This lower part starts with 160 cm of conglomerate with a matrix of grains up to about 1500 mu. In a few places some silt has also been found. The pebbles touch each other. The longest axes lie in all directions but more often parallel to the bedding plane than in other directions. This parallelism, however, is not very pronounced. The pebbles are angular to well rounded, most of them angular to subrounded. The maximum pebble size, like the matrix, shows no grading toward the top of these 160 cm, but the average pebble size diminishes upwards.

On an irregular plane, these 160 cm are overlain by a coarse sandstone bank of 90 cm consisting of two separate layers. This bank wedges out within 6 m laterally due to the appearance of pebbles. The upper boundary of the sandstone bank is sharp, also due to the sudden appearance of pebbles. Where the sandstone bank wedges out, the lower 160 cm of this part a is followed by another conglomerate without a bedding plane. For these reasons the sandstone bank could possibly be an olistolith.

The conglomerate overlying the sandstone bank is about 550 cm thick and contains angular to well rounded pebbles. These pebbles lie, not very conspicuously, with their longest axes parallel to the bedding plane and, although their maximum size (30 cm) shows no grading, their average size decreases upwards. The matrix is not graded. Via a gradual transition part a passes into part b.

b. In the second part the matrix grades from coarse sandstone to siltstone. Here, the pebbles, which are subangular to rounded, lie more distinctly with their longest axes in the bedding plane. The size of the pebbles (maximum longest axis 22 cm) does not show any grading. The transition to part c is gradual.

c. In the next 350 cm the pebbles do not touch each other and become scarcer toward the top. Their longest axes seem to be parallel to the bedding plane, but because of their roundness and low numbers this is difficult to confirm.

The maximum pebble size shows no grading, but the average size diminishes. The maximum longest axis is 24 cm. The pebbles in part c are subangular to rounded, most of them subangular to subrounded. Because the pebbles become scarcer toward the top, the transition to part d is gradual.

d. Most of the matrix in this upper part is still of the silt fraction. Some clay is also found. Pebbles are no longer present here.

The characteristics of the pebbles in this graded unit are obtainable from the author. The pebbles are almost all quartzites. They show bright white, pink, or blueish-green colours. In smaller quantities sandstone pebbles also occur; these are almost always more flattened than the quartzite pebbles. This is most probably due to erosion of thin sandstone layers. The source of the pebbles in this unit has not been traced.

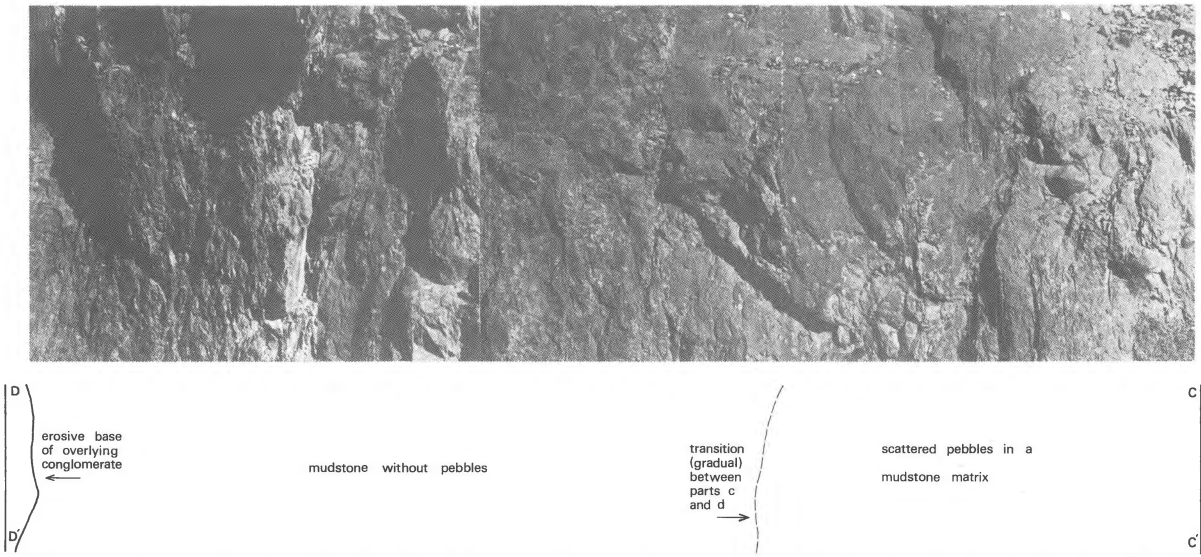
C. *Description of example 3.*

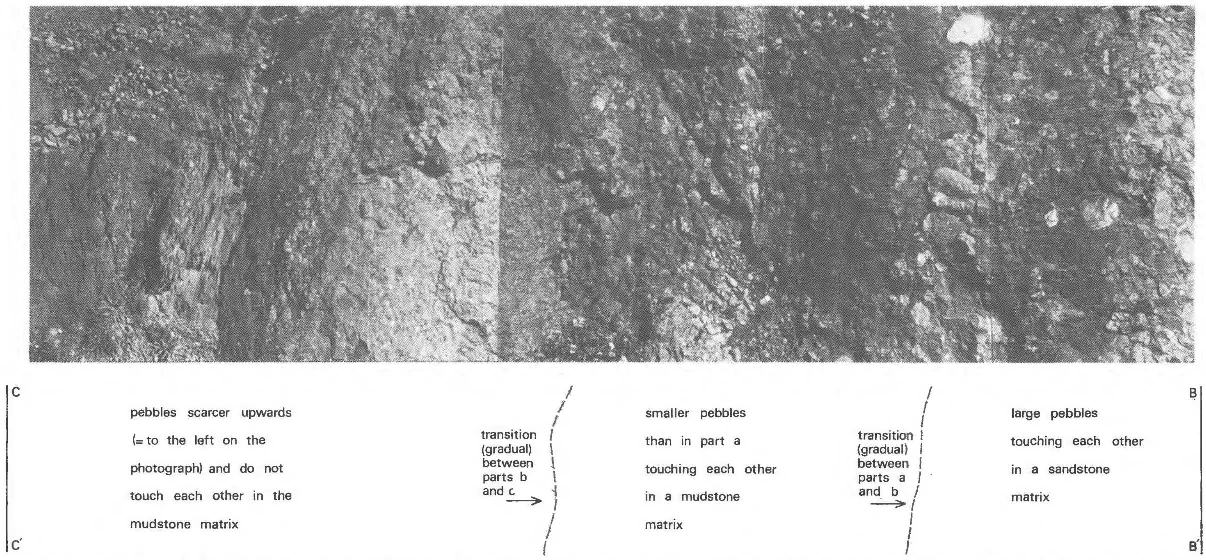
The locality of this unit is in the valley NW of Prioro. Its stratigraphic position is difficult to determine, because the unit occurs in the middle of a barren sequence of some hundreds of metres, but it is somewhere in the Westphalian, probably Westphalian C.

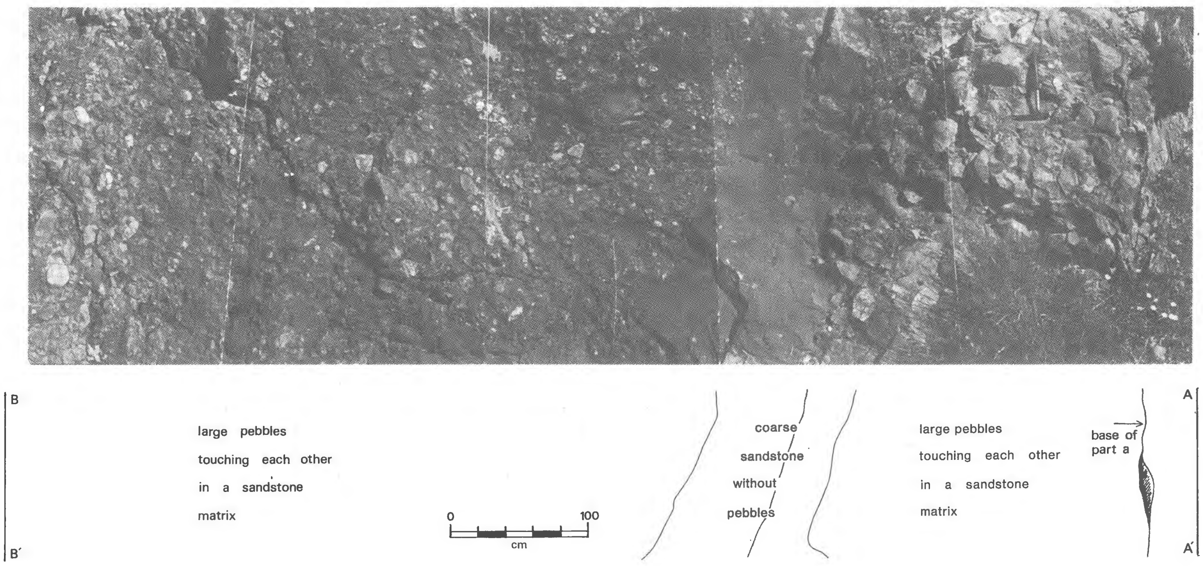
The unit forms part of a sequence of mainly mudstones, probably deposited by mudflows, as suggested by their chaotic character and by the frequent occurrence of quartzite pebbles. These mudstones sometimes alternate with sandstones that can be considered as a- and ab-turbidites, as described by B o u m a (1962), for the reasons given above. Sometimes at the top of these sandstones there is a mudstone layer which could belong to the e-division ("division" is preferable to "interval", used by Bouma; see W a l k e r, 1963). Fossils have not been found.

The graded unit can be divided into two parts:
a. The lower part of 375 cm, in which in matrix consists almost entirely of sandstone;
b. The upper part of 75 cm, in which the matrix grades from sandstone into mudstone.

a. In this lower part the pebbles consist of about 90% bright white quartzite. The longest axis of the largest pebble is 28.2 cm. About 10% of the pebbles derive from limestones. The maximum longest axis of the limestone pebbles is 12 cm. The base of part a shows more limestone pebbles than the top. The pebbles touch each other and the directions of their longest







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axes show much variation, but a position parallel to the bedding plane seems to be preferred. The pebbles are subangular to subrounded, only a few are rounded or well rounded. Neither the pebbles nor the matrix shows grading.

b. The boundary between the parts a and b is taken arbitrarily, because it is difficult to see where the matrix begins to grade. Due to grading from sandstone into mudstone, the conglomerate changes into a pebbly mudstone. Examined with a microscope, the mud consists of 80 to 90% grains of the silt fraction, 10 to 15% clay, and 0 to 5% sand grains. The sand grains are often concentrated, forming sandy patches in the mudstone.

Simultaneously with the grading of the matrix, the packing of the pebbles becomes less compact until no longer they touch each other. This tendency continues toward the top, for the pebbles become scarcer upwards. In the uppermost 30 cm there is only mud; the pebbles have entirely disappeared.

In part b, the longest axes of the well-flattened pebbles lie parallel to the bedding plane. The pebbles are subrounded, sometimes rounded or well rounded, and measure 6 to 15 cm; only one larger pebble, of 22 cm, was found. The average pebble size does not grade; in the maximum size some grading can be observed, but the uppermost pebble still has a longest axis of 10 cm.

The pebbles, which probably derive from Ordovician and Devonian quartzites, are strongly weathered. Tables with their characteristics are obtainable from the author.

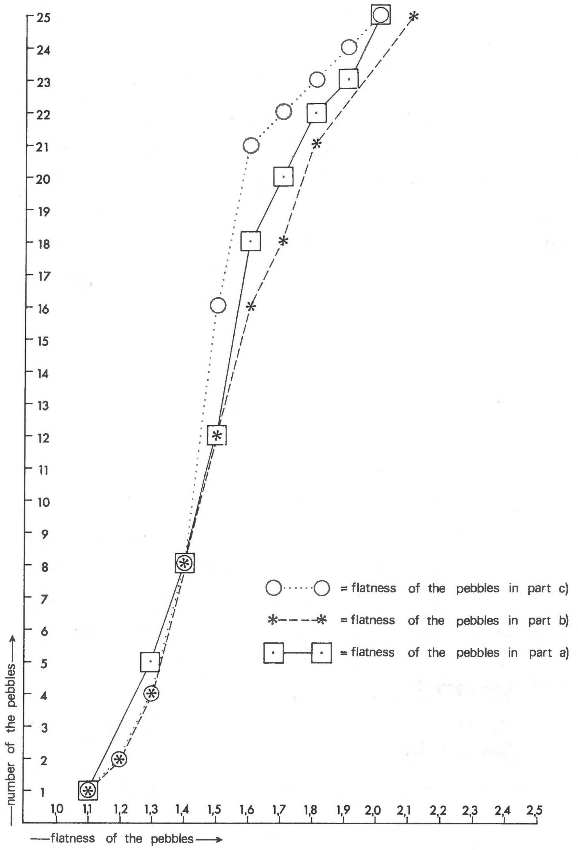

Fig. 5
Cumulative curves of the flatness values of 25 pebbles in the various parts of example 1.

CHARACTERISTICS OF THE PEBBLES

For each of the pebble-bearing parts of these three grading units, the characteristics of 25 pebbles were measured. It might be questioned whether it is justifiable to interpret the mechanism of deposition on the basis of pebble characteristics if only 25 pebbles of each part of a grading unit have been measured. On the one hand, in these areas the pebbly mudstones are usually badly exposed, which makes it difficult to find enough pebbles, at least in the upper parts where they become scarcer. Furthermore, the number of pebbles that could be measured was also restricted by their strongly weathered condition, which causes them to crumble when taken out of the matrix. But, on the other hand, the differences observed between the distinguished parts of all three examples appear to be significant, and can be explained in a logical way. Consequently, a total of 25 pebbles seems to be sufficient in this case.

From the measurements an attempt will be made to reconstruct the mechanism of deposition of these three units. The best evidence is supplied by the flatness of the pebbles. For that reason, we will start with this characteristic.

Foto 1
The grading unit near Portilla de la Reina (example 2).

I. FLATNESS

A. *Example 1*

Flatness of the pebbles was measured for parts a, b, and c of this unit. Fig. 5 shows cumulative curves of the flatness values of the pebbles in these three parts.

Up to a flatness value of 1.4 the curves of the different parts lie close together; after this point they diverge. The pebbles in part b prove to be flatter than those of part a. This may be explained as follows: in this unit no bedding plane can be observed, so the liquid limit (Fig. 6) must have been passed during the transport (D o t t, 1963). Almost immediately after this moment the mud mass must have started to freese, otherwise all the pebbles would have sunk down to the bottom. During the rather short moment between the passing of the liquid limit and the freezing, the mass formed a very viscous fluid, in which the pebbles could start to sink and to become sorted. The fact that the flattest pebbles have the smalles volume compared to their surface and therefore sink down stabilized and slowest explains the difference in flatness between parts a and b.

The pebbles in part c are less flattened than those in parts a and b. This can only be explained by assuming that this part did not behave like the other parts during the sorting of the pebbles in the viscous fluid. This is the more likely since in parts a and b the longest axes of the pebbles lie parallel to the bedding

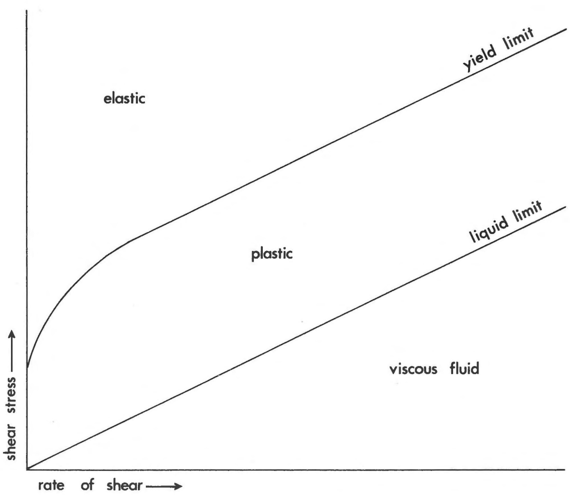

Fig. 6
Idealized graphic relation between plastic and viscous fluid flow (after Dott, 1963).

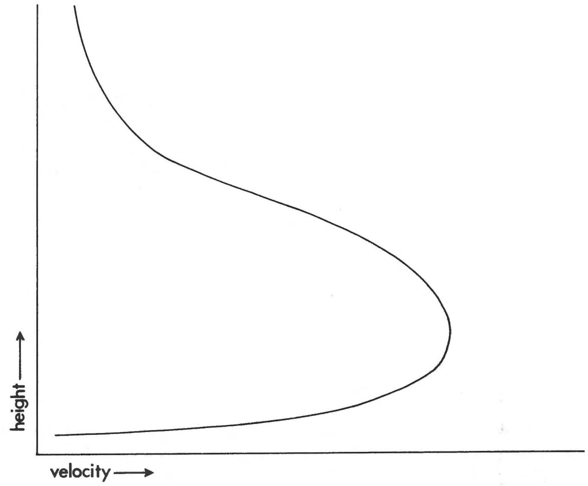

Fig. 7
Idealized graphic relation between height and current velocity in the plastic flowing mud mass.

plane but in part c they lie randomly. This means that in part c the time between passing the liquid limit and freezing was still shorter than in the other parts.

Since the three parts seem to have frozen simultaneously, part c must have passed the liquid limit later than parts a and b. Because this moment depends on the current velocity, this velocity must have been lower in part c than in the other two parts (Fig. 7). This is in accordance with what has been assumed for turbidites. Since this graded unit forms a transition between a slump and a turbidite, this agreement can be easily understood.

B. *Example 2*

Pebbles from parts a, b, and c were measured. Fig. 8 shows cumulative curves of the flatness of the pebbles in these parts. Since these curves diverge more than those of example 1, it may be said that as far as flatness is concerned, sorting is better than in example 1.

The flatness values for part a are distinctly lower than those for parts b and c. These latter two parts do not differ much, which indicates that their circumstances of deposition were more or less the same. Only in the area with lower flatness values does the curve of part c lie between those of parts a and b, appearing to equal the average of these parts. The fact that parts a and b are distinctly differentiated seems to imply that part c did not take part in the sorting or did so more briefly, perhaps because the liquid limit was passed later, due, as in example 1, to a lower current velocity at the top.

Since the flatness values for parts a, b, and c

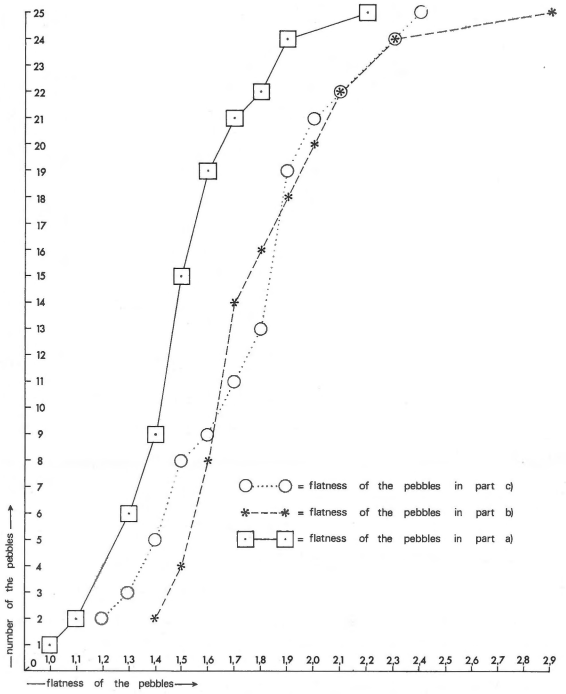

Fig. 8
Cumulative curves of the flatness values of 25 pebbles in the various parts of example 2.

indicate a better sorting than do the flatness values of parts a, b, and c of example 1, it may be assumed, that in example 2 there was more time between the passing of the liquid limit and the freezing than there was in example 1.

C. *Example 3*

Pebbles from parts a and b were measured. The pebbles in part b are much flatter than those in part a, as shown in Fig. 9. This indicates that the moment between the passing of the liquid limit and the freezing was relatively long, much longer than in example 1 and even longer than in example 2.

II. ROUNDNESS

Cumulative curves of the roundness of the pebbles in the different parts are shown in Figs, 10, 11, and 12. Comparison of the roundness of the pebbles in the different parts of the three grading units shows no regularity. This suggests that roundness is of no importance when the mud mass is sorting out. There is no relationship between flatness and roundness of the pebbles.

III. SYMMETRY

Asymmetry of the pebbles is caused mainly by breaking shortly before the moment of deposition. As a result of breaking, one side of a pebble is thicker and heavier than the other one. Consequently, when a pebble-containing mud mass has passed the liquid limit and behaves like a viscous fluid, the broken

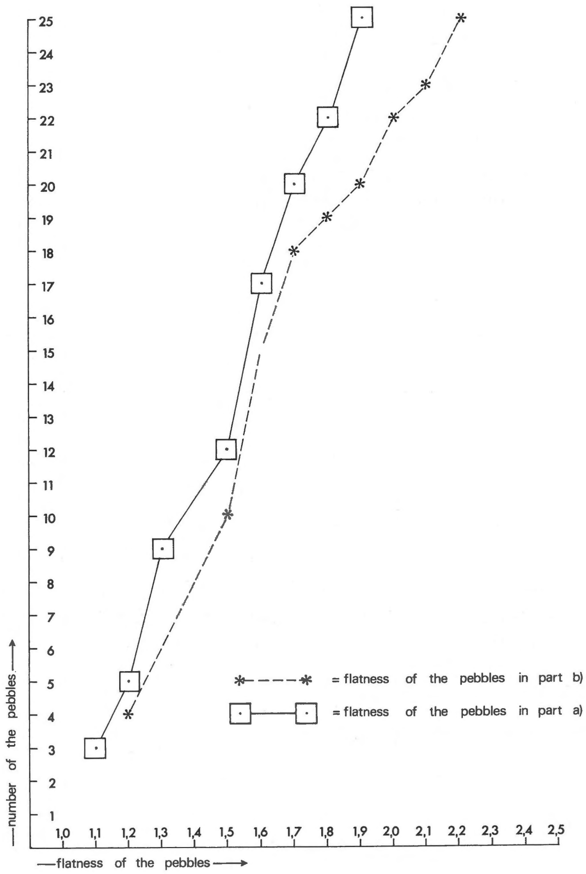

Fig. 9
Cumulative curves of the flatness values of 25 pebbles in the various parts of example 3.

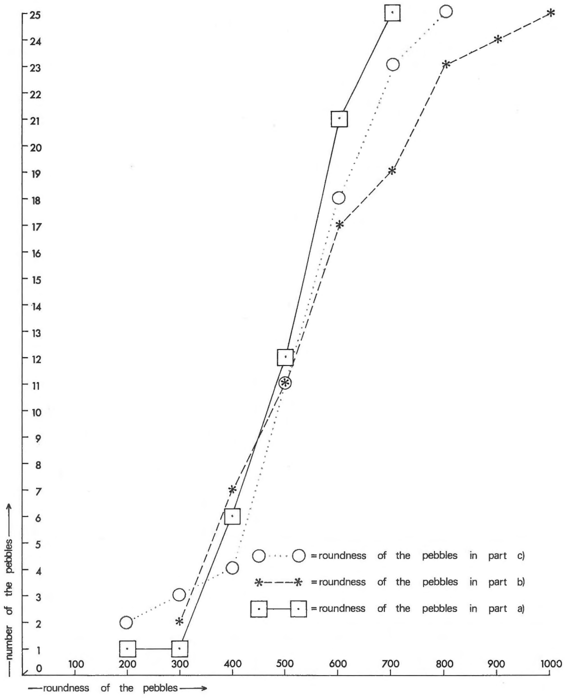

Fig. 10
Cumulative curves of the roundness values of 25 pebbles in the various parts of example 1.

pebbles will be less stable than the other pebbles and will sink more rapidly. This is shown in Figs. 13, 14 and 15, which give the cumulative curves of the symmetry of the pebbles in the various parts of the three units under study. It is evident that the pebbles in the sandstone matrix are more asymmetric than those in the mud matrix (Figs. 13 and 14). Only in example 3 is the symmetry in both parts about the same (Fig. 15). But since there was less breaking in this unit than in the other two and the pebbles in unit 3 are therefore more symmetric than those in units 1 and 2, this is logical.

The variations of the pebble characteristics enable us to arrange the three units in a series based on progressively better sorting. This series starts with the often described (e.g. Crowell, 1957; Dott, 1963), undifferentiated sandy pebbly mudstone. This form has not been described here, because only sediments with a grading matrix have been considered. With increasingly better sorting, the next places in this series are successively filled by examples 1, 2, and 3, described here. The last case in this series, not described here, would be a conglomerate with a mud layer lacking pebbles at the top. Of course, this series is only valid for sediments with an amount of pebbles, sand, silt, and clay, sufficient to allow such grading.

CONCLUSIONS AND SUMMARY

The three graded units described here show that an interpretation of the mechanism of deposition is not always possible if only the matrix of a pebble-containing sediment is considered. If a deposition consists of randomly floating pebbles in a mud matrix, the following conclusions may be drawn (not considering exceptions such as tillites, etc.):

1. The mass has passed the yield limit, causing a disturbance of the original bedding. After this, the mass passed the liquid limit, causing the total disappearance of any original bedding (Dott, 1963).

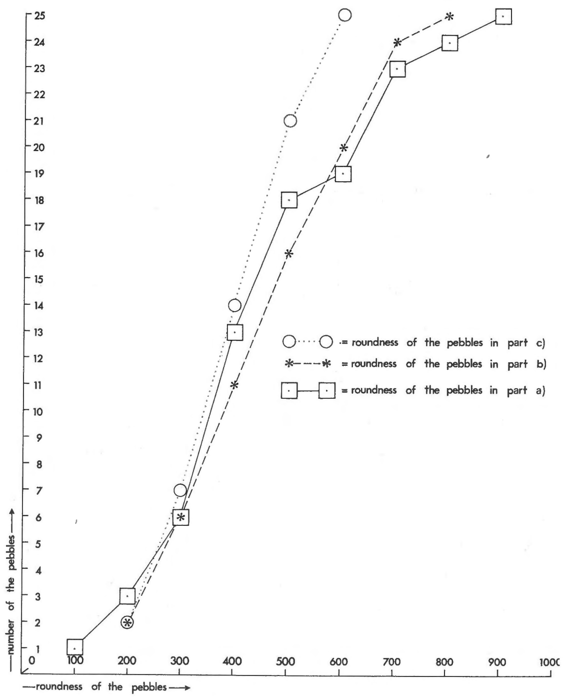

Fig. 11
Cumulative curves of the roundness values of 25 pebbles in the various parts of example 2.

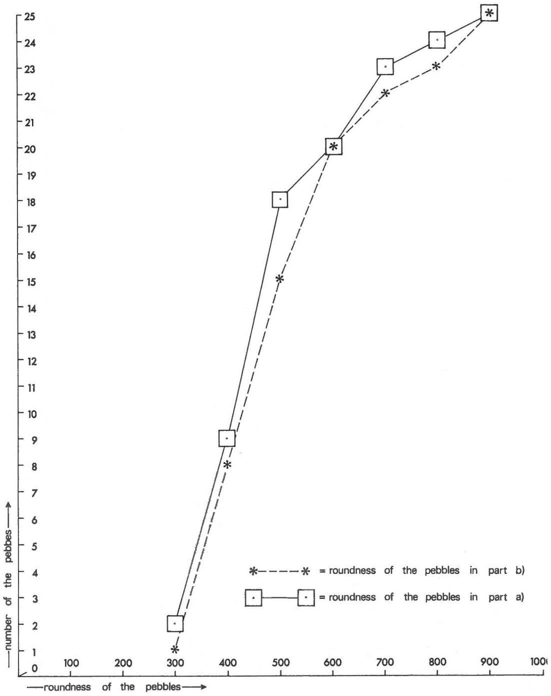

Fig. 12
Cumulative curves of the roundness values of 25 pebbles in the various parts of example 3.

2. After having passed the liquid limit, the sediment froze almost immediately, since otherwise the pebbles would have sunk to the bottom in the viscous fluid.

When the bed shows grading, as in the examples described here, this forms another indication:

3. After having passed the liquid limit, there was a moment before freezing, a moment long enough for the pebbles to start sorting and too short for all the pebbles to have sunk as far as the bottom. The ratio between the number of pebbles at the top and at the base of the unit is dependent on this time. Grading of course can only occur when there is enough material in the various fractions.

During sorting, the longest axes of the pebbles follow the laws of hydrodynamics and therefore lie horizontally, i.e. parallel to the bedding plane (if we neglect the natural slope, which we assume to have been only a few degrees). The occurrence of randomly directed longest axes at the top of the unit means that there was no sorting in the viscous fluid, so the current velocity must have been lower than in the lower parts of the unit, as mentioned above.

In some cases an imbrication, albeit never well developed, was seen at the base of a pebbly mudstone (photo 2). For this situation the following conditions are necessary:

1. there must be enough pebbles to touch each other but not too many, because that would prevent imbrication, as is known from recent fluviatile sediments.
2. The pebbles must be sufficiently flattened.
3. The sediment must have flowed before freezing completely. Even though the mass is very viscous, the mechanism is in principle the same as in a fluviatile environment.

The occurrence of directed pebbles and even imbrication in pebbly mudstones makes it difficult to determine the mechanism of deposition in con-

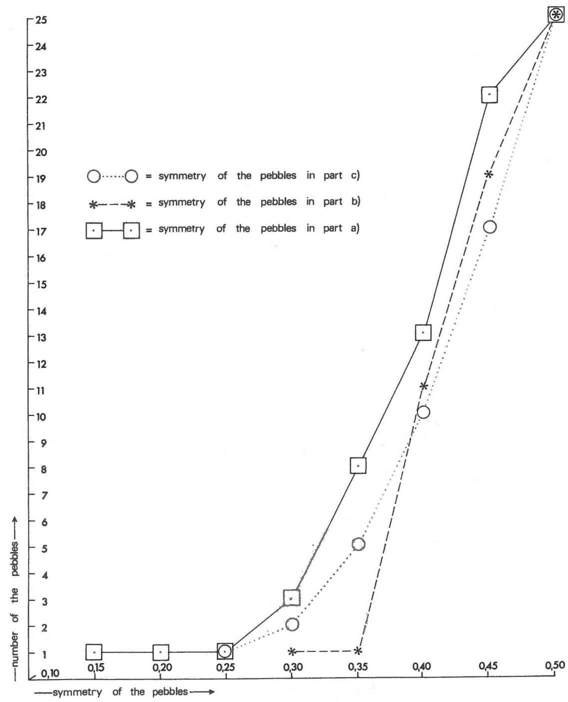

Fig. 13
Cumulative curves of the symmetry values of 25 pebbles in the various parts of example 1.

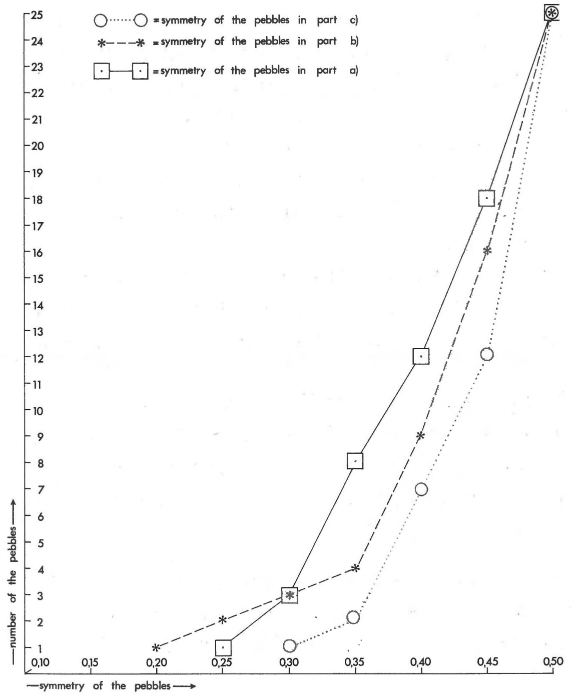

Fig. 14
Cumulative curves of the symmetry values of 25 pebbles in the various parts of example 2.

glomerates. A study of the whole sequence will be required to solve the problem.

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REFERENCES

Ackermann, E. (1949) – Thixotropie bei Umlagerungen feinkörniger Sedimente. Geol. Rundschau, 37, p. 100-101.

– (1951) – Geröllton! Geol. Rundschau, 39, p. 237-239.

Boschma, D. & van Staalduinen, C.J. (1968) – Mappable units of the Carboniferous in the southern Cantabrian Mountains. Leidse Geol. Med., 43, p. 221-232.

Bouma, A.H. (1962) – Sedimentology of some flysch deposits. Elsevier, Amsterdam.

Cailleux, A. (1952) – Morphoskopische Analyse der Geschiebe und Sandkörner und ihre Behaftung für die Palaeoklimatologie. Geol. Rundschau, 40, p. 11-19.

Crowell, J.C. (1957) – Origin of pebbly mudstones. Geol. Soc. Am. Bull., 68, p. 993-1009.

Dott, R.H. Jr. (1963) – Dynamics of subaqueous gravity depositional processes. A.A.P.G. Bull, 47, p. 104-128.

Evers, H.J. (1967) – Geology of the Leonides between the Bernesga and Porma rivers, Cantabrian Mountains, NW Spain. Leidse Geol. Med., 41, p. 83-151.

Ginkel, A.C. van (1965) – Carboniferous Fusulinids from the Cantabrian Mountains (Spain). Leidse Geol. Med., 34, p. 1-225.

Kanis, J. (1956) – Geology of the eastern zone of the Sierra del Brezo (Palencia, Spain). Leidse Geol. Med., 21, p. 377-446.

Koopmans, B.N. (1962) – The sedimentary and structural history of the Valsurvio Dome (Cantabrian Mountains, Spain). Leidse Geol. Med., 26, p. 121-232.

Kuenen, Ph.H. & Migliorini, C.I. (1950) – Turbidity currents as a cause of graded bedding. J. Geol., 58, p. 91-127.

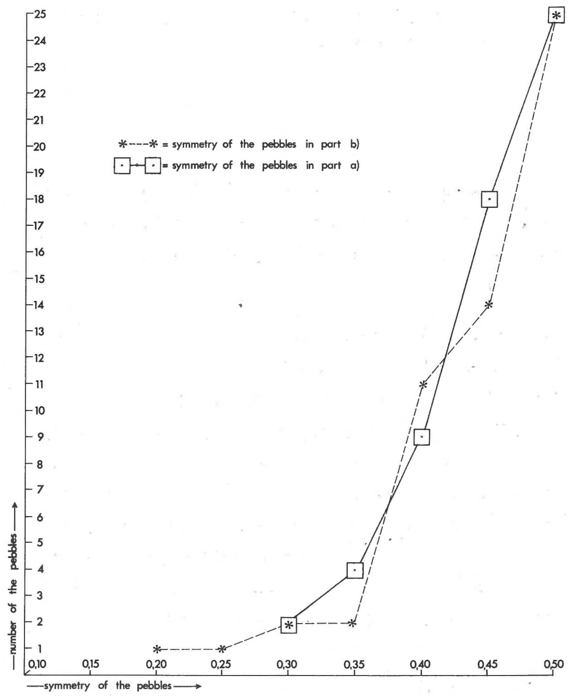

Fig. 15
Cumulative curves of the symmetry values of 25 pebbles in the various parts of example 3.

Foto 2
Imbrication at the base of a pebbly mudstone near Proro.

Oele, E. (1964) – Sedimentological aspects of four Lower-Paleozoic formations in the Northern part of the province of Leòn (Spain). Leidse Geol. Med., 30, p. 1-100.

Rupke, J. (1965) – The Esla nappe, Cantabrian Mountains (Spain). Leidse Geol. Med., 32, p. 1-74.

Savage, J.F. (1967) – Tectonic analysis of Lechada and Curavacas synclines, Yuso Basin, León, NW Spain. Leidse Geol. Med., 39, p. 193-247.

Sjerp, N. (1966) – The Geology of the San Isidro-Porma area (Cantabrian Mountains, Spain). Leidse Geol. Med., 39, p. 55-128.

Veen, J. van (1965) – The tectonic and stratigraphic history of the Cardaño area, Cantabrian Mountains, Northwest Spain. Leidse Geol. Med., 35, p. 45-104.

Walker, R.G. (1965) – The origin and significance of the internal sedimentary structures of turbidites. Proc. Yorksh. Geol. Soc., 35, p. 1-32.