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FOSSIL AND MUD FREQUENCIES IN SOME MARINE SILESIAN SEDIMENTS OF NORTHERN SPAIN

A.J. van LOON (*)

Abstract. — A Silesian succession near Prioro consists of four formations that represent a flysch facies, a shallow marine facies (partly erosive, partly non-erosive), an alluvial fan and fluvial facies, and a shallow marine and fluvial facies respectively.
These markedly different facies contain very different fossil assemblages and strongly varying fossil quantities. The percentages of calciclastic material and of mud occurring in the sediments seem to determine whether the environment was favourable to life of most of the fossil groups. The total quantity of fossils, however, in general shows no relationship with these two factors, but is related to the rate of sedimentation.

Stratigraphic data

This study was carried out in an area at the southern flank of the Cantabrian Mountains, near the village of Prioro in the NE of the province of León (Spain) (fig. 1).

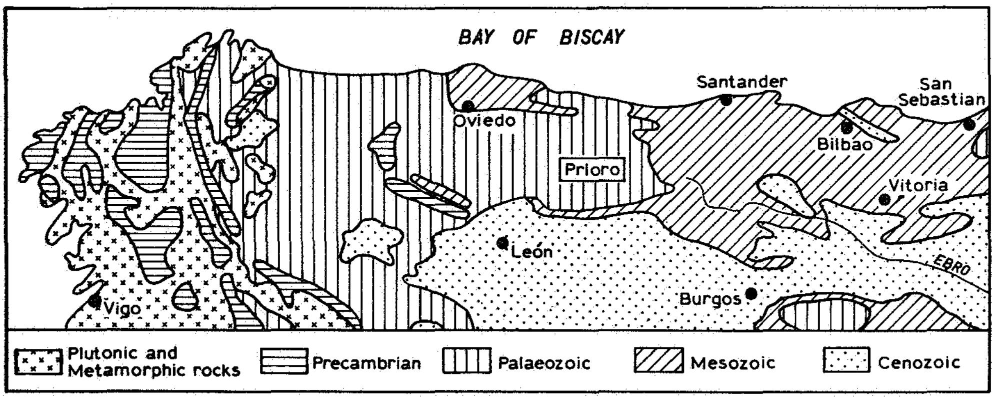

Fig. 1. — Schematical geological map of Northern Spain, showing position of the Prioro area.

This region was already previously studied by us, stratigraphically (van Loon, 1971) and with respect to the sedimentary geology (van Loon, 1972). In those studies a dating on a palaeontological basis was arrived at of the units present. For this dating various stratigraphic divisions were used for the various fossil groups :

1. West European division (Namurian, Westphalian and Stephanian);

2. East European division (Bashkirian, Moscovian, Gzhelian);

3. Fossil zones (e.g. for fusulinids).

(*) Instituut voor Aardwetenschappen der Vrije Universiteit, De Boelelaan 1085, Amsterdam-11, The Netherlands.

The correlation of these divisions, as used by us, is shown in fig. 2. In this study we use the West European terminology, even if the original dating was otherwise.

The sequence starts with the Prioro Formation, which was long considered as Namurian (e.g. HELMIG, 1965; RUPKE, 1965; MARTINEZ-ALVAREZ & TORRES-ALONSO, 1967) or lower Westphalian (e.g. BROUWER & VAN GINKEL, 1964; VAN GINKEL, 1965), always on the basis of insufficient palaeontological data. The relatively scarce fauna and drifted plant remains found by us now suggest an upper Westphalian B age at the base and a Westphalian B/C age at the top. This formation consists mainly of shales and pebbly mudstones in a flysch and pro-delta-facies.

This rather uniform sequence is followed by the Pando Formation, in which three members can be distinguished: the Lower Sandstone Member (lower Westphalian C), the Mesao Limestone Member (middle Westphalian C) and the Upper Sandstone Member (upper Westphalian C-lower or middle Westphalian D). This formation was formed in a shallow marine environment, and contains many (locally abundant) fossils. The two sandstone members represent a rather high-energy environment with many currents, as is indicated by the current ripples, channels, etc. These members may be considered as mainly erosive phases, although the net result of all actions is still a sedimentation. The Mesao Limestone Member, however, represents a much quieter environment of biogenic and clastic limestones, alternating with calcareous shales.

The Pando Formation is covered (via an angular unconformity) by the Ocejo Formation (uppermost Westphalian D). The hiatus between these two formations therefore only represents a part of the Westphalian D. The Ocejo Formation contains coal layers in rhyth-

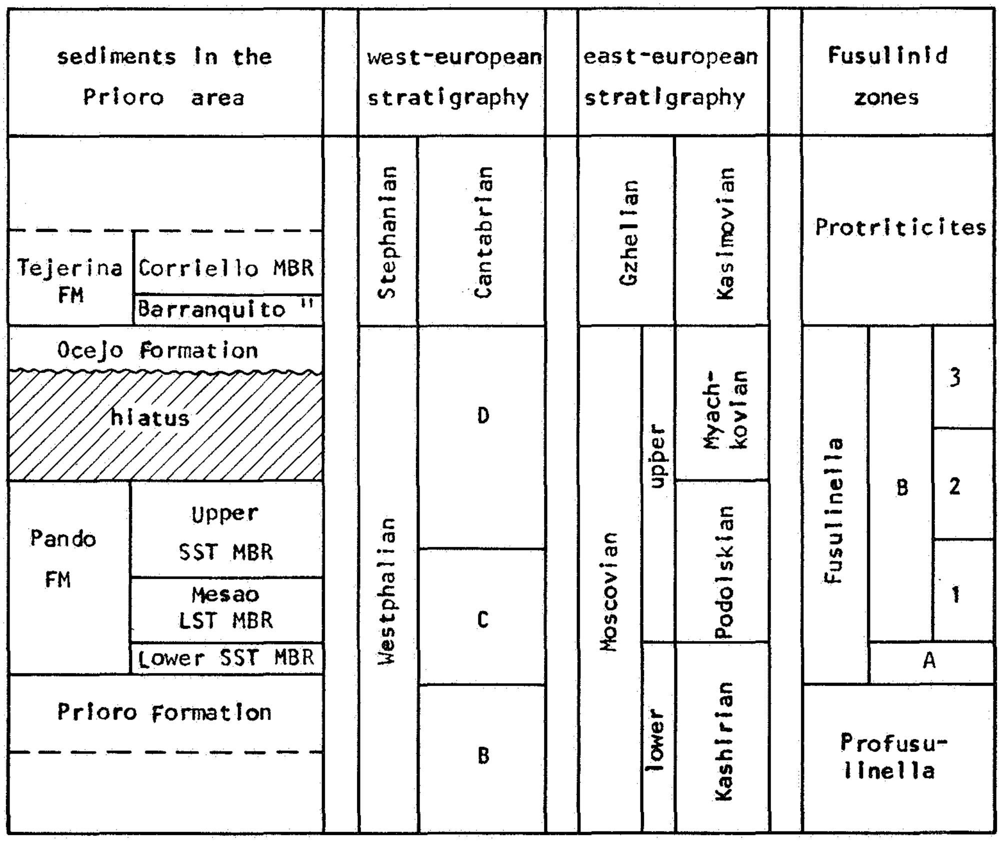

Fig. 2. — Stratigraphic correlation chart.

mic units which represent alluvial fan and fluvial environments. Although we are not absolutely certain that some littoral sediments will not occur, we consider this formation as entirely continental. For that reason this formation will not be dealt with further on in this paper.

The Ocejo Formation is overlain by the Tejerina Formation, which for the main part is also continental (the fluvial Corriello Member, that again contains units with coal layers), but at the base of which a shallow marine band occurs, not more than a few tens of metres thick. This band, that locally contains a rich fauna with mainly brachiopods, pelecypods and crinoids, is called the Barranquito Member. The age of the Tejerina Formation is lower Cantabrian (compare WAGNER, VILLEGAS & FONOLLÁ, 1969).

Environmental factors

The complete succession, that represents a regressive deltaic sequence, contains many different facies (coinciding with the formations and members distinguished), that contain strongly varying kinds and quantities of fossils, which, however, can reasonably well be compared with each other, since the total time-span is relatively small.

One of the most important questions is, which conditions are responsible for such differences in environment as result in the abundance, the presence or the absence of certain fossils. The most important factors that we detected in this sucession are:

1. Oxidizing or reducing conditions. Only locally (mainly in the "deep" sediments of the Prioro Formation) did reducing conditions temporarily prevail. This factor therefore only plays a minor role;

2. Rate of sedimentation. When the thickness of the units (see enclosures I and II by VAN LOON, 1972) are compared with the time span in which they were formed, there appears to exist a distinct relationship: the lower the rate of sedimentation, the more fossils occur. This is extremely clear for the Pioro Formation and the Mesao Limestone Member. The former was deposited very quickly, mainly by mass movements, while the latter represents a period of quiet, in which biogenic limestones could develop. The Prioro Formation contains extremely few fossils (it was considered barren by many previous investigators), that are nearly all washed in, whereas the Mesao Limestone Member is extremely rich, with hardly any transported fossils;

3. Quantity of calcareous matter. This factor, which is one of the most important facies-determining circumstances, hardly seems to play a role with respect to the quantity of fossils. Its influence on the type of fossils present can, however, hardly be overestimated. This is well shown in the Mesao Limestone Member;

4. Turbulence of the water. This is typically facies-controlled and is expressed in several ways, e.g. by sedimentary structures such as channels, and by the shape of fossils (e.g. brachiopods from the turbulent sandstone members are ball-like (such as *Schizophoria*), while those from the quiet Mesao Limestone Member (e.g. *Dictyoclostus, Rugosochonetes*) show more and longer spines). The turbulence of the water is well shown by the quantity of mud present. Low stream velocities allowed fine particles to settle, while they stayed in suspension in faster streams. Of course, the coarseness of the material supplied plays a role (the palaeogeographic picture indicates a relatively large supply of sand during the formation of the Lower Sandstone, Upper Sandstone and Barranquito Members), but subsequent erosion and the sand/shale ratio make this rather unimportant for the final sedimentary result. Hence the quantity of mud provides information on the physical processes that played a role.

The total picture is somewhat obscured as a result of transport of the fossils (almost all fossils in the Prioro Formation are reworked), so that the circumstances in their finding places need not be the same as in their original environment. However, in the Pando and Tejerina Formations, where most fossils come from, fossils generally seem to be *in situ* or transported over only very small distances.

Mud frequency

From this area many rock samples were examined petrographically (VAN LOON, 1972). From sections 4, 7, 10, 11 and 12 we collected a sample at every fifth stratigraphic metre, which was examined microscopically. These five sections yielded (for the units dealt with here) 116 calciclastic and 332 siliciclastic samples, in all of which the percentage of mud was determined by point-counting (300 points in each slide). As "mud" we considered all material smaller than 25 microns.

The curves of the modal distribution of mud in the calci- and siliciclastic sediments appear to run parallel in the middle part (fig. 3), but to diverge at percentages of less than 25 and more than 75 % of mud, since the limestones generally contain less fine-grained material.

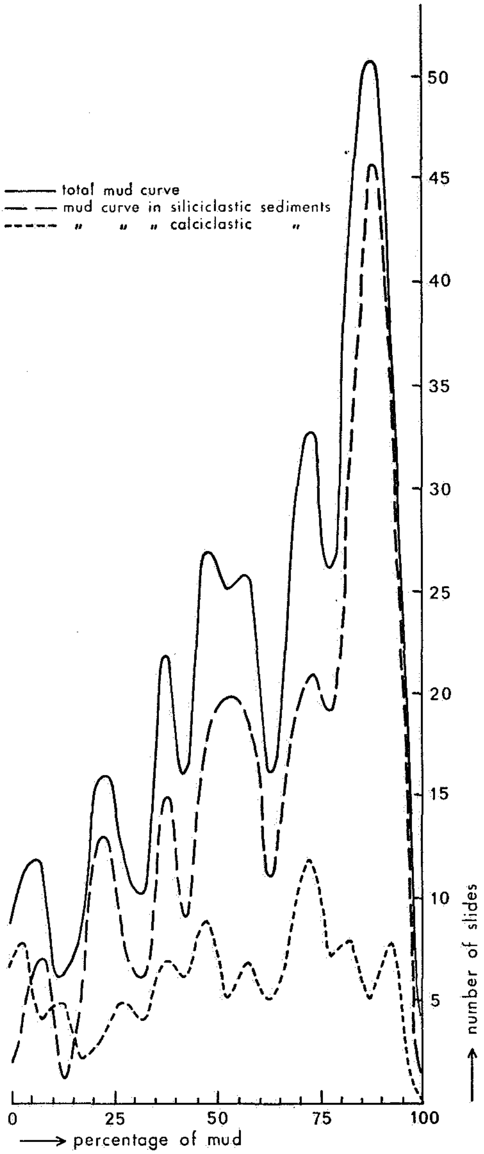

Fig. 3. — Mud frequency in the 448 samples under study.

These diferences are partly caused by variance in the modal distribution of the various units. Separate curves have therefore been made of the Prioro Formation (fig. 4), the sandstone members (the Lower and Upper Sandstone Members of the Pando Formation

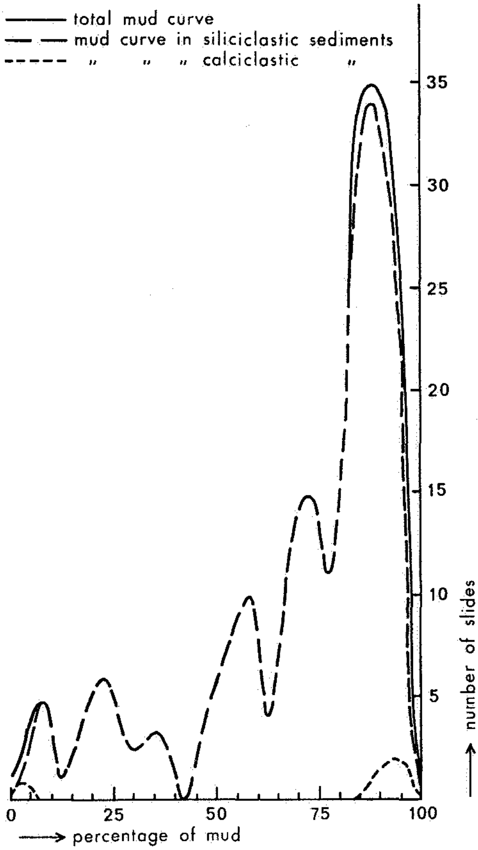

Fig. 4. — Mud frequency in the Prioro Formation.

are dealt with together, since they are much alike in nearly every respect) (fig. 5), the limestone member (of the Pando Formation) (fig. 6) and the Barranquito Member (of the Tejerina Formation) (fig. 7). It is striking that the curves in figures 5 and 7 (the most sandy facies) are very much alike.

The most distinct differences between the various units are :

1. The Prioro Formation consists almost entirely of siliciclastic material, and mainly contains very fine-grained sediments;

2. The limestone member is, though less, also fine-grained, but contains more limestones than siliciclastic sediments;

3. The sandstone members are considerably coarser, and contain few limestones;

4. The Barranquito Member (only 6 samples could be studied, since this band is very thin) resembles the sandstone members, but has no limestones at all (it is locally calcareous).

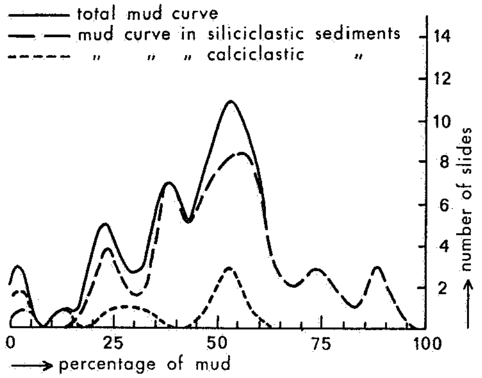

Fig. 5. — Mud frequency in the two sandstone members of the Pando Formation.

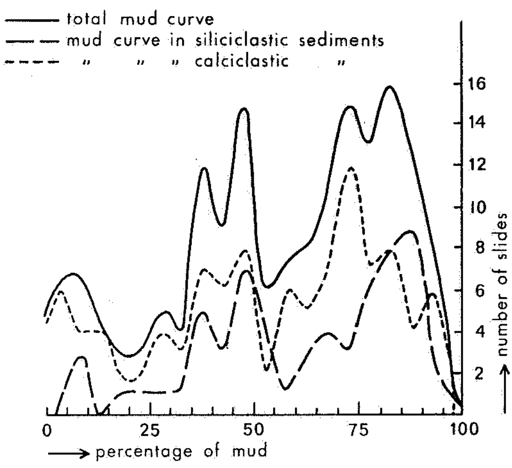

Fig. 6. — Mud frequency in the Mesao Limestone Member of the Pando Formation.

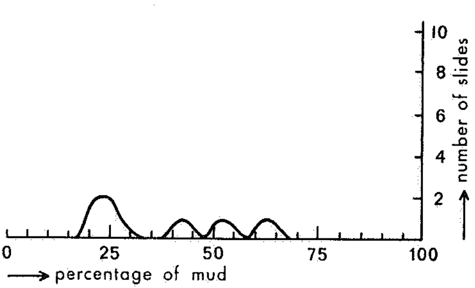

Fig. 7. — Mud frequency in the Barranquito Member of the Tejerina Formation.

The modal distribution in the silici- and calciclastic sediments separately, is represented in figures 8 and 9, respectively. These curves show that only in the limestone member must the quantity of limestone be thought capable of causing distinct differences in fossil content.

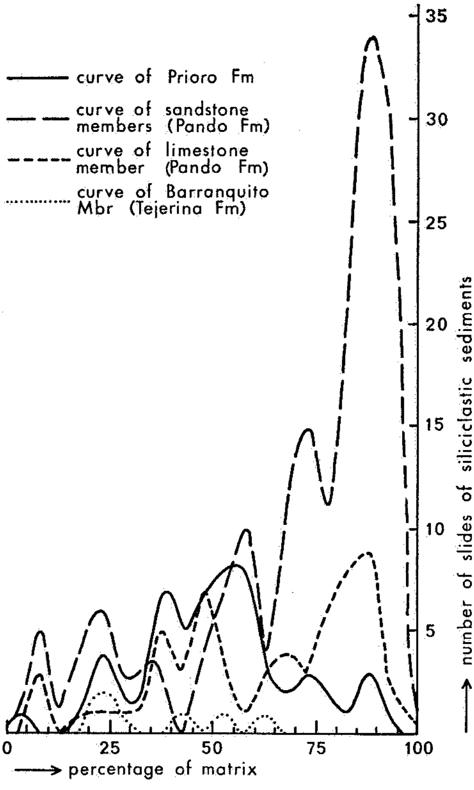

Fig. 8. — Mud frequency in all siliciclastic samples under study.

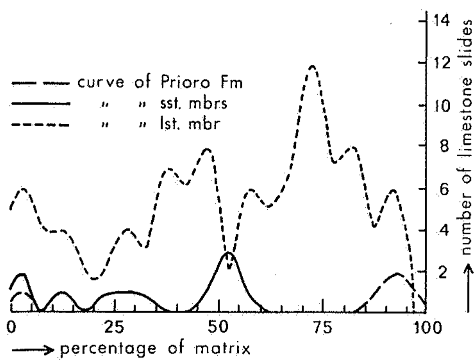

Fig. 9. — Mud frequency in all calciclastic samples under study.

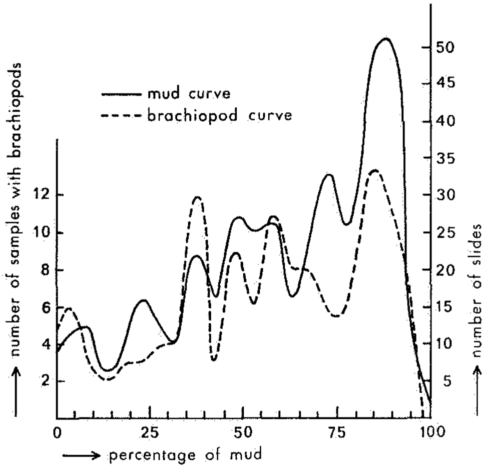

Fig. 10. — Relationship between the frequencies of mud and brachiopods.

Fossils

In the sediments studied we frequently found the following groups of fossils (in order of importance) : crinoids, plant debris (washed-in), brachiopods, foraminifers (excluding fusulinids and siliceous specimens), bryozoans, algae, pelecypods, gasteropods, fusulinids, siliceous foraminifers, ostracods, trilobites, terrestrial leaves (washed-in), sphinctozoan sponges and solitary corals. Rarer occurrences must further be mentioned of conodonts, fish teeth, goniatites, nautiloids and coral colonies.

Since many palaeontologists assume a relationship between the frequency of fine clastic

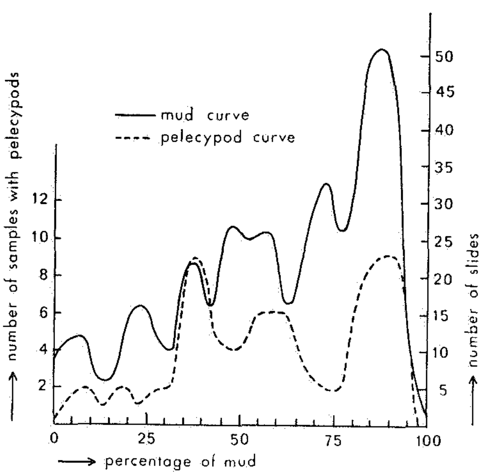

Fig. 11. — Relationship between the frequencies of mud and pelecypods.

material and the presence of fossils (e.g. VANGEROW, 1955, 1964*a*, *b*, 1970; CERETTI, 1963; WINKLER PRINS, 1968; VAN AMEROM, BLESS & WINKLER PRINS, 1970; BLESS, 1970; DE MEYER, 1971; VAN GINKEL, 1973), we tried to check this for our area, in which we presume to have collected sufficient numerical data on mud frequency to give a statistically reliable result.

This check was carried out by comparison of the frequency curves of the 15 fossil groups mentioned above with figures 3-9, in which the modal distribution of the mud is indicated.

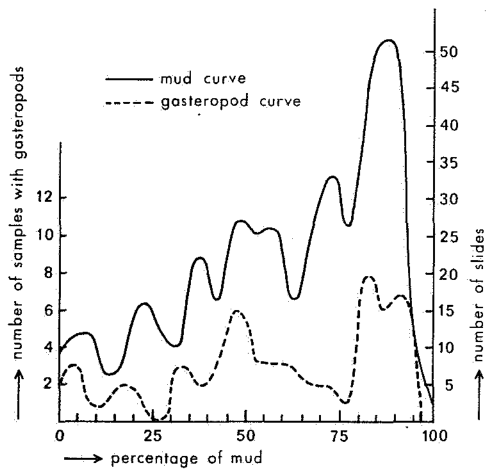

Fig. 12. — Relationship between the frequencies of mud and gasteropods.

Fossil frequency

A comparison of the frequency curves of the 15 fossil groups mentioned above with the modal-distribution curves of the mud shows that there are a few relationships :

1. some fossil curves resemble the curve of all the mud (fig. 3, upper curve);

2. other fossil curves can be compared with the modal distribution of mud in all limestones (fig. 3, lowest curve);

3. one fossil curve (of crinoid frequency) can be compared with both curves mentioned here.

Ad 1. Three groups of fossils can be distinguished, of which the frequency curve strongly resembles that of the modal distribution of all mud. In the first place, they are the most common shells : brachiopods (fig. 10), pelecypods (fig. 11), gasteropods (fig. 12) and even fusulinids (fig. 13). From this it is clear that these groups as a whole (this, of course, is not true for the separate species) do not show any preference for either a calcareous or a non-calcareous environment, and that the mud content is not of much importance generally. It may roughly be stated that the curves show an occurrence of fossils of each of these groups in each fifth or tenth sample.

At first sight it seems surprising that the fusulinids hardly prefer a calcareous environment, but the tendency present is distinctly influenced by the chief occurrence of genera

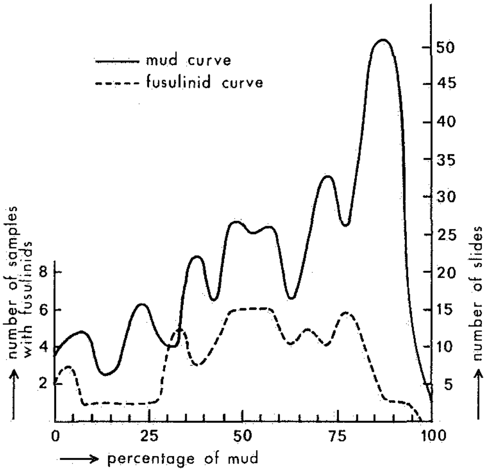

Fig. 13. — Relationship between the frequencies of mud and fusulinids.

such as *Hemifusulina, Ozawainella, Pseudostaffella* and a few specimens of *Schubertella* and *Fusiella,* which are fairly well adapted to a non-calcareous environment (VAN GINKEL, 1973).

It should be mentioned that all these groups of shells show a relatively low frequency in sediments with approx. 25 %, 40 % (except for the pelecypods) and 75 % of mud. Since this tendency is found in all these groups, we may assume — for reasons not yet understood — that these percentages of mud result in an unfavourable environment. On the contrary, a mud percentage of about 35 % seems to lead to a relatively rich fauna.

A similar picture is shown by the frequency curve of the trilobites (fig. 14), that, however, are less frequent than the shells mentioned above. These fossils, too, show extra low frequencies at about 25 %, 40 % and 75 % of mud.

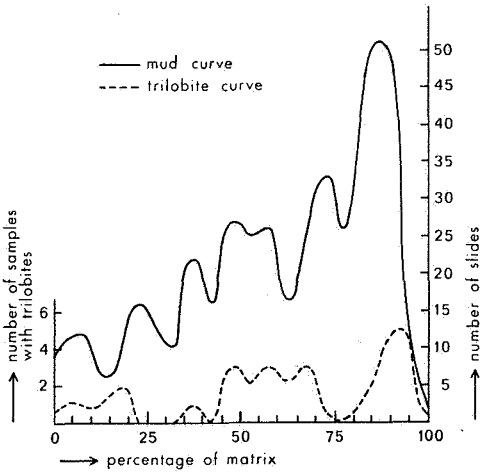

Fig. 14. — Relationship between the frequencies of mud and trilobites.

The third group consists of the distinctly washed-in terrestrial elements. Leaves (fig. 15) are rather scarce since they lack (except for *Linopteris*) a cuticle, so that they easily fall into pieces in the water (WAGNER *in* VAN LOON, 1971). Other plant debris (fig. 16) is much more resistant, even occurring in some 40 % of all samples. It is not amazing that these fragments have a frequency curve that shows a distinct similarity to that of the mud. Since they came from an entirely different environment, and beyond doubt arrived at their depositional site in a floating way, they cannot have any relationship with the lithology of the substratum.

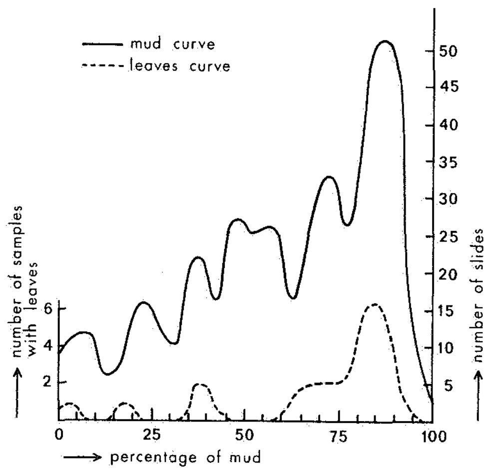

Fig. 15. — Relationship between the frequencies of mud and washed-in leaves.

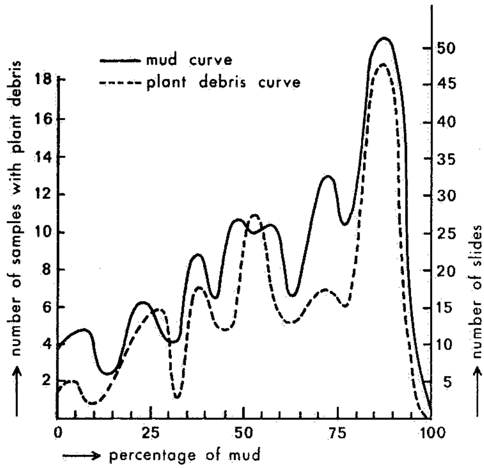

Fig. 16. — Relationship between the frequencies of mud and washed-in plant debris.

Ad. 2. There are seven groups of fossils, of which the frequency curve shows a similarity to that of the mud in the calciclastic part. Four of these seven groups are fairly common, three are somewhat rare. Their curves show that they prefer a calcareous environment, but are not very sensitive to the percentage of mud.

The four frequently occurring groups are : calcareous foraminifers (excluding the fusulinids) (fig. 17), siliceous foraminifers (fig. 18), bryozoans (fig. 19) and calcareous algae (fig. 20). It is clear from figures 17 and 19 that the frequency of the calcareous foraminifers and bryozoans is sometimes higher than that of the limestones. This is the result of the presence of these fossils in siliciclastic sediments, too, where they prefer the same percentage of mud as in the limestones !

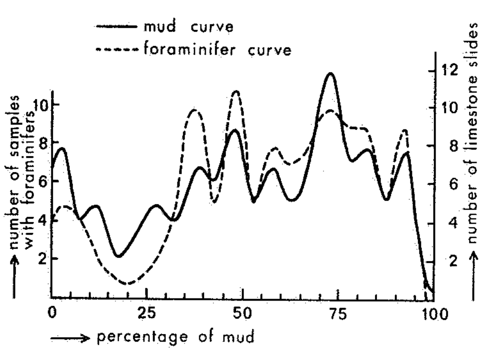

Fig. 17. — Relationship between the frequencies of mud in the calciclastic sediments and calcareous (non-fusulinid) foraminifers.

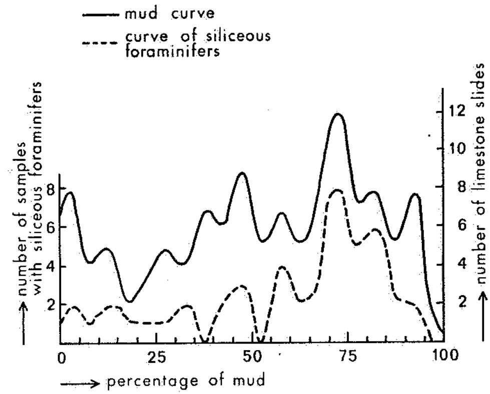

Fig. 18. — Relationship between the frequencies of mud in the calciclastic sediments and siliceous foraminifers.

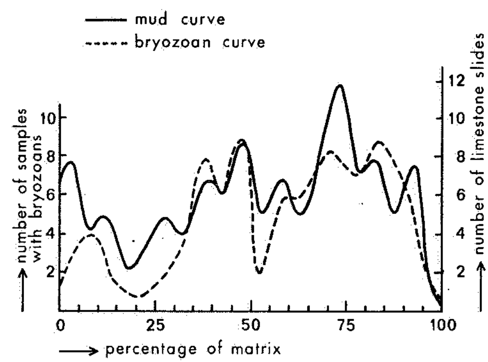

Fig. 19. — Relationship between the frequencies of mud in the calciclastic sediments and bryozoans.

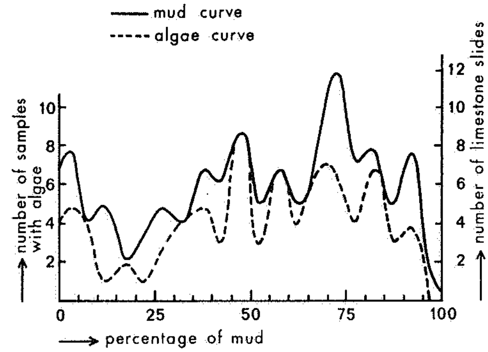

Fig. 20. — Relationship between the frequencies of mud in the calciclastic sediments and calcareous algae.

It is also striking that relatively many fossil specimens occur at mud values of about 35 %, 45 % and 80 %. The evidently favourable environment at 35 % of mud was also visible for the shells (figs. 10-13).

Algae are also — though seldom — found washed into mudstones, but never so often that the frequency curve is higher than that of the limestones. In both the biogenic and the calciclastic limestones they are, however, nearly always present.

The siliceous foraminifers (mainly *Glomospira* and some specimens of *Glomospirella*) strongly seem to be connected with limestones or extremely calcareous mudstones. This may be the reason for their relatively rather low frequency.

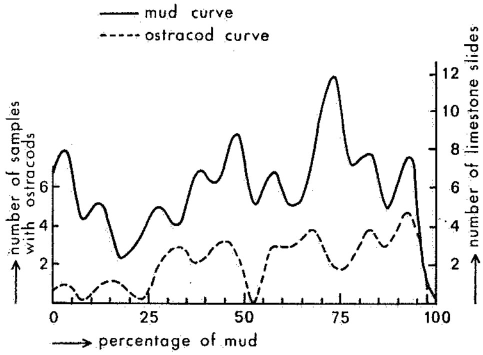

Fig. 21. — Relationship between the frequencies of mud in the calciclastic sediments and ostracods.

It should finally be mentioned that the frequency curves of these four common groups are quite similar, which, together with our field observations, seems to indicate the existence of a kind of assemblage at a high taxonomic level.

The three rarer fossil groups with frequencies related to the mud in the limestones, are the ostracods (fig. 21), sphinctozoan sponges (fig. 22) and solitary corals (fig. 23). They already occur too rarely to show very pronounced frequency curves. It is only clear that some relationship still exists with the modal distribution of mud in the limestones.

Ad. 3. The frequency curve of the crinoids (fig. 24) cannot be compared with only one of the two curves mentioned above, but is distinctly related to both of them. This means that crinoids show a slight tendency towards calcareous environments, but that the mud content is only of minor importance. Only at 35 % of mud, however, is there again a high frequency.

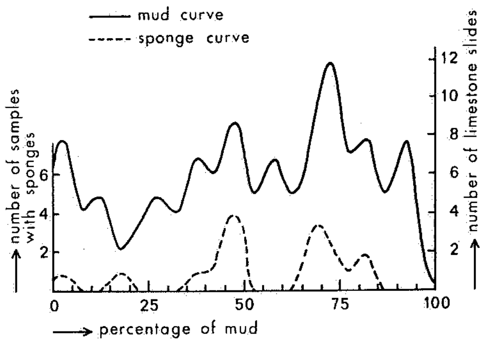

Fig. 22. — Relationship between the frequencies of mud in the calciclastic sediments and sphinctozoan songes.

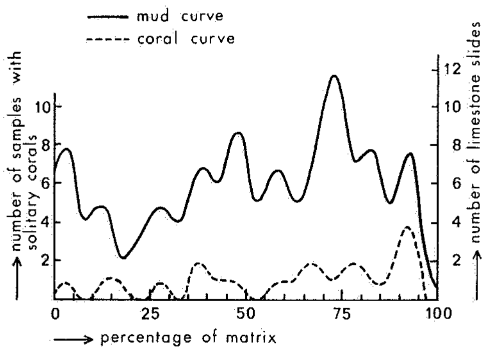

Fig. 23. — Relationship between the frequencies of mud in the calciclastic sediments and solitary corals.

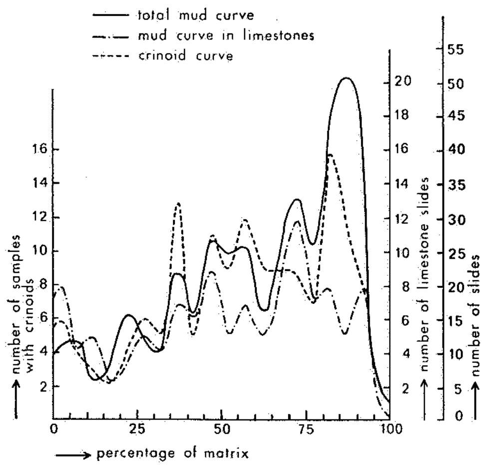

Fig. 24. — Relationship between the frequencies of mud (in all samples and in the calciclastic samples separately) and crinoids.

Summary and conclusions

The mud content of 448 samples was determined in thin sections (slides), while the fossil content of the interval belonging to each sample was also recorded.

In this Silesian sequence some relationships exist between the mud content in the silici- and calciclastic parts, and between the frequency of fossils and the lithology :

1. In limestones and mudstones there is the same tendency for mud relatively seldom to reach the value of about 30 %, 40 %, 65 % and 75 %. This is possibly due to post-sedimentary processes, that may relatively easily lead to recrystallisation of fine-grained material when it occurs in these percentages;

2. At less than 25 % or at more than 75 % of mud the frequency curves of mud in silici- and calciclastic sediments show no distinct relationship, while they run more or less parallel between these values;

3. Seven groups of fossils are equally represented in both calcareous and non-calcareous environments. These groups are : brachiopods, pelecypods, gasteropods, fusulinids, trilobites, leaves of land plants and plant debris;

4. An environment that leads to a sediment with 25 %, 40 % or 75 % of mud is relatively unfavourable for the brachiopods, pelecypods, gasteropods, fusulinids and trilobites. They seem to prefer about 35 % of mud to live on or in;

5. Washed-in material shows no relationship with the lithology of the substratum;

6. Seven groups of fossils prefer a calcareous environment, while it is usually of minor importance whether they live in or near limestones or calcareous mudstones. These groups are : calcareous and siliceous foraminifers, bryozoans, algae, ostracods, sphinctozoan sponges and solitary corals;

7. Most of these latter groups of fossils slightly prefer an environment with approx. 35 % of mud (see 4), 45 % or 80 % of mud;

9. Crinoids show a slight preference for a calcareous environment, and for a sediment with some 35 % of mud (see 4 and 7).

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