

BAILEY LIMESTONE (LOWER DEVONIAN) OF SOUTHWESTERN ILLINOIS: A CARBONATE TURBIDITE

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ABSTRACT

The Bailey Limestone (Lower Devonian) of southwestern Illinois consists of approximately one hundred complete and incomplete superpositions, decimetric in thickness, of the following five microfacies: M1: graded bedded to massive coarse-grained crinoidal calcarenite, M2: incipiently graded to parallel laminated fine-grained crinoidal calcarenite, M3: parallel laminated crinoidal and pelletal biocalcilitite, M4: massive to laminated spiculitic and pelletal biocalcilitite, M5: massive pelletal bioclastic micrite. The sedimentary structures and textures of the microfacies are those of the A-B-C-D Bouma sequence in which units A through D are interpreted as turbidity current deposits, and unit E as inter-turbidite sediment. Application of Walker's index of proximity P permits reconstruction of the vertical evolution of the sequence as representing a submarine fan system which displays oscillations from inner fan through mid- and outer-fan into basin plain subenvironments. The Bailey Limestone is the first carbonate turbidite reported in the Paleozoic depositional history of the Illinois Basin.

INTRODUCTION

The Bailey Limestone is the basal unit of the Lower Devonian Series in the Illinois Basin (Willman *et al.*, 1975). It underlies a large portion of the deepest part of the basin, reaches a maximum thickness of 120 meters, and is partially exposed in high cliffs of the Mississippi River bluffs in southwestern Illinois.

The Bailey Limestone consists of approximately one hundred thin to medium-bedded couplets (10-15 cm thick) of limestones and cherty limestones or cherts displaying the characteristic sedimentary structures of turbidites (Bouma sequence), among which sole markings and graded bedding are prominent.

Carbonate turbidites are relatively rare in cratonic basins where they occur

during the initial phases of filling. The Bailey Limestone is the first case of this type of carbonate deposition reported in the Illinois Basin.

TECTONIC FRAMEWORK

During Silurian to Early Devonian times a structural depression, called the Metropolis Depression (Rogers, 1970), occupied the southern portion of the Illinois Basin, and extended southwestward beyond the pre-Cretaceous truncation into the Mississippi Embayment (Fig. 1). During Early to Middle Silurian times, the depression was maintained because of the inability of carbonate sedimentation to fill more than the marginal areas of the subsiding Illinois Basin. During Late Silurian times, carbonate shelves related to reef development prograded from east and west and coalesced forming a platform which bordered the Metropolis Depression. Following a lowering of sea level at the end of Silurian times, the platform was subaerially exposed as a low lying landmass and the shoreline located high on its seaward slope. The platform was the source of substantial sediments transported into the depression. Fine-grained detrital quartz, silica, and argillaceous materials were eroded from older sediments exposed on the shelves whereas the relatively coarse-grained, shallow water components (crinoids, sponge spicules and glauconite) were of primary derivation from the shelf foreslope environments.

Deposition of sediments in the depression began in latest Silurian to Early Devonian times (Collinson, 1967; Rogers, 1970) and the resulting sequence is represented by Randol Shale, Bailey Limestone, Grassy Knob Chert, Backbone Limestone, and Clear Creek Chert. These units attain a maximum thickness of nearly 400 meters in the center of the Metropolis Depression (Rogers, 1970) and their geometry (Fig. 2) shows that they gradually filled the depression.

METHODS

The investigated section is a vertical cliff in a rugged wooded area called Pine Hills along the Mississippi River bluffs, located about eight kilometers southeast of Grand Tower, Union County (Wolf Lake Quadrangle, SE. 1/4, SW. 1/4, NE. 1/4, Sec. 16, T. 11 S., R. 3W).

The exposed column is 40 meters thick and was sampled at an average vertical interval of 10 centimeters in order to provide an adequate representation of the style of deposition of the turbidites. More than 400 thin sections oriented perpendicular to bedding were prepared and subjected to a detailed petrographic study following the statistical techniques used by Carozzi and coworkers for microfacies investigations (see for instance, Okhravi and Carozzi, 1983). This method calls for measuring indexes of clasticity and frequency of all detrital components, mineral or biogenic, and frequency of all in-place biogenic components over standard areas of the thin sections. These data are interpreted in terms of paleoenvironmental factors such as energy of transporting agents, and in terms of paleoecology of the various benthic and planktic biota. In this particular study (Banaee, 1981), clasticity indexes were determined for crinoid bioclasts, detrital quartz and glauconite grains. Frequency indexes were determined for bioclasts including crinoids, ostracods, brachiopods, sponge spicules, trilobites, radiolarians, and glauconite grains. The proportions of total bioclasts, matrix (bioclastic and/or lithic

pelletoidal), cement, and pyrite were established on the total surface area of a thin section in percentages (total bioclasts + matrix + cement + pyrite = 100%). The intensity of bioturbation was expressed in percentages as follows: 25% for low, 50% for medium, and 75% for high degree of bioturbation. Microscopic sedimentary structures such as massive or laminated structures or graded bedding were also recorded on standardized data sheets.

MICROFACIES

After detailed petrographic investigation, the thin sections were divided into five distinct microfacies on the basis of size, frequency and type of biogenic components, proportions of matrix (bioclastic and/or pelletoidal), total bioclasts and sedimentary structures. The validity of the five microfacies was verified by an INTERIM computer program (Demirmen, 1969), and the inter-relationships between microfacies were established by multivariate correlation of mean values of components against their respective microfacies using the SOUPAC correlation coefficient program (SOUPAC, 1976).

The microfacies are briefly described below in order of decreasing grain size, decreasing proportion of benthic bioclasts, increasing proportion of planktic bioclasts, and increasing amount of pelletoidal matrix (Fig. 3). These trends indicate a gradual decrease in the hydraulic energy of the transporting agent as expressed in turbidity current deposition.

Microfacies 1: coarse-grained crinoidal biocalcarenite with association of syntaxial rim cement and bioclastic matrix, texture graded bedded to massive, bioturbation low.

Microfacies 2: fine-grained crinoidal biocalcarenite with bioclastic to pelletoidal matrix, texture incipiently graded bedded to parallel laminated, bioturbation medium.

Microfacies 3: crinoidal and pelletoidal biocalcilitite with scattered sponge spicules and radiolarians, texture parallel laminated, bioturbation medium to high.

Microfacies 4: spiculitic, pelletoidal biocalcilitite, texture massive or laminated, bioturbation high.

Microfacies 5: pelletoidal bioclastic micrite, texture massive, bioturbation medium.

IDEAL DEPOSITIONAL SEQUENCE

The average values of the measured petrographic parameters allow to prepare a graphic representation of an ideal complete depositional sequence of the above-described five microfacies, interpreted by means of an energy level curve (Fig. 4). The behavior of the various parameters can be summarized as follows.

The curves representing the frequency and elasticity of crinoids, the frequency of ostracods, brachiopods, trilobites, total bioclasts, cement and the frequency and elasticity of glauconite grains display a decrease upward. The curves expressing the frequency of sponge spicules, the percentage of pelletoidal matrix, and the intensity of bioturbation (until microfacies 4) show an increase upward.

The curves showing elasticity of detrital quartz grains and frequency distribution of radiolarians show an increase and then a decrease upward. They both display a peak in microfacies 3, for quartz it is 0.10 mm. Because the average size of radiolarians is 0.18 mm, their frequency peak appears also size controlled. The

curves showing the behavior of bioclastic matrix and of pyrite are random. The energy level curve of the transporting agent decreases upward through the superposed microfacies.

In summary, the ideal depositional sequence (microfacies 1 through 5) shows that relatively coarse-grained detrital biogenic components (dominated by benthic fauna) are replaced gradually by smaller and lighter detrital (quartz) and biogenic components (planktic radiolarians, sponge spicules), and pelletoidal matrix. These variations are accompanied by sedimentary structures ranging from sole markings and erosional features at the base of beds through graded bedding to laminated and massive. The association of all these textural and compositional features indicates a mechanical redeposition of the entire sequence by waning hydraulic energy in a relatively deeper water environment.

The ideal sequence is similar to the fining upward sequence typical of deposition by turbidity currents in detrital siliciclastic sediments, and known as the Bouma sequence (Bouma, 1962). It consists of the turbidite units A, B, C, D, and the interturbidite unit E (Fig. 4). Complete Bouma sequences are relatively rare and incomplete sequences more commonly found (BCD, BC, CD, AD, etc.). This observation also applies to the carbonate turbidites of the Bailey Limestone (Fig. 5).

ORIGIN OF COMPONENTS

Bioclasts including crinoids, ostracods, brachiopods, trilobites, sponge spicules and detrital glauconite grains probably originated from the shelf foreslope or slope environments and are sub-contemporaneous with deposition. Radiolarians were contemporaneous planktic fauna. Detrital quartz grains occurring in limited size range, are probably recycled from Silurian or finely arenaceous earlier deposits. Silica (responsible for early chertification) and clay minerals were also derived from older Silurian sediments.

VERTICAL EVOLUTION OF INVESTIGATED SECTION

The typical succession of numerous carbonate turbidites which forms the Bailey Limestone is well expressed by the detailed graphic representation of the variations of the parameters and the energy curve interpretation (Banaee, 1981). A typical example of the 30 to 40 meters interval is sufficient (Fig. 6). However, since the present study dealt only with one vertical column it was not possible to establish by direct observation the evolution in time and space of the corresponding submarine fan. This situation of insufficient outcrops is not unusual also among siliciclastic turbidites in the flysch of mountain ranges. An elegant and successful technique for interpreting the evolution of the depositional environment of turbidites under such conditions has been proposed by Walker (1967). It uses the concept of proximity, that is the assumed distance along the basin slope from the point where deposition by turbidity currents begins. Walker divided turbidite sequences into groups based on changes in the thickness and/or frequency of occurrence of individual units of the Bouma sequence. He proposed a proximity index $P = A + 1/2 B$, in which A and B are the percentage of beds in each group beginning respectively with unite A and B , hence P varies from very proximal (100%) to very distal (0%).

The Bailey Limestone sequence having been subdivided into individual units (microfacies 1 to 5, equal to A to E in the Bouma sequence) on the basis of

petrographic observations and not according to megascopic field observations, it was necessary to modify accordingly the techniques of obtaining Walker's P index. By means of appropriate subroutines of INTERIM computer program (Banace, 1981), the frequency of occurrence of individual Bouma's divisions and their associations (corresponding to individual microfacies and their types of superpositions) were plotted at an arbitrarily selected constant interval of 1.5 meters (10 control points) of the stratigraphic section (Fig. 7). The values of P were calculated for the same interval. The numerical values of P vary for the entire section from proximal (60%) to very distal (0%). The value of P was equal to zero in two cases: where microfacies 1 (A) and 2 (B) were absent, and where there was only microfacies 5 (E).

The general trend of the stratigraphic variation of the P index (Fig. 7) displays three successive highs (at 5-7, 17, and 29-30 m.) separated by lows, followed by a final rise terminating at 40 m. A comparison with recognized depositional subdivisions of submarine fans (Mutti and Ricci-Lucchi, 1972; Mutti, 1974; Walker, 1969, 1978; Cook, Hine and Mullins, 1983) permits further interpretation of the variation in time of the P index in terms of inner, middle, and outer fan environments, as well as basinal plain environments (Fig. 7), that is in general terms of decreasing energy or increasing relative depth.

CONCLUSIONS

The Bailey Limestone (Lower Devonian) in southwestern Illinois consists of approximately one hundred complete and incomplete superpositions of five distinct carbonate microfacies which display the characteristics of the A-B-C-D-E Bouma sequence and are interpreted as carbonate turbidites. Application of Walker's index of proxinality P permits reconstruction of the vertical evolution of the investigated sequence as representing a submarine fan system which displays oscillations from inner fan through mid and outer fan into basin plain subenvironments.

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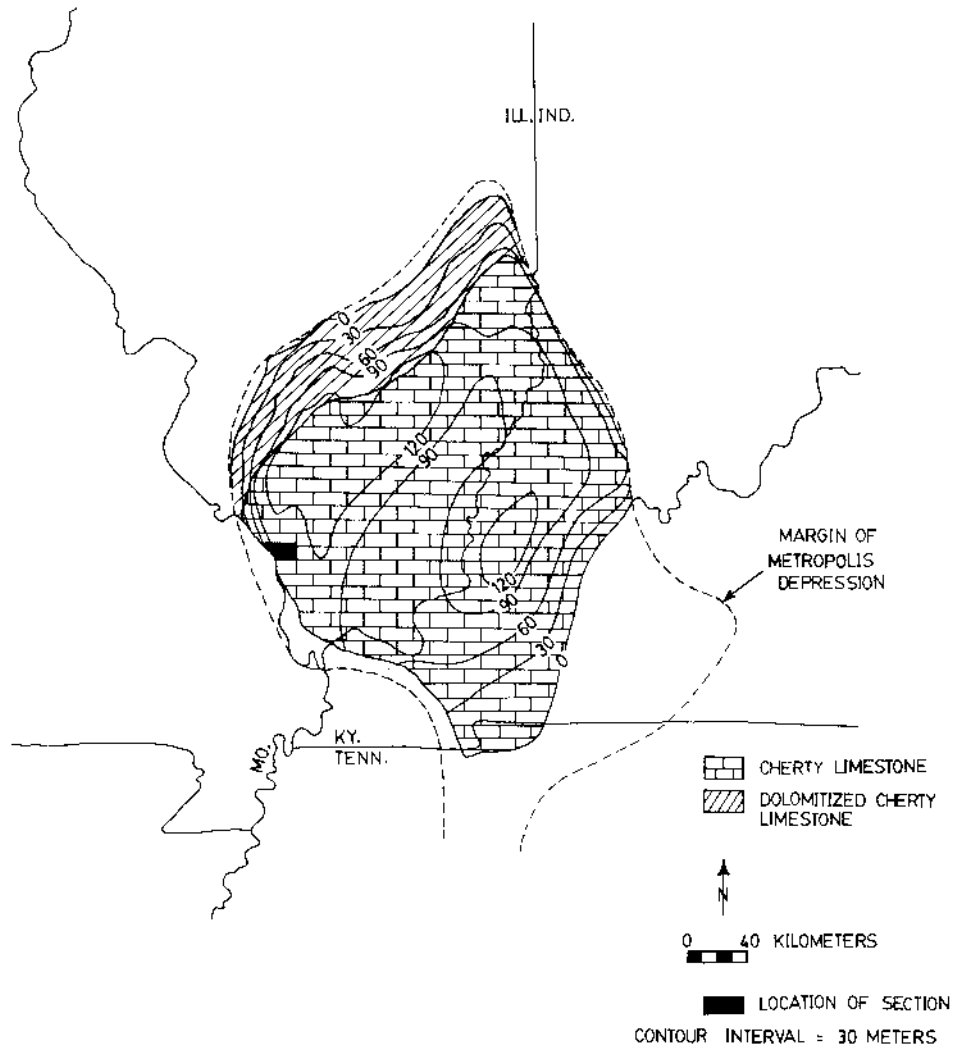


Fig. 1. Isopachs and lithofacies of Bailey Limestone (modified from Rogers, 1970).

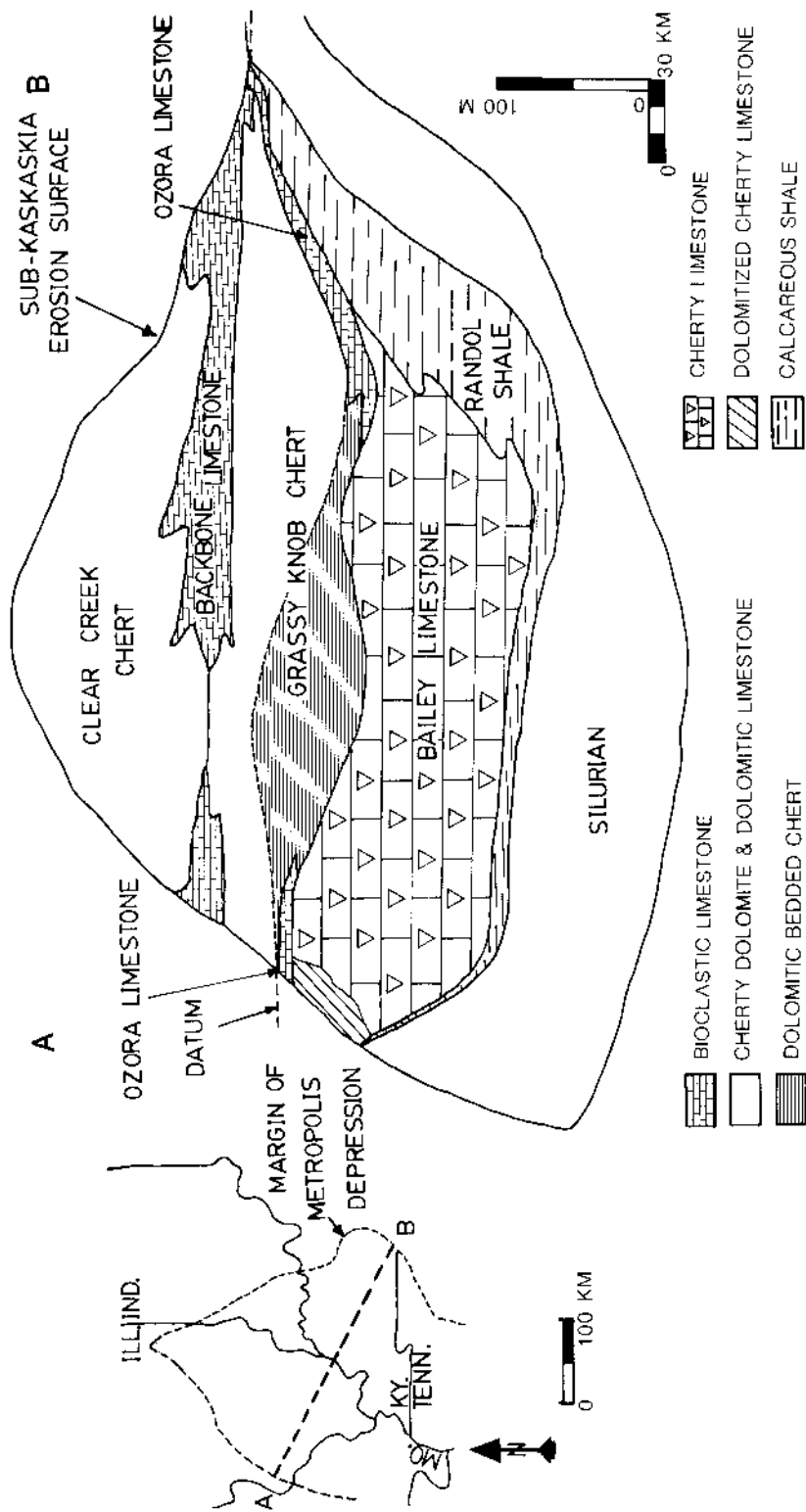


Fig. 2. Lithologic cross-section of the Uppermost Silurian and Lower Devonian rocks in Metropolis Depression (modified from Rogers, 1970).

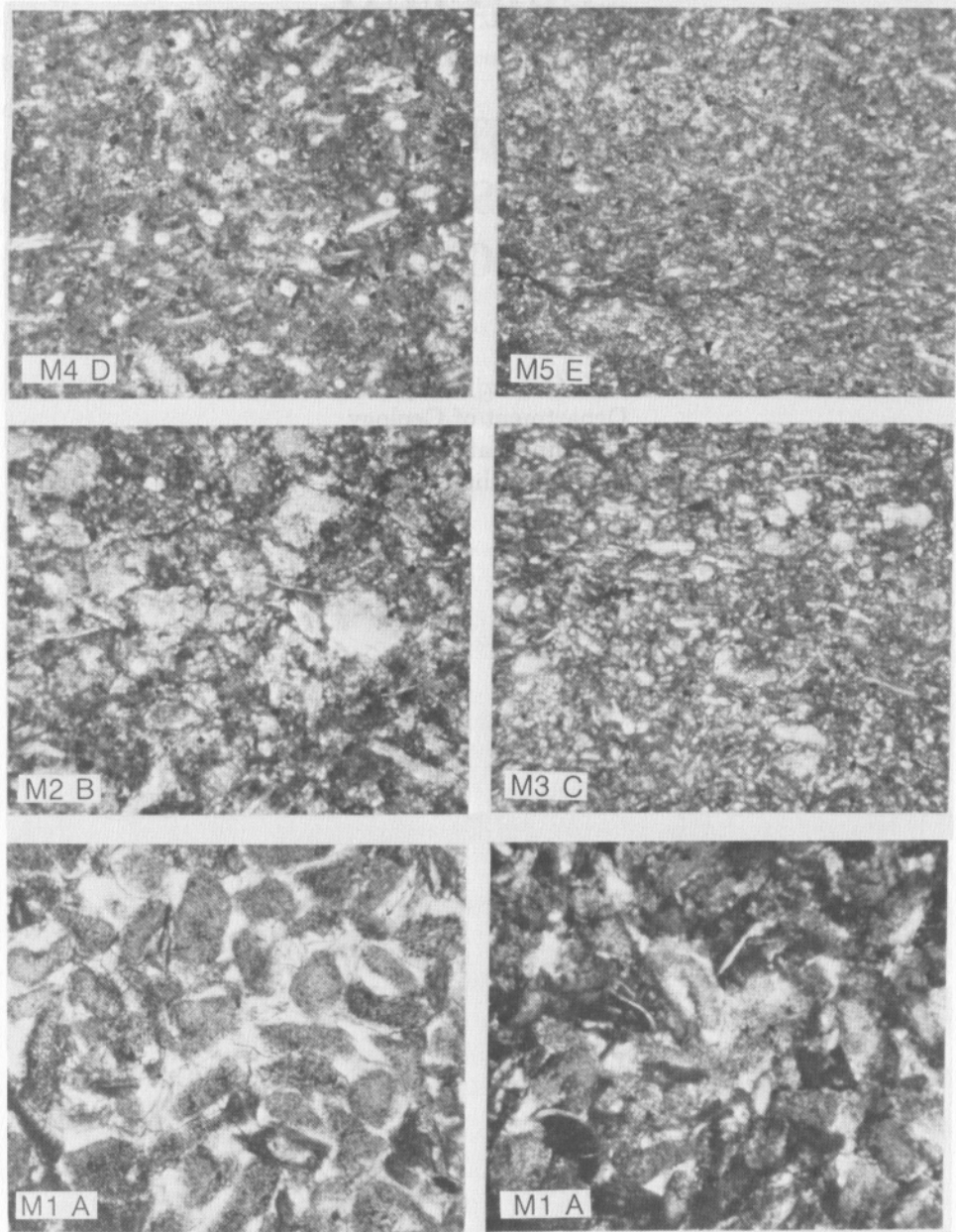


Fig. 3. Photomicrographs of microfacies M1 to M5 in order of superposition (A to E of Bouma sequence). Plane polarized light.

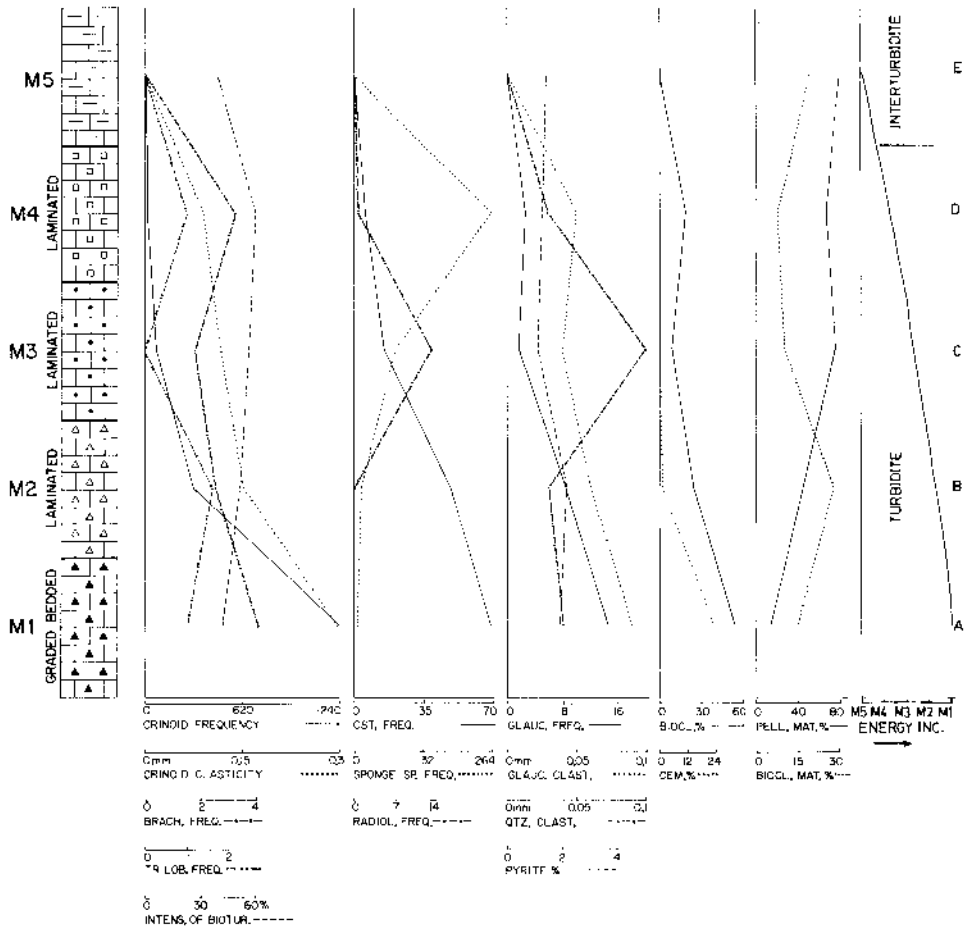


Fig. 4. Ideal depositional sequence (microfacies M1 to M5).

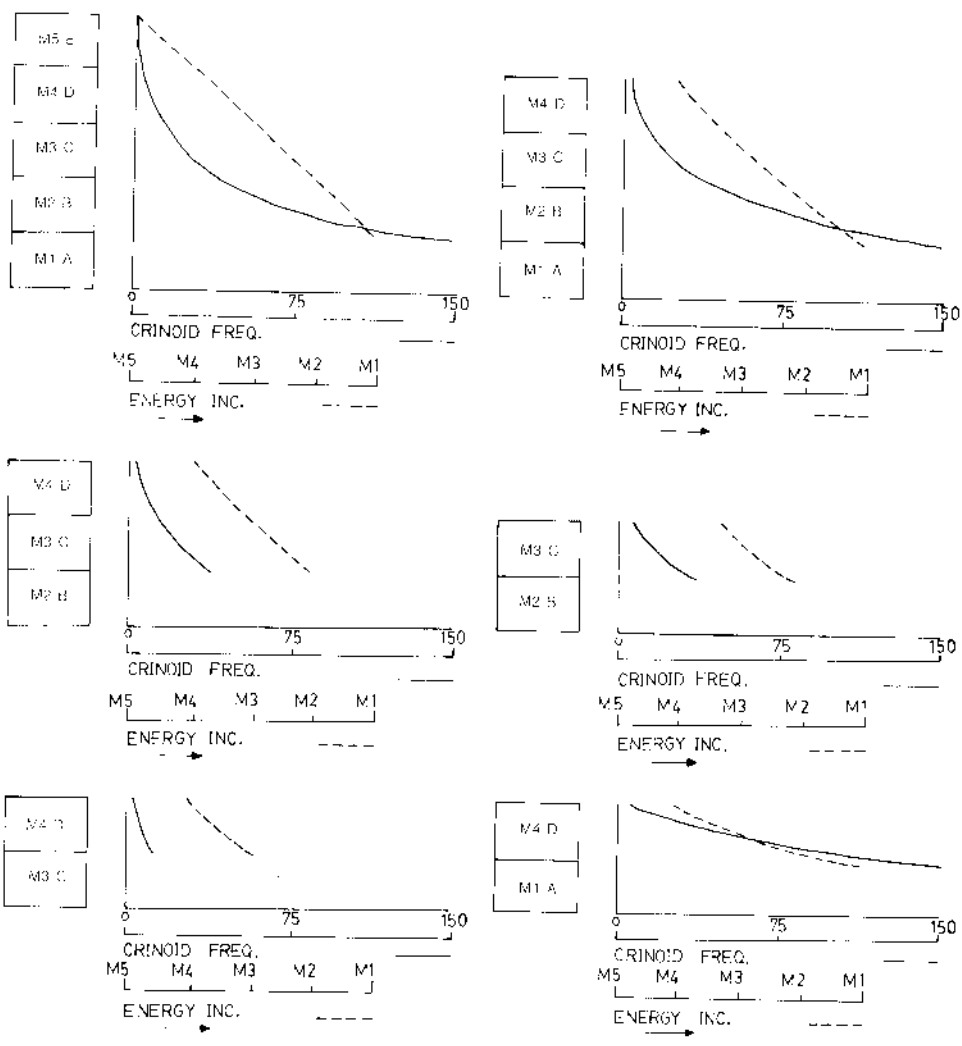


Fig. 5. Incomplete Bouma sequences.

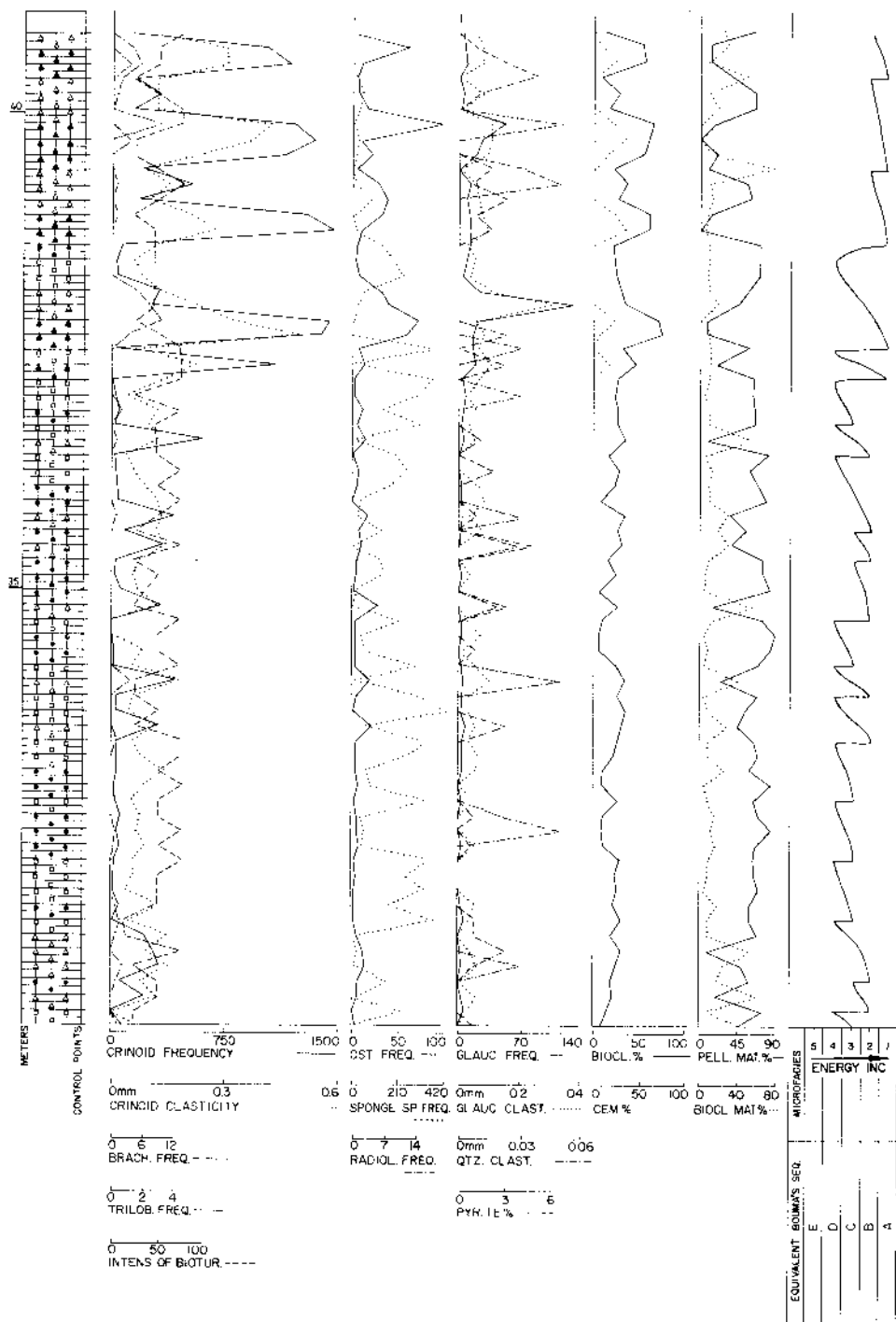


Fig. 6. Example of detailed graphic representation and interpretation of investigated section (30 to 40 m. interval).

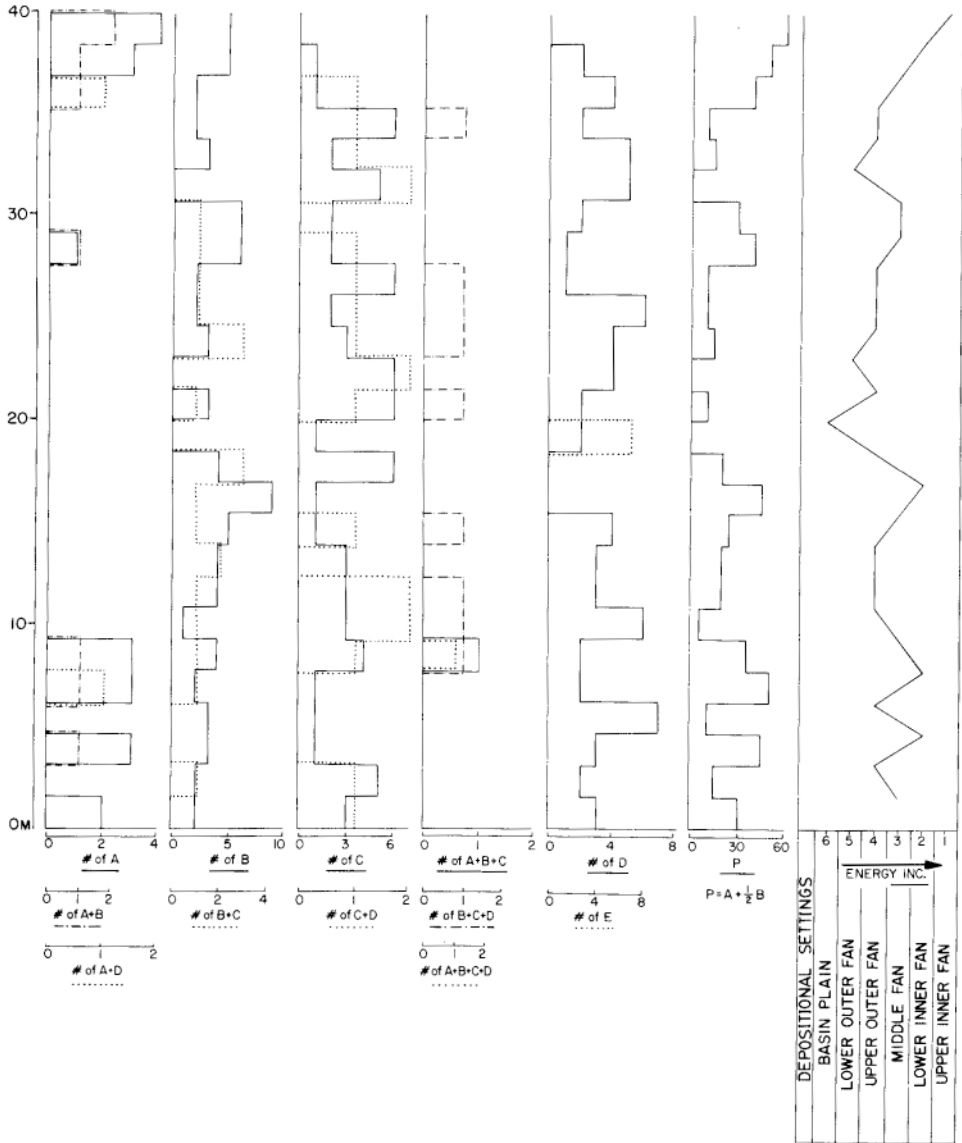


Fig. 7. Vertical variation of individual units of Bouma sequence, of complete and incomplete Bouma sequences, of P index, and environmental interpretation of investigated section.