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SEDIMENTOLOGY AND ELECTRIC LOG INTERPRETATION OF THE CABO BLANCO SANDSTONE, (LOWER EOCENE), TALARA BASIN, NORTHWEST PERU

BY

J. Roger PALOMINO CARDENAS and Albert V. CAROZZI [1]

ABSTRACT

The Talara Basin of northwest Peru, where the first oil well in Peru and South America was drilled, is the site of a 7000 m. thick clastic Cenozoic sequence which represents the sedimentary filling of the basin along two main directions of transport: NE-SW (longitudinal) and perpendicular to it (transverse).

The Cabo Blanco Sandstone with a portion of the underlying Clavel Shale, is a typical example of transverse filling of the Talara Basin. They represent sedimentation in a fluvio-deltaic environment with streams flowing in a general SE-NW direction.

The study of a set of characteristic sedimentary parameters in outcrops and their subsequent recognition in electric logs makes an integration of surface and subsurface information possible for sedimentologic studies. Grain size variation, channels, cross bedding and the nature of bedding contacts are among the most useful sedimentary parameters in this type of study. Their interpretation in terms of flow regime permits to distinguish areas over which either high energy or low energy of transport and deposition has prevailed. This distinction allows the recognition of trends of thick sand accumulation, hence of the most interesting potential reservoirs for petroleum exploration.

A prediction of the nature and thickness of the clastic sediments over unexplored areas and a better understanding of the reservoir characteristics in developed areas, are among the most important applications of this type of study.

RÉSUMÉ

Le bassin de Talara dans le nord-ouest du Pérou où le premier puits de pétrole du Pérou et de l'Amérique du Sud a été foré, contient une série clastique du Tertiaire, épaisse de plus de 7000 mètres, correspondant au remplissage du bassin le long de deux directions de transport: NE-SO (longitudinale) et perpendiculaire à celle-ci (transversale).

Le Grès de Cabo Blanco et une partie du Shale de Clavel sous-jacent sont un exemple typique de remplissage transversal du bassin de Talara. Ils représentent un système fluvio-deltaïque avec un écoulement des eaux dans la direction SE-NO.

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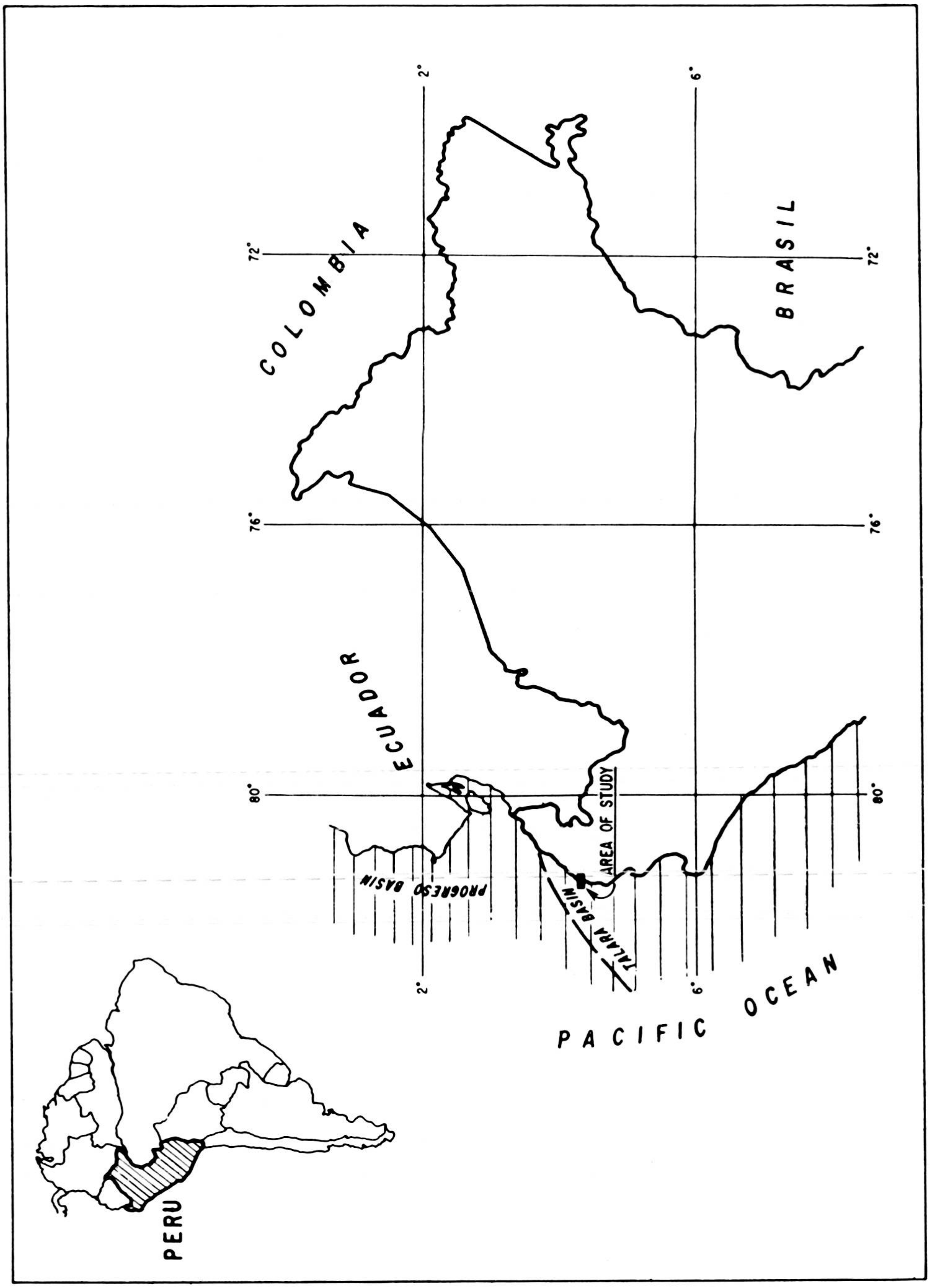

FIG. 1. — Location map of Talara Basin.

L'étude d'une série de paramètres sédimentaires à l'affleurement suivie par leur identification dans les diagraphies électriques permet d'obtenir une intégration sédimentologique des données de surface et de subsurface. Les variations granulométriques, les types de chenaux, de stratifications entrecroisées et de plans de stratifications sont les paramètres les plus utiles. Leur interprétation par le concept de régime d'écoulement permet de distinguer les zones dans lesquelles des conditions de transport et de sédimentation de haute ou de basse énergie ont été prédominantes. Par conséquent, il est possible de prédire la position des alignements d'accumulation des sables les plus épais, donc des réservoirs potentiels les plus intéressants pour l'exploration pétrolière.

La prédiction du type et de l'épaisseur des sédiments clastiques dans des régions inexplorées et une meilleure compréhension des caractéristiques des réservoirs dans des régions en production sont parmi les applications les plus importantes de ce genre d'étude.

INTRODUCTION

The Talara Basin of Northwest Peru (Fig. 1) is well-known for its long oil production history which goes back to 1863 when the first oil well in Peru and South America was drilled.

This basin is limited to the east by a spur of the Andes, the La Brea-Amotape Mountains. The northern limit is marked by the Trigal-Rica Playa "high", a horst consisting of Cretaceous igneous rocks against which all the Cenozoic sediments of the Talara Basin gradually disappear. Part of the basin falls on the present continental shelf and therefore its southern and eastern limits are only inferred.

A stratigraphic column consisting of 7000 m. of Cenozoic rocks overlying a Cretaceous and Paleozoic basement is known in the area (Bellido, 1969). It consists essentially of a complex association of conglomerates, sandstones, and siltstones with a very minor proportion of carbonates.

The Talara Basin seems to have been filled mainly longitudinally (from NE to SW) with sporadic incursions of fluvio-deltaic deposits and submarine fan-slope deposits extending basinward in a transverse fashion.

The Cabo Blanco Sandstone with a portion of the underlying Clavel Shale of Early Eocene age (Fig. 2) is a typical example of transverse filling. The purpose of the present work is to determine the modes of deposition of these units, to point out their possible source area, to outline their general geometry, and to define a methodology in order to predict their oil reservoir capability (Palomino, 1976).

DATA GATHERING AND SAMPLING PROCEDURES

The principal source of information has been the series of outcrops of Cabo Blanco Sandstone and its related Clavel Shale extending over a strip of land parallel to the coast (Fig. 3) and hundreds of well control points covering a total area of 80 km^2.

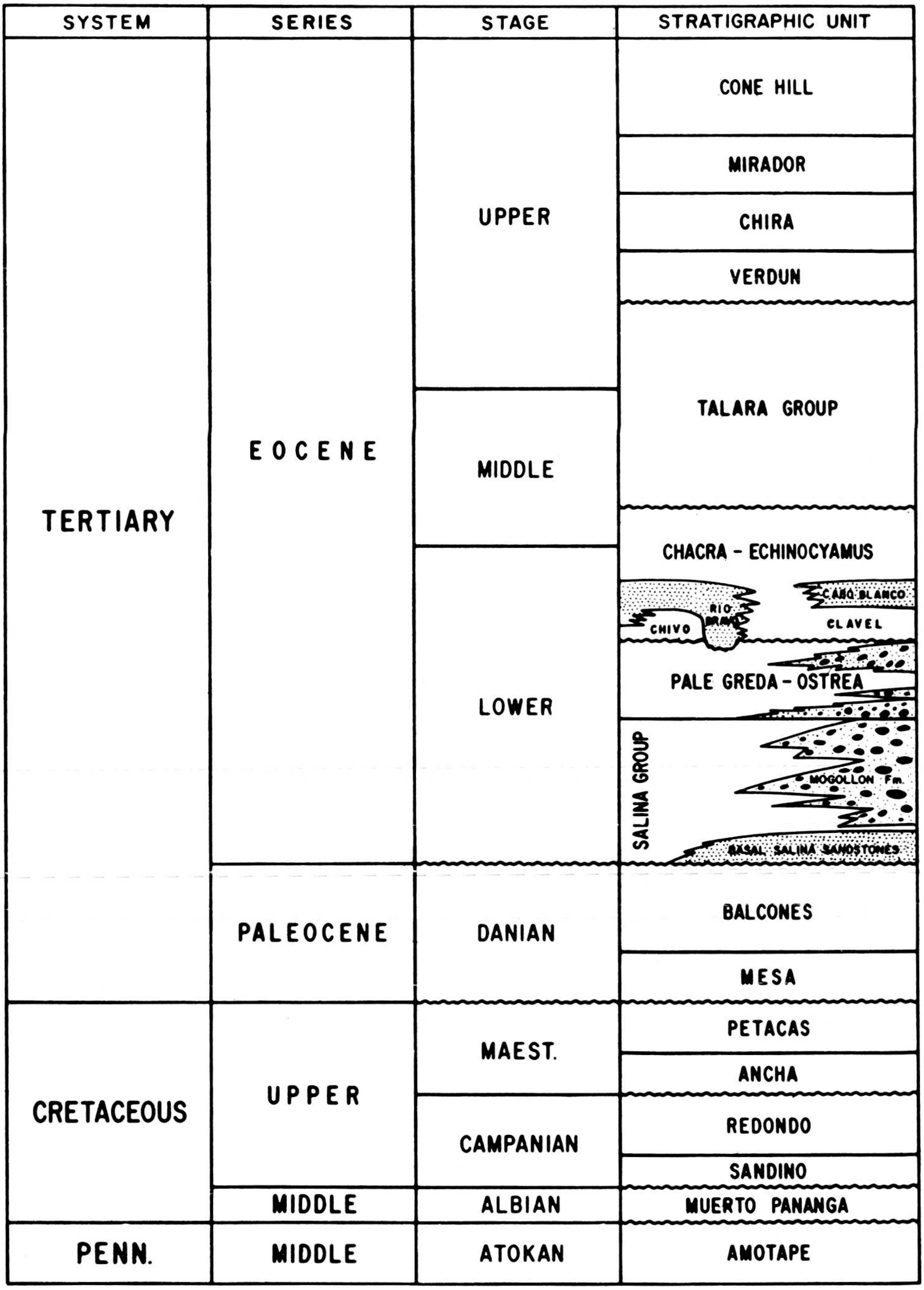

FIG. 2. — Generalized stratigraphic column of northwestern Peru.

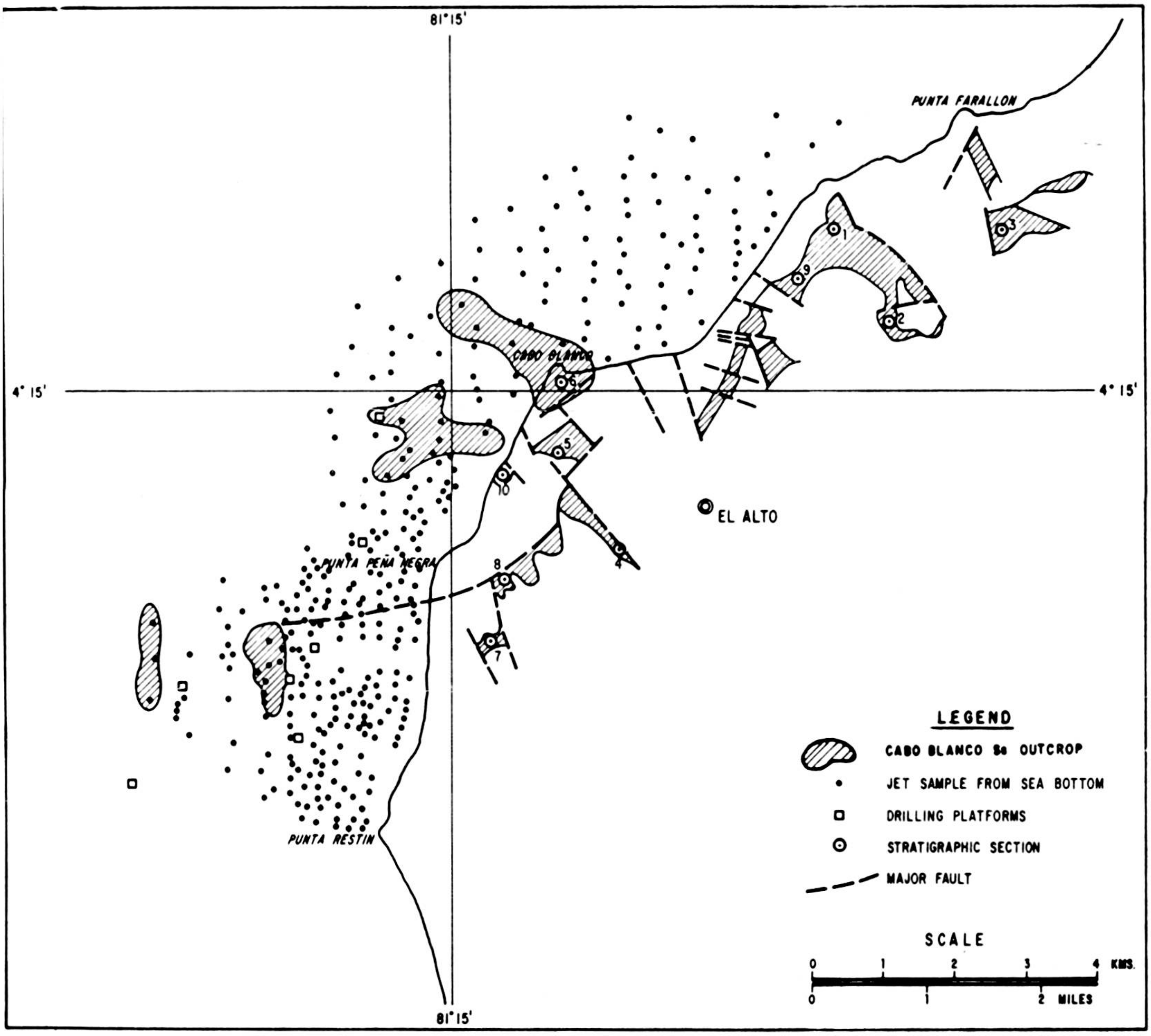

FIG. 3. — Outcrop map of Cabo Blanco Sandstone.

Ten main field sections were studied in detail and described following the procedure suggested by Bouma (1962) for facies interpretation. The recorded parameters, however, were slightly modified for the present study (Fig. 4 and 5). Samples were taken at intervals ranging from 30 cm. to 1 m. vertically in any given field section and corresponding thin sections were prepared for microscopic study.

Samples of the most friable sandstones were disaggregated and sieve-analyzed for granulometric study and for comparison of grain size estimates of the same sandstone bed using microscopic techniques. The graph proposed by Friedman (1958) for converting grain size estimates under the microscope to sieve-size equivalents, was used for this purpose.

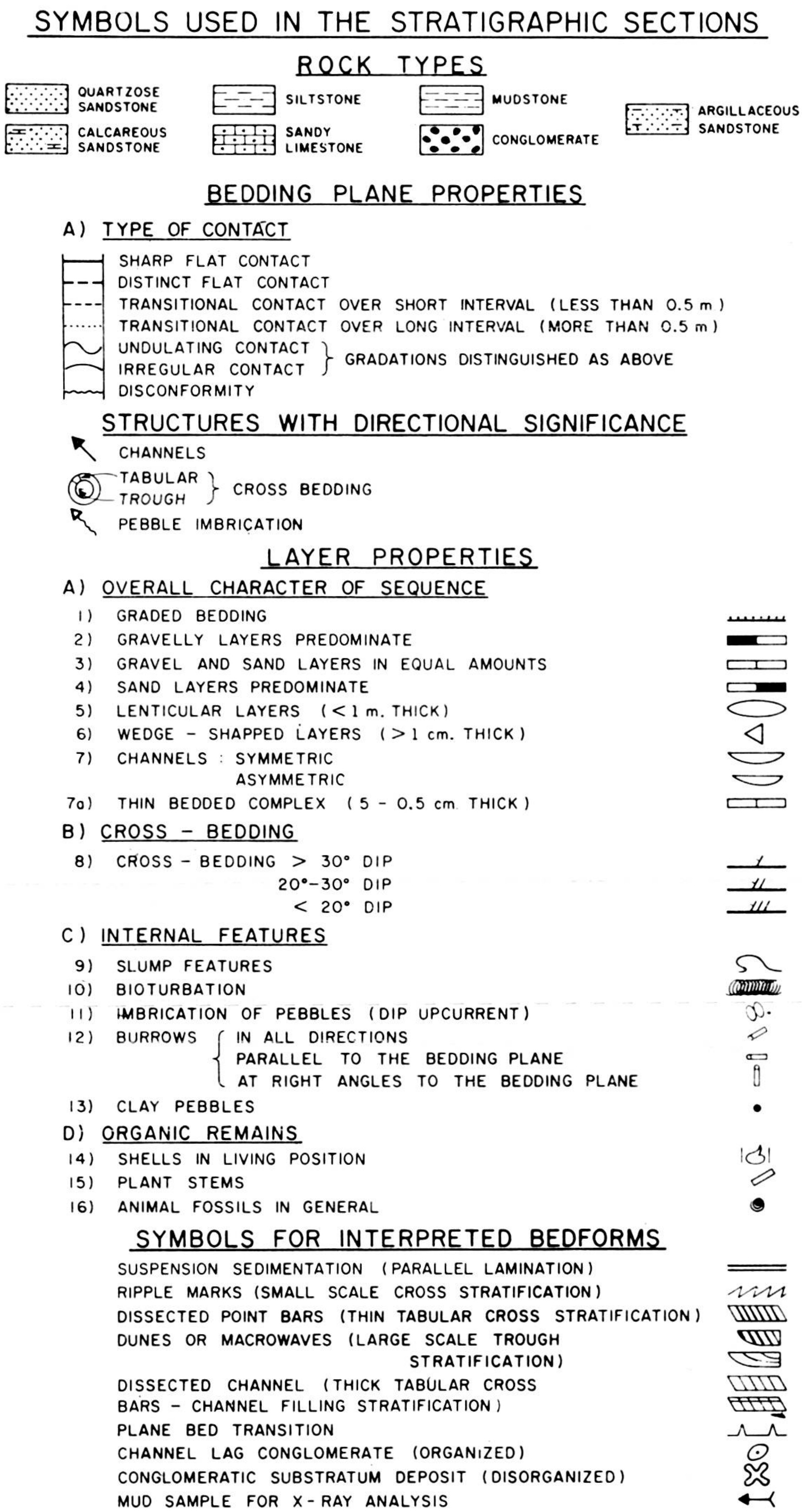

FIG. 4. — Symbols used for the description of the field stratigraphic sections.

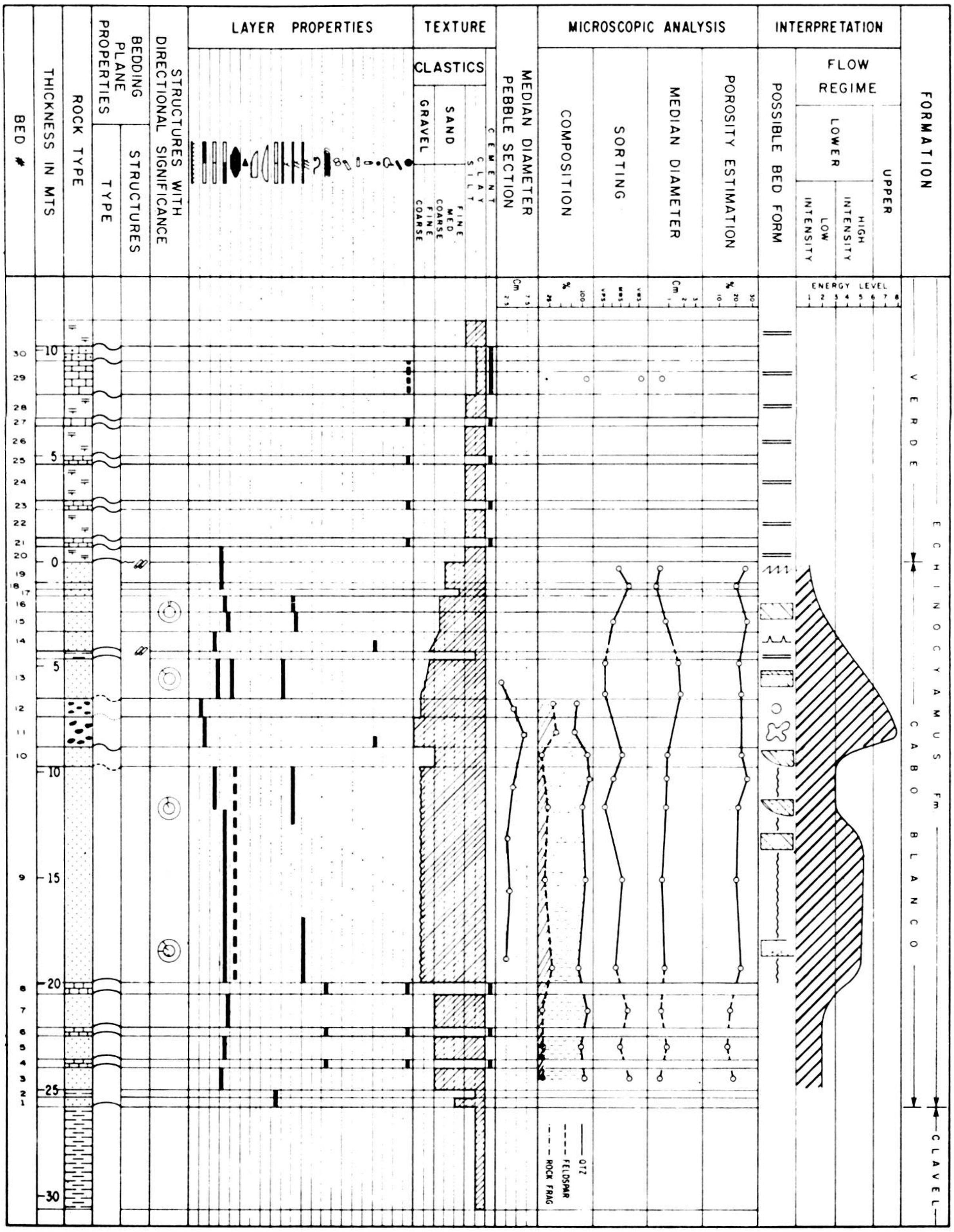

FIG. 5. — Record of sedimentary parameters for a typical Cabo Blanco field stratigraphic section.

No fauna occurs in the upper and coarser portion of the Cabo Blanco Sandstone being restricted to its basal 10 m. Scarce foraminiferal fauna is present in the uppermost part of the Clavel Shale. Petrified logs of the Cabo Blanco Sandstone are strikingly scarce in the upper coarser portion, but plant debris are present in the laminated sandstone and siltstone of the lower portion.

Sedimentary structures and bedding plane properties, combined with grain size distribution were interpreted in terms of the flow regime concept developed by Simons *et al.* (1965) and Harms and Fahnestock (1965). This procedure allowed the determination of main trends of sand transport and deposition.

LITHOLOGY

The Cabo Blanco Sandstone consists mainly of coarse sandstones and conglomerates with intercalated thin beds and lenses of shales. In general, the amount of conglomerate and the grain size of the sandstone decrease from south to north. Basal sandstones, are normally calcite-cemented and may contain macrofossils. Conglomerates and sandstones are lenticular in nature, often beginning and terminating within the same outcrop. However, persistence of beds and correlation from outcrop to outcrop is better in the lower 10 m. of section where laminated sandstones are interbedded with shales (Fig. 6).

The sand-size fraction was investigated petrographically in order to establish its mineralogic composition as well as its grain size and sorting characteristics. Mineralogically, the Cabo Blanco Sandstone is a quartz arenite (Fig. 7) in which 90-95% of the component mineral is quartz—either as single quartz grains or as quartzite grains. The remaining 5-10% consists of plagioclase, muscovite, and rare pyroxenes. The results of grain size analysis were plotted on probability paper for their interpretation which indicates a good degree of sorting at different levels within the Cabo Blanco Sandstone; their plot shows a proximity to normal or Gaussian arrangement (Fig. 8).

The pebble-size fraction (conglomerates and pebbly sandstones) were studied in outcrops. The mean pebble size was estimated within vertical intervals chosen between the most laterally persistent correlable units within an outcrop. Several superposed vertical intervals were treated in this way to cover representative sections. In these intervals an estimation was made of the percentage of pebbles (larger than 5 mm.) present. Stratigraphic variations of the mean pebble size were plotted in the field sections (Fig. 5).

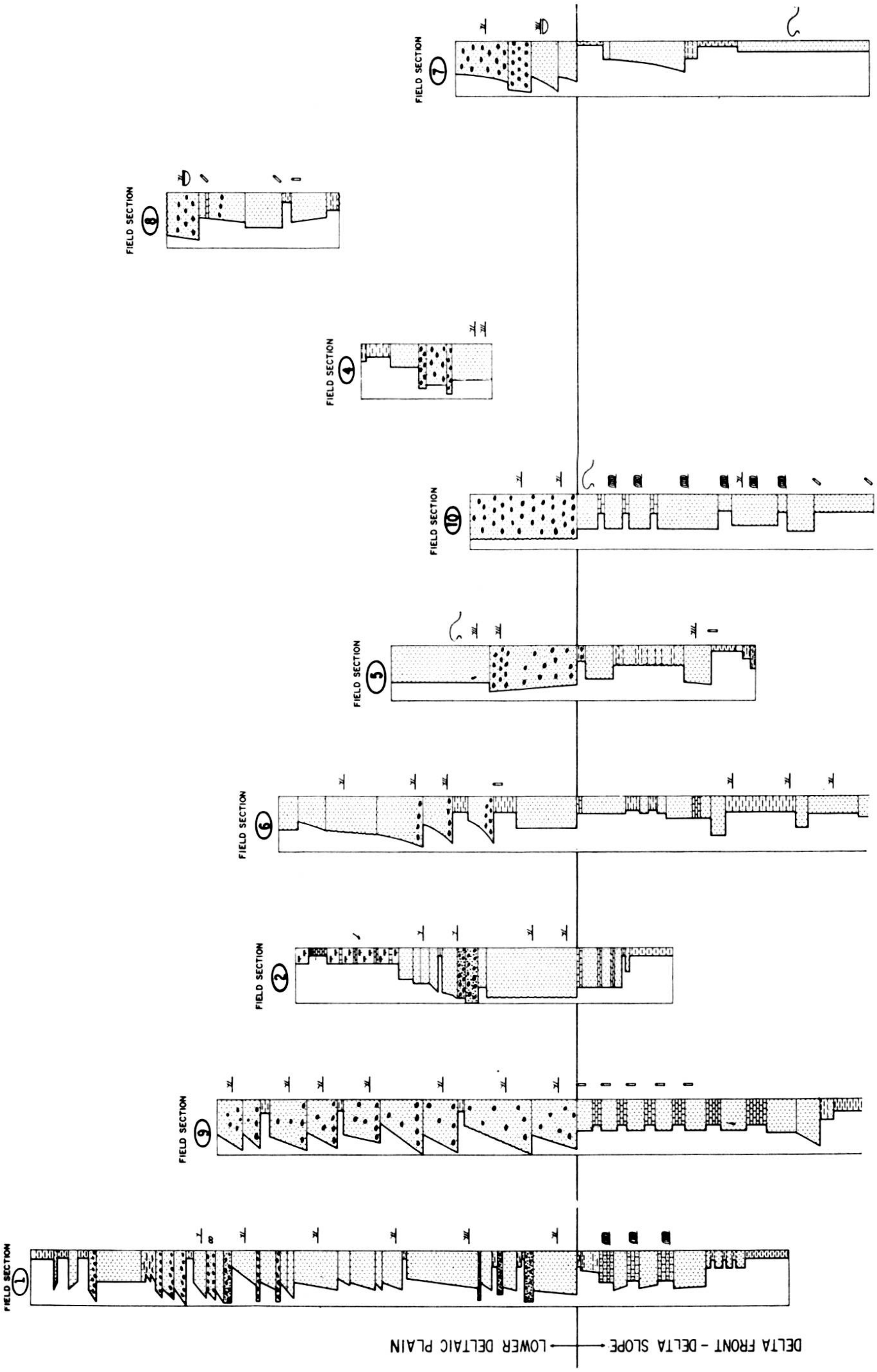

FIG. 6. — Correlation and environmental interpretation of outcrop sections of Cabo Blanco Sandstone.

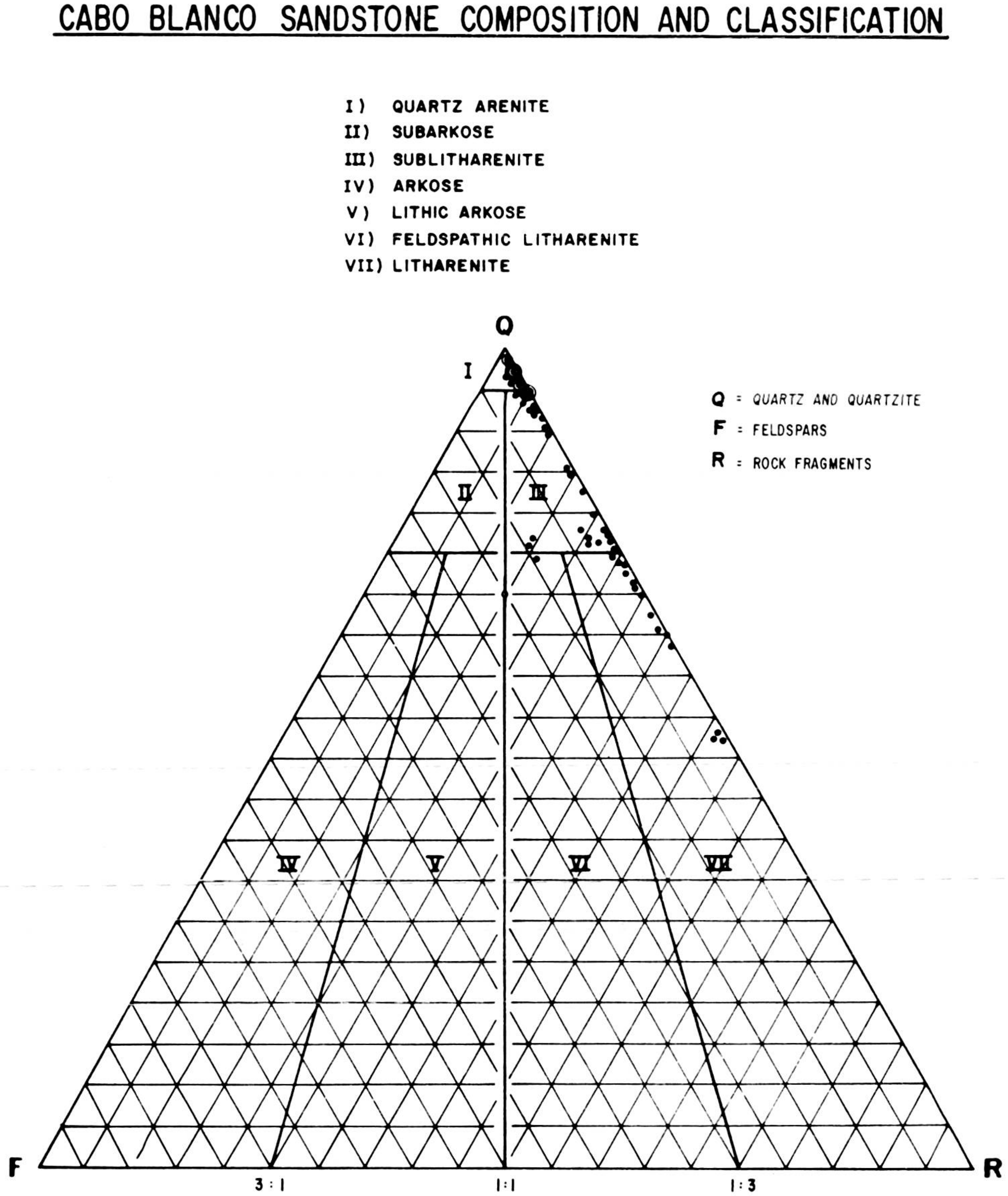

FIG. 7. — Petrographic composition and classification of Cabo Blanco Sandstone.

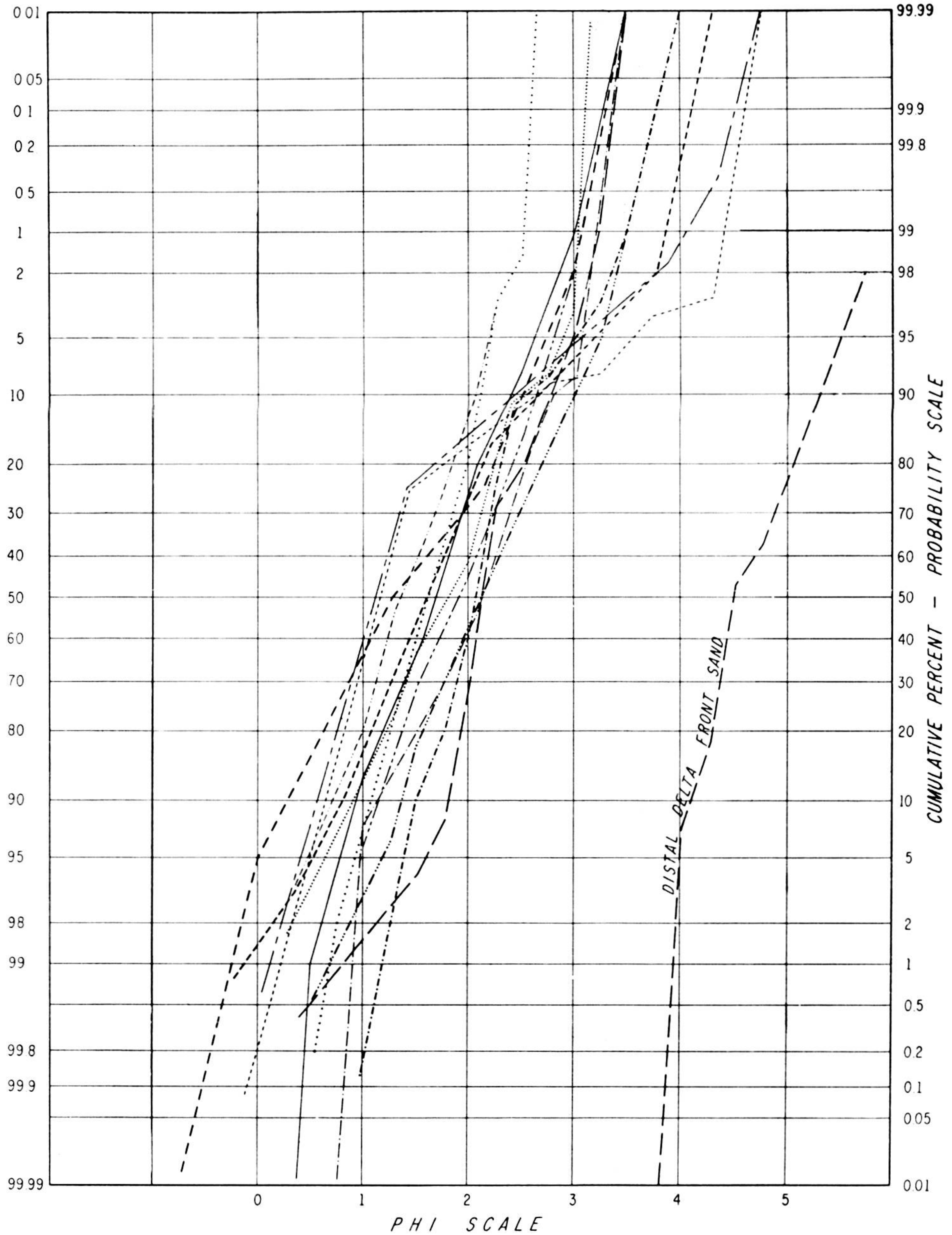

FIG. 8. — Log-probability plot of grain size distribution of sandstones from the Cabo Blanco fluvio-deltaic system.

SEDIMENTARY CYCLES

The conglomerates are distributed throughout the Cabo Blanco Sandstone and normally mark the base of fining-upwards cycles. Also, scattered pebbles occur in otherwise massive homogeneous sandstone intervals.

Fining upward cycles largely predominate over coarsening upward ones. They start ot the base with conglomerates or pebbly sandstones. Normally they show a sharp contact over the underlying unit with local channelling. Upwards, grain size decreases gradually through a coarse-grained sandstone to a fine sandstone or siltstone. The latter is usually bioturbated and randomly-oriented worm tubes are quite abundant. More frequently in northern sections, a shale horizon not thicker than 30 cm. covers the siltstone; in the latter case vertical worm tubes are present at the contact.

For the purpose of calibrating electric logs for integration of the subsurface and surface information into a model of deposition, it was necessary to classify fining upwards cycles into different categories. The latter are based on: 1) nature and lithology of base; 2) constancy of grain size gradation; and 3) thickness. In this classification cycles thinner than 1 m. were disregarded since they fall below the acceptable electric log resolution (Fig. 9).

Fining upwards cycles were ideally classified as follows:

1st order cycles: erosional base with small channelling into underlying material; basal lithology normally conglomerate grading continuously upward to finer grain sizes terminating in a shale bed at the top. *No shaly material is present within the cycle except as clay galls.*

2nd order cycles: erosional base with or without channelling into underlying material; basal lithology is conglomerate but gradation to finer grain sizes upward is interrupted by occasional shale intercalations. This is actually a composite of several thinner 3rd order cycles.

3rd order cycles: coarse sand at base with occasional pebbles. No evidence of erosion. Grain size variation upwards may be abruptly interrupted by the erosional base of the overlying cycle.

The nature and lithology of the base of cycles and the presence of shale intercalations within cycles are the two main features to be observed for applying the above classification. Thickness is a less diagnostic characteristic for cycle classification since many intervals result from a variable play of erosion and deposition processes.

As mentioned above, coarsening upward cycles are only locally present. Outcrop observations indicate that they result mainly from lateral wandering of the

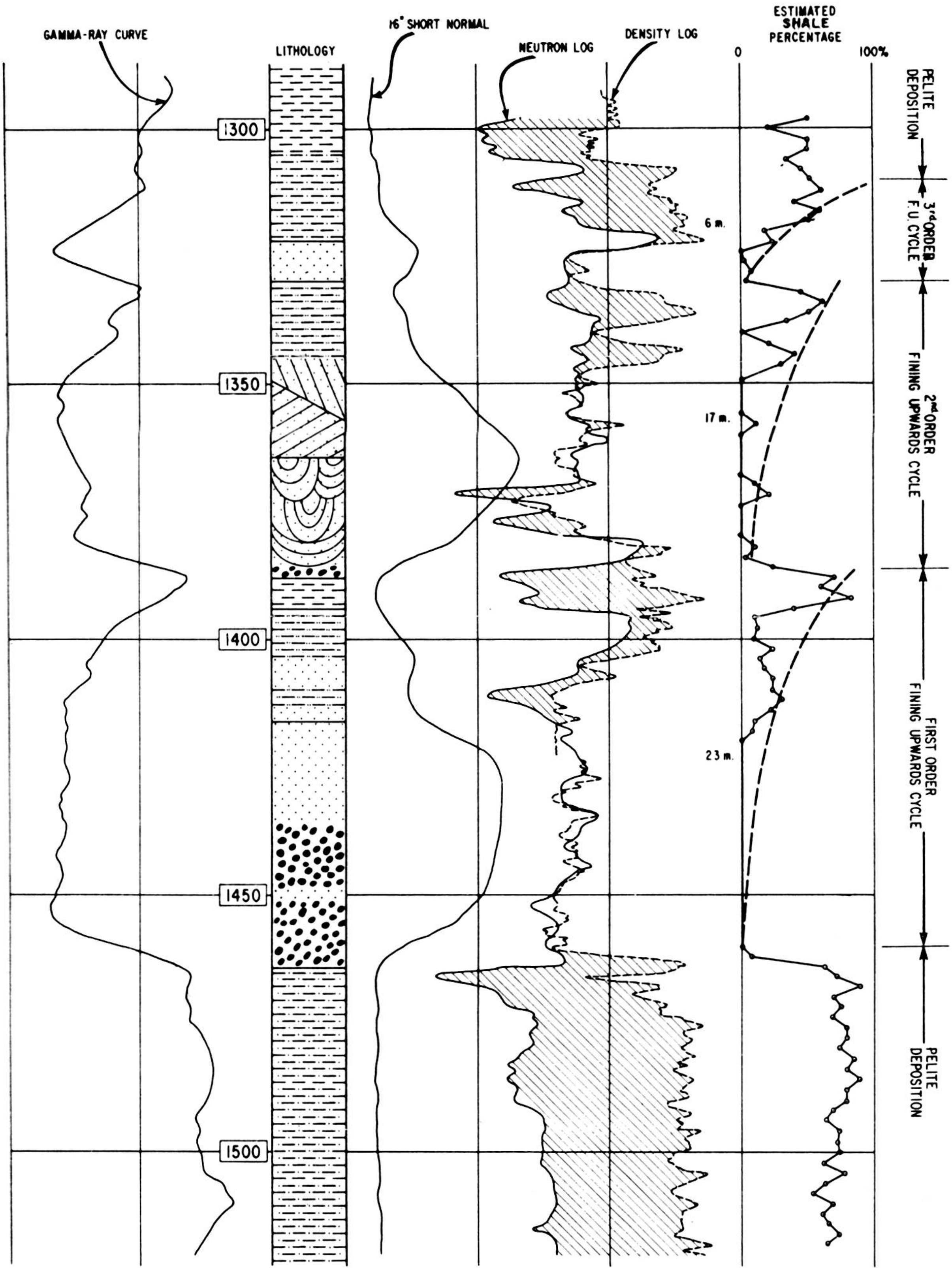

FIG. 9. — Recognition of sedimentary cycles by combination of various types of electric logs.

transporting medium, which caused reworking of previous lithologies and local progradation. The result is a general increase in energy upwards, reflected in the grain size arrangement.

SEDIMENTARY STRUCTURES AND BEDDING PROPERTIES

The major sedimentary structures of the Cabo Blanco Sandstone include several types of cross-bedding, channels, slumping, bedding plane features, and bioturbation.

The most common and predominant sedimentary structure is cross bedding of both tabular and trough types. Thickness of cross-bedded units vary from 0.30 m. to 2.30 m. Below 0.30 m. the unit is designated as cross-laminated. Tops of cross-bedded intervals are normally erosional.

Lithology and type of cross bedding show some degree of relationship. Sets of thick trough cross bedding are usually associated with conglomerates and are separated from one another by erosional surfaces. Tabular cross bedding, on the other hand, is associated with medium-grained, better sorted sandstones. Beds of the latter types are more continuous than the trough cross bedded intervals.

After correction for structural attitude, sedimentary dip directions of cross bedded units show a predominant north-west component (Fig. 10). Scatter of cross

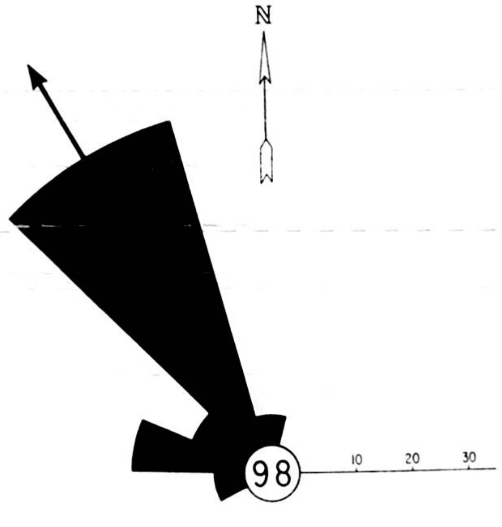

FIG. 10. — Rose diagram showing average cross bedding and channel directions (arrow) in Cabo Blanco Sandstone.

bedding direction is more pronounced in thick, pebbly poorly sorted units than in thin, medium-grained well sorted beds. However, the statistical treatment as suggested by Perrin (1975) gives a reliable indication of flow direction.

Channel structures are the next most striking sedimentary structures in the Cabo Blanco Sandstone. They vary in dimensions from 15 cm. high by 50 cm. in cross section perpendicular to flow, to 1.35 cm. high by 300 cm. across. Channels of larger dimensions are undoubtedly present but only partially preserved in outcrops as lenticular sand bodies often showing fining upward arrangements of grain-sizes. Channels preserved as a single structure are normally symmetric in cross section.

Channel axes are the most reliable indicators of average flow direction. They show a narrow scatter (Fig. 9) of about 10°. Slump features are always associated with well sorted, medium grained sandstones and practically never present in pebbly or coarse varieties. With respect to bedding plane properties, plant material carbonaceous is always disseminated in laminated silts and fine-grained sands. Although the smaller debris show a wide scatter in orientation, elongated stems can provide reasonable indications of flow direction.

Another very useful bedding plane property is the nature of the bedding contacts. This property is the response to the variation in the energy of the sediment transporting flow. Bedding contact is a property which can be detected on electric logs (Fig. 11) thus providing another calibration tool besides those already reported in the literature (Allen, 1975) for proper use of these geophysical devices in environmental interpretation.

The remaining of the sedimentary structures listed as layer properties (Fig. 4) are mainly environmental indicators and therefore limited to specific intervals and

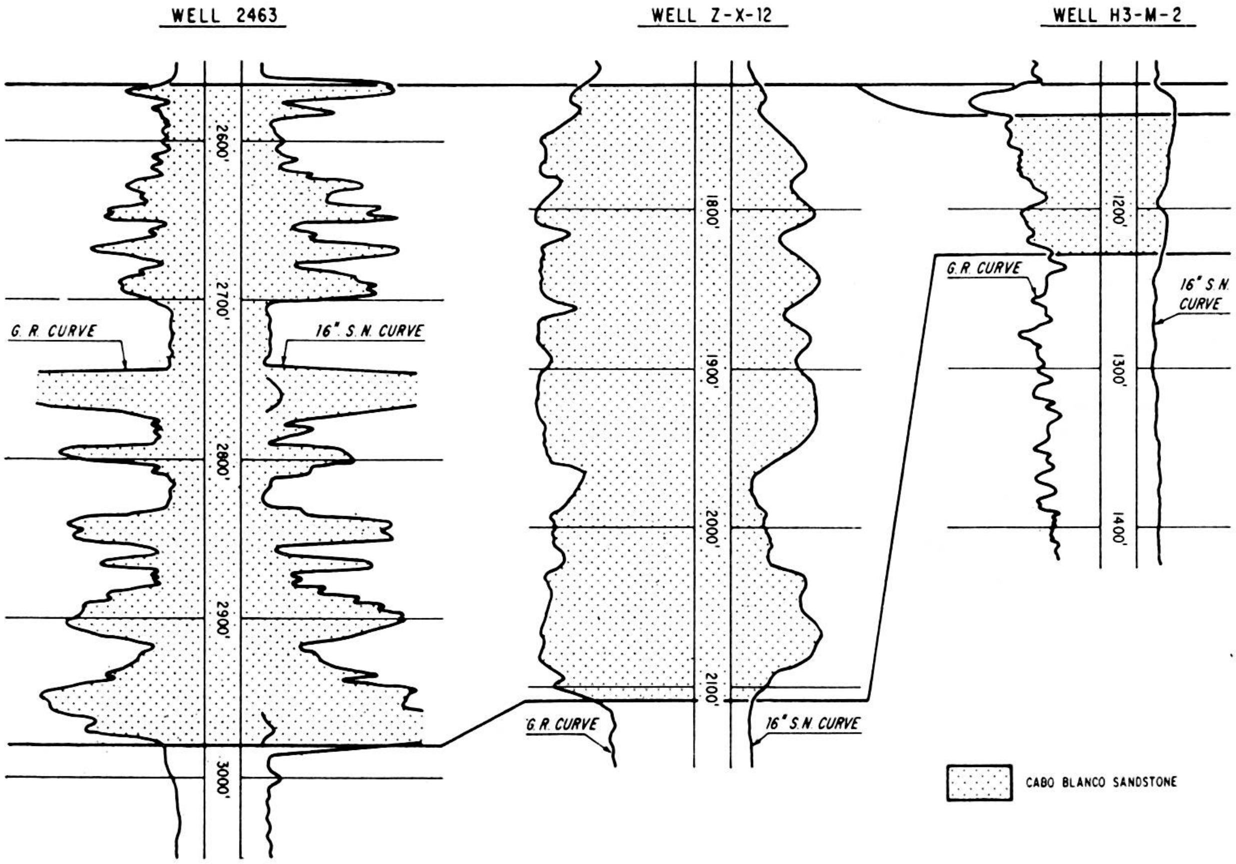

FIG. 11. — Types of bedding contacts in Cabo Blanco Sandstone as recognized in electric logs.

related lithologies. Thus, bioturbation is restricted mainly to the lower, fossiliferous sandstone-siltstone beds with a mottled appearance in which reddish and white colors predominate over yellow and gray tonalities.

GENETIC INTERPRETATION

The nature and horizontal persistence of beds, the particular distribution of the types of clastic sediments involved (Allen, 1965), the suite of sedimentary structures present, the absence of fossils except petrified logs and plant debris, and the general geometry of the Cabo Blanco Sandstone and underlying associated Clavel shales and siltstones indicate that this stratigraphic unit was deposited in a high-energy, fluvio-deltaic environment flowing preferentially from SE to NW. The Cabo Blanco lower deltaic sandstones strongly prograde over the prodelta shales and siltstones of the underlying Clavel. The flow seems to have originated from a positive area genetically related to the Andean Mountains and extended into the Talara Basin, perpendicularly to the longest axis of the basin (Fig. 12).

The main lobe of this delta appears to have its apical area in the vicinity of Carrizo (Fig. 12), and to reach its maximum development in the Punta Restin area. This appears to have been a major route along which the coarser grained, more continuous and massive sandstones with scarce inter-distributary shaly material were transported and deposited. Adjacent lobes farther to the north show sandstones with equal amounts of interdistributary shales. Bedding contacts in this latter area are abrupt, a characteristic easily recognized in electric logs and which contrasts with the gradual nature of the bedding contacts in deposits of the main lobe.

This deltaic progradation may have been repeated several times leaving sandstone deposits similar to the Cabo Blanco Sandstone at different stratigraphic levels. The study of the outcropping Cabo Blanco Sandstone representing but one deltaic episode provided, however, the necessary clues for the subsurface study of the other older similar sandstone deposits and their integration into the present study.

The stacking of different sub-environments within the deltaic depositional system, the narrow scatter of flow directions as inferred from cross bedding, the narrow wandering of channel axes (Fig. 9), and the grain size of the clastics involved, associated with other sedimentary features already described, demonstrate the highly progradational nature of the Cabo Blanco delta deposited in this area. Moreover, these features suggest a braided stream flow (Williams and Rust, 1969; Smith 1970) for the fluvial portion.

A submarine fan would be a possible alternative to the deltaic interpretation. However, this possibility seems remote because of the absence of evidence for debris flow common in such an environment and the predominance of thick cross bedded units indicating traction transport.

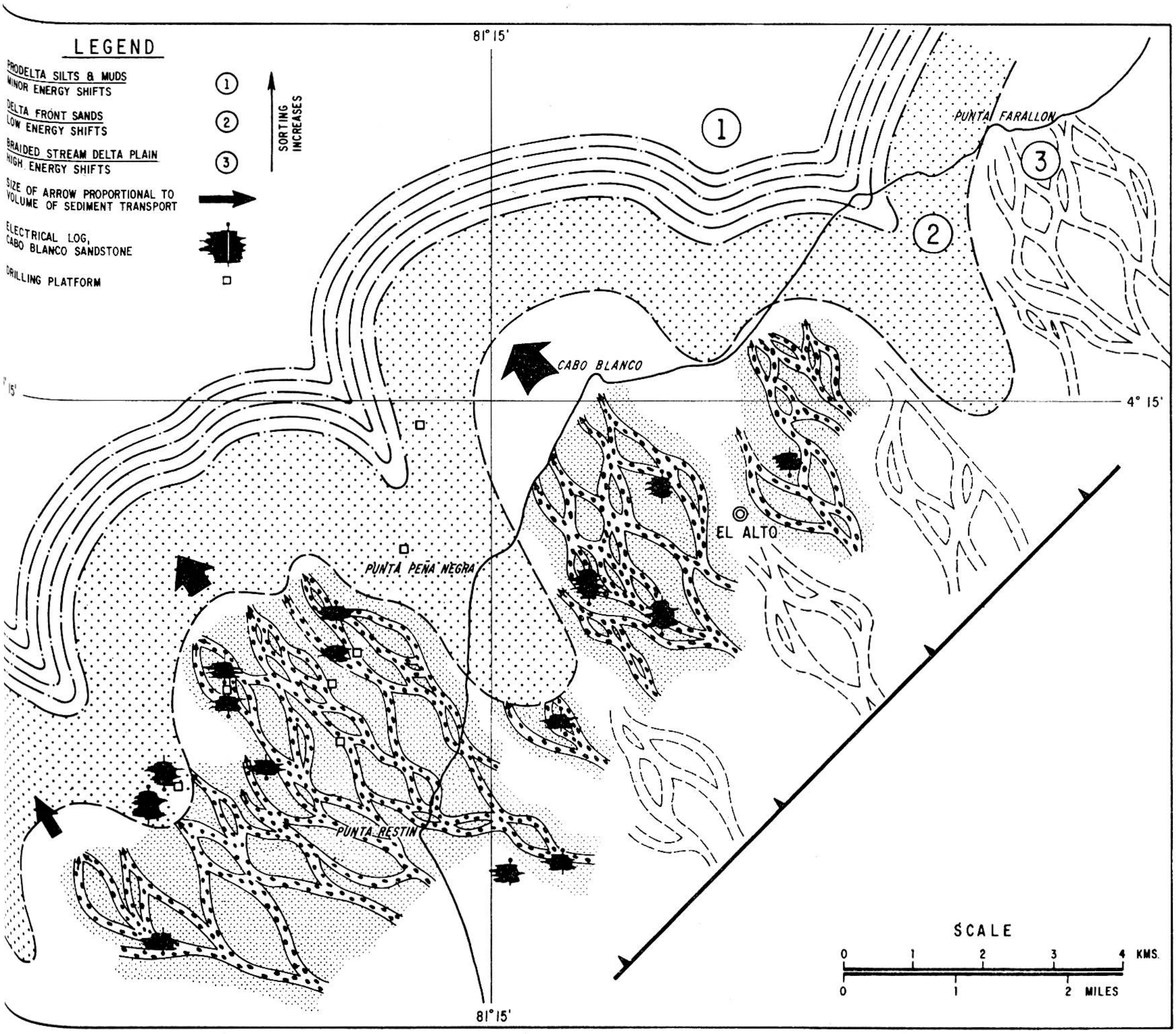

FIG. 12. — Map of depositional environments of Cabo Blanco Sandstone.

APPLICATION TO OIL EXPLORATION

The benefit that studies of this sort can give to oil exploration depends on the proper integration of subsurface information into the general model of sedimentation obtained from outcrop studies. This integration can only be attained through an appropriate calibration of electrical logs (Allen, 1975; Jaegeler and Matuszak, 1972; Perrin, 1975), by far the most utilized tool in subsurface studies. Not only is it necessary to recognize in electric logs most, if not all, the sedimentary features

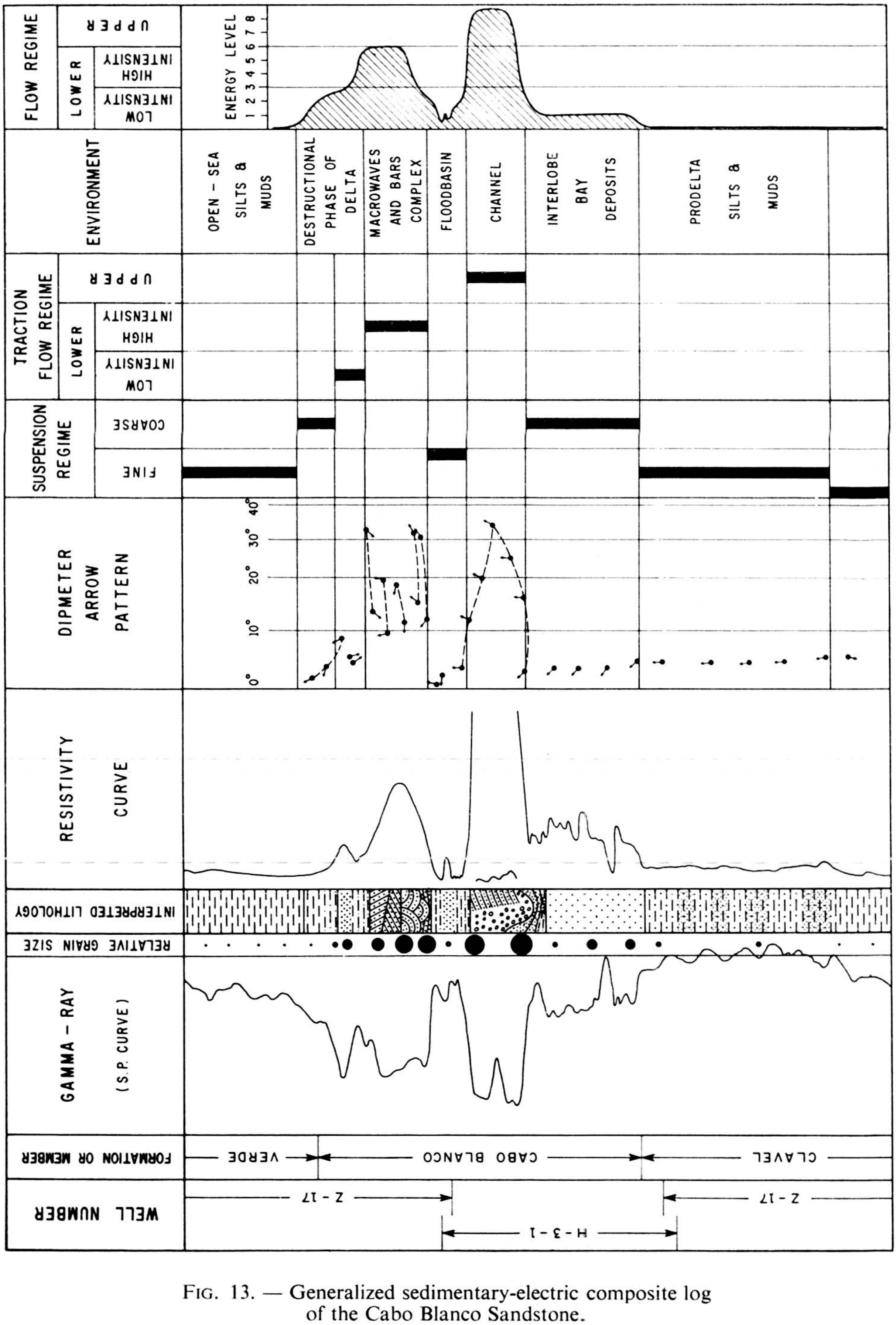

FIG. 13. — Generalized sedimentary-electric composite log of the Cabo Blanco Sandstone.

observed in the field, but means should also be found to determine best trends of reservoir sand accumulation.

Self-potential, gamma ray, gamma-gamma, and neutron curves were used for interpreting grain size variation, lithology, and porosity. Dipmeter attitudes properly corrected for structural attitude were also included in the present sedimentological studies. If conventional cores were available, direct comparison of core data with electric log characteristics should be done.

In the present study, after recognition of outcrop features in electric logs, and interpretation of the lithologies possibly involved, energy levels were assigned to the particular combination of sedimentary features in a fashion similar to what was done for outcrops (Fig. 13).

Because of the absence of laterally persistent key beds and the difficulty of carrying correlation for long distances, energy variation could not be estimated for specific intervals within the Cabo Blanco Sandstone, but had to be averaged for any given complete section. For this purpose, intervals deposited under low energy, lower flow regimes (fine-grained sandstones, coarse siltstones) were distinguished from intervals deposited under high-energy, lower flow regimes and higher flow regimes (coarse-grained sandstones, conglomerates), and complemented with estimation of thickness of suspended sediments (shales).

The ratio of thickness between the high-energy and low-energy deposits was then computed and the resulting value contoured to obtain the areal variation in energy (Fig. 14) during Cabo Blanco deposition. This variation shows three recognizable trends of high-energy transport of sediment. The southernmost trend (Restin trend) has the highest values which, together with the massiveness of the sandstones involved (gradual contacts) and the scarcity of substantial shale intervals, permits to recognize it as the major sand transport route during Cabo Blanco times. Over this route, erosion has been often more important than deposition resulting in the preservation of only the basal, coarser grades of the deposited fining upward cycles, probably filling topographic "lows", in the abundance of reactivation surfaces and in the massiveness of the sandstones preserved. The isochore map (Fig. 15) thus indicates a rather thin section in this area.

At the distal end of this route, a thick sandstone deposit is expected (Fig. 15) resulting from all the sand eroded along the high-energy route and deposited in mass when the energy of the transporting medium decreased, at the delta front.

The least energetic trend (Cabo Blanco trend) of the three recognized, is the one running almost north by the Cabo Blanco geographic locality, where a ratio of 1 is obtained between the high-energy and low-energy deposits. Sandstone depositional cycles appear to be complete, separated from each other by interbedded shales and, therefore, showing sharp bedding contacts. The Cabo Blanco Sandstone over this area appears thick (Fig. 7).

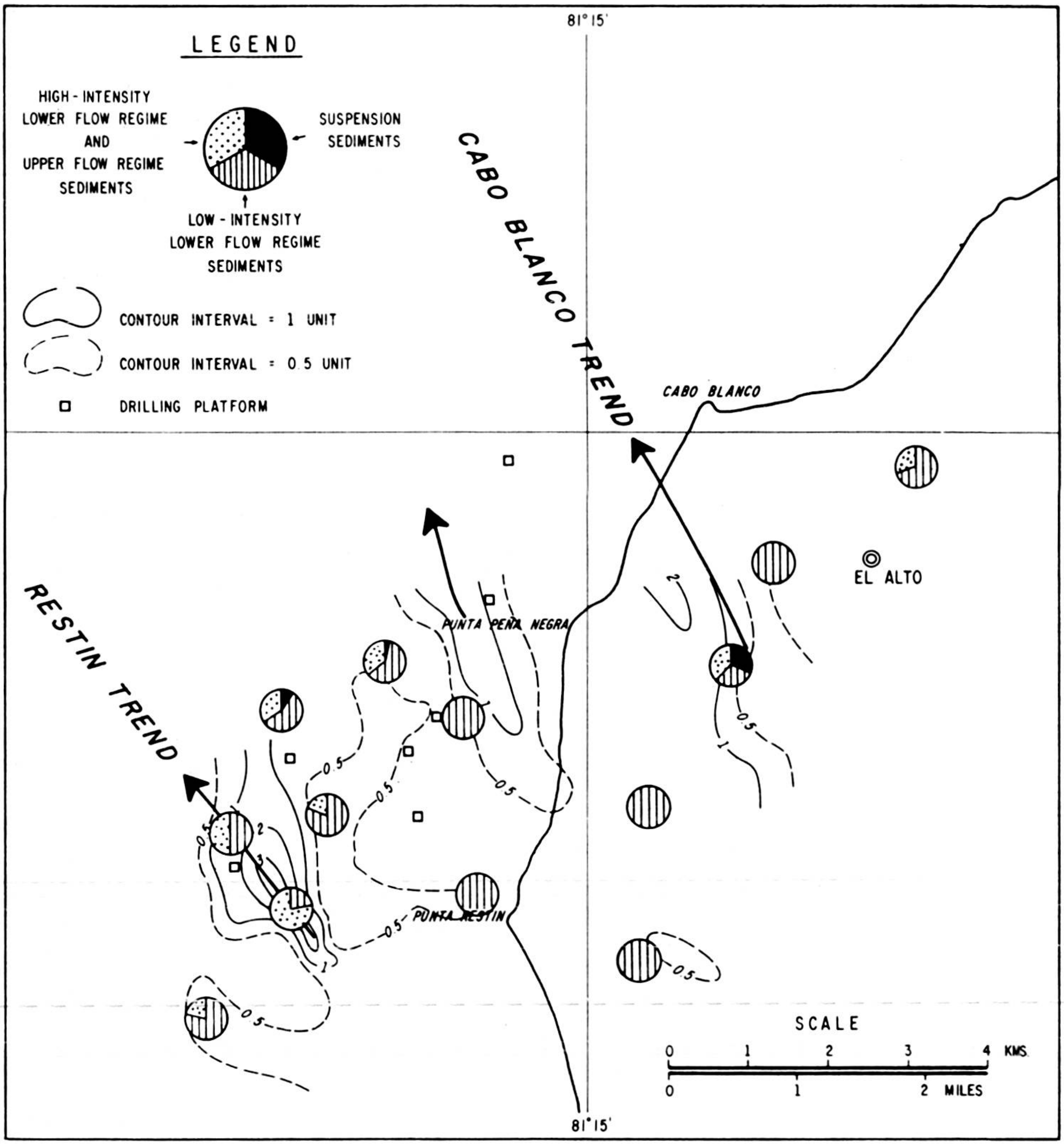

FIG. 14. — Pattern of high-intensity to low-intensity flow regime sedimentation in Cabo Blanco Sandstone.

The Cabo Blanco trend seems to have been a route of sporadic unusual sediment transport event, thus presenting a high preservation index (Allen, 1967) for the sediment deposited. Based on this reasoning it may represent an area of crevasse-splay deposits where stream flow from the major Restin trend overspilled its levees. This interpretation explains also the thick shaly material of the sections along this trend as compared with the sporadic relatively thin shale intervals of those along the

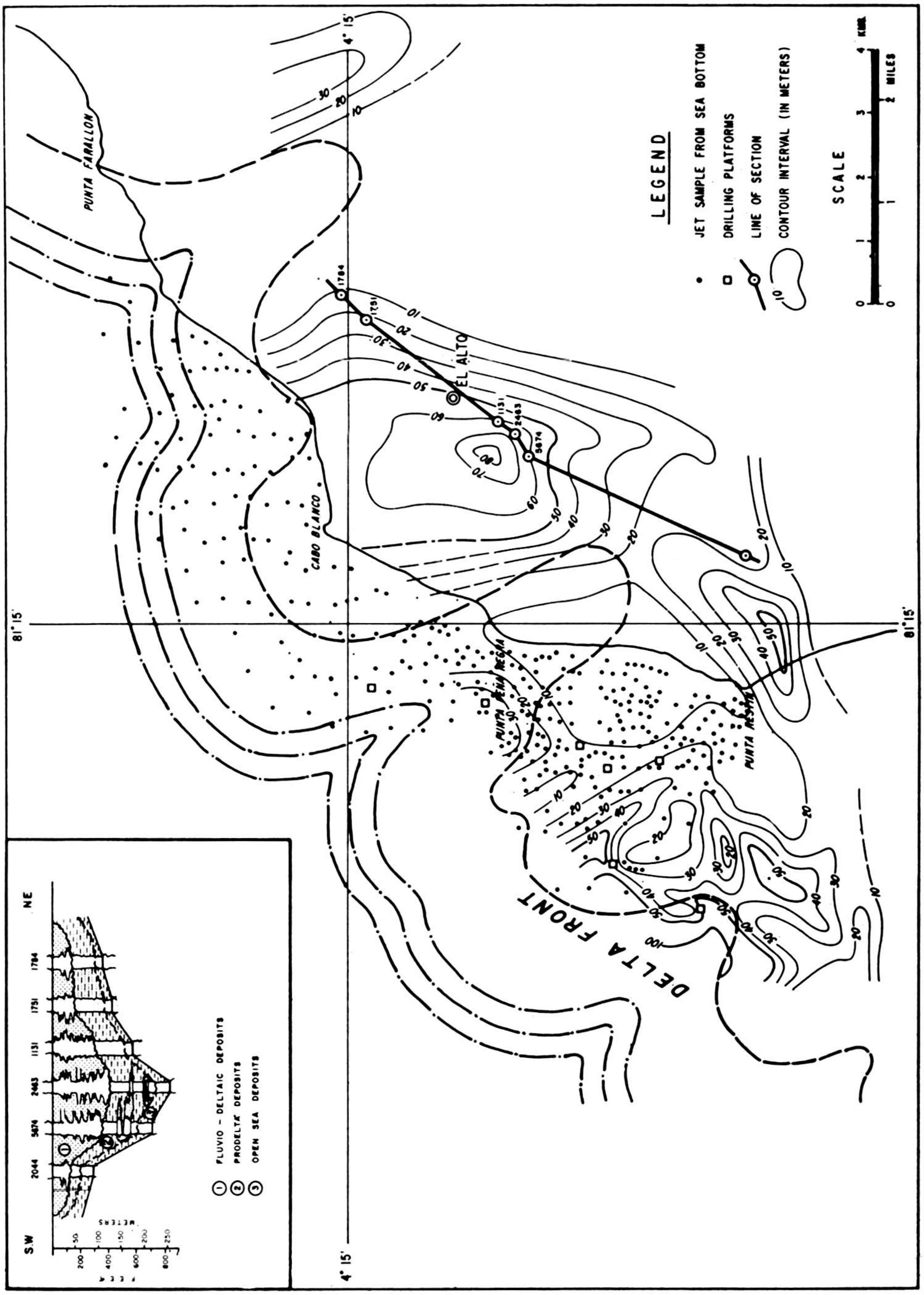

FIG. 15. — Isochore map of Cabo Blanco Sandstone.

more energetic Restin trend. Because deposition has been more important than erosion along the Cabo Blanco trend, a rather thin sand accumulation is expected at the distal edge.

The third trend (Peña Negra trend) shows intermediate characteristics.

APPLICATION TO RESERVOIR PREDICTION

Recent works (Harms and Fahnestock, 1965; Simons *et al.*, 1965) indicate that flows in the upper flow regime carry a higher volume of sediment than flows in the lower flow regime. If the sediment is sand, this premise is of outmost importance to detect thick sand reservoir in the search for oil.

If a trend can be recognized, over which high-energy transport has prevailed (as in the Restin trend) a reasoning like the one followed above could lead to a thick sand reservoir at the end of the trend or, in the case of the Cabo Blanco stratigraphic unit, specifically at the delta front (Fig. 7).

If, on the contrary, a trend is recognized over which low-energy transport has prevailed or has alternated with high-energy transport (as in the Cabo Blanco trend), most of the sand will be deposited along the transport route and thin sand deposits should be expected at the distal end.

However, these energy transport evaluations should be complemented by an estimation of the importance of erosion and deposition along the particular trends studied, to predict the nature and thickness of the deposits at the distal edges.

APPLICATION TO RESERVOIR DEVELOPMENT

As analyzed above, sandstones deposited along major transport routes are expected to present reservoir properties different from those of sandstones deposited in areas of crevasse-filling or sporadic flow. Sandstones of the first type are more massive and vertically continuous than those of the second type.

Massive sandstones present better vertical permeability than interbedded sandstones and shales. This property is important for completion works and secondary recovery projects.

Moreover in the case of NW Peru, shales are bentonitic in nature, and the percentage of this material is also an important factor for deciding on the type of drilling mud and of treated water for artificial stimulation of reservoir and secondary recovery.

CONCLUSIONS

A detailed study of sedimentary features in outcrops and their interpretation in terms of flow regimes (sediment transport energy) permits a calibration and a similar interpretation of electric logs with the subsequent integration of both sources of information to establish trends of thick sand accumulation in searching for oil. This type of work allows furthermore a prediction of reservoir properties which may help to establish appropriate exploration, drilling, and completion programs.

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