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MAIN FEATURES OF MEGATURBIDITES IN THE EOCENE OF SOUTHERN PYRENEES

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Abstract. Eocene sequences of the Ager-Jaca-Pamplona Basin and Terrades-Ripoll-Cadi Basin in the southern Pyrenees include carbonate megaturbidites. The main features of the megaturbidites are: (i) unusually great thickness, (ii) petrographical composition different from that of their host sequences, (iii) the presence of lower chaotic segment (breccia), and upper organized segment (grading), (iv) large lateral extent, (v) lateral variability of internal organization of beds, (vi) independence of the fan systems, (vii) transport directions different than in normal turbidites. These features are also characteristic of many other carbonate megaturbidites described from various sequences of Alpine Europe. Siliciclastic megaturbidites are less common: they are featured by their smaller thickness and the lack of the lower, chaotic part.

Key words: megaturbidites, sedimentary structures, lateral variation, Eocene, Pyrenees, Spain.

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INTRODUCTION

This paper is an attempt at defining those main features of megaturbidites which distinguish them from other gravity mass-flow deposits. The features of megaturbidites in the Eocene of the Pyrenees are accepted as representative for this type of beds in general.

Megaturbidites, as understood in this paper, are those beds deposited by debris flows and turbidity currents which are distinguished in their host sequences by their unusually great thickness, great lateral extent, and spatial independence of the fan systems. Such beds are often described as "megabeds" or "big beds", but these terms do not imply their mode of origin.

Megaturbidites, both carbonate and siliciclastic ones, have been described from many fossil sequences and from young sequences at modern continental margins (see Table 1). The number of described megaturbidites should increase in the near future, due to the interest they arouse in sedimentologists and petroleum geologists. Megaturbidites, with their great thickness and high porosity, are potential hydrocarbon reservoirs. They are also excellent marker horizons in geological mapping.

Table 1

Examples of megaturbidites

	Age	Reference
	Fossil megaturbidites	
Siliciclastic megaturbidites		
Tuscan Apennines, Marnoso-arenacea	Miocene	Ricci Lucchi & Valmori, 1980
Southern Apennines, Albidona Fm.	?Eocene	Colella & Zuffa, 1984
Betic Cordillera	Tortonian	Kleverlaan, 1987
Carbonate megaturbidites		
Pyrenees, Hecho Group	Eocene	Johns *et al.*, 1981
		Labaume *et al.*, 1983
		Mutti *et al.*, 1984
Pyrenees, Flysch Meuleon	Turonian-	Debroas *et al.*, 1983
	-Coniacian	Bourroilh *et al.*, 1984
Southern Alps, Bergamo Flysch	Campanian	Bernoulli *et al.*, 1981
Southern Alps, Friuli Flysch	Eocene	Gnaccolini, 1968
Southern Alps, Tolmin Flysch	Eocene	Tunis & Venturini, 1985
Dinarides	Senonian	Mrinjek *et al.*, 1986
Dinarides	Eocene	Marjanac, 1985, 1987
		Engel, 1970
Northern Apennines, Liguria Flysch	U.Cr-Eocene	Mutti *et al.*, 1984
Southern Apennines, Albidona Fm.	Eocene	Colella & Zuffa, 1984
Majorca	Miocene	Rodriguez-Perea, 1986
?Eastern Alps, Allgäu Fm.	L.-M. Jur.	Eberli, 1987
	Megaturbidites at modern continental margins	
Siliciclastic megaturbidites		
Hatteras Abyssal Plain		Elmore *et al.*, 1979
Carbonate megaturbidites		
Exuma Sound, Bahamas		Crevello & Schlager, 1980
Herodotus Abyssal Plain		Cita *et al.*, 1984
Mississippi Fan		Brooks *et al.*, 1986

EOCENE BASINS IN SOUTHERN PYRENEES

Two sedimentary basins existed in southern Pyrenees during the Eocene: eastern – Terrades-Ripoll-Cadi Basin, and western – Ager-Jaca-Pamplona Basin (Fig. 1). The basins have been separated by the Segre Fault which was active during the Eocene. Megaturbidites are present in the sequences of both basins (Pls. I–VI), but especially spectacular ones occur in the Hecho Group in the western basin and these are described here as representative of this type of beds in general.

Ager-Jaca-Pamplona Basin

This basin (Fig. 2), which opened toward the Bay of Biscay, was founded during the Eocene on the Gavarnie Nappe which was then being thrust toward the Ebro Depression (Mutti *et al.*, 1985). The sequences laid down in this basin

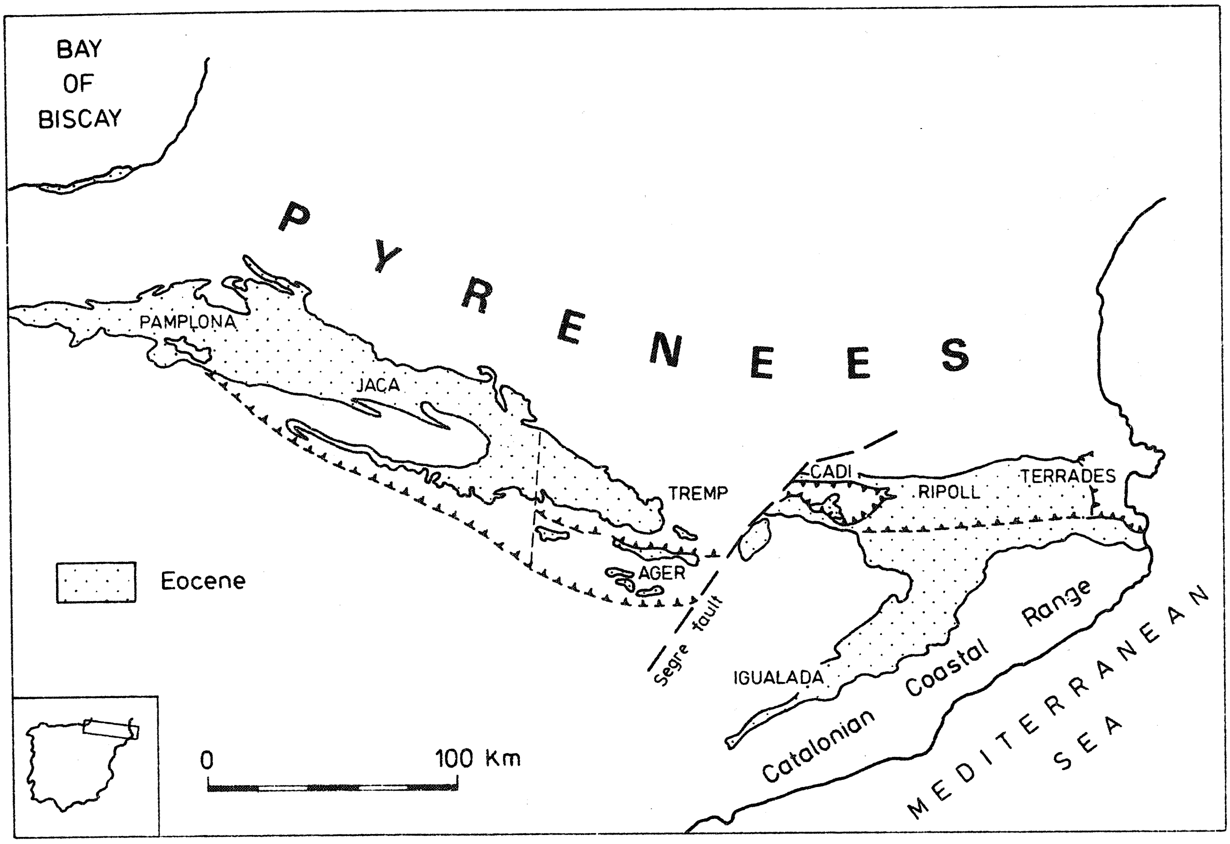

Fig. 1. Location map of Eocene basins in southern Pyrenees

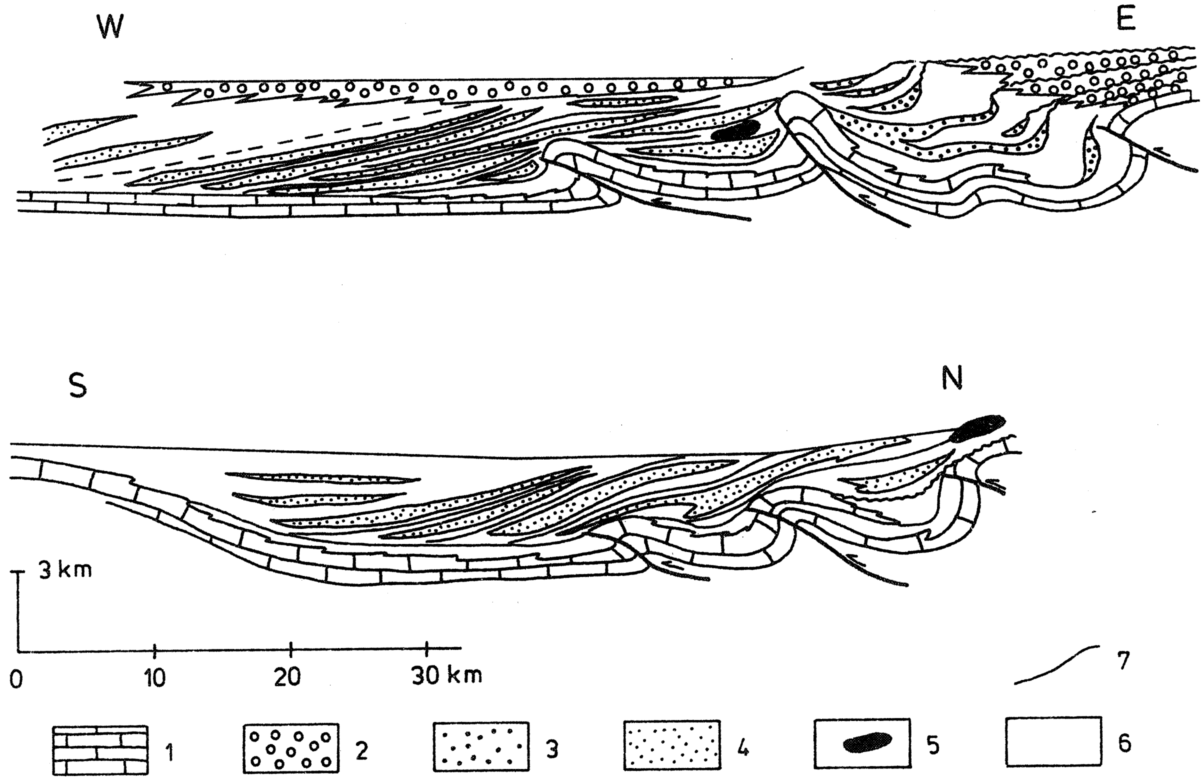

Fig. 2. Cross-sections through Ager-Jaca-Pamplona Basin. Lower section is through central part. *1* — carbonate platforms; *2* — siliciclastics platforms; *3* — channel and canyon fills; *4* — sandstone lobes; *5* — olistholites; *6* — hemipelagic and interchannel deposits; *7* — megaturbidites

display great variety of facies and are perfectly exposed. Their facies and sedimentology have been extensively studied during the last quarter of century (e.g. Soler & Puigdefabregas, 1970; Mutti *et al.*, 1972, 1985; Camara & Klimowitz, 1985; Puigdefabregas & Souquet, 1986).

Deltaic, alluvial and shelf sediments accumulated in the eastern part of the basin. The frontal zone of the advancing, higher, Montsec Nappe separated the Ager Basin in the south from the Tremp-Graus Basin in the north (*cf.* Mutti *et al.*, 1985). Both were piggy-back basins (Ori & Friend, 1984). In the Ager Basin, Palaeogene shelf limestones are overlain by the clastic Figols Sequence whose lower part is represented by the Barronia Formation, interpreted as a tide-dominated deltaic system (Mutti *et al.*, 1985).

The Barronia Formation includes two beds of bioclastic sediments, up to two metres thick, which may be considered megaturbidites. The material of these beds was redeposited from the carbonate platform which delimited the Ager Basin from the east. Similar beds have been recently described from the Pleistocene sequence of the Mississippi delta by Brooks *et al.* (1986).

Classical examples of megaturbidites are known in the Hecho Group (Mutti *et al.*, 1979; Johns *et al.*, 1981; Labaume *et al.*, 1983), Early-Middle Eocene in age. The group is 3.500 m thick and fills the basin 175 km long and 40 – 50 km wide, parallel to the axis of the Pyrenees (Mutti, 1984). The eastern part of the basin has been filled with deposits of channel facies (Pl. VII: 1 – 2; Pl. IX: 1) and channel-levee facies (Pl. VIII: 1 – 2). The western part of the basin comprises sediments of lobe (Pl. IX: 2), fan fringe (Pl. X: 1) and basin plane (Pl. X: 2) facies. The clastic material was supplied from the east and south-east.

According to Mutti (1985; *cf.* Fig. 3) the sedimentary regime in this basin was controlled by sea-level changes. During a low sea-level stand alluvial and deltaic sediments of the eastern margin of the basin (sequence *b* in Fig. 3) were

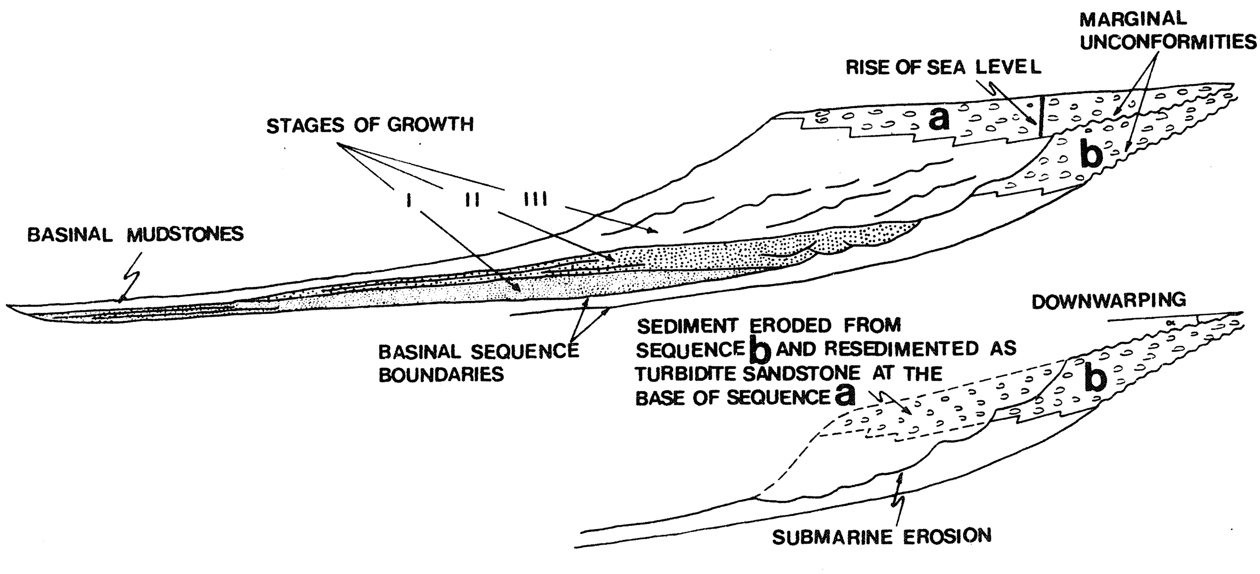

Fig. 3. Relative changes of sea level and different stages of growth of depositional sequences in elongate flysch basin (after Mutti, 1985). Earlier situation shown lower

being eroded, while turbidites were being laid down in the distal part of the basin (stage I). During a sea-level rise the deposition of deltaic and alluvial sediments was resumed in the eastern margin (sequence *a* in Fig. 3), and the turbidites were being laid down closer to the channel zone (stage II). Finally, the channel-levee facies sediments were accumulated adjacent to the deltaic facies (stage III).

Terrigenous sequence of the Hecho Group includes nine carbonate megaturbidites. They are intercalated mainly within the basin-plain and sandstone lobe facies, and only locally they occur within the channel facies.

Terrades-Ripoll-Cadi Basin

The sedimentary facies in this basin differ from those in the western basin, nevertheless the sequences in both can be correlated (Puigdefabregas *et al.*, 1986; Puigdefabregas & Souquet, 1986). The facies in the eastern basin are more shallow-water ones, mainly deltaic, with minor proportion of the turbidite facies. The marls that form distal parts of the deltaic systems include five megaturbidites (Pl. I).

MAIN FEATURES OF MEGATURBIDITES

The megaturbidites in the Eocene sequences of the southern Pyrenees are distinguished within their host sequences by their unusually great thickness – up to 200 m and by their petrographic composition. The megaturbidites are composed of redeposited shallow-water carbonates. They occur in sequences that are mainly siliciclastic (in the western basin) and locally in marly sequences (in the eastern basin). The megaturbidites are more resistant to weathering and hence they stand out in relief (Pl. I). For this reason they are perfect marker horizons in geological mapping, from the ground as well as from the air.

The megaturbidites occur within various facies of the Hecho Group and are spatially independent of the fan systems distinguished within this group (Mutti, 1984). Preliminary studies have shown palaeotransport of the megaturbidite carbonate material from the north and south. The main source was on the north, where the presence of a shallow-water carbonate platform, later destroyed, atop the moving Eaux Chaudes Nappe, was inferred by Labaume *et al.*, (1983, 1985).

Internal structure of megaturbidites

The vertical section of megaturbidites may be divided into four divisions (Fig. 4; Pl. II) grouped in two major segments. The lover segment (divisions I–II) is formed of chaotic breccia, while the upper (divisions III–IV) is a graded sequence.

Division I consists of great blocks (Pl. III: 1, 2) of shallow-water carbonates, arranged parallel to bedding. The greatest blocks are several hundred metres long and several tens of metres wide. Some blocks are plastically deformed (Pl. III: 2; Pl. V: 1), proving that they were transported prior to complete lithification. Smaller fragments of carbonates and shale clasts occur beneath the great blocks at some places. Locally they form mushroom-like diapiric structures (Pl. IV), formed due to overpressured conditions in the fine sediment (Labaume *et al.*, 1983). The lower boundary of division I is sharp, but usually not erosional. The upper part of division I includes numerous shale fragments eroded from the substrate. Transition to division II is gradual.

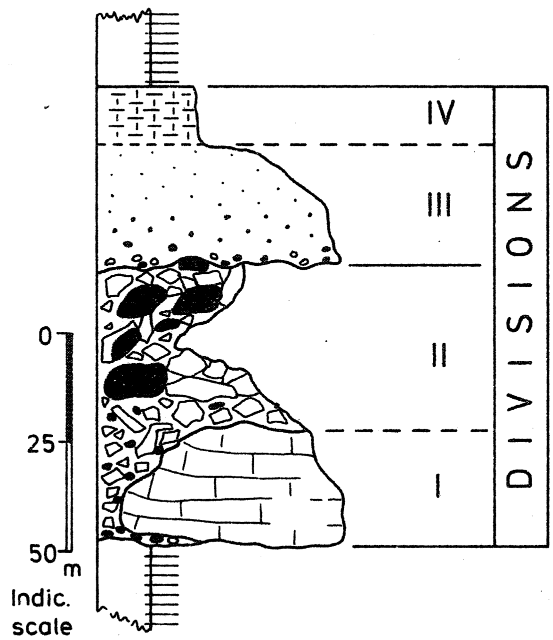

Fig. 4. Internal organization of megaturbidite. *I* — great blocks of platform carbonates and small fragments of limestones (white) and shales (black); *II* — breccia with limestone (white) and shale (black) clasts; *III*— graded division, changing upwards from calcirudite to calcarenite, greater fragments of limestone (white) and shale (black) at bottom; *IV* — marls. Beneath and above the megaturbidite is normal sequence of siliciclastic sediments

Division II is distinguished by numerous shale fragments (Pl. V: 2) Some of them are large, though smaller than those in division I. Some shale fragments are armoured with fragments of breccia. This division is more susceptible to weathering and it forms low relief. Usually it is also more covered with vegetation than division I. The upper boundary of division II is distinct but very irregular.

Division III is identical to normal turbidites. It is clearly graded. At the bottom it locally includes a microbreccia composed of bioclasts with minor shale clasts, the latter disappearing upwards. This microbreccia has been distinguished as a separate division in some papers (e.g. Labaume *et al.*, 1983).

Division IV corresponds to the pelitic part of normal turbidites.

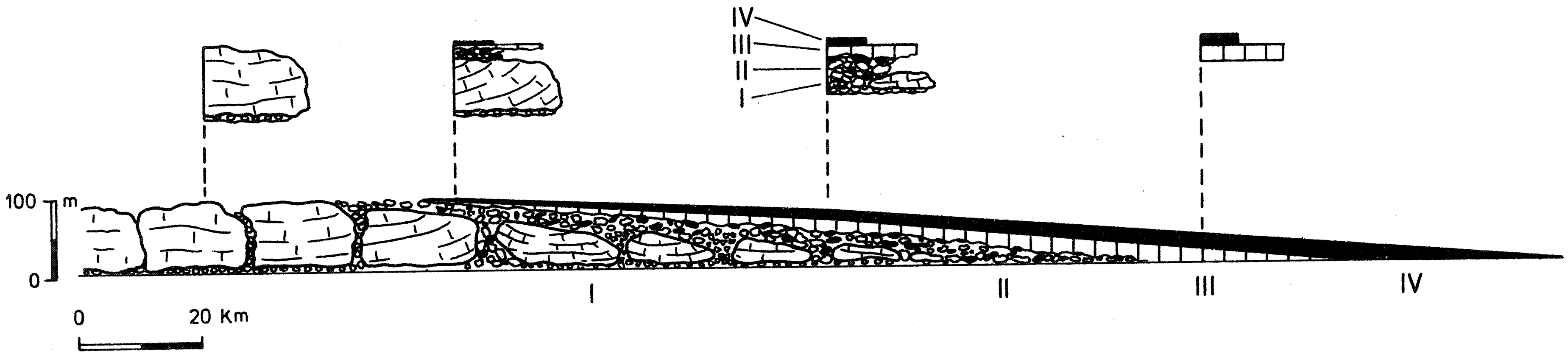

Fig. 5. Lateral variation of internal organization in megaturbidites. Second right section shows full megaturbidite sequence (divisions *I–IV*). To left is proximal zone (divisions *I* and *II*), to right is distal zone (divisions *III* and *IV*)

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Lateral variation of megaturbidites

The sequence of divisions I–IV is considered typical of megaturbidites. Tracing of the megaturbidites from proximal to distal zones reveals distinct changes in their vertical organization (Fig. 5). Divisions II–IV are absent in the proximal zone, while divisions I–II disappear in the distal zone.

The most proximal zones of megaturbidites are composed of giant olistholits, more distally lies a zone of great blocks of microbreccia associated with mushroom-like diapiric structures, still farther lies a zone of megaturbidites comprising all divisions I–IV. In the distal parts the megaturbidites comprise divisions III–IV and are similar to normal turbidites (Pl. VI: 1–2). The thickness and grain-size gradually diminish in the distal direction. This somewhat idealized picture of lateral variation may be used as a criterion for determining the relative distance from the source in megaturbidites.

One should be aware, however, that similar variation in internal organization of megaturbidites may be due to factors other than the distance from the source. Low inclination of the basin slope would favour the deposition of beds that have proximal features, i.e. comprise mainly division I, and the higher divisions poorly developed or absent. This type of proximal development of megaturbidites is characteristic of the Terrades-Ripoll-Cadi Basin. The megaturbidites in this basin have no division II, apparently because of the absence of lithified shales at the bottom over which the mass of carbonate material was moving. The strong development of breccias in the Eocene megaturbidites of the Pyrenees is related to the redeposition of lithified carbonate material. It should be expected that redeposition of weakly lithified carbonates, e.g. marly sediments would result in deposition of megaturbidites with distal characteristics.

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The main distinctive features of the megaturbidites in the Eocene of the southern Pyrenees are: (i) unusually great thickness, (ii) petrographical composition different from that of their host sequences, (iii) the presence of lower chaotic part (breccia), and upper organized part (grading), (iv) large lateral extent, (v) lateral variability of internal organization of beds, (vi) independence of the fan systems, (vii) transport directions different than in normal turbidites.

DISCUSSION

A literature review (Table 1) shows that the main features defined for the Eocene megaturbidites of the Pyrenees are also characteristic of many other megaturbidites in Alpine Europe. The term megaturbidite is still not popularized enough, hence it has been not used for many beds that display the features listed above.

Some objections to the term megaturbidite may arise from the fact that the internal organization of these beds suggests that only their upper divisions have turbidite origin, while the lower divisions were laid down by "debris flows". There is no reason, however, for using different terms for the lower and upper parts of the same bed, formed during one depositional act. It is to be noted that proximal parts of megaturbidites may be described as olisthostromes.

Similarly to megaturbidites, fluxoturbidites (Dżułyński *et al.*, 1959; Unrug, 1963) have been laid down from dense gravity mass-flows and turbidity currents. There is, however, a clear difference between megaturbidites and fluxoturbidites. The fluxoturbidites are contained in fan systems as a facies characteristic of the inner parts of the fans. The megaturbidites, on the other hand, are independent of the fan systems and have greater lateral extents than the fluxoturbidites. It should be stressed that the distinction between the fluxoturbidite and megaturbidite can not be based on a single drill core or outcrop, especially in siliciclastic beds.

According to the definition accepted by the authors, the use of the term megaturbidite is limited to well exposed areas where the internal organization of the beds can be studied laterally. Many sequences include beds that have some megaturbidite features, but the term has been not used for these beds. For instance, the detrital limestones that occur in the Lower Cretaceous hemipelagic sequence of the Križna Nappe in the Tatra Mountains, have some features of megaturbidites. Their beds are 10–50 m thick, but the lower divisions (breccias) are not known in these beds. They have large lateral extent and are important markers in geological mapping.

Megaturbidites are also referred to as seismoturbidites by some authors (Mutti *et al.*, 1984) because their origin is attributed to the seismic activity (Labaume *et al.*, 1985; Seguret *et al.*, 1984). However, not all megaturbidites are related to seismic events (Cita *et al.*, 1984; Brooks *et al.*, 1986), therefore the terms megaturbidite and seismoturbidite should not be considered synonimous.

Megaturbidites should not be identified with normal turbidites of great thickness, which are constituent parts of fan systems and do not differ from other turbidites in their sequences, neither in their petrographic composition nor in the palaeotransport direction.

The majority of known megaturbidites (see Table 1) are carbonate megaturbidites. Siliciclastic megaturbidites are less spectacular and less frequently described. They have smaller thickness, usually not more than 20 metres, because they lack the lower divisions of giant breccias and of mushroom-like diapiric structures.

Some siliciclastic megaturbidites are in fact of mixed type, because they contain important admixture of carbonate material in their lower parts. The Gordo megaturbidite in the Betic Cordillera is an example (Kleverlaan, 1987).

The most common are carbonate megaturbidites in siliciclastic sequences (e.g. megaturbidites in the Hecho Group, Missaglia Megabed in the Lombardian Flysch – see Bernoulli *et al.*, 1981), but there are also carbonate megaturbidites in carbonate sequences (e.g. in the Meulon Basin in the Pyrenees, see Debroas *et al.*, 1983). It should be noted that the distal parts of megaturbidites may be not distinct from normal turbidites, and they may be indistinguishable if their lithology is the same.

Most of the hitherto described megaturbidites occur in deep-water basinal sediments. Their material is redeposited from adjacent shallow-water platforms during seismic events or sea-level changes.

The origin of megaturbidites is related to rare events in the history of the basins. In some basins these were unique events, and in some others they occurred several times.

Megaturbidites, being rapidly accumulated beds, are excellent chronohorizons (Labaume *et al.*, 1985). Their value for correlation is accentuated by giving proper names to many of them, e.g Roncall Unit (Johns *et al.*, 1985), Contessa (Ricci Lucchi & Valmori, 1980), Missaglia Megabed (Bernoulli *et al.*, 1981), Gordo Megabed (Kleverlaan, 1987), Megastrato di M. Joanaz (Tunis & Venturini, 1984), Grande Barre d'Osquiche (Debroas *et al.*, 1983), Kamen-Sutikova Megabed (Marjanac, 1987).

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Streszczenie

GŁÓWNE CECHY MEGATURBIDYTÓW Z EOCENU POŁUDNIOWYCH PIRENEJÓW

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Artykuł stanowi próbę zdefiniowania głównych cech megaturbidytów, które wyróżniają je wśród innych osadów spływów grawitacyjnych.

Przez megaturbidyty rozumiane są takie ławice deponowane przez "debris flows" i przez prądy zawiesinowe, które wyróżniają się wśród goszczących sekwencji przede wszystkim niezwykle dużą miąższością, wielką rozciągłością i niezależnością od systemu stożków.

W pracy omówiono główne cechy megaturbidytów węglanowych z eocenu południowych Pirenejów. Megaturbidyty występują zarówno w basenie wschodnim (Terrades-Ripoll-Cadi), jak i w basenie zachodnim (Ager-Jaca-Pamplona). Właśnie w basenie zachodnim, w grupie Hecho występują najbardziej spektakularne megaturbidyty wapienne. Główne cechy tych megaturbidytów to: (1) niezwykle duża miąższość, (2) skład petrograficzny odmienny od petrografii sekwencji goszczących, (3) obecność w ławicy dolnego odcinka nieuporządkowanego (brekcje) i górnego uporządkowanego (frakcjonalne uziarnienie), (4) duża rozciągłość lateralna, (5) zmienność lateralna organizacji wewnętrznej ławic, (6) niezależność od systemu stożków, (7) kierunki transportu odmienne od kierunku transportu w normalnych turbidytach.

Megaturbidyty znane są również z innych sekwencji kopalnych, jak i z sekwencji młodych osadów na brzegach współczesnych kontynentów. Większość znanych megaturbidytów to megaturbidyty węglanowe, rzadziej opisywane są megaturbidyty siliciklastyczne, których ławice mają mniejszą miąższość i pozbawione są dolnego, nieuporządkowanego odcinka.

Wewnętrzna organizacja ławic megaturbidytów sugeruje turbidytową genezę jedynie wyższych członów takich ławic, niższe człony były deponowane w wyniku "debris flow". Nie ma jednak powodu stosować innych terminów dla dolnych i dla górnych członów tej samej ławicy, tym bardziej że stanowią one produkt jednego aktu depozycji. Podobnie ławice fluksoturbidytów były deponowane z gęstych spływów grawitacyjnych i z prądów zawiesinowych. Różnice między megaturbidytami a fluksoturbidytami są jednak wyraźne. Fluksoturbidyty wchodzą w skład systemu stożków jako facje charakterystyczne dla wewnętrznych partii stożków. Megaturbidyty są natomiast od systemu stożków niezależne i mają znacznie większą rozciągłość lateralną niż fluksoturbidyty. Należy zatem zaznaczyć, że na podstawie jednego odsłonięcia nie można odróżnić ławic fluksoturbidytów od ławic megaturbidytów, szczególnie jeśli tworzy je materiał siliciklastyczny. Zgodnie z definicją przyjętą przez autorów stosowanie terminu megaturbidyt jest ograniczone do obszarów dobrze odsłoniętych, w których organizacja przestrzenna ławic jest znana.

Można sądzić, że liczba opisanych megaturbidytów wzrośnie w najbliższym czasie, gdyż budzą one zainteresowanie zarówno sedymentologów, jak i geologów naftowych. Ze względu na duże miąższości i dużą porowatość megaturbidyty stanowią potencjalne kolektory węglowodorów. Stanowią również doskonałe horyzonty korelacyjne.

Termin megaturbidyt nie jest jeszcze dostatecznie spopularyzowany, toteż ławice o cechach megaturbidytów nie zawsze są określane tym terminem. Pewne cechy megaturbidytów mają detrytyczne wapienie występujące wśród hemipelagicznej, marglistej sekwencji dolnej kredy kriżniańskiej Tatr. Mają one od 10 do 50 m miąższości, ale dolne interwały (brekcje) nie są w nich znane. Mają jednak znaczny zasięg lateralny i stanowią ważne horyzonty przewodnie przy pracach kartograficznych.

Megaturbidyty są niekiedy określane mianem sejsmoturbidytów, gdyż ich geneza często jest związana z działalnością sejsmiczną. Nie wszystkie jednak megaturbidyty powstały w związku z wydarzeniami sejsmicznymi, stąd też nie należy terminów megaturbidyt i sejsmoturbidyt uważać za synonimy.

Nie należy też utożsamiać megaturbidytów z normalnymi turbidytami o dużej miąższości, które wchodzą w skład systemu stożków i nie różnią się składem petrograficznym ani kierunkami transportu od innych, normalnych turbidytów.

Należy też zaznaczyć, że proksymalne strefy ławic megaturbidytowych mogą być opisywane jako olistostromy.

EXPLANATIONS OF PLATES

Plate I

Five megaturbidites (*1–5*, in younging order) marked in relief, Gombren, eastern basin

Plate II

Megaturbidite exposed in Hecho-Urdes road, western basin, *1–4* – divisions *I–IV*

Plate III

Mushroom-like diapiric structure ca. 10 m high. Roncal, western basin

Plate IV

1 – Megaturbidite, division *I* – megabreccia. Women for scale (encircled). Hecho-Urdes road, western basin
2 – Block of plastically deformed platform limestone (arrow) at base of megaturbidite. Same locality

Plate V

1 – Megaturbidite with plastically deformed blocks of platform limostones. Same locality as Pl. IV
2 – Megaturbidite, division *II*, voids after large shale fragments. Same locality

Plate VI

1, 2 – Distal part of carbonate megaturbidite in siliciclastic deposits of fan-fringe facies. *1* – calcarenite; *2* – marl. Beds are overturned. Western basin, near Broto

Plate VII

1 – Conglomerate filling Arro Canyon – eastern part of western basin
2 – Example of channel facies, sandstone sequence filling Banaston Channel; eastern part of western basin

Plate VIII

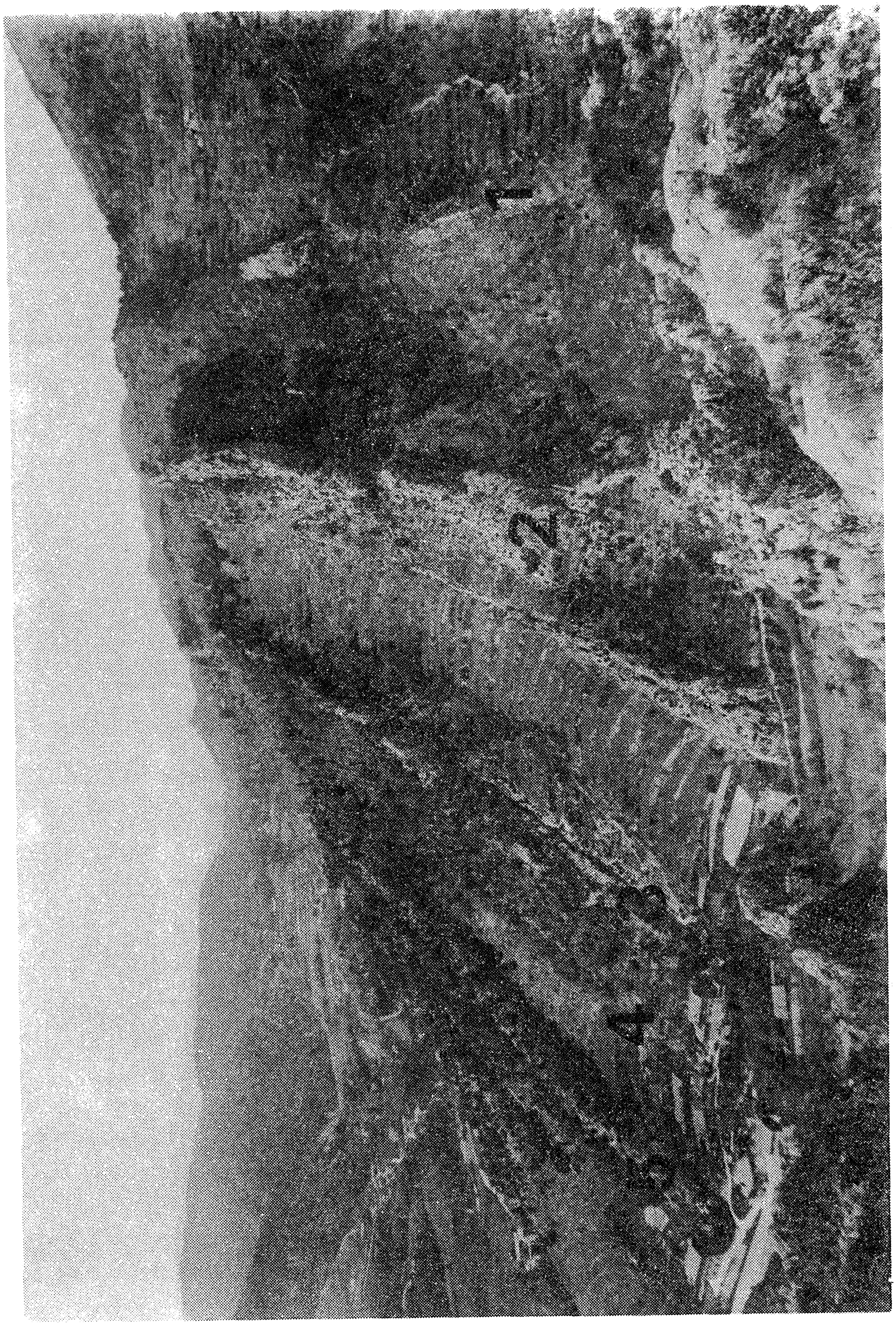
1, 2 – Examples of channel-levee facies. Angular unconformity within the sequence of sandstones and mudstones is visible in 2. Eastern part of western basin

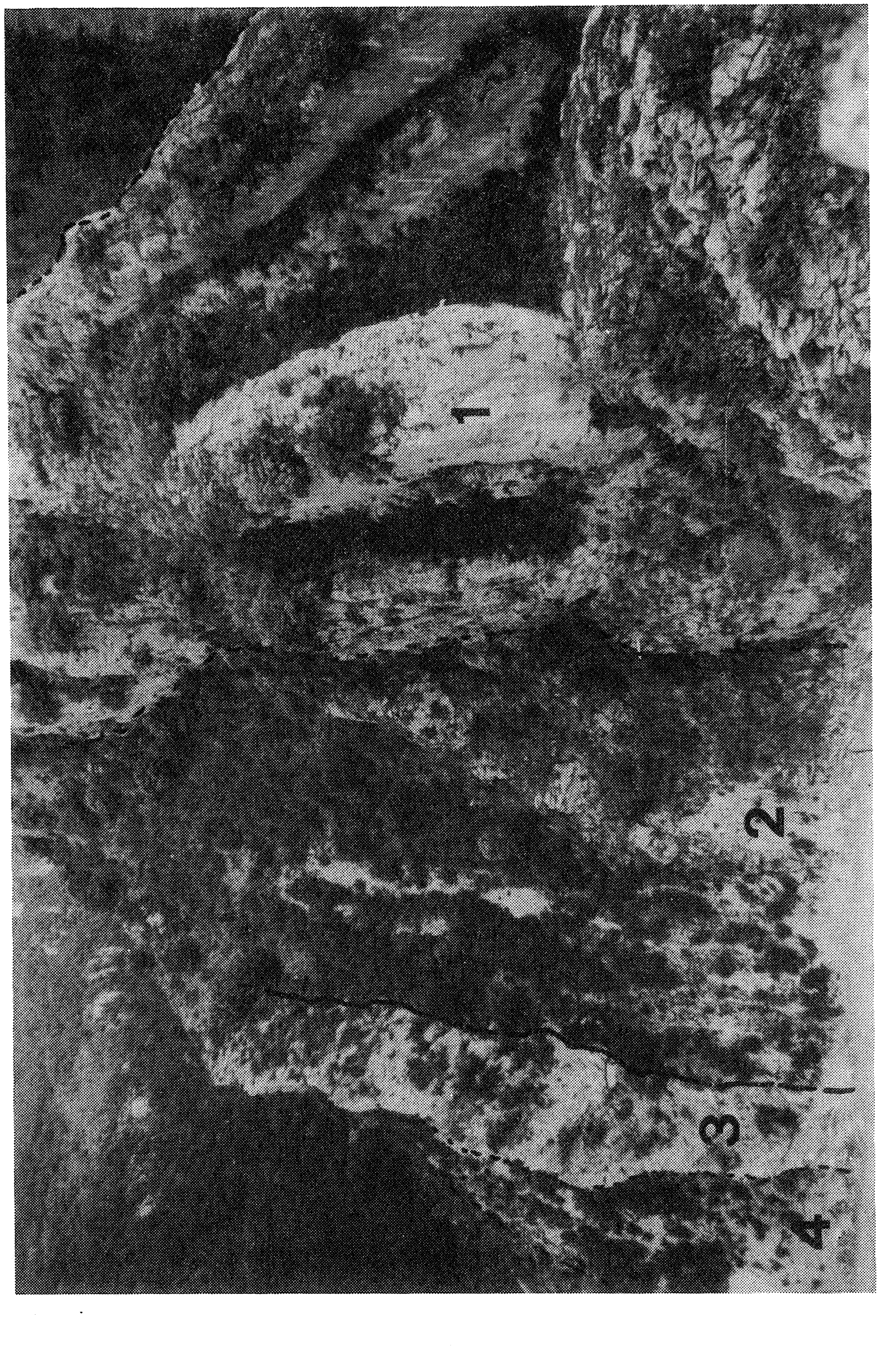
Plate IX

1 – Example of channel facies, thinning-upwards sequence filling Ainsa Channel. Eastern part of western basin
2 – Example of sandstone lobe facies. Overturned beds. Near Broto, western basin

Plate X

1 – Example of fan-fringe facies, thin-bedded sandstones. Central part of western basin
2 – Example of basin-plain facies, hemipelagic shales. Lighter beds are more calcareous. Central part of western basin

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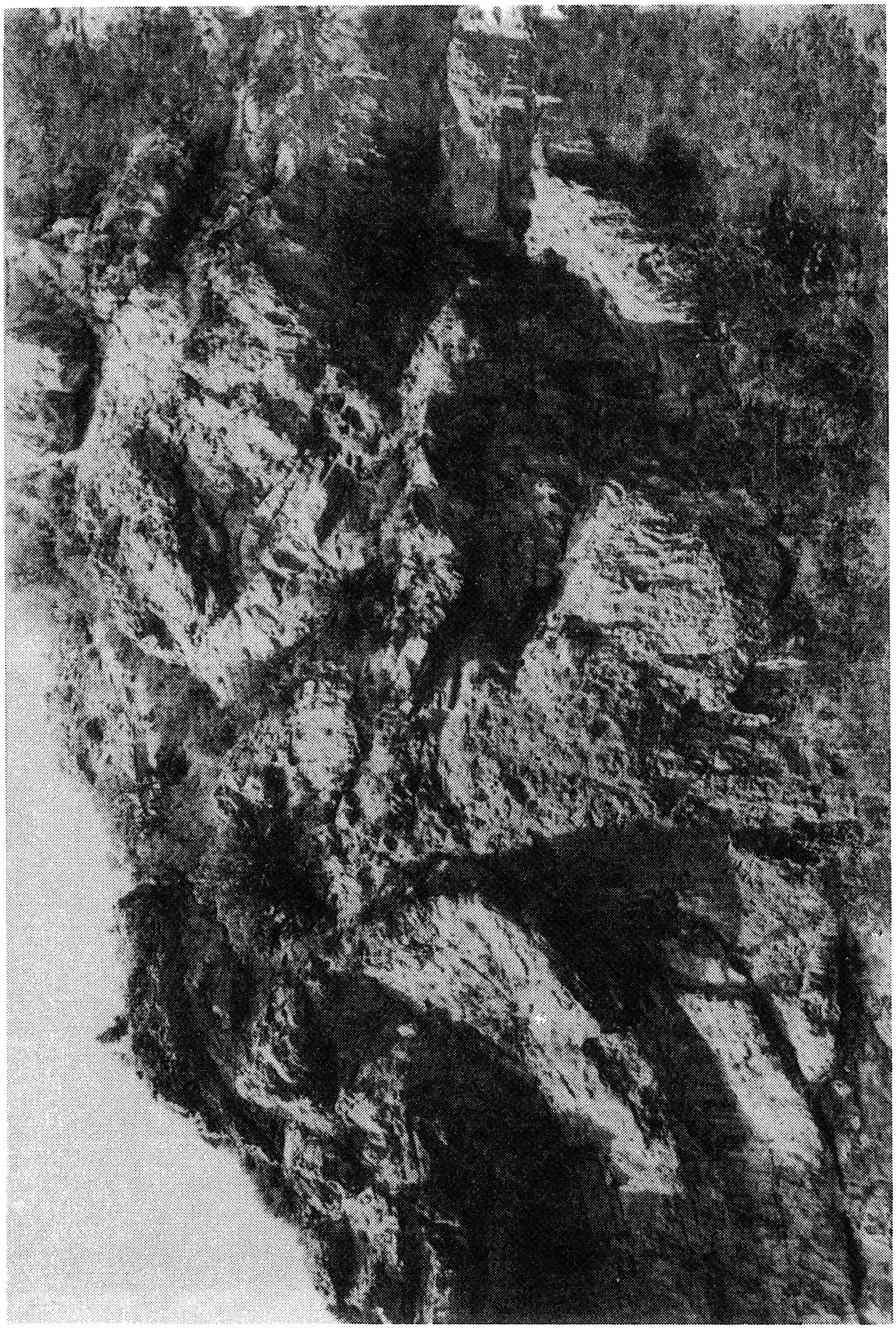

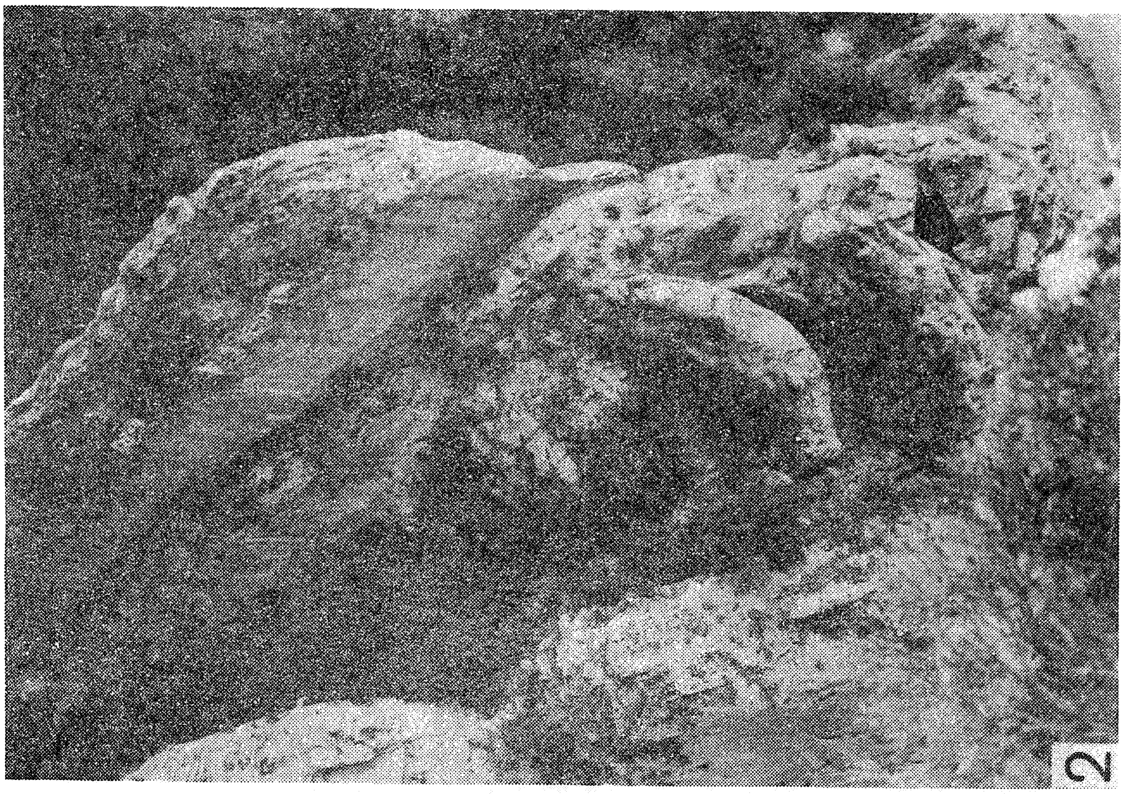

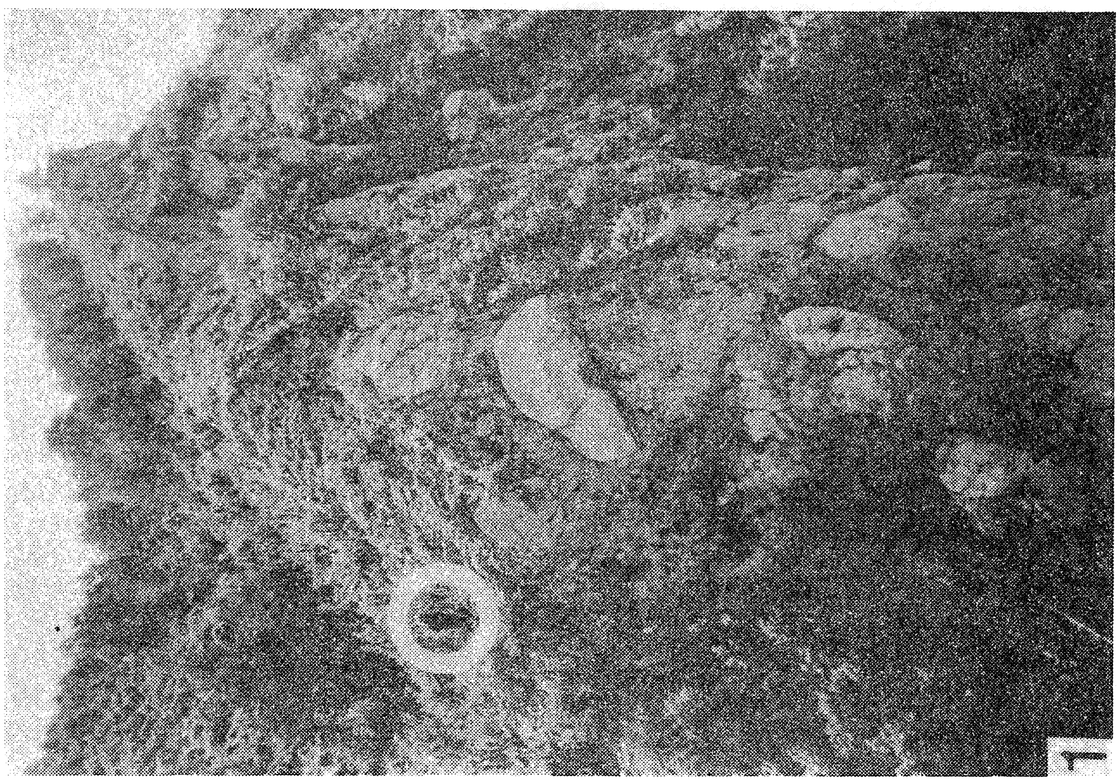

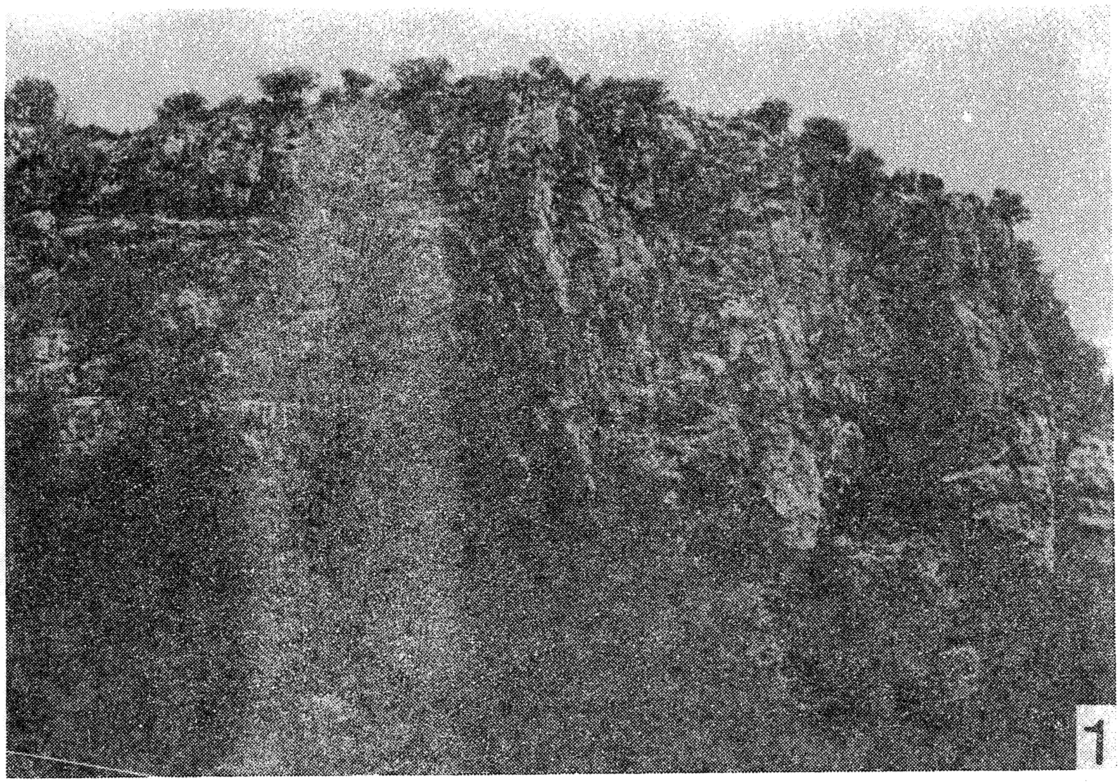

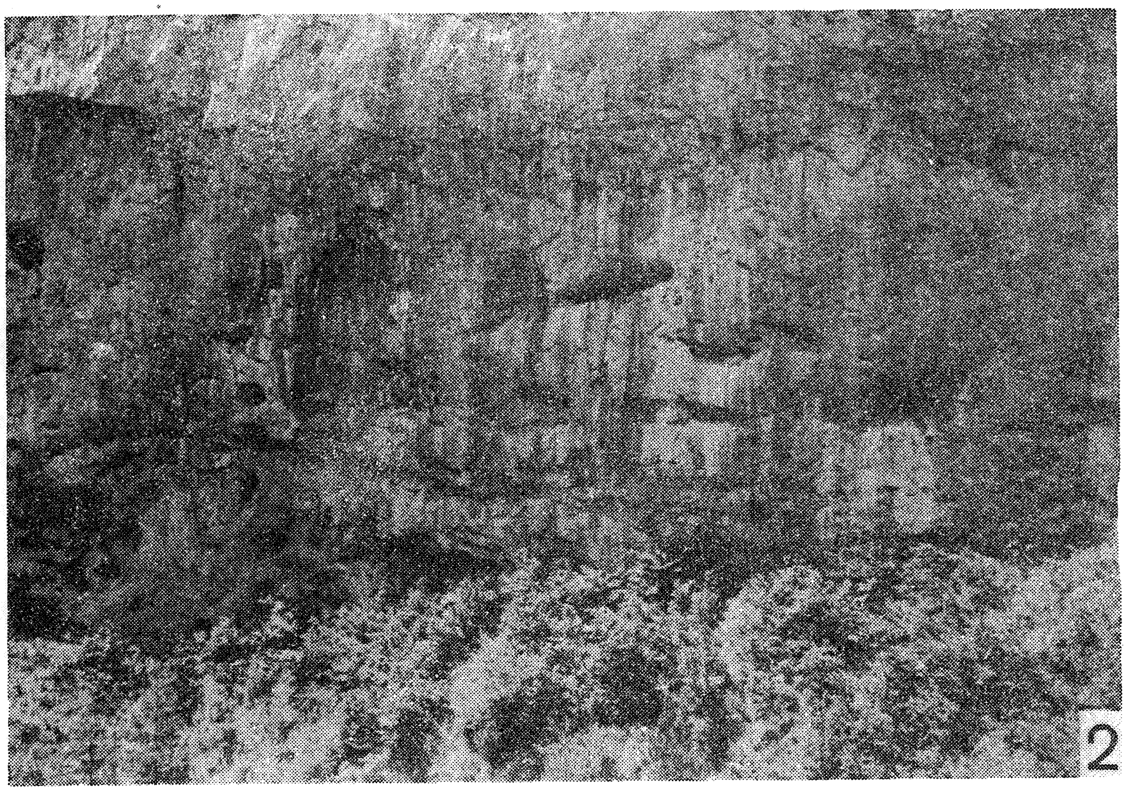

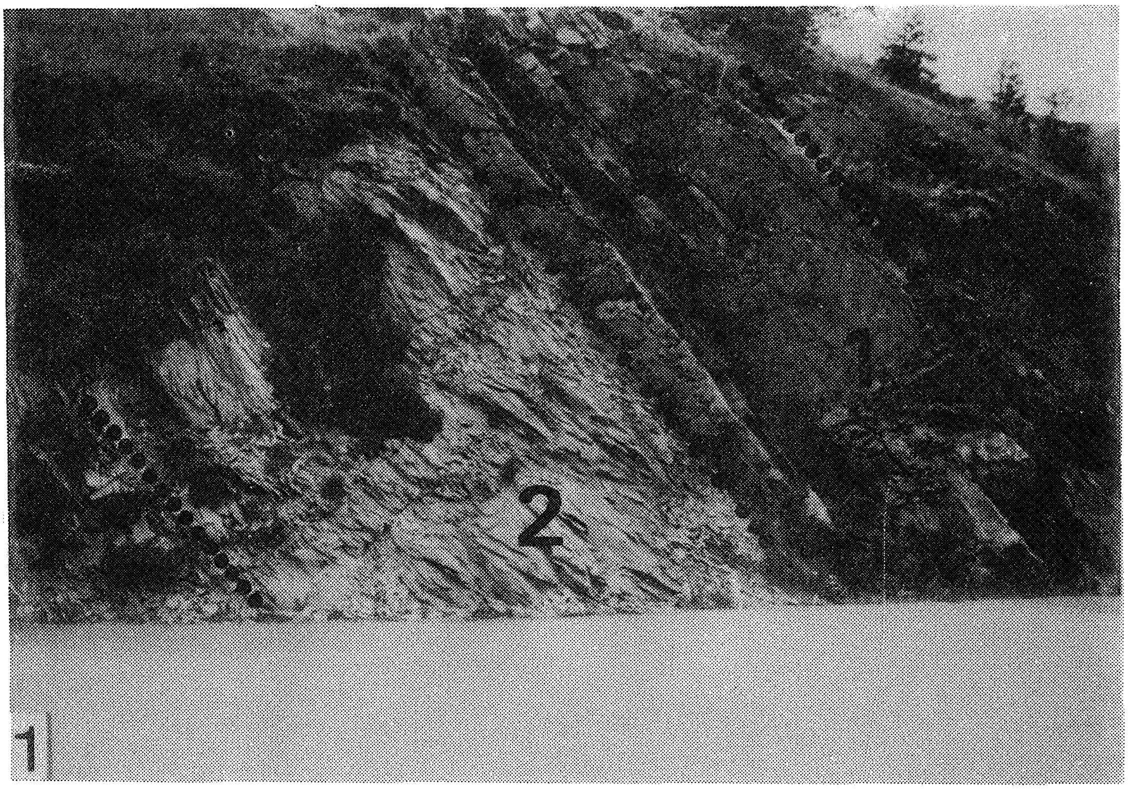
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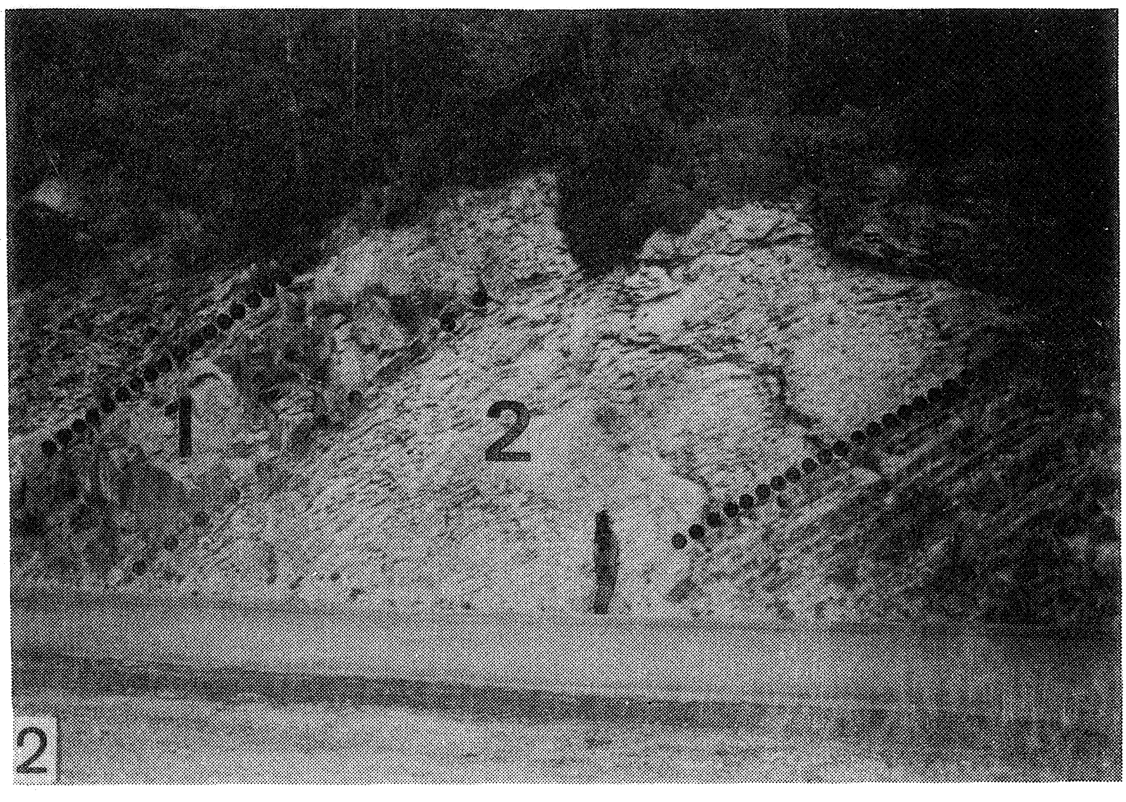
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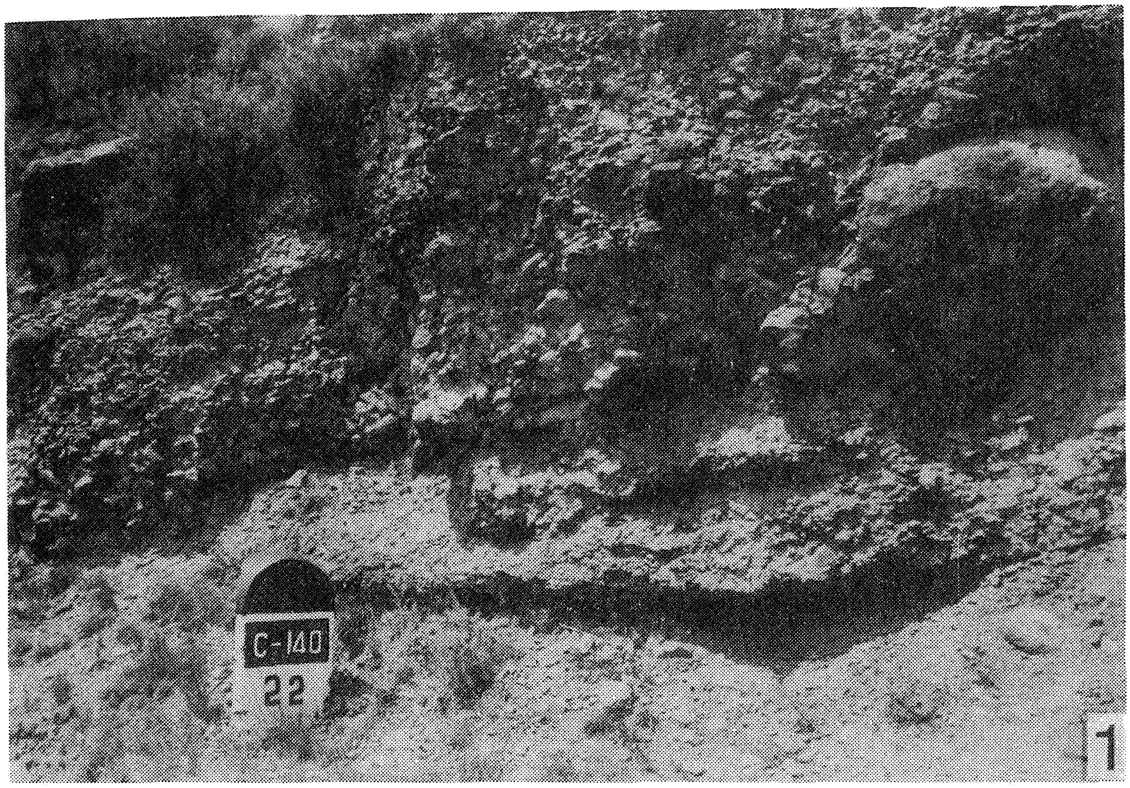
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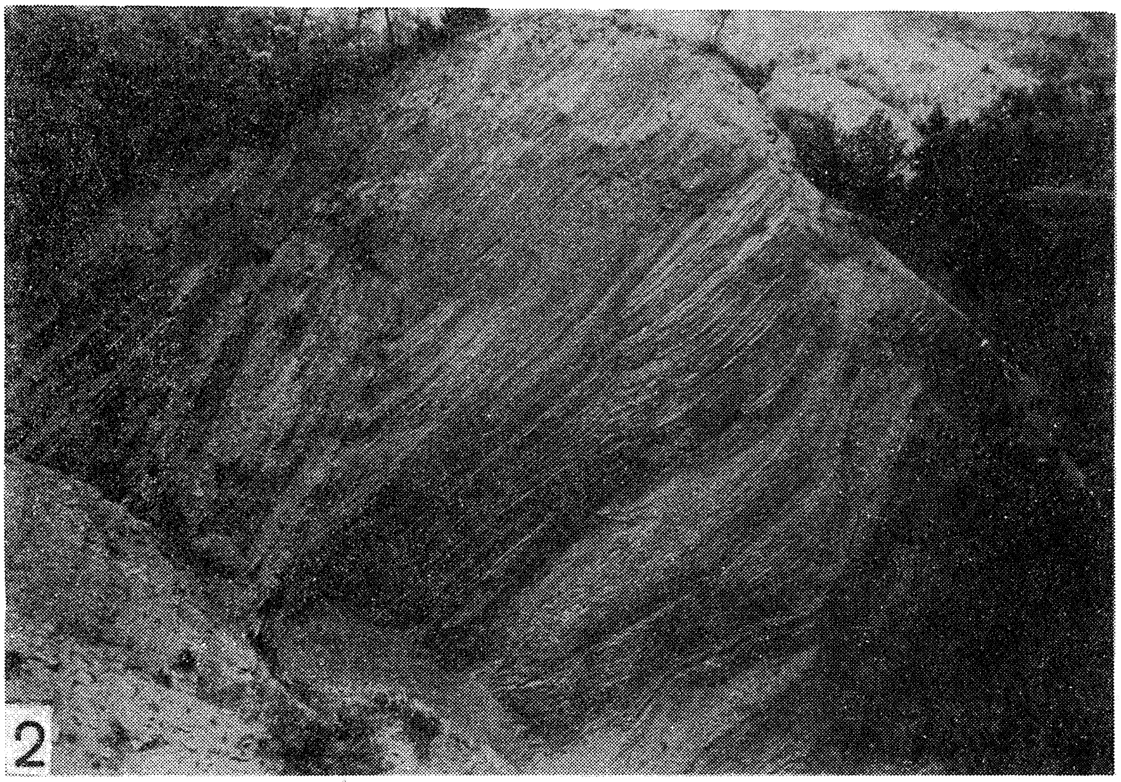

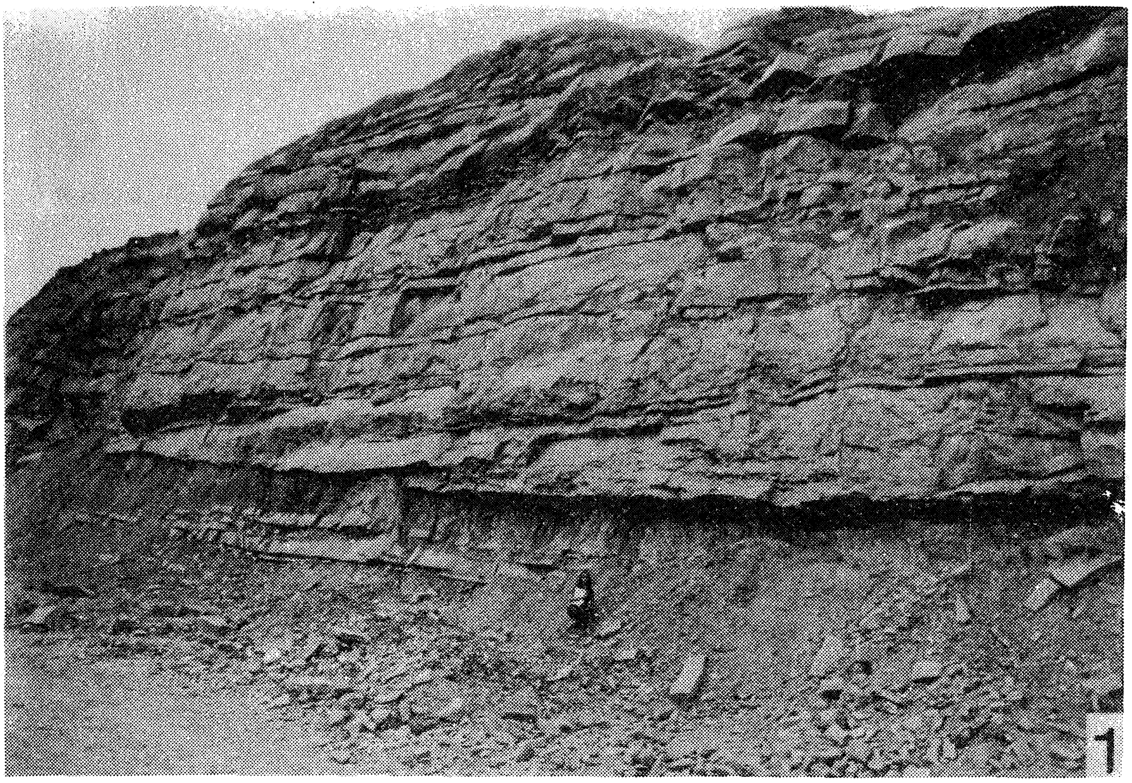
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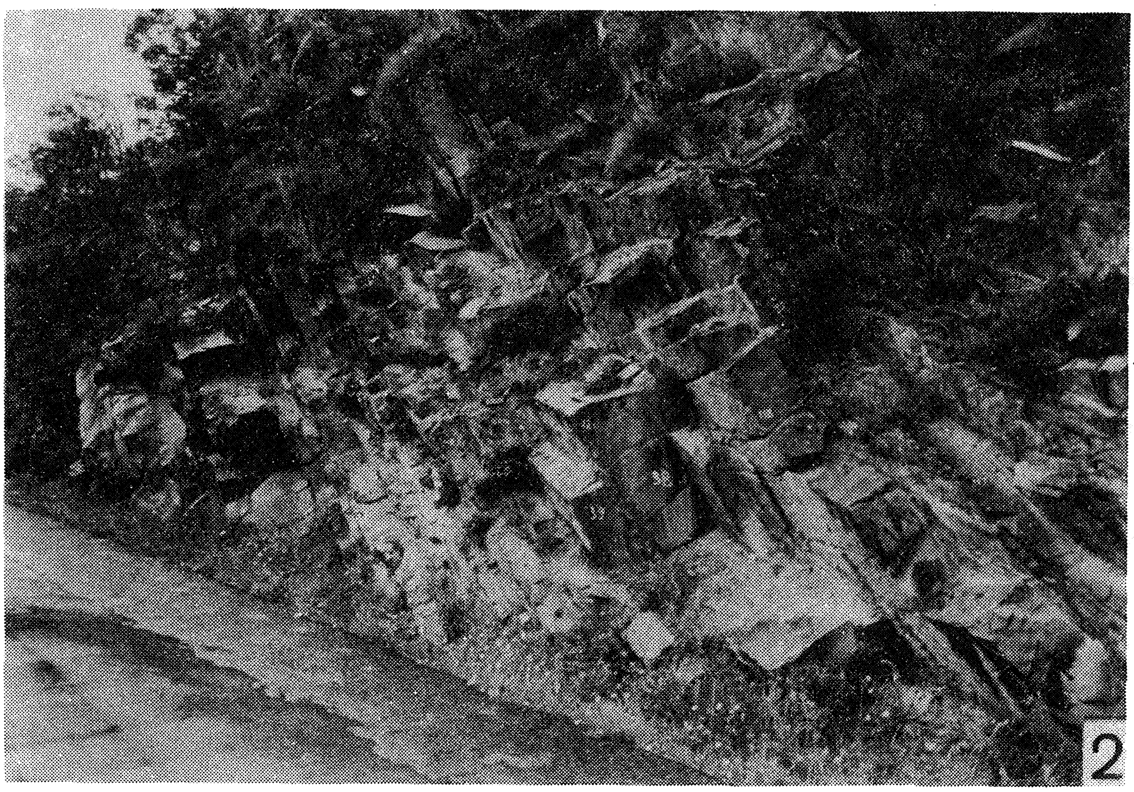
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