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SUBSURFACE STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND ASPECTS OF RESERVOIR CONTINUITY--RIO GRANDE DELTA, TEXAS.

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SUBSURFACE STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND ASPECTS OF RESERVOIR CONTINUITY-- RIO GRANDE DELTA, TEXAS

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I hereby recommend that the thesis prepared under my supervision by Kenneth James Fulton

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ABSTRACT

A subsurface study including 300 electric logs plus 7 cores, in addition to surface mapping from air-photo mosaics and 1 foot contour maps was used to delineate the subsurface stratigraphy, depositional environments, physiography, history of delta growth, delta type, and reservoir continuity associated with two prograding distributaries of the Rio Grande delta.

Age relationships of the distributaries on the delta plain indicate the presence of 3 subdeltas since early Holocene, while C-14 data from 5 boreholes verify the age differences of the De la Gringa system (5000 B.P.) and the Southern system (7000 B.P.).

Three major stratigraphic units - upper, lower, and basal - are defined from subsurface correlation of the De la Gringa system while four definable units - upper group, middle, lower, and basal units - are defined from the Southern system.

Environments of deposition based on geometry, paleocurrents, texture, bedding, and microfauna indicate that fluvial, fluvial-marine, brackish marsh, interdistributary bay, and natural levee characteristics are associated with the upper unit of the De la Gringa system, while prodelta and bay-distributary mouth characteristics are associated with the lower unit, and the basal unit is represented by a transgressive sheet sand. In relation to the Southern system, fluvial environments occupy the upper group, fluvial-marine the middle unit, prodelta environments are associated with the lower unit, and a transgressive sand (similar to that underlying the De la Gringa system)

occupies the basal unit. In addition to the parameters mentioned above, clay mineralogy, heavy mineralogy, petrography, and permeability and porosity were determined (where possible) for each environment.

Both the De la Gringa and Southern systems are post-Pleistocene and developed as two separate events. The progradation of the Southern system with subsequent channel shifting and erosion of underlying units took place approximately 7000 years B.P. Abandonment of that system occurred before progradation and onlap of the De la Gringa system to the north.

The delta model, which begins with the deposition of isolated sand elements on the prodelta and delta slope, and ends with the development of a wide multiple meander belt with cut-offs and clay plugs is discussed in detail. The relationship of this model to the constructive lobate-elongate models of the Lower Wilcox (Eocene) is confirmed.

Lateral and vertical indexes of continuity were determined for sands in each of the depositional environments. Lateral indexes indicate that the fluvial-marine sands are the most continuous (1.0) parallel and perpendicular to progradation, within a restricted depositional system. Delta front "sheet sands" which cross channel systems and are commonly shown in generalized delta models are not substantiated in this detailed study. Fluvial sands are more continuous parallel (.83) than perpendicular (.45) to progradation while in prodelta sands the reverse is true. Vertical continuities for the fluvial-marine sands are slightly better (.84) than down dip fluvial sands (.75). Updip vertical continuities of fluvial sands range .5-.6, while vertical continuities of prodelta sands average .58. The product of vertical continuity (X) average isopach thickness indicates the excellent relative measure of reservoir potential for fluvial-marine sands (17.0) as versus fluvial (10.0) or prodelta (2.0).

KEY WORDS: Continuity, stratigraphy, depositional environments, reservoir potential, delta model.

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INTRODUCTION

The close relationship between deltaic sedimentation and the formation of reservoirs for the accumulation of oil and gas has led to extensive study in recent years of the complexities associated with deltaic deposition.

Modern studies of deltaic sedimentation initiated by Harold N. Fisk contributed significantly to the knowledge of depositional and environmental aspects associated with recent deltaic sediments. The depositional framework of the Mississippi delta as studied by such workers as Fisk et al. (1954), Fisk (1961), Coleman and Gagliano (1964), Kolb and Van Lopik (1966), Frazier (1967), and Gould (1970) have led to the development of a deltaic model which is applicable to both modern and ancient deltaic complexes.

Publications concerning other modern deltas such as the Rhone (Oomkens, 1970), the Niger (Allen, 1964, 1970), the Guadalupe (Donaldson, 1970), and the Colorado (Kanes, 1970), have delineated the broad aspects of deltaic sedimentation in systems differing from that of the Mississippi.

Much of the work done concerning aspects of deltaic sedimentation is synthesized in summary volumes such as Recent Sediments of the Northwest Gulf of Mexico (Shepard, Phleger, and Van Andel, eds., 1960), Deltas in their Geologic Framework (Shirley and Ragsdale, eds., 1966), Delta Systems in the Exploration for Oil and Gas (Fisher, Brown, Scott, and McGowen, eds., 1969), Deltaic Sedimentation, Modern and Ancient (Morgan and Shaver, eds., 1970), and most recently, Deltas, Models for Exploration (1975, Broussard, ed.). Two of the above summary volumes deserve special mention. The volume by Fisher et al. (1969) is excellent for its broad coverage of delta types, delta models for exploration, bibliography, and voluminous figures (168) summarizing the thoughts and ideas of many previous workers. The recent volume (1975) edited by Broussard is a superb compilation of articles by numerous workers in the field of deltaic sedimentation. The book contains three sections, the first of which features review and general studies characterizing deltaic sedimentation. The second and third present studies of modern and ancient deltas respectively - comparison maps of ancient deltas are included in the appendix. Especially significant among the papers concerned with general delta studies in the above volume is the article by Leblanc (1975, p. 13-85). Leblanc has done an excellent job of summarizing significant studies of modern and ancient deltaic sediments. His summary table (Table 1) is included here as a substitute for what would otherwise be a lengthy discussion of previous work on delta systems.

A survey of work done on deltas, especially that which is published in the above volumes indicates that although the broad delta model is defined the details necessary to define and delineate the stratigraphy, as well as sandstone geometry, continuity, and variability within the modern delta complex is lacking.

Data available for the present study, including over 300 electric logs, spaced at 500 to 2000 foot intervals plus sedimentological data from seven cores presents the opportunity to develop the detailed,

YEAR	MODERN DELTAS		ANCIENT DELTAS	
	AUTHOR & NAME OF DELTA	SIGNIFICANCE OF PAPER	AUTHOR, GEOL. AGE & LOCATION	SIGNIFICANCE OF PAPER
1878	CREDNER Several deltas of the world	DISCUSSES STRUCTURE, FORM, AND DISTRIBUTION OF SEVERAL DELTAS OF THE WORLD. WRITTEN IN GERMAN, CONSEQUENTLY IS RELATIVELY UNKNOWN IN AMERICA.		
1885 1890			GILBERT Pleistocene lake deltas of East U.S. and Utah	DISCUSSES FORMATION OF DELTAS IN RELATIVELY SHALLOW LAKES. PRESENTS FIRST DIAGRAMS SHOWING THE VERTICAL SEQUENCE AND CROSS SECTION OF A DELTA. BASIS FOR DELTA SEQUENCE WHICH IS INCLUDED IN MOST GEOLOGICAL TEXTBOOKS.
1912			BARRELL Devonian of N.Y. & Pennsylvania	FIRST GOOD DISCUSSION OF FACTORS CONTROLLING DELTA CONSTRUCTION. DEFINES TOPSET, FORESET, & BOTTOMSET BEDS. RECOGNIZES SEVERAL TYPES OF DELTAS IN ADDITION TO THE TYPE DESCRIBED BY GILBERT.
1921-22	JOHNSTON Fraser River Delta of S.W. Canada	FIRST PAPER ON AMERICAN MODERN DELTA. DESCRIBES SMALL DELTA, TRANSPORT AND CHARACTER OF SEDIMENTS. ILLUSTRATES THE STRATIFICATION OF DELTA SEDIMENTS WITH CORE PHOTOGRAPHS.		
1930	TROWBRIDGE Mississippi Delta, Louisiana	FIRST GEOLOGICAL STUDY OF MISS. DELTAIC PLAIN. RECOGNIZED IMPORTANCE OF CREVASSING IN DEVELOPMENT OF DISTRIBUTARY CHANNELS. DESCRIBES RIVER-MOUTH BARS AND SEDIMENTS.	BARTON Pleistocene deltas of SE Texas	RECOGNIZED THAT COASTAL PLAIN WAS FORMED BY DELTAS OF THE TRINITY AND BRAZOS RIVERS. MARKS FIRST USAGE OF ADJECTIVE: DELTAIC COASTAL PLAIN.
1932			TWENHOFEL General discussion of deltas & sediments	EARLY TEXTBOOK SUMMARY OF DELTA COMPONENTS AND DESCRIPTION OF SEDIMENTS ASSOCIATED WITH TOPSET, FORESET, AND BOTTOMSET BEDS. MAINLY TAKEN FROM BARRELL, 1912, SEE ABOVE.
1936	RUSSELL Mississippi Delta	EXCELLENT PHYSIOGRAPHIC DESCRIPTION OF DELTAIC PLAIN, SEDIMENTATION ASSOCIATED WITH MODERN DELTA AND ALSO THE ABANDONED DELTAS OF MISSISSIPPI. RECOGNIZED TWO BASIC ENVIRONMENTS OF SAND DEPOSITION: DISTRIBUTARY CHANNELS AND RIVER-MOUTH BARS.		
1937	SYKES Colorado Delta in Mexico and Calif.	BASED ON OBSERVATIONS OVER 40-YEAR PERIOD. EXCELLENT DESCRIPTION OF DELTAIC PLAIN AND RIVER DIVERSIONS, AND TRANSPORT AND DEPOSITION OF SEDIMENTS ON DELTAIC PLAIN. UNIQUE DELTA IN THAT IT WAS BUILT IN BOTH MARINE ENVIRONMENT AND IN A CONTINENTAL BASIN. DOES NOT CONSIDER SUBAQUEOUS PORTION OF DELTA.		
1939	McKEE Colorado Delta, Mexico & Calif.	PHOTOGRAPHED AND SKETCHED THE CHARACTER OF SEDIMENTS ASSOCIATED WITH SEVERAL PARTS OF DELTA. EMPHASIS ON RELATIONSHIP BETWEEN ENVIRONMENT & STRATIFICATION.		
1939	RUSSELL & RUSSELL Mississippi Delta	FIRST PAPER ON DETAILS OF RELATIONSHIP OF SEDIMENT TO ENVIRONMENTS OF DEPOSITION: DISTRIBUTARY CHANNELS, LEVEES, BARS AND BEACHES ON DELTA FRONT. ALSO DISCUSSES PROCESSES OF MARINE TRANSGRESSION OVER AN ABANDONED DELTA. STRESSES IMPORTANCE OF CHANNEL DIVERSION ON DEPOSITION OF INTERBEDDED CONTINENTAL & MARINE, TYPICAL OF DELTAS.		
1944 1947	FISK Mississippi Delta	MAPPED ALL ABANDONED DELTAS OF THE RECENT DELTAIC PLAIN COMPLEX. CORRELATED DELTA SHIFTS WITH CHANNEL DIVERSIONS IN ALLUVIAL VALLEY. 1947 REPORTS INCLUDE FIRST CROSS SECTIONS OF DELTAIC PLAIN DEPOSITS.		
1952	FISK Mississippi Delta	DETAILED STUDY OF ENVIRONMENTS AND SEDIMENTS OF ATCHAFALAYA BASIN (UPPER DELTAIC PLAIN). EMPHASIS ON RIVER DIVERSIONS. STUDY BASED ON 200 BORINGS. FIRST STUDY OF PROGRADING DISTRIBUTARY CHANNEL (PASS) AND DEVELOPMENT OF FINGER-SHAPED MASSES OF SAND.		
1953			BUSCH Pennsylvanian of Oklahoma	STRESSES IMPORTANCE OF DELTA ENVIRONMENTS, BASED ON STUDY OF MODERN DELTAS, IN SUBSURFACE EXPLORATION. RECOGNIZED THREE TYPES OF DELTAS (BIRDFOOT, ESTUARINE, AND ARCUATE). STRESSED THAT GILBERT'S TRIPARTITE SUBDIVISION NOT TYPICAL OF MOST DELTAS. THIS IS FIRST MAP OF DELTAIC SAND DISTRIBUTION IN SUBSURFACE.
1954	FISK ET AL. Mississippi Delta	ONLY PAPER ON ALL OF THE DEPOSITIONAL ENVIRONMENTS AND SEDIMENTS OF DELTA. LOAD & DEPOSITIONAL PROCESSES DISCUSSED. DESCRIBES DISTRIBUTARY CHANNEL, LEVEE, AND MARSH FACIES OF DELTAIC PLAIN, RIVER-MOUTH BAR, AND PRODELTA. EMPHASIS WAS ON BAR FINGERS AND CLAY OF DELTA PLATFORM. PROBABLY BEST PAPER EVER WRITTEN ON MODERN BIRDFOOT DELTA.	PEPPER ET AL. L. Mississippian of Appalachian basin	FIRST INVESTIGATION OF SANDSTONE PETROLEUM RESERVOIRS BY U.S.G.S. DESCRIBES SEDIMENTS ASSOCIATED WITH LARGE DELTA COMPLEX, BASED LARGELY ON SEDIMENT DISTRIBUTION PATTERNS (DETERMINED FROM WELL DATA). CLAIMED BARRELL'S CRITERIA NOT USEFUL. THEY HAD TO DEVELOP THEIR OWN CRITERIA.
1954			NANZ Oligocene of South Texas	FIRST RESEARCH BY PETROLEUM INDUSTRY ON APPLICATION OF STUDIES OF RECENT SEDIMENTS TO INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS OF SUBSURFACE SANDSTONE RESERVOIRS.
1955	FISK Mississippi Delta	FIRST PAPER ON ORIGIN AND DISTRIBUTION OF SANDS OF THE SUBAQUEOUS PART OF DELTA (DELTA-FRONT SHEET SANDS). THESE ARE MOST COMMON SANDS IN DELTA. MAP AND SECTIONS ILLUSTRATE DISTRIBUTION OF DELTA-FRONT SHEET SANDS.		
1955	KRUIT Rhone Delta	FIRST DETAILED STUDY OF SEDIMENTS OF RHONE DELTA, WHICH IS QUITE DIFFERENT TYPE OF DELTA THAN THE MISSISSIPPI. DELTA SEQUENCE WAS DETERMINED FROM BORING DATA.		
1957	MOORE & SCRUTON Mississippi Delta	FIRST PAPER ON INTERNAL STRUCTURES OF SEDIMENTARY STRUCTURES OF SEDIMENTS OF EAST PART (SUBAQUEOUS) OF MISSISSIPPI DELTA. ILLUSTRATED WITH CORE PHOTOS. THIS ESTABLISHED IMPORTANCE OF STRATIFICATION AND STRUCTURES OF SEDIMENTS.		
1959	WELDER Mississippi Delta	EXCELLENT STUDY OF PROCESS AND SEDIMENTATION. WELL-DOCUMENTED HISTORY OF HISTORICAL DEVELOPMENT OF CUBITS GAP SUBDELTA. GOOD DISCUSSION OF RIVER-MOUTH-BAR SEDIMENTATION.	MOORE Carboniferous deltas of England & Scotland	VERY GOOD PAPER ON ORIGIN OF CYCLOTHEMS. EACH CYCLOTHEM DESCRIBED WAS FORMED BY A DELTA WHICH WAS BUILT IN SHALLOW CONTINENTAL SEA. SHIFTING DELTAS, AS A RESULT OF RIVER DIVERSIONS UPSTREAM, EXPLAINS THICK SECTION OF CYCLOTHEMS. MECHANISM OF CYCLIC ADVANCE OF DELTA ADEQUATE TO EXPLAIN ALL OBSERVED FEATURES OF CYCLOTHEMS. MAKES INTERPRETATIONS BASED ON FISK'S 1944 AND 1955 PAPERS. GOOD EXAMPLE OF APPLICATION OF PRINCIPLES, CRITERIA ETC. FROM RECENT TO ANCIENT SEDIMENTS.
1960	SCRUTON Mississippi Delta	GOOD SUMMARY PAPER ON WORK ON DELTA BY SCRIPPS (API PROJ. 51). DESCRIBES PROCESSES OF DELTA BUILDING AND DELTA SEQUENCE. ALSO DISCUSSES DELTA DESTRUCTION AFTER ABANDONMENT.	PRYOR Cretaceous deltas of Mississippi embayment	REGIONAL STUDY OF OUTCROP & SUBSURFACE DATA. CONCERNED WITH GEOMETRY, PATTERNS OF SEDIMENTATION (MAPS) DIRECTIONS OF SEDIMENTS TRANSPORT & SEDIMENTARY STRUCTURES. MAPS LARGE DELTA COMPLEX. ALSO PRESENTS A DEPOSITIONAL MODEL.
1960	FISK Mississippi Delta	CLEAR SUMMARY OF FISK'S CONCEPTS OF DELTAIC PROCESSES AND SEDIMENTATION. BLOCK DIAGRAMS ILLUSTRATE DEVELOPMENT OF DELTAIC SEQUENCE. CHANGES IN CHANNEL DEPTHS AS DELTA ADVANCE RECOGNIZED AND STRESSED.	MOORE Carboniferous delta of England	INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS OF TYNESIDE CYCLOTHEM. EMPHASIS IS ON MOST COMMON SHEET SANDSTONES. THEY WERE FORMED BY CREVASSING PROCESS AS DESCRIBED BY RUSSEL AND RUSSELL (1939). NOTE: THIS IS DELTA-FRINGE SAND.
1961	FISK Mississippi Delta	EXCELLENT SUMMARY PAPER ON BAR-FINGER SANDS FORMED BY PROGRADING DISTRIBUTARY CHANNEL. DISCUSSES DEVELOPMENT AND GEOMETRY AND SEDIMENTARY CHARACTERISTICS OF BAR FINGERS AND THEIR RELATIONSHIP TO OTHER DELTA FACIES. OUTLINES SUMMARY CRITERIA FOR RECOGNITION IN ANCIENT SEDIMENTS.	BEERBOWER Pennsylvanian & Permian deltas of Penn., W. Va., and Ohio	RE-EXAMINATION OF CYCLOTHEM PROBLEM. CYCLOTHEMS DESCRIBED WERE FORMED BY DELTAS DEVELOPED IN LAKES RATHER THAN MARINE (AS IS THE CASE IN ILLINOIS). USES MISSISSIPPI DELTA AS MODEL.
1961	VAN STRAATEN Rhone Delta and deltaic sedimentation	FIRST SUMMARY PAPER ON DELTAIC SEDIMENTATION BASED ON STUDIES OF SEVERAL MODERN DELTAS. RECENT ADVANCES IN CONCEPTS AND PRINCIPLES ARE OUTLINED. INCLUDES NEW DATA ON RHONE DELTA.	PRYOR Cretaceous and Mississippian deltas of Illinois	STUDY OF REGIONAL FACIES CHARACTERISTICS, THICKNESS, DISTRIBUTION, AND SEDIMENT TRANSPORT DIRECTIONS. COMPARISON OF SAND TREND IN TWO BASINS. [illegible] OF DELTAIC [illegible]. PROPOSES CONCEPTUAL DEPOSITIONAL MODEL.

Table I. Compilation of significant published literature on deltas (after Leblanc, 1975, Table I).

1962			ALLEN Devonian deltas of England	FIRST DETAILED STUDY OF PETROLOGY AND SEDIMENTARY FEATURES OF OLD RED SANDSTONE. SERIES OF CYCLOTHEMS ARE DESCRIBED. THEY ARE PRODUCT OF SUBSIDING DELTAIC PLAIN LIKE COLORADO DELTA OF MEXICO AND CALIFORNIA.
			MURPHY & SCHLANGER Cretaceous deltas - Brazil	DETAILED DESCRIPTION OF DELTAIC AND TURBIDITE SEDIMENTS. COMPARES CRETACEOUS DELTAS OF BRAZIL WITH MISSISSIPPI DELTA.
1963			[illegible] Cretaceous delta of Wyoming and South Dakota	DESCRIBES THREE DELTA UNITS: DISTRIBUTARY CHANNEL SANDS, AND INTER-CHANNEL AND [illegible] DEPOSITS. BLANKET SANDS WERE FORMED DURING MARINE TRANSGRESSION OF ABANDONED DELTA.
			WANLESS Pennsylvanian deltas of Central U.S.A.	SUMMARY OF REGIONAL STUDIES OF SEDIMENTS ASSOCIATED WITH CYCLOTHEMS. SERIES OF REGIONAL MAPS, WHICH OUTLINE LARGE DELTAS, ARE PRESENTED.
			TAYLOR Cretaceous delta of England	FIRST PAPER TO DESCRIBE COMPLETE DELTA SEQUENCE (FROM PRODELTA TO SUBAERIAL PLAIN). CHARACTERISTICS OF SEDIMENTS FROM PRODELTA, DELTA SLOPE, DELTA FRONT, AND ON-DELTA ARE GIVEN. NOTE NEW TERMINOLOGY! DELTA DESCRIBED WAS FORMED IN VERY SHALLOW AND FRESH WATER. RECOGNIZED THAT SEDIMENTARY STRUCTURES AND LITHOLOGIES OCCUR IN SEVERAL ENVIRONMENTS. THEY ARE GENERALLY CHARACTERISTICALLY REPRESENTED IN ONE OF THEM. ALSO POINTS OUT NONE OF FOUR DELTA FACIES DESCRIBED IS CHARACTERISTICALLY DIAGNOSTIC OF DELTA. IT IS JUXTAPOSITION OF ALL FOUR WHICH IS UNIQUE.
1964	LAGAAIJ & KOPSTEIN Rhone Delta, France	EXCELLENT, BRIEF SUMMARY PAPER ON SEDIMENTARY SEQUENCE OF DELTA; BASED ON CORE DATA. DIAGRAM ILLUSTRATES DELTA SEQUENCE, WITH CORE PHOTOS.	DOTT Cretaceous and Eocene deltas of Oregon	FIRST PAPER ON OCCURRENCE OF DELTAS IN A TECTONICALLY UNSTABLE AREA (EUGEOSYNCLINAL DELTS)
	COLEMAN ET AL. Mississippi Delta	SUMMARY OF TYPES AND CHARACTERISTICS OF SEDIMENTARY STRUCTURES OF MISSISSIPPI DELTA. WELL ILLUSTRATED WITH CORE PHOTOS. CONCLUDES THAT TOTAL SUITE OF STRUCTURES IN ONE ENVIRONMENT IS CHARACTERISTIC.	BOTVINKINA & YABLOKOV Deltas in Coal Measures, Donets Basin, Russia	DESCRIBES LITHOLOGY, STRUCTURE OF SEDIMENTS OF [illegible] PORTION OF DELTA. FACIES CHANGES AND RELATIONSHIPS TO BORDERING FORMATIONS ARE ILLUSTRATED.
	COLEMAN & GAGLIANO Mississippi Delta	SUMMARY PAPER ON CYCLIC DELTAIC SEDIMENTATION. DESCRIPTION OF COMPONENTS OF CYCLE, BASED ON CORES. DEVELOPS MODEL TO EXPLAIN COMPLEX DELTAIC FACIES.	[illegible] Mississippian deltas of Indiana and Illinois	PRESENTS SANDSTONE THICKNESS MAPS FOR FOUR FORMATIONS. INTERPRETS PATTERNS TO BE DELTAIC IN ORIGIN. POINTS OUT MOST SAND BODIES ARE NOT DISTRIBUTARY CHANNEL SANDS BUT ARE BAR-FINGER SANDS
1965	KANES Colorado Delta of Texas	VERY WELL DOCUMENTED STUDY OF SMALL BIRDFOOT DELTA FORMED IN PAST 30 YEARS IN LAGOON BEHIND BARRIER. CONTAINS DETAILED LOGS AND CORE PHOTOS FROM 17 CORES.	WANLESS Pennsylvanian deltas of Central U.S.A.	EMPHASIS ON COALS WHICH ARE OF DELTAIC-PLAIN ORIGIN. REGIONAL MAPS, BASED ON ONE WELL OR OUTCROP PER TOWNSHIP, SHOW REGIONAL PICTURE.
	ALLEN Niger Delta, W. Africa	FIRST DETAILED STUDY OF ENVIRONMENTS AND SEDIMENTS OF ARCUATE TYPE DELTA. DESCRIBES SETTING, DISTRIBUTIVE AGENTS, SUBAERIAL DELTA, & CONTINENTAL SHELF. WELL ILLUSTRATED WITH MAPS, SECTIONS, AND CORE PHOTOS. SUMMARY CHARACTERISTICS OF ENVIRONMENT AND LITHOFACIES GIVEN IN TABLE FORM.	GREENSMITH Mississippian deltas of Scotland	DESCRIBES GENERAL CHARACTER, PETROGRAPHY AND SEDIMENTARY STRUCTURES OF: ON-DELTA, DELTA-FRONT PLATFORM, DELTA SLOPE AND PRODELTA SLOPE (NOTE NEW TERMINOLOGY AND COMPARE WITH SCRUTON, 1960 ABOVE). ALSO DESCRIBES RETROGRADING DESTRUCTIVE PHASE, AFTER DELTA ABANDONMENT.
1966	KOLB & VAN LOPIK Mississippi Delta	BEST SUMMARY PAPER ON THE GEOLOGIC HISTORY, ENVIRONMENT, AND SEDIMENTS OF THE MISSISSIPPI DELTAIC-PLAIN COMPLEX. BASED ON ABUNDANT CORE DATA. SUBAQUEOUS PARTS OF DELTA NOT CONSIDERED.	[illegible] Importance of deltas	GOOD SUMMARY ON PHYSIOGRAPHIC OUTLINES OF DELTAS, SUBAQUEOUS PARTS OF DELTAS AND THE VERTICAL AND LATERAL SEQUENCE OF SEDIMENTS. GEOMETRY OF DELTAIC MASSES ARE GIVEN. IMPORTANCE OF DELTA IN PETROLEUM GEOLOGY IS SUMMARIZED.
	DONALDSON Guadalupe Delta, Texas	WELL-DOCUMENTED SUMMARY OF THE ENVIRONMENTS AND SEDIMENTS OF SMALL DELTA FORMED IN SHALLOW BAY. CONTAINS CORE PHOTOS AND SECTIONS SHOWING DELTAIC SEQUENCE AND FACIES RELATIONSHIPS. EXAMPLE OF VERY LOW SAND-CONTENT DELTA.	HOROWITZ Ordovician deltas of Central Appalachians	WELL-DOCUMENTED PAPER ON THREE SUCCESSIVE STRATIGRAPHIC UNITS. ENVIRONMENTS AND SEDIMENTS RANGE FROM SUBAERIAL DELTA, TOPSET PORTION OF SUBAQUEOUS DELTA, FORESET SLOPE DEPOSITS AND TURBIDITES DERIVED FROM DELTA SEDIMENTS. POINTS OUT RELATIONSHIP OF TURBIDITES TO DELTAS.
	MOORE Deltaic sedimentation	SECOND SUMMARY PAPER ON DELTAIC SEDIMENTATION BASED ON STUDIES OF SEVERAL MODERN DELTAS BY SEVERAL GROUPS OF GEOLOGISTS. UNFORTUNATELY NOT A SINGLE ILLUSTRATION IS INCLUDED.	LINEBACK Mississippian deltas of Southern Illinois	STUDY BASED ON 400 ELECTRIC LOGS AND 100 SAMPLE LOGS OF STRATIGRAPHIC RELATIONSHIP OF FOUR LITHOLOGIC UNITS. ONE UNIT WAS OF DELTAIC ORIGIN. GOOD EXAMPLE OF DEVELOPMENT OF DELTA IN ABOUT 600 FEET OF WATER AS TOPSET, FORESET, AND BOTTOMSET BEDS.
			GREENSMITH Carboniferous deltas of Scotland	A REVIEW AND REAPPRAISAL OF PREVIOUS STUDIES OF ORIGIN OF CYCLOTHEMS. PRESENTS SUMMARY OF CHARACTER OF SEDIMENTS OF: ON-DELTA, DELTA-FRONT, PRODELTA SLOPE. INCLUDES CORE PHOTOS. REJECTS PREVIOUS EXPLANATIONS FOR ORIGIN OF CYCLOTHEMS (SEA-LEVEL RISES, UPLIFTS, ETC.). EXPLAINS CYCLOTHEM WITH SIMPLE DELTAIC PROCESSES.
			DOTT Eocene deltas of Oregon	DESCRIBES DELTAIC SEDIMENTATION (SMALL DELTAS) IN VERY UNSTABLE BASIN. STUDY BASED ON SEDIMENTARY STRUCTURES AND PETROGRAPHY. WELL ILLUSTRATED AND GOOD SUMMARY TABLE GIVEN.
1967	VAN ANDEL Orinoco Delta, Venezuela	GOOD SHORT SUMMARY OF THE GEOLOGY OF THE ORINOCO. OUTLINES BASIC ASPECTS OF THIS DELTA AND COMPARES IT WITH THE MISSISSIPPI, RHONE, AND NIGER DELTAS.	FISHER & McGOWEN Eocene deltas of Texas	REGIONAL SURFACE AND SUBSURFACE STUDY OF THICK SECTIONS OF CLASTICS. DESCRIBES ROCKDALE DELTA COMPLEX SIMILAR TO MISSISSIPPI DELTA. SEVERAL INDIVIDUAL LOBES ARE MAPPED. RELATIONSHIP OF DELTAS TO ALLUVIAL PLAINS, COASTAL INTERDELTAIC ENVIRONMENTS, AND MARINE GULF ARE SHOWN BY MAPS AND SECTIONS.
	FRAZIER Mississippi Delta	PRESENTS SERIES OF DIAGRAMS TO SHOW THE DEVELOPMENT OF REPETITIVE DELTAIC FACIES SEQUENCES. EACH DELTA LOBE IS CHARACTERIZED BY PRODELTA CLAYS, OVERLYING DELTA-FRONT SANDS AND UPPER DELTAIC-PLAIN FACIES. CONTAINS SERIES OF DETAILED CROSS SECTIONS.		
	OOMKENS Rhone Delta, France	SUMMARY OF THREE TYPES OF DEPOSITIONAL SEQUENCES CHARACTERISTIC OF RHONE DELTA. REGRESSIVE, CHANNEL-FILL AND TRANSGRESSIVE.		
1968	THOMPSON Colorado Delta of Mexico	DETAILED STUDY OF SEDIMENTS OF NW PORTION OF COLORADO DELTAIC PLAIN AND EXTENSIVE MUDFLATS ON DELTA FLANK. EMPHASIS IS ON HIGH TIDAL FLATS, INTERTIDAL, AND SUBTIDAL FLATS. CORE PHOTOS ILLUSTRATE SEDIMENTARY STRUCTURES.	LAURY Pennsylvanian deltas of Illinois & Iowa	OUTCROP STUDY OF TWO TYPES OF DELTA SANDSTONES: DISTRIBUTARY CHANNEL-FILLS AND DELTA-FRONT SHEET SANDS. MODEL IS MISSISSIPPI DELTA.
			COLLINSON Carboniferous deltas of England	STUDY OF ANCIENT ANALOGUE OF THE CLASSICAL GILBERT-TYPE DELTA. LARGE-SCALE CROSS-BEDDED SETS OF COARSE SANDSTONES UP TO 40 M THICK, WITH UP TO 20° DIPS REPRESENT FORESET BEDS. MEDIUM-SCALE CROSS-BEDDED CHANNEL SANDS OCCUR UPON FORESETS. BOTTOMSET BEDS NOT OBSERVED.
1969	McEWEN Trinity Delta, Texas	STUDY OF COMPLETE SEQUENCE OF SMALL BIRDFOOT DELTA BUILT IN SHALLOW BAY. SERIES OF CORE PHOTOS ILLUSTRATES VARIOUS DELTA FACIES. FACIES RELATIONSHIPS AND CHARACTERS SUMMARIZED WITH BLOCK DIAGRAM AND TABLE.	BROWN Pennsylvanian and Permian deltas of North Texas	DETAILED STUDY (OUTCROP AND SUBSURFACE) OF THICK REPETITIVE SEQUENCES OF CLASTICS DEPOSITED IN MARINE, DELTAIC, INTERDELTAIC AND ALLUVIAL ENVIRONMENTS. SANDSTONES OF DELTA-FRONT, DISTRIBUTARY MOUTH BAR, AND DISTRIBUTARY CHANNEL ORIGIN ARE DESCRIBED. SANDS OF DESTRUCTIVE PHASE OF ABANDONED DELTA ALSO DESCRIBED. GOOD DISCUSSION OF FACTORS WHICH CONTROL SANDSTONE DISTRIBUTION: GEOMETRY, COMPOSITION, PALEOTOPOGRAPHY, AND [illegible].
			FISHER ET AL. Summary of delta systems	SPECIAL VOLUME PREPARED FOR RESEARCH COLLOQUIUM ON DELTA SYSTEMS IN EXPLORATION FOR OIL AND GAS. CONTAINS MATERIAL BY SEVERAL AUTHORS ON [illegible], ON DELTA SYSTEMS, AND DELTAIC DEPOSITION, GULF COAST TERTIARY DELTA SYSTEMS AND DELTA SYSTEMS OF OTHER REGIONS. SELECTED REFERENCES ON MODERN AND ANCIENT DELTAS.

Table I con't.

fine-scaled stratigraphy necessary to aid exploration and development of reservoirs in deltaic deposits. It is the purpose of this study to develop the detailed stratigraphy and depositional environments associated with two prograding distributary systems of the Holocene Rio Grande delta. In addition, special emphasis is placed on delineating continuity indexes associated with sands of the various depositional environments in order to better quantitatively describe (and predict) reservoir potential analagous to prograding delta systems.

PREVIOUS WORK

Previously published work on the Rio Grande delta is sparse and nothing has been done until now to delineate the complexities of the subsurface deltaic environments.

Beck (1928) studied the soil types of Cameron County and included in his report a discussion of the soils of the Rio Grande delta plain. Beck separated the soils of the delta plain portion of the county into several series on the basis of drainage and the content of soluble salts. The best drained soils in the delta are those lying on the natural levee ridges. These are members of the Laredo soil series, of which three types, a clay, silty clay, and fine sandy loam, were mapped. Lying along the lower slopes of the natural levees or resaca ridges between the belt of Laredo soils and the heavier soils in the inter-resaca troughs is the Cameron clay. This soil is made up of recently deposited alluvium as is the Laredo series but is finer in grain. Occupying the broad, shallow, inter-resaca troughs is the Harlingen clay, a soil which is fine grained, poorly drained, and markedly gray in color. The Rio Grande soils occupy the most recently deposited Rio Grande flood plains. These are light-brown to brown soils and are composed of material that has been washed down from various soils of the Rio Grande drainage basin.

Trowbridge (1922) did a geologic reconnaissance of the Gulf Coastal Plain of Texas near the Rio Grande which was incorporated into a detailed report of the Tertiary and Quaternary geology of the Lower Rio Grande Region (Trowbridge, 1932). The latter report is a comprehensive study incorporating the geography, topography, stratigraphy, structure, and economic resources of the area between the Brazos and the Rio Grande rivers. Very little consideration is given, however, to the Rio Grande delta which Trowbridge includes as a topographic division of the Rio Grande valley. That part of the river near the mouth of the Rio Grande is simply mapped as "recent fluviatile deposits". Trowbridge in his 1932 report does make mention, however, of "numerous mounds, 5 to 30 feet in height, made of clay and known as clay buttes". He suggested that they may be "clay dunes"--a proposal later exemplified by Huffman and Price (1949) for such mounds found along the coast on the surface of the delta. It is also notable that the 1932 work contains a fairly detailed section on previous work in southwest Texas from 1846 until 1926.

Foscue (1932) notes various drainage aspects of the delta plain in his discussion of the physiography of the Rio Grande. Such drainage features include: (1) the Rio Grande river, (2) arroyo-type intermittent tributaries of the Rio Grande at the head of the delta, (3) one important distributary of the Rio Grande, the Arroyo Colorado, and (4) various cutoff meanders, and oxbow lakes known as "resacas", which have no outlet.

Bullard (1942) in his study of the beach and river sands of the Gulf Coast of Texas demonstrated that the dominant heavy minerals contributed by the Rio Grande river are basaltic hornblende and pyroxene followed by green hornblende, garnet, rutile, stautolite, tourmaline, and zircon.

The most extensive study to date in the vicinity of the Rio Grande delta was that done by Lohse (1952). However, Lohse's work had very little to do with the delta itself as all samples were collected between the beach and 10 fathom depth from 20 nautical miles north to 71 miles south of the Rio Grande river. The main emphasis was placed on distribution of sediment away from the mouth of the Rio Grande and the controlling factor of surface winds on such sediment dispersal. His study showed that shallow marine and beach sediments are transported northwestward along the north flank of the delta and southwestward along the south flank and the remainder of the Texas Gulf coast. Lohse's work showed that the modern shallow marine sediments are generally uniformly distributed north and south from the delta apex except for a slight increase of organic detritus southward and downslope to a depth between 9 and 9 3/4 fathoms--the depth interpreted as the base of wave action.

Both Cook (1958) and Lohse (1958) have contributed to the recent literature concerning the physiography and distribution of sub-deltas of the Rio Grande. Cook (1958, p. 53) suggests that the surface of the Rio Grande deltas is similar in many ways to that of the Mississippi River delta and implies that the Rio Grande deltaic development has been essentially the same as that of the Mississippi except for the volume of water carried, the sediment load, and the local oceanographic conditions at the river mouth.

Lohse (1958, p. 55) discusses the Recent history of the Rio Grande deltaic plain and the position of three subdeltas during Early Recent, Middle Recent, and Late Recent or Modern.

Leblanc and Hodgson (1959) consider the physiography of the Rio Grande delta and its relationship to the post-Pleistocene sea level rise in their discussion of the origin and development of the Texas shoreline.

Harrison (1972) and Fulton (1973) completed preliminary work on the Rio Grande delta, some of which is incorporated into this study.

METHODS-DRILLING, LOGGING, AND CORING

Wells in the study area were drilled with a Failing 1500 drill rig and logged with a WIDCO Logger. Deep holes (150 feet) were drilled with a Franks 1500 rig. For sand sections, cores were taken with a modified Osterberg piston core 1 meter in length. Clay material (in cores) was taken with a straight hydraulic push Shelby tube. The cores were oriented and the Osterberg cores were retained in the Shelby tubes. Those holes that were not cored were drilled with a fishtail bit using Baroid Aqua Gel drilling fluid. All drill hole locations were surveyed by plane table.

GEOLOGIC SETTING

The post-Pleistocene Rio Grande delta has a subaerial area of approximately 3,000 square miles and forms the terminus of the Rio Grande River, which drains over 171,000 square miles (Smith, 1956, p. 250). The following discussion of the drainage basin of the Rio Grande is from Lohse (1952, p. 35).

> The Rio Grande originates at the crest of the continental Divide in the Tertiary volcanic rocks of the San Juan Mountains of Colorado. From there, it flows south and southeast across the andesite and rhyolite lava flows, the Archean schists, the conglomerates and other Quaternary deposits of New Mexico, receiving sediment from scattered but significant outcrops of Tertiary granite and Lower Permian sedimentary formations. From the Texas border to the Gulf, the Rio Grande receives sediment from the Tertiary volcanic and intrusive rocks of the Big Bend and Rio Conches watershed, the Pecos River, the Cretaceous system of southern west Texas and northern New Mexico and finally the Cenozoic and Quaternary deposits of the Coastal Plain.

In the immediate vicinity of the Rio Grande delta (Fig. 1) Pliocene and Pleistocene formations flank the Quaternary alluvium of the Rio Grande valley. These "terraces" from oldest to youngest are Pliocene Citronelle, and Pleistocene Lissie, Oberlin, and Eunice. Doering (1956) gives a detailed discussion of the correlation of these units from the Rio Grande delta to the Apalachicola area of western Florida.

Although the Rio Grande river system presently has an average water discharge of 5,180 cu. ft./sec and an annual sediment discharge of 19,000,000 tons (Smith, 1966, p. 250), it no longer carries sufficient sediment either to advance the delta seaward or to maintain it against the erosive energy of the Gulf of Mexico on the east or Laguna

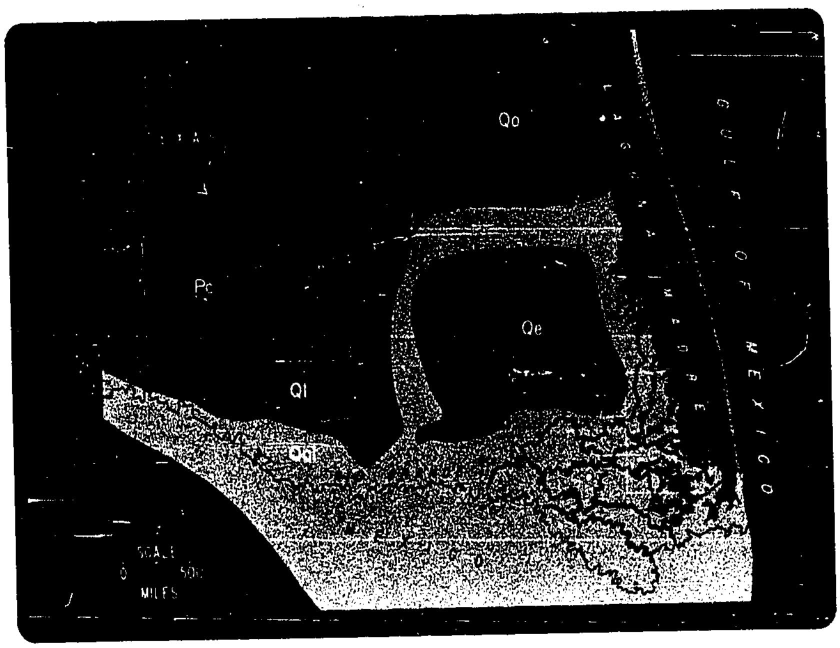


Fig. 1. Map of Pliocene and Pleistocene terraces adjacent to the Rio Grande delta.

Qal = Alluvium
Qe = Eunice
Qo = Oberlin
Ql = Lissie

Quaternary (Pleistocene)

Pc = Citronelle

Pliocene

Madre on the north (Lohse, 1958, p. 56). As a consequence, the present Rio Grande deltaic plain is undergoing regional transgression and the delta front has become a high energy coastline.

PHYSIOGRAPHY

A summary of the physiographic features of the Rio Grande deltaic plain is presented by Leblanc and Hodgson (1959, p. 205) in their discussion of the formation of the present shoreline configuration of the Texas coast. The principal physiographic features of the Rio Grande segment of the shoreline and the topography of the adjacent inner continental shelf are shown in Fig. 2.

The Recent alluvial valley of the Rio Grande, which widens downstream of Harlingen, becomes part of a much wider deltaic plain. This deltaic plain is characterized by abandoned meander belts (locally called resacas), mud flats, inter-meander belt lowlands, and clay dunes (Leblanc and Hodgson, 1959, p. 206). The best developed meander belts, which contain numerous oxbow lakes, average about 1.5 miles in width and rise about 5 to 15 feet above the inter-meander belt lowlands. The seaward gradient along these abandoned courses is approximately the same as that of the modern Rio Grande--about 1.25 feet per mile. Resaca De la Gringa (see Fig. 3), which is one of the abandoned distributary systems studied in this report, is similar to the general physiographic description given by Leblanc and Hodgson (1959). Meander belt width of the resaca ranges between 1 and 1.5 miles. Natural levees adjacent to the resacas averages between 10 and 15 feet high and slope gradually into inter-resaca lowlands which are approximately 5 feet above sea level. Resaca number 6 (Fig. 3) and its associated distributary systems which were examined in detail in this study are older than the De la Gringa system and consequently have much poorer

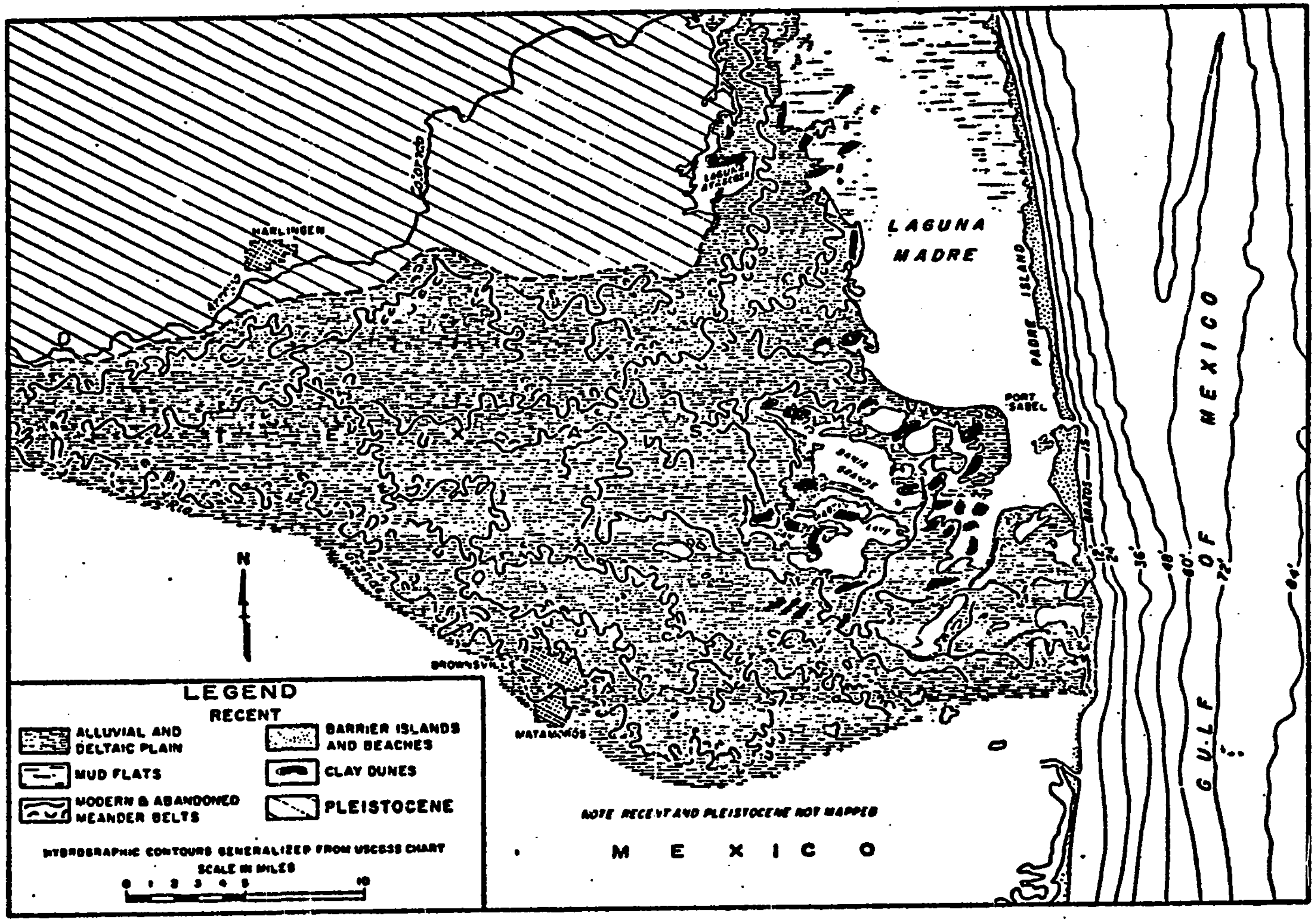


Fig. 2. Physiography of the Rio Grande delta (after Leblanc and Hodgson, 1959, p. 205).

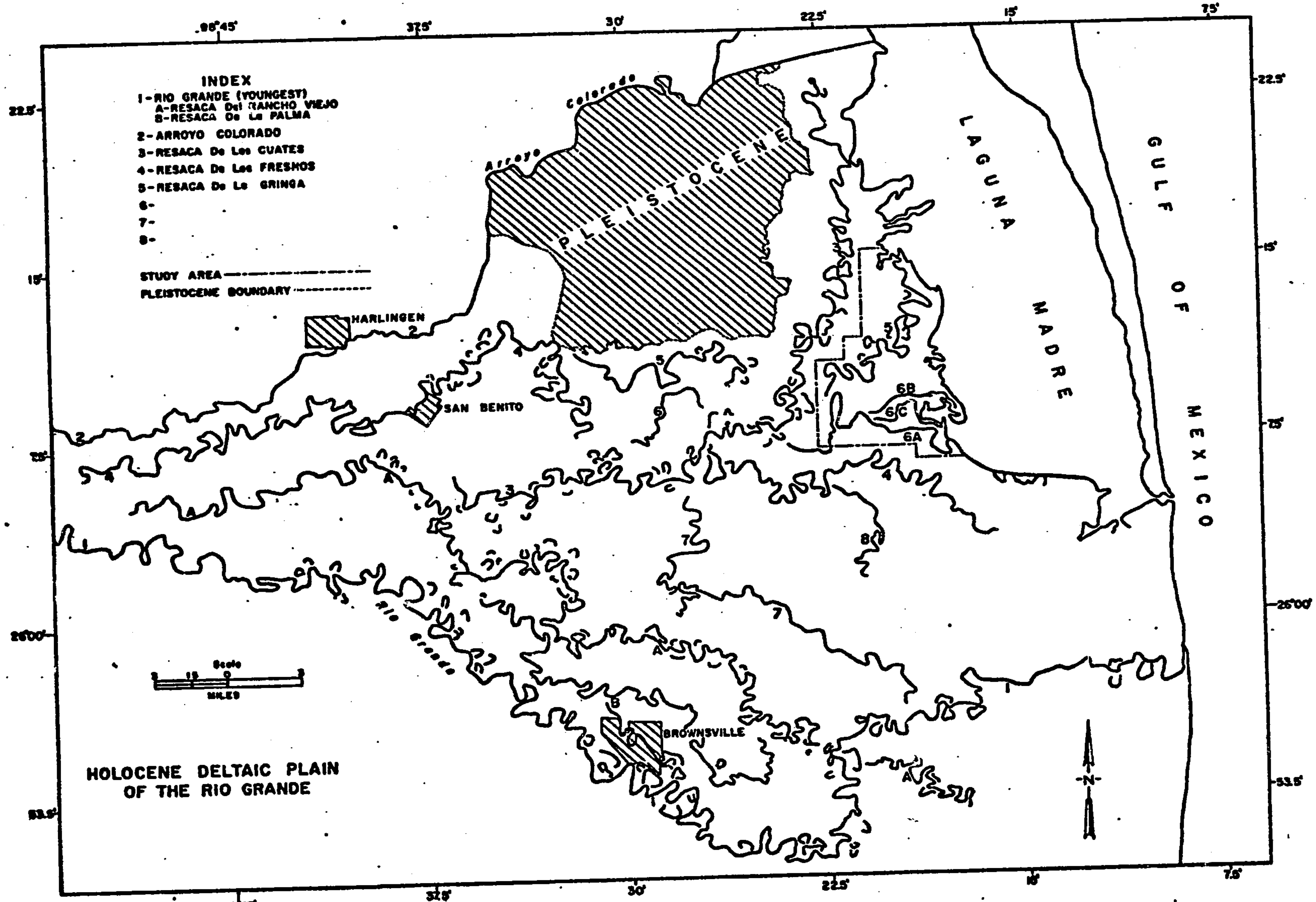


Fig. 3. Distributaries of the Rio Grande delta plain.

topographic expression. Natural levees average only about 5 feet above the inter-resaca lowlands and meander patterns are very poorly exposed.

That portion of the Rio Grande deltaic plain which lies within 10 to 15 miles from the Gulf and south of Laguna Madre has an inter-meander belt characterized by extremely shallow water bodies (Bahia Grande and San Martin Lake) and also a number of large mud flats. Other distinctive topographic features of the area are the clay dunes, which reach elevation of 30-40 feet above sea level and vary in length from one-fourth mile to about eight miles. Huffman and Price (1949) and Price (1958) have interpreted that these clay dunes were formed by windblown fine-grained sediments derived from the adjacent mud flats occurring between the meander belts. Observation of these "clay dunes" during a visit to the Rio Grande delta in the summer of 1972 indicated the presence of oyster shell layers and contorted bedding within these "windblown" deposits. It is highly possible that the previous interpretation of the origin of these deposits is incorrect and represents an area of future study.

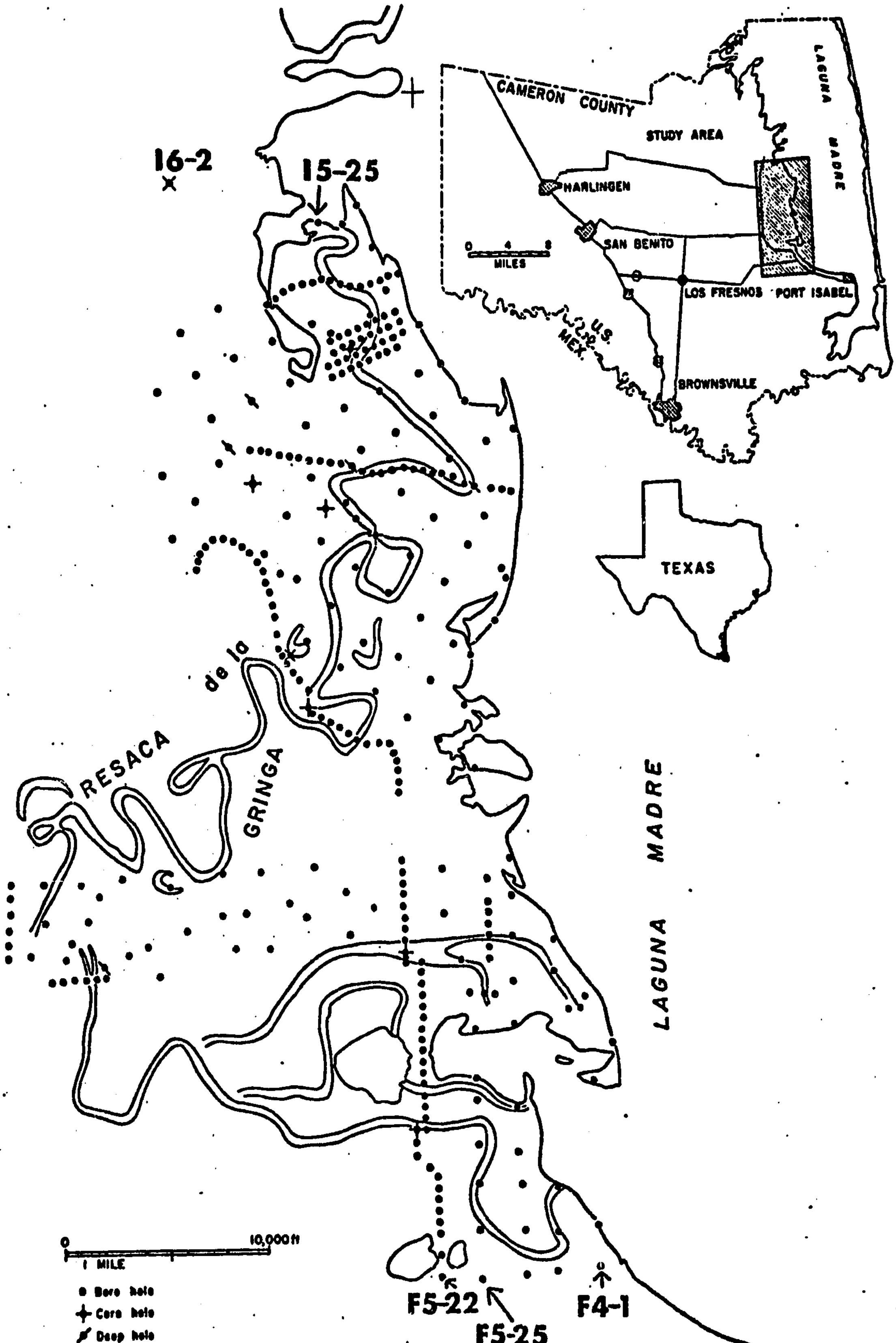
Mapping of the Rio Grande deltaic plain from air-photo mosaics and one foot contour topographic maps indicates the presence of at least 10 distributaries associated with Recent deltaic progradation (Fig. 3). Relative ages of the channels were determined by cross-cutting relationships and sharpness of topographic expression. The oldest resacas mapped (7, 8) are unnamed, have poor topographic expression, and are not well defined chronologically in relation to more continuous younger distributaries.

Resaca 6 (also unnamed) is characterized by three associated channels within the study area. Relative age relationships indicate that channel 6-A is the youngest, 6-B intermediate and 6-C the oldest. C-14 wood dates in cores F5-22, F5-25, and F4-1 (Fig. 4) at depths of 60-65 feet associated with this system indicate that active sedimentation was occurring approximately 7,000 years before present. Resaca De la Gringa located in the northern part of the study area is younger than resaca number 6. C-14 wood dates from cores I5-25 at a depth of 37 feet and I6-2 at a depth of 55 feet (Fig. 4) indicate that this channel was actively prograding approximately 5,000 years before present. Resaca De los Fresnos and Resaca De los Cuates, which are present between Resaca De la Gringa and the Pleistocene boundary, give evidence of continuous deltaic progradation in this area at some time since 5,000 years ago.

In the southern part of the mapped area bordering the present Rio Grande are Resaca Del Rancho Viejo and Resaca De la Palma, the upper portion of the modern Rio Grande and both Town Resaca and Resaca Del Tigre (which are outside the mapped area), all of which are part of the "Middle Recent" Del Tigre Subdelta (Fig. 6). Resaca Del Rancho Viejo and Resaca De la Palma are denoted as A (younger) and B (older) to show their close association with the present Rio Grande, even though both pre-date the present Rio Grande channel.

The age relationships between Arroyo Colorado and Resaca Del Rancho Viejo, Resaca De la Palma, and the present Rio Grande is not clearly defined within the mapped area. Lohse (1958, p. 55) states

Fig. 4. Location of C-14 data points.



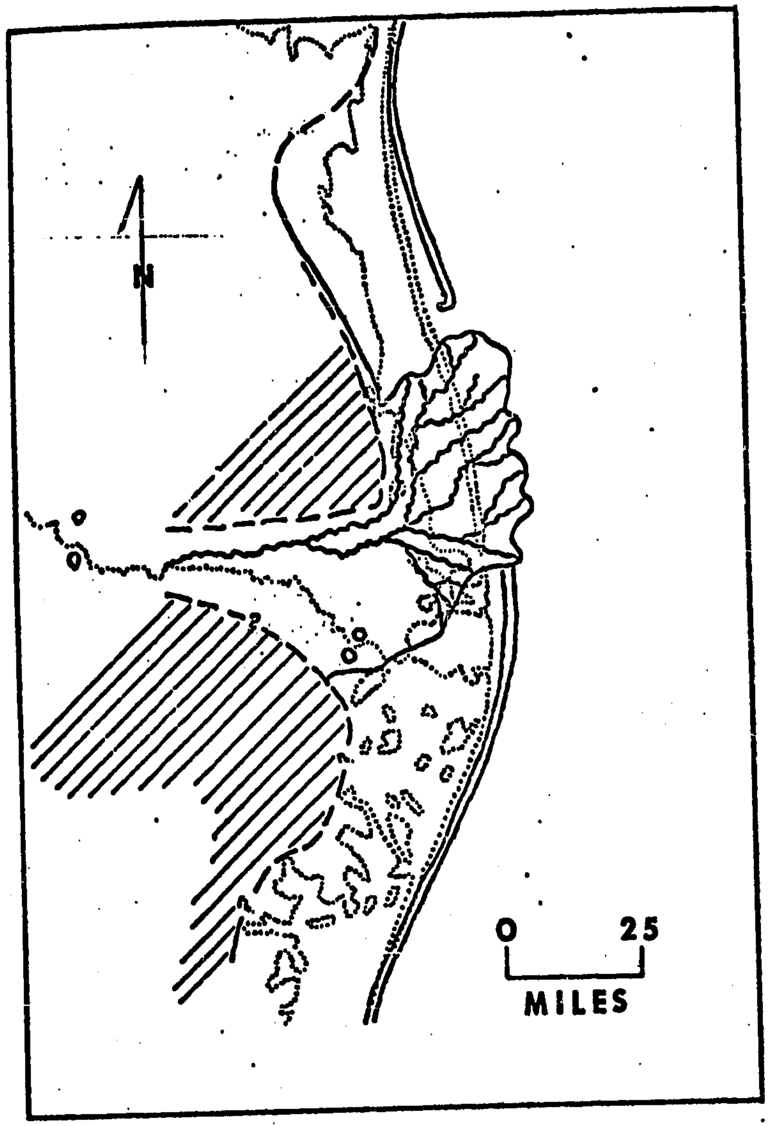


Fig. 5. Los Cuates Subdelta-Early Recent. Main drainage in Resaca De Los Cuates and Resaca De Los Fresnos. Deltaic platform prograded seaward of present coastline. (After Lohse, 1958, p. 56).

that during the building of the Middle Recent Del Tigre subdelta the Arroyo Colorado entrenched the Montgomery Pleistocene surface. This seems to agree with the age relationships defined by present mapping and would chronologically closely associate the Arroyo Colorado with delta progradation to the south.

The relative age relationships of the abandoned meander system of the Holocene deltaic plain within the mapped area indicates at least two main centers of delta progradation: one to the north which is reflected by Resaca De los Cuates, Resaca De los Fresnos, Resaca De la Gringa, Resaca 6, and possibly resacas 7 and 8. This system corresponds with the Los Cuates subdelta (Fig. 5) defined by Lohse (1958, p. 85). The present Rio Grande and older sub-parallel distributaries including Resaca Del Rancho Viejo and Resaca De la Palma as well as other channels outside the mapped area reflect a delta progradation to the south and correspond to the Del Tigre subdelta defined by Lohse (1958, p. 55, Fig. 6). In addition, Lohse (1958, p. 56) defines a third subdelta (Fig. 7) in which the ancestor of the modern Rio Grande shifted northward to occupy the lower portion of the modern course. This most recent shift in deposition occupied a delta flank depression common to both the Los Cuates and Del Tigre subdeltas. Concurrently with the development of the modern subdelta, the two older subdeltas were continuing to undergo subsidence and marine transgression.

The Rio Grande delta plain is presently undergoing regional transgression and the delta front has become a high energy coastline.

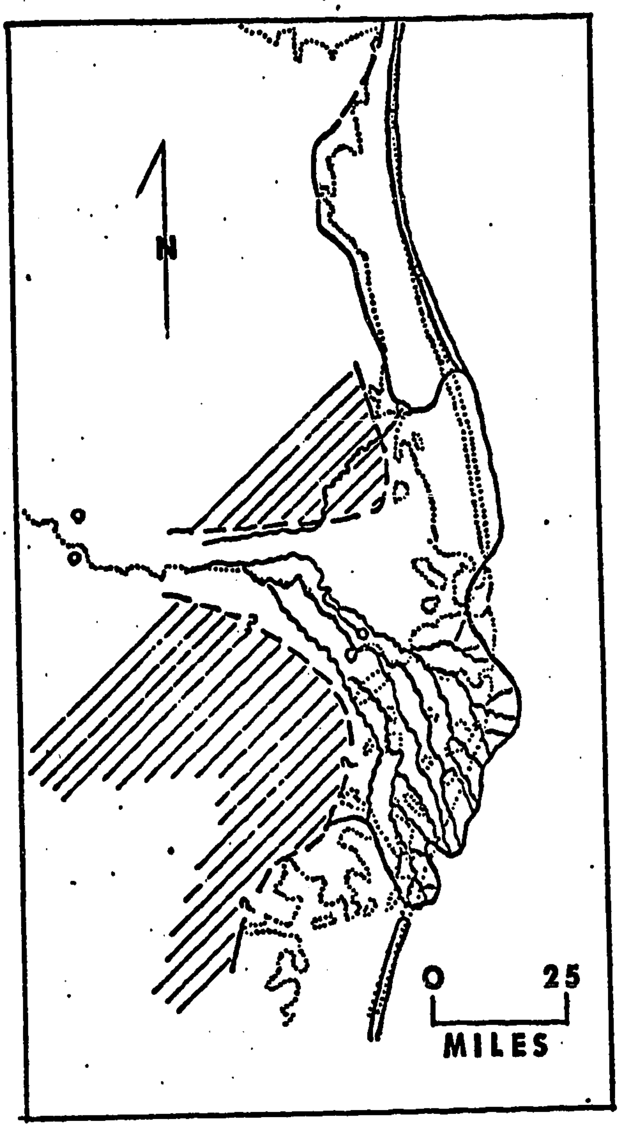


Fig. 6. Del Tigre Subdelta-Middle Recent. River shifts southward occupying Resaca Del Rancho Viejo, Resaca De La Palma, Town Resaca, and upper portion of modern course. Resaca De Los Cuates subsided and was transgressed. Arroyo Colorado entrenched Montgomery surface. (After Lohse, 1958, p. 56).

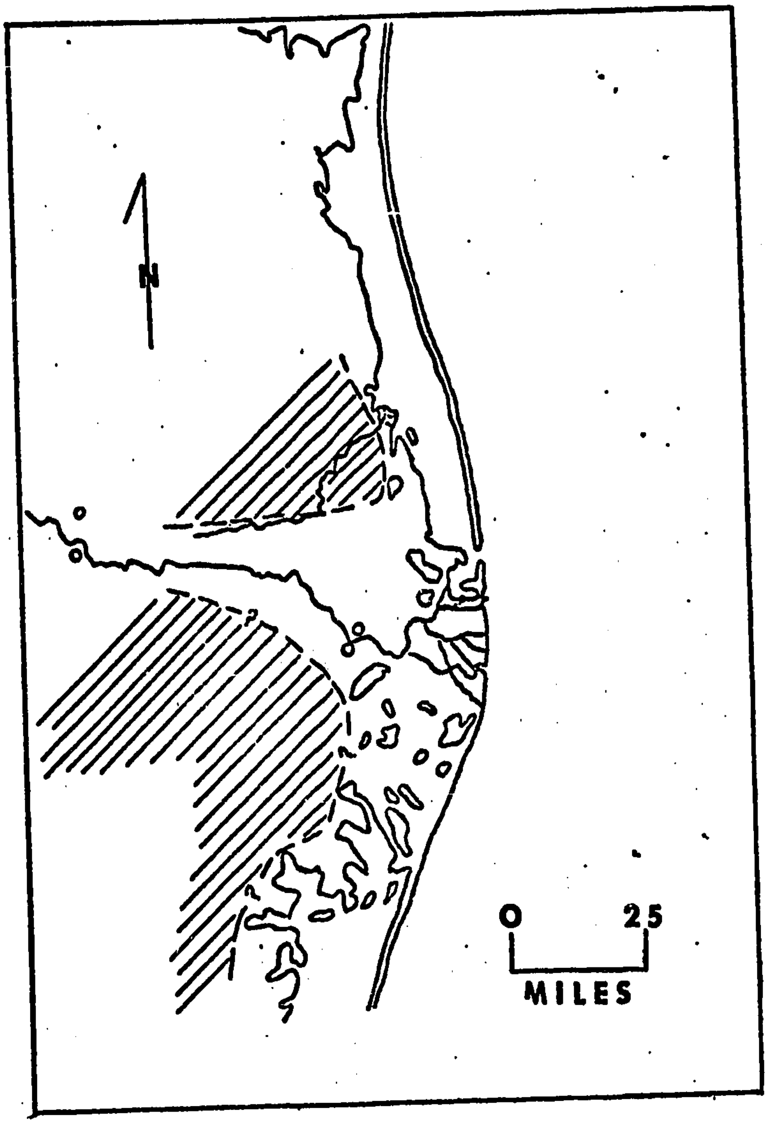


Fig. 7. Boca Chica Subdelta-Late Recent or Modern. River shifts northward to occupy the lower portion of modern course. Los Cuates subdelta eroded by Laguna Madre; Del Tigre subdelta subsiding and being transgressed. (After Lohse, 1958, p. 56).

STRATIGRAPHY

Stratigraphically, the two major distributary systems studied are complex. For convenience and future reference, the two systems will be referred to as the De la Gringa system and the Southern system--the latter referring to the progradational package associated with the unnamed Resaca number 6. For clarity of discussion, the stratigraphy of the two systems will be discussed separately before an analysis of depositional environments is made.

DE LA GRINGA SYSTEM

The De la Gringa system is younger than the Southern system and consequently onlaps it from the north. In order to determine the stratigraphy of subsurface units associated with the Resaca De la Gringa distributary system, 12 cross-sections were constructed using data extracted from electric logs. The characteristic electric log patterns and their corresponding lithologies are shown in Fig. 8. The patterns shown in Fig. 8 are associated with three 150 foot cores drilled essentially perpendicular to the direction of progradation of Resaca De la Gringa. Core G5-60 (Fig. 9) is located in the meander belt of Resaca De la Gringa near the southern limit of data control while H5-88 (Fig. 10) was drilled off the channel flank in an area of close well control in the northern part of the Resaca. The log characteristics are matched with core descriptions available at these five bore holes. The E-log characteristics at these control points combined with gamma ray and spontaneous potential log interpretations (Schlumberger, 1969, Chapter 2 & 10) were used to determine the litho-

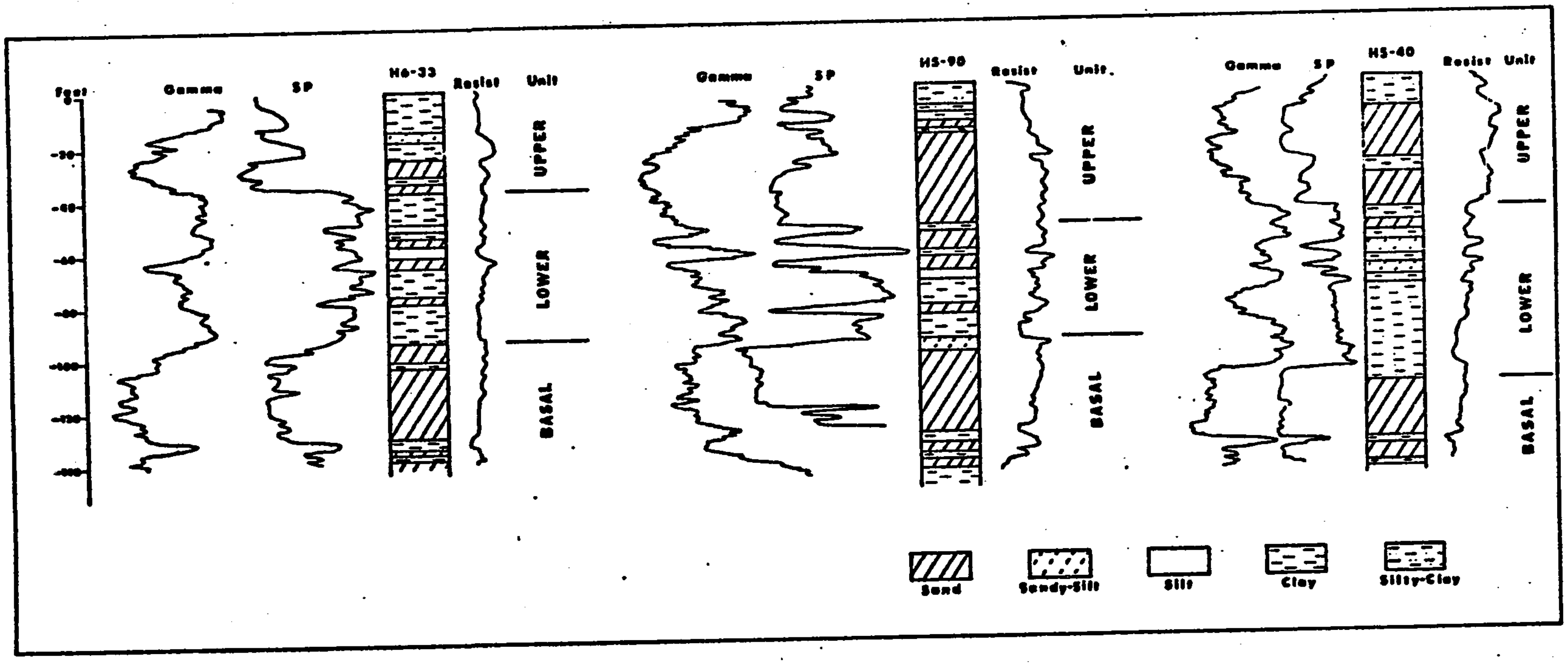


Fig. 8. E-logs and associated lithologies--Cores H5-90, H5-40, and H6-33

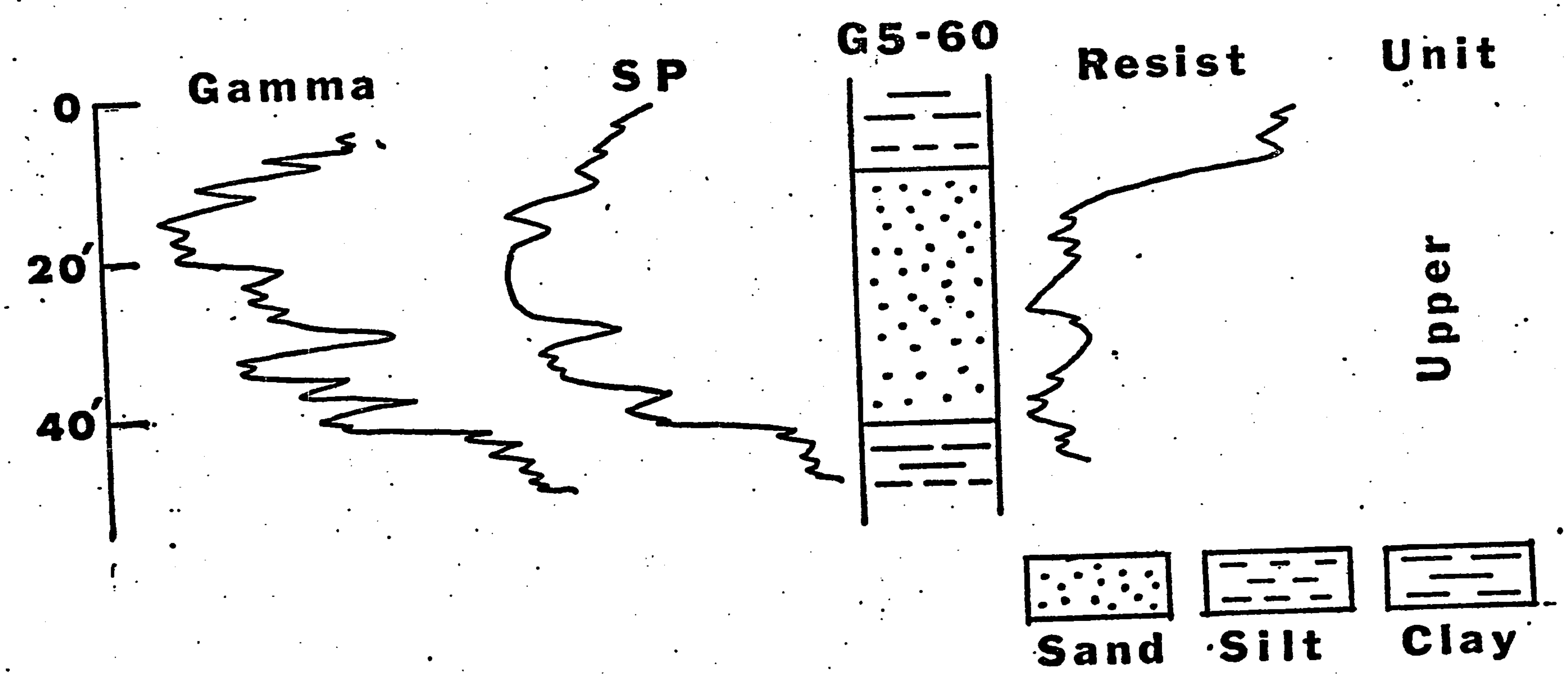


Fig. 9. E-logs and associated lithologies--Core G5-60

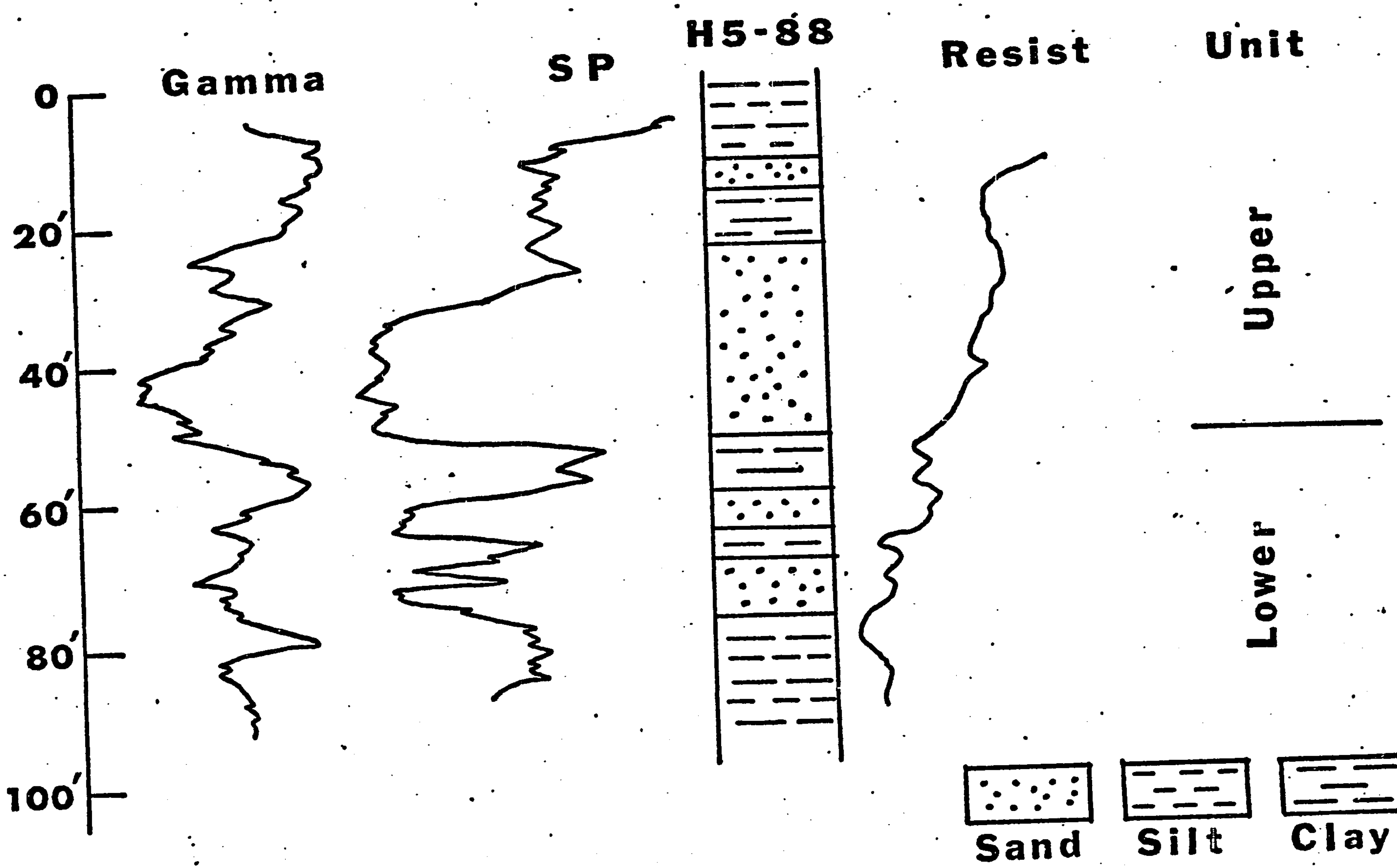


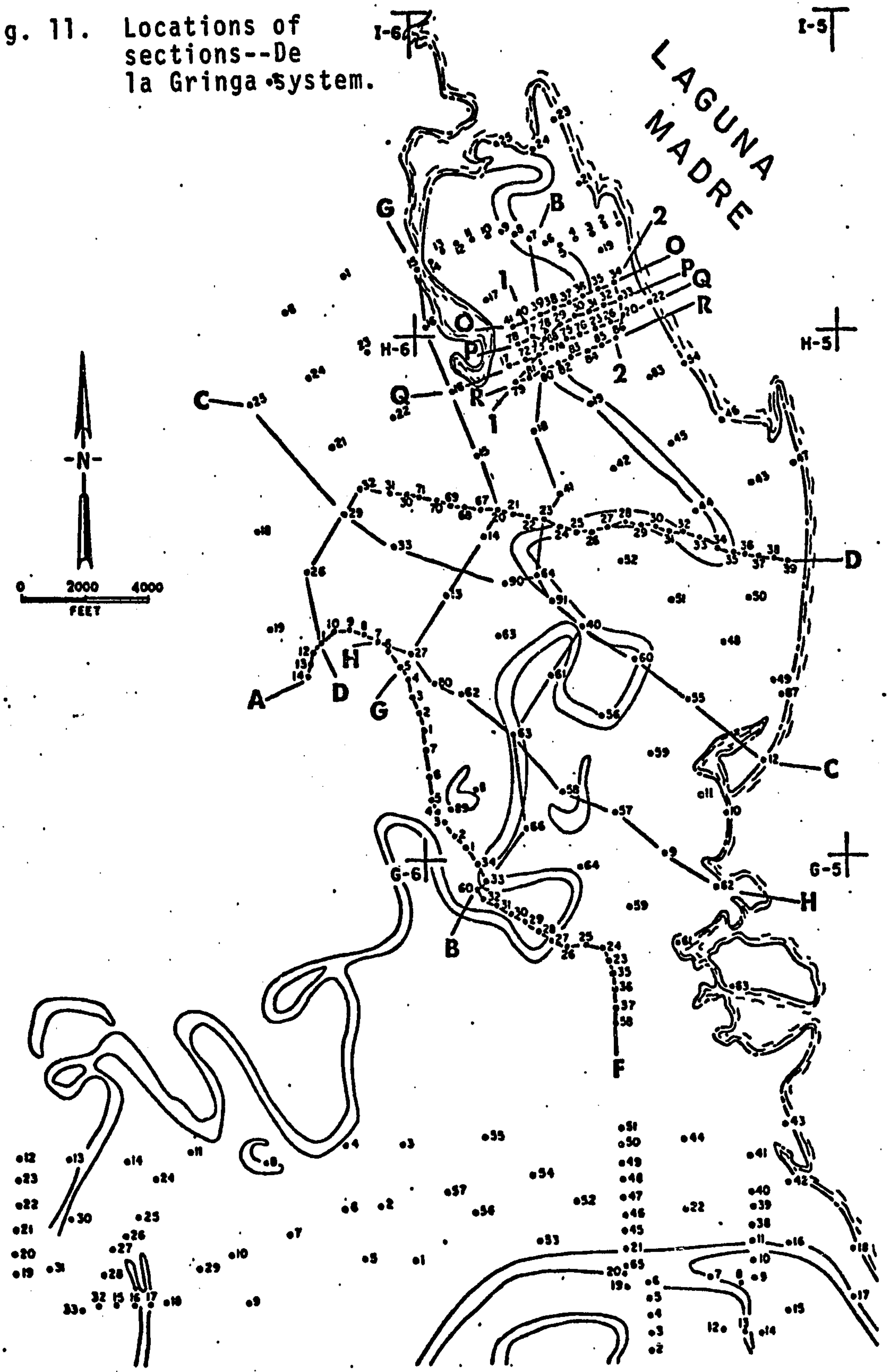
Fig. 10. E-log characteristics and associated lithologies--Core H5-88.

logic characteristics of drill holes lacking core control. As can be seen from Figs. 8, 9 and 10, the resistivity curve is relatively featureless and of little use in marking lithologic boundaries. Consequently, lithologic breaks were interpreted primarily from gamma ray and S.P. fluctuations.

Stratigraphically, three major units can be defined within the depositional system associated with the De la Gringa distributary system. These units include: (a) an upper unit characterized by two distinctive sand members. The upper sand member has sharp contacts with underlying silts, clays, and sands and is surrounded vertically and laterally by silts and clays. The lower sand lies below and occassionally in contact with the upper sand member. This lower sand is the dominant lithologic member of the upper unit, although it grades laterally and vertically into silts and clays; (b) a lower unit composed of thin imbricating sand members. silty clays, and clays; and (c) a widespread basal sand unit. These three major units and their associated electric log characteristics are shown in Fig. 8. The location of sections and drill holes used in the stratigraphic discussion of the Resaca De la Gringa distributary system are shown in Fig. 11.

Upper Unit. The upper unit with its two characteristic sand members is well defined in section C-C' (Fig. 12) which is approximately perpendicular to the direction of progradation of the De la Gringa system. The upper sand member here reaches a maximum thickness of approximately 30 feet from core H5-90 eastward to H5-60 where it thins

Fig. 11. Locations of sections--De la Gringa system.



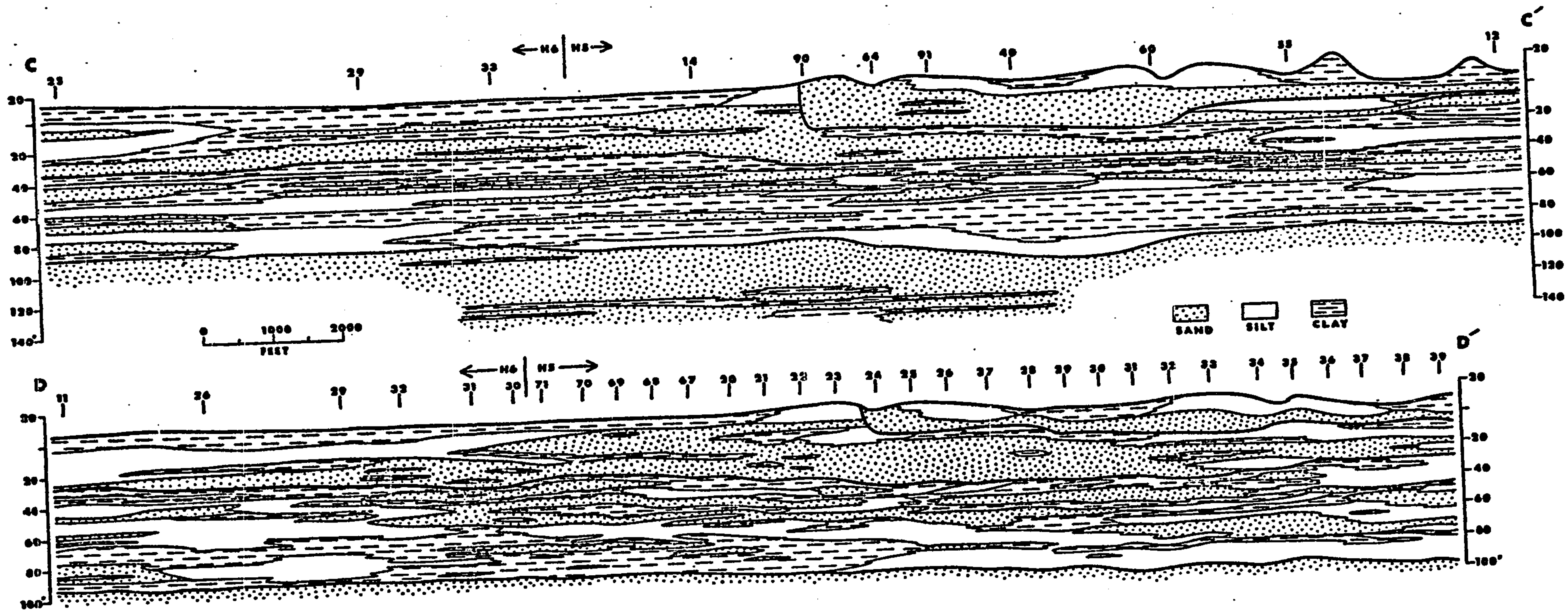


Fig. 12. Sections C-C' and D-D'--De la Gringa System

to a thickness of approximately 10 feet. The sand of the upper member has a sharp contact with the underlying sands, silts, and clays as exemplified in wells H5-90 and H5-40 where core contact is present. Between H5-90 and H5-14 the upper sands are replaced laterally by silts and clays. Basal contact of the upper sand is primarily with silts and clays except in core H5-90 where the contact of the upper and lower sand are gradational with one another and reach a thickness of approximately 40 feet. Southeastward away from the approximate channel meander belt of the De la Gringa system the upper sands thin rapidly and are bounded laterally and vertically by silts and clays.

In section B-B' (Fig. 13), which is a long north-south cross-section drawn parallel to the direction of progradation of the De la Gringa system, the upper sand member of the upper unit is less well defined and interbedded with silts and clays. Thickness here of the sand is highly variable and ranges from 2-4 foot lenses of sand at well H5-66 to a thickness of approximately 20 feet at well H5-40. Because of the way the cross-section is constructed, the upper sand is not present north of well H5-23. North of this well the upper sand is displaced by silts and clays and thin lenses of sand which are 4-10 feet thick. As in section C-C', the upper sand has sharp contacts both laterally and vertically with surrounding silts and clays. Southward of core H5-40, where the sand member reaches its maximum thickness, the sand breaks up into 4 or 5 separate units at core H5-66, with each of the sand members being approximately 4 feet thick and interbedded with clays. The continuity of the upper sand member here is not as

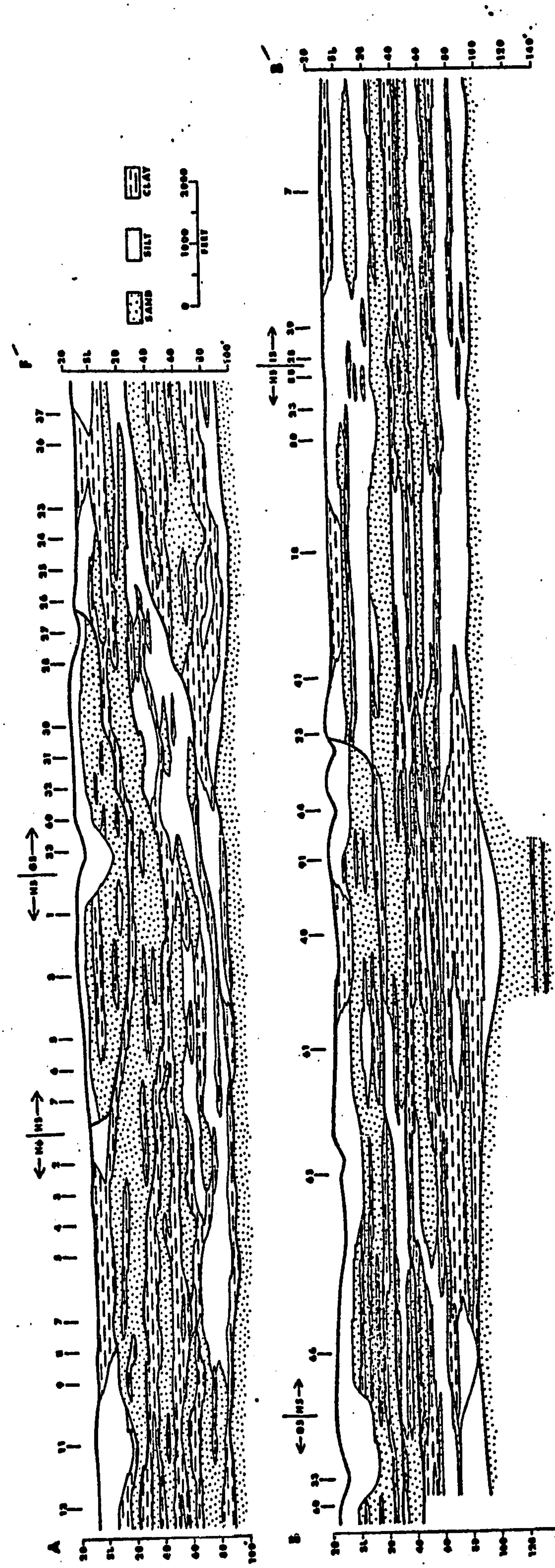


Fig. 13. Sections A-F' and B-B'.

good as that previously described in section C-C' at places being ill-defined or entirely absent. The implication of this discontinuity will be discussed in a later section dealing with sand body geometry and continuity of these bodies.

To the NW of section B-B' (away from the surface expression of Resaca De la Gringa) the upper sand member is completely lacking, except for one instance. This is exemplified in two N-S sections drawn parallel to the approximate present channel direction. In Section G-G' (Fig. 14), which is approximately 1000-2000 feet northwest of section S-S', the upper sand is completely lacking except for a small isolated sand body in cores H5-16 and I5-16, which is surrounded vertically and laterally by silts and clays of the upper unit. To the west of this cross-section is another short section which is incorporated into section D-D'. In cross-section D-D' from core H5-32 south to core H6-11 the upper sand member is completely lacking and is replaced by silts and clays.

In section D-D' (Fig. 12), which has closely spaced control points at 500 foot intervals, the upper sand member is continuous from core H5-24 to H5-39 (app. 8000 feet). In this section which is oriented perpendicular to the direction of progradation, the upper sand unit here is relatively thin and reaches a maximum thickness of approximately 20 feet at cores H5-33 and H5-24. Lateral contacts of the upper sand member such as exemplified between cores H5-23 and 24 as well as basal contacts are sharp. Sands of the upper member grade both vertically and laterally into silts and clays.

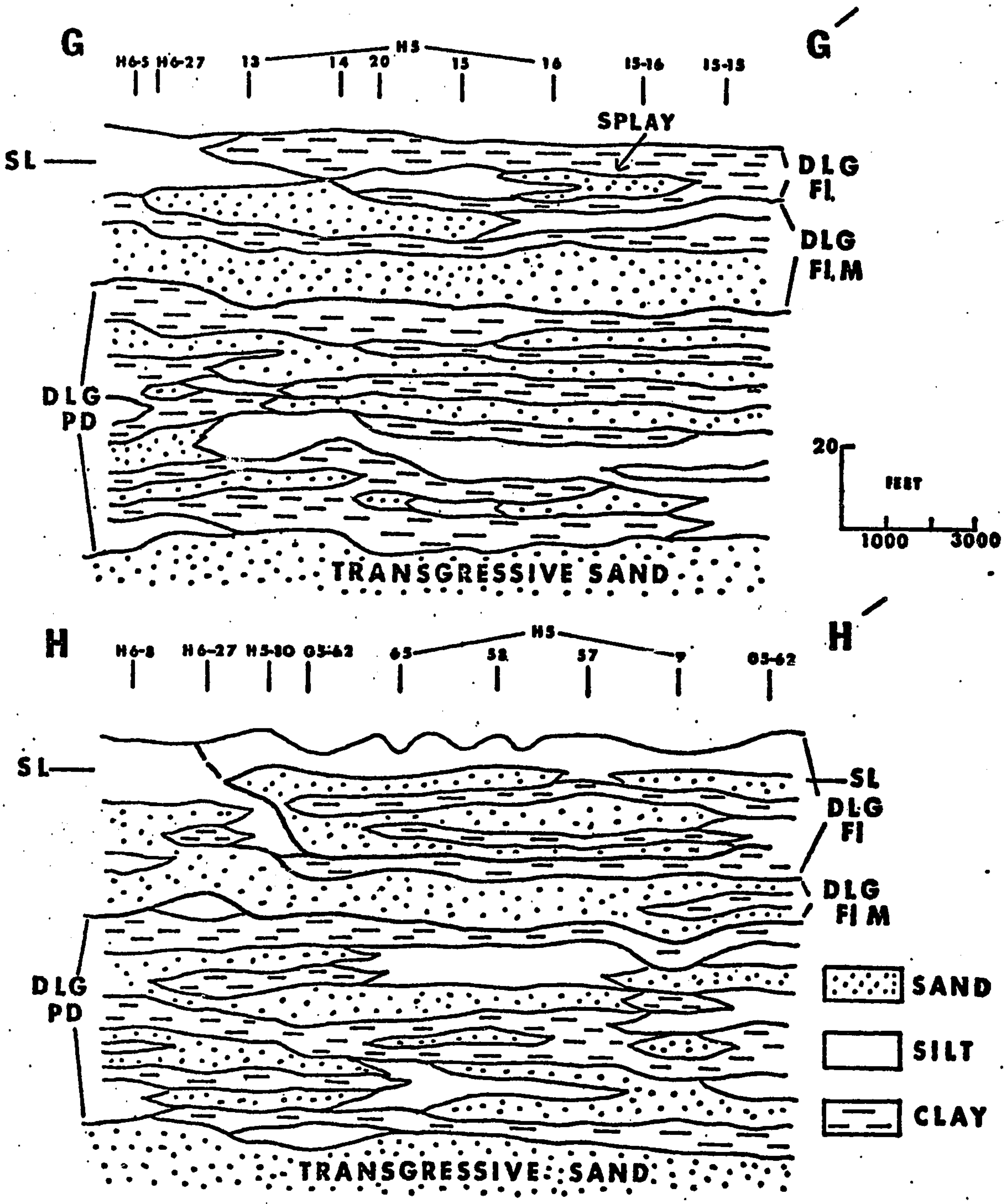


Fig. 14. Sections G-G' and H-H'.

In section H-H' (Fig. 14), which is perpendicular to the direction of the De la Gringa system, sands of the upper unit are somewhat thicker than in the section previously discussed. The upper sand here consists of essentially three sand members ranging in thickness from 4-12 feet and separated by intervals of clay. These sands grade laterally into silts and clays and are overlain by silts.

In section A-F' (Fig. 13), where once again drill hole data points are approximately 500 feet apart, the upper sand member is continuous from core H5-7 to core G5-27, a distance of approximately 8000 feet. Thickness is variable as the sand unit is lense shaped, but varies from about 10 to 20 feet thick. The sand is vertically discontinuous and is interbedded with silts and clays throughout. The unit is overlain by silts and laterally equivalent to silts and clays. The basal and lateral contacts of the upper sand member are sharp and disconformable.

The upper sand member of the upper unit is well expressed in the fence diagram which was constructed in the area of closely spaced drill hole data at the northern end of Resaca De la Gringa (Fig. 15). In this locality the upper sand is present in all east-west sections, although lacking in a north-south section which is drawn parallel to the direction of progradation. As in other sections drawn perpendicular to the direction of progradation, the upper sand member shows a nice lense shape bounded laterally by silts and clays of the upper unit. Vertically, the sand lense grades into silts and sandy silts. Thickness of the sand is variable but ranges between 10-25 feet thick.

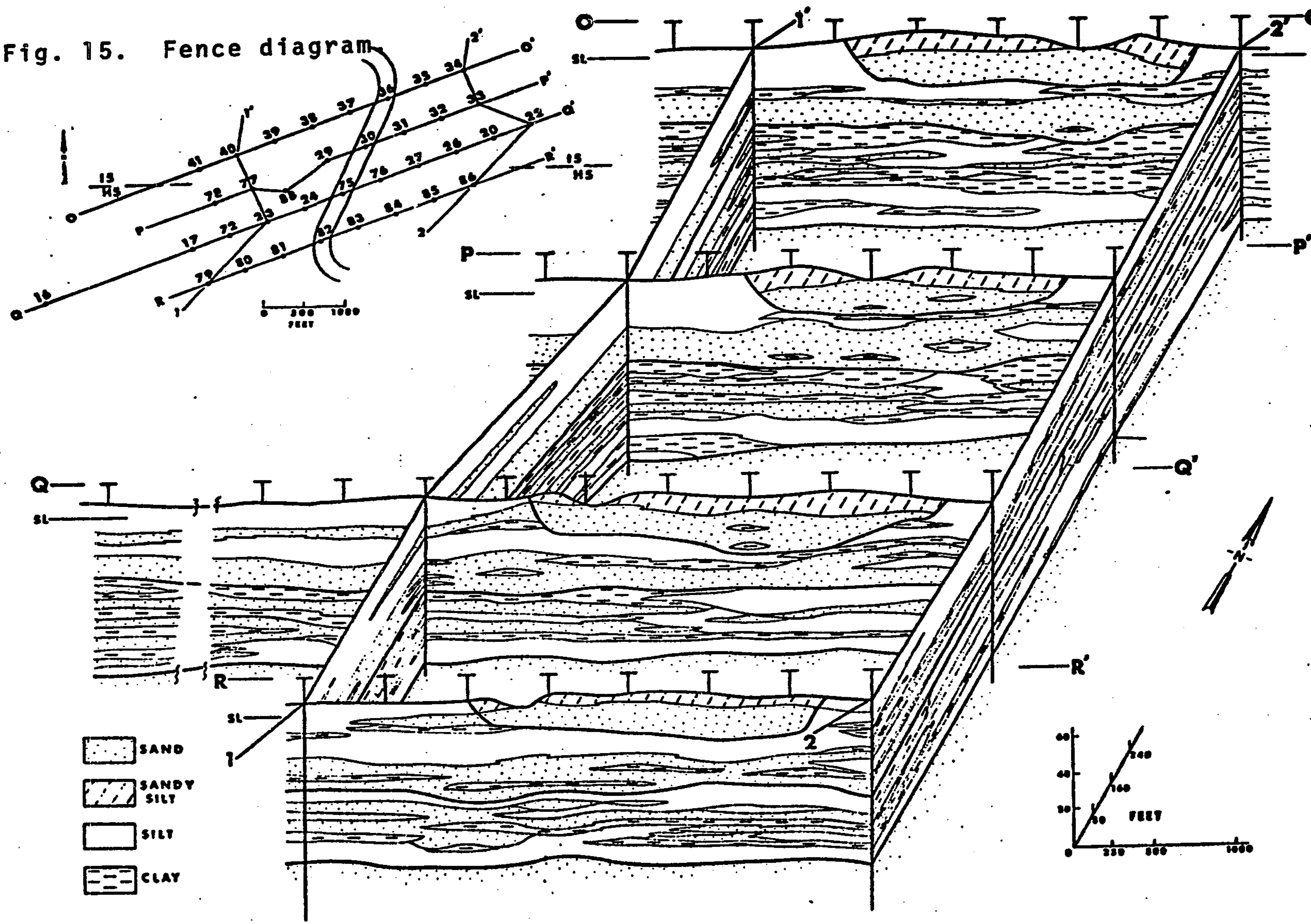


Fig. 15. Fence diagram

Lateral continuity of the upper sand member in these sections is less than in those previously discussed and averages about 4000 feet. Lateral and basal contacts of the sand member with the surrounding unit are erosional.

In summary, the upper sand member of the upper unit ranges in thickness from 10-20 feet thick and is bounded both laterally and vertically by silts, sandy silts, and clay. Both the basal and lateral contacts are sharp and appear to the erosional. Both the thickness and continuity of the unit are variable and both decrease away from the present surface expression of the De la Gringa system. The inverse is true of silts and clays that flank this upper sand member.

The lower sand member of the upper unit is well defined in all cross-sections of the De la Gringa system. For stratigraphic purposes the base of this sand and equivalent lateral units of silt mark the base of the upper unit. The lower sand of the upper unit is well shown in section C-C' (Fig. 12) where it is continuous for some 17,000 feet from core H6-25 southeastward to core H5-60. From core H5-60 to the limits of data control at core H5-12 this sand member is replaced laterally with silts and clays. The lower sand in this section varies in thickness from 10 feet at its northeastward extremity (core H6-25) to approximately 40 feet just east of core H5-90. West of core H5-14 the lower sand member of the upper unit splits into essentially two parts--the upper part being thinner and eventually replaced laterally by silts and clays. The upper part of this lower sand member is replaced by the previously discussed upper sand member between cores H5-64 and H5-60 before reappearing again as a thin sand in cores H5-55 and H5-12. Both the upper and lower contacts of this sand are fairly sharp, although lateral interfingering of this lower sand member with surrounding silts and clays is common.

In section B-B' (Fig. 13) which is the north-south section, the lower sand member is fairly well defined and is continuous northward from core H5-61 to I5-7, a distance of some 17,000 feet. From core H5-61 southward to H5-60, the lower sand member loses its integrity as a continuous sand and is replaced for the most part by silts and clays. The lower sand member as expressed in this cross-section varies in thickness from 6 feet at core H5-61 to approximately 20 feet at core H5-18. The lower sand member is gradational both laterally and vertically with silts and clays.

In section G-G' (Fig. 14), which is approximately parallel to the north-south section previously discussed, the lower sand member retains its integrity in opposition to the overlying upper sand member which is almost entirely absent from this section. The lower sand member as shown here is composed of two separate sand bodies separated by a thin (4-6') clay. The upper sand body of this lower member which is continuous from cores H6-27 to H5-25 is lense shaped and varies in thickness from 5-20 feet. The lower body of the sand member is relatively uniform in thickness from cores H6-5 to I5-15 averaging about 20 feet thick. The N-S part of section D-D' which extends from core H6-32 south to core H6-11 exemplifies the continuity of the lower sand member in relation to the absence of the upper sand member previously discussed.

The lower sand member in section D-D' which contains closely spaced (500') drill hole data is similar to that discussed in section C-C' which also is drawn perpendicular to the direction of progradation but lies slightly to the south of D-D'. The upper part of the lower sand member is present from core H6-30 to H5-23 where it is truncated by the upper sand member. The upper part of the lower sand member is replaced laterally by silts and clays away from the present location of the De la Gringa channel. The lower part of the sand member is well shown throughout the limits of data control in section D-D' (14,000) although it does thin both eastward and westward and become interbedded with silts and clays at its extremities. Thickness of the lower sand member in this section is variable and ranges from 10-30 feet, the average being about 18-20 feet thick. Contacts with vertical and lateral equivalents are in many places interfingering although sharp uneven contacts especially at the base of the lower sand member are by no means uncommon.

To the north of section D-D' in Section H-H' (Fig. 14) the lower sand member is fairly uniform in thickness averaging 10 feet where it is overlain by the upper sand member and about 25 feet thick in core H6-27 where it is laterally equivalent to the upper sand.

The continuity of the lower sand member of the upper unit is probably best expressed in the area of close bore hole control at the northern part of the De la Gringa distributary system. Isometric projection of the stratigraphic data from wells at this location show the lower sand member is continuous in all sections both N-S and E-W at a depth of 30-50 feet. Thickness of the sand member is relatively uniform averaging 15-20 feet thick and ranging from 10-30 feet thick. Interbedded clays and silts are common within the lower sand member as they are throughout the study area and are well shown especially in sections R-R' and Q-Q'. Bounding lithologies consist of silts and clays with the upper contact being somewhat gradational while the lower contact is usually sharp and well defined.

Although the lower sand member may at times be in contact with the upper sand member or be partly composed of silts and clays, it is characteristically more continuous than the upper sand member of this unit. The thickness of the lower sand is somewhat variable ranging generally between 10 and 30 feet. Like the upper sand member, the lower sand usually thins and becomes less well defined away from the surface meander system (De la Gringa). The bounding lithologies both laterally and vertically are silts and clays except where the lower sand is in contact with the overlying upper sand member.

Lower Unit. The lower unit of the De la Gringa system extends from the base of the lower sand member to the top of a continuous sand unit which is well expressed in section C-C' at a depth of approximately 100 ± 20 feet. Lithologically, this unit is composed of sands, silts, and clays. The sands and silts occur as lenses and pods bounded laterally and vertically by clays which tend to be the dominant lithology of this unit. Observation of the lower unit as expressed in sections A-F', B-B', C-C', and D-D' show immediately that any attempted discussion of detailed stratigraphy, especially of the sand members, would be difficult and unnecessarily repetitive. For that reason, discussion of the stratigraphy of this unit will be somewhat more generalized than that of the sand members of the overlying unit.

As can be seen from any of the cross-sections, sand members of this lower unit are best described as sheets, lenses, and pods of sand. Thicknesses of sand within this unit are somewhat variable ranging from 15 feet thick (Sec A-F', Core H6-13) to thin 2 foot thick sands such as those shown in the lower part of this unit in section D-D'. Continuity of sands in this lower unit will be discussed in detail in the appropriate section, however, some general observations are necessary at this time. In sections A-F' and B-B' (Fig. 13) maximum continuity of sands of the lower unit reach approximately 6000 feet laterally while various sands at the base of the unit range between 500-1000 feet laterally. The same situation is exemplified in sections C-C' and D-D' (Fig. 12) where sands in the upper part of the unit are continuous for 6-8000 feet in NE-SW direction while sands in the lower part of the unit reach 500-1000 feet laterally. The discontinuity of sands in the lower unit in relation to the lower sand member of the upper is well shown in all the E-W sections of the fence diagram. Here as in the other sections, the sands occur as relatively thin (4-12' thick) lenses and pods surrounded by silts and clays.

Although the upper unit has two readily definable sand members, the lower most of which is fairly continuous, the lower unit is characterized by silts, clays, and silty clays. Within these silts and clays are lenses and pods of sand which rarely exceed 10 feet in thickness. These intervals of sand form a significant part of the stratigraphy of the lower unit in all the sections, although no one sand member is distinctly dominant throughout. Geometrically, the sands are imbricated both laterally and vertically and their continuity is poor compared to the sands of the upper unit.

In summary, observations of the lower unit in all sections and the fence diagram indicate that it is the most complex unit to define and summarize stratigraphically. Generally, however, the sand members in this lower unit are less than 10 feet thick, imbricated, discontinuous, and best defined as lenses, pods, or sheets.

Problems presented by the previous discussion such as: (1) are the sand members more continuous parallel or perpendicular to the depositional strike, or (2) what is the vertical continuity of sands in this unit, are discussed in detail in a later section.

Basal Unit. The lowest stratigraphically defined unit encountered in this study is shown in section L-L' where it is penetrated by the three deepest bore holes. This unit is characterized by sand although clay members are present in the lower 10-15 feet. This basal sand unit, which is overlain by silts and clays of the lower unit, ranges in thickness from approximately 50 feet at core H6-33 to 30 feet thick at core H5-40. Observation of two other deep drill holes in the area at cores H5-89 and I6-2 (Fig. 16) indicate the presence of a major sand unit between 100-120 feet. The upper part of this sand unit is

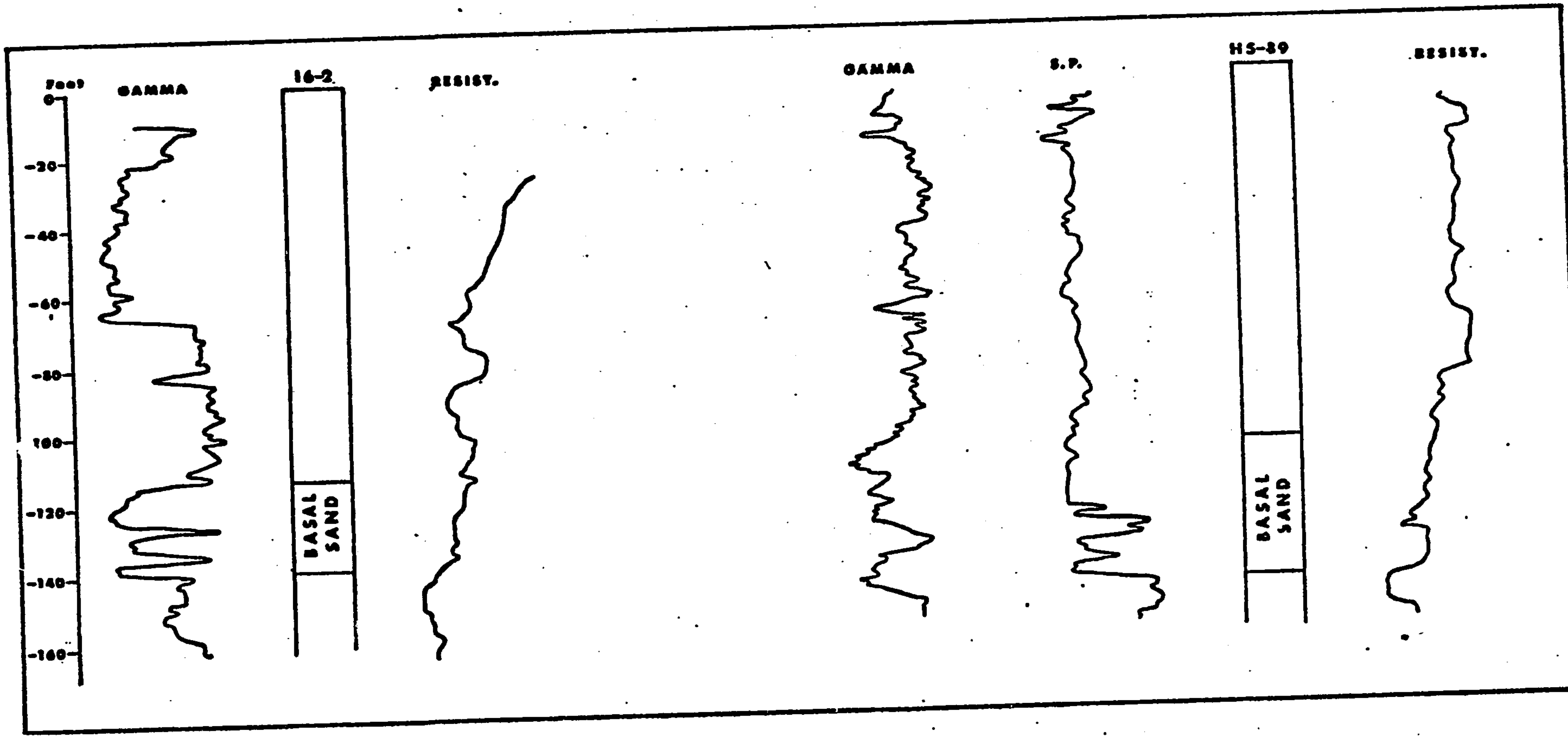


Fig. 16. Basal sand in cores I6-2 and H5-89.

present in the base of nearly all the shallower (100 $\pm$ 10 feet) cores drilled and formed the basis of drilling operations in the area. The evironmental aspects of this unit are important and will be considered in more detail in the section concerning environmental discussion.

SOUTHERN SYSTEM

Stratigraphic units associated with the progradation of Resaca number 6 (herein referred to as the Southern system) are shown in both a generalized and a detailed manner in Fig. 17. As shown in this figure, units of the previously discussed De la Gringa system are younger than that associated with the Southern system and onlap it from the north. The stratigraphy of the Southern system is somewhat more complex than that associated with the De la Gringa system for reasons that will be discussed in relation to depositional environments of these various units.

In order to determine the subsurface stratigraphy associated with the Southern system, five cross sections were constructed both parallel and perpendicular to the direction of progradation of the resaca. The location of these cross-sections is shown in Fig. 18 and 19. Two core holes, G5-65 and F5-42 are present within the Southern system. Data obtained from these two core holes (see Fig. 20 and 21) in relation to gamma and S.P. logs associated with wells in the area were used to construct the cross-sections as in the manner previously described for Resaca De la Gringa.

For the purposes of stratigraphic discussion and for maintaining sand body integrity in the Southern system, one group and three units

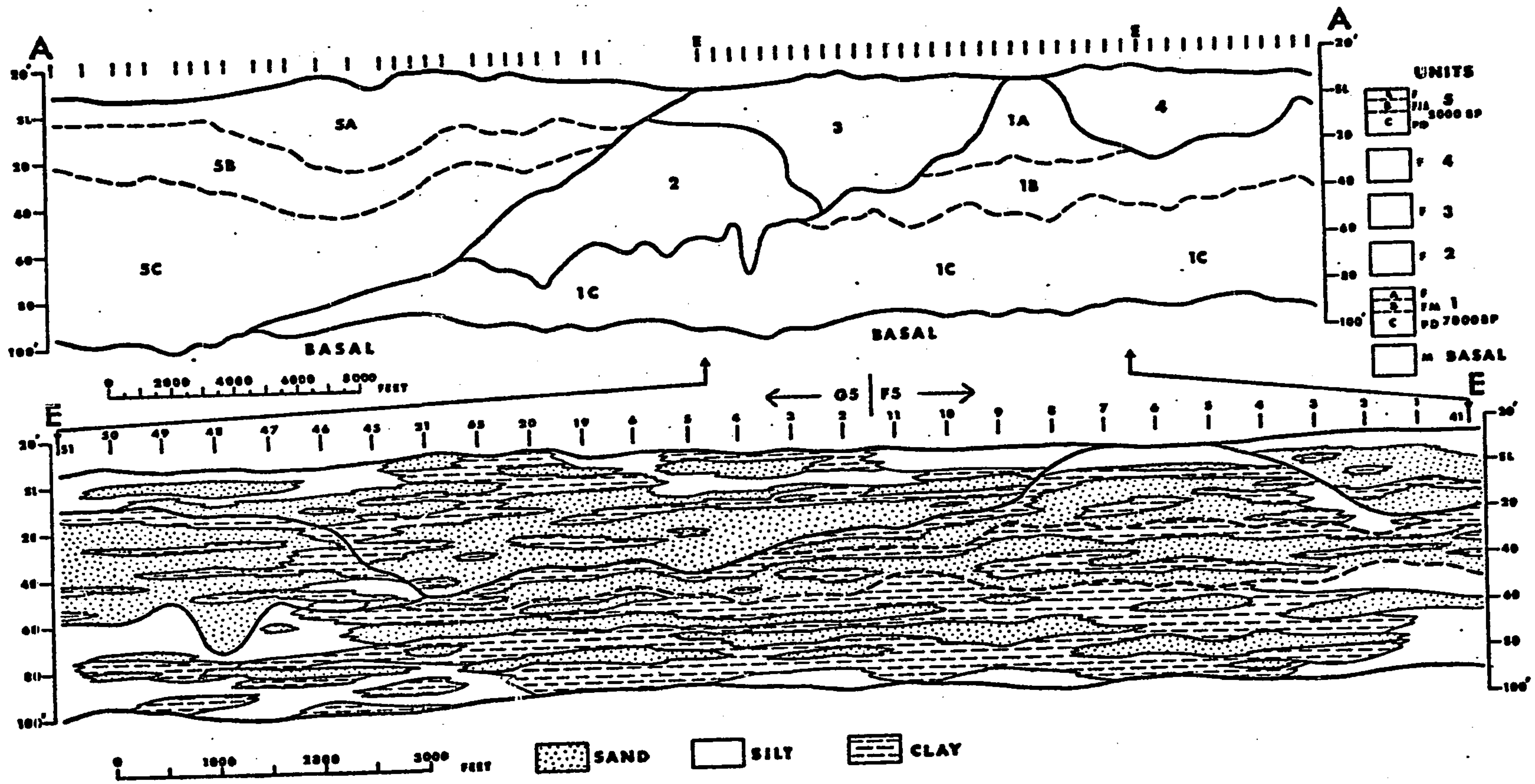


Fig. 17. Stratigraphic units associated with the Southern system.

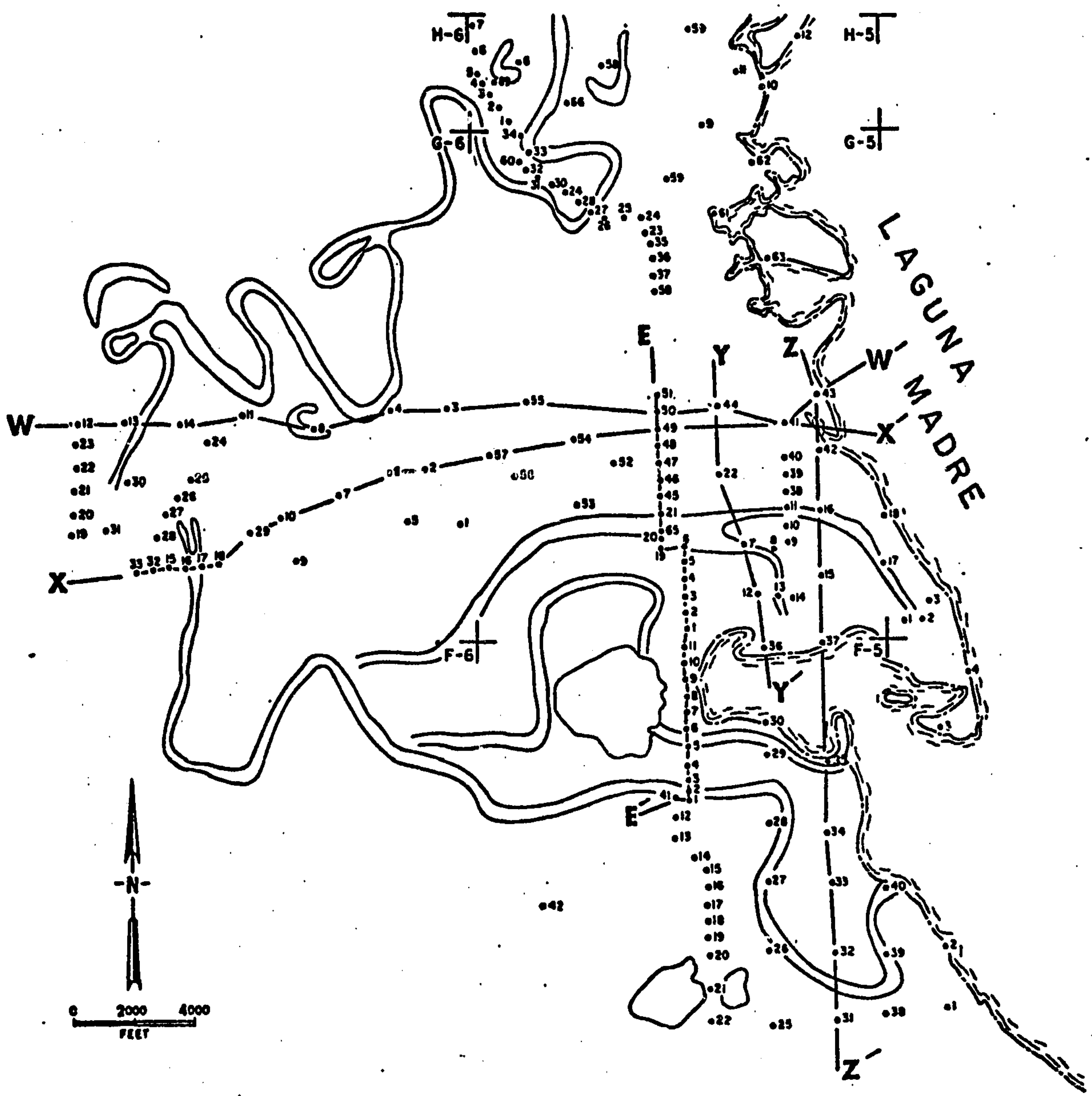


Fig. 18. Location of cross sections--Southern system.

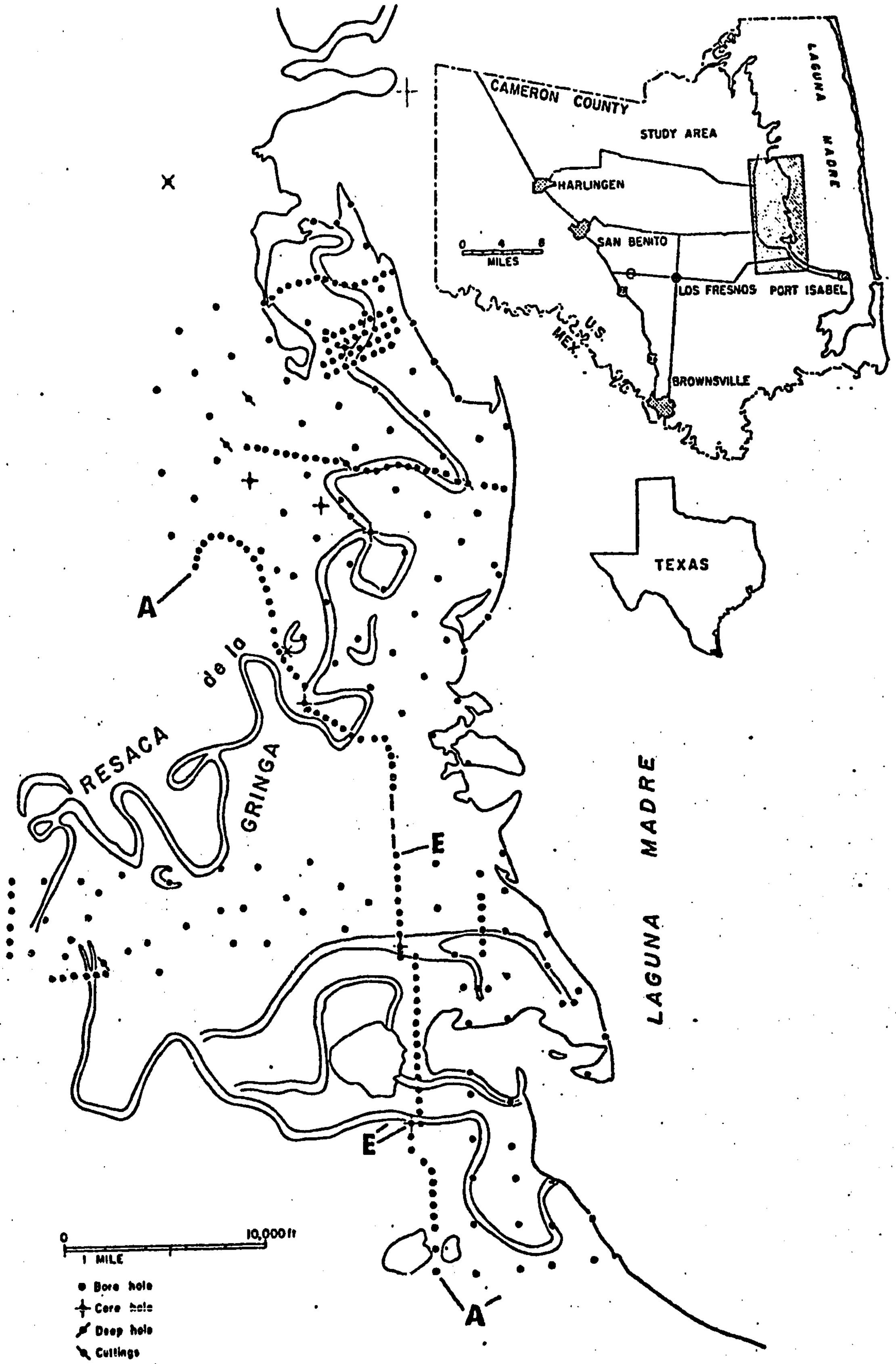


Fig. 19. Location of cross-sections across both systems. (See Fig. 18).

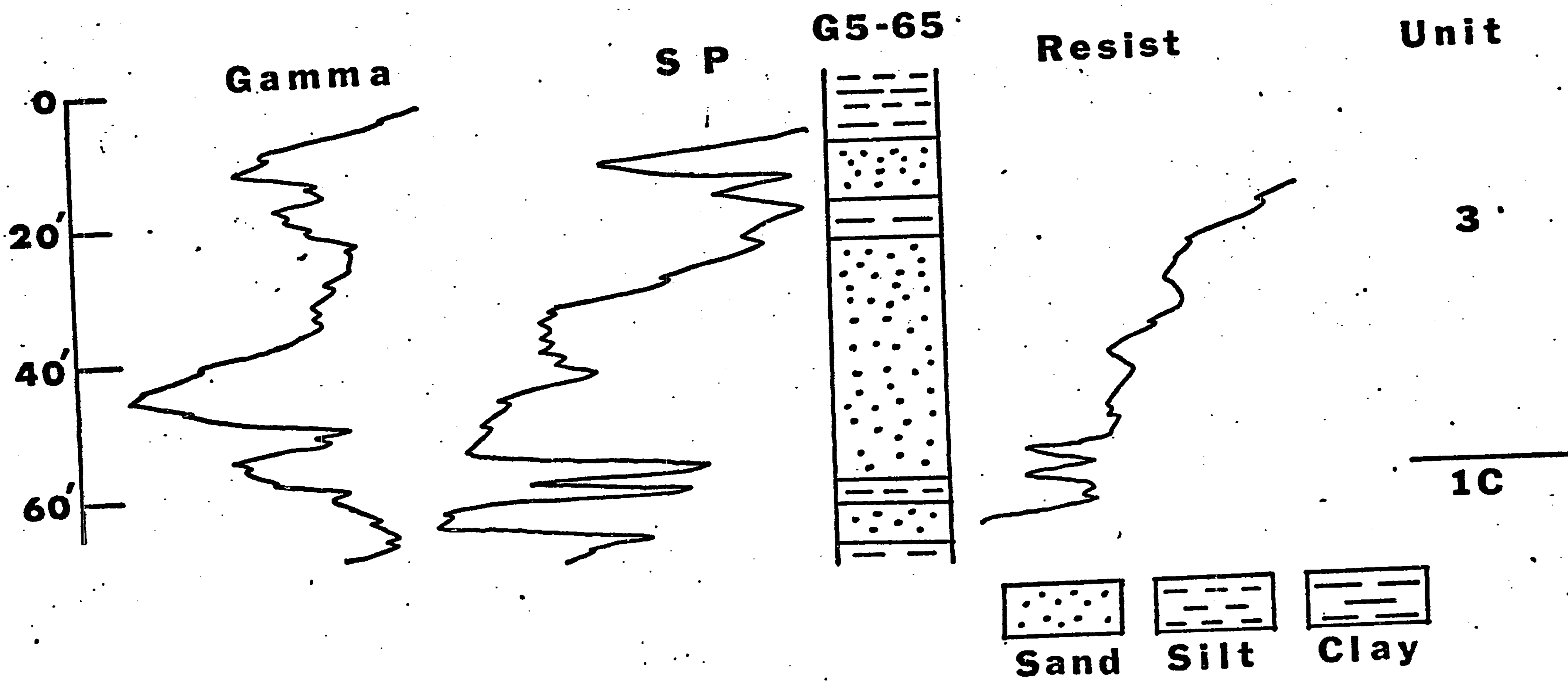


Fig. 20. E-log characteristics and associated lithologies Core G5-65.

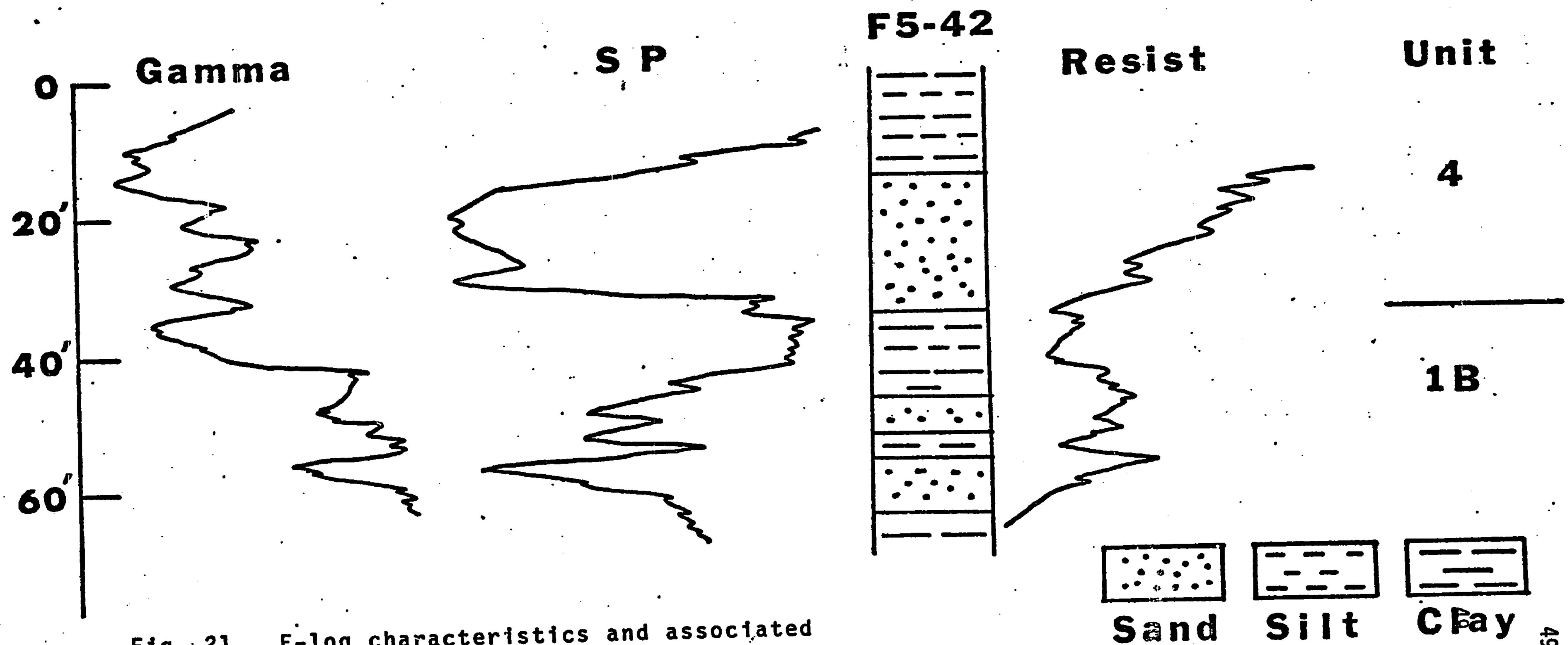


Fig. 21. E-log characteristics and associated lithologies--Core F5-42.

have been designated. The upper group contains four major sand units each separated by surfaces of sharp erosional contacts (see Fig. 17). Underlying this group is what is designated as the middle unit--a unit containing a sand member which for environmental reasons is not present throughout the area associated with the Southern system. The lower unit is characterized by sands, silts, and clays--the sands occurring as lenses and pods as they did in the lower unit of the De la Gringa system. The basal unit of the Southern system is a continuous sand layer interrupted as being a continuation of the basal sand previously described underlying the progradational system to the north.

Upper Group. The upper group and associated complex stratigraphy is best shown in Fig. 17. This unit contains four distinct sand units which are numbered as 1A, 2, 3, and 4 for purposes of stratigraphic as well as environmental discussion. Although section A-A' (Fig. 17) shows the general stratigraphic relationship of the units of the Southern system, reference must be made to section E-E' for the detailed sand body relationships of these units. Section E-E', which is drawn perpendicular to the direction of progradation of the Southern system, was constructed from closely spaced (500 foot) well data.

Sand unit 1A (Fig. 17) is the least well exposed of the units of the upper group. Sand thicknesses range from 4 feet at well G5-2 to approximately 20 feet at well F5-11. Lateral continuity of the sands in this unit are poor ranging from 2000-5000 feet and are laterally replaced by silts and clays. In addition to poor lateral continuity, the sands of this unit are highly interbedded with silts and clays which impart to it a poor vertical continuity--a factor which will be discussed in detail in a later section.

Unit 2 (Fig. 17) of the upper group lies to the north of unit 1A and is onlapped from the south by unit 3 and from the north by the De la Gringa system. Sand thicknesses of this unit are generally somewhat thicker than unit 1A and vary from 10-20 feet thick between interbeds of clay. Lateral continuity of the sands in this unit are somewhat difficult to ascertain because of the lack of data from the northern end of section E-E', and the southern end of the onlapping De la Gringa system. Continuity does appear to be better than in Unit 1A--perhaps on the order of 6-8000 feet. This is only a rough estimate and is made in conjunction with sections A-F' (Fig. 13) which shows in detail the onlap of the De la Gringa system onto this sand unit. In a vertical sense, the continuity of these sands is poor as they are highly interbedded with silts and clays. Lateral and vertical contacts of this unit with surrounding units is sharp and interpreted as being erosional.

In section E-E', unit 3 is the best exposed unit of the upper group containing numerous individual sand bodies surrounded vertically and laterally by silts and clays. Thickness of the sands in this unit is highly variable ranging from 4-6 feet in isolated lenses such as that in the upper part of cores G5-19 and 20 to 20-30 feet thick such as the lower sand member of this unit present at cores G5-65 and 5. Vertically sands of this unit are interbedded with silts and clays and exhibit very poor continuity. The poor vertical continuity and lensatic shape of the sands in this unit have important implications in relation to depositional environment. Lateral and vertical boundaries of the unit with adjacent units are sharp and disconformable.

Unit 4 of the upper group is not well shown in the detailed section of Fig. 17. For purposes of illustration the detailed section E-E' does not contain the extreme southern end of this unit. Detailed stratigraphy of this southernmost unit of the upper group is shown in section Z-Z' (see Fig. 22) and will be discussed in relation to that section. Unit 4, as expressed in E-E', contains 2 sand members each averaging about 15 feet in thickness and separated by a thin 2-4 foot clay. The unit onlaps unit 1A from the south and has a sharp erosional contact with both the adjacent and underlying units.

Two other north-south cross-sections were constructed perpendicular to the direction of progradation of the Southern system. The position of these two sections Z-Z' and Y-Y' are shown in Fig. 22. These two sections parallel the section previously discussed although well control is at 2000 foot spacing rather than at closely spaced 500 foot intervals. Section Y-Y' is a short N-S section extending from well G5-44 south to F5-36 and is designed mainly to show the detailed stratigraphy and geometry associated with unit 3. The section was not extended southward because S.P. and gamma ray data from wells G5-29 and 30 are lacking. It was felt that projection of data across these two points would essentially defeat the purpose of constructing the cross-section any further to the south.

Section Y-Y' (Fig. 22) shows very nicely the lense shape geometry

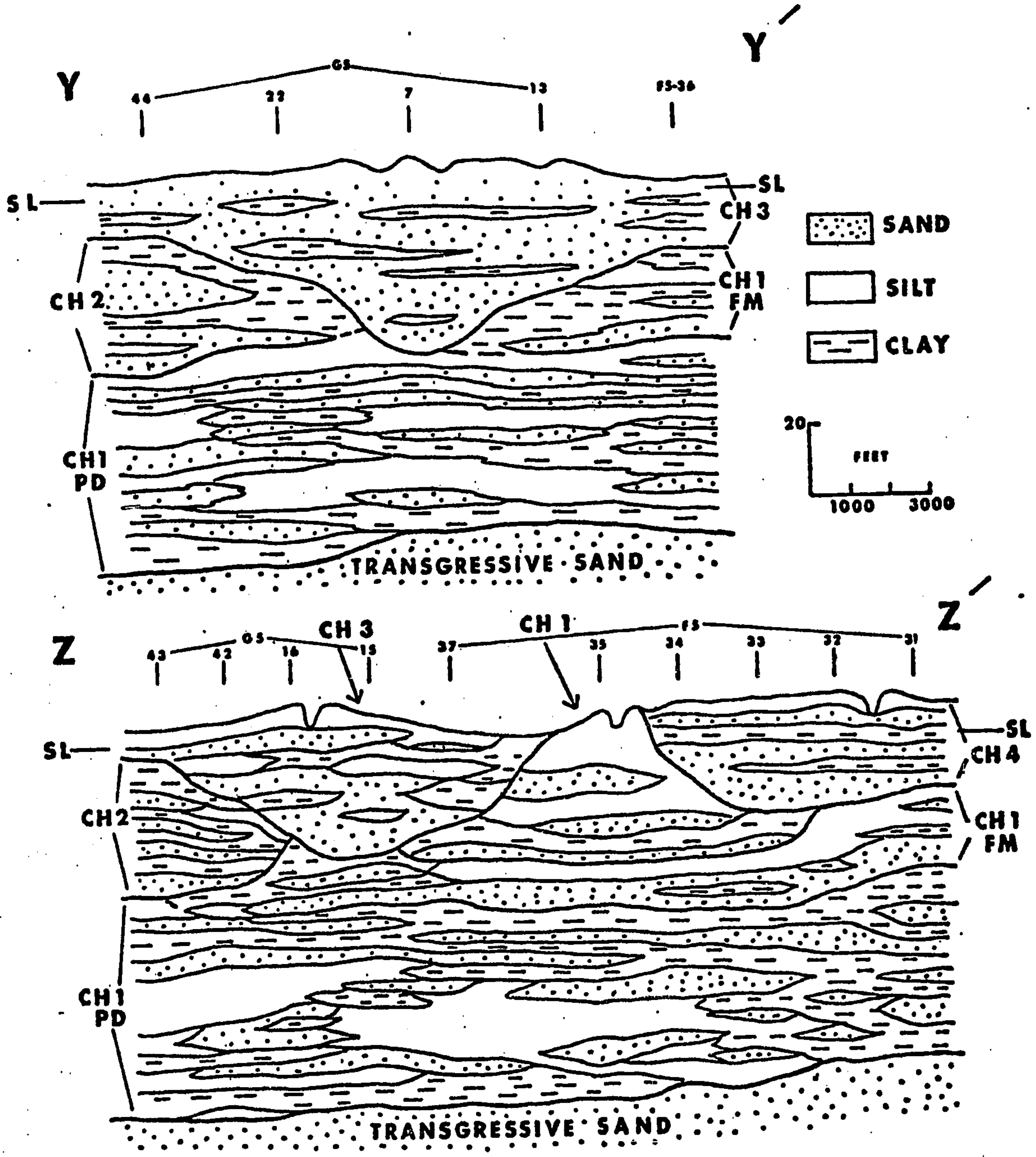


Fig. 22. Sections Y-Y' and Z-Z'--Southern system.

and sharp basal contacts associated with unit 3 at this locality. Maximum thickness of the unit is about 50 feet at core G5-7 and thins both north (G5-44) and south (F5-36) to about 20 feet. Sand is the dominant lithology of the unit although sandy silts are common toward the top of the unit and clay interbeds are numerous. Laterally equivalent to the sands of this unit are sands, silts, and clays of the middle unit (1B) and unit 2 of the upper group.

Section Y-Y' is a vertical slice parallel to section E-E' and located approximately 4000 feet east of it. A detailed stratigraphic discussion of the various units of the upper group in this section is not needed as it essentially mirrors what is shown in section E-E'. Some general stratigraphic analysis is however appropriate. Unit 1A here is somewhat thicker than discussed in the previous section, reaching a thickness of approximately 40 feet at well F5-35 and thinning rapidly north-south to about 10 feet where it is truncated by the overlying units 3 and 4. The unit contains 3 sand bodies each averaging about 10 feet thick and separated vertically by silts and clays. Unit 2 is penetrated in wells G5-43 and 42 where it reaches a maximum thickness of about 40 feet and is composed of numerous sand members each averaging 6-8 feet thick. Unit 3 maintains a thickness comparable to that shown in section Y-Y' at about 40 feet, and thins both north and south where it has a sharp disconformable contact with units 1A and 2. Sand is the characteristic lithology although interbedded commonly with silts and clay members averaging 6-8 feet in thickness. Unit 4, which was not well shown in section E-E', is exposed in this section from its sharp lateral contact with unit 1A (F5-34) southward to the limits of data control at core F5-31. The unit ranges from about 15 feet thick at core F5-34 to approximately 30 feet thick at F5-32. Sand members averaging 8-10 feet thick comprise the dominant lithology of this unit although they are interbedded with clay lenses 2-4 feet thick. Both lateral and basal contacts of this unit are sharp and disconformable with lateral and underlying units.

Section W-W' and X-X' are generally based on data control points that are 2000 feet apart and are drawn perpendicular to the depositional strike (parallel to progradational direction) of the Southern system.

The stratigraphy as expressed in section W-W' is somewhat more complicated than the upper group stratigraphy previously discussed because of the presence of sand from the De la Gringa system in this locality from the north. Sands of the De la Gringa system are present in section W-W' (Fig. 23) from well G6-12 eastward to G5-55. Sand thickness of this unit ranges from 30 feet at well G6-14 to approximately 4 feet at well G5-66. Approximately 2000 feet east of well G5-55 sands of the De la Gringa system are in sharp disconformable contact and onlap unit 3 of the Southern system. These sands which have sharp basal and lateral contacts are overlain by silts and sandy silts, and are interbedded with discontinuous 2-4 foot thick clays, are interpreted as being the upper sand of the De la Gringa system. These sands which are from the upper unit of the De la Gringa system disappear from the section as the channel veers northward away from the depositional units associated with Resaca 6.

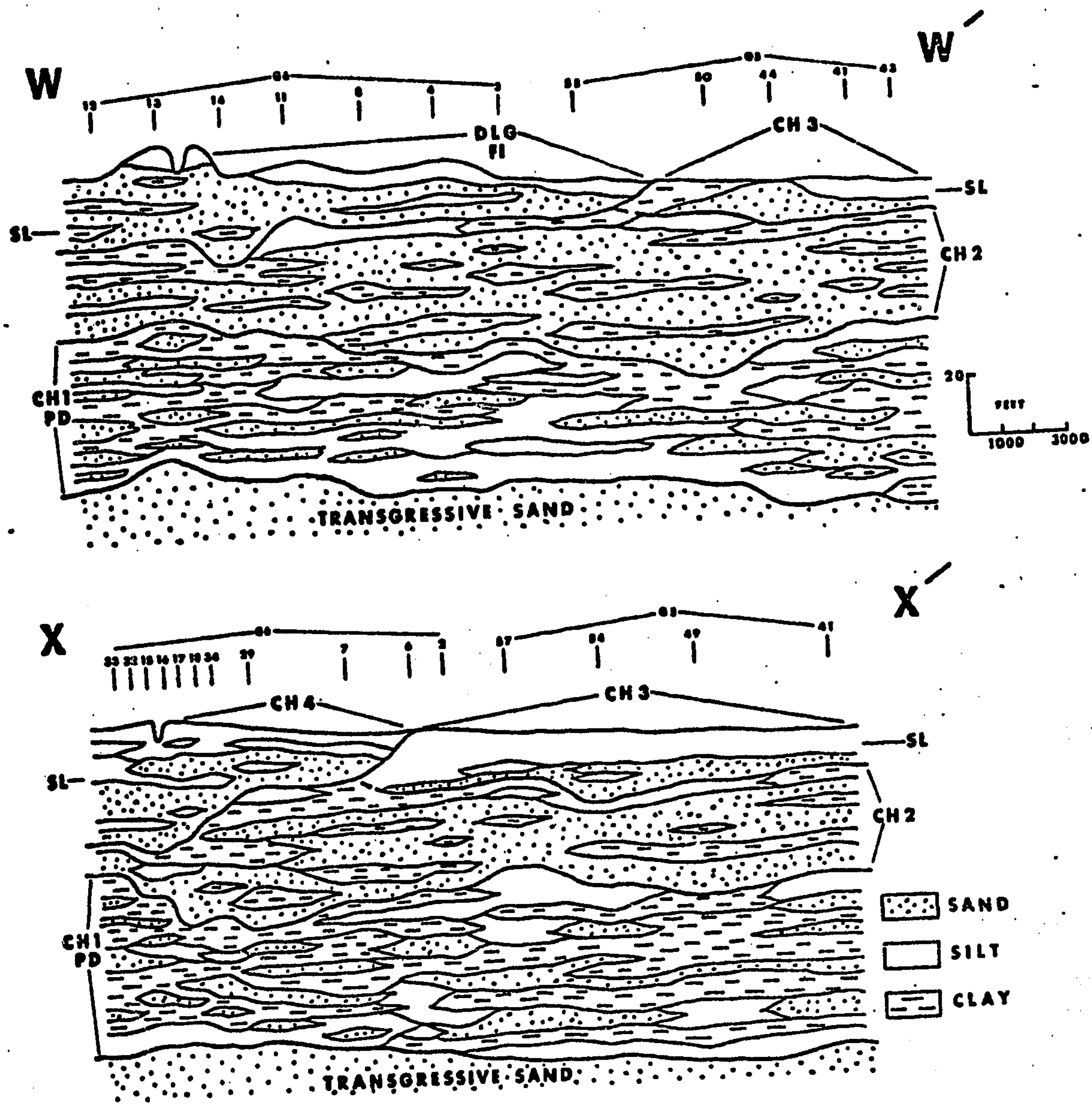


Fig. 23. Sections W-W' and X-X'--Southern system.

In section W-W' the only units associated with the upper group of the Southern system are units 2 and 3. Unit 3 is represented by a thin 4-10 foot thick sand overlain by thin units of silts and clays. The contact with the underlying and lateral units is sharp and erosional as in previous sections.

The unit which dominates the upper group of the Southern system in section W-W' is unit 2. This unit reaches a maximum thickness of some 50 feet at well G5-50 where it is dominated by 30-35 feet of sand interbedded with thin discontinuous lenses of clay averaging 2-4 feet thick. Because this section is constructed parallel to the direction of progradation, the thickness of the unit does not vary appreciably and averages about 40 feet thick throughout the limits of data control. Although lateral continuity of the sand in this section is good, vertical continuity is poor as is evidenced by numerous interbedded clays. Contacts with both the overlying and underlying units is sharp and disconformable.

To the south of section W-W' the stratigraphic picture changes somewhat as is shown by section X-X' (Fig. 23). In this section the sands of the upper unit of the De la Gringa system are absent and all major sand units in this section belong to the upper group of the Southern system.

Unit 2 is somewhat thinner than discussed in the previous section reaching a maximum thickness of approximately 40 feet at core G6-29 and averaging about 30 feet thick. Sands are the dominant lithology of the unit, although interbedded silts and clays are common. Lateral continuity of the sands is good but frequent clay lenses inhibit the formation of good vertical continuity. Basal, lateral, and overlying contacts of this unit with surrounding units is sharp and considered to be erosional.

Unit three is better developed in this section than in section X-X' which lies some 2-4000 feet to the north. The unit reaches a maximum thickness of about 20 feet at well G5-54 and averages about 15 feet thick. Thin sands averaging 8-10 feet thick are common at the base of the unit, although silts, sandy silts, and thin discontinuous clays are the dominant lithology.

Unit 4 in section X-X' reaches a maximum thickness of about 40 feet at well G6-15 and thins eastward to well G6-6 where it has a sharp lateral contact with unit 3. Sands are the dominant lithology of the unit reaching a maximum thickness of about 25 feet at well G6-15 and averaging about 10-15 feet thick throughout the unit. Lateral and vertical equivalents of the sands are the silts and clays of surrounding units.

In summary, the upper group of the Southern system contains four major sand units with definable boundaries. Sands of these units vary greatly in thickness (from 0 to 40 feet thick) depending on where the cross-sections are located and whether or not the sections are taken parallel or perpendicular to depositional strike of the sands. All units exhibit sharp disconformable contacts with surrounding units and onlap and offlap one another in a consistent fashion throughout all the limits of data control. In general, both lateral and vertical continuity is poor regardless of cross-section location. The already complex stratigraphy of the upper group is further complicated by the sands from the upper unit of the De la Gringa system such as those that occur in section X-X' which truncate both units 2 and 3 of the Southern system.

Middle Unit. The middle unit (1B) is not present in all cross-sections and as is shown in Fig. 17 is truncated both laterally and vertically by units of the overlying group. The approximate northern limit of sediment associated with the middle unit is marked by an E-W line passing through well H5-21. In section E-E' the unit is dominated by a laterally continuous sand which ranges in thickness from 6-15 feet and contains interbeds of discontinuous sand layers averaging 4-6 feet in thickness. Thickness of the entire middle unit averages 20-25 feet except at the extreme southern end of section A-A' where it thickens to approximately 40 feet.

In north-south section (Y-Y') the middle unit is penetrated only in wells G5-13 and F5-36 and varies in thickness from 0 to 25 feet. Thin 4-8 foot sands are present in the lower part of the unit which is characterized by silts and clays.

Section Z-Z' which parallels E-E' approximately 4000 feet to the west shows a similar stratigraphic configuration of the middle unit as was previously discussed. The middle unit here is somewhat thinner than shown in section E-E' ranging from about 10 feet thick at well F5-37 to about 25 feet thick at F5-32. Sands in the lower part of this unit average 10-15 feet thick and are continuous throughout the limits of data control as they were in section E-E'. Upper contact of the middle unit (1B) in this section is interpreted to be disconformable in nature although the lower contact is more likely to be gradational. Silts averaging 8-10 feet thick are common in the upper part of the middle unit while thin 2-4 foot clay beds are commonly interbedded with and laterally equivalent to the sands at the base of the unit.

In summary, the middle unit of the Southern system varies in thickness from 0-25-40 feet thick. The highly variable nature of the unit is a response to the fact that its upper surface is in sharp disconformable contact with the overlying units of the upper group. The lower contact of the unit is marked by a sand layer ranging 8-20 feet thick. This lower sand layer has good lateral continuity but contains numerous 4-6 foot thick clay and silt layers which are detrimental to its continuity in a vertical aspect.

Lower Unit. The lower unit (1C) associated with the Southern system is very similar lithologically to the lower unit described in the De la Gringa system and will be discussed here in only a brief general fashion--in essence a summary of the unit. Lithologically, the unit is composed of sands, silts, and clays although in opposition to the previously discussed units sands are not the dominant entity and compose approximately 1/5-1/3 of the unit, the remainder being silts and clays. Sand within the unit vary (see Fig. 17) from 8-10 feet in thickness and are very discontinuous both laterally and vertically. The upper contact of this lower unit is usually gradational where it is overlain by the middle unit and sharp and truncated where it underlies unit 2 (see Fig. 17). At its northern extremity, the lower unit underlies depositional units of the De la Gringa system as is exemplified by the general stratigraphic cross-section A-A' (Fig. 17).

Basal Unit. The basal unit underlies the entire depositional packet associated with the Southern system. This unit has a slightly irregular top and is penetrated in all wells at 100 ± 15 feet. The E-log data associated with well F5-41 (see Fig. 18) indicate that the thickness of the unit is approximately 30-40 feet--similar to that penetrated in the basal unit underlying the De la Gringa system to the north.

CORE CHARACTERISTICS

Clay Mineralogy

Methods. All samples for clay analysis were treated with sodium hexametaphosphate and subjected to ultrasonic disaggregation. The samples were allowed to settle 14-16 hours to obtain the spherical diameter equivalent of the less than 2 micron fraction. If the clay was not adequately dispersed at this time, it was washed by decantation or centrifugation, stirred and allowed to settle another 14-16 hours. At this time a 50 ml amount was gently poured into a centrifuge tube. One drop 5N HCL was added and the mixture was centrifuged for 2-3 minutes or until the supernatant liquid was clear. The supernatant liquid was decanted off and distilled water was added to flocculate the clay and develop a clay water suspension. The mixture was then resubjected to ultrasonic disaggregation for 30-60 seconds at which time a clay-water suspension was pipetted to a glass slide and allowed to air dry to achieve maximum particle orientation. Samples were run in the untreated, glyocated, and heated forms using CuKα radiation at 2^{o} and 4^{o}/min.

Results of the clay mineral analysis indicate that montmorillonite, illite, and kaolinite are the clay minerals present. Peak heights of each of the clay minerals were measured. The measured values of montmorillonite was multiplied by 3, illite by 2, and kaolinite by 1. The resulting values were then normalized to 100 percent to give a relative estimate of the clay mineral abundance.

Samples from cores H6-33, H5-40, and H5-90 (Figs. 26, 27, and 28) were taken at 4-foot intervals producing a total of 154 clay samples. The samples were X-rayed at the Gulf Research and Development Lab, Pittsburg, under the direction of Dr. Wayne Pryor. X-ray traces from this earlier work were available for inspection and were compared with various "spot check" samples that were re-examined during work on this study. No discrepancies in X-ray patterns were observed, allowing peak height data from the Gulf X-ray traces to be used for semi-quantitative clay mineral percentages from this study.

Samples from cores G5-60, G5-65, F5-42, and H5-88 were collected from the core at 2-4 foot intervals allowing of course for missing core and clay poor sediment. Samples from the remaining cores (see Appendix) were taken from bags containing cuttings from these wells. Samples were generally run at 10-20 foot intervals depending on the depth of the well and the intervals at which cuttings were taken.

In total 333 samples were X-rayed, the results (see Fig. 26, 27, 28 and Appendix) indicate that montmorillonite is the dominant clay mineral, followed by minor amounts of kaolinite and illite. These results agree with what Morton (1972, p. 85) found for the Holocene Guadalupe delta which is located about 125 miles north of the Rio Grande delta. Morton found that montmorillonite (smectite), illite, and kaolonite were the predominant constituents of the less than 2 micron size fraction for all environments sampled. These environments included delta plain, delta front, prodelta, and bay. In addition, Morton also sampled the Pleistocene sediment surrounding the delta. The work done by Morton (1972) and that done in this study do not agree with that done by Grim and Johns (1954). Grim and Johns (1954, p. 94) collected samples from Aransas Bay, San Antonio Bay, and the Guadalupe delta (Rockport area). All samples collected were from core depths of less than 60 cm. The results of their clay mineral mineralogical analysis indicate the presence of montmorillonite, chlorite, and illite as being the dominant clay minerals--kaolinite in their study was considered to be present in only trace amounts. Furthermore, Grim and Johns (1954, p. 95) found that samples from the Guadalupe delta contained 20 percent illite and chlorite, the rest being montmorillonite, while those in the bay areas and inner Gulf localities contained 70 percent illite and chlorite (in approximately equal amounts) and about 30 percent montmorillonite. He attributed this change, i.e. the development of illite and chlorite from montmorillonite, to diagenitic affects after ruling out preferential sedimentation, change in source, and samples which represent material of different geologic age. The writer, although not attempting to rule out diagenesis of clay minerals or their usefulness as environmental indicators, agrees with Morton that the work of Grim and Johns (1954) may be in error due to the interpretation of X-ray data.

Kunze et al. (1955) sampled the Harlingen clay (Recent Holocene) and Willacy soils of the Beaumont Formation (Pleistocene) which are on and adjacent to the Rio Grande delta plain surface. Their findings for both the Holocene and Pleistocene sediments were that the predominant clay minerals were montmorillonite with minor amounts of illite and kaolinite (p. 381)--there was no mention of chlorite in any of their analyses.

The conclusions reached by Morton (1972, p. 85) for the Guadalupe delta are that the clay minerals of the area studied are interpreted as being an indicator of clay minerals in the source area based on evidence that they: (1) are the same for both Pleistocene and Holocene sediments, (2) are not related to changes in depth, (3) are not significantly different for fresh water and brackish environments, and (4) are essentially the same as those in the source area. The same conclusions appear to be applicable to the clay mineralogy of the Rio Grande delta.

Bedding and Texture

Techniques. Grain size analysis of sand from core G5-60, H5-88, G5-65, and F5-42 were made using a Hydraulic Equivalent Sediment Analyzer (HESA) similar to that designed by Anan (1971) and that produced by BENTHOS, Inc.*

The principal component of the sediment analyzer is a vertically mounted, clear plastic tube 10 inches in diameter filled with distilled water to a depth of 1 meter. Sediment samples weighing between 3-5 grains are deposited at the top of this column and allowed to settle to the bottom. A sensitive differential pressure transducer located near the base of the settling tube measures variations in the tube pressure as a result of introduction of the sample and the effective increase of the column density. These variations are compared with

*BENTHOS type 341 Rapid Sediment Analyzer--BENTHOS, Inc., North Falmouth, Massachusetts 02556.

the pressure at the base of an adjacent reference water column to which no sediment has been added. Output of the transducer is fed to the electronic console containing necessary signal processing networks and the X-Y chart recorder. The larger particles tend to settle past the transducer more quickly than do the smaller grains such that a plot of pressure versus time at the column base corresponds to a trace of the grains size distribution for the sample.

Calibration of the settling column was made using St. Peter sand (US size ranges 30-230) so that settling times could be compared to that acquired by Anan (1971, p. 206). The results are tabulated in Table II, and show the close correlation between settling times for that acquired by Anan (p. 206) and that determined in this study. In addition, Anan (p. 210) found that the shape effect on settling velocity is neglible on sizes smaller than .38 mm (1.5Ø) and absent in sizes smaller than .2 mm. This is indicated by the fact that the difference in the drag coefficient-Reynolds number (C_d-R_e) between St. Peter sand and the glass spheres becomes neglible for sizes smaller than .38 mm. In addition, sizes up to .45 mm differ only slightly in settling velocity (see Table III after Anan, 1971, p. 207). For this reason it was felt that the St. Peter sand could be used without negating the concept of hydraulic equivalency although Cook (1969, p. 782) preferred to use glass beads in the calibration of the USC automatic recording device which Felix (1969, p. 279) calibrated using Navajo and St. Peter sands.

The St. Peter sand was sieved into the various phi sizes and 10-

Ø	US Size	Settling Time* this study (sec)	Settling Time* Anan, 1971 (sec)
.75	30	9.75	N/A
1.0	35	12.2	N/A
1.25	40	14.0	12.8
1.5	45	16.0	16.1
1.75	50	19.0	18.8
2.00	60	22.0	22.3
2.25	70	28.8	26.8
2.50	80	34.0	31.2
2.75	100	42.0	38.5
3.00	120	54.0	47.6
3.25	140	65.7	59.0
3.50	170	86.9	83.0
3.75	200	108.5	105.2
4.00	230	142.0	147.0

Fall distance - 1 meter

* At 22° C

Table II. Comparison of settling times--University of Cincinnati and University of Massachusetts settling columns.

Size fraction (phi)	Diameter (mm)	Temperature (°C)	Masses of quartz spheres (calculated data) — From St. Peter Ss. (determined data): C_D-R_e	From St. Peter Ss. (determined data): Settling velocity (cm/sec)	From glass spheres (determined data): C_D-R_e	From glass spheres (determined data): Settling velocity (cm/sec)
1.00-1.25	0.45850	22.0	59.02655	8.00917	56.99382	8.29482
1.25-1.50	0.38555	22.0	52.23378	6.39980	48.09989	6.94982
1.50-1.75	0.32421	22.0	43.26410	5.46363	43.09140	5.48553
1.75-2.00	0.27263	22.0	36.32872	4.60101	36.42290	4.58912
2.25-2.50	0.19278	22.0	25.64256	3.25926	25.43663	3.28565

Table III. Comparison of determined settling velocity and calculated C_D-R_e for quartz spheres calculated from data of St. Peter Sandstone and glass spheres of equal size. (After Anan, 1971, p. 207).

20 runs were made for each phi size to get an average time for the size group.

There are inherent problems to using a device such as this although they are probably outweighed by the rapidity with which samples can be run (as versus sieving) and the small sample size which can be used (ideal for cores). One problem is introduction of the sample, i.e. having all the sample release into the column at exactly the same time with minimum "noise" to the recorder. This was done by placing the sample on a nylon stocking (fine mesh) fitted over a tilt pan. The sample was then wetted with a wetting agent (Kodak Photoflo) which insured immediate release upon contact with the water (see schematic drawing - Fig. 24).

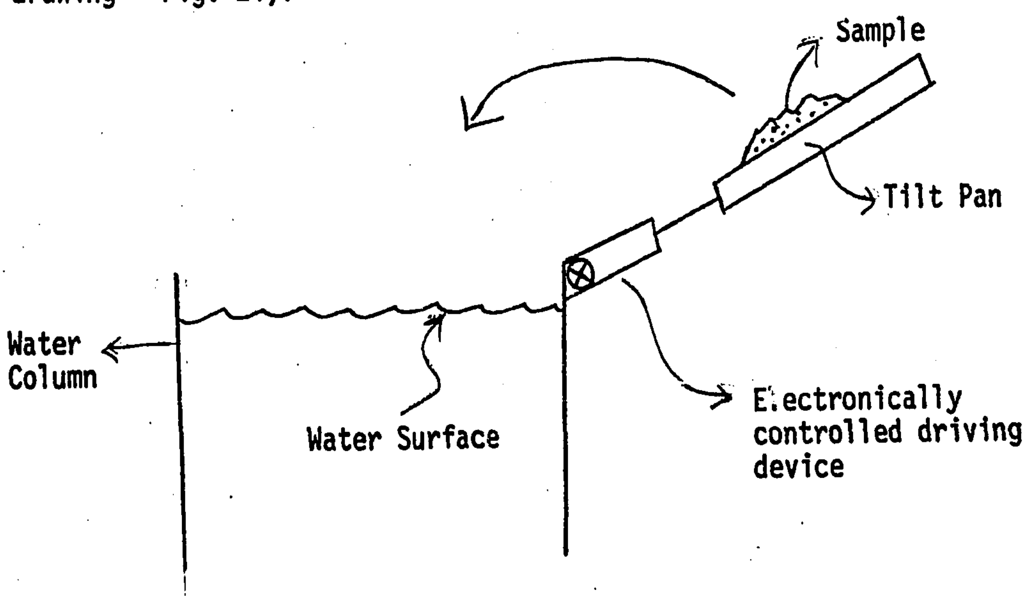


Fig. 24. Sediment introduction device - HESA.

A secondary problem is that phi groupings are a range of sizes, i.e. 2.0 phi includes diameters from .3 to .25 mm in diameter. When phi sizes groupings settle through a column of water the sample "tails out" (like a comet) as it passes the recording point. For this reason, the midpoint diameter of the phi grouping was used instead of either of the end points (which is commonly used when recording sieve data).

The data curve produced by the HESA recording device is shown in Fig. 25. Because time is equivalent to diameter which is equivalent to phi sizes, the phi sizes can be plotted along the base line, or, as is standard procedure, reproduced on a size-time overlay which can be used again and again for each data curve. The phi size plots are then simply projected upward until they intersect the recording curve. Cumulative percentages are read off the curve for the phi class boundaries desired using a Gerber variable scale. This device divides the deflection distance (the distance between the base line and maximum pen deflection as averaged over the first 2 or 3 seconds of the run) into 100 increments. Once set, the scale is moved to the size grades ruled on the size-time overlay, and the cumulative percentages are read off.

For sample runs, the 3-5 gram sample is weighed and then wet sieved to remove silt and clay ($< 4.00\phi$) and reweighed to determine percent $<$ .062 mm. The sample is then introduced into the column using the technique described above and the resulting data curve is read using the Gerber variable scale. Each analysis takes as much as 3 minutes in the settling tube plus a minute or two to load. (Weighing and wet sieving can be done in advance and takes approximately 5-10 minutes per sample). Reading the curve takes 1-3 minutes depending on how many classes are present. From 40-60 analyses per day can

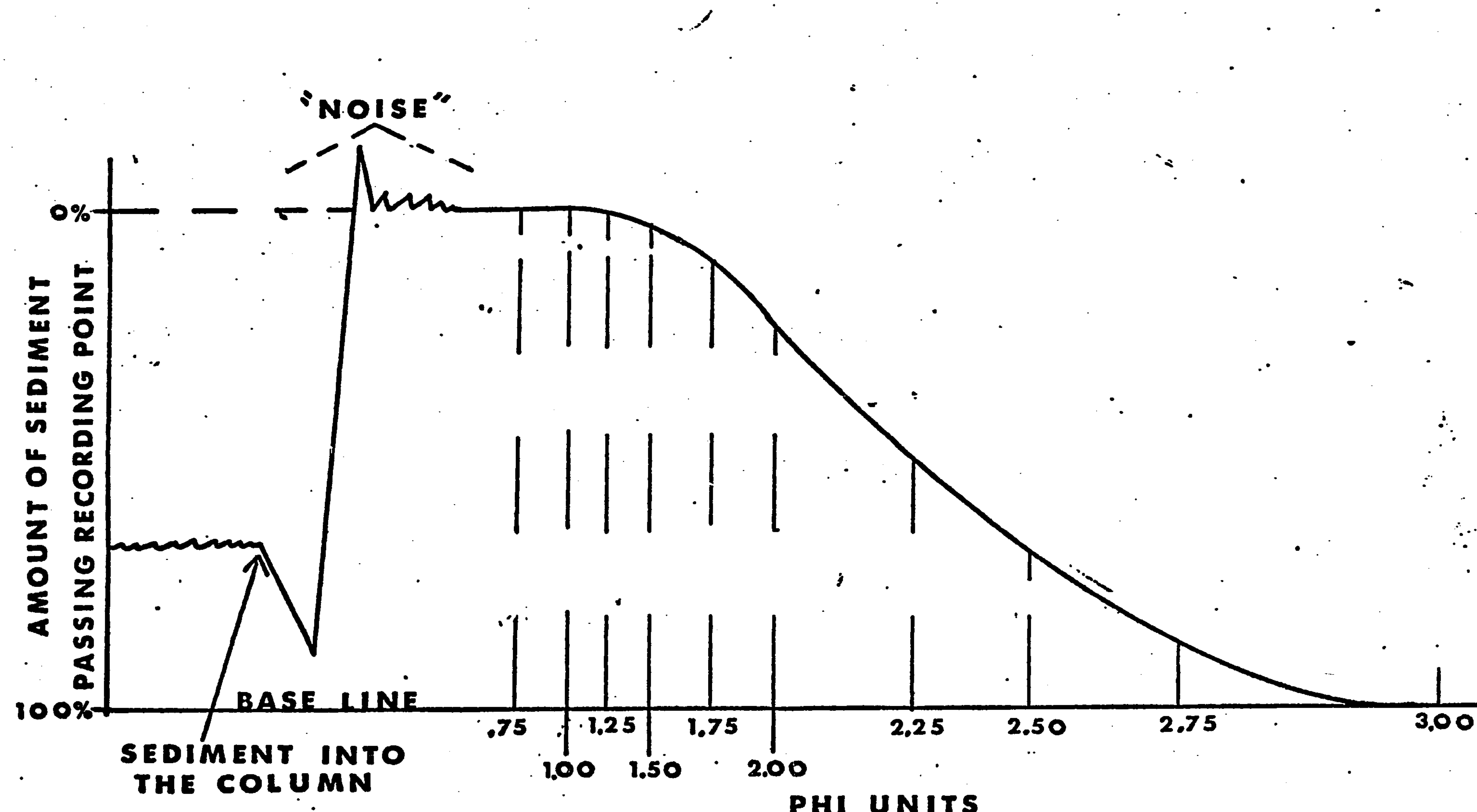


Fig. 25. Data curve from HESA recorder.

be made if the samples have been weighed, wet sieved, and dried.

Textural studies on sands from cores H5-40, H5-90, and H6-33 were done using standard sieving techniques. The typical grain size curves from these analyses are shown in the Appendix. Bedding descriptions, textural analysis, and clay mineralogy of cores H5-40, H5-90, and H6-33 were done under the direction of Dr. Wayne A. Pryor at Gulf Research and Development, Pittsburg.

Textural parameters computed from 1/4 phi interval data included skewness, kurtosis, graphic mean, and sorting--the latter of which are used in this investigation. Formulas for the computations are after Folk (1968, p. 44-48). Verbal classification for sorting used in this study are those recommended by Folk (1968, p. 46) and are as follows:

.35Ø	very well sorted
.35-.50Ø	well sorted
.50-.71Ø	moderately well sorted
.71-1.0Ø	moderately sorted
1.0-2.0Ø	poorly sorted

<u>H5-40</u>. Log characteristics of core H5-40 (Fig. 26) show an upper interval of massive to horizontally bedded silt and clay below which is a cross-bedded sand with a mean cross-bedding direction of 2°. This sand interval from 10-30 feet corresponds to the upper sand of the upper unit shown in section C-C'. Present in this interval at a depth of 20-30 feet are two zones of clay gall conglomerates. These two zones of clay galls correspond with changes in graphic mean, sorting and percent "less than 0.062 mm". At approximately 30 feet the

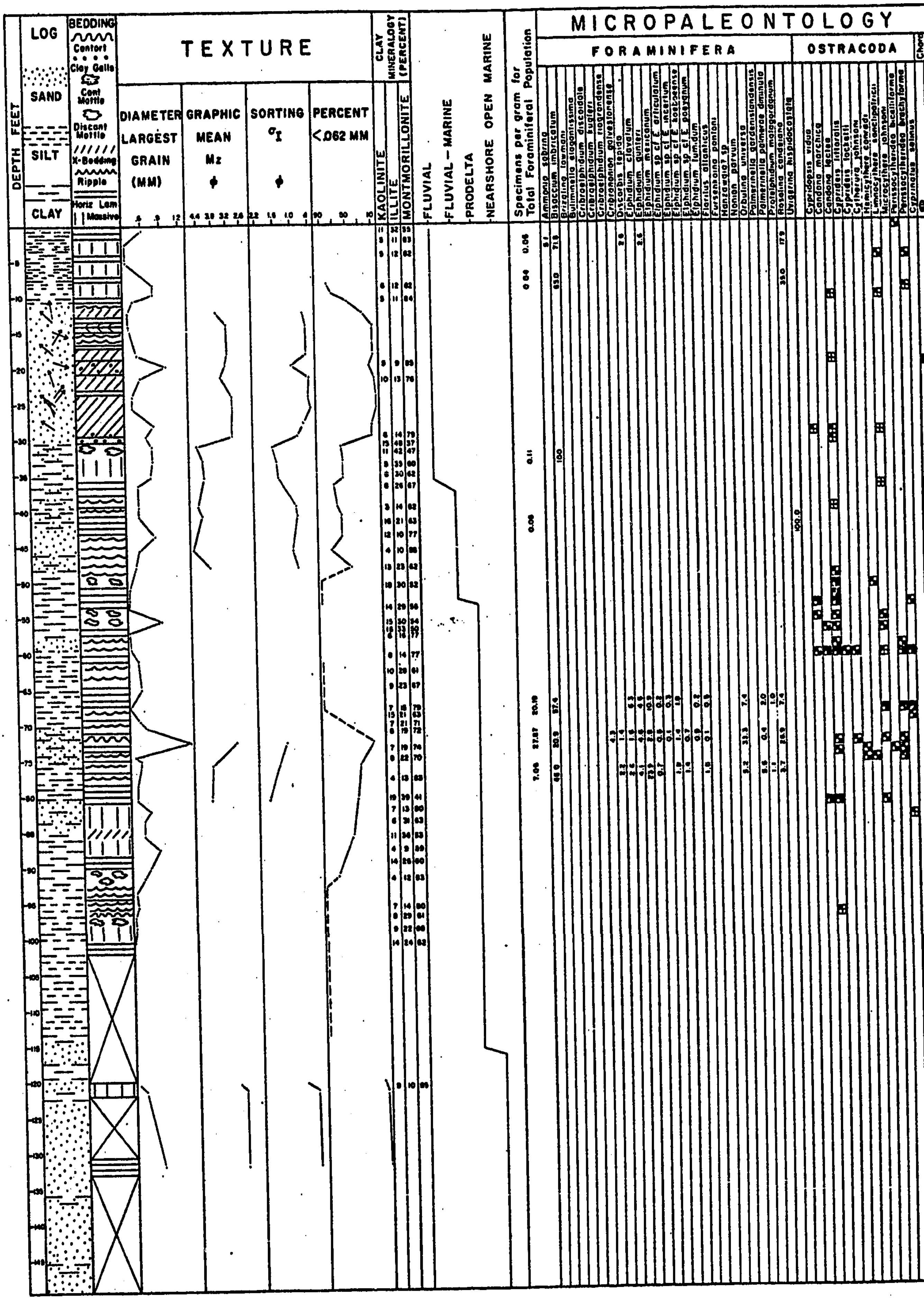


Fig. 26. Core characteristics--H5-40.

mean grain size becomes coarser and remains so until it fines upward between a depth of 20-24 feet. At 20 feet, which corresponds to the location of the upper clay gall conglomerate the mean size becomes coarser and remains constant until it fines upward again at approximately 14 feet. Sorting within this upper 30 feet increases from poorly sorted sediment below (greater than 1.0Ø) to well-sorted-moderately well sorted within the interval, except at 17.5-18.5 feet where the sample is poorly sorted and corresponds to the interval containing clay gall conglomerates. Percent "less than 0.062 mm" in this upper unit ranges from 10-30 percent up to a depth of about 12 feet when the percent "less than 0.062" increases. This is in marked contrast to the higher percentage of silt and clay below 30 feet.

Below this unit from a depth of 30 feet until sand is completely displaced by clay at a depth of 50 feet is the lower sand member of the upper unit. Bedding characteristics of this unit are markedly different from that above and include horizontal lamination, ripple bedding, massive bedding and some discontinuous mottling. Graphic mean of the sediment in this interval coarsens upward slightly. Sorting ranges from moderate (at the base of the interval) to poor at the top. Percent "less than 0.062 mm" is in all cases greater than 50 percent except at the base. From 50 feet to a depth of approximately 115 feet is the lower unit which is dominated by silts and clays except for thin (less than 10 feet) intervals of sand and sandy silts. Bedding in this interval is mostly horizontally laminated, although rippled bedding and some minor cross-bedding are present in intervals containing silts and sandy silts. Textural data is sparse except for diameter of the largest grain, which is less than above units with the exception again of the sandy members.

The basal unit from 115 feet to the bottom of the core is characterized by sand. Textural analysis of three samples from within this unit indicate the sand is well sorted and contains less than 20 percent silt and clay. Data from the basal unit is sparse due to lost core and is better observed in the cores discussed below.

In core H5-90 (Fig. 27) the upper and lower sand members of the upper unit are in contact as is shown in section C-C'. The division between the two is placed at 30-35 feet. This depth not only stratigraphically agrees with the base of the upper sand as in core H5-40, but also corresponds with changes in diameter of largest grain, mean grain size, sorting, and percent "less than 0.062 mm". Bedding of the sand in the upper member at this locality differs from that described in core H5-40 by being horizontally laminated, massive, and mottled although cross-bedding is present at a depth of 25 feet and rippled bedding is present at the top of the unit. The diameter of the largest grain of the sand in this member sequentially coarsens upward to a maximum of 1.0 mm at 25 feet and then fines upward from 3.4Ø at 33 feet to 3.9Ø at 16 feet. The sorting of this sand decreases from moderately well sorted at 33 feet to poorly sorted at 15 feet, while the percent "less than 0.062 mm" increases upward from 20 to 40 percent. Overlying the upper sand member from 15 feet to the top of the core are silts and clays which are characterized by horizontal, massive

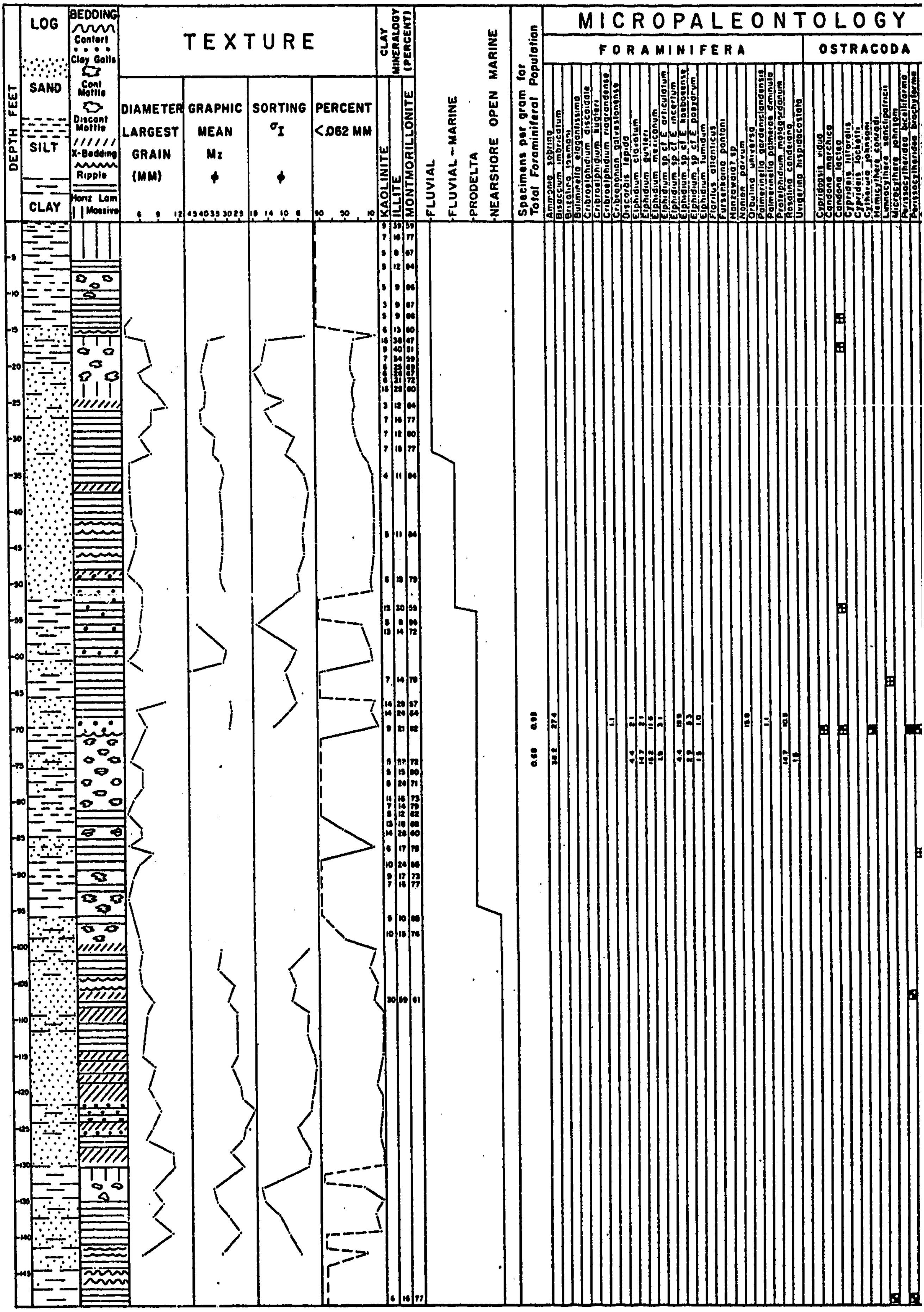


Fig. 27. Core characteristics--H5-90.

and mottled bedding.

The lower sand in this core is defined as that interval above the clay break at 55 feet. This unit is characterized by horizontally laminated sand although cross-bedding, ripple bedding, and clay galls are present at the base of the unit. Maximum grain diameter is fairly uniform between 0.4 and 0.5 mm through the unit. Graphic mean varies between 3.5Ø and 3.0Ø which is coarser than the sand in the overlying unit. Sorting varies between 0.38σ_I and 0.67σ_I and is better than that of the overlying sand. Percent "less than 0.062 mm" is also less than the sand above and varies between 9 and 15 percent, increasing toward the top of the member.

From 50-100 feet is the stratigraphically defined lower unit which is dominantly silts and clays although thin sand members are present at 55, 65, and 85 feet. The bedding of this lower unit is best described as laminated although mottling is a prominent feature. Again textural data for this interval is sparse except for diameter of the largest grain which is in the same size range (0.6-0.3 mm) as the overlying unit except for the sand members previously described where the maximum grain size may be as high as 1 mm.

Textural data for the sand member between 55 and 60 feet indicate that it is moderately sorted except for the contact near the top where it becomes poorly sorted. Percent "less than 0.062 mm" ranges between 13-14 percent with the exception of the top of the member where it is 30 percent and the bottom where it reaches 88 percent. A second thin sand member between 65 and 70 feet has the same sorting range as the above member with percent "less than 0.062 mm" within the member between 6 and 13 percent.

The basal unit from approximately 100 feet where the contact is gradational to 130 feet where clay layers become a prominent feature, is markedly different from the overlying units. Bedding within this interval is dominantly cross-bedded, although horizontal laminations are present as are ripple bedding and clay galls. Maximum grain diameter of 1.18 mm at 130 feet decreases upward to 0.52 mm at 100 feet. Maximum grain diameter of samples from this unit are greater than that of the previously described lower sand of the upper unit although they are within the same range as the upper sand member. Sorting of this unit above 130 feet ranges from predominantly well sorted to moderately sorted at the upper contact and is similar to the lower sand of the upper unit.

Graphic mean of samples of this unit indicate that all samples except two at the upper contact are coarser than those from sands of the upper and lower unit. Percentage of silt and clay in this unit from 105 to 130 feet indicate that 80 percent of the samples have less than 10 percent silt or clay while at least half have 5 percent or less. This is in marked contrast to the overlying lower and upper unit sands where none of the samples have that low percentage of silt or clay.

H6-33. The upper sand member of the upper unit is lacking in core H6-33 (Fig. 28). The interval where the upper sand member is present in cores H5-90 and H5-40 is represented in this core by silts

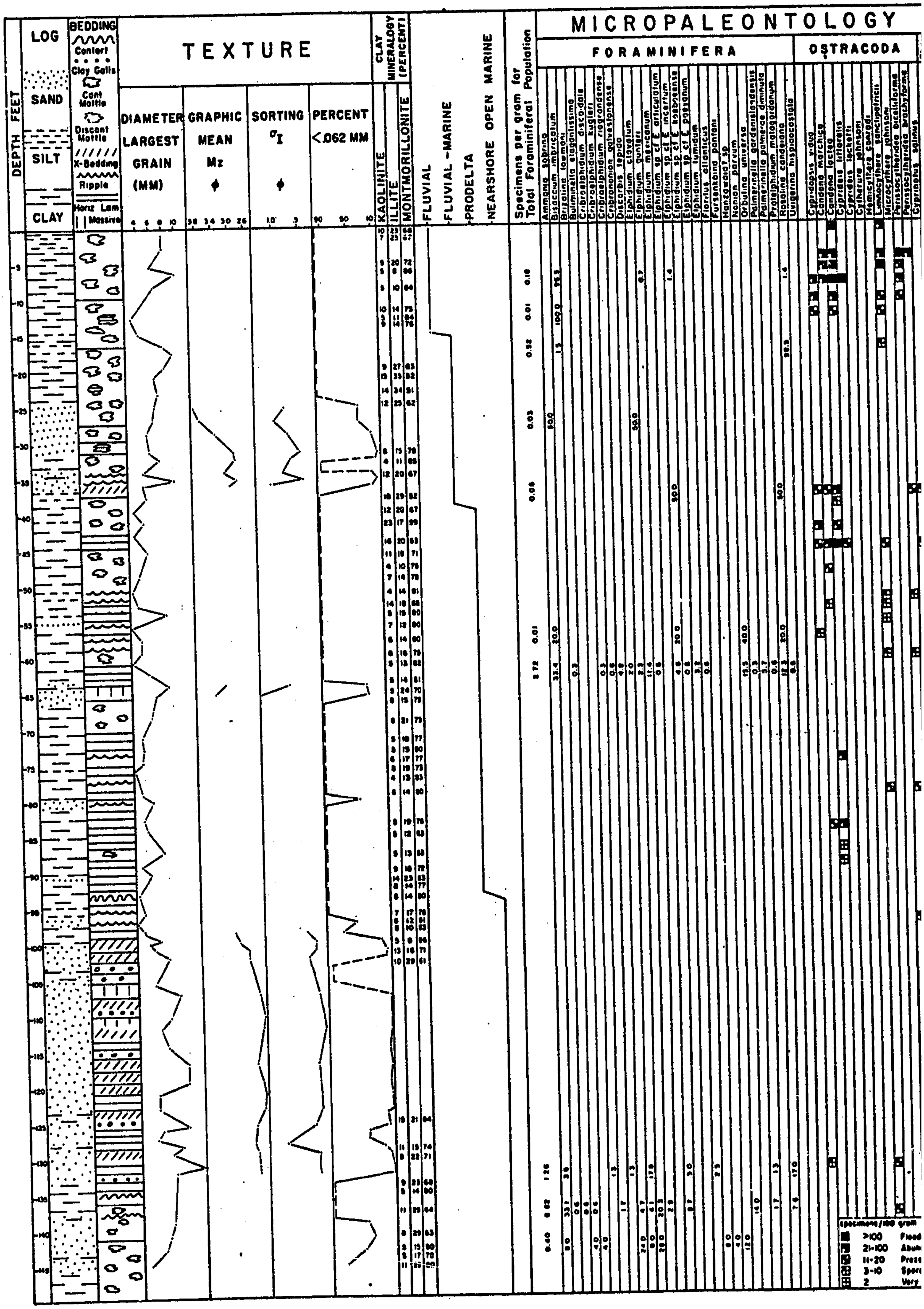


Fig. 28. Core characteristics--H6-33.

and clays except for a thin zone of sandy silts just below 15 feet. Bedding in this interval is dominantly mottled although some horizontal bedding is present. Textural data within this unit is sparse although maximum grain diameter is extremely variable and ranges from 0.3 to 1.0 mm.

The lower sand of the upper unit is present from a depth of 25 to 35 feet although there is a thin clay break at 30-32 feet. Mottling is the characteristic bedding feature within this sand although cross-bedding, horizontal lamination, and rippled bedding are present. Graphic mean of this interval indicates a fining upward sequence from 2.85Ø to 3.9Ø. Sorting varies from moderate to poor while percent "less than 0.062 mm" varies from 15 to 35 percent and becomes greater at the top of the interval.

The lower unit, from approximately 35 to 100 feet, is mostly silt and clay except for two thin sand members at 65 and 80 feet. Two samples from the sand interval at 65 feet have an average mean size of 3.3Ø, are moderately-to-poorly sorted, and have 28-30 percent "less than 0.062 mm". One sample from the interval at 80 feet indicates that the sand is moderately sorted with 43 percent silt and clay. Bedding within these sand units is extremely varied and consists of horizontal, massive, parallel-laminated and rippled bedding. Silts and clays within this unit are dominantly horizontally bedded although mottled bedding is conspicuous especially at the top of the unit.

The basal unit from 100 feet to 135 feet is dominantly cross-bedded although there are some horizontal laminae and clay galls as in the basal unit in core H5-90. From 135 feet to the base of the core the sands become mottled and contorted. Maximum grain character fines upward from 135 to the top of the unit at approximately 100 feet, the inverse of which is true from 145 to 135 feet. Graphic mean stays fairly constant from 130 feet (2.6Ø) until it fines upward between 107 (2.8Ø) to 98 feet (3.4Ø). The sands of this interval are well sorted with over 85 percent of the 16 samples falling below 0.5 . Percent "less than 0.062 mm" is very low from 132 to 100 feet with 75 percent of the samples having less than 5 percent silt or clay.

H5-88. The upper unit of H5-88 (Fig. 29) which is 52 feet thick does not contain an upper sand member. That part of the core which in previous wells contained the upper sand member is represented in this core by silts and clays. These silts and clays which are 32 feet thick contain a variety of bedding types including mottled, laminated, and massive. Clays are more prevalent at the top of the core down to about 16 feet where they are replaced by silts and silty clays which overlie the lower sand member of the upper unit. The lower sand member of the upper unit is approximately 20 feet thick and is predominantly horizontally bedded although cross-bedding does occur near the base of the unit. Mean grain size of the sand member shows a slight trend to fine-upward from about 2.9Ø at the base of the member to 3.1Ø at the top. Sorting ranges from well to moderately well sorted with the better sorted intervals being present at the bottom and near the top of the sand member. Percent "less than 0.062 mm" is fairly consistent ranging from 10 to slightly more than 20 percent.

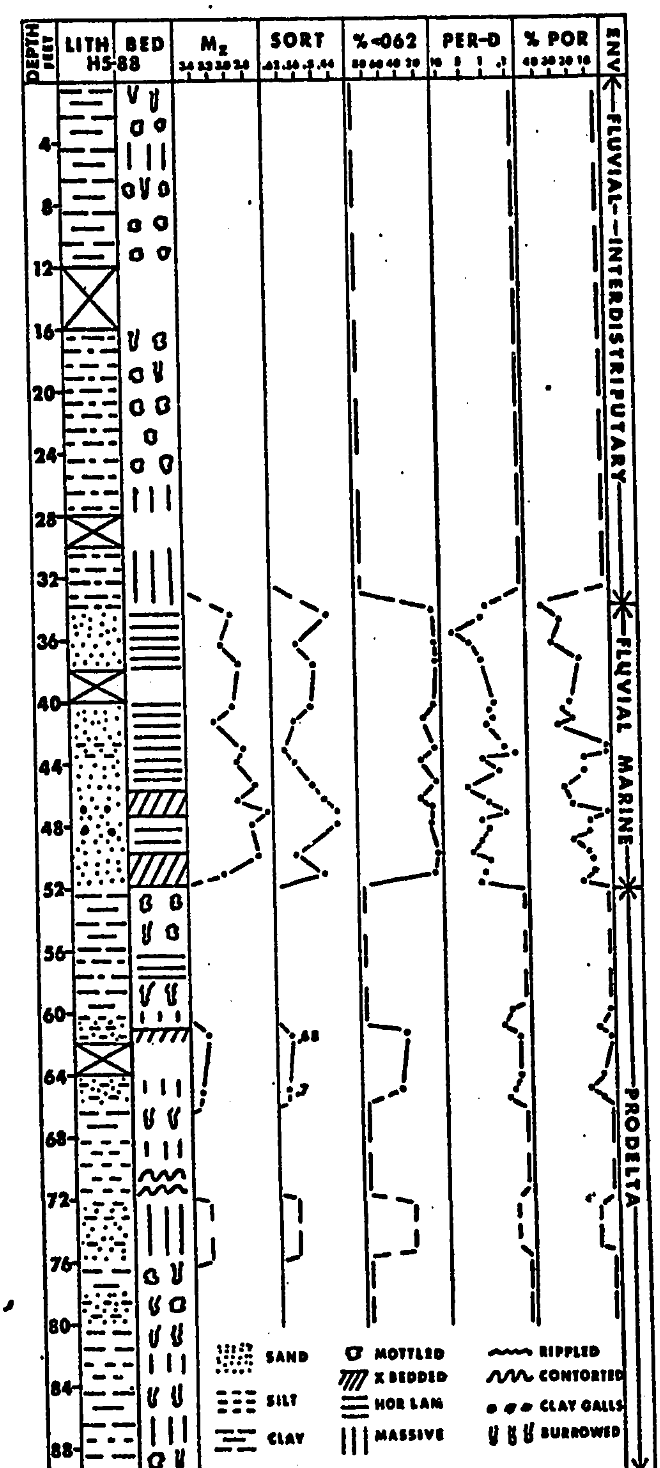


Fig. 29. Core characteristics--H5-88.

The lower unit in this core is present from 52 feet to the base of the core at 90 feet. This 40 feet of section is characterized predominantly by silts and clays with thin (4 foot) sand members present at 60, 72, and 80 feet. Bedding types of silts and clays in this lower unit are extremely varied and consist of mottled, horizontally laminated, massive, burrowed, and in one instance contorted. The thin sand lenses are predominantly massive bedded although cross-bedding is present in the sand at 62 feet. Textural data on these lower unit sands is sparse but does indicate that the medium grain size is 3.4-3.5 phi while sorting is at the upper limit of the moderately-well sorted range at .68-.7 phi units. Percent of silt and clay is high and ranges between 50-60 percent in contrast to the overlying sand member previously described.

G5-60. Core G5-60 (Fig. 30) penetrates lithologies related only to the upper unit as previously described stratigraphically. From 12 to 44 feet is the upper sand member of the upper unit. This unit is primarily cross-bedded although some horizontal lamination as well as a thin zone of ripple bedding does occur. At the base of the unit clay gall conglomerates are characteristic as are wood fragments. Mean grain size fines upward from approximately 2.9Ø units at 42 feet to approximately 3.4Ø units at 18 feet. Sorting ranges from moderately well sorted at the base where the clay galls are present to well sorted throughout the middle of the member and back to moderately well sorted at the top. Percent "less than 0.062 mm" is fairly consistent throughout the sand interval ranging from 15-18 percent at the base to

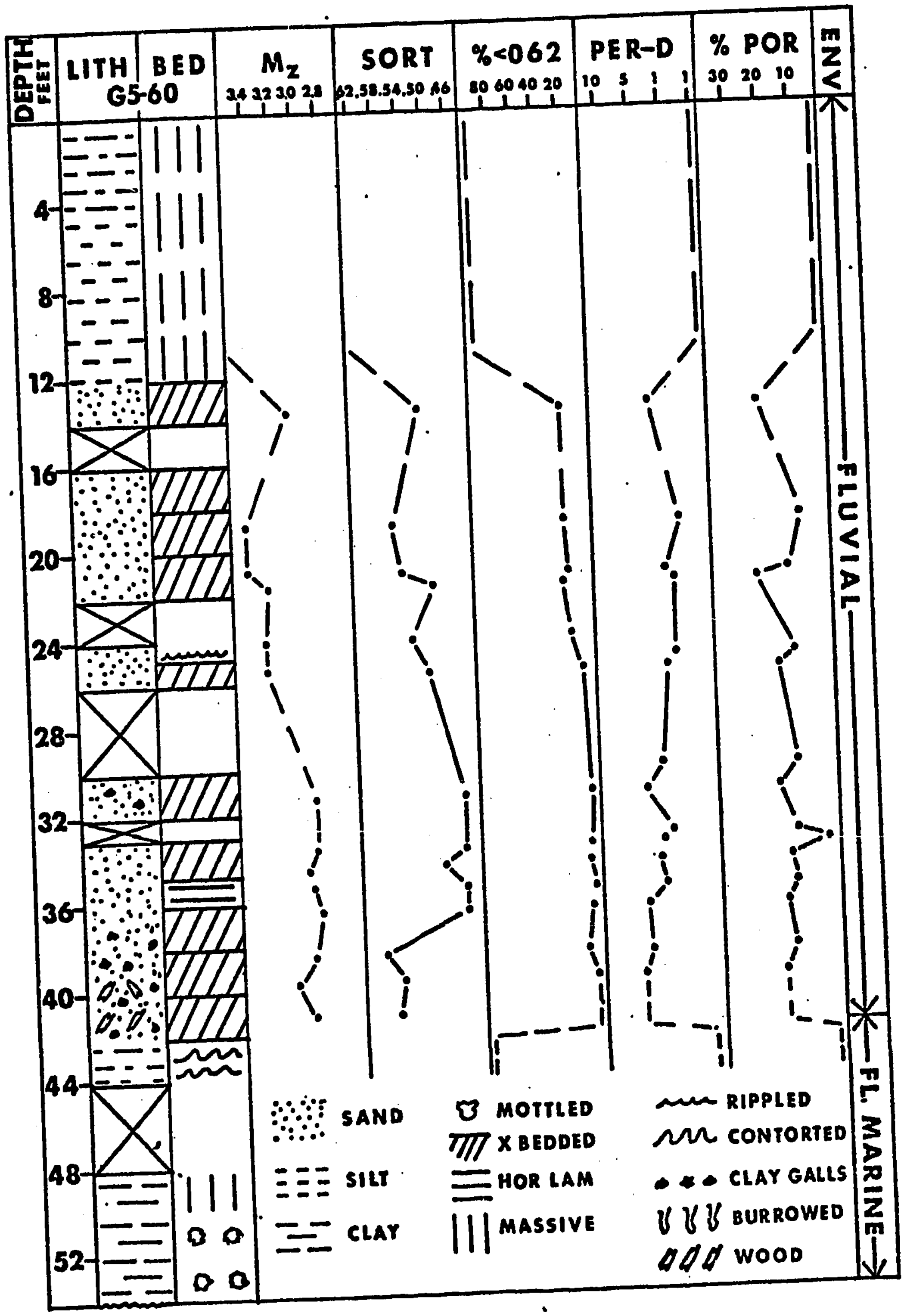


Fig. 30. Core characteristics--G5-60.

20-30 percent at the top. Overlying this sand interval is a 12 foot thick sequence of clay and silty clay characterized throughout by massive bedding. Underlying the upper sand member from a depth of 42 feet to the base of the core at 54 feet are silts and silty clays of the upper unit. These sediments have massive and contorted bedding.

G5-65. The previously discussed cores penetrated lithologies associated with the De la Gringa system. The core under discussion at this time as well as the core to be discussed next (F5-42) are both located in the Southern system. From the top of core G5-65 (Fig. 31) to a depth of 60 feet is what was previously stratigraphically defined as unit 3 of the upper group of the Southern system. This unit is predominantly sand from a depth of about 24 to 60 feet where clay gall conglomerates are present. Overlying this sand interval from a depth of about 24 feet to the top of the core are silts and clays. Bedding of this sand is predominantly cross-bedded in the lower 20 feet and massive to horizontally laminated in the upper part where the sand becomes somewhat silty in nature. Overlying the sand interval from a depth of about 24 feet to the top of the core are silts and clays with a thin interbedded sand lense between 8 and 12 feet. These silts and clays show predominantly massive bedding with mottling becoming conspicuous in the clays of the upper 8 feet. Median grain size of sand from 60 feet to 24 feet show a nice tendency to fine upward from 3.0Ø at the base to 3.5Ø at the top. The sand lense that occurs in silts and clays toward the top of the unit also shows a nice fining upward tendency from 2.8Ø at a depth of 14 feet to 3.4Ø at 8 feet. Sorting of the sands from 24-60 feet ranges from well (.48Ø) at the base to

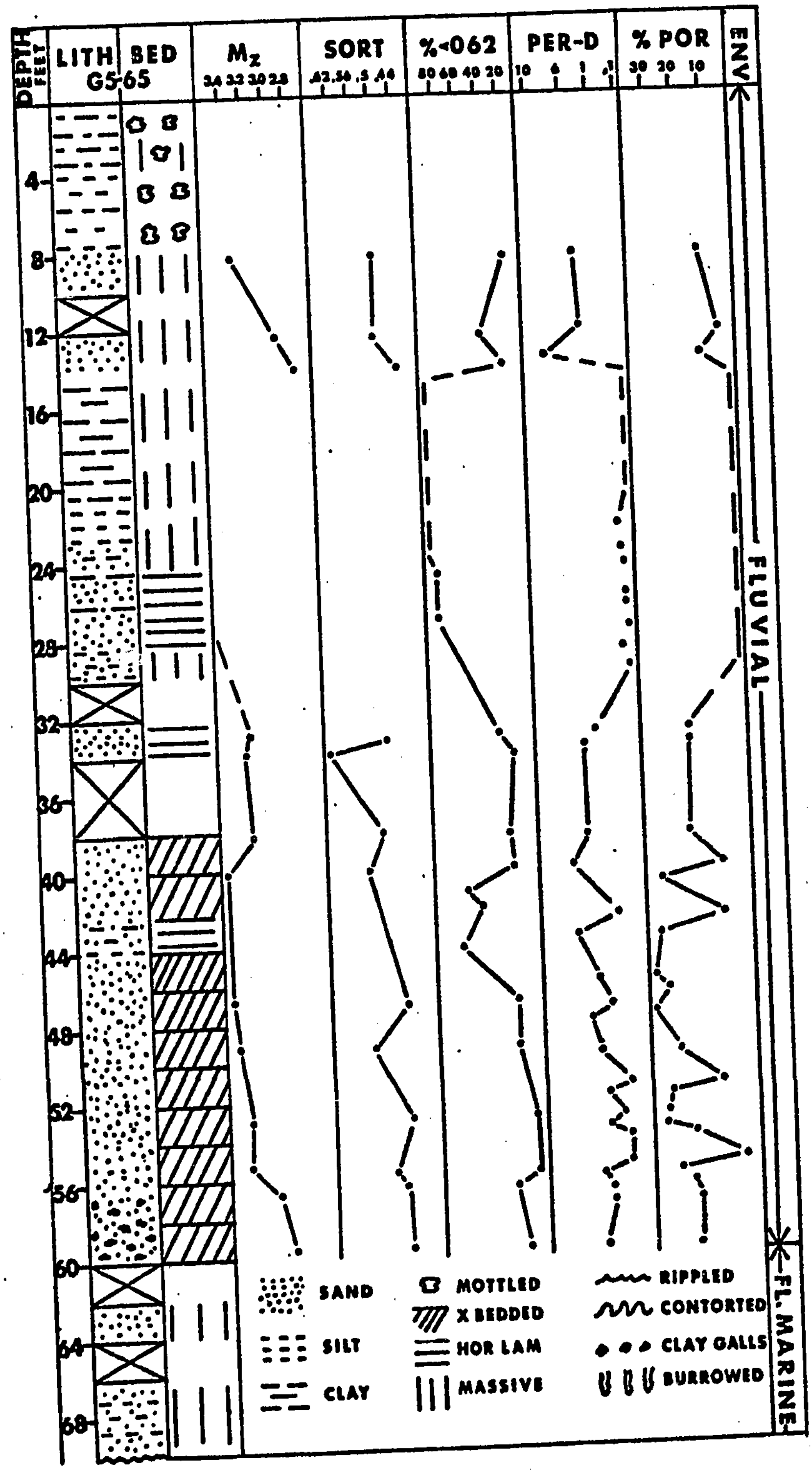


Fig. 31. Core characteristics--G5-65.

moderately well (.64Ø) near the top. Sorting of the upper sand lense is similar being well sorted near the bottom and moderately well sorted at the top. Percentage of silts and clays shows a general but consistent tendency to fine upward from about 20 percent at the base of the sands (60') to 40 percent (32') and eventually 80 percent where the sand becomes silty at the top (24').

Underlying the sands of unit 3 (Upper Group) are sand and sandy silts of the middle unit from a depth of 60 feet to the base of the core penetration at 70 feet. Data on these sands, which are predominantly massive bedded, are lacking mainly due to missing core.

F5-42. The upper part of core F5-42 (Fig. 32) from 32 feet to the top of the core penetrates what was previously stratigraphically defined as unit 4 of the upper group. The upper 18 feet of this core is represented by silts and clays which are massively bedded toward the bottom and mottled toward the top. Sands underlie these silts and clays from a depth of 18 feet to the base of the unit at 32 feet. These sands which contain clay gall conglomerates and wood fragments are mostly cross-bedded although some massively bedded sand does occur near the top of the unit. Median grain size of the unit fines upward from 2.6Ø units at the base to 3.5Ø units at the top. Sorting within the unit is variable although within the range of moderately well sorted sands. Sorting tends to be poorest where clay gall conglomerates are present and near the top of the member where the sand becomes silty. Percent of silt and clay in the sand is relatively low (20 percent) except near the top of the sand member where the percent "less

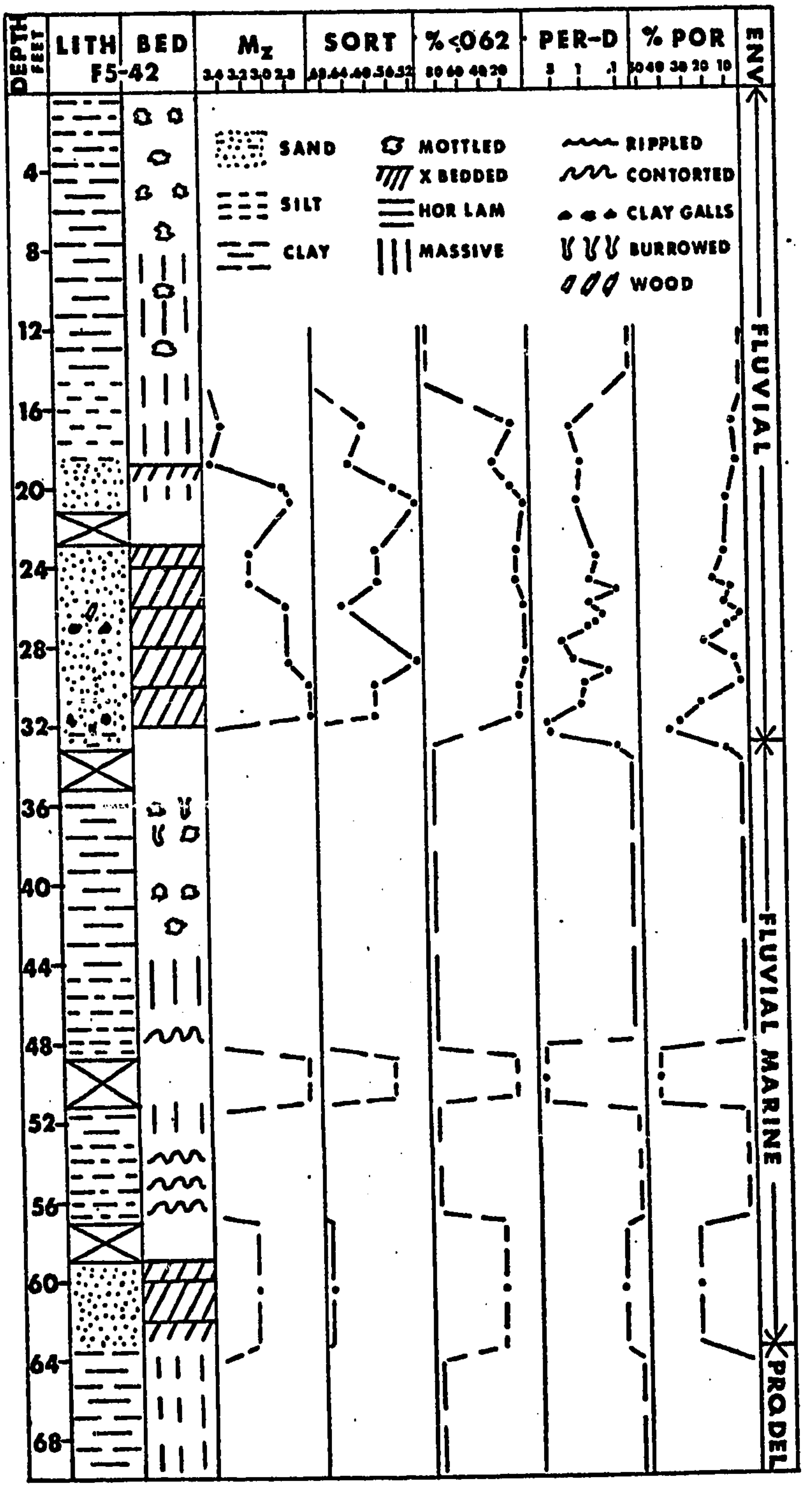


Fig. 32. Core characteristics--F5-42.

than 0.062 mm" approaches 40 percent.

Underlying unit 4 of the upper group from a depth of 32 feet to 64 feet is the middle unit as defined for the Southern system. This unit is predominantly silts and clay although 4 and 8 foot thick sand members occur at 48 and 56 feet. Silts and clays of this unit show a variety of bedding types ranging from contorted to massive to mottled and burrowed. Although textural data for the sands in the middle unit are sparse, it does indicate that the lower sands (56'-64') approach the upper limit of moderately well sorted range and contain about 40 percent silt and clay. Median grain size is about 3.4∅ units.

The lower unit in this core is only barely penetrated and occurs from 64 feet to the base of the core at 70 feet. Lithologically the unit is characterized by massively bedded clays.

Permeability and porosity

Technique. Samples for permeability and porosity were collected in aluminum cylinders which were 2.54 cm in diameter and 5.08 cm in length. The aluminum tubes were pushed into the sediment contained in place in split cores. Because the tubes were not completely filled with sediment the resulting space was filled with steel wool for the sample runs and length of sediment in the tube was appropriately corrected.

The coefficient of permeability, k , for the sample sediment was determined with a Soiltest Permeameter model K-670 which is applicable for performing either constant head of falling head permeability. Fine grained sediment required the falling head method. Water passing through the sample caused water in the standpipe to drop from h_1 to h_2 in a measured period of time.

Falling head coefficient of permeability values in cm were determined using the following equation (Curtis, 1971, p. 351).

$$k_{cm^2} = 2.3 \frac{d^2 uL}{D^2 pg \Delta t} \log \frac{h_1}{h_2}$$

where k_{cm^2} = permeability in cm^2

d = internal diameter of the measuring tube

D = internal diameter of the sample

u = viscosity in centipoises

L = length of specimen along flow path

p = density in cgs units

g = gravitational acceleration in cgs units

Δt = number of seconds between the observations of fluid height

h_1 = original hydraulic head

h_2 = final hydraulic head

The equivalency which serves to correct a permeability expressed in square centimeters to one in units of darcy is expressed by Curtis (1971, p. 349) as

$$k_{cm^2} = 9.869 \times 10^{-9} \text{ darcys}$$

Coarser grained sands and silts required the constant head method. The water which passed through the sample in a known period of time was measured and the following equation (modified from Peck *et al.*, p. 53, 1953) was used:

$$k_D = \frac{Q}{T \times A \times \frac{h}{L}}$$

where k_D = permeability in darcys

Q = discharge in cm^3

T = time of discharge in seconds

A = cross-section area of the sample

h = hydraulic head in atm

L = length of sample in direction of flow

An alternate equation proposed by Peck, et al., 1953, p. 54

$$k = \frac{QL}{hAT}$$

where k = permeability in cm/sec

Q = discharge in cm^3

L = length of sample in direction of flow

h = hydraulic head in cm

A = cross-section area of the sample

T = time of discharge

A conversion equation (Davis and DeWiest, 1966, p. 165) can be used to convert centimeter per second to darcy units. That conversion equation is as follows:

1 centimeter/sec = 1165.25 darcys

Either equation can be used with similar results. In comparisons done in this study it was found that results from both equations varied by less than 1 darcy which is acceptable concerning the many variables involved. For purposes of this study, the former equation using h in atm rather than cm was used to avoid using the approximate conversion equation of Davis and DeWiest (1966, p. 165).

Porosity was determined using the following equation:

$$\frac{V_t - V_{ts}}{V_t} \times 100 = \% \text{ Porosity}$$

where V_w = Volume of water

$V_w + V_{ts}$ = Volume of water with sediment added

V_{ts} = Volume of sediment in water

V_t = Volume sediment dry

Permeability and porosity were computed in samples from cores H5-88, G5-60 (De la Gringa system) and G5-65 and F5-42 (Southern system). Samples were taken from the sediment which was intact within the core tube. Samples were not taken from the three deep holes, H6-33, H5-40, and H5-90 because the samples within the core tube were not available--samples had been removed and bagged before shipment from the Gulf lab to the University of Cincinnati.

Permeability of sands from the upper member of the upper unit (De la Gringa system) range from a maximum of 5 darcys to a minimum of 1 darcy as shown in Fig. 30. These sands in core G5-60 have an average permeability of 2.4 darcys, a variance of 1.54, and a standard deviation of 1.24 (see Table IV). Porosity of sands in this interval ranges from a maximum of 25 percent to a minimum of about 5 percent. Average porosity is 14 percent, variance 22, and standard deviation 4.7. Both permeability and porosity show a general decrease in an upward direction

Permeability				Porosity			
Depth	X_i	X_{i-u}	$(X_{i-u})^2$	Depth	X_i	X_{i-u}	$(X_{i-u})^2$
12'	3	.6	.36	12'	22	8	64
	1	-1.4	1.96		10	-4	16
	2	- .4	.16		12	-2	4
	1	-1.4	1.96		25	11	121
	1	-1.4	1.96		12	-2	4
	2	- .4	.16		15	1	1
	3	.6	.36		12	-2	4
32'	5	2.6	6.76		18	4	16
	1	-1.4	1.96	32'	12	-2	4
	2	- .4	.16		5	-9	81
	2	- .4	.16		12	-2	4
	2	- .4	.16		12	-2	4
	3	- .6	.36		15	1	1
	3	- .6	.36		12	-2	4
40'	5	2.6	6.7	40'	15	1	1

$2.4 = \overline{m}$ $\qquad$ $13.9 = \overline{m}$

$1.54 = \sigma^2$ $\qquad$ $22 = \sigma^2$

$1.24 = \sigma$ $\qquad$ $4.7 = \sigma$

Table IV. Permeability and porosity data - Core G5-60. Permeability in darcys, porosity in percent.

as does mean grain size and sorting. This upward decrease in permeability and porosity coincides with an upward increase in percent silt and clay. Permeability varies from about 5 darcys at the base to 1 darcy at the top of the sand. Porosity varies from 25 percent at the base of the sand member to 10 percent at the top.

Permeability of sand of the lower member of the upper unit (Core H5-88, Fig. 29), ranges in permeability from 200 millidarcys to 8 darcys (see Table V). Mean permeability is 2.6 darcys, variance 4, and standard deviation 2. Porosity ranges from 8 percent to 45 percent. Average porosity is 24 percent, variance 76 and standard deviation 8.7. Both permeability and porosity show a general tendency to increase upward in contrast to sands of the overlying upper member (see G5-60 above). This increase in permeability and porosity toward the top of the sand member coincides with an upward increase in sorting, the very low amount of silt and clay (10-15 percent) in the upper part of the sand, and the tendency of the member to fine only slightly at the top. Permeability ranges from about 4 darcys at the base of the unit to 5-8 darcys at the top. Porosity ranges from 25 percent at the base to 35-40 percent in the upper part of the sand member.

Permeability and porosity of unit 3 (Upper Group-Southern system) are shown in Fig. 31. These sands range in permeability from 100 millidarcys to 7 darcys with a mean of 2.1 darcys, a variance of 3.7, and a standard deviation of 1.9 (see Table VI). Porosity varies from a maximum of 35 percent to a minimum of about 8-10 percent. Mean porosity is 21 percent with a variance of 54 and a standard deviation

Permeability				Porosity			
Depth	X_i	X_{i-u}	$(X_{i-u})^2$	Depth	X_i	X_{i-u}	$(X_{i-u})^2$
	3.0	.4	.16		45	21	441
	3.0	.4	.16	36'	30	6	36
36'	9.0	6.4	41.0		35	9	81
	5.0	2.4	5.76		20	-4	16
	3.0	.4	.16		28	4	16
	1.9	- .7	.49		30	6	36
	2.0	- .6	.36		25	1	1
	1.0	-1.6	2.56	44'	32	8	64
	2.0	- .6	.36		8	-16	256
	.3	-2.3	5.29		8	-16	256
	.2	-2.4	5.76		18	- 6	36
44'	2.0	- .6	.36		18	- 6	36
	.8	-1.8	3.24		30	6	36
	6.0	3.4	11.56		28	4	16
	1.7	-1.9	3.61		8	-16	256
	.2	-2.4	5.76	48'	20	4	16
	3.0	.4	.16		20	4	16
	2.0	- .6	.36		30	6	36
	3.0	.4	.16		22	-2	4
	4.0	1.4	1.96		20	-4	16
	1.0	-1.6	2.56		20	-4	16
	2.0	- .6	.36	52'	25	1	1
52'	3.0	.4	.16				

Table V. Permeability and porosity data - Core H5-88. Permeability in darcys, porosity in percent.

Table V con't

$2.6 = \bar{m}$	$24 = \bar{m}$
$4 = \sigma^2$	$76 = \sigma^2$
$2 = \sigma$	$8.7 = \sigma$

Permeability				Porosity			
Depth	X_i	X_{i-u}	$(X_{i-u})^2$	Depth	X_i	X_{i-u}	$(X_{i-u})^2$
	5.0	2.9	8.4		12	- 8.75	76.0
	4.0	1.9	3.6		8	-12.75	162.0
	7.0	4.9	2.4		12	- 8.75	76.56
20'	.2	-1.9	3.6		20	- .75	.56
	.2	-1.9	3.6		20	- .75	.56
	.2	-1.9	3.6		20	- .75	.56
	.1	-2.0	4.0	40'	12	- 8.75	76.5
	.1	-2.0	4.0		30	9.25	85.5
	.2	-1.9	3.6		12	- 8.75	76.5
	.1	2.0	4.0		30	9.25	85.0
	1.7	- .4	.16		31	10.25	105.0
	2.5	- .4	.16		30	9.25	85.0
	4.0	1.9	3.6		31	10.25	105.0
	6.0	-3.9	15.2	50'	22	1.25	1.56
40'	1.7	- .4	.16		15	- 5.75	33.0
	6.0	-3.9	15.2		25	4.25	18.0
	2.0	- .1	.01		28	7.25	52.5
	1.7	- .4	.16		30	9.25	85.0
	4.0	1.9	3.6		20	- .75	.56
	2.0	.9	.81		7	-13.75	189.0

Table VI. Permeability and porosity data - Core G5-65
Permeability in darcys, porosity in percent.

Table VI con't.

Permeability				Porosity			
Depth	X_i	X_{i-u}	$(X_{i-u})^2$	Depth	X_i	X_{i-u}	$(X_{i-u})^2$
	.51	-1.6	2.56		22	1.25	1.56
50'	2.0	- .1	.01		21	.25	.06
	1.0	-1.1	1.2		20	- .75	.56
	2.0	- .1	.01	60'	20	- .75	.56
	.58	-1.5	2.25				
	.51	-1.6	2.6		20.75 = $\bar{m}$		
	2.0	- .1	.01		54.0 = σ^2		
	1.5	- .6	.36		7.4 = σ		
	1.1	-1.0	1.0				
	1.1	-1.0	1.0				
60'	4.0	1.9	3.6				
	2.1 = m						
	3.7 = σ^2						
	1.9 = σ						

of 7.4. Both porosity and permeability of this unit show a definite tendency to decrease upward as does median grain size and sorting. This upward decrease in permeability and porosity agrees nicely with the upward increase in percent silt and clay. Permeability decreases from approximately 6 darcys at the base of the unit to 200 millidarcys at the top of the sand. Porosity decreases upward from 30 percent at the base to 5 percent at the top of the unit where sands have 60 percent silt and clay.

In core F5-42 (Fig. 32) permeability and porosity data are available for both unit 4 of the upper group as well as for the middle unit although data for the latter unit is sparse. Permeability of sands of the upper unit range from 700 millidarcys to 5 darcys with a mean of 1.7 darcys, a variance of 2.2, and a standard deviation of 1.5 (see Table VII). Porosity ranges from a maximum of 5 percent to an upper limit of 40 percent. Average porosity is 16 percent, variance 103, and standard deviation 10.1. Both permeability and porosity of the upper unit decrease upward as does the grain size and sorting. This upward decrease in permeability and porosity agrees with the upward increase in percent silt and clay from 10 percent at the base of the unit to 40 percent at the top. Permeability decreases from 5 darcys at the base of the sand to slightly more than 1 darcy at the top. Porosity decreases from 40 percent at the base of the unit to about 10 percent at the top.

Permeability and porosity data on sands of the middle unit are sparse but indicate that both increase upward in the unit. Permeability

Permeability

Depth	X_i	X_{i-u}	$(X_{i-u})^2$
	1.2	- .5	1.96
	1.0	- .7	.25
	2.0	- .3	.49
24'	1.2	- .5	.09
	1.0	- .7	.25
	.3	-1.4	.49
	1.0	- .7	.49
	.7	-1.0	1.0
	.9	- .8	.64
	1.0	- .7	.49
	4.0	2.3	5.3
	3.0	1.3	1.7
	.8	- .9	.81
	.9	- .8	.64
	1.0	- .7	.49
	5.2	3.5	12.2
32'	5.0	3.3	10.89
	.3	-1.4	1.9

$1.7 = \overline{m}$

$2.2 = \sigma^2$

$1.5 = \sigma$

Porosity

Depth	X_i	X_{i-u}	$(X_{i-u})^2$
	10	- 5.6	31.3
	7	- 8.6	73.9
	10	- 5.6	31.3
24'	15	.6	.36
	20	4.4	19.3
	10	- 5.6	31.3
	12	- 3.6	12.9
	5	-10.6	112.3
	12	- 3.6	12.9
	25	9.4	88.4
	10	- 5.6	31.3
	5	-10.6	112.3
	25	9.4	88.4
	35	19.4	376.3
32'	40	24.4	595.0
	10	- 5.6	31.3

$16 = \overline{m}$

$103 = \sigma^2$

$10.1 = \sigma$

Table VII. Permeability and porosity data - Core F5-42. Permeability in darcys, porosity in percent.

increase from 500 millidarcys at 62 feet to 7 darcys at 49 feet. Likewise porosity increase upward from 30 percent to 50 percent. This data is important because it infers that both median grain size and sorting (in which data are lacking) increase upward, which is important for environmental considerations.

Heavy Mineralogy. Twelve heavy mineral samples were collected representing all stratigraphic intervals defined in the study. Ten samples were collected from units associated with the De la Gringa system. Two were collected from the upper sand of the upper unit, 3 from the lower sand of the upper unit, 2 from sands of the lower unit, and 3 from sands of the basal unit. In addition, 2 samples were collected from units 3 and 4 of the upper group (Southern system). The heavy minerals were separated using standard bromoform techniques and were mounted in Monsanto Aroclor with a refractive index of 1.67. The results of the heavy mineral analysis are summarized in Table VIII. The dominant heavy minerals of all samples are basaltic hornblende and pyroxene. These two heavy minerals commonly compose 28 percent of the heavy mineral fraction. Opaque minerals are about equally represented and comprise 27.8 percent of the total heavy mineral suite. These opaques include hematite, magnetite, illmenite, pyrite, and leucoxene although no attempt was made to determine relative percentages of each species. Blue-green hornblende is common and comprises about 10 percent of the total percentage of heavies. The remaining 40 percent of the heavy minerals is comprised primarily of zircon (both rounded and euhedral--7.6 percent), garnet 5.3 percent, epidote 3.2 percent, and

UNIT		No. of Samples	Augite	Bas. Horn	Biotite	Corundum	Enstatite	Epidote	Garnet	Bl. Gr. Horn	Hypersthene	Kyonite	Muscovite	Opaque Black**	Rutile	Spodumene	Tourmaline	Zircon E/R*
Upper D.L.G.	Upper Sand	2	18.5	17	2.5	1	2	3	4	11.5	.5	2	.5	23.5	4.5	.5	3	3.5/2.5
Upper D.L.G.	Lower Sand	3	9.6	16.9	3	.3	.6	3	6	8	1.3	1	1	28.9	3.3	4.6	4.3	5.6/2.6
Lower D.L.G.		2	6.5	16.5	3.5	.5	1.5	4.5	7	9.5	1.5	1	.5	31.5	2	2	3	5/4
Unit 3 Southern System		1	11	18	3	2	2	3	6	15	3	3	2	22	1	1	2	2/4
Unit 4 Southern System		1	17	9	9	1	2	2	3	11	2	2	2	23	3	2	4	4/4
Basal Unit		3	11.6	16.6	3.3	.6	1	3.3	4.6	10.6	.6	1	1.6	31	3	3.3	2	4.5/2.6
Total by Percent		12	12.3	15.8	4.0	1.0	1.5	3.1	5.1	10.9	1.4	1.6	1.2	26.8	2.8	2.2	3	4.1/3.2

* Euhedral/Rounded

** hematite, magnetite, illmenite, pyrite, Leucexene

Table VIII. Summary of heavy mineral data.

tourmaline 3.1 percent. Rutile and spodumene in approximately equal amounts comprise 5.3 percent while muscovite, kyanite, hypersthene, enstatite and corundum average about 1 percent and make up 5.8 percent of the suite. It is significant to note that there are no differences in heavy mineral species (other than minor percentage variations) regardless of depth or stratigraphic interval. This should be expected as the time-stratigraphic interval studied reflects a short period of geologic time (approximately 10,000 years) allowing essentially no change in provenance.

Because the Rio Grande river (and its Holocene distributaries) traverses a basin containing varied rock types (see geologic setting) it is not unusual to get the multi-variety suite of heavy minerals discussed above. This group of heavy minerals reflects the following provenance rock types (after Krumbien et al., 1963, p. 140).

MAFIC AND ULTRAMAFIC

Augite
Hypersthene
Rutile
Basaltic Hornblende
Ilmenite
Leucoxene

METAMORPHIC

Garnet
Blue-green Hornblende
Kyanite
Sillimanite
Epidote
Corundum

SILICEOUS AND INTERMEDIATE IGNEOUS

Biotite
Muscovite
Zircon (Euhedral)

VOLCANIC

Basaltic Hornblende

REWORKED SEDIMENTARY

Opaques (Magnetite & Hematite)
Zircon (rounded)
Rutile
Tourmaline

This organization of heavy mineral species reflect the source area materials which contribute sediment to the Holocene Rio Grande river. Those materials include Tertiary volcanics, intrusives, and andesite and rhyloite lava flows, Archean schists, Tertiary granites, Lower Permian sedimentary formations (sandstone and carbonate), and Cretaceous, Cenozoic, and Quaternary deposits.

Both Bullard (1942, p. 1027) and Lohse (1958, p. 60) agree with this investigation that basaltic hornblende and pyroxene are the dominant heavy minerals associated with the Rio Grande river deposition.

A summary of heavy mineral percentages by stratigraphic interval is shown in Table VIII.

Petrography

Techniques. For petrographic analysis 37 samples were collected from the 7 cores in such a fashion that all environments were represented. The samples, which were unconsolidated, were split to obtain an approximately 25-30 gram increment. This portion was then placed in a plastic vial and impregnated with epoxy. Thin sections were then cut from the impregnated samples by standard thin-sectioning techniques. The resulting thin section was then stained for plagiocalse and orthoclase feldspar using Potassium Rhodiaonate and sodium colbaltinitrite (Friedman, 1971, p. 523). Thin sections were point counted (200 counts/slide) and photographed using a Zeiss Photomicroscope II.

Classification. The classification of sandstones since Fischer's first usage of a triangular diagram (Pettijohn et al., 1972, p. 156) for sandstone classification in 1933 has, as many other classifications, been expanded and condensed. There are sandstone classifications based on (1) mineralogy, (2) texture and mineralogy, and (3) structure, texture, and mineralogy. There are classifications ranging from the simple and useful (Kyrnine, 1948; Folk, 1954; McBride, 1963; and Pettijohn, 1957) to the awkward and cumberson (Shutov, 1967 and Teodorovich, 1967). Teodorovich is especially fascinating in that his classification has 18 subdivisions of the triangle in which addition of pyroclastic material requires tetrahedral representation and 11 additional subclasses.

Classifications that receive current attention are those of Pettijohn (1954, 1957), McBride (1963), Folk (1968), and Pettijohn et al. (1972). The classification used by Pettijohn et al. (1972) is nicely summarized diagramatically (Fig. 5-3, p. 158). Basically it uses only framework grains of quartz, feldspar, and rock fragments of sand size. As a secondary criterion, the classification distinguishes between the "clean" sands or arenites--sands with less than 15 percent matrix--and the "dirty" sands or wackes--those with more than 15 percent matrix. However, the classification of modern sands where the quantitative estimation of clay "matrix" is impossible makes that classification somewhat less than useful. In addition, Blatt et al. (1972, p. 313) concur that "the disadvantage of basing the core of the rock name on the amount of clay are great, in view of all the different factors that may be responsible for the presence of "matrix" (i.e. diagenesis, squashed rock fragments) and particularly the difficulty of achieving an accurate estimate of its abundance. In addition, the significance of a given fraction of clay is related to the mean grain size of the sandstone and is not the same for fine as for coarse sands."

Blatt et al. (p. 313) summarize by saying that an acceptable compromise, if not the best of all possible choices, is achieved by adopting as the end members of a mineralogically oriented sandstone classification (a) quartz plus chert, (b) feldspars, and (c) all rock fragments other than chert and polycrystalline quartz grains, i.e. all unstable or "labile" rock fragments. They suggest that "immature" be used instead of the term "wacke" or "graywacke" to describe a sandstone containing a clay matrix.

The same general reasoning is used by McBride (1963) and Folk (1968), who have erected classificatory schemes without the fourth component (clay matrix). Both Folk and McBride feel that the term "graywacke" should be discarded from any place in a quantitative mineralogically oriented classification and should revert to a status of a field classification--essentially a "very hard, ugly, dirty, dark rock that's hard to describe in the field." This also avoids the environmental inference of graywacke=turbidite. Both McBride (1963) and Folk (1968) have proposed triangular classifications that are based on a non-clay end member scheme. Their diagrams differ only slightly in field boundaries--their reasoning being the same. Classificatory designations used in the following petrographic descriptions is after Folk (1968, p. 124).

For purposes of grouping and discussion, the petrography of the sandstones is discussed in accordance with the appropriate stratigraphic unit.

Basal Unit. Six samples were point counted from the basal unit which underlies both the De la Gringa and Southern systems. The samples were taken from the 150 foot cores which penetrate the De la Gringa system.

Typically the sands from this basal unit are well-moderately well sorted (.35-.6Ø) subangular to subrounded fine grained lithic arkoses (see Figs. 33, 34, and 35). Composite results from point counts of all thin-sections are as follows:

	Qtz			Feld			Rock Frag			
Sample*	Mono	Poly	Chert	Ortho	Micro	Plag	SRF	VRF	Carb	Anhy
RG1	50	10	3	20	--	10	3	3	1	6
RG2	45	10	2	20	tr	13	4	3	1	2
RG12	56	4	5	13	tr	7	2	9	1	3
RG13	47	6	2	18	--	9	7	7	4	-
RG14	53	5	2	13	1	11	7	5	2	1
RG20	48	7	3	8	tr	12	10	2	4	5
Total %	49.6	7	2.8	15.3	tr	10.3	5.5	4.6	2.1	2.8

SRF = sed. rock fragments exclusive of carbonate

VRF = volcanic rock fragments

Table IX. Summary, petrographic data - basal unit.

*Sample numbers in relation to depth are shown in Table X.

Thin Section Number	Core	Depth (feet)
1	H5-90	105-106
2	H5-90	114.5-115.0
3	H5-90	60.0-61.0
4	H5-90	67.0-68.0
5	H5-90	86.0-86.5
6	H5-90	85.0-85 3/7
7	H5-90	58.5-59.0
8	H5-90	66.0-66.5
9	H5-90	40.0-40.5
10	H5-90	50.0-50.5
11	H5-90	34.5-35.5
12	H6-33	123.0-124.0
13	H6-33	130.0-131.0
14	H6-33	114.0-114.5
15	H6-33	36.0-35.0
16	H5-40	28.5-29.0
17	H5-40	25.0-25.5
18	H5-40	13.5-14.5
19	H5-40	47.5-48.0
20	H5-40	122.0-122.5
21	G5-65	13.5
22	G5-65	33.0
23	G5-65	56.0

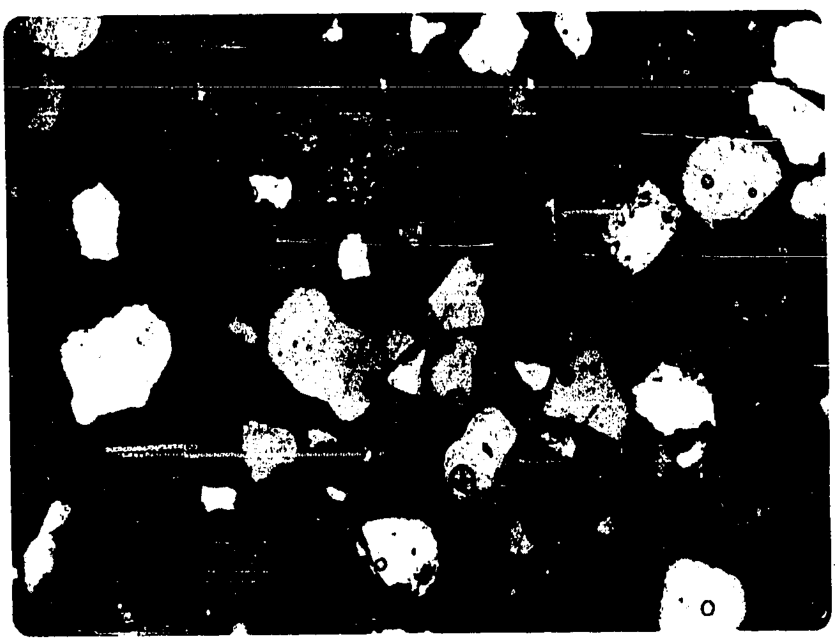
Table X. Thin section sample locations

Table X con't. Thin section sample locations.

Thin Section Number	Core	Depth (feet)
24	G5-65	49.0
25	H5-88	43.5
26	G5-65	60.0
27	H5-88	49.5
28	H5-88	35.5
29	G5-60	18-20
30	G5-60	24.0
31	G5-60	34.5
32	F5-42	19-21
33	G5-60	38.5
34	F5-42	26.0
35	F5-42	28.75
36	F5-42	61.0
37	H6-33	26.0-26.5

.1 mm

Fig. 33. Well-moderately well sorted subangular to subrounded fine grained lithic arkose - Basal unit Core H6-33, 123-124'. Note lack of clay.



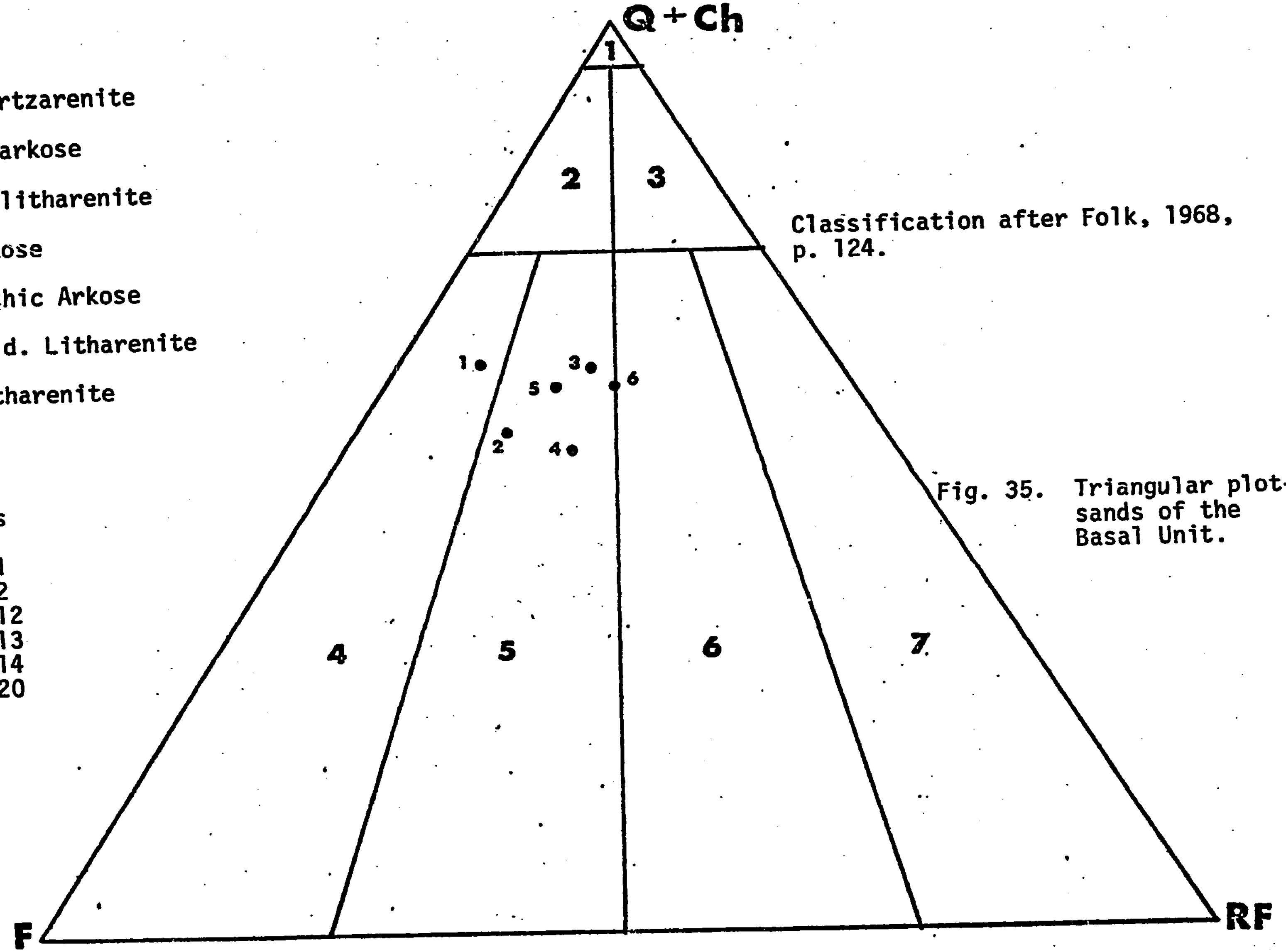
.1 mm

Fig. 34. Well-moderately well sorted subangular to subrounded fine grained lithic arkose - Basal unit Core H6-33, 123-124'.

1. Quartzarenite
2. Subarkose
3. Sublitharenite
4. Arkose
5. Lithic Arkose
6. Feld. Litharenite
7. Litharenite

Samples

1. RG1
2. RG2
3. RG12
4. RG13
5. RG14
6. RG20



Classification after Folk, 1968, p. 124.

Fig. 35. Triangular plot-sands of the Basal Unit.

Texture. Because these sands are unconsolidated, impregnated sands, fabric (grain to grain relations, grain orientation, cementation, and porosity) was not considered.

Quartz grains are of two sizes. Larger grains (.15 mm) vary from subangular to subrounded with an occassional large grain being rounded-well rounded. Average visual roundness of large grains is 3.2 (Pettijohn et al., 1972, p. 586). Smaller quartz grains (.05-.07 mm) vary from angular to subangular (roundness 2.5). Composite quartz has a roundness of approximately 3.0 and is in the same general range as the larger unit quartz grains. Both orthoclase and plagioclase are of approximately equal size (.1 mm) and vary from angular to subangular. There is a tendency for the plagioclase feldspar to be slightly more angular than the orthoclase probably because of breakage along twinning planes.

Without taking into consideration matrix, sands of this unit vary from mature to submature based on sorting and roundness (Pettijohn et al., 1972, p. 588).

Terrigenous detritus

(a) Quartz is dominantly mono-crystalline, showing both undulose and non-undolose extinction. Overgrowths are not unusual especially on the rounded quartz grains. A few composite grains contain more than 6 crystals per grain which may suggest a metamorphic origin. Quartz (especially the monocrystalline variety) appears highly fractured. Inclusions of what appears to be rutile and tourmaline are not uncommon.

(b) Feldspars include orthoclase (dominant) and plagioclase with only a trace of microcline. Some feldspars, both orthoclase and plagioclase, have inclusions of tiny flakes of sericite or illite perhaps indicating hydrothermal activity (Folk, 1968, p. 84). In some appearances both orthoclase and plagioclase have a fresh appearance and do not appear to have been subjected to long or intense weathering. Like quartz, fracturing in feldspar grains is not uncommon.

(c) Rock fragments include sedimentary (siltstone and carbonate) and volcanic. All types are commonly well rounded. Volcanic fragments consist of a dark (glassy?) groundmass and commonly contain microlites of feldspar and quartz.

(d) Mica is present only in trace amounts and consists of muscovite and biotite, the former occurring in shreds and plates.

(e) Heavy minerals of the basal unit were discussed previously and indicate a varied source (acid igneous, volcanic, metamorphic, mafic and ultra-mafic, and sedimentary). Petrographic work adds little to this aspect except that some composite quartz may indicate a metamorphic source. In addition, Folk (1968, p. 71) suggests that fractured quartz may be derived from pegmatites hydrothermal, and sedimentary vein fillings--all of which are in agreement with the heavy mineral diagnosis of source area rock type.

Chemical constituents

(a) Anhydrite is present in low percentages and occurs as dis-associated shreds and plates intertwinned with the surrounding grains. It is thought that this anhydrite is secondary after gypsum which formed in trapped pore waters after burial--perhaps caused by the breach of reflux of fresh water in a semi-arid environment.

(b) Authigenic quartz is present as secondary overgrowths deposited in optical continuity with detrital grains. This authigenic quartz is distinguishable where clay films are present between it and the grain. It is reasonable to believe that cathode-luminescence would delineate perhaps more overgrowths than are noticeable in transmitted light. These overgrowths (because of their abraded nature) are thought to have formed in the source area rather than at the site of deposition.

Lower Unit. Seven samples were collected from the lower unit (6 from the De la Gringa system and 1 from the Southern system). Typically sands from the lower unit are moderately-poorly sorted (1.6-2.2Ø) subangular to subrounded very fine grained lithic arkoses (see Figs. 36 and 37).

Composite results from point counts of all thin sections of this unit are shown in Table XI (see also Fig. 38). The description of a typical lower unit sand is discussed below.

Texture. Quartz grains are of two sizes. Larger grains (.1 mm) vary from subangular to subrounded with an occasional large grain being rounded-well rounded. Average visual roundness of larger grains is 3.2 (Pettijohn *et al*., 1972, p. 586). Smaller quartz grains (.03 mm) vary from angular to subangular (roundness 2.5). Composite quartz has a roundness of 3.4 and is in the same general size range as the larger unit quartz grains. Feldspars vary from subangular to subrounded with

		Qtz			Feld		Rock Fragments						
Sample	Mono	Poly	Chert	Orth	Micro	Plag	SRF	VRF	MRF*	Carb	Anhy	Ost	Foram
RG3	36	8	3	14	--	14	4	3	-	7	8	-	-
RG4	59	6	2	11	tr	12	3	-	1	2	2	-	2
RG5	44	5	-	17	--	12	6	2	-	4	9	tr	1
RG6	48	5	1	7	2	11	3	4	-	6	11	1	1
RG7	51	7	1	10	tr	11	tr	5	-	11	2	-	2
RG8	51	2	3	9	2	13	4	9	-	5	2	-	-
RG30	41	12	1	76	-	9	5	3	-	3	10	-	2
Total %	47.1	6.42	1.5	12	.5	11.7	3.5	3.7	tr	5.4	6.3	tr	1.0

Lower Unit

*MRF = Metamorphic rock fragments

Table XI. Summary, petrographic data - lower unit

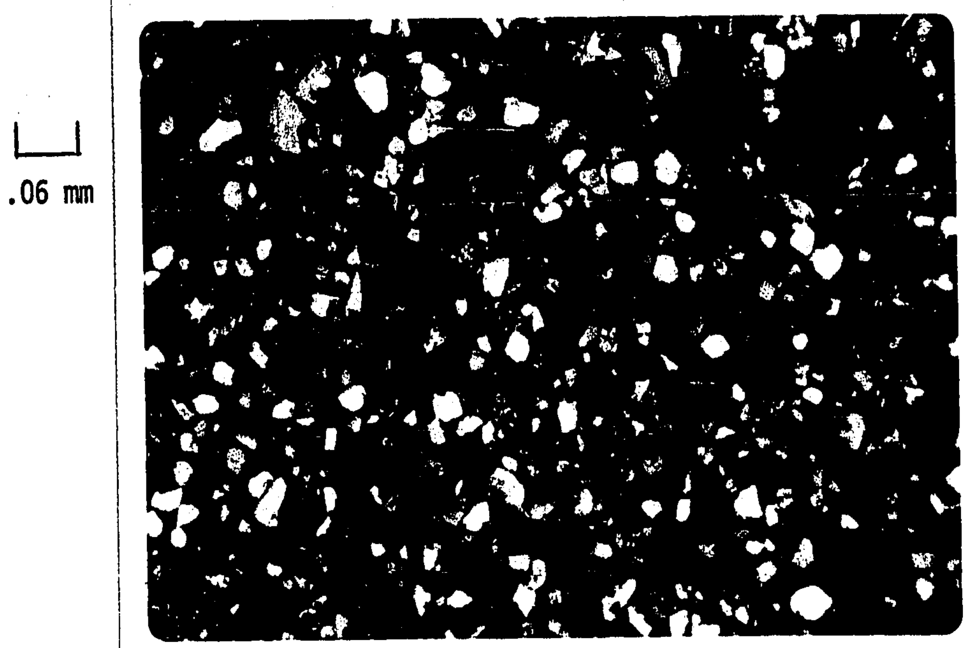


Fig. 36. Moderately-poorly sorted subangular to subrounded very fine grained lithic arkose - Lower unit Core H5-90, 85-85 3/4'. Note "dirty" appearance caused by clay material.

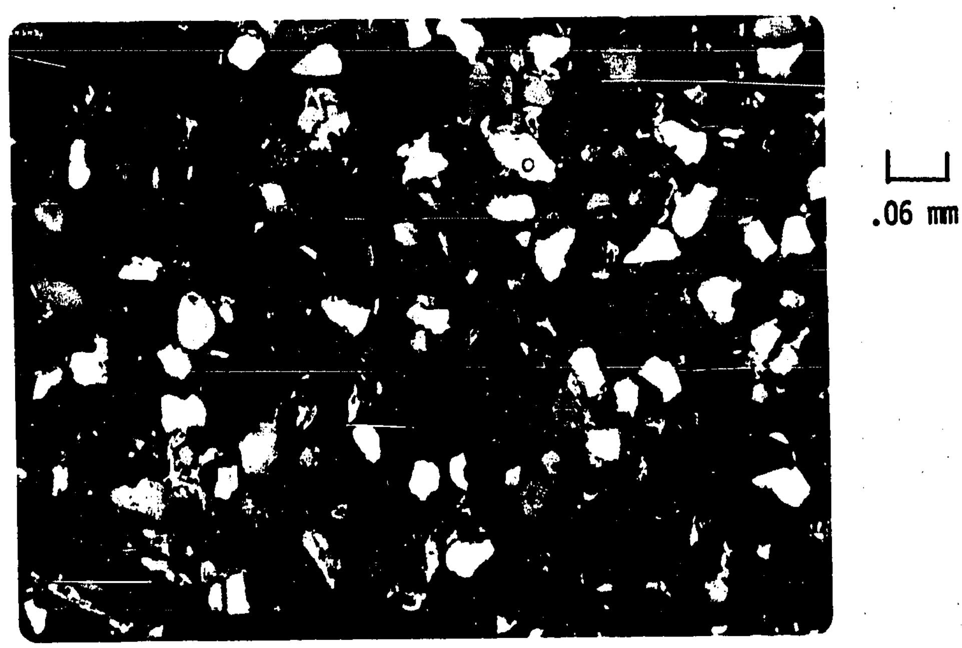
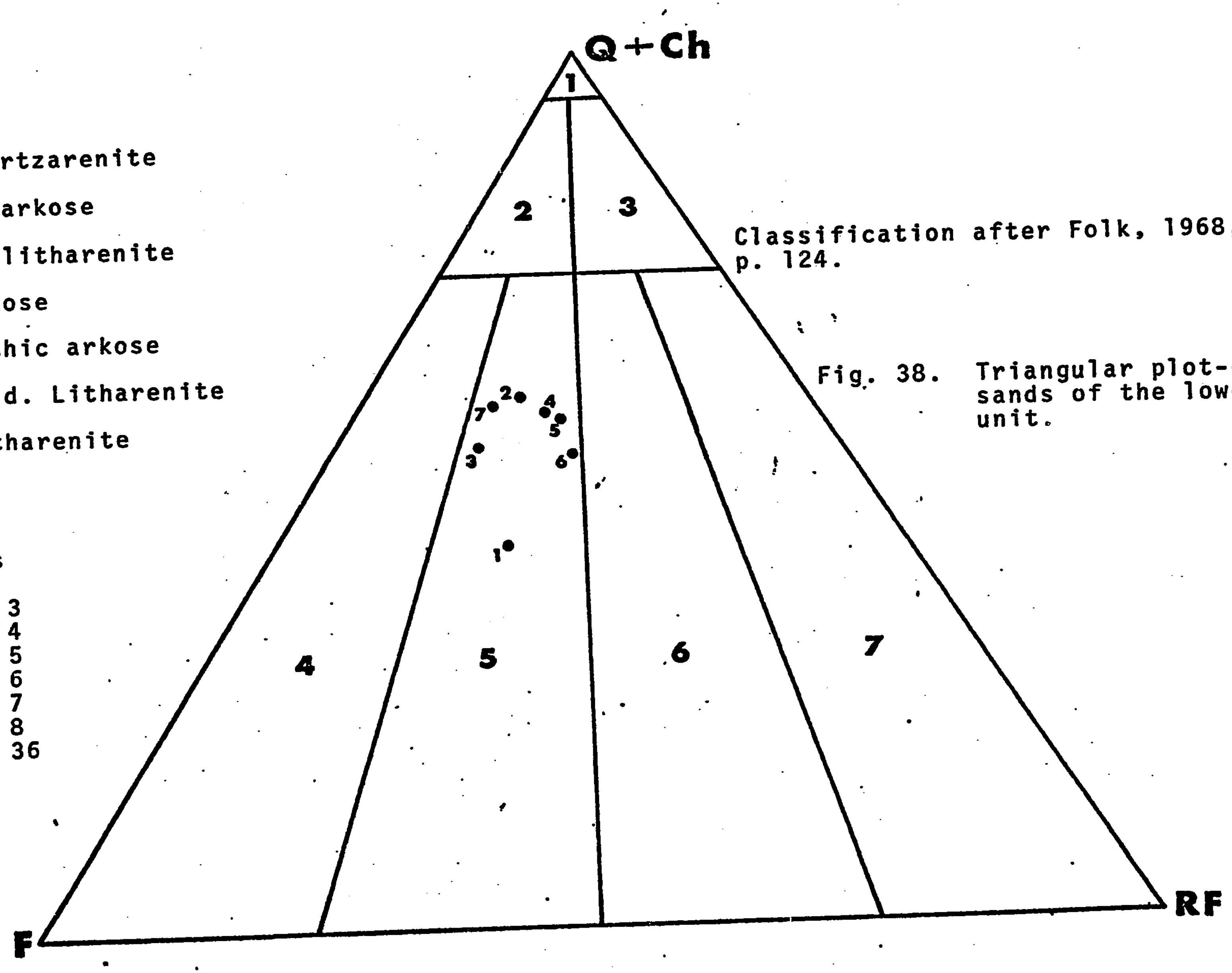


Fig. 37. Moderately-poorly sorted subangular to subrounded fine grained lithic arkose - Lower unit Core H5-90, 67-68'.

1. Quartzarenite
2. Subarkose
3. Sublitharenite
4. Arkose
5. Lithic arkose
6. Feld. Litharenite
7. Litharenite

Samples

1. RG 3
2. RG 4
3. RG 5
4. RG 6
5. RG 7
6. RG 8
7. RG 36



Classification after Folk, 1968, p. 124.

Fig. 38. Triangular plot--sands of the lower unit.

an average visual roundness of 3.0. Orthoclase feldspars has an average size approaching that of the larger quartz grains (approximately .1 mm). Size range of plagioclase feldspar is variable ranging from 0.3-.1 mm.

This sandstone is submature based on the poor sorting (Pettijohn et al., 1972, p. 588). Percent silt and clay determined from textural studies averages 30-40 percent and is in agreement with the textural maturity as inferred from sorting.

Terrigenous detritus

(a) Quartz is dominantly mono-crystalline, showing both undulose and non-undulose extinction composite quartz typically contains very fine crystals (.03 mm). Overgrowths, which are usually abraded, are a common feature of the mono-crystalline quartz as is fracturing. Rounded chert is present in only very small (approximately 1 percent) amounts.

(b) Feldspars include orthoclase, plagioclase, and trace amounts of microcline. In most instances, both orthoclase and plagioclase appear fresh and probably have not been subjected to long or intense weathering. Some feldspars of the orthoclase and plagioclase varieties have inclusions of tiny flakes of sericite or illite. Kaolinization, however, was not noted.

(c) Rock fragments include sedimentary (carbonate, coarse siltstone, and sandstone), volcanic, and a trace of metamorphic. These fragments are typically well-rounded and in the case of siltstone and sandstone fragments have a clay "matrix".

(d) Mica is present in trace amounts and consists of muscovite and biotite. The muscovite typically occurs as elongate shreds and plates.

(e) Heavy minerals were discussed under a previous section, although the fractured quartz grains and inclusions of illite and sericite in the feldspars adds emphasis to the acid igneous source contributions noted previously. The trace of metamorphic rock fragments is indicative of the metamorphic source suggested by the heavy minerals.

(f) Clay minerals were not point-counted or included as matrix because of the impregnation techniques used for making the thin sections. Relatively speaking, samples from this lower unit contain a much higher percentage of clays than those of the basal unit probably averaging 15-20 percent as compared to 5 percent in the basal unit. Clay films are common surrounding and coating both quartz and feldspar. Clay minerals as determined by X-ray diffraction of the less than 2 micron fraction are montmorillonite, kaolinite, and illite.

Chemical constituents

Anhydrite and quartz overgrowths as discussed in relation to the basal sands are the only authigenic constituents.

Organic constituents

Trace amounts of ostracods and a low percentage of forams are occasionally encountered throughout samples of this lower unit.

Lower Sand-Upper Unit. Nine samples were collected from the lower sand of the upper unit from cores associated with the De la

Gringa system (H6-33, H5-40, H5-90, and H5-88). Typically sand from the lower sand member are moderately well sorted (.5-.71Ø) fine grained lithic arkoses (66 percent) and feldspathic litharenite (33 percent) (see Fig. 40).

Composite results from point counts of all nine thin sections of the sand member are shown in Table XII (see also Fig. 39).

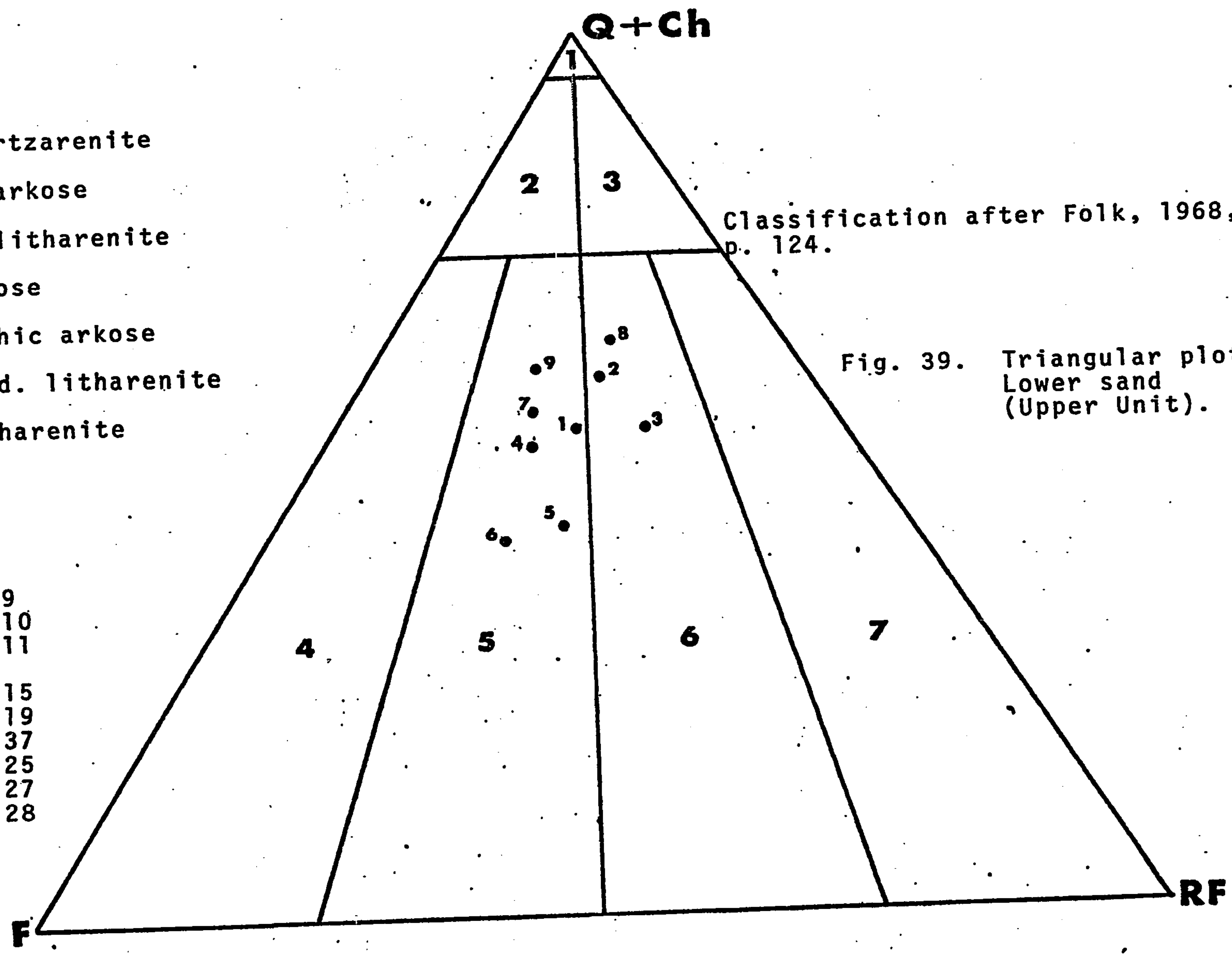
Texture. Quartz grains are of two sizes. Larger grains (.05-.08 mm) vary from subangular to subrounded with an occasional large grain being rounded-well rounded. Average visual roundness of the larger grains is 3.0 (Pettijohn et al., 1972, p. 586). Smaller quartz (.03-.05 mm) vary from angular to subangular (roundness 2.7). Composite quartz is composed of very fine crystals and ranges from small (.03-.05) grains to grains comparable in size to the larger quartz grains (approximately 1.0 mm). Roundness varies from subangular to subrounded with the larger grains being better rounded. Orthoclase feldspars have a size range comparable to that of the larger quartz grains while the plagioclase feldspars tend to be large (0.5-.1 mm) and small (< .05 mm). Roundness of the orthoclase feldspars varies from subangular to subrounded for the orthoclase while the plagioclase is less well rounded especially in the smaller grain sizes. The angularity of the smaller plagioclase grains is probably caused by the breaking of feldspar along twinning planes.

This sandstone is submature based on its sorting (Pettijohn et al. 1972, p. 588).

1. Quartzarenite
2. Subarkose
3. Sublitharenite
4. Arkose
5. Lithic arkose
6. Feld. litharenite
7. Litharenite

Samples

1. RG 9
2. RG 10
3. RG 11
4. RG 15
5. RG 19
6. RG 37
7. RG 25
8. RG 27
9. RG 28



Classification after Folk, 1968, p. 124.

Fig. 39. Triangular plot-- Lower sand (Upper Unit).

Fig. 40. Moderately well sorted fine grained lithic arkose. Lower Sand (upper unit). Core H5-90, 34.5-35.5'.

Sample	Qtz Mono	Qtz Poly	Chert	Orth	Feld Micro	Plag	Rock Fragments SRF	VRF	MRF	Carb	Anhy	Ost	Foram
RG9	49	4	-	9	-	13	2	7	-	11	4	-	1
RG10	51	5	1	7	tr	9	4	5	-	9	9	-	-
RG11	47	5	2	7	-	9	7	7	-	11	3	-	2
RG15	48	3	1	13	-	14	5	4	-	7	5	-	-
RG19	35	6	1	15	-	14	7	6	-	11	3	-	2
RG37	35	7	-	15	-	17	3	3	-	12	6	-	2
RG25	43	12	3	14	1	10	5	3	-	5	2	-	2
RG27	55	9	2	8	1	6	9	4	-	5	-	-	1
RG28	42	15	1	9	tr	12	3	3	-	7	6	-	2
Total %	45.6	13	1.2	10.7	tr	11.5	5.0	4.6	-	8.6	-	-	1.3

Lower Sand - Upper Unit

Table XII. Summary, petrographic data - lower sand, upper unit.

Terrigenous detritus

(a) Quartz is dominantly mono-crystalline showing both undulose and non-undulose extinction. An occasional grain is slightly embayed (typical of volcanic quartz). Composite quartz is extremely fine-grained and usually subrounded to rounded. Chert is present in very low percentages and is occasionally difficult to distinguish from composite quartz. Overgrowths (usually abraded) are a common constituent of the mono-crystalline quartz grains. Most of the quartz grains show some degree of fracturing.

(b) Feldspars include orthoclase and plagioclase with only trace amounts of microcline. Orthoclase and plagioclase occur in nearly equal amounts with plagioclase in some cases showing a slightly higher percentage.

(c) Rock fragments (as in other units) include sedimentary (carbonate, siltstone, and sandstone) and volcanic. The fragments are usually well rounded and in the case of siltstone and sandstone contain quartz grains in a clay matrix. The volcanic fragments usually have microlites of feldspar and quartz in a glassy groundmass.

(d) Mica is present in trace amounts and consists of muscovite and biotite.

(e) Heavy mineral analysis of this sand member were discussed previously and show no variation as compared to other stratigraphic levels. Embayed quartz found in the member agrees with the heavy mineral analysis indicating the presence of volcanic material in the source area.

(f) Clay minerals as indicated by X-ray diffraction of the less than 2 micron fraction are montmorillonite (dominant) followed by minor amounts of kaolinite and illite. Although clay minerals (as matrix) were not measured in the thin sections of this interval, textural analysis shows that sands of the interval have somewhat more silt and clay (15 percent) than sands of the basal unit (5 percent) and considerably less than sands of the lower unit (25-40 percent).

Authigenic Constituents

Authigenic constituents consist of anhydrite and quartz overgrowths as discussed for sands of the basal unit.

Organic Constituents

Minor amounts of forams are present in this lower sand unit. Approximately 1/3 of the forams noted in thin section and in picked samples are reworked Cretaceous varieties.

Upper sand, Upper unit (De la Gringa) and Upper Group (Southern system). Fifteen samples were collected from sands associated with the upper unit and upper group of these two prograding systems. Seven samples were taken from the upper sand member of the upper unit of the De la Gringa system. Three were taken from core H5-40 and four from G5-60. In the Southern system, 8 samples were taken, 5 from G5-65 (Unit 3 upper group) and 3 from F5-42 (Unit 4 upper group).

The composite summary of petrographic analyses of these 15 samples is shown in Table XIII (see also Fig. 45).

Eighty-six percent of the samples are classified as lithic arkoses, the remaining percentage are feldspathic litharenites.

Sands from the upper sand member (Upper unit De la Gringa) and

		Qtz			Feld			Rock Fragments					
Sample	Mono	Poly	Chert	Orth	Micro	Plag	SRF	VRF	Carb	MRF	Anhy	Ost	Foram
RG16	29	11	2	14	1	17	6	3	13	-	4	-	-
RG17	42	4	3	13	1	15	6	5	7	-	2	-	2
RG18	47	4	1	14	-	10	6	5	9	-	2	-	2
RG21	43	13	-	12	-	16	5	3	5	-	0	tr	1
RG22	53	5	1	13	-	10	3	3	12	-	0	-	-
RG23	47	8	2	6	-	8	4	3	10	-	7	1	-
RG24	42	14	2	8	2	10	4	4	8	-	3	1	1
RG26	40	15	2	9	1	11	7	5	2	-	6	-	2
RG29	44	16	tr	7	tr	10	3	2	10	-	7	tr	1
RG30	50	14	1	7	tr	5	6	5	7	-	1	-	4
RG31	45	9	1	8	1	13	8	2	8	-	-	2	3
RG33	40	18	1	13	2	12	4	3	4	-	-	tr	3
RG32	50	6	2	12	2	10	6	4	6	-	-	tr	2
RG34	37	12	2	14	1	14	4	4	4	-	3	1	4
RG35	42	11	1	16	-	13	4	4	3	-	3	-	3
Total %	44.2	10.6	1.5	11.0	.7	11.6	5.0	3.6	7.2	-	2.7	tr	1.8

Table XIII. Summary, petrographic data - upper sand (upper unit), upper group.

the upper units (Upper Group-Southern system) are typically moderately well sorted (.5-.7∅) fine grained lithic arkoses and feldspathic litharenites (see Figs. 41, 42, 43 and 44). Triangular plot of petrographic data is shown in Fig. 45.

The following petrographic analysis is from a typical sand associated with these samples.

Texture. Quartz grains are of two sizes. Larger grains (.07-.19 mm) vary from subangular to subrounded with an occasional large grain being rounded-well rounded. Average visual roundness of larger grains is 3.0 (Pettijohn _et al._, 1972, p. 586). Smaller quartz grains (.04-.07 mm) vary from angular to subangular (roundness of 2.3) to subrounded (3.2). Composite quartz has variable roundness (2.5-3.2) and is generally in the same size range as the larger quartz. Feldspars range from subangular to subrounded with an average visual roundness of 2.7.

This sandstone is submature because of its sorting (Pettijohn _et al._, 1972, p. 588).

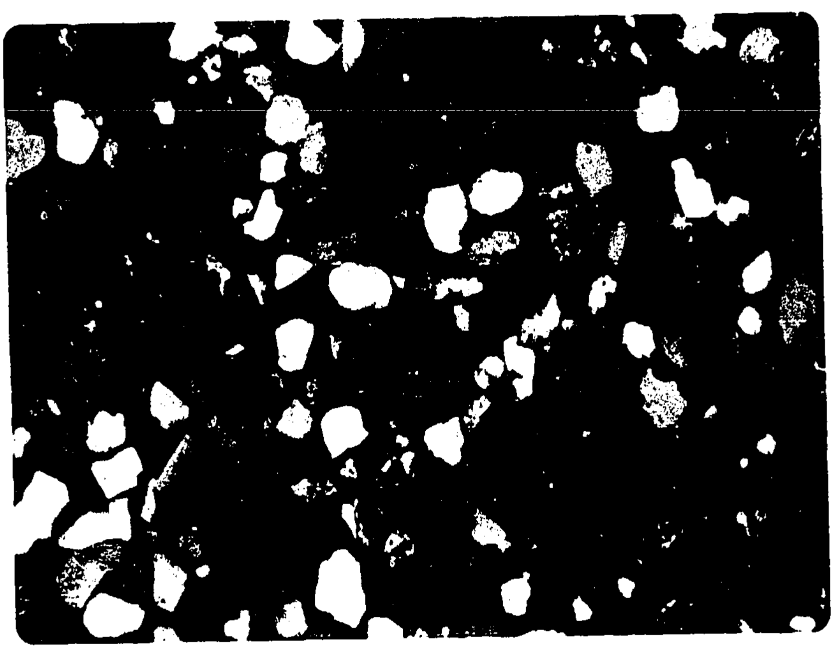
Terrigenous detritus

(a) Quartz is dominantly mono-crystalline, showing both undulose and non-undulose extinction. Overgrowths are a common constituent of the mono-crystalline grains. Quartz grains are commonly fractured. Composite quartz is rounded to subrounded and usually fine grained. Extremely fine grained rounded chert occurs in very low percentages.

(b) Feldspars include orthoclase and plagioclase which occur in approximately equal amounts as well as trace amounts of microcline.

.1 mm

Fig. 41. Moderately well sorted lithic arkose from upper sand (upper unit) De la Gringa system. Core G5-60, 38.5'.



.06 mm

Fig. 42. Moderately well sorted lithic arkose from upper sand (upper unit) De la Gringa system. Core H5-40, 25-25.5'.

.1 mm

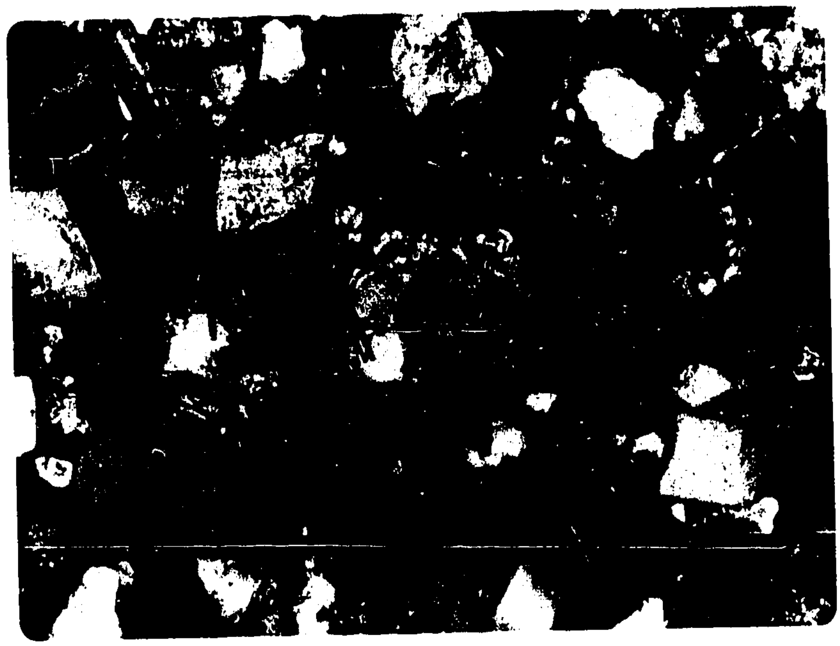
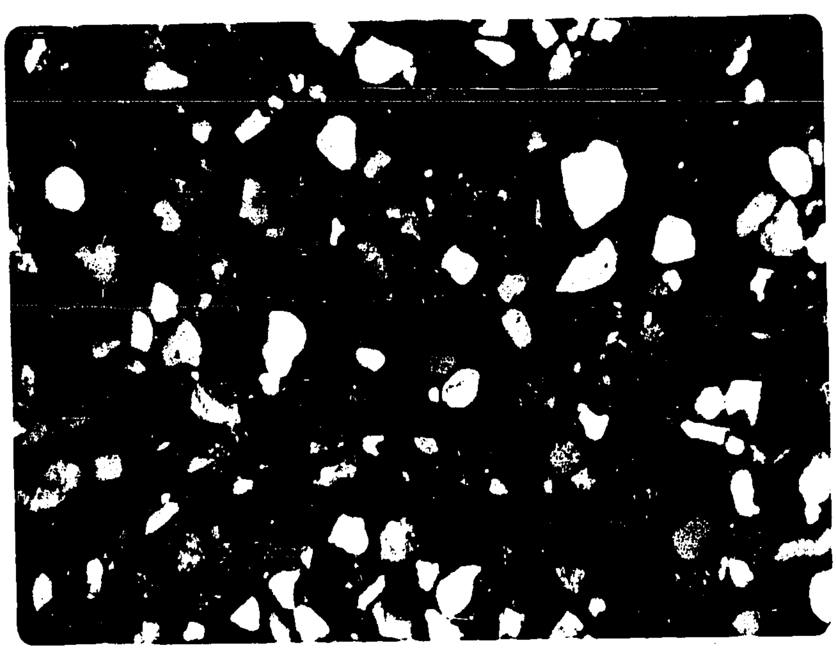
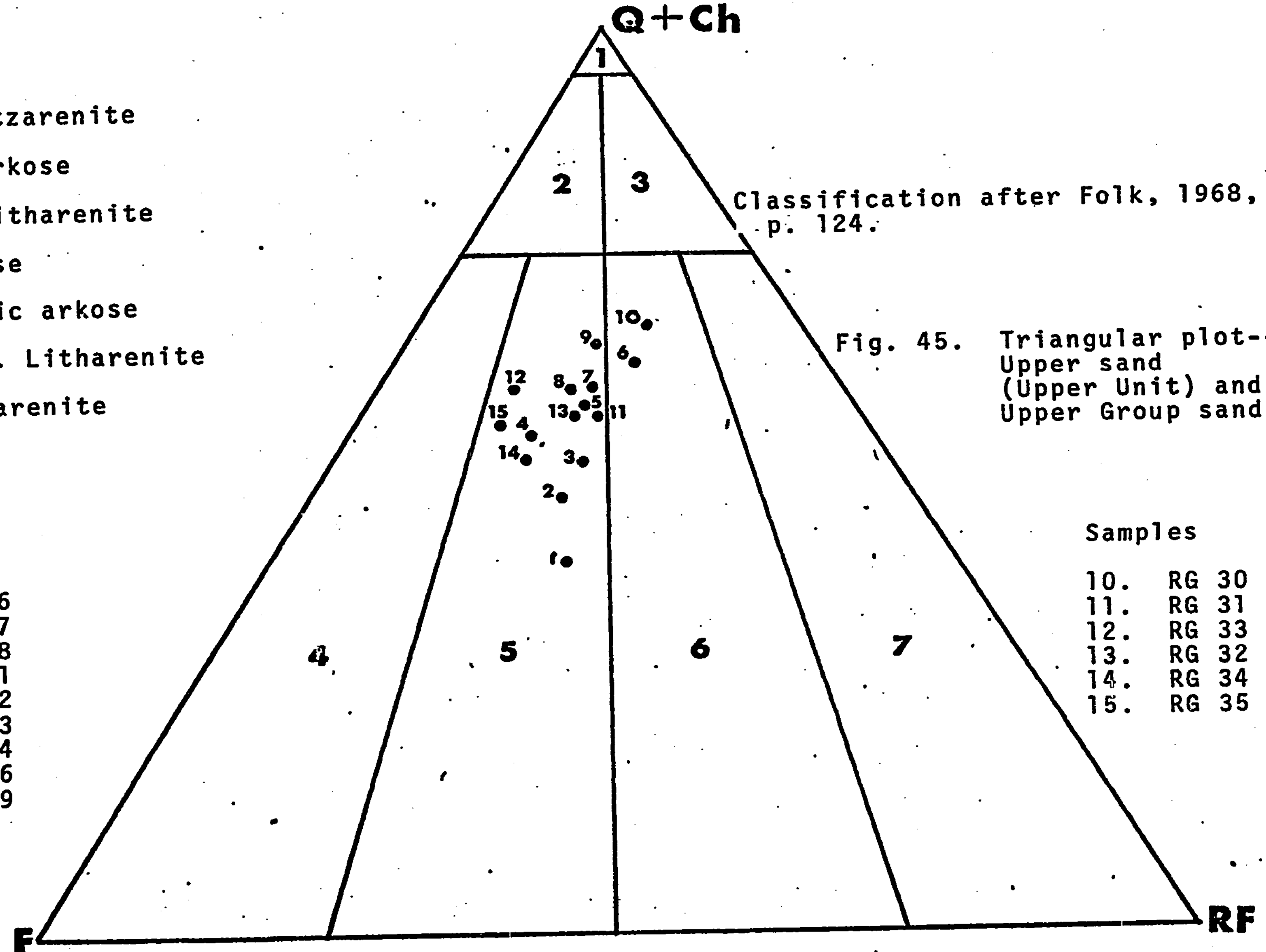


Fig. 43. Moderately well sorted fine grained lithic arkose. Upper group sand, Southern system. Core G5-65, 13.5'. Note reworked Cretaceous foram.



.06 mm

Fig. 44. Moderately well sorted fine grained lithic arkose. Upper group sand, Southern system, Core F5-42, 19-21'.



1. Quartzarenite
2. Subarkose
3. Sublitharenite
4. Arkose
5. Lithic arkose
6. Feld. Litharenite
7. Litharenite

Classification after Folk, 1968, p. 124.

Fig. 45. Triangular plot-- Upper sand (Upper Unit) and Upper Group sands.

Samples

1. RG 16
2. RG 17
3. RG 18
4. RG 21
5. RG 22
6. RG 23
7. RG 24
8. RG 26
9. RG 29

Samples

10. RG 30
11. RG 31
12. RG 33
13. RG 32
14. RG 34
15. RG 35

In most cases all three species have a fresh appearance and do not appear to have been subjected to long or intense weathering.

(c) Rock fragments are sedimentary (siltstone, sandstone, and carbonate) and volcanic. The fragments are usually well-rounded and in the case of siltstone and sandstone contain quartz grains in a clay matrix. The volcanic fragments usually have microlites of feldspar and quartz in a glass groundmass.

(d) Heavy minerals were discussed previously and show no variation from other stratigraphic units.

(e) Mica is present in trace amounts and consists of muscovite and biotite.

(f) Clay minerals as determined from X-ray diffraction are montmorillonite and minor amounts of kalinite and illite. Clay matrix was not determined although percent less than 0.062 ranges from <10 percent to 20-30 percent which is considerably more than the basal unit and in most cases is more than the lower sand of the upper unit.

Authigenic constituents

Disassociated shards and "feathered" edged plates of angydrite and authigenic quartz overgrowths as discussed for sands of the basal unit are the only authigenic constituents.

Organic constituents

Trace amounts of ostracods and low percentages of forams are the organic constituents. Cretaceous reworked forams are not uncommon.

In summary, samples from all the units differ very little in detrital framework components. The major differences, which have environmental application and significance are textural (i.e. grain size, sorting, and percent "less than 0.062 mm").

ENVIRONMENTAL CONSIDERATION AND DISCUSSION

The stratigraphy, sedimentary parameters and microfauna data (Tables XIV and XV) can be integrated to interpret the environmental framework of both the De la Gringa and the Southern system. These two distributary systems and their associated depositional environments are discussed spearately before being integrated into a complete framework package.

DE LA GRINGA SYSTEM

As shown on Figs. 26, 27, and 28, the major depositional environments associated with the De la Gringa system are fluvial, fluvial marine, prodelta, and nearshore open marine. The different environments in relation to E-log characteristics are shown in Fig. 46. These environments and their corresponding sub-environments are discussed below.

Fluvial. Fluvial environments as considered here encompass marsh, natural levee, interdistributary bay, and sands associated with the deposition of a meandering distributary. The upper 10 feet of core H5-40 penetrate silty clays with massive to horizontal bedding. Microfauna including Bisaccium imbricatum typical of brackish marsh fauna indicate the filling of this abandoned channel since the last active deposition. Cross-bedded sands occur in the 10-30 foot interval of this core with 2 fining upward sequences. Each interval has clay galls at the base and are interpreted here as two overlapping point bar deposits formed during channel migration. An average cross-bedding direction of 2^{o} indicates that active progradation during this time was

Core	Unit	Member	Lithology	Bedding	Maximum Grain Diameter	M_Z Graphic Mean	σ_I Sorting	% < 0.062	Clay Mineral	Environment
H5-40	Upper	U. SS	sand - silty clay at top	cross-bedded clay galls massive at top	Coarsens Upward	two intervals of fining upward	well-moderately well sorted	5-25% increasing at top	MONTMORILLINITE	fluvial
		L. SS	sandy-silt	horizontal lamination rippled massive & mottled		coarsens upward slightly	moderately sorted to poor at top	75%		fluvial-marine
	Lower		silts and clays thin sand members	horizontal lamination rippled-massive		--	--	50-100%		prodelta
	Basal		dominantly sand	--	Fines Upward	297ϕ - 290ϕ (3 samples)	well sorted	3-10%		near shore - open marine
H5-90	Upper	U. SS	sand-silty clay at top	horizontal lamination cross-bedded (minor) massive-mottled	Coarsens Upward	fines upward	moderate - poor ↓ base ↓ top	25-45% increased upward		fluvial
		L. SS	sand	horizontal lamination rippled		constant 3.2ϕ - 3.4ϕ	well-moderately well	9-13%		fluvial-marine
	Lower		clay and silty clay- thin sand members	horizontal lamination - mottled		--	sand members moderately sorted	90-100%		prodelta
	Basal		sand-interbedded with clays at the base	cross-bedded clay galls	Fines Upward	fines upward	well-sorted	less than 10%		near shore - open marine
H6-33	Upper	U. SS	silty-clay and clay	mottled	Coarsens Upward	—	--	90-100%		fluvial
		L. SS	sand	mottled- horizontal lamination minor cross-bedding		fines upward	moderately-poor	10-30% increases at top		fluvial-marine
	Lower		silts & clays thin sands	horizontal lamination rippled-mottled		--	--	90-100%		prodelta
	Basal		sand-clay layers at base	cross-bedded clay galls contorted	Fines Upward	fines upward	well-sorted	characteristically less than 5%		near shore-open marine
H5-88	Upper	U. SS	absent-silt and clay facies	burrowed-mottled massive	--	--	--	80+ %		fluvial - Int. Dist. Bay.
		L. SS	sand	horizontal some cross-beds clay galls	--	fines slightly	moderately-well	10-15%		fluvial-marine
	Lower		clay-silty clay thin sand members	massive	--	--	moderately	60-70%		Prodelta
					—	—	—	—		—

Table XIV. Summary of texture, bedding, and lithology data, Cores H5-90, H5-40, H6-33, and H5-88.

FLUVIAL-FLUVIAL MARINE

*Bisaccium imbricatum (brackish marsh)

Candona lactea

Candona marchia

Candona obtusa

Cypridopsis vidua (fresh water)

Limnocythere santipatricii

BAY-DISTRIBUTARY MOUTH

Candona marchia

Cyprideis littoralis

Hemicythere johnsoni

*Palmerinella gardenislandensis

*Palmerinella palmerae diminuta

PRODELTA

Cyprideis locketti

Cytherura johnsoni

Hemicythere conradi

Microcythere johnsoni

Perissocytheridea bicelliforma (all environments)

Perissocytheridea brachyforma (all environments)

NEARSHORE-OPEN MARINE

*Florilus atlanticus

*Fursonkoina pontoni

*Foraminifera

Table XV. Foraminifera and Ostracod associations.

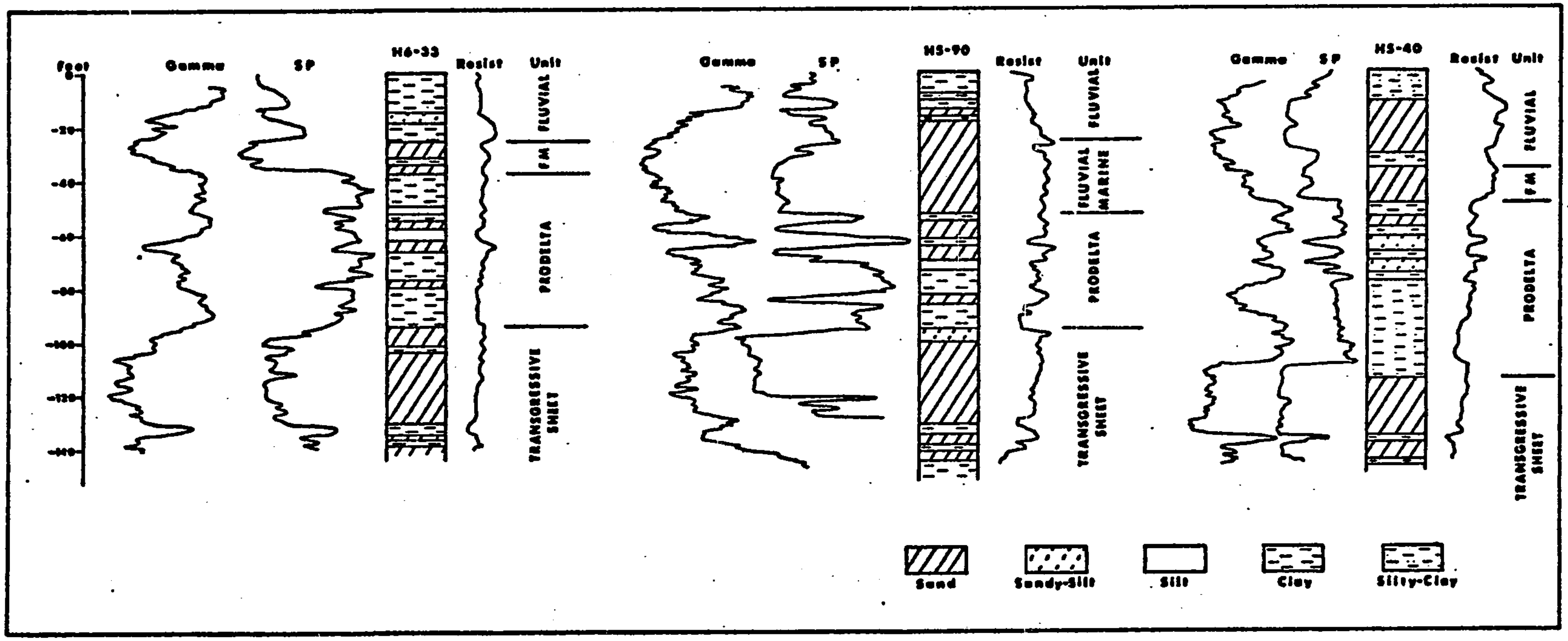


Fig. 46. E-log characteristics and associated depositional environments, Cores H5-90, H5-40, and H6-33.

to the north similar to the abandoned meander system which has incised the present deltaic plain. The sand within this interval closely resembles the fluviatile sands discussed by Oomkens (1970, p. 201) in the meandering distributary channels characteristic of the post-Pleistocene Rhone delta. The fluviatile sands described by Oomkens were deposited as point bars and range in thickness from 15 to 30 feet. Within these fluviatile sands of the Rhone delta, fauna are practically absent and the sands are generally cross-bedded although horizontal bedding may occur at any interval. Clay pebble conglomerates are present and there is an upward decrease in grain size.

Sediment interpreted as fluviatile in origin is present in Core H5-90 to a depth of 25-30 feet. The upper ten feet of this interval, which is silty clay and interpreted as natural levee shows massive to horizontal bedding with some mottling. Both foraminifera and ostracods are lacking. Below this interval there is a thin zone containing Bisaccium imbricatum which is interpreted as brackish marsh. The lower part of the fluvial environment at this locality is characterized by sands which are markedly different from those previously described in core H5-40. Here the sands are interbedded with clays, are primarily mottled, and show massive to horizontal lamination although cross-bedding is present. The mean grain size is less, the sorting poorer, and the percent of silt and clay is greater than in the cross-bedded sand found in core H5-40. These sands, although related to fluvial deposition, were most likely deposited away from the active channel sedimentation at the time of deposition thus accounting for the changes in sedimentary parameters discussed above.

The fluvial environments in core H6-33 is represented by silts and clays although there is a thin sandy silt unit at approximately 15 feet. Mottling due either to burrowing or plant roots has destroyed all recognizable bedding. Bisaccium imbractum is the diagnostic foram of this brackish marsh environment. Fluvial-fluvial-marine facies ostracods including Perrissocytheridea brachyforma, Cypridopsis vidua, Candona marchia, and Candona lactea, are abundant as are two more saline species, Limnocythere santipatricii and Perissocytheridea bicelliforma. These latter two species indicate the influence of an interdistributary bay environment occurring away from the flanks of fluvial sedimentation.

Fluvial sands are well exposed in core G5-60 where they reach a thickness of approximately 30 feet. Cross-bedding predominates in these sands, although minor amounts of horizontal bedding are present. Clay gall conglomerates and wood fragments are present at the base of the cycle. Permeability and porosity both decrease upward in this fluvial (point bar) sequence. The entire sand member is overlain by massively bedded silts and clays of the delta plain. Petrographically, sands from this fluvial environment are typically moderately-well sorted (.5-.7Ø) fine-grained lithic arkoses and feldspathic litharenites containing reworked Cretaceous foraminifera.

Fluvial associated sands are completely lacking from core H5-88 which is located in the area of closely spaced data toward the northern limit of the De la Gringa system. This core was taken off the flank of the active channel migration and is not located in an area of point bar deposition. The fluvial environment at this locality is represented by clays in the upper 12 feet and silty clays in the lower 16-20 feet. Mottled and burrowed sediment is characteristic although some massive bedding does occur at the base (28-34 feet). Foraminifera in this interval include Palmerinella and Miliolids both of which suggest a shallow low salinity environment typical of a fluvially influenced interdistributary bay area. The upper 2-4 feet of the core contain a very sparse number of forams which include Ammonia, Elphidium, and Protoelphidium which are indicative of marine conditions. Their significance is discussed later in relation to the position of the delta plain during high standing sea level.

Sand percent and isopach maps of the fluvial sediment associated with the De la Gringa system are shown in Figs. 47 and 48. Sand percent mapping shows very nicely the boundaries of the De la Gringa fluvial system and the increase in sand percent from 0 to 60. Sand percent is generally highest in the inside of meander loops where point bar accumulation occurs. It should be mentioned that these accretionary point bar sequences show very nicely on aerial photographs which were an invaluable aid in helping unravel the interpretation of the shallow subsurface stratigraphy. Isopach mapping of fluvial sands follows closely the pattern of the sand percent map. Thicknesses of the sands ranges from 0-5 feet at the limit of fluvial sedimentation to 20 feet near the channel axis. The increased thickness at the channel axis is of course dramatically influenced by point bar accumu-

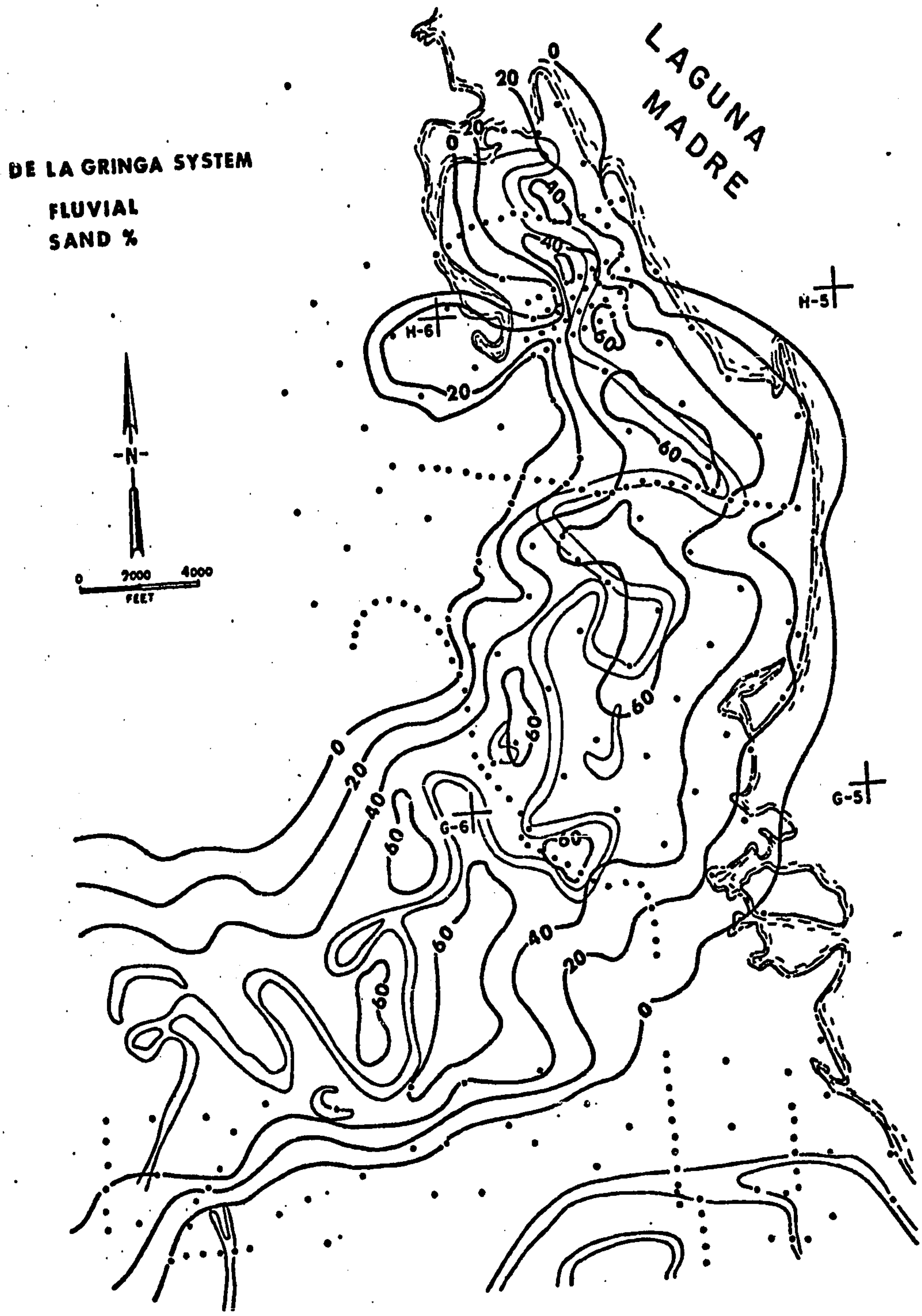
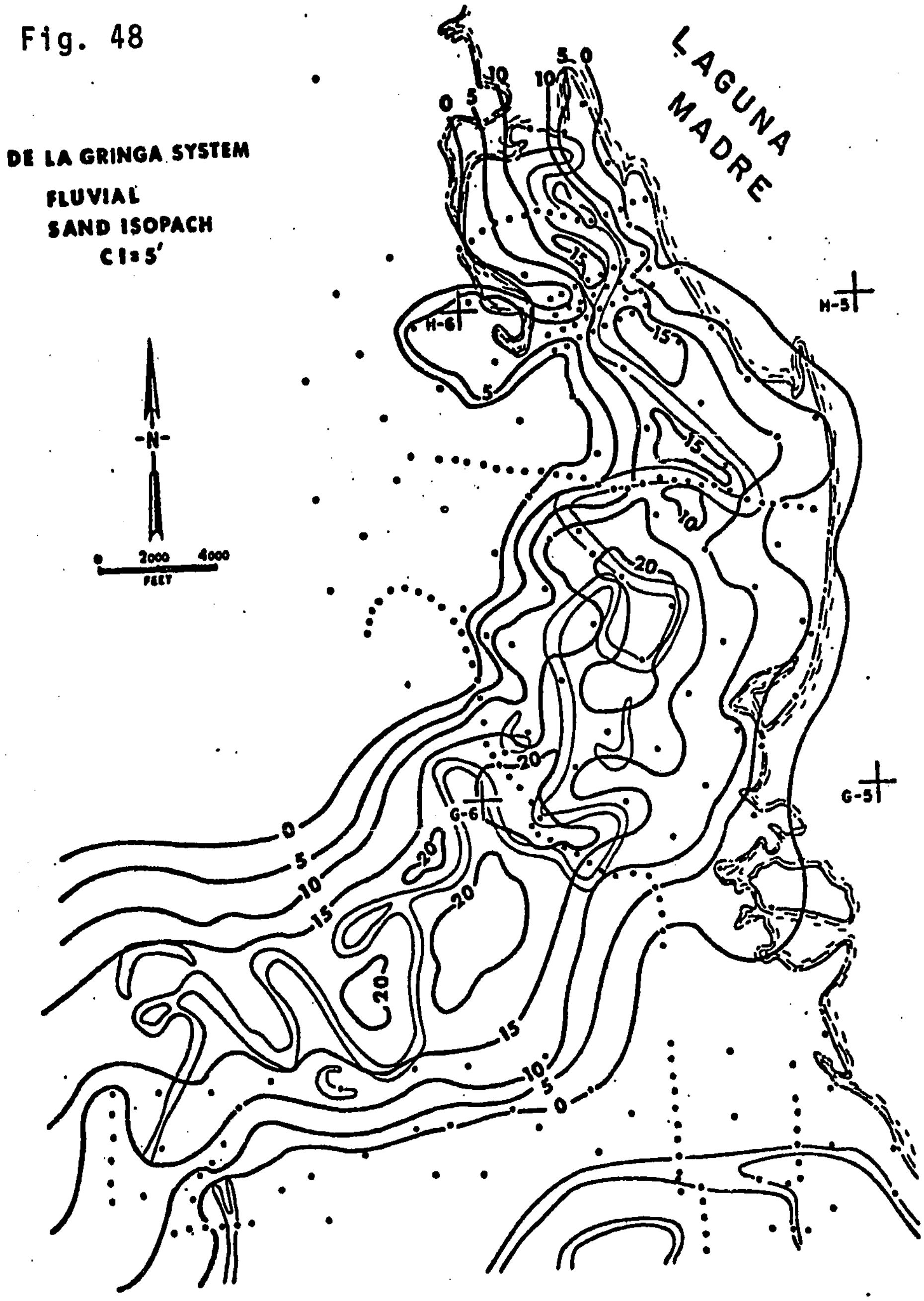

DE LA GRINGA SYSTEM
FLUVIAL
SAND %
LAGUNA MADRE
N
0 2000 4000
FEET
H-6
H-5
G-6
G-5
0
20
40
60

Fig. 47

Fig. 48


DE LA GRINGA SYSTEM
FLUVIAL
SAND ISOPACH
C I = 5'
N
0 2000 4000
FEET
LAGUNA MADRE
H-6
H-5
G-6
G-5
0
5
10
15
20

lation. It should be noted that both the sand percent and isopach maps show very well the splay deposit in the northern part of the area.

The three environments, natural levee, brackish marsh, and inter-distributary bay are associated stratigraphically with the upper sand member (fluvial) as discussed previously. Silts and clays are characteristic of the environments which flank the upper fluvial sand member and grade both laterally and vertically into channel sands in all sections and the fence diagram. The upper sand member, which was previously shown to be discontinuous or poorly defined in certain sections, owes this discontinuity to its channel associated fluviatile origin. This similar problem of discontinuous sand bodies of channel origin is noted by Oomkens (1970, p. 209) in the Rhone delta, where channel filled sequences vary in thickness from 12-30 feet. He states that the width of the belt in which channel deposits occur varies from 1500 feet to more than 15,000 feet. This extreme variability in width is also noted in this study. In section C-C', the upper sand member is continuous for approximately 8,000 feet while in sections shown by the fence diagram this upper fluviatile sand is continuous for 1500-2000 feet. Oomkens (1970, p. 209) interprets this variability in width as being due to channel migration. It should also be noted that the upper sand member in this study area becomes more poorly defined away from the present channel and is completely absent in section G-G'. Channel systems and point bar sequences are well documented in many delta studies, including those by Meckel (1975, p. 257 - Colorado delta), Maldonado (1975, p. 310 - Ebro delta), Kanes (1970, p. 90 - Colorado delta), Donaldson (1970, p. 117 - Guadalupe delta), Fisk (1955, p. 388 - Mississippi delta), and Allen (1970, p. 144 - Niger delta). Leblanc (1972, p. 151) has an excellent summary of the sandstone geometry of point bar sequences, although not necessarily those associated with deltaic plain environments.

Meckel (1975, p. 257) has an excellent summary of meander belt distributary channels which is shown in Table XVI in comparison with those of the De la Gringa system of the Rio Grande delta.

Fluvial marine. Fluvial marine environment is here defined as that depositional environment where fluvial or river-borne sediment comes in contact with an environment characterized by marine processes and ostracod fauna such as *Perrisocytheridea bracyforma*, *Candona lactea*, *Candona marchia*, and *Cypridosis vidua*. The sediment type associated with this environment is best exemplified in core H5-90 (Fig. 27) at a depth of 25 to 50 feet. The sediment is characterized by a horizontally bedded sand with a larger graphic mean than the overlying fluvial sand. In addition, the sorting is much better and the percentage of silt and clay is much less than in the overlying sand. Fauna of any type within this interval is completely lacking, indicating perhaps an environment unfavorable for fauna because of high rate of sand influx and/or reworking.

In core H5-90, the fluvial-marine sand is poorly defined and is essentially a sandy-silt with a poorer sorting coefficient and a larger percentage of silt and clay than the overlying fluviatile sand. The bedding, although somewhat mottled, is characterized by horizontal

	Colorado delta Gulf of Calif. Meckel - 1975	Rio Grande delta De la Gringa system This study
Thickness	Variable-up to 100 feet	Variable - 20-30 feet
Grain size	Pronounced fining upward from fine and coarse sand to very fine in upper part of the deposits	Fining upward - fine sand at base with clay galls to sandy silt at the top
Sorting	Moderate to very well	Moderate to well
Clay clasts	Both scattered throughout section and concentrated in well defined beds	Throughout section and at base of point bar sequences
Clay interbeds	Only a few at the top	Present at the top
Organic debris	Both macerated and fragments scattered throughout	Wood fragments common
Basal lag	Rounded clay clasts and wood common at the base	Same
Granules and pebbles	Common near the base	Absent
Cross-bedding	Dominant	Dominant
Massive and horizontal bedding	May occur anywhere in section	Rare - occur anywhere in section
Root markings	Common near top	Probably cause of some mottling in overlying clays
Fauna	Plant remains	Plant remains

Table XVI. Comparison of fluvial systems - Colorado and Rio Grande deltas.

lamination and ripple marks. Foraminifera are sparse, although ostracods such as Cypridopsis vidua and Candona lactea are present as are charophytes.

In core H6-33 (Fig. 28), the sand interpreted as fluvial-marine which occur between 25-35 feet show mottled to horizontal bedding and are moderately well sorted corresponding to a low percentage of silt and clay. Ostracods present in silts and clays at the base of the sand are indicative of a fluvial-marine assemblage and include Cypridopsis vidua, Candona lactea, Candona marchia, and Perrisocytheridea brachyforma.

Fluvial marine sediment in core H5-88 (Fig. 29) is represented entirely by well-moderately well sorted sand. Horizontal bedding predominates, although some cross-bedding is present. Clay gall conglomerates and occasional thin silt layers are present. Percent of silt and clay is very low ($<$ 20 percent). Permeability and porosity both show an upward increase in this fluvial marine sand.

Petrographically, sands from the fluvial marine unit are moderately well sorted (.5-.7Ø) fine grained lithic arkoses and feldspathic litharenites.

Sand percent and thickness of the fluvial marine sands are shown in Figs. 49 and 50. Sand percent ranges from 0 at the edge of the unit to 60-80 percent at the axis of the fluvial marine wedge. Sand thickness increases from 0-5 feet at the margins of the sand body to a maximum of 25 feet at the center of the unit. The axis of sand percent and sand thickness of the fluvial marine environment is closely related

Fig. 49

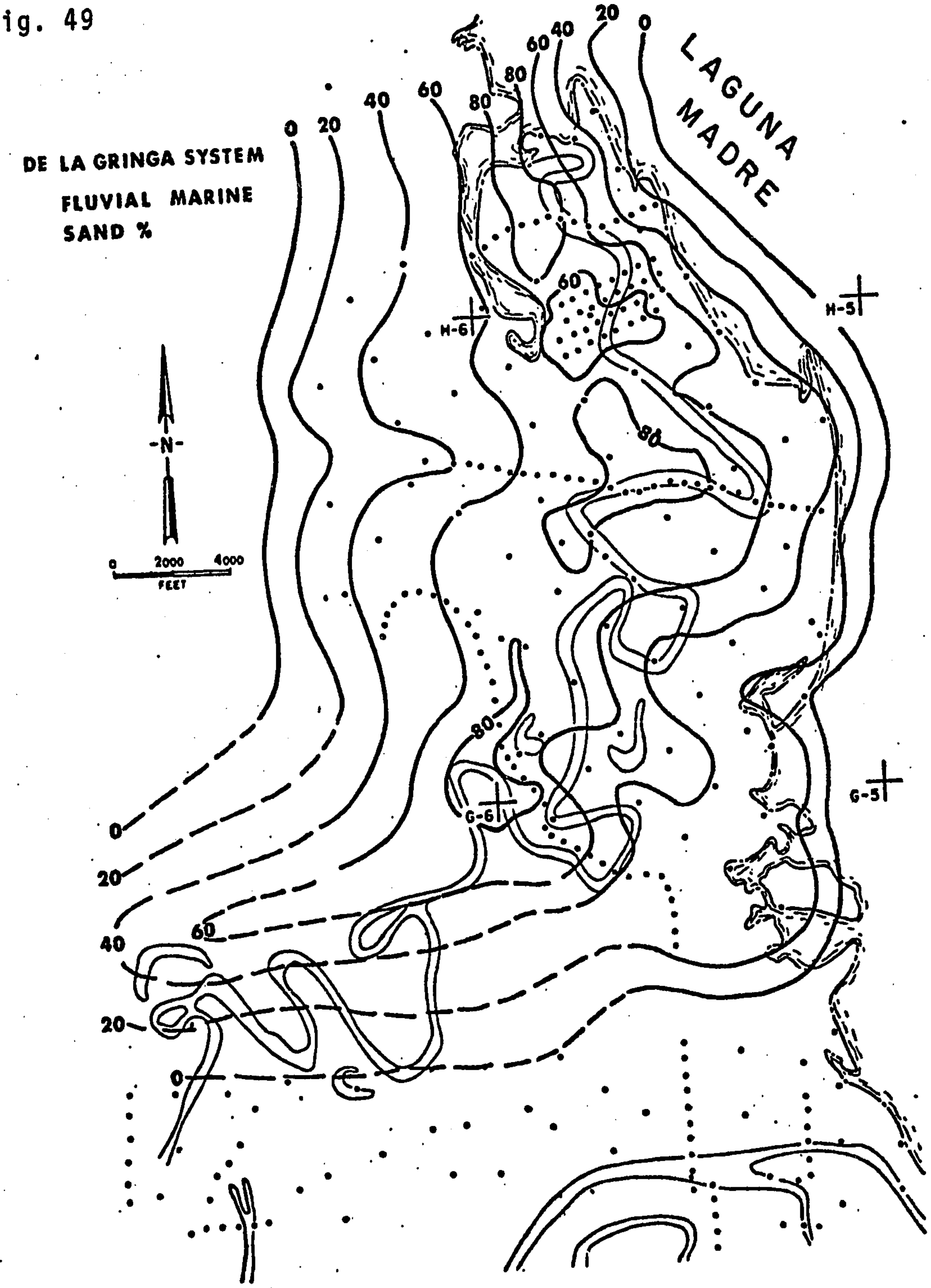
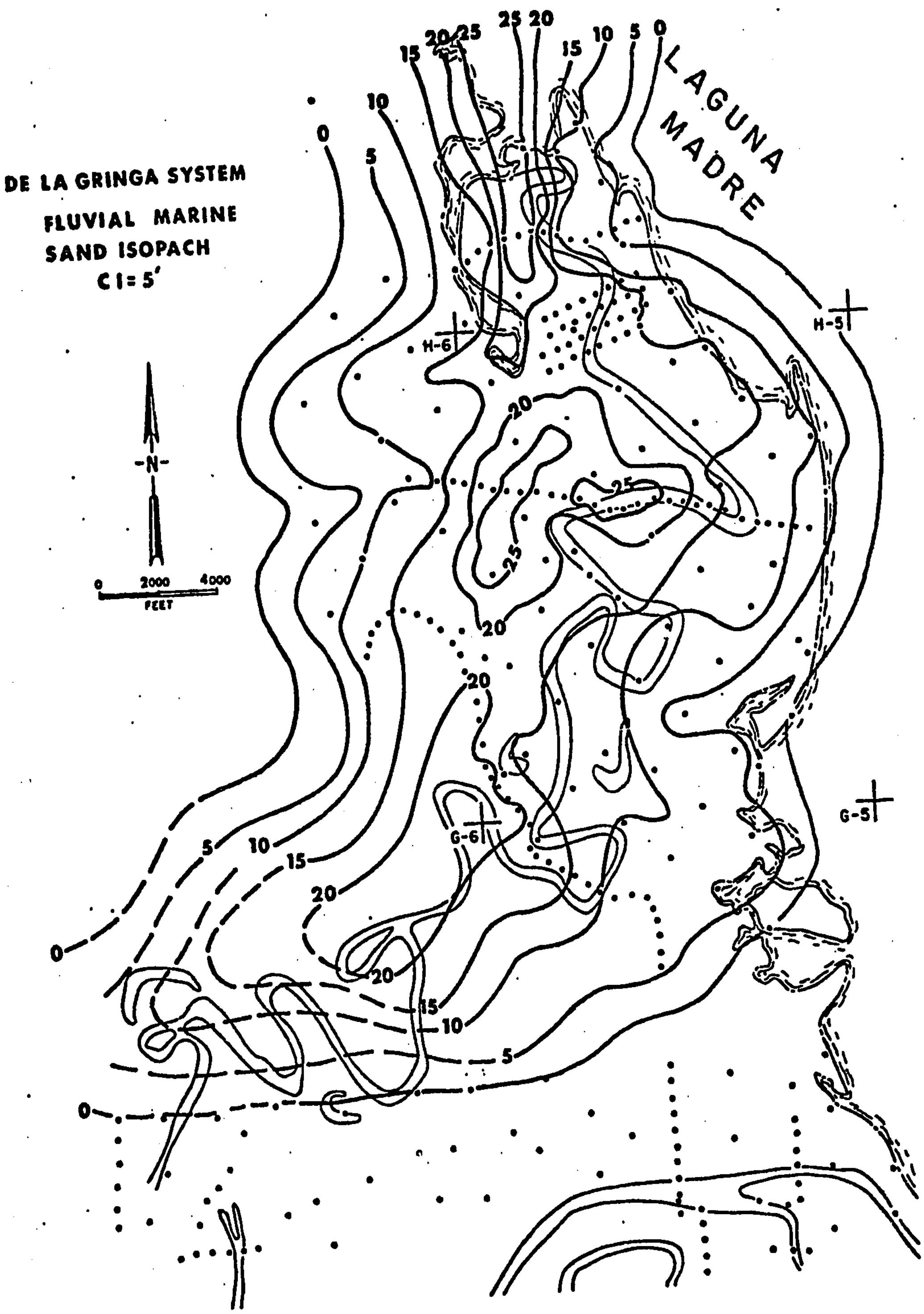

DE LA GRINGA SYSTEM
FLUVIAL MARINE
SAND %
LAGUNA
MADRE
-N-
0
2000
4000
FEET
H-6
H-5
G-6
G-5
0
20
40
60
80

Fig. 50


DE LA GRINGA SYSTEM
FLUVIAL MARINE
SAND ISOPACH
C I = 5'
N
0 2000 4000
FEET
LAGUNA
MADRE
H-6
H-5
G-6
G-5

to that of the fluvial environment which is not unusual since the former derives its sediment from fluvial input.

Stratigraphically, the fluvial-marine sands which dominate the lower part of the middle unit are the most continuous sand within the deltaic complex as was demonstrated by the previous discussion of physical stratigraphy. The base of this unit is readily defined by gamma and S.P. curves on the majority of E-logs used throughout the study area and is in marked contrast to fine-grained silts and clays lying below it.

The widespread distribution of this unit in addition to the fact that it is in places gradational with overlying channel (fluvial) sands and intergrades laterally with silts and clays makes it similar to distributary mouth bar sands of Fisk (1954, p. 89). In addition, the mean grain size of this interval is coarser than those of underlying units and the maximum grain diameter of this fluvial-marine deposit coarsens upward in all sections. The fact that silts or sandy silts comprise some of this unit is not unusual for fluvial-marine environments, as Fisk (1961, p. 39) lumps three lithologic zones, an upper zone of silty sands and sandy silts, a "clean" sand zone of less than 20 percent silt and clay, clayey silt, into what he terms distributary mouth bar sands. Also, Allen (1970, p. 148) mentions very fine sands and coarse silts, which are found in river-mouth bars of the Rhone delta. On a smaller scale, Donaldson (1970, p. 117) describes mouth bar sediments of the Guadalupe delta as being sand, sandy silt, and silty sand. Similarly Kanes (1970, p. 101) refers to mouth bar deposits of the Holocene

Colorado delta of Texas as sand and silty sand.

Because the Mississippi River delta system has been so extensively described by several workers, it is oftem tempting, and without fault, for other workers to use the Mississippi delta as a model for their interpretations. However, the high constructive lobate nature of the Holocene Mississippi birdfoot delta may in some ways be analomous when compared to deltas which drain a smaller area, have a high sand/mud ratio, and empty sediment into a higher energy shallow-marine reservoir (Busch, 1971, p. 1137). Such deltas are termed destructive deltas (Swift and Fisher, 1970, p. 14) and modern Holocene examples include such deltas as the Po, Nile, Rhone, Danube, Appalachicola, Irrawady, and Niger.

Of these destructive deltas, the one most studied by core data is the Rhone. Oomkens (1970, p. 205) mentions that as soon as river-mouth bar has been built up, wave energy is concentrated against it. Material reworked from the bar is moved laterally by littoral drift and fashions or nourishes coastal barriers linking the mouth bar with the coastline. This process produces a vertical sedimentary sequence that coarsens upward and is interpreted by Oomkens as part of a deltaic-fluviomarine offlap sequence. As described by Oomkens, these sands reach a thickness of 30 feet and comprise a sheet 30 by 12 miles in extent. The fauna is predominantly marine but includes a notable percentage of fresh and brackish water ostracods. The sand is well sorted and generally horizontally bedded, although low angle cross-bedding is commonly present. Oomkens (1970, p. 209) shows in a core description that barriers may be in contact with overlying channel deposits, the same of which is true for Fisk's model.

In both cases mentioned above, sediment is derived from a fluvial origin and is redistributed by wave action forming continuous sand lithologies of either mouth bars or barriers depending on the wave energy and depth of water. An interpretation of the processes necessary to produce the fluvial-marine sands of the Rio Grande delta is somewhat difficult from the core data available. Micro-fauna data are sparse within this zone, although in core H6-33 the basal silts and clays of the fluvial-marine environment do contain ostracods, including Perissocythere brachyforma, Candona marchia, Candona lactea, and Cypridopsis vidua (fresh water) as well as charophytes. Fisk (1961, p. 51) notes that bar mouth sands are free of fauna but do grade into facies containing fauna. Both Donaldson (1970, p. 128) and Kanes (1970, p. 101), however, show the presence of faunal assemblages in the distributary-infuenced mouth bars. Bedding within the fluvial-marine sands is dominantly horizontally bedded in contrast to cross-bedded sands described by Fisk (1961, p. 50) and Coleman and Gagliano (1970, p. 144) which are dominant in distributary mouth bar sands. Shannon and Dahl (1971, p. 1200), however, do refer to "laminated" sandstones being present in mouth bar sands which are distinguishable from overlying channel cross-bedded sands. Similarly, Swann (1964, p. 647) in his discussion of Late Mississippian (Chesterian) sands of the Illinois Basin indicates that major sandstone bodies, which he compares to mouth bar sands of the Mississippi delta, are massive with parallel-toflat bedding and are distinguishable from cross-bedded channel sands which may cut into them. In addition, Allen (1970, p. 148) states that in the Niger delta, the varied character of the river mouth bar sediments reflects the broad range of energy conditions to which mouth bars are subjected. Sands of the bar crest are well sorted, fine to medium grained, and generally show gently inclined laminae in cross-cutting sets. Large scale cross-bedding and cut and fill structures are rare although ripple laminations may be found. On the flanks of the bars are well-sorted very fine grained sands which show even laminations.

Both the mouth bar sands of Fisk and the barrier complex described by Oomkens give essentially the same product. The processes forming the product is dependent on the energy level of the marine reservoir into which the sediment is introduced. From the data available, it is safe to say that the continuity, bedding, textural parameters, and lateral distribution of the sands of the middle unit indicate the influence of wave distribution in front of a source of sediment (distributary mouth bar).

It is possible that these sands could be similar (at least in depositional process) to the delta front sheet sands of Fisk (1955, p. 388, 1958) which are termed inner fringe sands by Leblanc (1972, p. 156). However, the term "sheet sand" carries an implication of continuity not applicable to the fluvial marine sands considered here and the term "inner fringe" sands is somewhat vague especially in relation to depositional process. In addition, sedimentary characteristics (grain size, bedding, etc.) of delta front sheet sands are not well defined by Fisk or Leblanc and are thought to form by wave reworking of fluvial and distributary mouth bar sands. Furthermore, the barrier (fluviomarine offlap) sequence described by Oomkens does not seem applicable for two reasons: (1) the sands are not oriented properly for a barrier system, and (2) the thickness of the sands thins rapidly away from the location of the channel mouth which is not typical of barrier systems. In summary, the term fluvial-marine sands (distributary mouth bar?) seems most applicable as a descriptive term for these sands, although the process of deposition is probably similar to that mentioned by Leblanc for the "inner fringe" sands or by Fisk for his delta front sheet sands.

Prodelta. Below the fluvial marine sands interval is what was previously stratigraphically described as the lower unit. Environmentally, this unit is defined as being prodelta with a sub-environment considered to be bay-distributary mouth.

Lithologically, this unit is dominantly silts and clays with thin interbeds of sand and sandy silt. Clays show both horizontal and mottled bedding, the mottling perhaps due to the influence of burrowing organisms. Contorted bedding, especially in the clays and silty clays, is not uncommon. Sands, sandy silts, and sandy clays show predominantly rippled and horizontal bedding; cross-bedding is rare. Sand members within the prodelta unit are thin and rarely exceed 5 feet. Textural data are sparse, although percent "less than 0.062 mm" is high (50-80 percent), and sorting is moderate to poor.

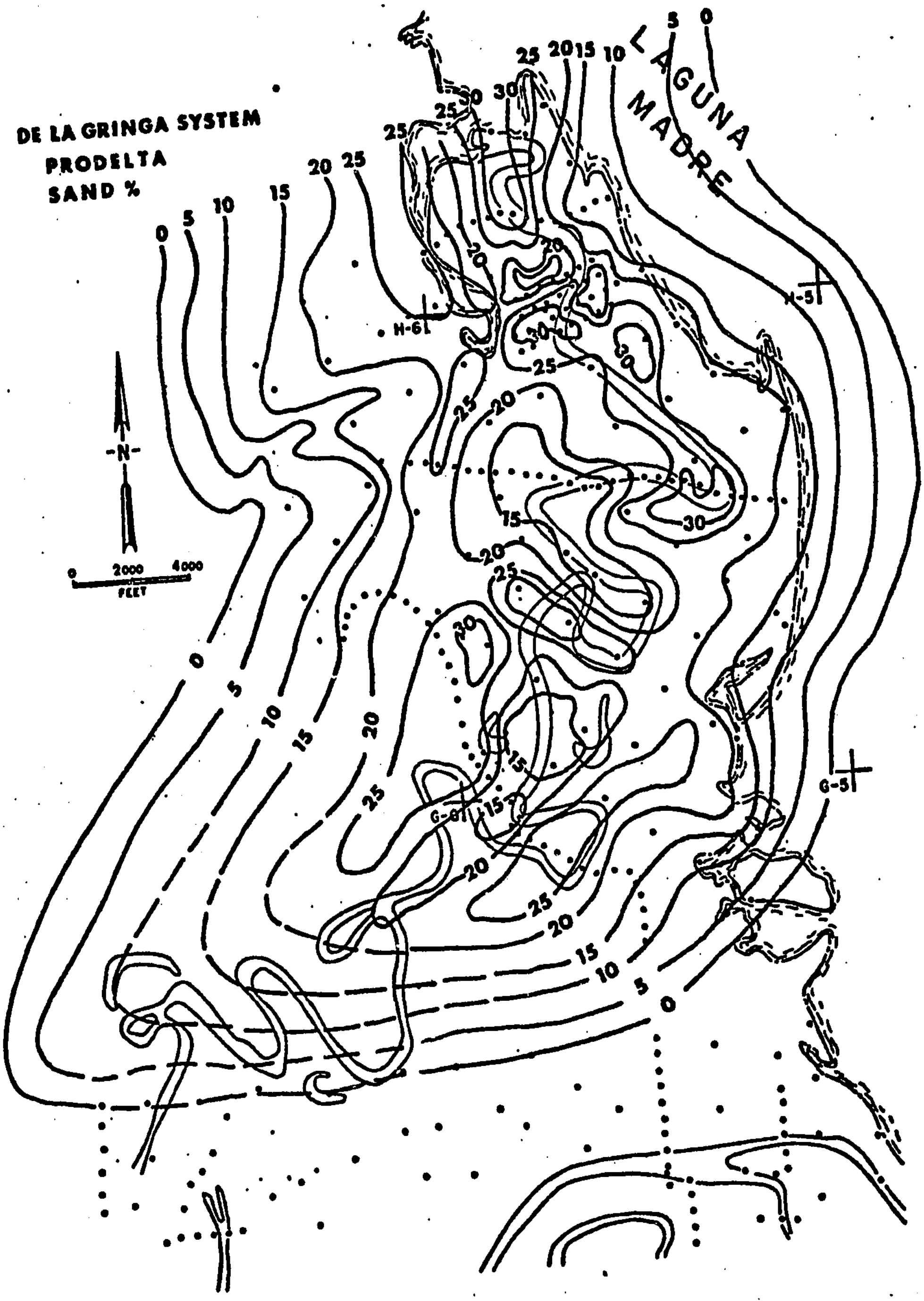
Sands from this unit are moderately-poorly sorted (1.6-2.2Ø) sub-angular to subrounded very fine grained lithic arkoses.

Sand percent of the De la Gringa prodelta environment is shown in Fig. 51. Sand percentages range from 0-5 percent at the margins of the prodelta environment to 25-30 percent at the center of the prodelta unit where sediment influx derived from fluvial and fluvial-marine sands is higher.

Below the fluvial-marine environment from a depth of 50 to approximately 70 feet is what is considered a subenvironment of the prodelta - the bay-distributary mouth facies. This interval in all three cores (H5-90, H5-40, and H6-33) contains prolific fauna, both foraminifera and ostracods. Characteristic of the bay-distributary mouth environment are two foraminiferal species - Palmerinella gardenislandensis and P. palmerae diminuta. Lankford (1959, p. 2095) states that P. gardenislandensis apparently requires a highly variable salinity and "is most abundant in the fluvial marine assemblage". Both P. gardenislandsis and P. palmerae dimunita are also common diagnostic forms found in bay environments (see Appendix). Terms such as bay-distributary mouth, bay, prodelta-bay, etc., are awkward but out of necessity for communication and labeling must be used. A more precise means of describing this subfacies would be to call it "an environment of highly variable salinity affected by fresh water (fluvial) discharge". Hopefully the term bay-distributary mouth is somewhat indicative of this complex environment.

It was mentioned earlier that both foraminifera and ostracods are

Fig. 51


DE LA GRINGA SYSTEM
PRODELTA
SAND %
LAGUNA MADRE
-N-
0 2000 4000
FEET
H-6
H-5
G-6
G-5

prolific in this environment, which is somewhat problematical. Lankford (1959, p. 2094) considers some of the reasons for high production in areas inclunced by river discharge and relatively rapid sedimentation. Lankford states that there are several features associated with river effuents which may be important. These are concentrations of nutrients and trace elements, large bacterial population adhering to the surfaces of the surfaces of the finely divided detritus, and an abundance of organic solids.

Not only is the prodelta environment complex paleoecologically, but sand members within this unit also present some problem. As discussed stratigraphically these sand members are thin, imbricated, and discontinuous both north-south and east-west within the deltaic-marine/prodelta environment. The literature on such sand bodies, especially in recent deltas, is not extensive. Oomkens (1970, p. 206) mentions that the lower part of a fluviomarine regressive sequence in the Rhone delta contains clays interbedded with thin silts and sand beds. These silt and sand beds increase upward in number toward the fluvially influenced part of the section. However, Oomkens makes no attempt to correlate such sand units due to lack of subsurface control. Allen (1970, p. 149) in reference to the Niger delta, mentions that layered deposits of interbedded clayey silt with coarse silt or very fine sand persist to the edge of the prodelta slope. Again any sort of subsurface data or correlations is lacking.

Workers in ancient deltas have encountered such sand bodies, although in a larger depositional framework than is being considered here. Shannon and Dahl (p. 1202), in their discussion of deltaic stratigraphic traps in West Tuscalosa Field, Texas, mentions pods of sandstone virtually enclosed in bar slope (silty claystone) deposits. Their explanation is that during times of normal river discharge, stream bed load is carried to the shoaling crest of a stream mouth bar, where sand is deposited then reworked and spread laterally by marine action into a crescent shaped bar as described by Fisk (1961, p. 30). As river flow increases either annually or catastrophically, the channel may cut through the bar crest allowing bedload sand to be spread as bulge onto the frontal bar slope. The sand settles into the finer material on the bar slope and as river stage drops is covered by silts and clays creating the pods described above. Shannon and Dahl (1971, p. 1203) further add that these sands would have much poorer continuity than those of the river mouth bar - an association typical of such sands in the present study area.

Potter (1963, p. 84) considers the origin of some pod and ribbon sandstones in his discussion of Late Paleozoic sandstones of the Illinois basin. One of the possibilities (p. 85) is that some of the isolated pods and ribbons may have been formed by jet currents off the mouths of delta distributaries. Potter also mentions that tidal currents (p. 84) or turbidites (p. 85) may have been influential in forming these sand bodies although bedding structures seem to negate the latter hypothesis.

Swann (1964, p. 648), in his discussion of sandstone bodies in the upper Mississippian of the Illinois basin mentions sand bodies which are smaller than the mouth bar sands and have a variety of origin and shapes. Some are like sheets, others are thicker, elongate, and either straight or curved. Some are attached and form part of the main sandstone framework of their respective units, while others are isolated, surrounded by shale or shale and limestone. Swann feels that many of the small sandstone bodies are composed of sand that was eroded from mouth bars and redistributed by waves or tidal currents. He states (p. 643) that a river mouth bar is not static and is subjected to wave and tidal attack that tend to destrov it and redistribute the sand as beaches, delta front sheets, or tidal current ridges. He concludes (p. 649) by saying that although minor sandstone bodies are of many origins, most are closely related to delta growth.

Although the sand members within the lower unit presently under discussion have been shown to be stratigraphically significant, their origin is probably twofold. Because they directly underlie and are at times gradational with continuous sands that are interpreted as fluvial-marine (mouth bar), it is suggested that their origin is similar to that offered by Shannon and Dahl for discontinuous sand of the lower bar slope or to that offered by Swann in which sand eroded from mouth bars is redistributed by waves or tidal currents. A third possibility although difficult to substantiate is that sediment eroded from the Southern system was redeposited to the north in the areas later to be occupied by the advancing De la Gringa system. This origin is highly possible and probably as acceptable as the two mentioned above.

Nearshore Open Marine. The lowermost interval previously defined as the basal unit is dominated by sands which have interbedded silts and clays at the base. These sands are well sorted, have a very low percentage of silt and clay, are coarser than sands in the overlying units and have a maximum grain diameter that generally fines upward. The sands are dominantly cross-bedded with some horizontal bedding, rippled bedding, and clay galls. Petrographically, these sands are well-moderately well sorted (.35-.5Ø) subangular to subrounded fine grained lithic arkoses. Silts and clays at the base are characterized by mottled bedding. Foraminifera are completely lacking and ostracods are extremely rare. This unit which was penetrated at between 90-110 feet in all the deep wells formed the base for the drilling operations in the area.

Because of its continuity, textural parameters, and lack of microfauna, this sand is interpreted as a destructional phase sand perhaps due to the last post-glacial rise in sea level which affected the Texas shoreline 9-10,000 years B.P. (Nelson and Bray, 1970, p. 67). Similar transgressive sands underlie other modern deltas of the world, including the Orinico (Van Andel, 1967, p. 203), the Niger (Allen, 1970, p. 150), the Rhone (Oomkens, 1970, p. 200), and the Mississippi (Kolb and Van Lopik, 1966, p. 21).

In addition, Curray and Moore (1963, p. 79) report a continuous fine-grained well-sorted sand which overlies the pre-transgressive Pleistocene flood plain surface of the Rio Grande de Santiago and other small adjacent rivers of the Coasta De Nayarit continental shelf-coastal plain complex of western Mexico. This sand, which is continuous along the strand plain even though it does have an irregular surface due to sub-aerial erosion, is partially covered with younger or modern Holocene alluvium much like the basal sand considered here.

Underlying this sand in the lowermost 10-15 feet of the basal unit are well sorted sands with interbedded silts and clays. The clays show mottled bedding which may be due to burrowing organisms. Ostracods are extremely rare within this interval. Foraminifera are absent except in core H6-33, where the presence of bay sound as well as near shore-open marine foraminifera such as Florilus atlanticus and Fursenkoina pontoni suggest a marine environment related to an earlier deltaic system.

SOUTHERN SYSTEM

Both stratigraphically and environmentally the Southern system is more complex than the De la Gringa system previously discussed. The surface expression of three channels is indicated from mapping of the delta plain and one channel is evident from subsurface mapping. The surface expression was of invaluable aid in unraveling the subsurface stratigraphy and was an extremely useful bit of data that workers in ancient environments unfortunately do not have.

Combination of surface expression combined with subsurface mapping has elucidated the presence of 4 channels here defined as 1A (oldest), 2, 3, and 4 (youngest). The fluvial environment encompassing these channels, as well as the fluvial marine and prodelta environments, are discussed below.

Fluvial. Channel 1A. Channel 1A (Fig. 52) is the oldest channel present in the Southern system. Although only an erosional remnant of

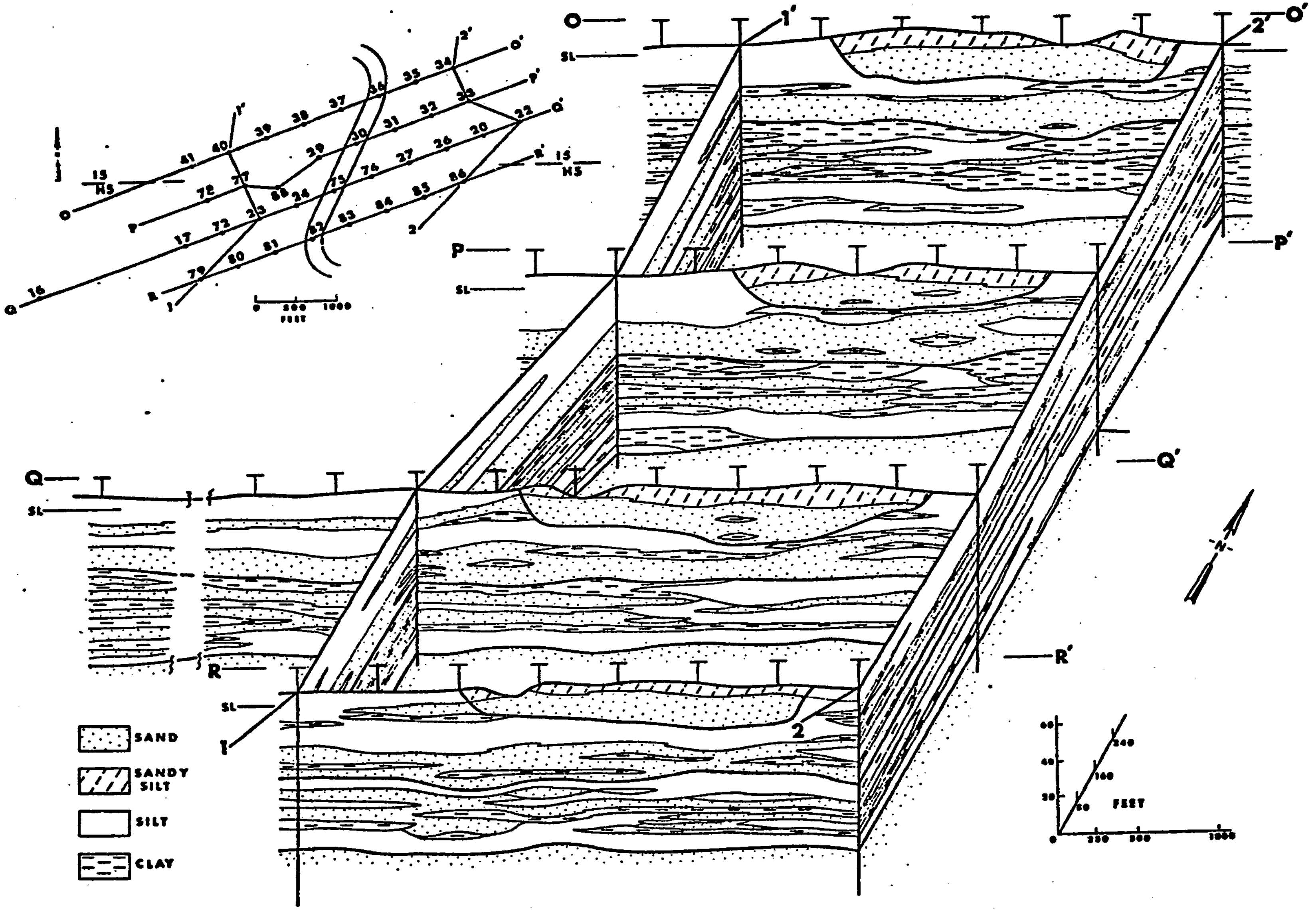


Fig. 52. Stratigraphic units associated with the Southern system.

the channel now remains, fluvial marine and prodelta sediment derived from the prograding distributary underlies the other channels of the system (Fig. 52). Because there was no core hole through the actual channel, its position was deduced from surface location and relationship to channels 3 and 4, which truncate channel 1A and which do have core hole data. An isopach of sediment genetically related to channel 1A (i.e. fluvial, fluvial-marine, and prodelta) is shown in Fig. 59. Position of sediment associated with the present erosional remnant of channel 1A is nicely shown where the contour intervals become closely spaced and the total sediment package is the thickest.

Channel 2. This channel (Fig. 52) is the least well defined of those in the Southern system. Aside from the fact that there is no surface expression, the stratigraphy is complicated by truncation of the channel from the north and by channel 3 from the south. In addition, drill hole data is lacking between section E-E' and the De la Gringa system to the north at a most critical place where the two systems converge. Subsurface data, however, shows the presence of a thick sand sequence cut into prodelta sediments at drill holes G5-47 and 48. In addition, thick sand sections occur at drill holes G5-50 and 51 which are not correlative with sands associated with channel 3 or with thin sands of the De la Gringa prodelta unit to the north.

Sand percent and isopach characteristics of this channel are shown in Figs. 53 and 54. Sand percent is higher than that associated with the De la Gringa system and is as high as 80 percent near the channel axis. Isopach mapping indicates that the sands are as thick

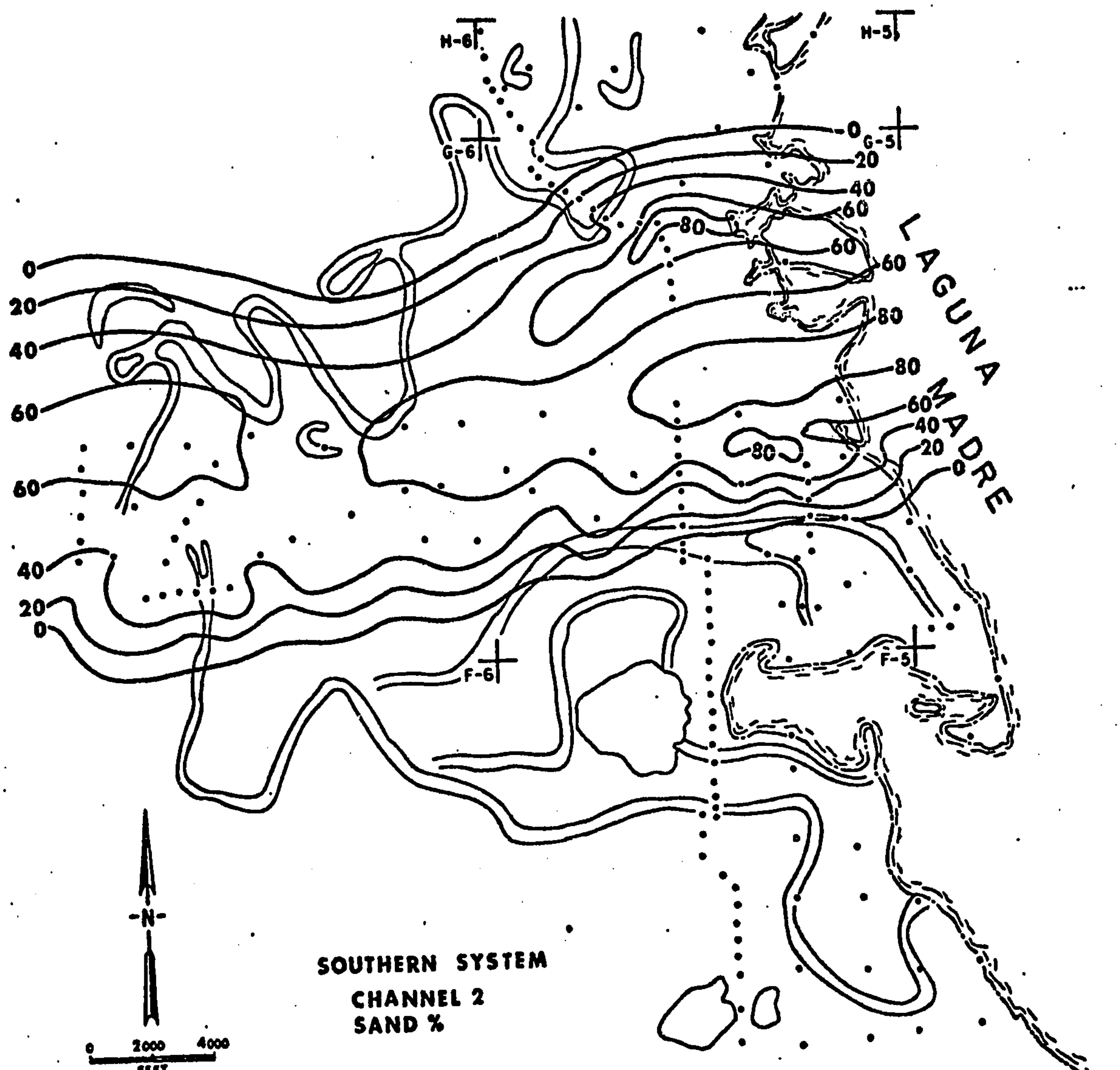

H-6
H-5
G-6
G-5
F-6
F-5
LAGUNA MADRE
0
20
40
60
80
-N-
0 2000 4000
FEET
SOUTHERN SYSTEM
CHANNEL 2
SAND %

Fig. 53

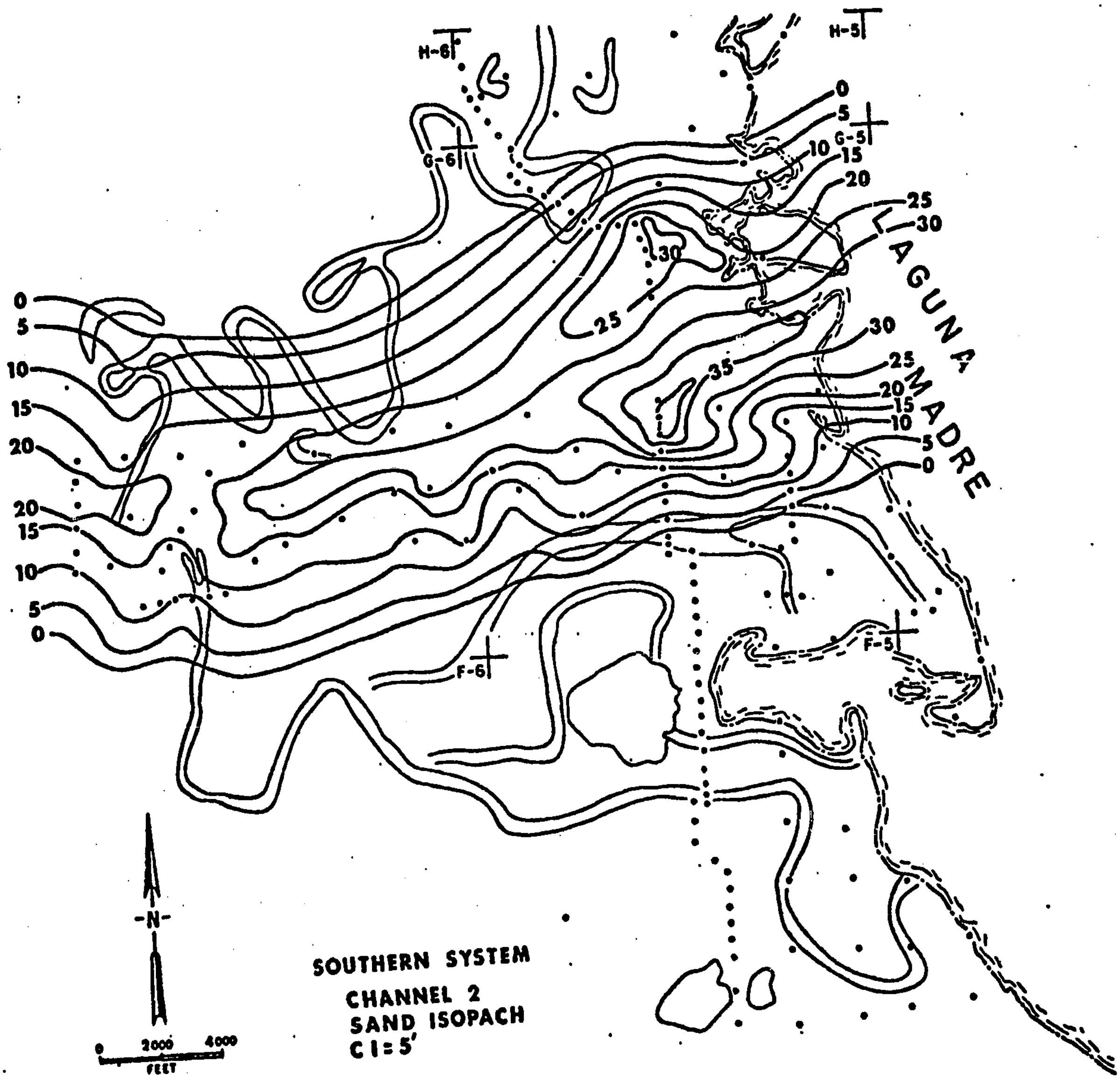

H-6
H-5
G-6
G-5
F-6
F-5
0
5
10
15
20
25
30
35
LAGUNA MADRE
-N-
0 2000 4000
FEET
SOUTHERN SYSTEM
CHANNEL 2
SAND ISOPACH
C I = 5'

Fig. 54

as 30-35 feet but thin rapidly away from the channel axis. Both sand percent and isopach thickness of the sands indicate that this channel system may have two distributaries. This is indicated by two linear areas of 30-35 foot sand thickness corresponding to sand percent highs of 80 percent.

Channel 3. Fluvial sediment associated with channel 3 is nicely shown in core G5-65 (Fig. 31) where fluvial sands reach a thickness of 30 feet. These sands are cross-bedded and have clay gall conglomerates at the base. Both mean grain size and sorting decrease upward in the classical sequence associated with channel (point bar) development. Percent "less than 0.062 mm" increases upward from 20 to 50 percent, while both permeability and porosity decrease upward. Permeability decreases upward from 4-5 darcys to about 1 darcy at the top of the unit, while porosity decreases from 30 to about 15 percent. Petrographically, these fluvial sands are moderately-well sorted (.5-.7Ø) fine grained lithic arkoses and feldspathic litharenites. Overlying the point bar sands are silts and clays and occasionally thin, massively bedded sand so typical of flood plain deposits. These silts and clays are massive to horizontal bedded becoming mottled at the top where burrowing and root activity undoubtedly express their influence. The ostracod species Candona lactea occurs in these silts and clays at a depth of 14-16 feet. This species is typical of fresh to brackish water and occurs in interdistributary areas as reported by Swain (1955, p. 570).

Channel 3 is the best expressed of all channels in the Southern system and is very well shown in section E-E' (Fig. 52), which is drawn perpendicular to the direction of progradation. Sections X-X' and Y-Y' (Figs. 22 and 23) also show very nicely the development of channel 3 and its subsequent truncation of channels 1 and 2. The sands of channel 3 that are so well illustrated in section E-E' have a striking relation to the sands of the floodplain point bar model illustrated by Busch (1974, p. 74). The generalized S.P. curve shown by Busch is also similar to that for core G5-65 which penetrates the channel at its thickest portion (see Fig. 20).

Sand percent and sand thickness associated with channel 3 are shown in Figs. 55 and 56. Sand percent is again high as it was in channel 2 and averages around 60 percent, although reaching as high as 80 percent in some isolated pockets. Sand thickness is greatest at the channel axis where it reaches 30-40 feet and then thins rapidly to the channel margins.

Channel 4. Fluvial sediment associated with channel 4 is shown in core F5-42 (Fig. 32), where the sands are approximately 15 feet thick. Point bar sands here are not as thick as those shown in core G5-65 as this core was taken further from the channel axis. Sands associated with this channel are cross-bedded with some massive bedding at the top. Clay gall conglomerates are present at two localities, both at the base and toward the middle of the unit. The upper conglomeratic zone also has wood associated with it and may mark the location of a second point bar sequence, although grain size which fines upward through this interval seems to negate this possibility. Sorting is

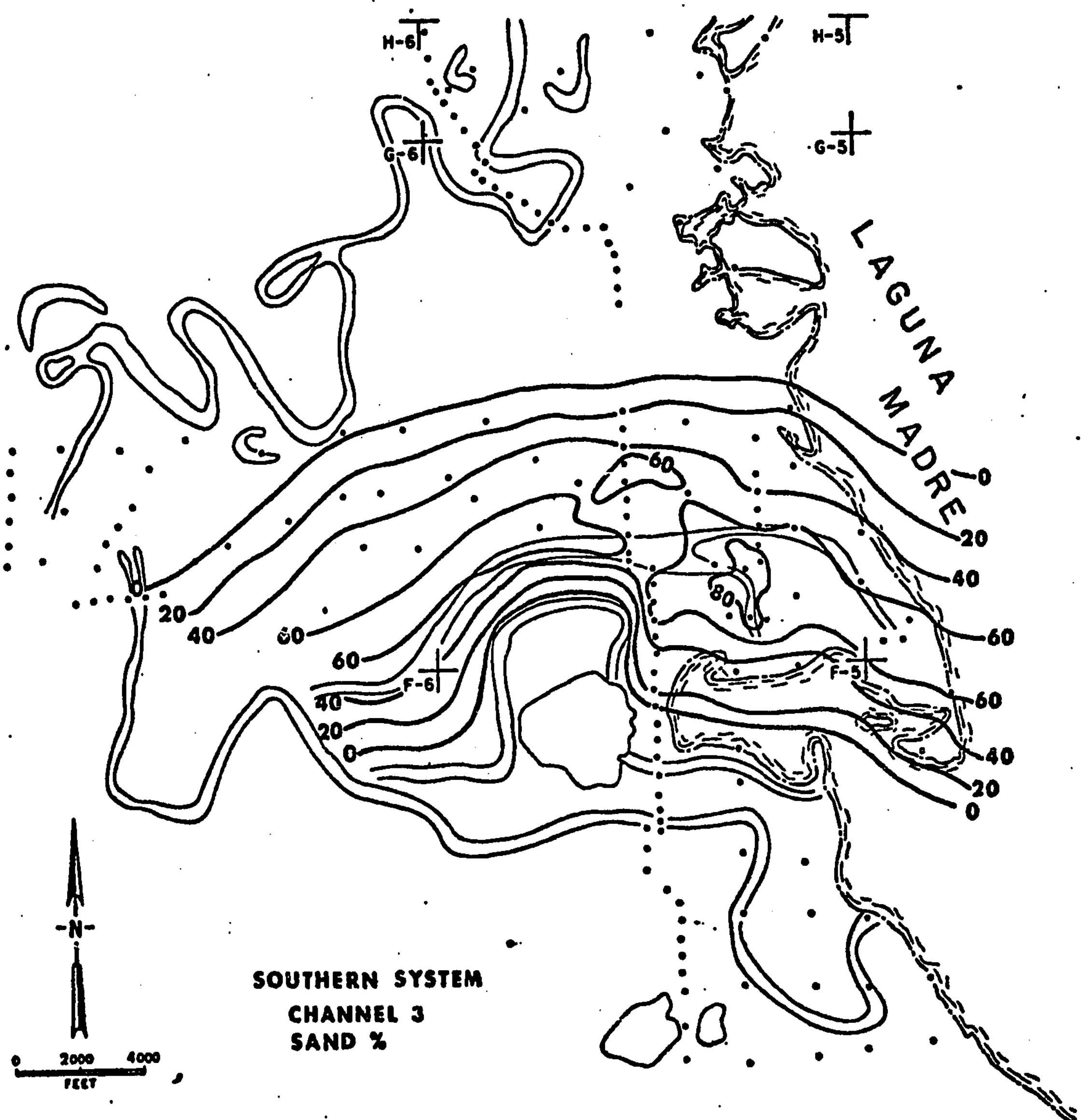

H-6
H-5
G-6
G-5
F-6
F-5
LAGUNA MADRE
0
20
40
60
80
N
0 2000 4000
FEET
SOUTHERN SYSTEM
CHANNEL 3
SAND %

Fig. 55

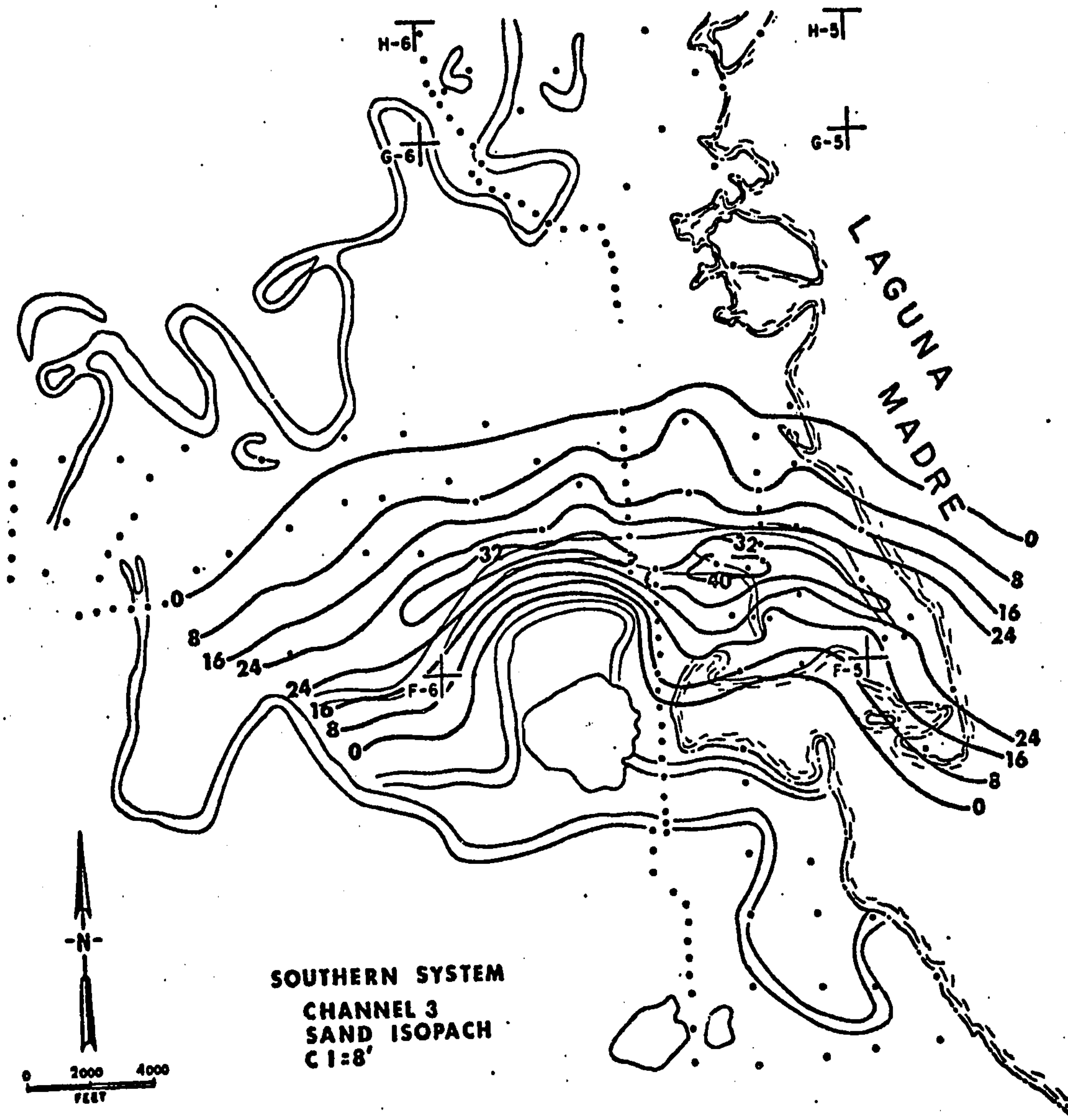

H-6
H-5
G-6
G-5
F-6
F-5
LAGUNA MADRE
0
8
16
24
32
40
N
0 2000 4000
FEET
SOUTHERN SYSTEM
CHANNEL 3
SAND ISOPACH
C I=8'

Fig. 56

erratic but does show a general tendency to decrease upward. Percent "less than 0.062 mm" is low (15-28 percent) although it does increase slightly at the top. Both permeability and porosity decrease upward. Petrographically, sands are similar to those in channel 3, typically moderately well sorted fine grained lithic arkose and feldspathic litharenites.

Sand percent and thickness associated with channel 4 is shown in Figs. 57 and 58. Sand percent is somewhat less than that in the previously discussed channels, averaging about 40 percent but reaching as high as 50-60 percent on the inside of meander loops where point bar thickness is at a maximum. Sand thickness corresponds naturally with sand percent being the thickest on the inside of meander loops (20-25 feet) and thins abruptly to the channel margins.

Channel 4, although not well expressed stratigraphically in section E-E', is better shown in sections Y-Y' and Z-Z' (Fig. 22) where it truncates channels 1A, 2, and 3.

Fluvial marine. Fluvial marine sediment which stratigraphically occupies the middle unit (1B) discussed earlier is penetrated in only one core (F5-42). Lithologically, the fluvial-marine sediment at this locality is predominantly silts and clays which show massive, burrowed, mottled, and contorted bedding. Ostracods associated with the fluvial marine environment include Candona lactea (dominant), Cyprideis torosa, Candona obtusa, and Cypridopsis vidua. These species represent a salinity range from fresh to brackish water which is what would be expected in a fluvial-marine environment. Thin cross-bedded sands are

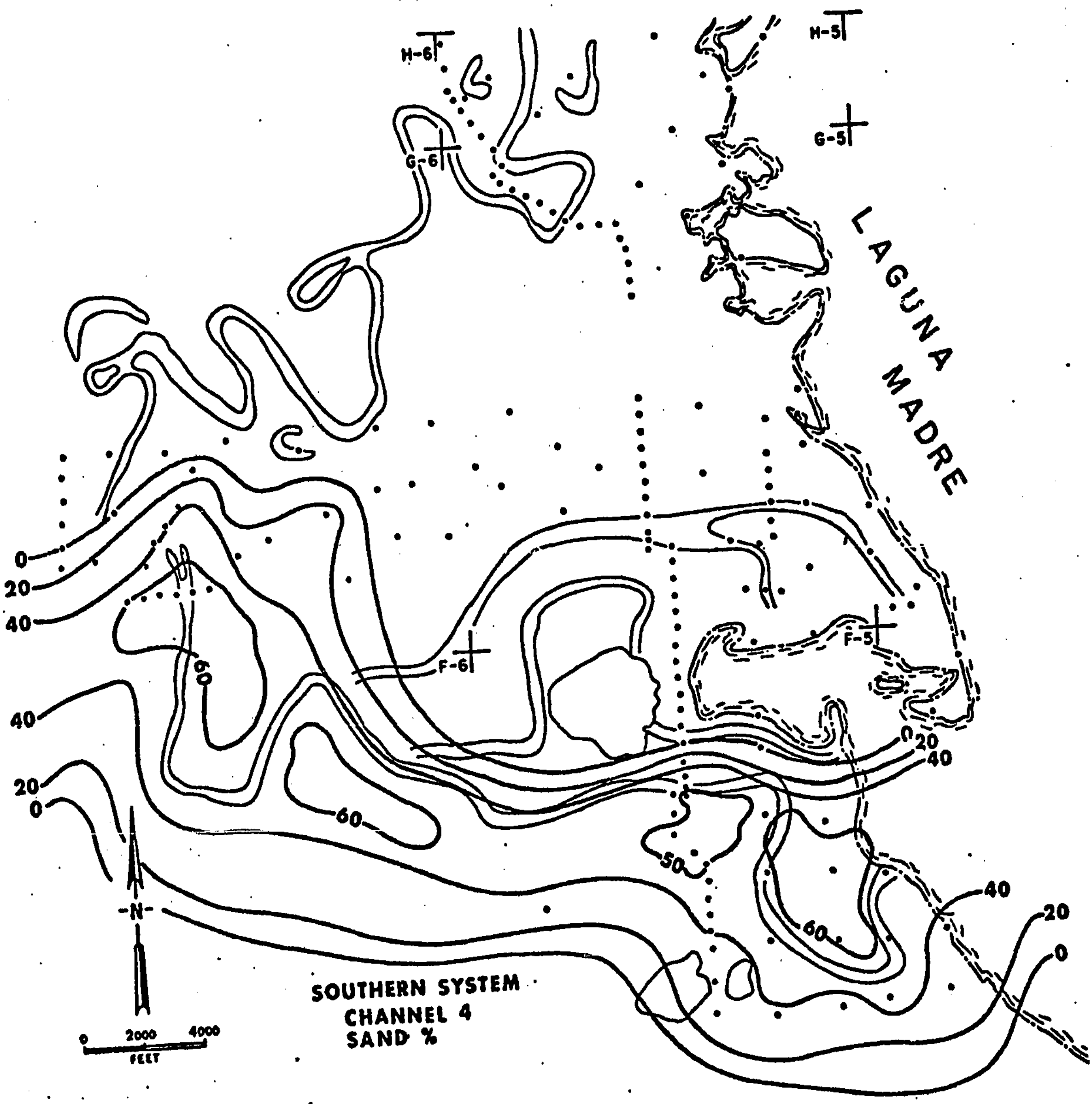
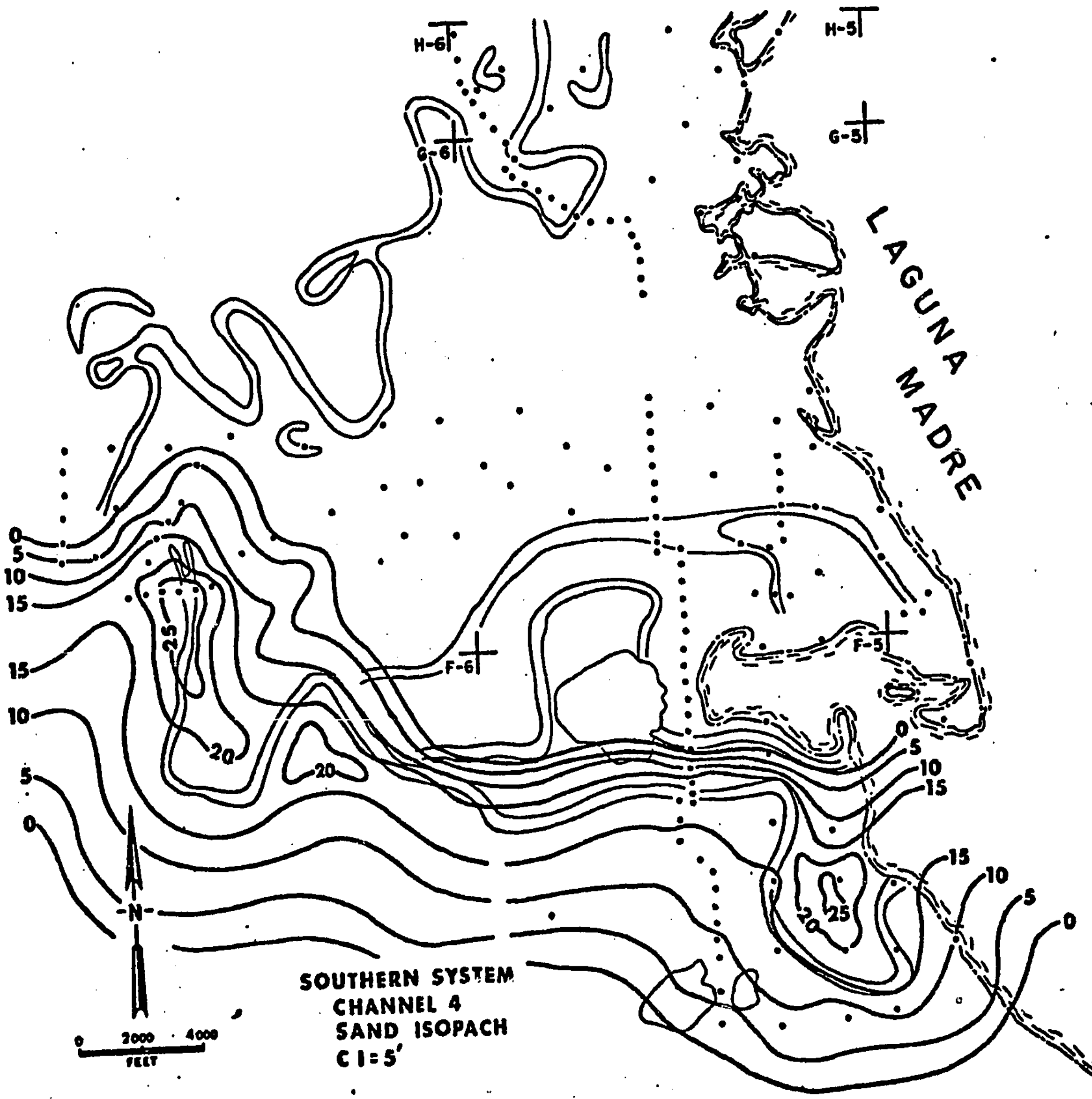

H-6
H-5
G-6
G-5
LAGUNA MADRE
F-6
F-5
0
20
40
40
20
0
60
60
60
50
60
40
20
0
20
40
-N-
0 2000 4000
FEET
SOUTHERN SYSTEM
CHANNEL 4
SAND %

Fig. 57



H-6
H-5
G-6
G-5
LAGUNA MADRE
F-6
F-5
0
5
10
15
15
10
5
0
25
20
20
20
25
0
5
10
15
15
10
5
0
N
0 2000 4000
FEET
SOUTHERN SYSTEM
CHANNEL 4
SAND ISOPACH
C I = 5'

Fig. 58

present especially at the base of the unit. These sands are moderately sorted, have about 40 percent silt and clay, a permeability of about 100 millidarcys, and a porosity of 15 percent.

Sands within this fluvial marine environment (as in the De la Gringa system) are fairly continuous as a consequence of their being reworked by marine conditions in front of a source of sediment supply. Thicknesses of the total fluvial marine bundle (sands, silts, and clays) is quite erratic and in many places entirely eroded by overlying fluvial activity. Because of this fact, as well as lack of data due to absence of drill holes, a sand percent and isopach of the fluvial marine environment in this system was not attempted. An approximate erosional limit of fluvial marine sediment is shown in Fig. 59. Generally sand percent of this environment ranges 20-40 percent. Thickness of course is variable being as much as 40 feet where slightly eroded to absent where truncated by channels; average thickness is estimated at 20-35 feet.

Prodelta. The prodelta environment (lower unit stratigraphically) is very similar to that discussed for the De la Gringa system, i.e. it contains thin discontinuous lenses and pods of sand surrounded by silts and clays. Sand percent (Fig. 60) of the prodelta system ranges from 10-15 percent at the margins to 25-30 percent toward the center where a source of sediment either directly from fluvial input or eroded from the fluvial marine source was available. Because the prodelta sediment of this system was deposited previous to that of the De la Gringa system, it is onlapped from the north as is shown nicely in section A-A'

Fig. 59

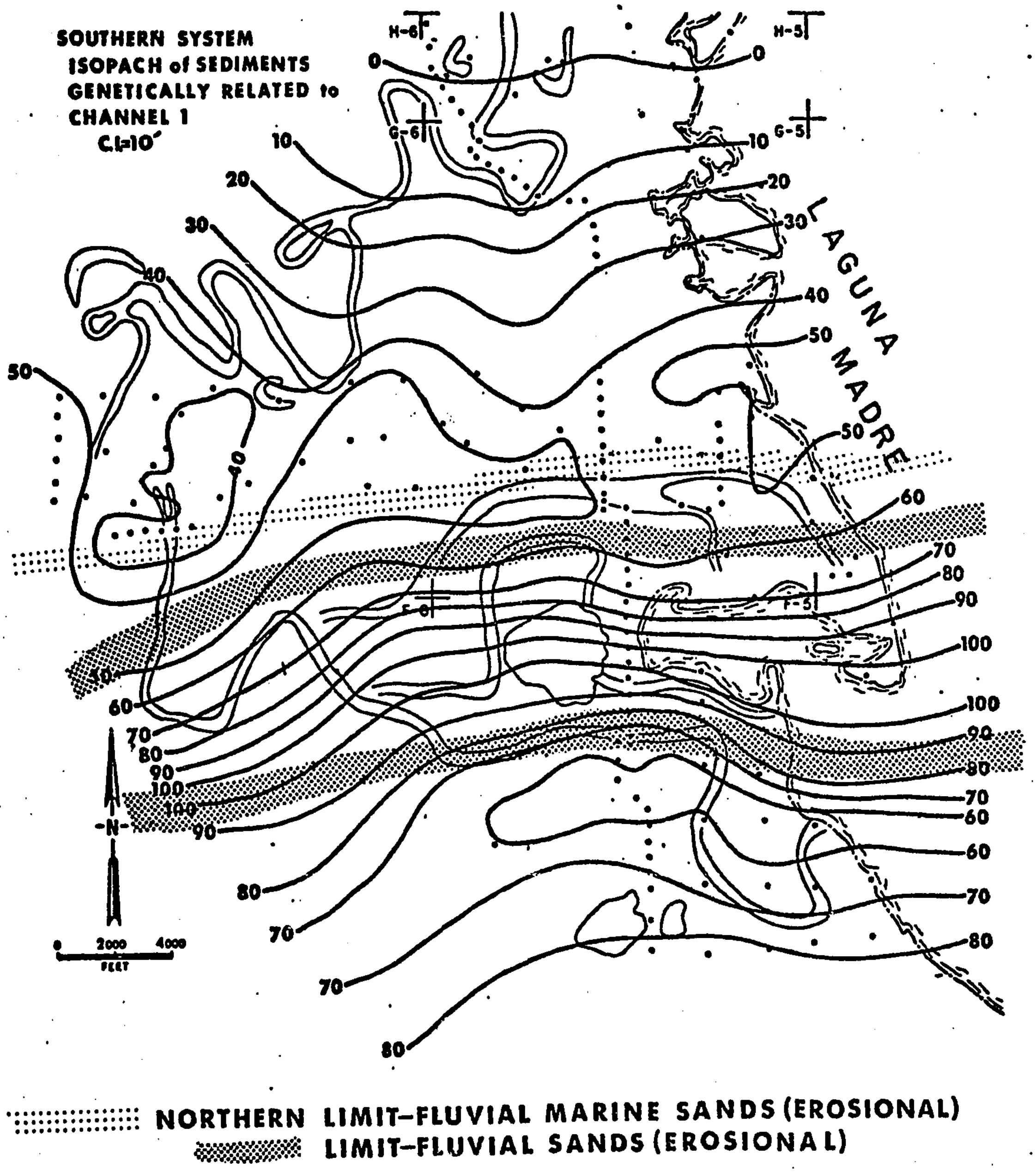
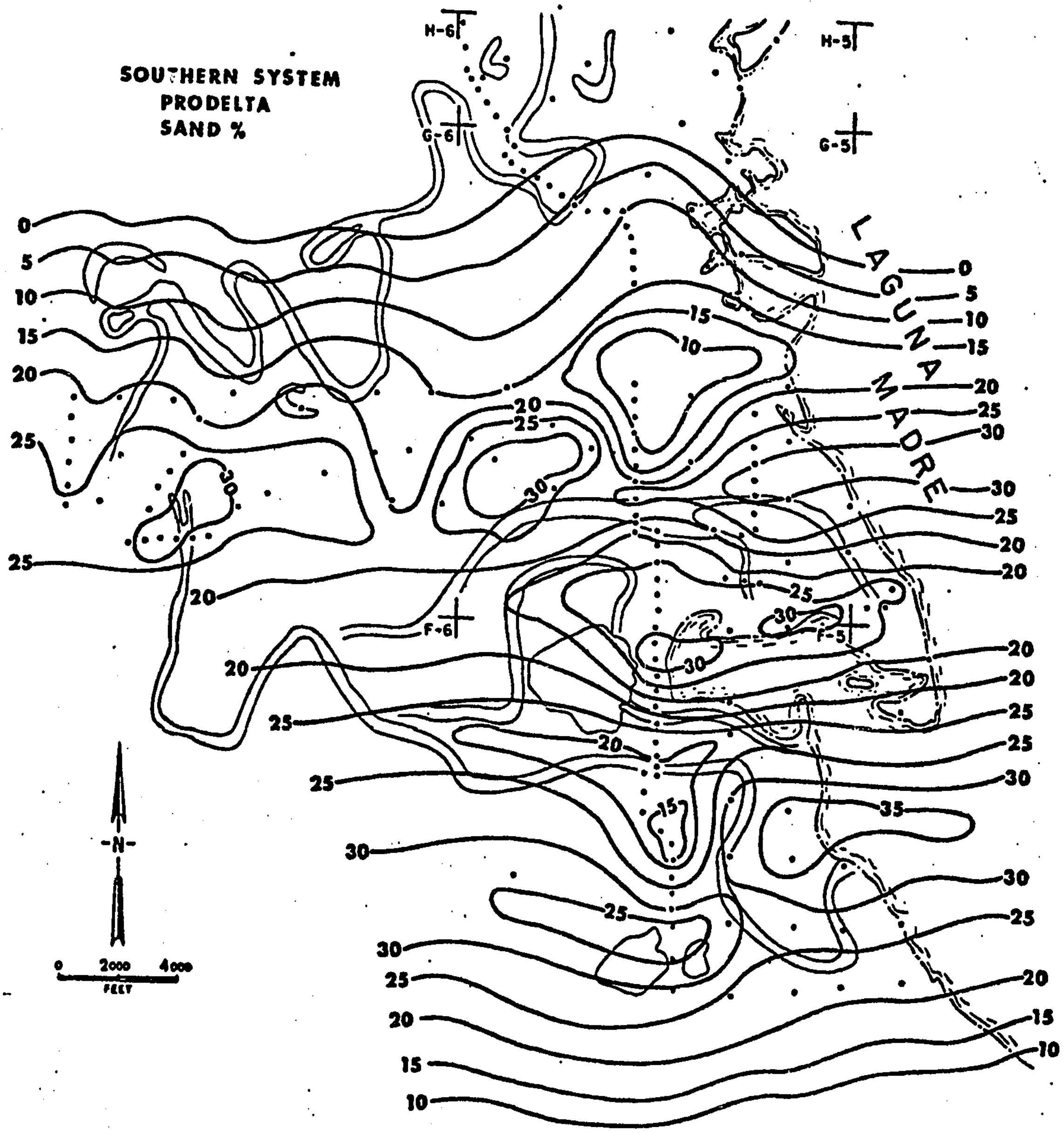

SOUTHERN SYSTEM
ISOPACH of SEDIMENTS
GENETICALLY RELATED to
CHANNEL 1
C.I=10'
LAGUNA MADRE
H-6
H-5
G-6
G-5
F-6
F-5
N
0 2000 4000
FEET
NORTHERN LIMIT–FLUVIAL MARINE SANDS (EROSIONAL)
LIMIT–FLUVIAL SANDS (EROSIONAL)

Fig. 60


SOUTHERN SYSTEM
PRODELTA
SAND %
LAGUNA MADRE
H-6
H-5
G-6
G-5
F-6
F-5
-N-
0 2000 4000
FEET

(Fig. 52). Because the origin of sand lenses in this unit is similar to that discussed for the prodelta of the De la Gringa system, it will not be reiterated here. The reader is referred to that section for elucidation of processes producing the sands of the unit.

Nearshore Open Marine. The basal transgressive sand nearshore open marine is simply a continuation of the sand underlying the De la Gringa unit and the discussion will not be repeated here.

LITHOFACIES

Lithofacies mapping of the entire sediment package associated with the De la Gringa and Southern systems is shown in Fig. 61. Clayey sand, silty sand, and sandy silt dominate the sediment pattern and define very nicely the channel systems. Sandy clay and sand-silt-clay are the common lithofacies on the margins and between the two channel systems. On the outer flanks of the distributary plain, in areas occupied by interdistributary troughs, clayey silts are the dominant lithologic pattern.

1. Sand
2. Clayey Sand
3. Silty Sand
4. Silt
5. Sandy Silt
6. Clayey Silt
7. Clay
8. Sandy Clay
9. Silty Clay
10. Sand-Silt-Clay

Fig. 61. Lithofacies - De la Gringa and Southern systems.

CL
8
2
10
1
SS
SL
RESACA
de-la
GRINGA
LAGUNA
MADRE
-N-
0
10,000 ft
1 MILE
Bore hole
Core hole
Deep hole
Cuttings

CHRONOLOGY OF DELTA DEVELOPMENT

DE LA GRINGA AND SOUTHERN SYSTEMS

It is obvious from the previous discussion that the De la Gringa and Southern systems developed as two separate events. The development of the Southern system was as follows: (a) The oldest channel (1A) prograded seaward of the present shoreline developing a fluvial marine and prodelta sequence both of which are now only partially preserved; (b) when the extended gradient of channel 1A became unfavorable for progradation, sedimentation shifted (probably up the fluvial valley) to a position which resulted in development of channel 2 to the north. Because of a higher gradient this channel eroded into the delta flank of channel 1A destroying previously deposited fluvial marine sediments; (c) when the gradient of channel 2 became unfavorable for further progradation it too was abandoned, which resulted in subsidence and marine erosion of its flanks. The fluvial pattern then shifted into the low between channel 2 and 1A (forming channel 3), which truncated previously deposited sands, silts, and clays; (d) final shifting took place by up slope diversion to form channel 4 which eroded the south flank of channel 1A and incised only slightly previously deposited fluvial marine sediments; (e) with the development of channel 4, sedimentation ceased in the Southern system and the De la Gringa system prograded to the north depositing prodelta, fluvial-marine, and fluvial sediment away from the flanks of the Southern system. As noted before, it is possible that destruction and erosion of the northern flank of the Southern system produced sands, silts, and clays which are considered prodelta sediment of the De la Gringa system. If that's the case, the De la Gringa distributary probably prograded into fairly shallow (<70 feet) of water.

RELATION OF DELTA PROGRADATION TO SEA LEVEL RISE

The progradation and development of Resaca De la Gringa and the Southern system is closely linked to post-Pleistocene sea level rise. During the early rising sea level stage (10,000-9400 B.P.?) the Rio Grande entrenched valley was drowned and an estuary is believed to have existed in the area now covered by the delta plain (Leblanc and Hodgson, 1959, p. 206; Nelson and Bray, 1970, p. 67). It was during this period of rapidly rising sea level that the basal transgressive sand was probably formed through reworking and destruction of previously deposited fluvial sediment. Cuttings from cores F5-40 and H5-89 penetrate gravel at 160 and 140 feet respectively. It is suggested that this gravel represents the old Pleistocene fluvial surface that lies below the basal transgressive sand which is here interpreted as the base of the Holocene. From 9400 B.P. to 3600 B.P. sea level rose rapidly (except for a minor 10 foot regression at 7800 B.P.) until it reached its present level approximately 5000-3600 years B.P. (the former age; Leblanc and Hodgson, p. 206, the latter Nelson and Bray, p. 69). During this interval both the Southern system (7000 B.P.) and the De la Gringa system (5000 B.P.) prograded their deltas seaward of the present shoreline (see Lohse, 1958, and 1975, p. 532). At the beginning of the standing sea level stage (5000 B.P., Leblanc and Hodgson; 3600 B.P., Nelson and Bray) barrier chains began forming (culminating in the present Laguna Madre) and the Rio Grande subdeltas were transgressed and eroded.

One problem remains and does deserve mention - that is, why is the Rio Grande delta plain presently so far above sea level? Although interdistributary lows are only 1-2 feet above sea level, natural levees rise 10-15 feet above the sea level datum. In addition, in core H5-88, from 0-6 feet depth which at maximum is still 3 feet above sea level which is at -9 feet, marine forams such as Ammonia, Elphidium, and Protoelphidium are present. This core was taken at a position away from the interdistributary lows and it is unlikely that the 1.5 foot western Gulf tides (Lohse, 1968, p. 30) could have affected it although storm generated (hurricane?) waves could conceivably have pushed marine waters over the area where the core was taken.

Two possibilities exist that could explain the high standing natural levees and delta plain. One is that the delta has been slightly uplifted in Recent times. This, however, seems highly unlikely, as delta regions are characterized by subsidence and compaction. It is, nonetheless, a possibility as so-called "clay dunes" flanking the delta plain may be fault scarps reflecting recent tectonism. The second alternative is that sea-level has been somewhat higher than present in post-Pleistocene time. The major proponent of this school of thought is probably Fairbridge (1958, 1961). In his 1961 work (p. 177), Fairbridge cites 4 periods since 6000 years B.P. when sea level could have been higher: Older Peron Submergence 10-15 feet* (6000-4600 B.P.), Younger Peron Submergence 10 feet* (4000-3400 B.P.), Abrolhos Submer-

*Above present sea level.

gence 5-6 feet* (2600-2100 B.P.), and the Rottnest Submergence 2-3 feet* (1600-1000 B.P.). These periods are interspersed with minor regressions of 2-3 feet. Shepard (1960, p. 340), in his discussion of the rise of sea level along the northwest Gulf of Mexico, considers Fairbridge's claim of high standing post-Pleistocene sea level but concludes that "it is conceivable but very improbable."

That data used by Fairbridge in many instances is world-wide (including Gulf Coast) and is carefully cognizant of factors such as tilting, warping, "old" C-14 incorporation, and compaction. Gulf Coast data is especially susceptible to compaction rates which complicate sea level studies. For instance, deposits associated with the Younger Peron submergence (3 meters-3550-38000 B.P.) in the Mississippi delta are now -2 to -4 m. below datum, indicating a not unreasonable compaction rate of 1.5-2 mm/year or a total of 5.7 m.

The 1961 article by Fairbridge is long, detailed, argumentative, well referenced, and is mentioned here only briefly. Furthermore, data from this study does not confirm or deny a higher standing post-Pleistocene sea level, but it certainly is a more reasonable hypothesis than "delta uplift" and suggests that careful geomorphic and geochronologic studies (especially of chenier ridges such as the Perdue chenier, Louisiana) could be helpful in further solving or complicating the problem of post-Pleistocene sea level changes.

*Above present sea level.

DELTA MODEL

Previous discussion of stratigraphy and depositional environments of the De la Gringa and Southern systems can be incorporated into a generalized model typical of shallow water deltas. The Rio Grande distributaries of the present study are particularly applicable to the model as they encompass both an upslope element (thick fluvial sand of the Southern system) and a downslope element (fluvial and fluvial-marine sands of the De la Gringa system).

The delta model with six associated serial cross-sections is shown in Fig. 62. The following discussion of depositional environments associated with the model is from the furthest downslope section to the highest upslope sequence. The downslope section begins with the deposition of isolated sand elements on the prodelta and delta slope (section A-A'). These prodelta sands are thin, imbricated pods, and lenses which are probably eroded from the upslope fluvial marine sands, or deposited as isolated events when sediment bypasses the river mouth bars during periods of high sediment influx. Next (section B-B') is the deposition of distributary mouth bar sands and submarine levee deposits. These distributary mouth bar sands when subjected to marine current and wave action culminate in the fluvial-marine sands characteristic of the De la Gringa sequence. Section C-C' shows the progradation of subaerial levee deposits and the beginning of excavation by fluvial processes onto the underlying fluvial-marine sands. Bay deposits are present flanking the fluvial-marine and natural levee sequences. With further progradation (section D-D'), the principal process is the

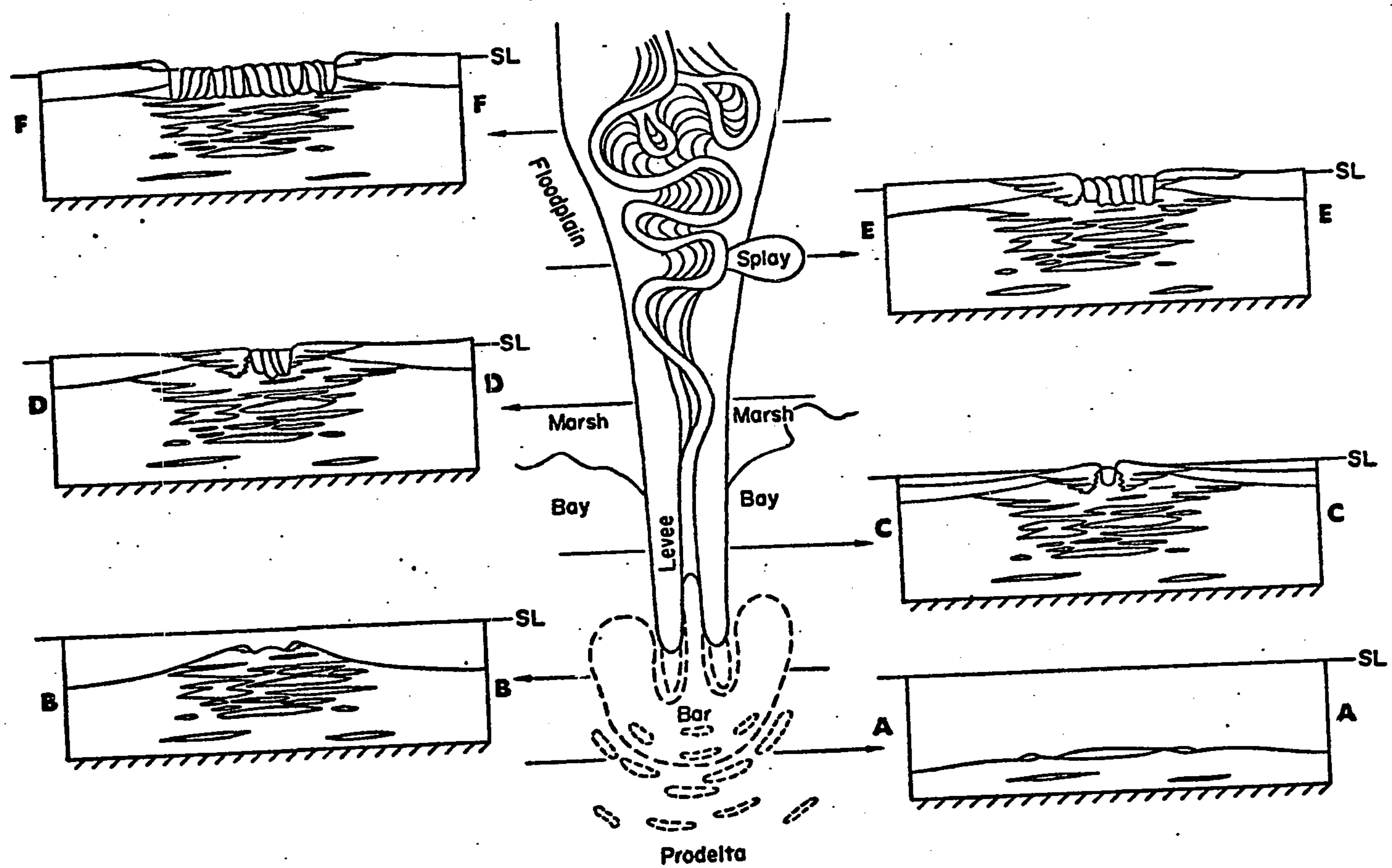


Fig. 62. Delta model--Rio Grande (see text for discussion of cross-sections).

initiation of meander belts with erosion of underlying units and adjacent marine levee units. Occurring simultaneously with the beginning of meander processes is the lateral accretion of point bar deposits and the building of marsh and subaerial levee deposits. As progradation continues, the meander system develops wider loops and deeper erosion of the distributary bar sands and levee deposits occur. Splay deposits begin forming on the outside of meander outbanks (section E-E'). The final stage is the development of a wide multiple meander belt with cut-offs and clay plugs (section F-F'). Meander processes destroy most of the upper part of the distributary system and levee system. The end result is a multistory sand unit, composed of remnants of a lower coarsening upward distributary sequence, unconformabley overlain by a fining upward sequence. Distributary abandonment and shifting of channels results in the complex sedimentary body arrangement as shown in section F-F'.

The model developed here is somewhat similar to the model developed for the Lower Wilcox (Eocene) shallow water deltas (see Fig. 63) after Fisher and McGowen. The model also corresponds closely to that developed for the shallow water Guadalupe delta by Donaldson (see Malone, 1971, p. 11A), as shown in Fig. 64. As Malone (p. 11) points out, the diagnostic characteristic of the shallow-water delta is that the channel commonly cuts entirely through the previously deposited delta sequence. The channel may at times scour deeper than the bay depth resulting in channel sands resting directly on bay or sea floor sediments which is characteristic especially of the Southern system of the Rio Grande.

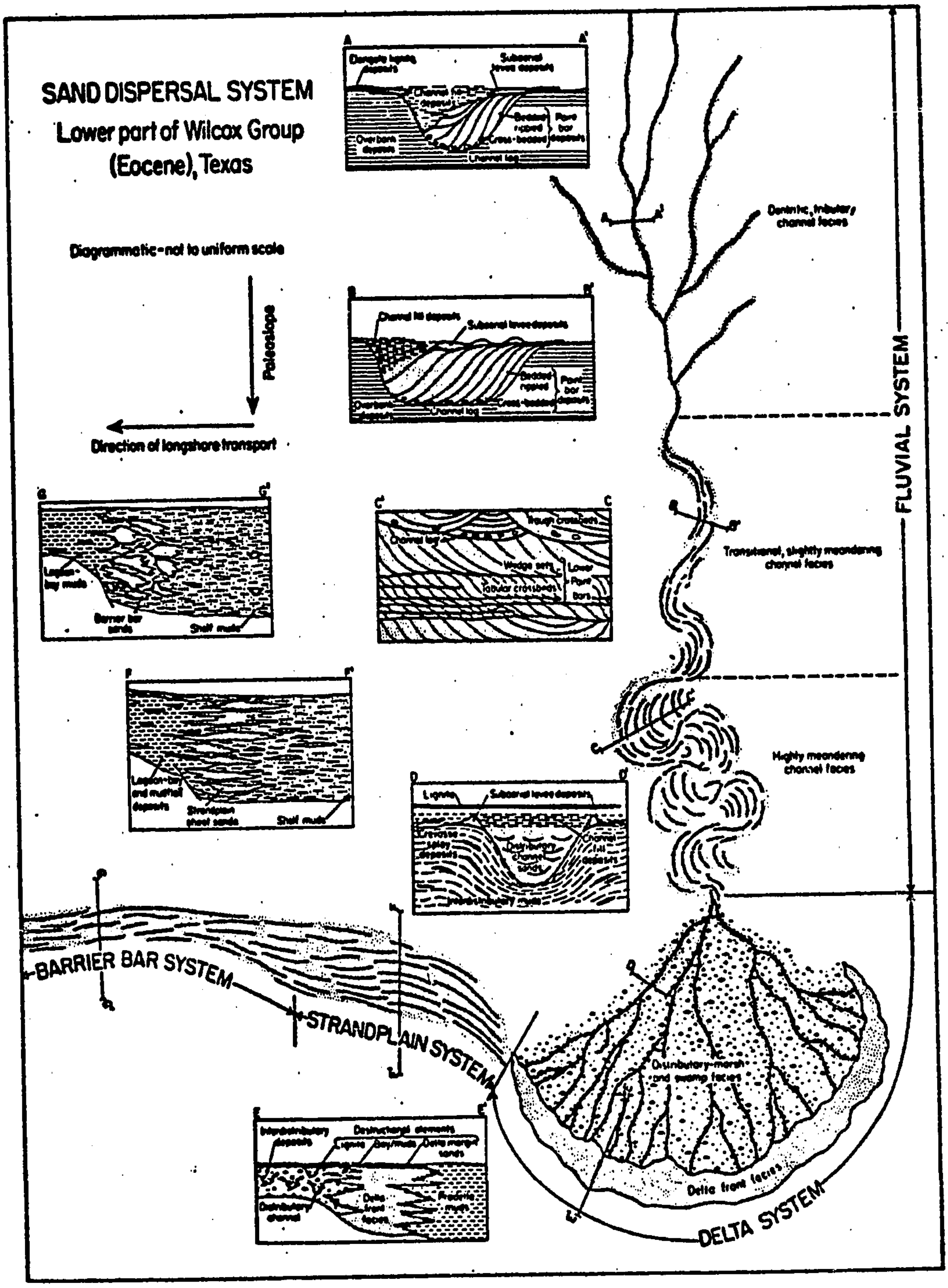


Fig. 63. Sand dispersal system, Lower Wilcox high-constructive delta and associated depositional systems, after Fisher et al, 1969, Fig. 62).

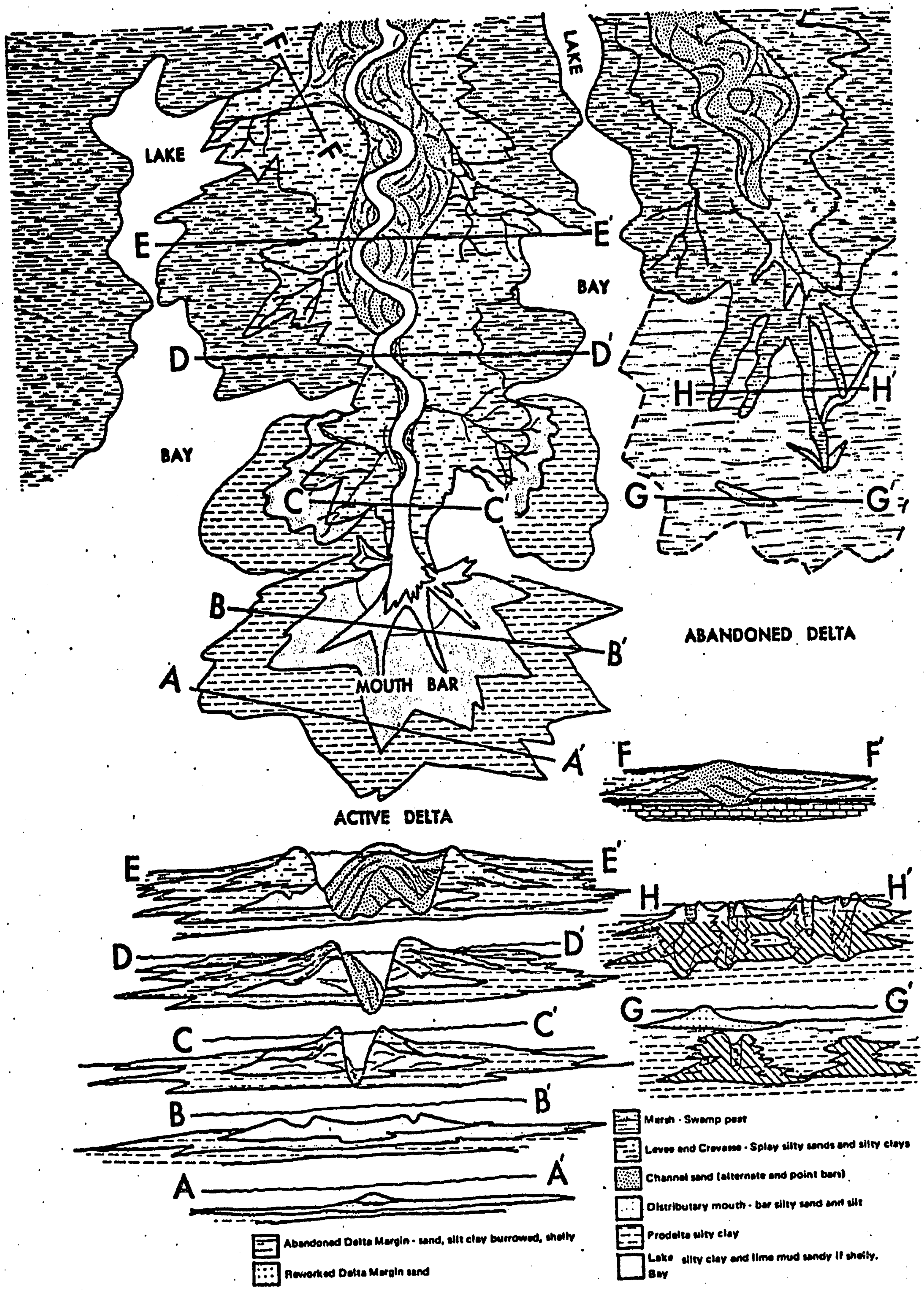


Fig. 64

Hypothetical model of a shallow-water delta (Guadalupe type). Cross sections A-A' through F-F' indicate lithofacies of actively prograding subdelta. Cross sections G-G' and H-H' show marine-dominated lithofacies overlying abandoned delta.

(After Malone, 1971, p. 11A).

RELATIONSHIP OF THE RIO GRANDE TO GENERAL DELTA MODELS

Various authors in recent years have proposed general stratigraphic classifications of delta systems. Among these the most notable are Fisher et al. (1969, p. 31) and, more recently, Coleman and Wright (1975, p. 123). Galloway (1975, p. 92) has proposed a ternery classification system with three end members - fluvial, wave, and tide dominated. Although Coleman and Wright's classification is extensive, usage is somewhat awkward as deltaic models are indicated by a Roman numeral type, i.e. I, II, etc., which then necessitates further description. The classification proposed by Fisher et al. is, as a good classification should be, rather general, simple to use, applicable to many delta types, and easily transferrable to Galloway's ternery diagram.

The classification proposed by Fisher et al. is as follows (1969, p. 29):

HIGH CONSTRUCTIVE DELTAS:	Preponderance of fluvial or fluvially influenced facies
Lobate type:	lobate delta front sand geometry
Elongate type:	elongate or bar finger sand geometry
HIGH DESTRUCTIVE DELTAS:	preponderance of marine facies
Wave dominated:	cuspate, strike-oriented sand trend
Tide dominated:	commonly digitate or elongate tidal sand bodies

Fluvial and marine processes as related to these delta types are shown in Fig. 65.

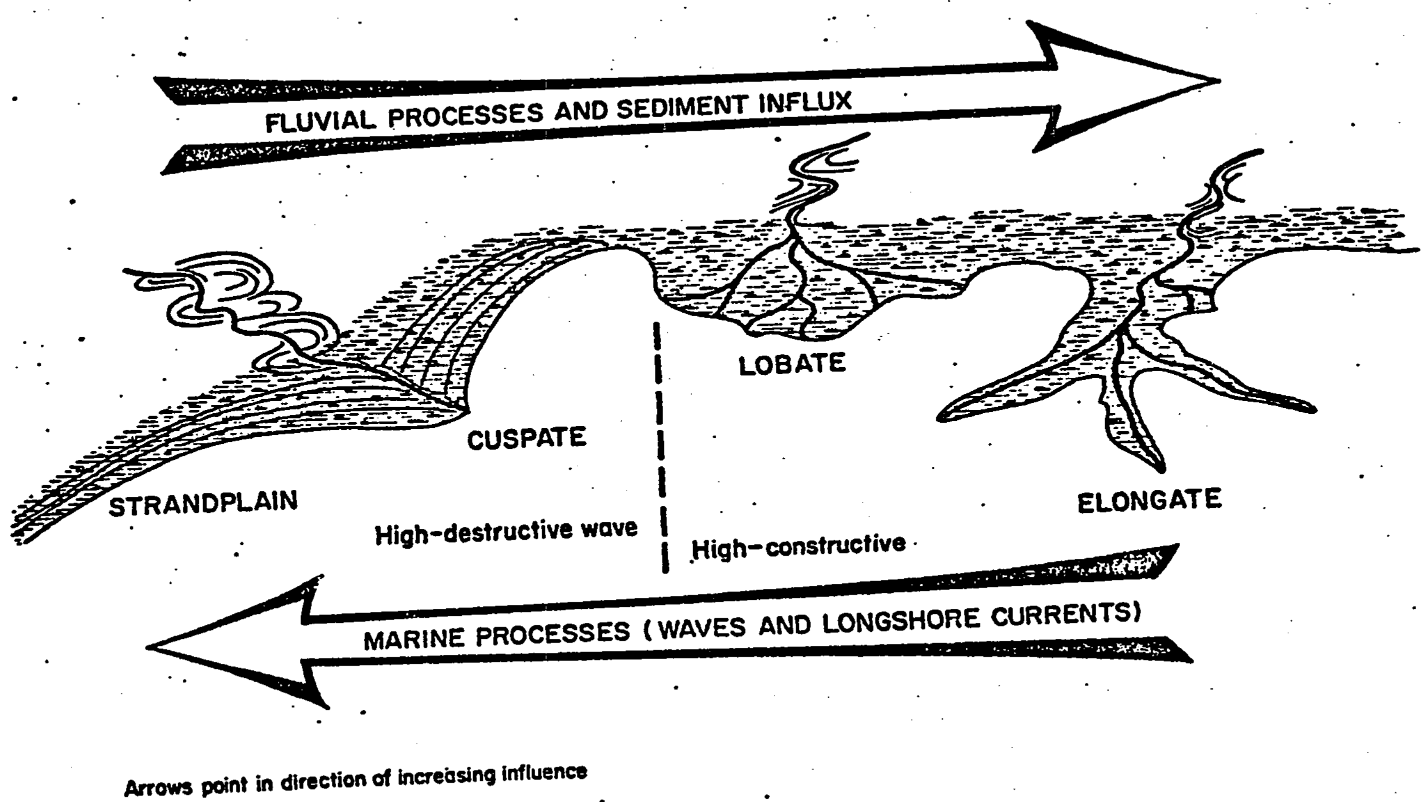


Fig. 65. Fluvial and marine processes in relation to delta types (after Fisher <u>et al</u>, 1969, Fig. 7).

Anyone who has done extensive research or worked with delta systems realizes that almost every single delta is unique depending on source, climate, structural setting, wave energy of the marine reservoir, sediment input, etc., which is why Coleman and Wright have such an extensive, complicated classification. The Rio Grande delta is no exception to this classificatory problem and, although is of constructive nature, has characteristics of both lobate and elongate types. This is not in itself unusual and is in fact typical of Lower Wilcox (Eocene) deltas (Fisher et al., 1969, p. 42) which, as discussed previously, are similar in nature to the Rio Grande delta.

Three main groups of facies characterize the lobate high-constructive deltas of the Lower Wilcox which are here compared to the Rio Grande. (It must be kept in mind that descriptive terms such as thick, thin, intensive, etc., are not totally applicable when comparing deltas of different chronological or physical systems, although the process is essentially the same). The three facies are: (1) an extensive delta plain made up of thick distributary channel sands and a variety of interdistributary or non-channel deposits, (2) a down dip delta front facies consisting chiefly of sands, and (3) a "gulf-ward" prodelta facies made up mainly of dark, organic rich laminated muds.

The description of these facies is very similar to that of distributary systems of the Rio Grande. The description of these facies is given below (after Fisher et al., 1969, p. 31-32) for comparison purposes.

The fluvial sands (of the lower Wilcox deltas) occurring updip of the delta system consists of sand bodies made up of several coalescing channel lag, lower point bar, and chute front deposits which accumulated chiefly as multilayer, coarse-grained meander belt units. On subsurface logs this facies shows a characteristic bell-shaped resistivity pattern, marked by a sharp basal deflection and a gradually decreasing deflection in the upper part showing the transition from channel sands to muddy levee and overbank deposits.

Characteristic features of the delta plain facies are elongate sand bodies that show a distinctive pattern in plan and symmetry in cross-section, alternating with lignite-bearing interdistributary muds and thin, crevasse splay and levee sands and silts. The non-channel pattern is marked by thin, poorly developed sands (crevasse splay and levee deposits), muds (interdistributary bays and floodplain deposits), and lignites (interdistributary marsh and swamp deposits).

Several depositional units are recognized in the delta front sand facies which accumulated seaward of the delta plain. Immediately at the terminus of distributary channels and forming a prominent sand unit in the delta front facies is a characteristic progradational sequence, marked by upward coarsening and increasing sand content. The lower part of the sequence consists of more distal sands and silts of the delta front interbedded with prodelta muds, grading upward to thicker sands of the upper part of the channel mouth bar. Seaward or downdip of the distributary mouth bar sequence in what are designated by Fisher et al. as delta front slope and distal delta front units, sands decrease in amount and thickness and generally become muddy. Downdip and seaward of the delta front facies, sands are gradually lost and the sequence consists entirely of prodelta muds. This section is particularly characteristic of the Rio Grande delta with the distributary mouth bars (and subsequent marine reworking) producing the fluvial marine sands typical of this study.

Fisher et al. (1969, p. 32) further mention that in the lobate type of high-constructive delta there is some marine reworking of delta front sands, producing a coalesced, continuous lobate sand fringe (probably similar to Fisk's delta front sheet sands). These continuous sand sheet are not typical of the Rio Grande delta system although reworking of fluvial marine sands by wave action does produce discontinuous sand downdip of the distributary mouth bars. Because of this the Rio Grande distributaries have characteristics typical of elongate high-constructive deltas. In the elongate high-constructive deltas (Fisher et al., p. 33) most of the delta facies are shown in a single sequence, beginning with prodelta muds, upward through distal, slope, and distributary mouth bar sands of the delta front; these sands are overlain by aggradational delta plain facies (levee, channel fill, crevasse, marsh, swamp, interdistributary bay, and floodbasin deposits). The vertical variety of facies in the elongate deltas sequence contrasts with the prominent vertical persistence of specific facies in lobate high-constructive deltas.

Further discussion of the differences between lobate and elongate constructive deltas would probably belabor the point. Let it suffice to say that the Rio Grande delta lobe (Los Cuates) under discussion here is of the lobate-elongate constructive type. Its relationship to other such deltas is shown in Fig. 66, which is a schematic diagram after Galloway (1975, p. 92) illustrating the three field division of deltas into fluvial-dominated, wave dominated, and tide dominated types.

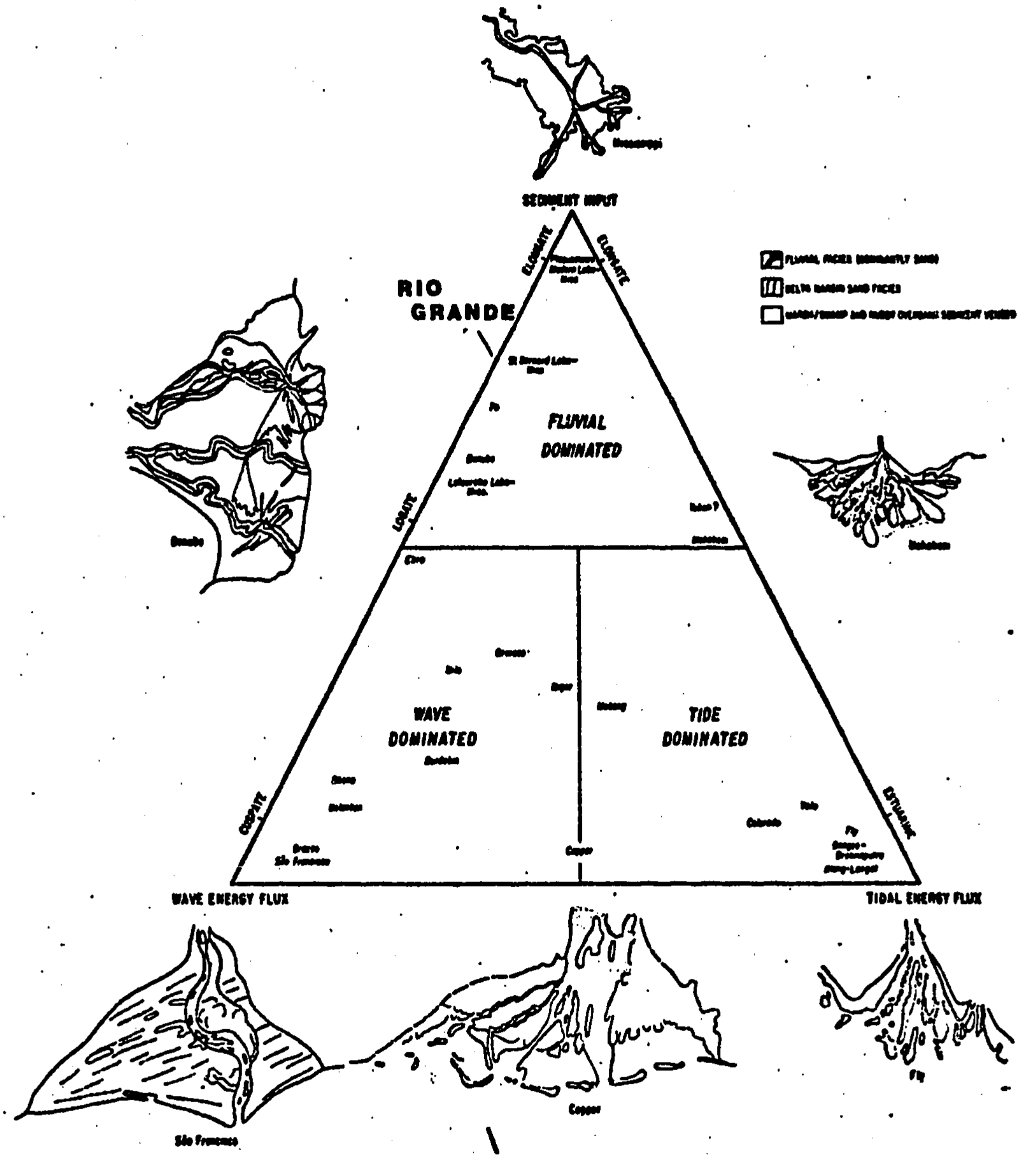


Fig. 66. Triangular classification of deltaic depositional systems (after Galloway, 1975, p. 92).

CONTINUITY OF SANDSTONE BODIES

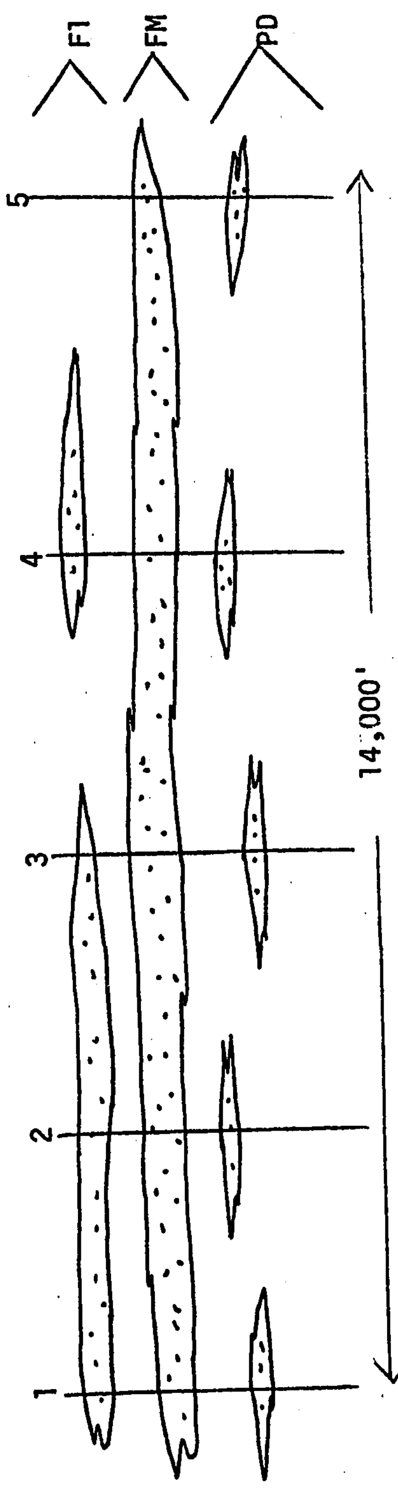
When this study was originally initiated by Dr. Pryor at Gulf Research and Development Co., it was designed to gain better understanding of sandstone geometry, trend, and continuity in deltaic systems. Hence, the drilling program was based on closely spaced drill holes (500-2000 feet) to provide what is probably the most detailed stratigraphy available on delta distributary systems. Historically, the Fisk model of distributary bar sand bodies has been known for 20 years and has served well in the understanding of deltaic deposition and prediction of ancient analogues. Other delta systems (such as those referred to and discussed in this study) have been added since then and have verified the Fisk model geometries, but have added little to the details of sand body geometry related to delta distributaries. Non-critical use of the Fisk model and subsequent generalized studies of delta systems have led us to think of the bar finger sands and delta front "sheet sands" as relatively uniform sand masses with very little variation other than a coarsening upward sequence. Since the internal stratigraphy and style of these sand bodies are poorly known, the present study has dealt heavily with stratigraphic analysis to point out and delineate deficiencies and shortcomings in previous models and to suggest a more reasonable (although complex) nature of deltaic associated sands.

It was felt necessary to carry the stratigraphic analysis one step further in order to place a continuity index (both lateral and vertical) on sands associated with the delta progradation. This type of study is difficult, especially since no previous studies are available for comparison. The only other study which may be similar is that by Polasek and Hutchinson (1967, p. 405), who attempted to devise a heterogenity factor (HF) for predicting reservoir behavior. Their HF, however, is plagued by the fact that it is not related to depositional environment, has no predictive qualities, says nothing about sandstone trends, and is poorly presented making it extremely confusing and difficult to use.

With that in mind, it is attempted here to devise an index which is generally applicable to delta systems, easily used, and is predictive concerning sandstone continuities in both a lateral and vertical nature as well as parallel and perpendicular to the direction of progradation.

In order to do this the two systems, De la Gringa and the Southern system, were separated as different entities. Cross-sections of equal length were set up in each system for the lateral continuity indexes. These cross-sections were selected both parallel and perpendicular to the direction of progradation. Because drill hole data is more abundant in the De la Gringa system, index cross-sections are naturally more abundant there (see Figs. 69 and 72).

Lateral continuity indexes were measured as follows (see Fig. 67): (a) cross-sections were made at approximately equal length for comparison purposes; (b) maximum and minimum sandstone continuities for each environment were measured at each section and that length was divided by the standard cross-section length; the resulting number being the continuity index for the sand in that section. Where sandstone bodies were numerous in each section (such as the prodelta environment), maximum, minimum, and average continuities were measured. This method is graphically shown below for clarity.



Env.	Max. Cont.	Min. Cont.	Max. Cont. Index	Min. Cont. Index	Avg.
FI	7,000	2,000	$\frac{7,000}{14,000} = .5$	.14	--
FM	14,000	N/A	$\frac{14,000}{14,000} = 1.0$	N/A	--
PD*	2,000	1,000	$\frac{2,000}{14,000} = .14$	.09	.12

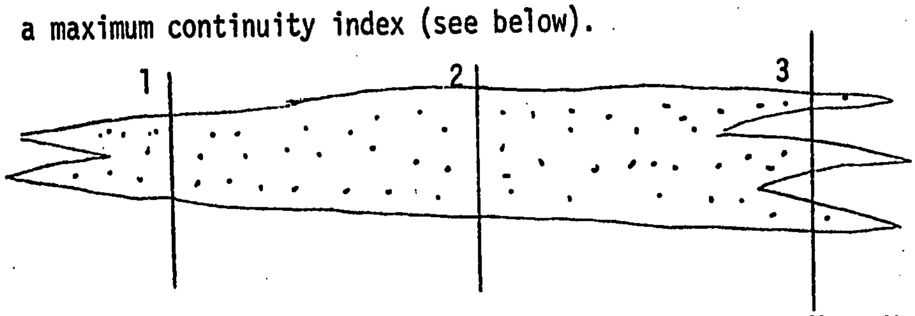
*Avg. Cont. based on 5 sand bodies. $\frac{15,000}{14,000} = .12$ = Cont. Index

This is done for sections both parallel and perpendicular to the direction of progradation.

Fig. 67. Method for measuring lateral continuity indexes.

Continuity indexes devised in this manner have connotations of depositional environment as well as trends (parallel or perpendicular) to progradation direction.

For purposes of a vertical continuity index (Fig. 68), the following method was used: (a) maximum sand thickness for each well for each environment was determined; (b) maximum continuous sand for each well for each environment was determined; (c) the thickness determined in step (b) was divided by the total thickness in step (a) resulting in a maximum continuity index (see below).



Env.	Well	Max. Th.	Max. Cont. ss Th.	Max. Vertical Cont. Index
Fl.	1	12'	6'	6/12 = .5
Fl.	2	15'	15'	15/15 = 1.0
Fl.	3	10'	2'	2/10 = .2

Fig. 68. Method for measuring vertical continuity indexes.

An index devised in this manner gives an indication of the maximum sand thickness uninhibited by clay or shale boundaries which tend to reduce sandstone permeability and porosity. In other words, it is the maximum continuity unbroken by boundary layers.

The resulting index number for each well can then be plotted in a manner similar to sand thickness or sand percent. In environments where sand bodies are numerous and approximately the same thickness, total average vertical continuities are more applicable than trying to contour continuities for each well.

One problem inherent to this vertical continuity index (V.C.I.) calculation is that many times sands will thin toward the edge of the depositional system but will nonetheless remain as a single unit - this tends to produce high vertical continuity indexes (i.e. 1.0) at the sand body edge. In fact, the boundary of channel sands (especially in the Southern system) is marked by a vertical index of 1.0, indicating a thin but continuous sand. This also points out the need for using sand isopach maps of the various environments in relation to the V.C.I. maps in order to predict maximum sand thickness as well as maximum vertical continuity. This problem of thin sands with a continuous thickness can be somewhat alleviated by simply multiplying average thickness of the sands by average V.C.I. This, in general, combines both vertical continuity and isopach thickness and shows at a glance the relative reservoir potential for individual environments in a vertical sense.

DE LA GRINGA SYSTEM

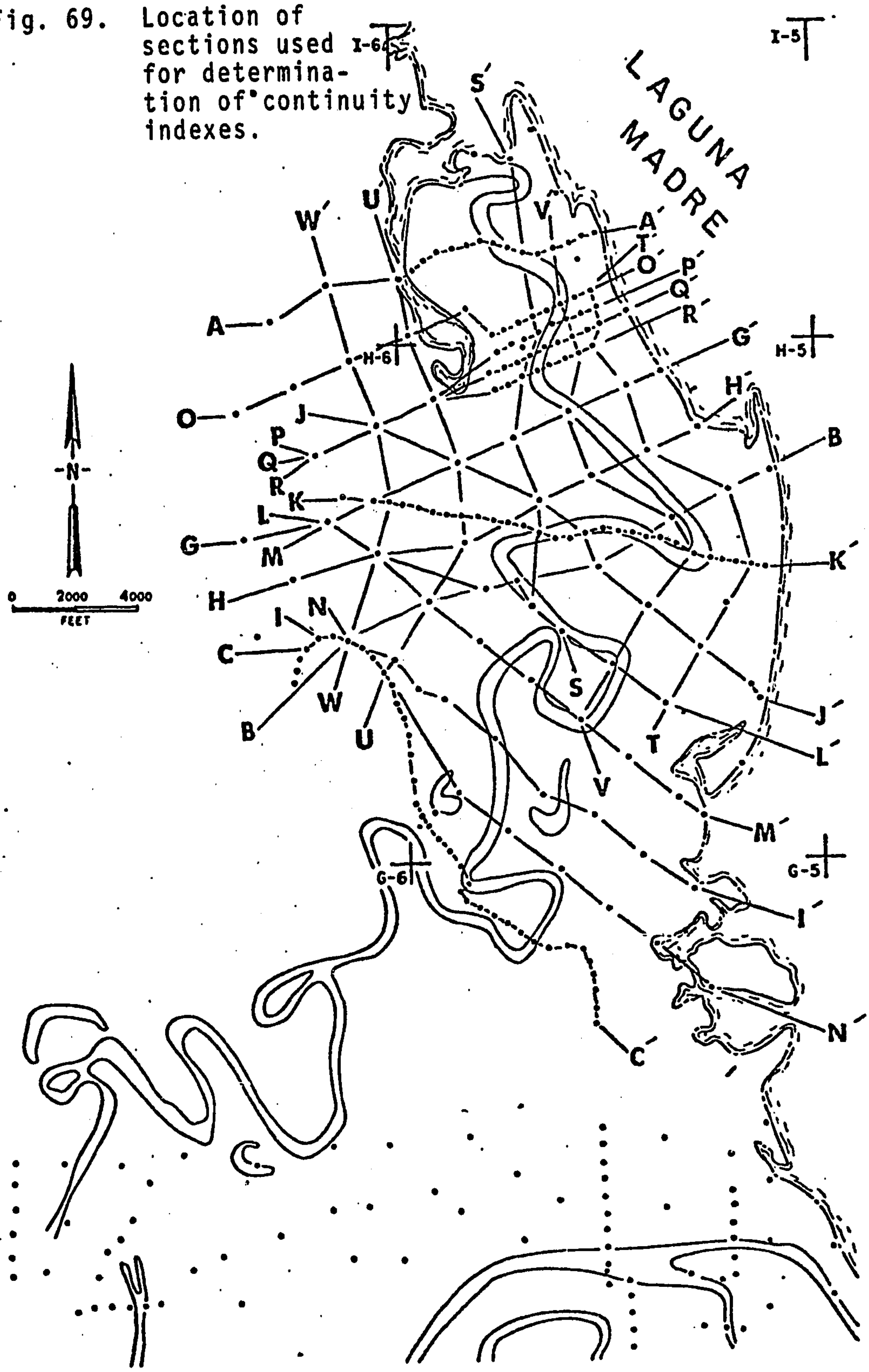
Fluvial. Twenty cross-sections were constructed in the De la Gringa system for determination of lateral continuity associated with fluvial sands. (The position of these sections is shown in Fig. 69). Fifteen sections were constructed perpendicular to the direction of progradation and 5 were constructed parallel. The resulting data is summarized in Tables XVII and XVIII. Perpendicular to the direction of progradation, maximum continuity is found in section L-L' (L.C.I.*= .71) while minimum continuity is in section A-A' and P-P' (L.C.I.=.14). Average maximum continuity is .49 while average minimum continuity is .45.

Parallel to the direction of progradation, maximum continuity is 1.0 (sections V-V' and T-T') while minimum continuity is 0.0 (where fluvial sands are lacking) to .21 (section S-S').

Average maximum continuity is .5 and minimum continuity is .4. Results of the L.C.I. for fluvial sands both parallel and perpendicular to the direction of progradation indicate that the indexes are approximately the same. One fact must be considered, however, if section W-W' and U-U' are omitted, the continuity of sands parallel to the direction of progradation is much better (.73-.83) than perpendicular to the direction of progradation. It seems legal to omit these sections, although they are included so that fluvial, fluvial-marine, and pro-delta sands have the same continuity index basis. It can be said that

*Lateral Continuity Index

Fig. 69. Location of sections used for determination of continuity indexes.



Sec	Length in Feet	Max Cont	Min Cont	Max Ind	Min Ind
K-K'	13,500	6,750	6,750	.5	.5
L-L'	14,000	10,000	10,000*	.71	.71
M-M'	14,000	9.000	9,000*	.64	.64
Q-Q'	11,000	3,200	3,200*	.29	.29
O-O'	13,000	2,400	2,400*	.2	.2
A-A'	13,000	8,400	1,800	.64	.14
P-P'	13,000	1,800	1,800*	.14	.14
R-R'	17,000	2,400	2,400*	.20	.20
B-B'	14,000	8,400	8,400*	.6	.6
H-H'	14,000	6,000	6,000*	.42	.42
G-G'	13,400	5,000	5,000*	.37	.37
J-J'	14,000	8,000	8,000*	.57	.57
I-I'	14,000	10,000	10,000*	.71	.71
N-N'	14,000	10,000	10,000*	.71	.71
C-C'	14,000	9,000	9,000*	.64	.64
				.49	.45

*indicates same sand body

Table XVII. Fluvial continuities, De la Gringa system, perpendicular to progradation.

Sec	Length in Feet	Max Cont	Min Cont	Max Ind	Min Ind
W-W'	14,000	not present 0	not present 0	0	0
U-U'	14,000	not present 0	not present 0	0	0
S-S'	14,500	7,000	3,000	.5	.21
V-V'	14,000	14,000	14,000*	1.0	1.0
T-T'	14,000	14,000	14,000*	1.0	1.0
				.5	.4
				(.83)	(.73)

*indicates same sand body.

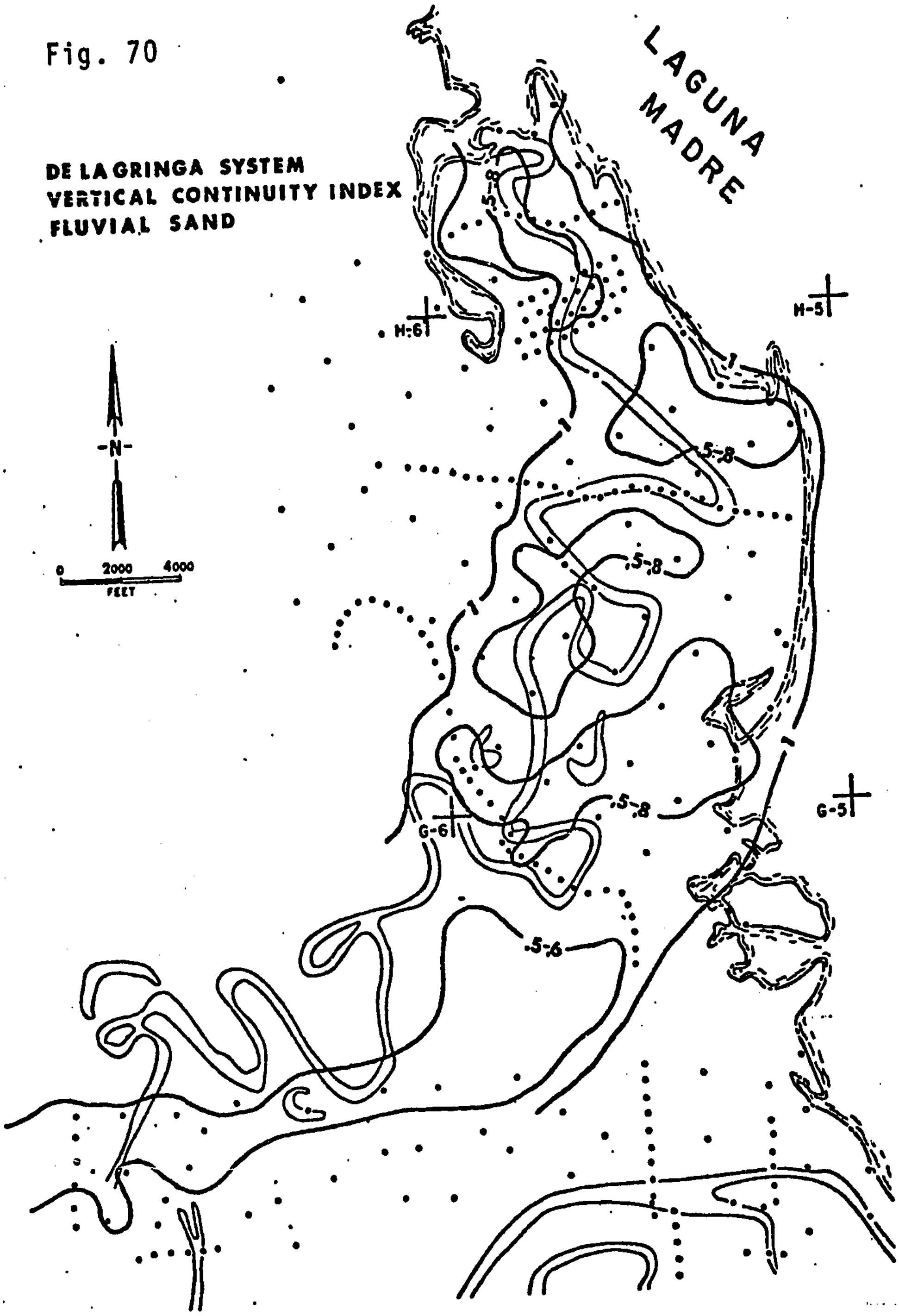
Table XVIII. Fluvial continuities, De la Gringa system, parallel to direction of progradation.

within the channel complex itself, continuity is better parallel than perpendicular to the direction of progradation. Perpendicular to progradational direction, fluvial continuity is hampered by clay drape deposits, channel filled clay plugs and overbank silts, and clays. Parallel to progradational direction these continuity boundaries, although present, tend to be masked by downdip meander system migration resulting in more continuous point bar accumulations.

Maximum vertical continuity index of fluvial sands for the De la Gringa system is shown in Fig. 70. Maximum continuities (1.0) occur toward the edge of the fluvial system and less distinctly toward the center. Combination of the sand isopach maps (Fig. 48) and V.C.I. map (Fig. 70) for the fluvial system indicates that the thickest continuous sands are near the center of the system where vertical continuities range from .5-.8 to 1.0 and thickness reach 20 plus feet. Vertical discontinuities toward the center of the system are undoubtedly caused mainly by clay drape deposits and cider incorporated flood plain silts and clays.

Fluvial-marine. Lateral continuity indexes associated with the De la Gringa fluvial-marine environment are shown in Tables XIX and XX. Location of cross-sections used for determination of these indexes are the same as those used for the De la Gringa fluvial index and are shown on Fig. 69. (It should be noted that the cross-sections are not redrawn in detail as they are simply cross-sections, or combinations of cross-sections, discussed previously). Maximum continuity associated with fluvial-marine sediments, as shown in Tables XIX and XX, is

Fig. 70


DE LA GRINGA SYSTEM
VERTICAL CONTINUITY INDEX
FLUVIAL SAND
LAGUNA
MADRE
-N-
0
2000
4000
FEET
H-6
H-5
G-6
G-5
5-8
5-6
1

Sec	Length in Feet	Max Cont	Min Cont	Max Ind	Min Ind
K-K'	13,500	13,500	13,500*	1.0	1.0
L-L'	14,000	14,000	14,000*	1.0	1.0
M-M'	14,000	1,500	2,500	.8	.2
Q-Q'	11,000	11,000	11,000*	1.0	1.0
O-O'	13,000	13,000	13,000*	1.0	1.0
A-A'	13,000	13,000	13,000*	1.0	1.0
P-P'	13,000	13,000	13,000*	1.0	1.0
R-R'	12,000	12,000	12,000*	1.0	1.0
B-B'	15,000	15,000	15,000*	1.0	1.0
H-H"	14,000	14,000	14,000*	1.0	1.0
G-G'	13,400	13,400	13,400*	1.0	1.0
J-J'	14,000	14,000	14,000*	1.0	1.0
I-I'	14,000	14,000	14,000*	1.0	1.0
N-N'	14,000	14,000	14,000*	1.0	1.0
C-C'	14,000	14,000	14,000*	1.0	1.0
				.98	.94

*indicates same sand body.

Table XIX. Fluvial marine continuities, De la Gringa system, perpendicular to progradation.

Sec	Length in Feet	Max Cont	Min Cont	Max Ind	Min Ind
W-W'	14,000	14,000	14,000*	1.0	1.0
U-U'	14,000	14,000	14,000*	1.0	1.0
S-S'	14,500	14,500	15,000*	1.0	1.0
V-V'	14,000	14,000	14,000*	1.0	1.0
T-T'	14,000	14,000	14,000*	1.0	1.0
				1.0	1.0

*indicates same sand body.

Table XX. Fluvial marine continuities, De la Gringa system, parallel to progradation.

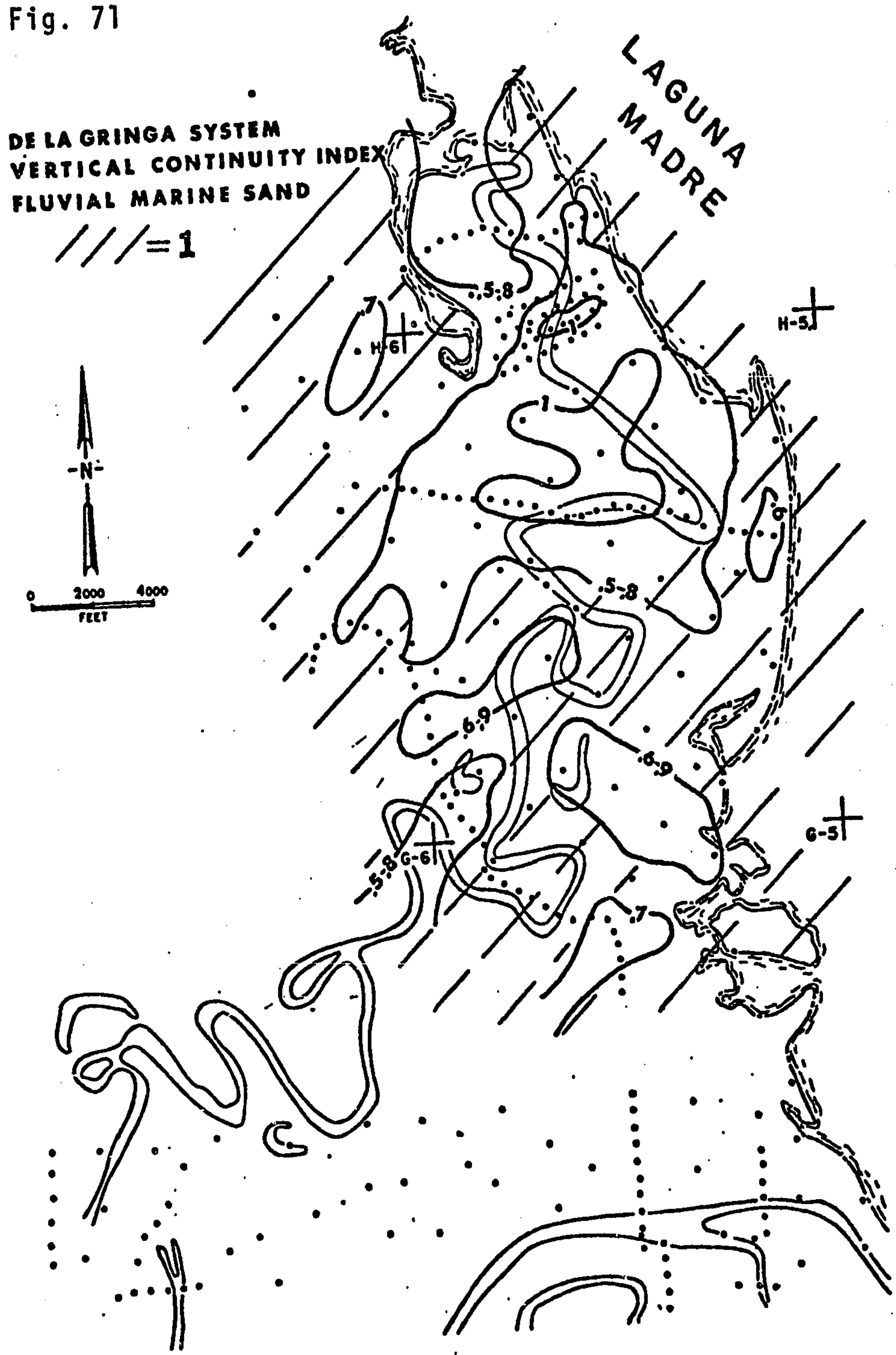
essentially 1.0 both parallel and perpendicular to the De la Gringa system, and as was shown in previous stratigraphic discussion, much more continuous than the overlying fluvial or underlying prodelta sands.

Combination of the sand isopach map (Fig. 50) and the V.C.I. map (Fig. 71) for the fluvial-marine system indicates that the thickest, most continuous sands of the fluvial-marine environment are near the axis of deposition. Thicknesses range 20-25 feet while vertical continuity indexes range from .5-.8 to .6-.9 to 1.0. Vertical discontinuities in fluvial-marine sediments are caused by silts and clays incorporated by marine wave action of adjacent (or nearby) sources or contributed directly by distributary input.

Prodelta. Because the prodelta environment is so complex stratigraphically with numerous discontinuous sand bodies an average as well as maximum and minimum continuity were calculated (see Tables XXI and XXII). Although maximum continuity is slightly greater parallel than perpendicular to the direction of progradation (.65 vs. .59), average continuity perpendicular to the direction of progradation is about twice as good as that parallel (.30 vs .17). This is important, especially if attempting primary, secondary, or tertiary recovery from prodelta sands and indicates that the sands are more continuous parallel than perpendicular to the depositional strike.

Because the sands of the prodelta unit are relatively thin, numerous, and of approximately the same thickness, the vertical continuity index was treated somewhat differently than in previously de-

Fig. 71



DE LA GRINGA SYSTEM
VERTICAL CONTINUITY INDEX
FLUVIAL MARINE SAND
///=1
LAGUNA MADRE
-N-
0 2000 4000
FEET
H-5
H-6
G-5
G-6

Sec	Length in Feet	Max Cont	Min Cont	Avg Cont	Max Ind	Min Ind	Avg Ind
K-K'	13,500	10,000	500	3,900(7)*	.74	.03	.29
L-L'	14,000	8,500	500	4,000(5)	.60	.03	.30
M-M'	14,000	8,000	1,000	4,800(5)	.57	.13	.34
Q-Q'	11,000	8,500	1,000	4,400(3)	.77	.09	.4
O-O'	13,000	3,000	500	2,600(3)	.23	.04	.21
A-A'	13,000	7,500	850	3,700(3)	.57	.06	.29
P-P'	13,000	8,000	1,000	5,800(2)	.61	.07	.45
R-R'	17,000	7,500	1,000	6,500(1)	.62	.08	.5
B-B'	15,000	6,000	1,000	2,400(6)	.4	.06	.16
H-H'	14,000	10,000	1,000	3,200(4)	.71	.07	.23
G-G'	13,400	9,000	2,000	4,700(4)	.68	.15	.35
J-J'	14,000	8,000	750	3,000(4)	.57	.05	.22
I-I'	14,000	12,000	1,000	5,700(5)	.85	.07	.41
N-N'	14,000	5,500	1,000	1,800(4)	.39	.07	.13
C-C'	14,000	8,000	750	3,200(4)	.57	.05	.23
					.59	.07	.30

*indicates number of sand bodies measured.

Table XXI. Prodelta continuities, De la Gringa system, perpendicular to progradation.

Sec	Length in Feet	Max Cont	Min Cont	Avg Cont	Max Ind	Min Ind	Avg Ind
W-W'	14,000	7,000	500	2,500(5)*	.5	.03	.18
U-U'	14,000	9,500	750	3,000(4)	.67	.05	.22
S-S'	14,000	7,500	1,000	2,500(4)	.53	.07	.18
Z-Z'	14,000	7,500	750	1,400(5)	.53	.05	.1
T-T'	14,000	14,000	500	2,400(6)	1.0	.04	.17
					.65	.04	.17

*indicates number of sand bodies measured

Table XXII. Prodelta continuities, De la Gringa system, parallel to progradation.

scribed fluvial and fluvial-marine environments. Instead of contouring V.C.I. data from each well, an average vertical continuity based on data from 173 drill holes was calculated. This avoids producing a complex, low information contour map showing the vertical continuity index. The average vertical continuity of the prodelta sands of the De la Gringa system is .57. This combined with an average maximum vertical thickness of 5.4 feet and an average minimum vertical thickness of 3.1 feet demonstrates very nicely the thin discontinuous nature of these sands in a vertical sequence.

In summary, the most continuous sand unit of the De la Gringa system is the fluvial-marine sand (lower member of the upper unit). This unit has a lateral continuity index of 1.0 both parallel and perpendicular to the direction of progradation, while fluvial sands have an index of approximately .8 parallel and .5 perpendicular to progradation and prodelta sands a low .3 index perpendicular to progradation and .17 parallel. Vertical continuity indexes of the fluvial and fluvial-marine environment are similar and range .5-1.0. Average vertical continuity of fluvial sands is .84 compared to .8 for fluvial-marine sands. Both are better than the thin sands of the prodelta environment which have an average overall vertical continuity index of .57.

It is obvious that the fluvial-marine sands by virtue of being the most continuous sand present, having a high vertical continuity index, being clean and well sorted and adjacent to potential high-organic source beds, make the best oil and gas reservoirs in the delta system.

(Basal transgressive sands are not considered since they are not part of the delta progradation system, are unique to specific instances of geologic time, and are not typical of many delta reservoir systems). The problem, as is well illustrated in previous stratigraphic and depositional discussions, is that these sands are genetically associated with only one progradational system and cannot be traced into other earlier systems - a problem critically overlooked by workers dealing with generalized models who speak of "sheet sands" occupying several hundred square miles of the delta framework. Even in systems such as the Mississippi River delta (which is probably geologically anomalous) it is suggested that more concise correlations and delineation of depositional environments would produce a more complicated environmental package and less continuous sand bodies than have been previously suggested.

SOUTHERN SYSTEM

Stratigraphic continuities in the Southern system were done by environment as in the De la Gringa system with the exception of the fluvial-marine environment which is highly eroded and truncated and does not present an applicable model for continuity measurements. Likewise, continuity measurements were omitted for channel 2 because of lack of close control data across the northern part of the channel. Because the Southern system is a more updip sequence than the De la Gringa system and channels are consequently thicker and juxtaposed laterally, the lateral continuity index (L.C.I.) was somewhat modified (see Table XXIII). The procedure for determining L.C.I. for the two

Sec	Channel	Max Cont Possible Feet	Max Cont	Min Cont	Avg Cont	Cont Index**
D-D'	3	9,100	6,000	1,500	3,800(7)*	.42
	1	6,500	5,000	1,100	2,800(3)	.46
	4	8,000	6,000	1,000	3,300(4)	.55
Z-Z'	3	11,000	6,600	1,600	4,800(4)	.43
	1	10,000	9,000	4,000	6,000(3)	.6

**determined by dividing $\frac{\text{Avg cont}}{\text{max possible cont}}$

* number of sand bodies measured

Table XXIII. Fluvial continuities, Southern system, perpendicular to progradation.

sections perpendicular to the direction of progradation was as follows: (a) a maximum possible continuity for sands in the channel was determined (based on channel width); (b) a maximum continuous sand within the channel confines was measured as well as a minimum continuous sand; (c) sand bodies not included in (b) were measured and an average was taken to determine the average continuity; (d) the average continuity of the channel sands was determined by dividing C/A (i.e. average continuity/maximum possible continuity). Location of sections for continuity measurement is shown in Fig. 72.

Fluvial. Lateral continuity of the fluvial sands of the Southern system as determined from sections D-D' and Z-Z' (perpendicular to progradational direction) are shown in Table XXIII. Continuities are fairly low (ranging from .42 to .6) with the average continuity of the sands in the channel system being about .48. This is similar to channel sands of the De la Gringa system as would be expected for a continuity index in a similar depositional environment.

Data points for a measure of continuity parallel to the direction of progradation in the Southern system are not plentiful. However, section W-W' shows both channel 3 and channel 1 parallel to the direction of progradation while section X-X' shows channels 2 and 3 in a parallel sequence. Although limits of the channel boundaries in a parallel section are not shown, continuity is good (approximately 1.0) with sands being continuous throughout the length of section - this is especially true for basal channel sands. In the Southern system then, as in the De la Gringa system, fluvial sands are more continuous

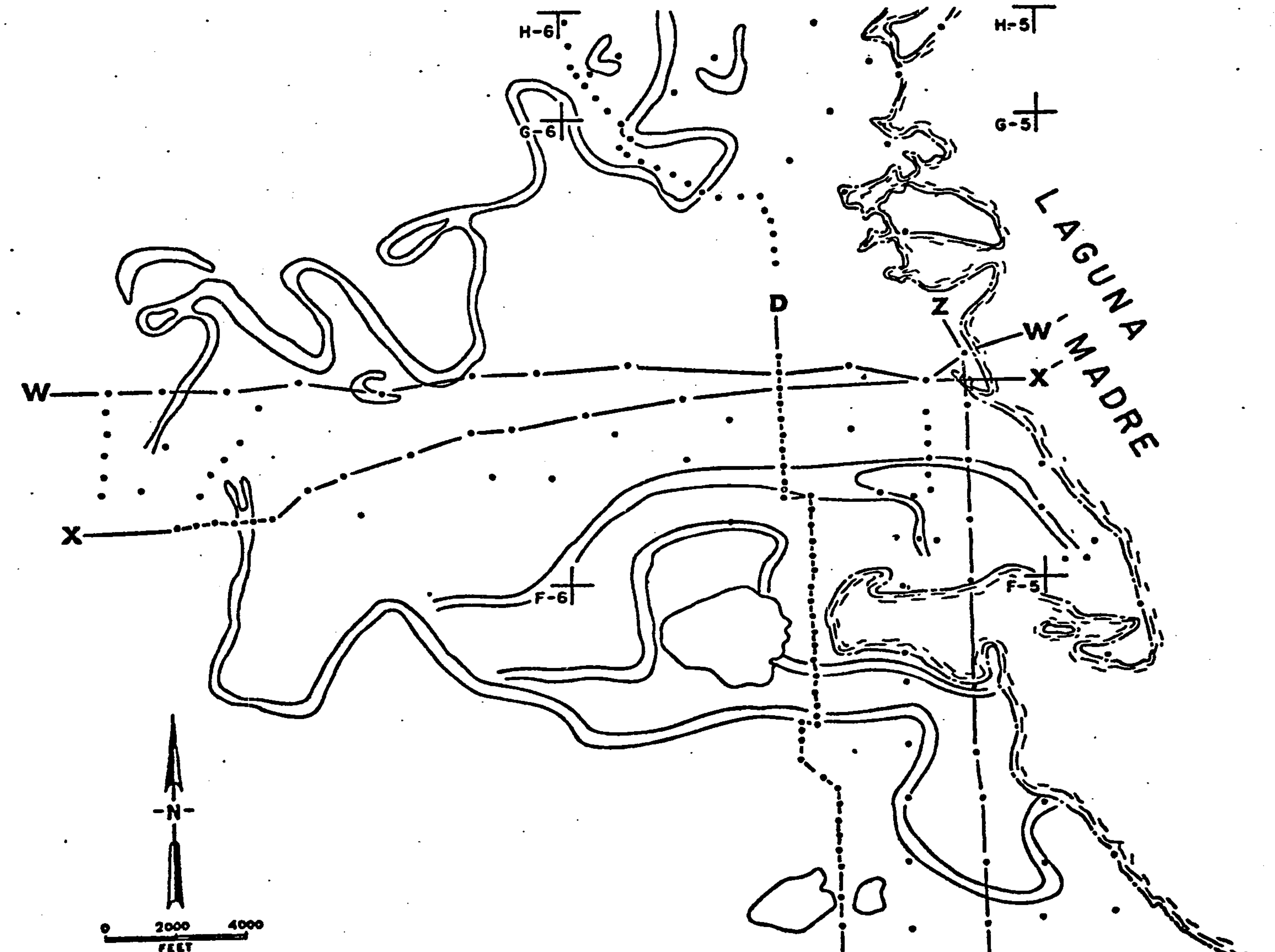


Fig. 72. Location of sections used for determination of continuity indexes, Southern system.

parallel than perpendicular to the direction of progradation.

Vertical continuity indexes (V.C.I.) were measured in the same fashion as for the De la Gringa system. Because channel sands of the Southern system are essentially multistory sands (updip vs. downdip fluvial sands of the De la Gringa system), their vertical continuity indexes are poor. Indexes for channel 2 range from .3-.5 to .51-.6 and are generally better toward the center of the system (see Fig. 73). As is inherent to this means of measuring continuity, the index is 1.0 at the channel boundaries where sands are thin but continuous. Average vertical continuity based on 65 data points is .51 which is less than that for the De la Gringa system.

Vertical continuity index associated with channel 3 (Fig. 74) is very low ranging .2-.4 to .41-.6, with occasional areas (near the channel flanks) reaching 1.0. Average vertical continuity is .48 based on 42 data points. Channel 3 exemplifies probably better than any other channel the vertical discontinuity associated with floodplain point bars as discussed by Busch (1974, p. 74, 78-82).

Data control points for channel 4 are rather limited but do indicate a vertical discontinuity pattern much like that associated with channels 2 and 3. Continuity in the bulk of the fluvial system ranges from .3-.5 to .51-.7 (see Fig. 75), being slightly better than channels 2 and 3. This is to be expected since channel 4 is the youngest and does not have an extensively developed multistory sand. Average vertical continuity is .61 based on 42 observations.

Fluvial vertical continuity index of all channels combined (1A,

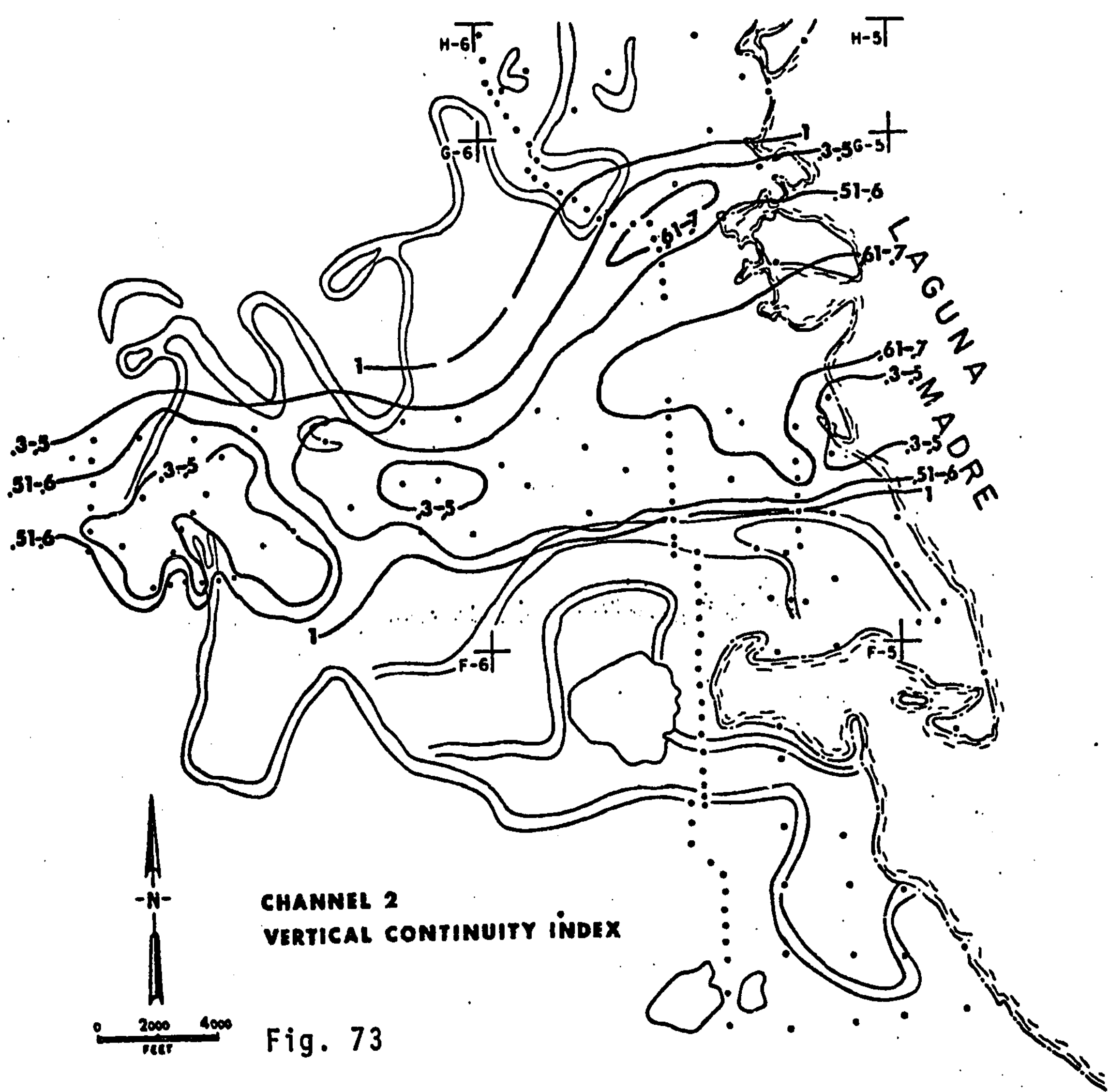

H-6
H-5
G-6
G-5
F-6
F-5
1
.3-5
.51-6
.61-7
LAGUNA MADRE
-N-
0 2000 4000
FEET
CHANNEL 2
VERTICAL CONTINUITY INDEX

Fig. 73

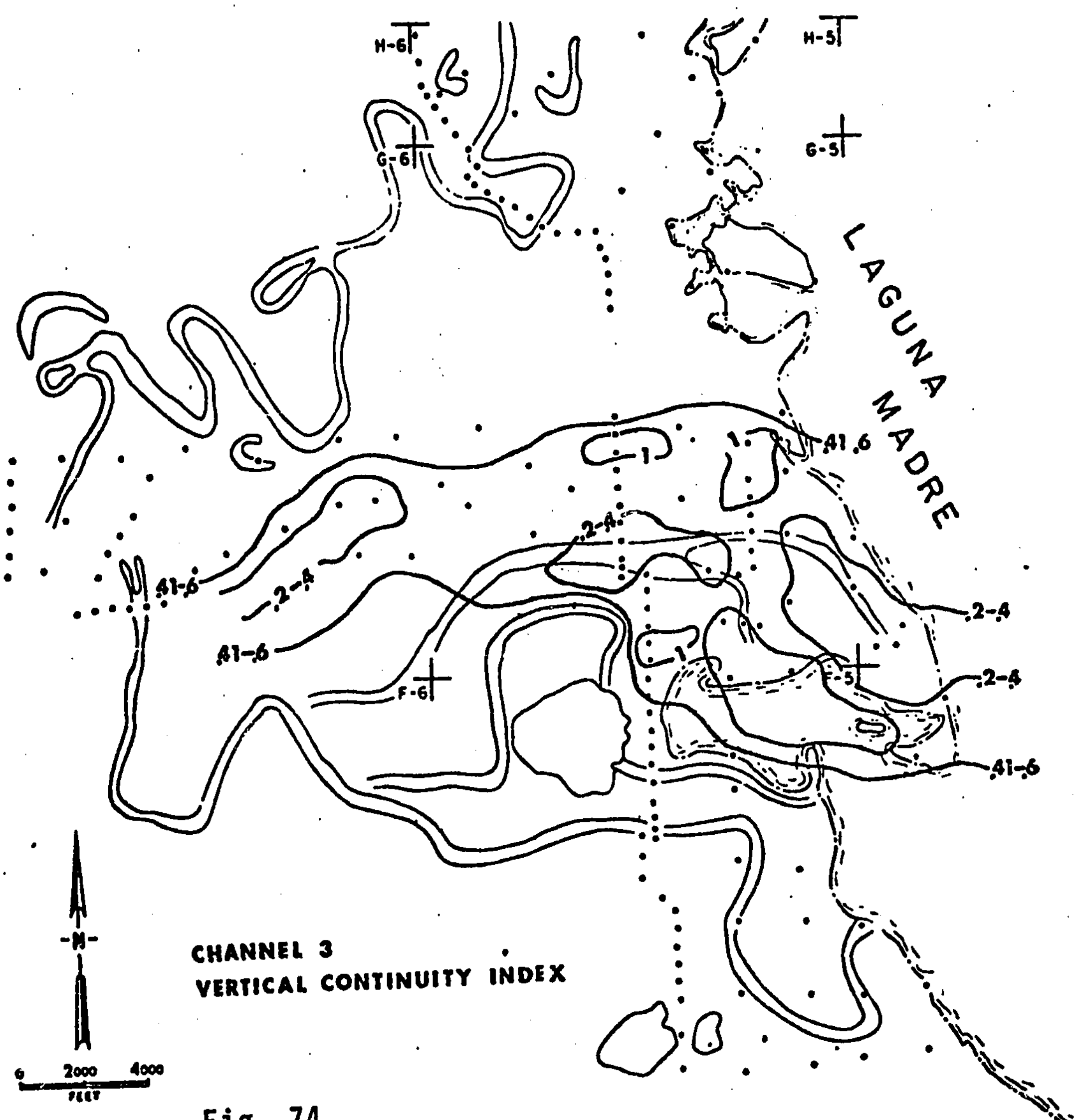
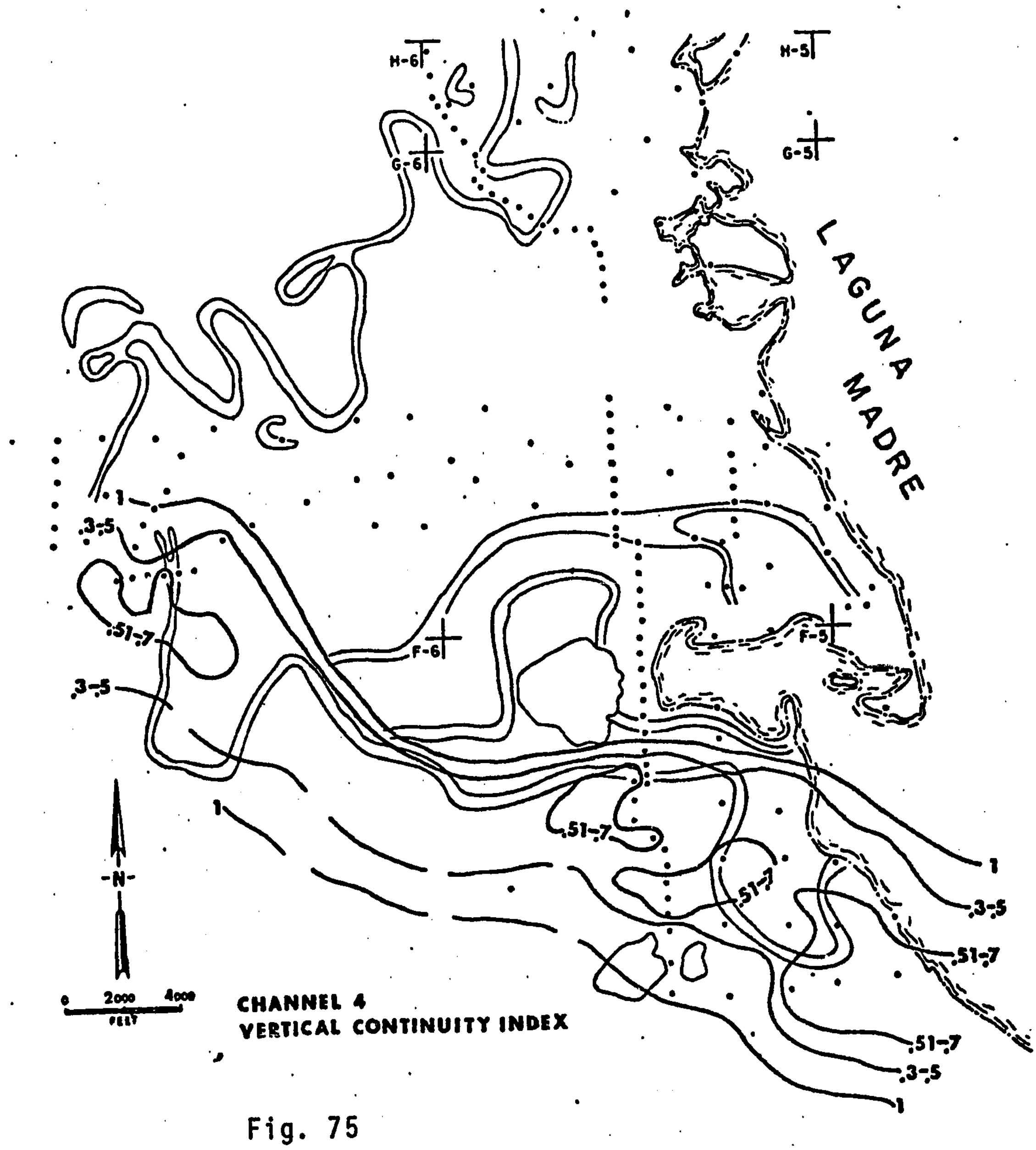

H-6
H-5
G-6
G-5
LAGUNA
MADRE
1
1
.1.6
.2-4
.1-6
2-4
.1-6
.2-4
.2-4
1
F-5
F-6
.2-4
.1-6
-N-
CHANNEL 3
VERTICAL CONTINUITY INDEX
0 2000 4000
FEET

Fig. 74



H-6
H-5
G-6
G-5
F-6
F-5
LAGUNA MADRE
1
.3-.5
.51-.7
-N-
0 2000 4000
FEET
CHANNEL 4
VERTICAL CONTINUITY INDEX

Fig. 75

2, 3, and 4) is shown in Fig. 76. This map, although rather complex, does indicate the rather poor vertical continuity of these updip channel sands as compared to, say, fluvial-marine or downdip channel sands. Vertical continuity ranges from a minimum of .2-.3 to a maximum of .51-.7. Average continuity of all channels combined is a low .44 (based on 121 observations). Implications of these poor vertical continuities are obvious in relation to production results, especially since boundary layers (clays) tend to reduce permeability and porosity of adjacent sands (see Fuchtbauer, 1967, p. 357).

Prodelta. Continuity of prodelta sands in the Southern system were calculated similarly to prodelta sands of the De la Gringa system (see Table XXIV). As in the De la Gringa system, prodelta sands are continuous perpendicular to progradation direction (.30) than parallel (.18). Average vertical continuity of the sands is .57 (compared to .56 of the De la Gringa system). Average maximum thicknesses of the prodelta sands 5.5 feet and average minimum thicknesses is 2.5 feet. This also compares nicely with prodelta sands of the De la Gringa system which have corresponding thicknesses of 5.4 feet and 3.1 feet respectively.

In summary, continuity indexes, such as those presented here (see Table XXV) give invaluable insight into reservoir potential of various sand facies of the delta environment. Such continuity indexes could undoubtedly be applied to other environments (e.g. barrier chains, turbidites, etc.) if detailed correlation data were available. Continuity indexes, although somewhat difficult to apply and subject to

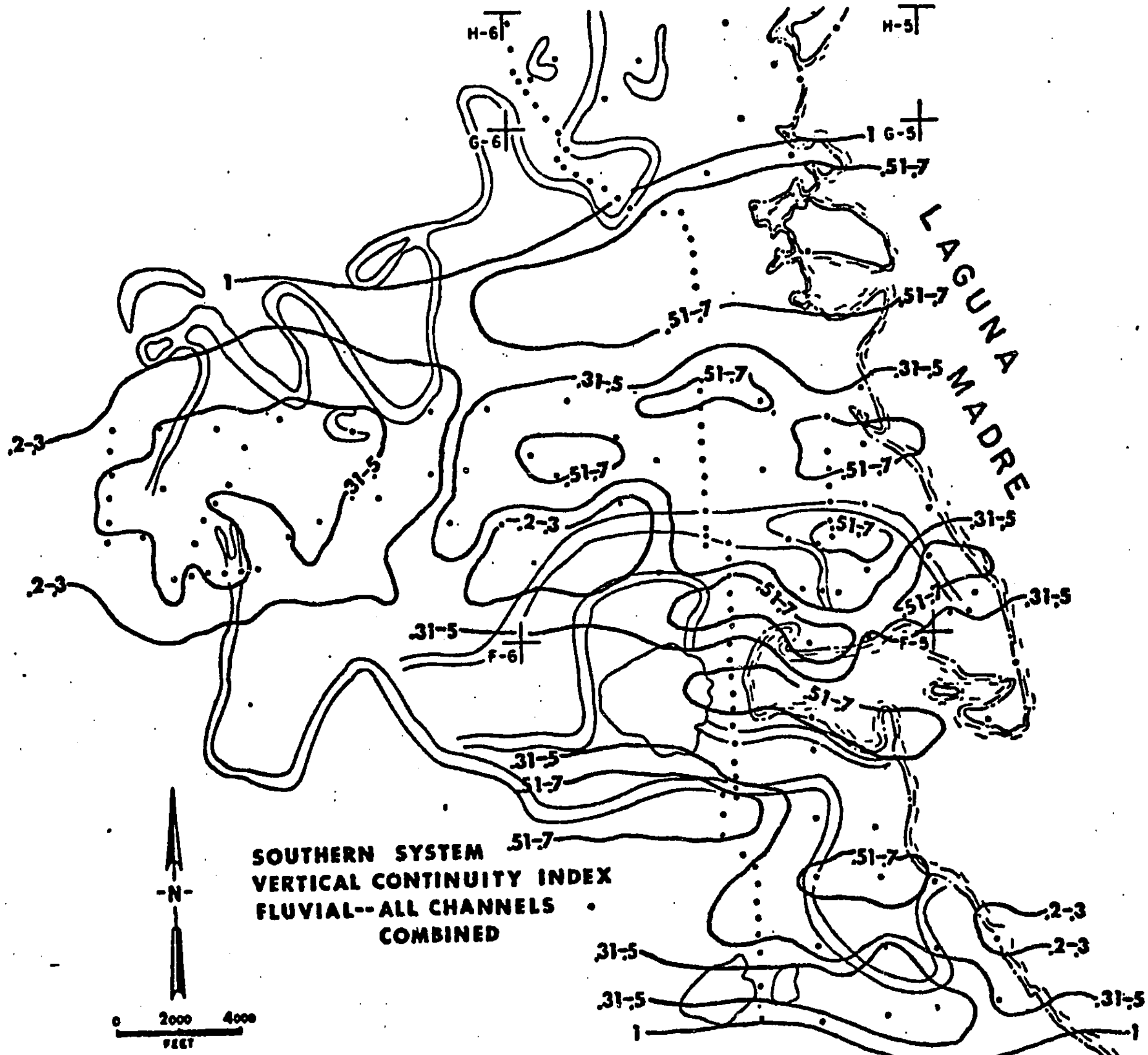

H-6
H-5
G-6
G-5
LAGUNA MADRE
F-6
F-5
SOUTHERN SYSTEM
VERTICAL CONTINUITY INDEX
FLUVIAL--ALL CHANNELS
COMBINED
-N-
0 2000 4000
FEET

Fig. 76

Sec	Length in Feet	Max Cont	Min Cont	Avg Cont	Max Ind	Min Ind	Avg Ind
D-D'	18,000	8,000	1,000	5,000(6)*	.44	.05	.27
Z-Z'	18,000	12,000	1,000	7,000(6)*	.66	.05	.38
					.55	.05	.32

*indicates number of sand bodies measured

Table XXIV A. Prodelta continuities, Southern system, perpendicular to progradation.

Sec	Length in Feet	Max Cont	Min Cont	Avg Cont	Max Ind	Min Ind	Avg Ind
W-W'	18,000	6,000	1,000	3,000(7)*	.3	.05	.16
X-X'	18,000	10,000	1,000	3,500(7)*	.55	.05	.2
					.42	.05	.17

*indicates number of sand bodies measured

Table XXIV B. Prodelta continuities, Southern system, parallel to progradation.

SYSTEM	ENV.	AVG. MAX. CONT. PERPEN.	AVG. MAX. CONT. PARALLEL	(A) AVG. MAX. VER. CONT.	(B) AVG. SAND THICKNESS	A(X)B	RESERVOIR POTENTIAL	RELATION TO DELTA FRAMEWORK
DE LA GRINGA	FLUVIAL	.49	.83*	.75	15-20'	11.0	GOOD	DISTAL (DOWNDIP)
	FL.-MARINE	1.0	1.0	.84	20-25'	17.0	EXCELLENT	DISTAL (DOWNDIP)
	PRODELTA	.3	.17	.56	4.0**	2.0	POOR	PROXIMAL
SOUTHERN	FLUVIAL							
	CH. 1A	.53	1.0	-	10-15'	--	POOR	PROXIMAL (UPDIP)
	CH. 2	-	1.0	.51	20'	10.0	GOOD	PROXIMAL (UPDIP)
	CH. 3	.43	1.0	.48	15-20'	7.0	GOOD	PROXIMAL (UPDIP)
	CH. 4	.55	1.0	.61	15'	9.0	GOOD	PROXIMAL (UPDIP)
	FL.-MARINE	NOT APPLICABLE - MOSTLY ERODED BY FLUVIAL						
	PRODELTA	.3	.18	.57	4'**	2.0	POOR	PROXIMAL (UPDIP)

* See discussion

** Calculated from average maximum and minimum thicknesses

TABLE XXV. Summary - Continuity Indexes.

modification, are a much more meaningful basis for reservoir properties than are descriptive terms such as "good", "poor", and "fair", etc. In addition, such indexes reduce large amounts of data to a conveniently usable number and give concise usable information about predictability of sand trends in a production area.

Perhaps most importantly, the usage of continuity indexes in this study has undoubtedly pointed out that sand bodies in delta plain settings are not as simple as current models suggest. Sands in this environment are not deposited as widespread sheets or fingers, but rather as bundles of isolated and discontinuous sand waves and bars at the mouths of distributaries and superimposed meander belt units. Indeed, careful and detailed work such as that done by Shepard (1960, p. 68) of the bottom sediments of the Mississippi delta distributaries do show irregular and discontinuous character of sand deposits in distributary environments. Furthermore, correlations in complex delta environments based on widely spread data are extremely suspect and undoubtedly account for the generalized stratigraphy shown in so many delta models. It is obvious from this study that correlation, especially by computer techniques without regard to environment or chronologic development, would result in highly misleading correlations. From E-log patterns, for example, it is easy to correlate between wells of the Southern and De la Gringa systems producing nicely continuous sands which are of course in error. Such correlations not only cross discontinuous facies boundaries, but also cross time boundaries as well as the northern and southern systems are of different ages. Granted that such problems are much easier to unravel in recent deltas (with surface expression) than in ancient subsurface deltas, it is hoped that the detailed correlation and continuity problems exposed in this study will have an impact on the thinking of those dealing with correlation in delta units, especially to reservoir geologists and engineers handling the complexities of primary, secondary, and tertiary recovery operations. It is apparent that the adage "the further apart the data, the easier the correlation and interpretation" holds true. Hopefully, the detailed work in this study will serve as a warning against generalizations, especially in complex stratigraphic sequences, of which the delta environment is probably the epitome.

RELATIONSHIP OF THE RIO GRANDE DELTA TO ANCIENT DELTA MODELS

In the previous discussion of stratigraphy, depositional environments, and aspects of reservoir continuity, references were made to numerous analogs of the Rio Grande system. The majority of these comparable delta systems were, however, recent (i.e. Holocene) in nature. The exceptions being the comparisons of the Rio Grande to deltas studied by Shannon and Dahl (1971, Pennsylvanian), Potter (1963, late Paleozoic), Swain (1964, Mississippian), and Fisher et al (1969, Eocene-Wilcox).

The elongate-lobate constructive nature of the Rio Grande delta makes it similar to many ancient deltas in depositional process, although naturally such parameters as thickness, tectonic influence, basin shape, etc., differ.

Because of the shallow water nature of the Rio Grande delta it is especially comparable to other shelf delta systems such as those so common to the late Pennsylvanian-early Permian. The shallow water model discussed previously in relation to Malone's (1971) work is directly applicable to Conemaugh (Pennsylvanian) deltas of the Appalachian basin as of course is the Rio Grande model (see Fig. 62). The late Paleozoic deltas of the Illinois basin as discussed by Wanless et al (1970, p. 215-233) are similar to the Rio Grande being constructive in nature, having channels 20 feet in nature, and commonly being 100-120 feet in total thickness. In addition the Permo-Pennsylvanian high constructive elongate to lobate delta systems (Virgil-Wolfcamp) of the Eastern shelf in north-central Texas are similar to the Rio Grande, especially in relation to individual facies of the framework sandstones (see Fischer et al., 1969, p. 47). Those delta sands of the Virgil-Wolfcamp Series (Cisco-Bowie Group) exhibit vertical sequences composed upward of constructional delta front sheets and distributary mouth bars, and 50 foot thick distributary channel facies. Fluvial channel deposits, which prograded over the upper delta plain and occupy many previous distributary channels, are difficult to differentiate from distributary channel deposits, especially in the subsurface. E-log characteristics of the Cisco sandstones are shown in Fig. 77 for comparison to those previously illustrated for the Rio Grande delta. Most (but not all) E-log patterns are applicable to the Rio Grande depositional environments. Limestone-bounded stratigraphic units common to the cycles of the Cisco-Bowie facies are of course lacking in the modern Rio Grande system.

Pennsylvanian clastics in Oklahoma and Kansas are comparable to the Rio Grande delta in regards to depositional environments, although the thickness and tectonic style are different. Busch (1953) in his classic study, clearly demonstrated the distributary nature of the Booch Sandstone of eastern Oklahoma (McAlester Fm.) and compared it to modern deltas. The Booch delta shows an upward gradation from prodelta mudstones into a complex body of prograding distributary mouth bars and channels called bar-finger sands (Fisk, 1961). Visher et al. (1975) studied the Coffeyville Format (Pennsylvanian) of Northern Oklahoma, which they considered an epeiric sea delta forming on the Central

Fig. 77. Characteristic electric log patterns of Cisco sandstone (from Fischer et al., 1969, Fig. 98). (1) Progradational distributary mouth bar and distributary flank-delta front sands. a. Prodelta and distal bar capped abruptly by massive bar crest and distributary channel sand. b. Thin prodelta sequence capped by bar and distributary fill. c. Prodelta mud capped by thick sequence of bar flank sands. (2) Distributary channel fill capped by thin calcareous destructional sheet. (3) Delta plain aggradational channel-fill sandstones characterized by abrupt lower boundaries and blocky S.P. patterns. Channeling into underlying facies, including limestones, is pronounced. (4) Delta plain aggradational channel fill characterized by abrupt erosional lower boundary and fining upward sequence. (5) Multistory sands. a. Progradational sequence of distributary mouth bars capped by massive distributary fill. b. Superposed aggradational channel fill of types 3 and 4. All except type 2 are similar to E-logs from the Rio Grande.

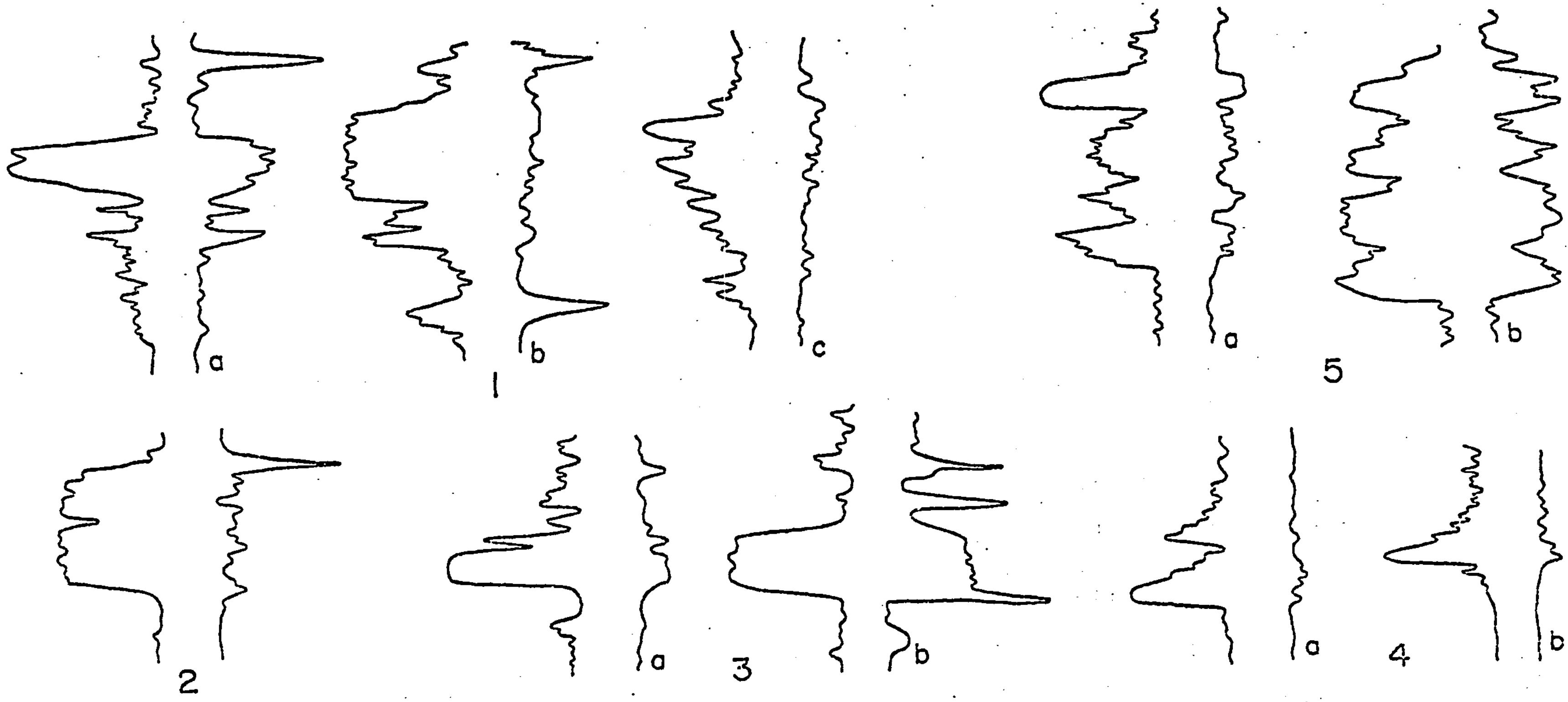


Fig. 77. Characteristic electric log patterns of Cisco sandstones (from Fisher et al, 1969, Fig. 98, see discussion on preceding page).

Oklahoma platform. Thickness of the delta (100-120 feet) and depositional environments (channel sandstone, natural levee and crevasse splay, marsh and bay, and prodelta depositional units) are similar to those discussed for the Rio Grande.

A comparison of the Holocene Rio Grande delta to ancient delta systems is a lengthy process and for that reason a comparison table (Table XXVII) has been added to give some insight to the relationship of ancient deltas (not previously discussed) to the modern Rio Grande counterpart. It is hoped that the similarities between the Rio Grande delta and ancient analogues, especially in the aspect of reservoir continuity, will prove fruitful in future exploration attempts.

Delta	Location	Age	Type	Max Th.	Hydrocarbons	Reference
Holocene Rio Grande	South Texas	Holocene	Const. Elongate-lobate	120'	-	This study
Upper Frio	Upper Texas Coast	Oligocene	High dest.	150'	Oil and Gas	Smith, A.E., 1974
Queen City Fm.	East Texas	Eocene	High Const.	500'	Minor Oil & Gas	Guevara, E. H. and Garcia, R., 1972
Wilcox-Rockdale	Texas Gulf Coast	Eocene	High Const. lobate	5000'	Gas	Fisher, W. L. and McGowen, J. H., 1967
New Castle	Mont.-Wyom.	E. Cret.	High Const.	400'	Prolific oil from distributary sands	Wulf, G. R., 1962
Bartlesville	Oklahoma	Penn.	High Const. Elongate	250'	1.5 billion bbls oil	Visher, G.S. et al., 1971
Middle Cisco	North Texas	Penn.	High Const. Elongate-lobate	1200'	Oil & gas in meander belt & delta front	Brown, L. F., 1973
Early Berea	Ohio	Miss.	Elongate-lobate	150'	Oil & Gas from from Berea SS.	Pepper, J. F., et al., 1954
Watt Mt.	Central Alberta, Canada	M. Dev.	High Const. Elongate	100'	Major oil reserves	Kramers, J. W. and Lerbekmo, J. F., 1970
Clinton	Ohio	Silurian	Dest.	50'	Oil in Dist. mouth & channel sands	Overbey, W. K. and Henniger, B. R., 1971

Table XXVII. Comparison of the Holocene Rio Grande delta to some ancient similar deltas (constructed from Ancient Deltas: Comparison Maps: Smith, 1975, pp. 529-555).

CONCLUSIONS

The discussion of the physiography, subsurface stratigraphy, environments of deposition, history of delta growth, delta type, and stratigraphic indexes of continuity associated with the Holocene Rio Grande delta can be summarized as follows:

(1) Age relationships of distributaries of the deltaic plain indicate the presence of three subdeltas since early Holocene. C-14 data from 5 core holes verify the age differences of the De la Gringa system (5000 B.P.) and the Southern system (7000 B.P.)

(2) Three major stratigraphic units, a) upper, b) lower, and c) basal, are defined from subsurface correlation of the De la Gringa subdelta while four definable stratigraphic units, d) upper group, e) middle, f) lower, and g) basal units are present in the Southern system.

a) The upper unit contains an upper and lower sand member; the upper sand member which is 15-20 feet thick intergrades with silts and clays both laterally and vertically and is discontinuous both parallel and perpendicular to the direction of progradation. The lower sand member is 20-25 feet thick and is the most continuous sand stratigraphically defined within the study area, although it too intergrades with silts and clays both laterally and vertically.

b) The lower unit is dominantly silts, clays, and silty clays with thin, discontinuous and imbricating sand members which are best defined as sheet or pods.

c) The lowermost unit of the De la Gringa system is the basal unit which is predominantly sand with interbedded silts and clays at the base.

d) The upper group of the Southern system is complex stratigraphically and contains four distinct units which overlie, onlap, and truncate one another in a relative chronological sense. Sands within these stratigraphic units occur as distinct bundles usually more continuous at the base and separated vertically by silts and clays.

e) The middle unit of the Southern system is characterized by a thin (10-15 foot) sand member which is truncated and eroded by overlying units of the upper group.

f) The lower unit of the Southern system is much like that of the De la Gringa system and contains 3-5 foot sands that are discontinuous both vertically and laterally and are best described as imbricated pods and lenses.

g) The basal unit which underlies the Southern system is similar to that discussed in relation to the De la Gringa system.

(3) Major environments of deposition of the De la Gringa system include: a) fluvial, b) fluvial-marine, c) prodelta, which contains bay-distributary mouth, and d) nearshore open-marine. Although the stratigraphy of the Southern system is more complex, environments of deposition are essentially the same and include: e) fluvial, f) fluvial-marine, g) prodelta, and h) nearshore-open marine.

a) The fluvial environment of the De la Gringa system includes brackish marsh, interdistributary bay, natural levee, splay and distributary channel sands (point bar), all of which are stratigraphically associated with the upper sand member of the upper unit. Sediments of the brackish marsh and channel fill are mottled silty clays and clay. Foraminifera, including Bisaccium imbricatum are present, as are ostracods such as Cypridopsis vidua, Candona lactea, Candona marchia, and Perissocytheridea brachyforma. Charaphytes are common. Sediments of the natural levee are silty clay to sandy silt. Bedding is massive to parallel with extensive mottling which may be caused by rootlets. Foraminifera, ostracods, and charaphytes are lacking in this environment. The sand member which characterizes the upper part of the upper unit and intergrades laterally and vertically with the brackish marsh and levee is cross-bedded, fines upward, and has clay gall conglomerates at the base, indicating its association with a meandering distributary channel.

Sand percent associated with the fluvial system ranges from 0 (near the channel boundary) to 60 percent (in areas of point bar deposition) and averages 30-40 percent. Isopach mapping indicates that the thickest sands (20-25 feet) are associated with point bar deposition.

Permeability of these fluvial sands decreases upward from 5 to 1 darcy, while porosity decreases upward from 25 to 5 percent.

Petrographically, sands of the fluvial environment are typically moderately well sorted (.5-.7Ø) fine grained lithic arkoses and feldspathic litharenites.

b) The fluvial-marine environment is stratigraphically associated with the lower sand of the upper unit. Sediment type is horizontally bedded, well-sorted sand with minor cross-bedding. Ostracods present in silts and clays within this interval are typical of a fluvial-marine sequence and include Cypridopsis vidua, Candona marchia, Perrisocytheridea brachyforma and Candona lactea. This sand member is the most continuous defined unit stratigraphically and is associated with distributary mouth bar deposition and subsequent marine reworking.

Sand percent ranges from 0 at the edge of the unit to 60-80 percent at the axis of the fluvial-marine wedge. Sand thickness increases from 0-5 feet at the margins of the sand body to a maximum of 25 feet at the center.

Permeability of sands in the unit increase upward from 1 to 5 darcys. Porosity increases upward from about 10 to 30 percent.

Typically sand from the fluvial-marine environment is moderately well sorted (.5-.7Ø) fine grained lithic arkoses (dominant) and feldspathic litharenites.

c) The prodelta environment and associated bay-distributary mouth environment occur stratigraphically in the lower unit. Bay-distributary mouth sediments are clays with interbedded sands. Various types of bedding including horizontal, rippled, massive, and contorted are present. Mottling is also present, perhaps indicating the influence of burrowing organisms. Foraminifera indicative of this bay-distributary mouth environment include Palmerinella palmerae diminuta and P. gardenislandisis. Ostracod associations such as Candona lactea, Limnocythere santiparticii, and Perissocytheridea bicelliforma indicative of fluvial-marine to prodelta environments are present.

Prodelta sediment which stratigraphically occupies the lowermost interval of the lower unit are clays and silty clays with horizontal and massive bedding. Foraminifera are absent although ostracods such as Perissocytheridea brachyforma and Limnocythere santipatricii occur rarely.

Textural aspects of sands within this lower unit are sparse but do indicate that the sands are only moderately sorted and contain 40-60 percent "less than 0.062 mm". Permeability ranges .5-1.5 darcys while porosity ranges 10-20 percent. Petrographically these sands are moderately poorly sorted (1.6-2.2Ø) subangular to subrounded very fine grained lithic arkoses. Sand percent ranges from 0-5 at the margins of the prodelta environment to 25-30 percent at the center of the depositional unit.

Origin of the imbricated discontinuous sand members within this lower unit are probably similar to lower bar slope deposits discussed by Shannon and Dahl (1971, p. 1203) or to discontinuous sands formed by erosion of sediment from mouth bars by marine action (Swann, 1964, p. 643). A third alternative possibility for the formation of the sands is that they were eroded by marine wave action from the older Southern system and deposited to the north before progradation of the De la Gringa system.

d) Nearshore open marine. Sands within this environment are very well sorted, cross-bedded to horizontally laminated and contain clay galls. Foraminifera in silts and clays at the base of this sand include Florilus atlanticus and Fursenkoina pontoni; ostracods occur very rarely. This sand which corresponds to the basal unit stratigraphically is interpreted as a destructional phase (transgressive) sand.

e) The upper group of the Southern system contains four stratigraphic units which are interpreted as fluvial in origin. These units onlap and truncate one another in such a fashion that they can be dated relatively (with the aid of surface expression). Sands within these fluvial units are moderately sorted and fine upward nicely. Cross-bedding predominates although some horizontal bedding occurs near the top of these sands. Percent "less than 0.062 mm" increases upward sporadically from about 20 to 50 percent. Permeability decreases upward from approximately 5 darcys to about 500 millidarcys; porosity decreases from 30 percent to 10-15 percent. These fluvial sands are overlain by floodplain and interdistributary bay silts and clays which show massive and mottled bedding.

Sand percent of these channels ranges 40-80 percent near the axis and averages about 60 percent. Isopach thickness of the channels is variable; channels 2 and 3 have maximum thicknesses of about 35-40 feet while channel 4 has maximum point bar thickness of about 25 feet. Maximum thicknesses are found in the channel axis or in the vicinity of point bar deposits.

Petrographically, sands from these fluvial units are typically moderately well sorted (.5-.7Ø) fine grained lithic arkoses and feldspathic litharenites.

f) Fluvial-marine sands occupy the middle unit stratigraphically in the Southern system. Data on these sands are sparse as they are penetrated in only one core. Data that is available indicate that these sands are moderately sorted and contain about 40 percent "less than 0.062 mm". Permeability is about 1 darcy while porosity is close to 15 percent. Silts and clays within this unit show contorted and massive bedding while sands are cross-bedded. Ostracods associated with this fluvial-marine environment include Candona lactea (dominant), Cyprideis torosa, Candona obtusa, and Cypridopsis vidua. Sands of this unit are not as continuous as those of the fluvial-marine environment of the De la Gringa system and are eroded by the overlying fluvial sands.

g) Prodelta sediments of the lower unit (Southern system) are similar to that discussed for the De la Gringa system and consist of thin, discontinuous sands, and sandy silts surrounded by silts and clays. Sand percent of the prodelta system ranges from 10-15 percent at the margins to 25-30 percent toward the center where a source of sediment influx was greater.

h) The basal unit of the Southern system consists of sands similar to those underlying the De la Gringa system (destructive phase-transgressive).

(4) Lithofacies mapping of the entire sediment package associated with the 2 delta distributaries indicate that clayey sand, silty sand, and sandy silt dominate the sediment pattern and define very nicely the channel systems.

(5) Clay mineralogy is dominantly montmorillonite with minor amounts of kaolinite and illite. The clay mineralogy does not vary with either stratigraphic position or depositional environment reflecting perhaps the source area contribution to the deltaic environments.

(6) Heavy mineralogy is dominated by basaltic hornblende and pyroxene although 14 other species are present. Five heavy mineral suites are present and indicate that sediment to the delta area was contributed by a) mafic and ultramafic igneous, b) metamorphic, c) siliceous and intermediate igneous, d) volcanic, and e) reworked sedimentary rocks of the complex provenance area.

(7) The De la Gringa and Southern system developed as two separate events. The progradation of the Southern system with subsequent channel shifting and erosion of underlying fluvial-marine sediment occurred approximately 7000 years B.P. Abandonment of this system and erosion of its northern flank took place before progradation and onlap of the De la Gringa system to the north (5000 B.P.)

(8) Both the De la Gringa and the Southern system developed during the post-Pleistocene sea level rise. During the early sea level

stage (10,200-9400 B.P.) the Rio Grande entrenched valley was drowned and an estuary existed in the area now occupied by the delta plain. It was during this period of rapidly rising sea level that the basal transgressive sand was probably formed through reworking and destruction of previously deposited fluvial sediment. From 9400 B.P. to 3600 B.P. sea level continued to rise (except for a minor 10 foot regression at 7800 B.P.) until it reached its present level 5000-3600 B.P. During this interval, both the De la Gringa and Southern system maintained their deltas seaward of the present shoreline. Fairbridge (1958, 1961) cites 4 periods since 6000 B.P. when sea level has been higher than present which could account for the rather "high-standing" delta plain which is concurrently being transgressed.

(9) Initiation of the delta model in the downslope sequence begins with the (1) deposition of isolated sand elements on the prodelta and delta slope. (2) Next is the deposition of distributary mouth bar sands and submarine level deposits. This is followed by (3) the progradation of subaerial levee deposits and the beginning of excavation by fluvial processes into the underlying fluvial-marine sands. With further progradation, the principal activity is (4) the initiation of meander processes with the subsequent erosion of underlying and adjacent marine levee units. Occurring simultaneously with the beginning of meander processes is the (5) lateral accretion of point bar deposits and the buildup of marsh and subaerial levees. As progradation continues, (6) the meander system develops wider loops and deeper erosion of distributary bar sands and levee deposits occur. Splay deposits begin

forming on the outside of meander outbanks. The final stage is the development of a wide multiple meander belt with cut-offs and clay plugs.

(10) In relation to general delta models, the Rio Grande is best described as an elongate-lobate constructive delta with characteristics similar to both. An ancient analog is the lower Wilcox (Eocene) of the Gulf Coast Tertiary.

(11) Continuity indexes (both lateral and vertical) for all environments point out strikingly the discontinuous nature of the sands associated with the fluvial-deltaic-prodelta environment. Maximum continuities of fluvial sands in the downdip direction are better parallel (.83) to progradational direction than perpendicular (.49). In the updip direction where fluvial sands are thicker, average maximum continuity parallel to progradational direction approaches 1.0 while perpendicular it ranges .43-.55. Continuity of fluvial-marine sands (where not eroded by overlying fluvial deposits) is good and approaches 1.0 both parallel and perpendicular to the direction of progradation. Lateral continuity of prodelta sands is better parallel to depositional strike than perpendicular to it (.17). Average maximum vertical continuity is best for fluvial-marine sands (.84) and somewhat lower for fluvial sands (.75 in the downdip direction and .53 in the updip direction). Average maximum vertical continuities for prodelta sands are .56. The product of vertical continuity (X) average sand thickness indicates that in the vertical sense the fluvial-marine environment is the best reservoir (17.0), the fluvial environment fairly good (1.0), and

the prodelta sands poor (2.0). The numbers, of course, are only relative, but do quantitatively describe reservoir priorities in a vertical sense.

It is hoped that the usage of continuity indexes, although difficult to apply and subject to modification, have pointed out that such indexes: a) give insight into reservoir potential of various sand facies in the deltaic environment, b) are more meaningful to use for reservoir properties than are descriptive terms such as "good", "fair", "poor", etc., c) reduce large amounts of data to conveniently usable numbers and give concise information about the predictability of sand trends in a particular area, and d) could be applied to other environments (e.g. barrier chains, turbidites, shallow marine sands, etc.). Perhaps most importantly, continuity indexes in this study have undoubtedly pointed out that sand bodies in delta plain settings are not as simple as current generalized models suggest and hopefully will have an impact on the thinking of those dealing with correlation and continuity problems in the deltaic environment.

APPENDIX I

I. DISCUSSION OF FORAMINIFERA DATA

Although foraminifera were mentioned in the discussion of environmental aspects, it is felt that some further consideration of the microfauna is not only appropriate but necessary. The following summary of foraminifera species is taken from Harrison (1972, p. 26-80). Ms. Harrison worked on the foraminifera from the Rio Grande cores as part of her Masters thesis research which was completed in 1972. Her thesis contains an excellent and detailed discussion of all foram species present. Her section dealing with systematic paleontology includes a diagnosis, description, discussion, and occurrence of each species. For purposes of this study, it was felt that reiteration of her work dealing with "pure systematics", i.e. diagnosis, description, and discussion, was not necessary. It was felt, however, that a summary of the occurrence of the species would be helpful as the main emphasis of this study is paleocological rather than "paleotological".

One note of discussion is necessary here before continuing with a summary of Harrison's work. Harrison (1972, p. 19) defines an environment which she indicates as bay-sound, based primarily on the small population of Palmerinella species. She also goes on to say (p. 16) that "it is obvious that the distribution of benthonic foraminifera of the Gulf of Mexico cannot be generalized from depth data from any one locality or from environments described by such biased and nebulous terms as "bay" or "sound". Generalizations would be better based on salinity and turbidity considerations." Harrison points out that the Palmerinella species "are known to indicate less than full marine salinity environments (Saunders, 1957; Akers, 1952; Lankford, 1959; Phleger, 1955). The greater their abundance, the greater the fluvial influence." In addition, Palmerinella gardenislandensis is found in abundance in the fluvial-marine environment of the Mississippi delta and is considered diagnostic of the fluvial-marine environment (Lankford and Shepard, 1960, p. 416). In addition to Palmerinella, open ocean species Elphidium gunteri, Ammonia sobrina, and Discorbis tepida occur in the "bay" environment reflecting periods of low fluvial discharge approaching prodelta conditions.

For the above reasons, Harrison's terminology has been changed from bay-sound to bay-distributary mouth. It is felt that this terminology retains the fluvial influence while being consistant with stratigraphic and environmental interpretations. Perhaps terminology as "less than full marine" or "fluvially-influenced bay-prodelta" would be more appropriate descriptively although they are not used because of their cumbersome and awkward nature.

The following discussion of occurrence of foraminifera species is summarized after Harrison (1972) and is included here for the reader's convenience. Those wishing a more detailed analysis should consult the original work (Harrison, 1972).

Ammonia sobrina (Shupack)

This species is common in all foraminifera facies of the Rio Grande. Parker et al. (1953) reported the frequencies of the species in San Antonio Bay as 30-50 percent in the bay, 30 percent in beach samples, and 10 percent in the open Gulf. Post (1951) reported the species in all facies. It was abundant in all but the open gulf facies where it occurred rarely. Lankford (1959) found it most abundant in the bay and sound environment in the eastern Mississippi delta area.

Bisaccium imbricatum (Anderson)

This species is diagnostic of the brackish marsh subfacies of the fluvial environment. Anderson (1961) reported Bisaccium imbricatum from tidal creeks and shallow bays of South and Southeast Pass of the Mississippi delta. Warren (1956) reported it at low frequencies in saline marsh environments only.

Brizalina lowmani (Phleger)

This species occurs in the bay-distributary mouth environments at low frequencies. In the Rockport area of Southeastern Texas, Parker et al. (1953) report its occurrence in most open marine samples and at several bay stations.

Buliminella elegantissima (d'Orbigny, 1839)

In the Rio Grande, this species occurs in nearshore, open marine facies. In the Rockport area of southeast Texas, it occurred at most open marine stations at low frequencies (Parker et al., 1953).

Criboelphidium discoidale (d'Orbigny, 1839)

In the Rio Grande, this species occurs rarely in the nearshore-open marine environment. The type locality was not given. Forms similar to those from the Rio Grande have been reported from the Gulf of Mexico (Bandy, 1954), off the Texas and Louisiana coasts (Parker et al., 1953), and from the Recent of Mexico (Ayala-Castanares, 1963).

Cribroelphidium kugleri (Cushman and Bronnimann)

In the Rio Grande, this species occurs rarely in the bay distributary mouth environment. Todd and Bronnimann (1957) reported the species is common in their Mangrove I zone off the eastern Gulf of Paria along the western coast of Trinidad.

Cibroelphidium riograndense n.sp.

This species is common in the bay-distributary mouth environment. Parker et al. (1953) reported this morphologic form confined to bay areas.

Cribrononion galvestonense (Kornfeld)

This species is common at the top of the bay distributary mouth environment. Parker et al. (1953) reported that this species occurred rarely in the open marine stations and at most of the bay stations, usually at low frequencies.

Discorbis tepida (Cushman)

In the Rio Grande, this species occurs abundantly in the prodelta, bay-distributary mouth, and nearshore open marine facies. The type locality is San Juan Harbor. It has been reported from the Northeast Gulf of Mexico (Bandy, 1956), the northeast Gulf of Mexico (Phleger and Parker, 1951), the Mississippi delta area (Phleger, 1954), and off the Texas and Louisiana coasts (Kornfeld, 1931; Post, 1951; Parker et al., 1953; Shenton, 1957; Kane, 1962; Walton, 1960; Warren, 1956; Anderson, 1961). (For a more complete list see Harrison, 1972, p. 33).

Elphidium clavatum (Cushman)

This species is common in the bay-distributary mouth and nearshore open marine environments. The type locality is the Recent of Spar Landing, Frenchman's Bay, Maine. This form has been reported from the Gulf of Mexico, sometimes as E. incertum.

Elphidium gunteri (Cole)

In the Rio Grande, this species is a common constituent of all foraminiferal facies. The type locality is the Pliocene Calo-Osahatchee Marl, Orange City, Florida. (See Harrison, 1972, p. 45, for complete occurrence list.)

Elphidium mexicanum (Kornfeld)

Type locality is Galveston Island, Texas. This species has been reported from the northeast Gulf of Mexico (Bandy, 1956), the north-east Gulf of Mexico (Phleger and Parker, 1951), Heald Bank (Shifflett, 1961), the Mississippi delta area (Phleger, 1954; Phleger, 1955; Shepard, 1956), off the Texas and Louisiana coasts (Kornfeld, 1931; Parker et al., 1953), off Florida (Bendi and Puri, 1962), and from the Recent of Mexico (Ayala-Castanares, 1963).

Elphidium sp. cf. E. articulatum (d'Orbigny)

In the Rio Grande this species is found only in the bay-distributary mouth environment.

Elphidium sp. cf. E. incertum (Williamson)

In the Rio Grande this species is common in the bay-distributary mouth environment, but also occurs in the brackish marsh at very low frequencies.

Elphidium sp. cf. E. koeboeense (LeRoy)

In the Rio Grande this species is common in the bay-distributary mouth environment.

The type specimens are from the Miocene of central Sumatra. E. sp. cf. E. Koeboneese has been reported from the Texas and Louisiana coasts by Parker et al. (1953) and the Recent of Mexico by Phleger and Ewing (1962).

Elphidium sp. cf. E. poeyanum (d'Orbigny)

In the Rio Grande, this species is common in the bay-distributary mouth environment.

Elphidium tumidum (Natland)

This species occurs rarely in the bay-distributary mouth environment. The type locality is off Santa Catalina Island, California. This species has also been reported from the Texas and Louisiana coasts by Lehmann (1957).

Florilus atlanticus (Cushman)

This species occurs only in the nearshore-open marine environment at low frequencies.

The type locality is off Cape Canaveral, Florida. This species has also been reported from the Gulf of Mexico (Bandy, 1954), the northeast Gulf of Mexico (Bandy, 1956; Ludwick and Walton, 1957); the northwest Gulf of Mexico (Phleger and Parker, 1951), the Mississippi delta area (Phleger, 1954; Phleger, 1955; Shepard and Lankford, 1959; Anderson, 1961), off the Texas and Louisiana coasts (Kellough, 1956; Walton, 1960; Loep, 1956; Warren, 1956), and from the Pleistocene of the Gulf Coast (Akers and Dorman, 1964). It is reported at all open marine stations in the Rockport area (Parker et al., 1953).

Fursenkoina pontoni (Cushman)

In the Rio Grande, this species occurs only in the nearshore-open marine environment; although it is a diagnostic species, it occurs at low frequencies.

The type locality is the Miocene Oak Grove sand in Oklahoma County, Florida. In the Rockport area of southwestern Texas, Parker et al. (1953) reported that this species occurred at very low frequencies at most stations in the open Gulf facies. This species has been reported from the northeast Gulf of Mexico (Ludwick and Walton, 1957), the northwest Gulf of Mexico (Phleger and Parker, 1951), the Mississippi delta area (Phleger, 1954; Phleger, 1955; Shepard, 1956; Shepard and Lankford, 1959), the Texas and Louisiana coasts (Walton, 1960; Warren, 1956; Anderson, 1961), off Florida (Lynts, 1962), from the Pleistocene of the Gulf Coast (Akers and Dorman, 1964) and from the Recent of Mexico (Ayala-Castanares, 1963).

Hanzawai sp.

In the Rio Grande, this species occurs only in the nearshore-open marine environment. Lankford (1959, p. 2083) considers Hanzawia strattoni characteristic of open shelf environments.

Nonion parvum n. sp.

In the Rio Grande, this species is a common constituent of bay-distributary mouth faunas only.

Orbulina universa (d'Orbigny)

In the Rio Grande, this species is common in the bay-distributary mouth environment where it is represented by a single specimen. The type locality was not given. This species has been reported from the northeastern Gulf of Mexico (Bandy, 1956).

Palmerinella _gardenislandensis_ (Akers)

In the Rio Grande, this species occurs only in the bay-distributary mouth environment where it is diagnostic.

The type locality is Garden Island Bay, Louisiana. This species has also been reported from the Mississippi delta (Shepard, 1956; Lankford, 1959; Shepard and Lankford, 1959), and the Pleistocene of the Gulf Coast (Akers and Dorman, 1964). In addition, Lankford and Shepard (1960, p. 416) consider it to be the diagnostic species of the fluvial-marine association.

Palmerinella _palmerae_ _diminuta_ (Saunders)

In the Rio Grande, this species occurs only in the bay-distributary mouth environment. The type material was collected north of Monkey Point, west coast of Trinidad, B.W.I. "in fine black silt from just below low-water mark about 20 feet from the outer edge of a mangrove swamp" (Saunders, 1957). In this locality the water was brackish and turbid.

The specimens identified by Parker _et_ _al_. (1953) as _Palmerinella_ _plamerae_ occurred at most bay localities usually at low frequencies. This species was also reported off the Texas and Louisiana coasts by Lehmann, 1957; Shenton, 1957; and from the Recent of Mexico (Ayala-Castanares, 1963).

Protoelphidium _matagordanum_ (Kornfeld)

In the Rio Grande, this species is common from the bay-distributary mouth environment.

The type locality is Matagorda County, Texas. This species has been reported from the NW Gulf of Mexico (Phleger and Parker, 1951), the Mississippi delta area (Phleger, 1954; Phleger, 1955; Shepard, 1956; Shepard and Lankford, 1959), off the Texas and Louisiana coasts (Kornfeld, 1931; Parker et al., 1953; Kellough, 1956; Lehmann, 1957; Kane, 1962; Walton, 1960; Warren, 1956), and off Florida (Benda and Puni, 1962). Lankford (1959, p. 2078) reported this species from fluvial-marine and sound environments of the east Mississippi delta area, with the species being more common in the latter environment.

Rosalina candeiana (d'Orbigny)

This species occurs in the brackish marsh facies in abundance, and rarely in the bay-distributary mouth environment.

Uvigerina hispidocostata (Cushman and Todd)

In the Rio Grande delta, this species occurs as a single specimen in the bay-distributary mouth environment.

The type specimens are from the Miocene Buff Bay, Jamaica, B.W.I. Cushman and Todd (1945) listed the following localities where specimens described under other names were found which were judged to be members of this species: Miocene of Haiti, Ponce Formation (U. Oligocene to L. Miocene), Puerto Rico, and the Pliocene Charco Azul Formation, Panama. It has also been reported from the northeast Gulf of Mexico (Bandy, 1956), the northwest Gulf of Mexico (Phleger and Parker, 1951), and off the Florida coast (Benda and Puri, 1962).

The following plates and descriptions are taken directly from

Harrison (1972) and are included here for the reader's convenience and reference.

fig. PLATE 1

1a-c Ammonia sobrina (Shupack). 1a, umbilical view of specimen showing umbilical apertures, umbilical plug with fissures, and bosses on umbilical terminations of chambers, UCGM 40972, X80; 1b, side view showing interiomarginal aperture and bosses at umbilical terminations of chambers, X75; 1c, spiral view showing limbate, elevated sutures throughout, X84. 2, spiral view of specimen with limbate, elevated sutures in earlier-formed portion and depressed sutures in later-formed portion, UCGM 40969, X78. 3, side view showing interiomarginal aperture, bosses at umbilical chamber terminations of specimen which is less convex on the umbilical side than the umbilical side figured in 1a-c, UCGM 40971, X77. Specimens were colored with water soluble ink. p. 37.

4, 5a-c Bisaccium imbricatum Andersen. 4, side view of untouched untransparent specimen, UCGM 40974, X111. 5a, side view of untouched specimen showing sutural and umbilical extensions with sutural cavities, UCGM 40973, X103; 5b, side view of whitened, colored specimen, emphasizing extension of median apertural slits onto side of specimen and sutural cavities, X103; 5c apertural view of whitened colored specimen showing "hip-pocket-like" openings on median portion of apertural face above terminal chamber extension, X96. p. 74.

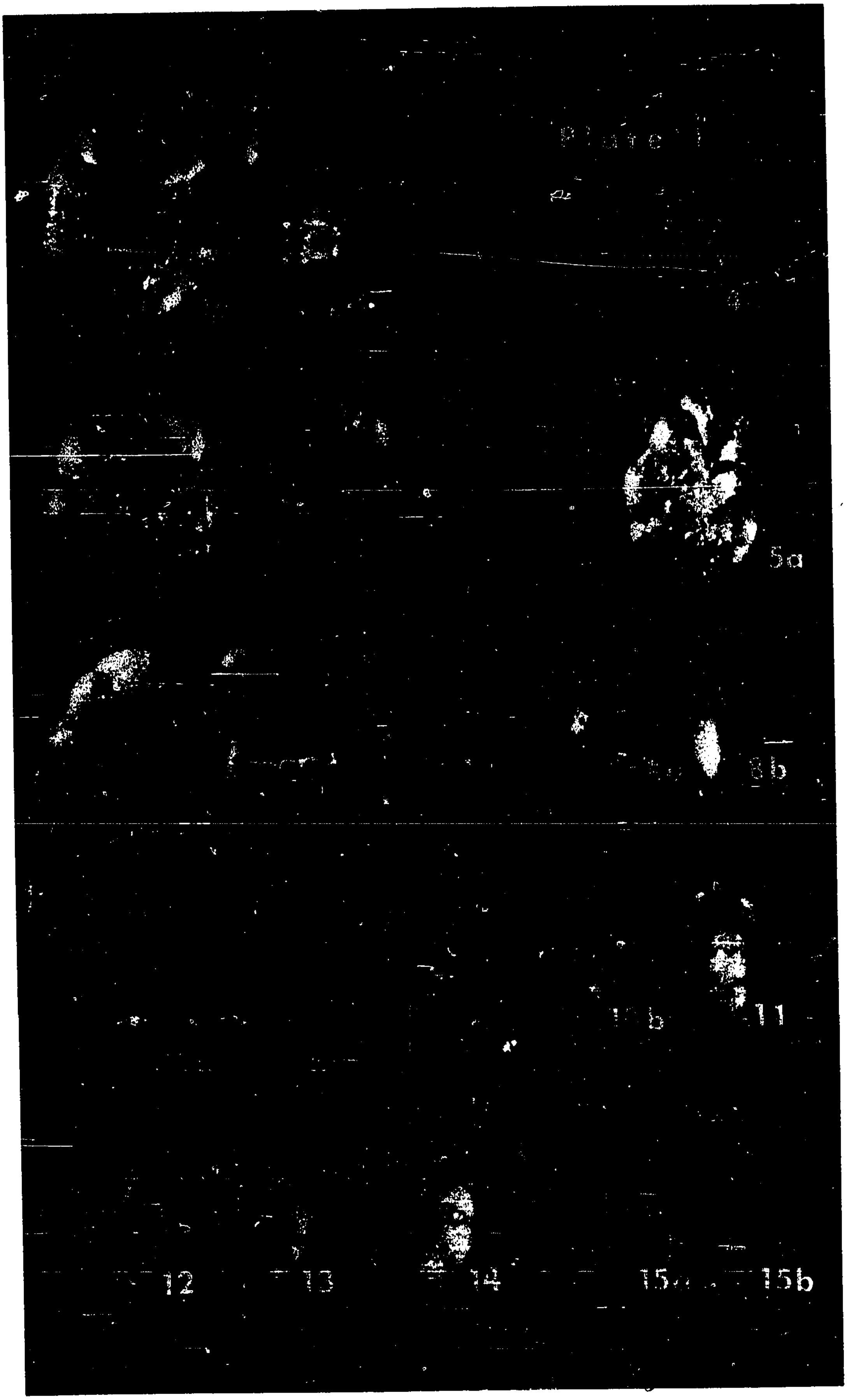
6 Brizalina lowmani (Phleger). UCGM 40975, X119. Specimen was colored with water soluble ink. p. 29.

7a,b Buliminella elegantissima (d'Orbigny). 7a, microspheric test, illustrating pointed initial end, UCGM 40976, X115; 7b, apertural view showing widest portion of aperture toward the middle, X115. Specimen was colored with water soluble ink. p. 26.

8a,b Cribroelphidium discoidale (d'Orbigny). 1a, side view, UCGM 40977, X73; 1b, apertural view showing cribrate aperture, X70. Specimen was colored with water soluble ink. p. 57.

9a,b Cribroelphidium kugleri Cushman and Bronnimann. 1a, side view showing prominent septal bars and enlarged terminal chamber, UCGM 40978, X70, 9b, apertural view, showing areal pores, X73. Specimen was colored with water soluble ink. p. 59.

10a,b;- 15a,b Cribroelphidium riograndense, n. sp. 10a, apertural view of holotype (UCGM 40979) showing areal aperture, X71; 10b, side view of holotype, showing septal bars directed into umbilicus, X81. 11, apertural view of paratype (UCGM 40980) showing infrequent type aperture of two arcuate rows of areal pores, X106. 12, side view of paratype (UCGM 40981) showing limbate elevated septal bars in earlier-formed portion and umbilically directed septal bars in later-formed portion, X91. 13, side view of paratype (UCGM 40989) showing thickened, elevated umbilical terminations of chambers surrounding single umbilical boss, X92. 14, side view of paratype (UCGM 40994) showing limbate, elevated septal bars, X93. 15a, side view of paratype (UCGM 40998) with limbate elevated septal bars and several small umbilical bosses, X140; 15b, side view showing arcuate row of areal pores and basal pores, X153. All specimens were colored with water soluble ink. p. 61.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figs. PLATE 2

1a,b; 2 Cribrononion galvestonense (Kornfeld). 1a, side view of specimen with one large umbilical boss and limbate, imperfoate septal bars, UCGM 40982, X82; 1b, apertural view showing basal silt and protuberant umbilical plugs, X80. 2, side view of specimen with several smaller umbilical bosses and limbate, imperforate septal bars, UCGM 40983, X90. Specimens were colored with water soluble ink. p. 63.

3-5 Discorbis tepida (Cushman). 3, spiral view, UCGM 40985, X88. 4, umbilical view showing interiomarginal arch, UCGM 40988, X92. 5, umbilical view showing comma-shaped umbilical aperture, UCGM 40986, X86. Specimens were colored with water soluble ink. p. 31.

6a,b Elphidium clavatum Cushman. 6a, side view showing one prominent septal bar on last formed suture, UCGM 40990, X94; 6b, apertural view, X89. Specimens were colored with water soluble ink. p. 40.

7-8 Elphidium gunteri Cole. 7, side view showing elongate retral processes and coarse pores, UCGM 40991, X67. 8, apertural view, showing basal pores, UCGM 40992, X83. Specimens were colored with water soluble ink. p. 43.

9a,b Elphidium mexicanum (Kornfeld). 9a, side view showing numerous small retral processes per suture, UCGM 40993, X68; 9b, apertural view showing basal pores and parallel sides, X73. Specimens were colored with water soluble ink. p. 45.

10a,b Elphidium sp. cf. E. articulatum (d'Orbigny). 10a, side view UCGM 40995, X90; 10b, apertural view showing basal low arch, X80. Specimen was colored with water soluble ink. p. 48.

11, 12 Elphidium sp. cf. E. incertum (Williamson). 11, side view showing oval pits adjacent to umbilical region, UCGM 40996, X103; 12, apertural view, showing indistinct row of pores, UCGM 40997, X129. Specimens were colored with water soluble ink. p. 49.

13a,b Elphidium sp. cf. E. koeboeense LeRoy. 13a, specimen with depressed area surrounding single large umbilical plug, UCGM 40999, X90; 13b, apertural view, showing basal row of pores and subacute periphery with protuberant umbilical bosses, X79. Specimen was colored with water soluble ink. p. 51.

14a,b Elphidium sp. cf. E. poeyanum (d'Orbigny). 14a, side view showing short retral processes and high chambers, UCGM 41000, X82; 14b, apertural view showing basal pores and two areal pores, X92. Specimen was colored with water soluble ink. p. 53.

15a,b Elphidium tumidum Natland. 15a, side view, UCGM 41002, X85; 15b, apertural view showing interiomarginal row of pores, X81. Specimen was colored with water soluble ink. p. 56.

16 Elphidium translucens Natland. Holotype, USNM 22549, X41.

17 Elphidium tumidum Natland. Holotype, USNM 22550, X51.

18a-c Elphidium poeyanum (d'Orbigny). 18a and 18c side views of topotype material showing high chambers and numerous short retral processes, UCGM 41001, X62; 18b, apertural view, showing double vertical column of areal pores, X56. Specimen is untouched.

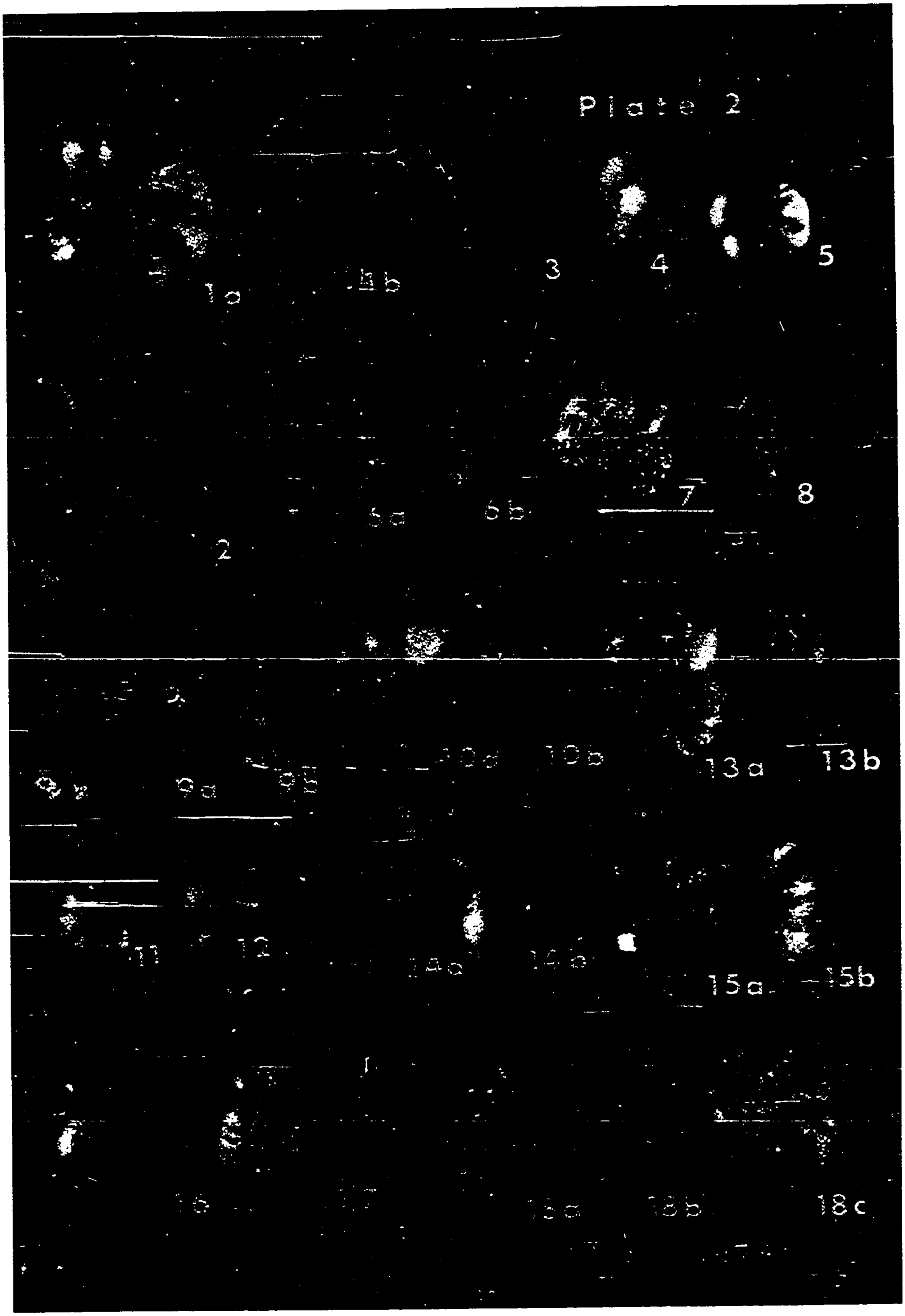
Plate 2
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fig. PLATE 3

1a,b Florilus atlanticus (Cushman) 1a, umbilical view, X87; 1b, spiral view showing granular material in umbilicus, UCGM 41003, X87. Specimen was colored with water soluble ink. p. 76.

2 Fursenkoina pontoni (Cushman). Side view, UCGM 41004, X86. Specimen was colored with water soluble ink. p. 71.

3 Hanzawaia? sp. 3a, umbilical view showing limbate sutures, UCGM 41005, X87.5; 3b, apertural view showing extraumbilical interiomarginal arch, X163; 3c, spiral view showing umbilical and sutural extensions and sutural cavities, X85. Specimen was colored with water soluble ink. p. 77.

4a,b; 5, 6 Nonion parvum, n. sp. 4a, apertural view of holotype (UCGM 41022) showing basal arch, X128; 4b, side view of holotype, showing granular material in umbilicus, X100. 5, side view of paratype UCGM 41022 showing circular outline of adult and granular material in umbilicus, X108. 6, paratype (UCGM 41023) showing ovate outline of juvenile, X87.5. Specimens were colored with water soluble ink. p. 73.

7 Orbulina universa d'Orbigny. UCGM 41008, X92. Specimen was colored with water soluble ink. p. 69.

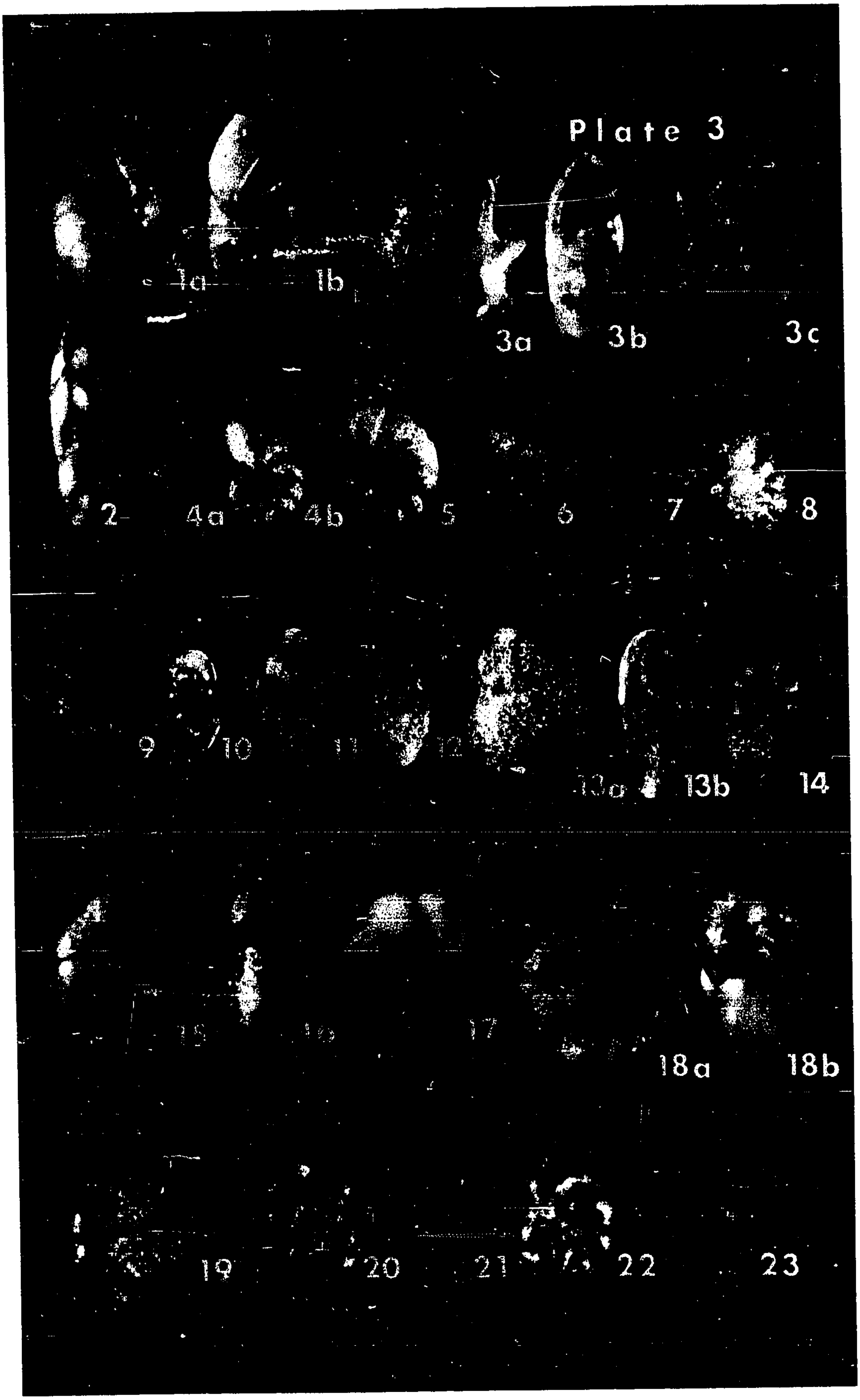
8-12 Palmerinella gardenislandensis (Akers). 8, side view, UCGM 41024, X93. 9, side view, UCGM 41025, X89. 10, apertural view of juvenile with aperture characteristic of Eponidella, UCGM 41026, X92. 11, apertural view of intermediate form with vertical septum seen adjacent to apertural periphery, almost separated therefrom, UCGM 41028, X108. 12, apertural view of adult with aperture characteristic of Palmerinella, UCGM 41027, X73. Specimens have been colored with water soluble ink. p. 34.

13a,b; 14 Palmerinella palmerae Bermudez subsp. diminuta Saunders. 13a, side view showing imperforate umbilical area and coarse pores, UCGM 41009, X79; 13b, apertural view showing Palmerinella aperture, X82. 14, apertural view of more biconvex specimen, UCGM 41028, X52. Specimens were colored with water soluble ink. p. 35.

15-19 Protelphidium matagordanum (Kornfeld). 15, Side view with flush umbilical region, UCGM 41013, X118. 16, umbilical view showing pustulose skeletal material which obstructs view of aperture, UCGM 41014, X100. 17, side view of specimen which undergone solution, causing an opaque test with depressed sutures, UCGM 41012, X90. 18a, side view of specimen showing granular material in umbilicus and along the basal portions of sutures, UCGM 41015, X87; 18b, apertural view showing horizontal low arch with vertical pillars, X103. 19, holotype, LSJU 701, X108. Specimens (except holotype) were colored with water soluble ink. p. 67.

20-22 Rosalina candeiana d'Orbigny. 20, spiral view, UCGM 41017, X92. 21, apertural view showing extraumbilical interiomarginal arch, UCGM 41018, X92. 22, umbilical view showing apertures open to the umbilicus and triangular umbilical chamber terminations, UCGM 41016, X92. Specimens were lightly colored with water soluble ink. p. 33.

23 Uvigerina hispidocostata Cushman and Todd. UCGM 41019, X136. Specimen was colored with water soluble ink. p. 30.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II. DISCUSSION OF OSTRACOD DATA

Identification and determination of relative abundance of ostracods was done by Dr. W. A. Pryor while he was with Gulf Research and Development Corporation. The following is a summary of ostracod occurrences based on the work of Swain (1955) and Curtis (1960). For an excellent systematic treatment of the ostracods discussed below, the reader is referred to Swain (1955).

The ostracod classification used by Pryor is after Swain (1955, p. 603). This classification differs at highest taxanomic levels (Subclass, Order, Superfamily, Subfamily, etc) from that of Pokorny (1958) who proposed the first all inclusive effort to classify Recent and fossil ostracods (Treatise, 1961, pt Q (3), p. 77).

The classification used here is from Swain (1955, p. 603). The changes as indicated in the Treatise are shown by the letter T.

Order Ostracoda Latreile 1802 (Subclass Latreille, 1806 T)

Suborder _Podocopa_ Sars, 1866 (Order Podocopida _Porknoy_ 1753 recte Sars, 1866 T)

Family _Cyprididae_ Baird, 1845

Subfamily _Cypidinae_ Baird, 1845
Genus _Cyprinotus_, Brady 1886

Subfamily _Cypridopsinae_ Kaufmann 1900
Genus _Cypridopsis_

Subfamily _Candoninae_ Kaufmann 1900
Genus _Candona_ Baird, 1845

Family _Cytheridae_ Baird, 1850

Subfamily _Limnocytherinae_ Sars, 1925
(Family _Limnocytheridae_ Klie, 1938 T)
Genus _Limnocythere_ Brady 1867

Family _Cytherideidae_ Sars 1925 (T)

Subfamily _Cytherideinae_ Sars, 1925
Genus _Cyprideis_ Jones 1856
Genus _Perissocytheridea_ Stephenson 1938

Subfamily _Cytherurinae_ Muller 1894
Family _Cytheruridee_ Muller 1894 T
Genus _Cytherura_ Sars, 1866

Family _Trachyleberidae_ (Sylvester-Bradley, 1948)

Family _Hemicytheridae_ Puri, 1952 T
Subfamily _Hemicytherinae_ Puri, 1953
Genus _Hemicythere_ Sars, 1925

Family _Paradoxostomatidae_ Bradly & Norma, 1859 T
Subfamily _Midrocytherinae_ Klie, 1938 T
Genus _Microcythere_ Muller 1894

Swain considers the problem of classification of _Hemicythere_ and _Microthere_, the latter which he assigns to "_Cytheridae_ of uncertain subfamily relationships". He concludes (p. 603) that "it seems improbable that the family _Trachyieberidae_ and subfamily _Trachyleberinae_ as now formed, would be a satisfactory place for the problematical genera, and much additional taxanomic study is needed". Reclassification (see above) in the Treatise bears out this prediction.

The following discussion of ostracod occurrences is based primarily on work done by Swain (1955) in the San Antonio Bay, Texas. Because his work was restricted to bay and shallow delta areas, it is necessary to indicate his subfacies by salinity to get some idea of the environment range where the ostracod species are found. For instance, his terminology "prodelta" doesn't mean too much when compared with prodelta of the Rio Grande as "prodelta" is perhaps 6-8 feet thick and dominated by fluvial influx of the Guadalupe River. On the other hand his "bay" facies has salinities approaching that of the open Gulf which could be similar to prodelta facies salinity of larger deltas. This is a common problem when trying to extrapolate paleo-ecological inferences from one area to another. For that reason, Swain's sub-facies and chlorinity range in 0/00 are given below (Swain, 1955, p. 566), (Table XXVI).

Cypridopsi vidua

In the Rio Grande delta this species occurs most abundantly in the fluvial facies (100/100 G.S.)*, present (11/100 G.S.) in the fluvial marine environment and sparse (3-10/100 G.S.) in the bay-distributary mouth environment.

Swain (1955, p. 607) reports that the occurrence of Cypridopsis vidua is restricted to the Guadalupe River distributaries and in the small bay north of the delta. This species is one of the commonest fresh water ostracods in North America and Europe and evidently cannot withstand more than a trace of salinity.

Candona lactea

This species is abundant in the fluvial-fluvial marine environments (100/100 G.S.) and is sparse (2/100 G.S.) in the prodelta environment. Swain (p. 608) reports that this species is common in the upper part and rare in the middle part of the bay. It commonly occurs where chlorinity range is brackish (1-16 percent). Type species of the genus (Cypris candida Muller) is typical of fresh to brackish water.

*G.S. = Grams of sediment

Biofacies	Subfacies	Bottom Materials	Chlorinity Range	Ave. depth (ft.)	pH	Eh[2] (mv)	Surface Total N (%)	Sediment Total C (%)	Sediment % Carbonate[3] Gasom.	Sediment % Carbonate[3] Org.
A. Typical Bay	A.1. Upper Bay	peat-clay, gyttja-clay, silt sand	1-16 ‰	3	7.46	+ 56	.17	.84	23	2.5
	A.2. Lower Bay	gyttja-silt-sand, shell-marl	16.5-21 ‰	5.5	7.35	+202	.07	.49	4.1	3.1
	A.3. Marginal	sand, silt, clay	15-20 ‰	5	7.5	+181	.06	.46	4.7	6.7
B. Fluvial		peat-clay, clay silt, very fine sand	1 ‰[1]	2.5	6.6	+157	.41	1.61	31?	?
C. Open Gulf		silt, sand	20 ‰	60	7.4	+120	.05	.37	3.1	2.5

[1]Layering observed in February, 1952, with water of 7 ‰ chl. underlying nearly fresh water.

[2]To refer the tabulated Eh values to the potential of the standard hydrogen electrode, add 245 mv.

[3]The carbonate content of the -200 mesh fraction of the sediments is referred to as "gasometric", while that of the coarser fraction, including fragments of macrofossils, foraminifers, ostracodes, etc. is "organic".

Table XXVI. Physical and chemical data for San Antonio Bay and vicinity. (After Swain, 1955, p. 566, Table I).

Candona marchia

Candona marchia is common in the Rio Grande at localities similar to Candona lactea (fluvial-fluvial marine-bay-distributary mouth). Swain (p. 609) reports that the species is frequent in the upper part of San Antonio Bay near the Guadalupe delta.

Candona obtusa

In the Rio Grande, this species occurs in the fluvial-marine environment indicating its relationship to fresh and saline environments. Swain (p. 608) reports occurrence of this species abundant in the Guadalupe River, near the mouth of the river, and in the bay.

Cyprideis littoralis

This species is present in the fluvial-marine and bay-distributary mouth environments in "present" amounts (11-20/100 G.S.). Swain (p. 616) reports that Cyprideis littoralis is rare to common at scattered localities in middle and lower parts of San Antonio Bay. This species is commonly found in nearshore or brackish waters in Europe, Asia, and northern Africa.

Cyprideis locketti

This species occurs in "present" amounts (11-20/100 G.S.) in two samples associated with bay-distributary mouth environment. Swain (p. 615) reports that this species is common to abundant in upper bay-prodelta region of the Guadalupe delta. It seems to be absent along the western side of the bay where the influence of the river is perhaps significant. Similar non-fluvial conclusions seem applicable in this study as C. loketti is not present in samples associated with the fluvially influenced environments.

<u>Cyprideis torosa</u>

This species occurs in the fluvial marine environment. Swain (p. 617) notes that it is usually an inhabitant of brackish water although it has been found in quite fresh water, and shallow littoral situations exposed to purely marine influences.

<u>Cyprinotus salinus</u>

This species occurs in the Rio Grande in two samples at present (11-20/100 G.S.) amounts. Environmentally this species is associated with the fluvial-marine and bay-distributary mouth environments. Swain (p. 605) indicates that this species is found in brackish water and is more rare off the Guadalupe delta.

<u>Cytherura johnsoni</u>

In the Rio Grande, this species occurs in two samples near the top of the prodelta environment in present amounts. In the San Antonio bay area Swain (p. 627) reports that this species is very abundant in San Antonio bay with greatest frequency more toward margins than middle of the bay. The genera <u>Cytherua</u> occurs worldwide typically in marine and brackish water.

<u>Hemilocythere conradi</u>

In the Rio Grande, this species occurs in two samples in the fluvial marine-bay distributary mouth environment. This species occurs in "present" amounts 11-20/100 G.S.

Swain (p. 635) reports that this species is common to abundant in the lower bay assemblage (16.5-21 0/00 chlorinity). Worldwide distribution indicates that the species is found in marine and brackish water.

Limnocythere santipatricii

This species occurs in the Rio Grande most abundantly in the fluvial environments (100/100 G.S.), although it is present (11-20/100 G.S.) to abundant (21/100 G.S.) in fluvial-marine to bay-distributary mouth environments. This agrees very well with what Swain (p. 614) reports. Swain indicates that Limnocythere santipatricii is frequent to abundant in the upper part of San Antonio bay, particularly near the front of Guadalupe river delta. In sampling living species, Swain (p. 594) found Limnocythere santipatricii characteristically at the mouth of the river. They commonly occur worldwide in fresh and brackish water.

Microcythere johnsoni

In the Rio Grande this species occurs in one sample near the base of the bay-distributary mouth environment in present amounts (11-20/100 G.S.). Swain (p. 642) reports this species as rare to common in the lower bay (16.5-21 0/00 chlorinity).

Perissocytheridea brachyforma

In the Rio Grande, this species occurs in all depositional environments from fluvial to nearshore open marine. Swain (p. 620) indicates that this is the most abundant species in the San Antonio bay area and occurs in all environments (in both living and dead assemblages - see maps p. 590 and 595). Curtis (1960, p. 481, Fig. 7) shows the presence of P. brachyforma in all environments of the southeast Mississippi delta.

Perissocytheridea bicelliforma

Like P. brachyforma this species is common from fluvial to near-shore open marine environments although more so in the former where it ranges from present (21/100 G.S.) to abundant (21-100/100 G.S.). Swain reports that P. bicelliforma is most common in the marginal bay facies although the species occurs in all bay facies as well as near the edge of the Guadalupe delta (p. 589).

APPENDIX II

GRAIN SIZE CURVES

(Figs. 78-96)

Note: Core 1 = H6-33

Core 2 = H5-90

Core 3 = H5-40

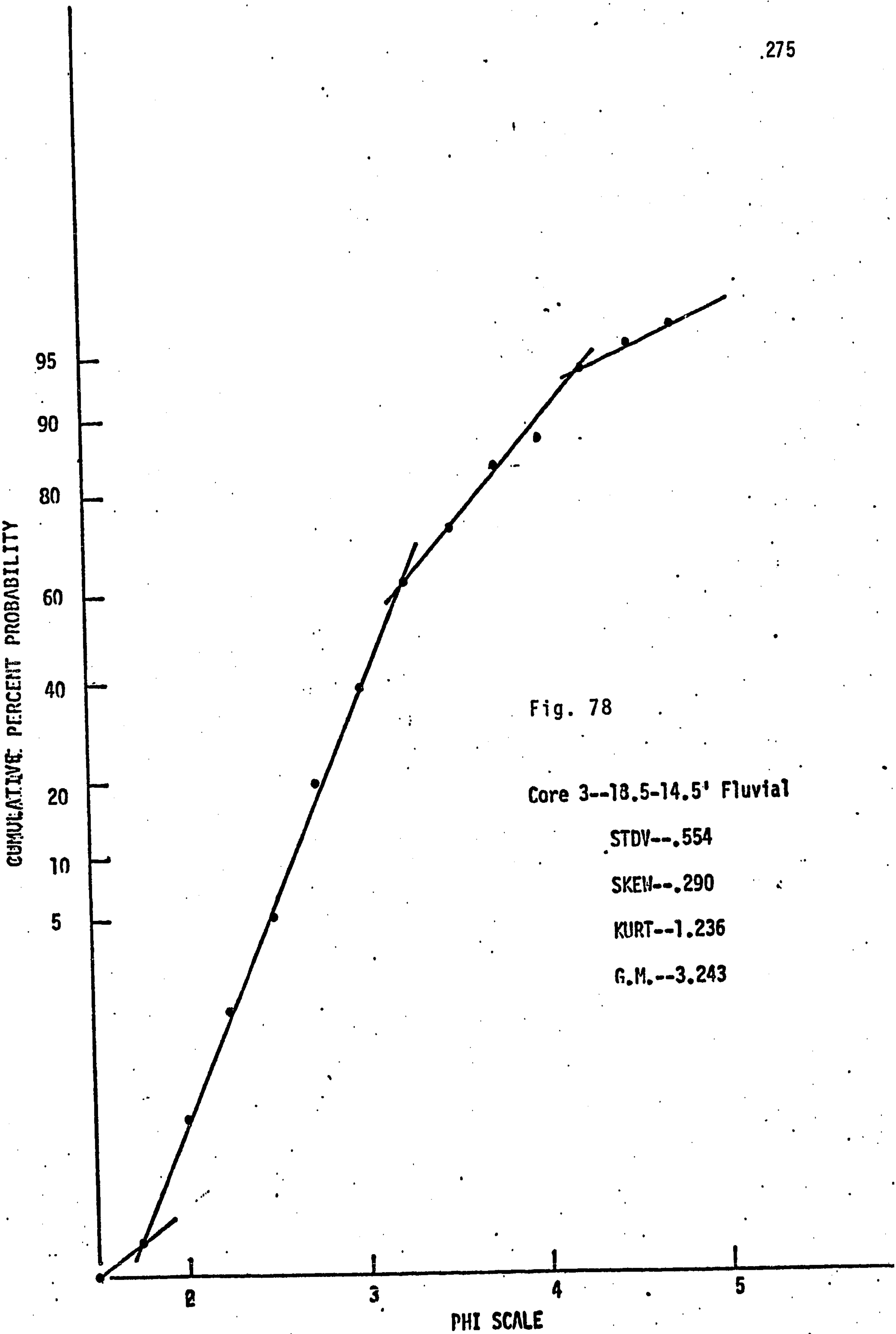


Fig. 78

Core 3--18.5-14.5' Fluvial

STDV--.554

SKEW--.290

KURT--1.236

G.M.--3.243

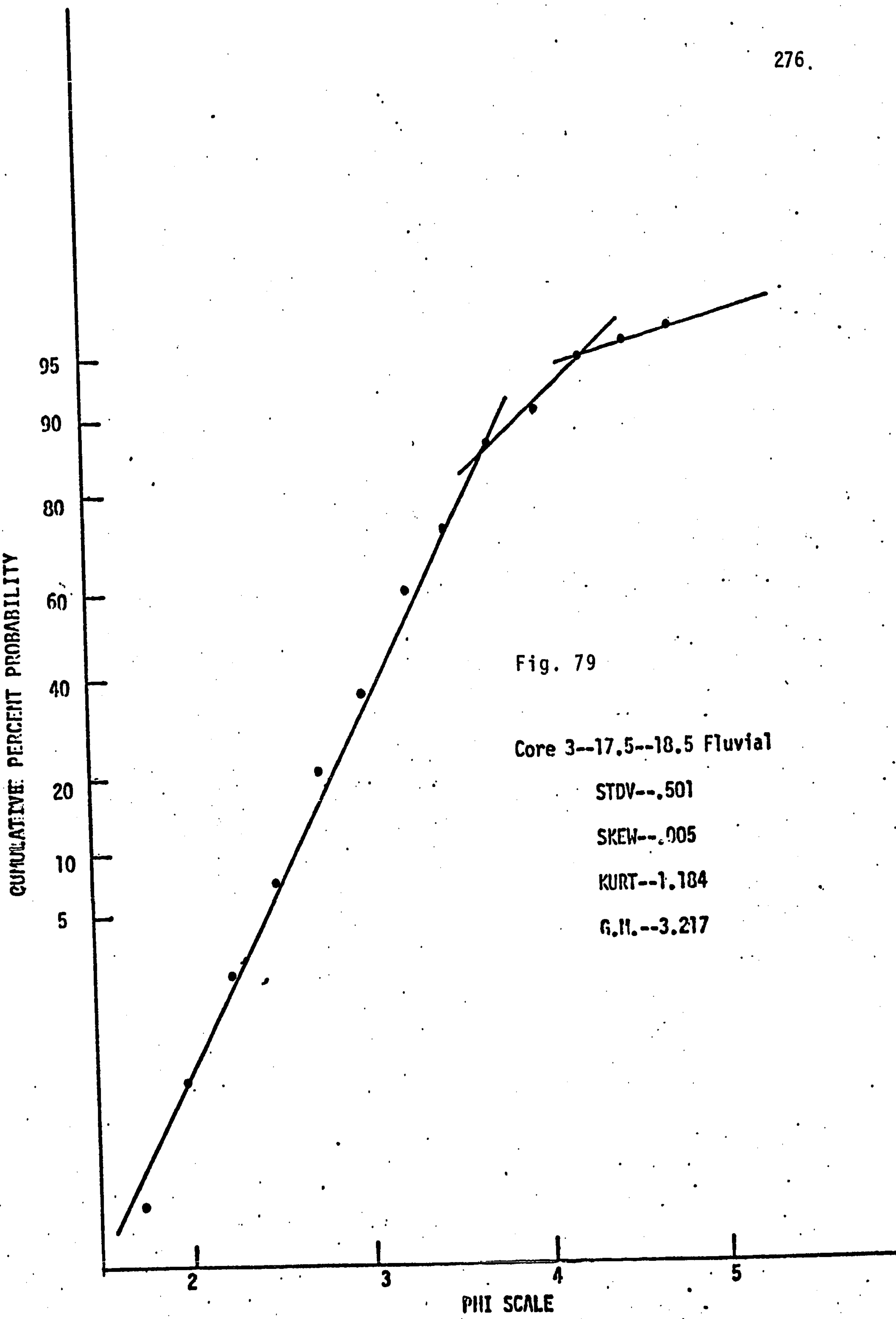


Fig. 79

Core 3--17.5--18.5 Fluvial

STDV--.501

SKEW--.005

KURT--1.184

G.M.--3.217

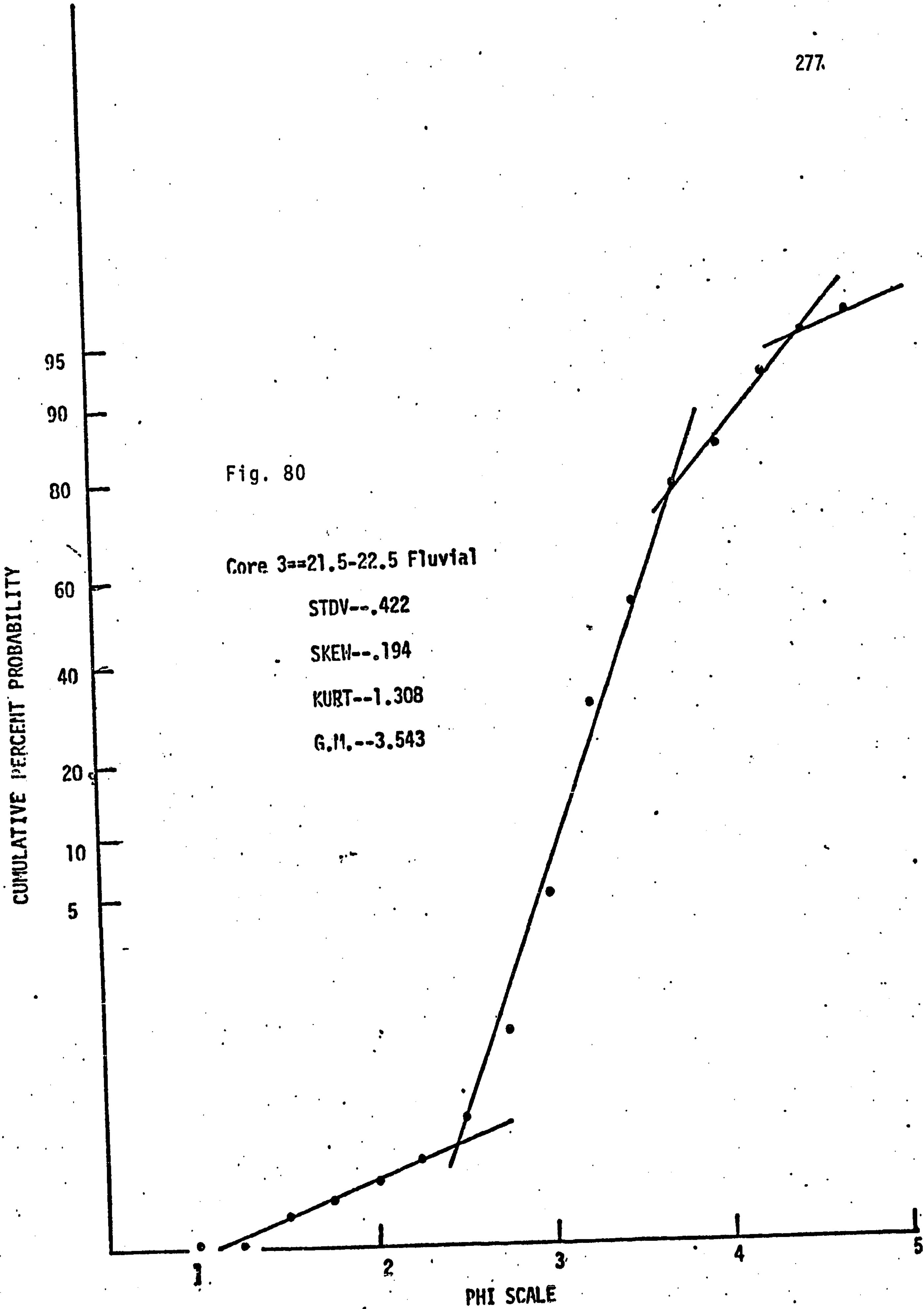


Fig. 80

Core 3==21.5-22.5 Fluvial

STDV--.422

SKEW--.194

KURT--1.308

G.M.--3.543

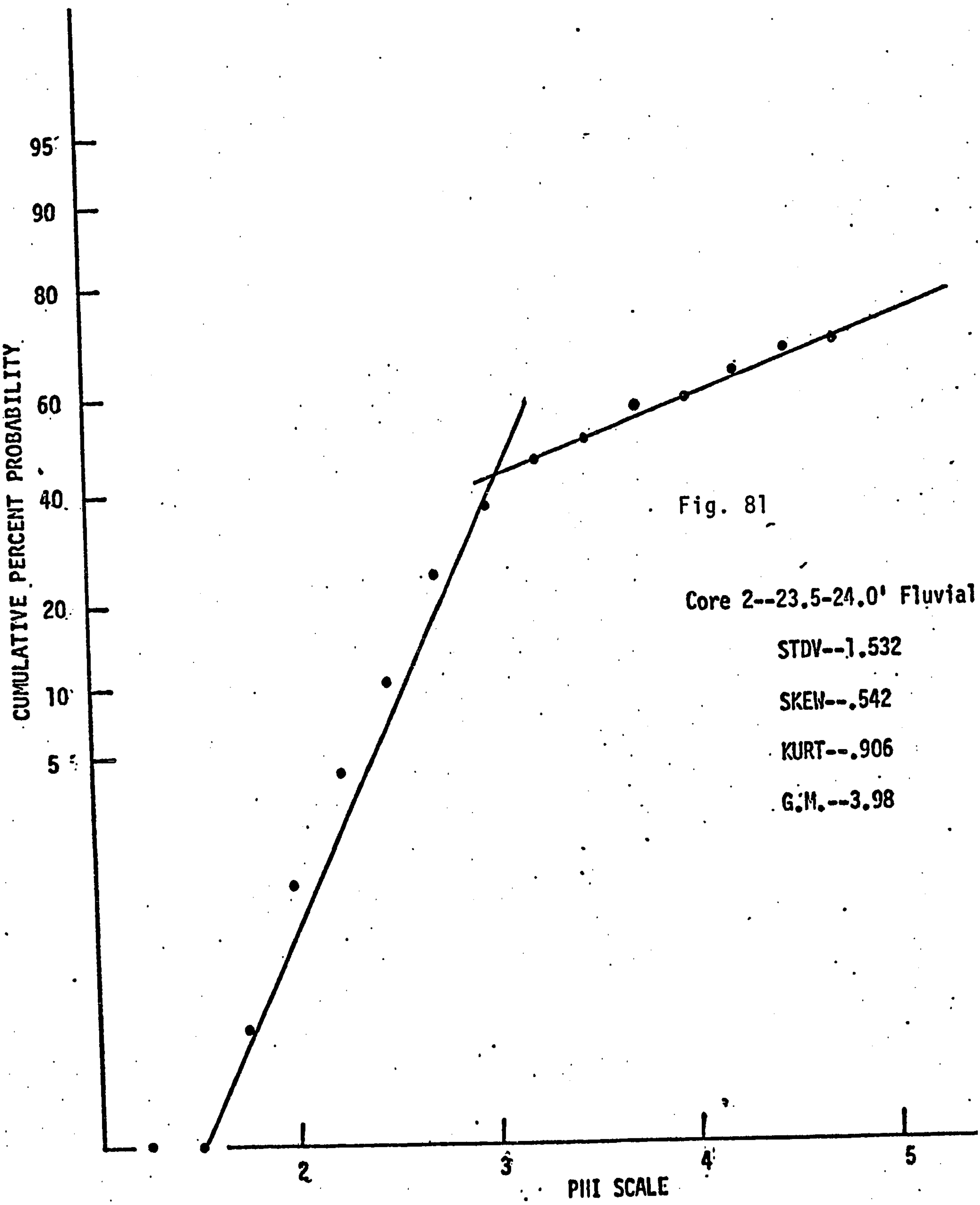


Fig. 81

Core 2--23.5-24.0' Fluvial

STDV--1.532

SKEW--.542

KURT--.906

G.M.--3.98

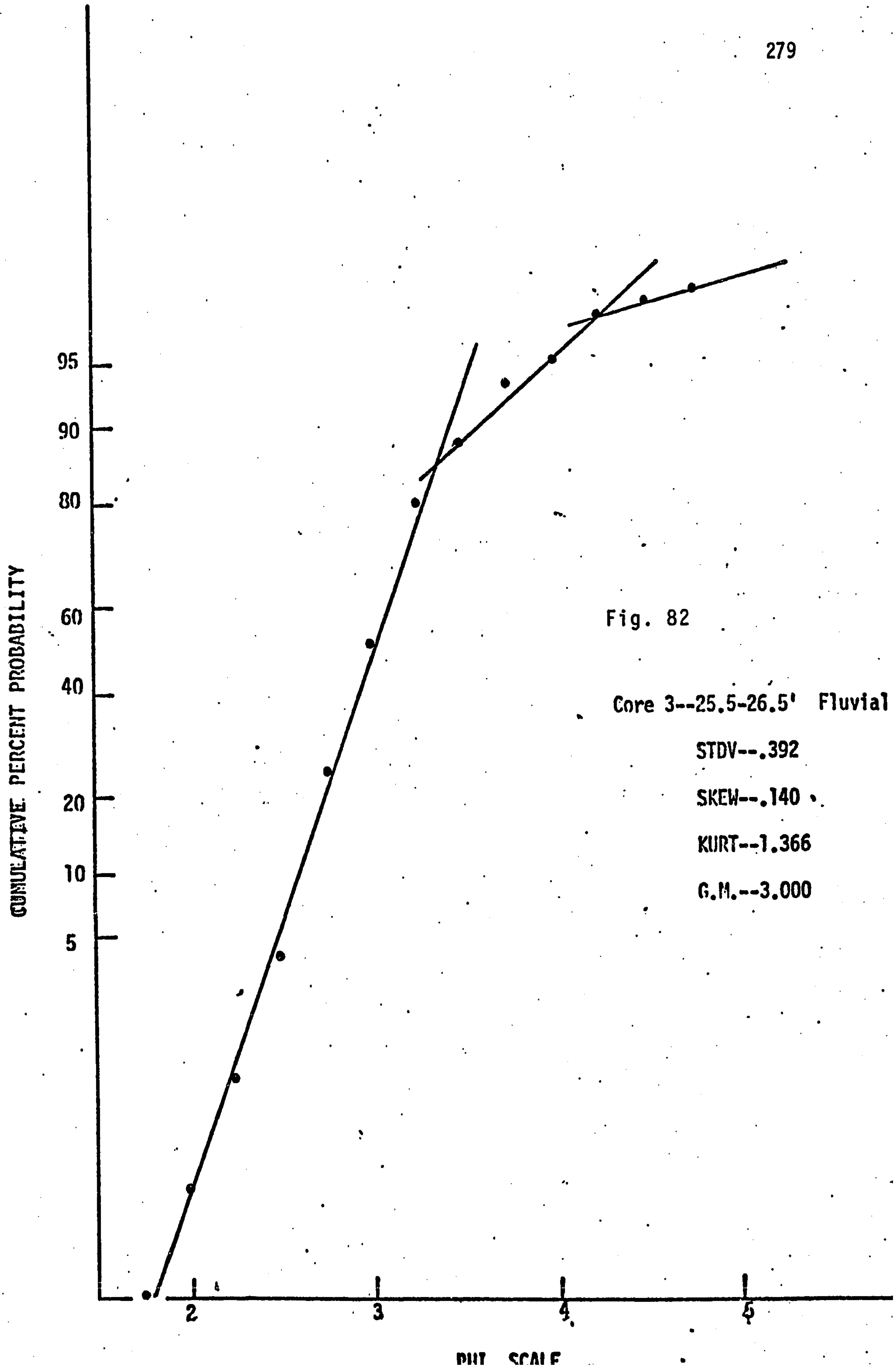


Fig. 82

Core 3--25.5-26.5' Fluvial

STDV--.392

SKEW--.140

KURT--1.366

G.M.--3.000

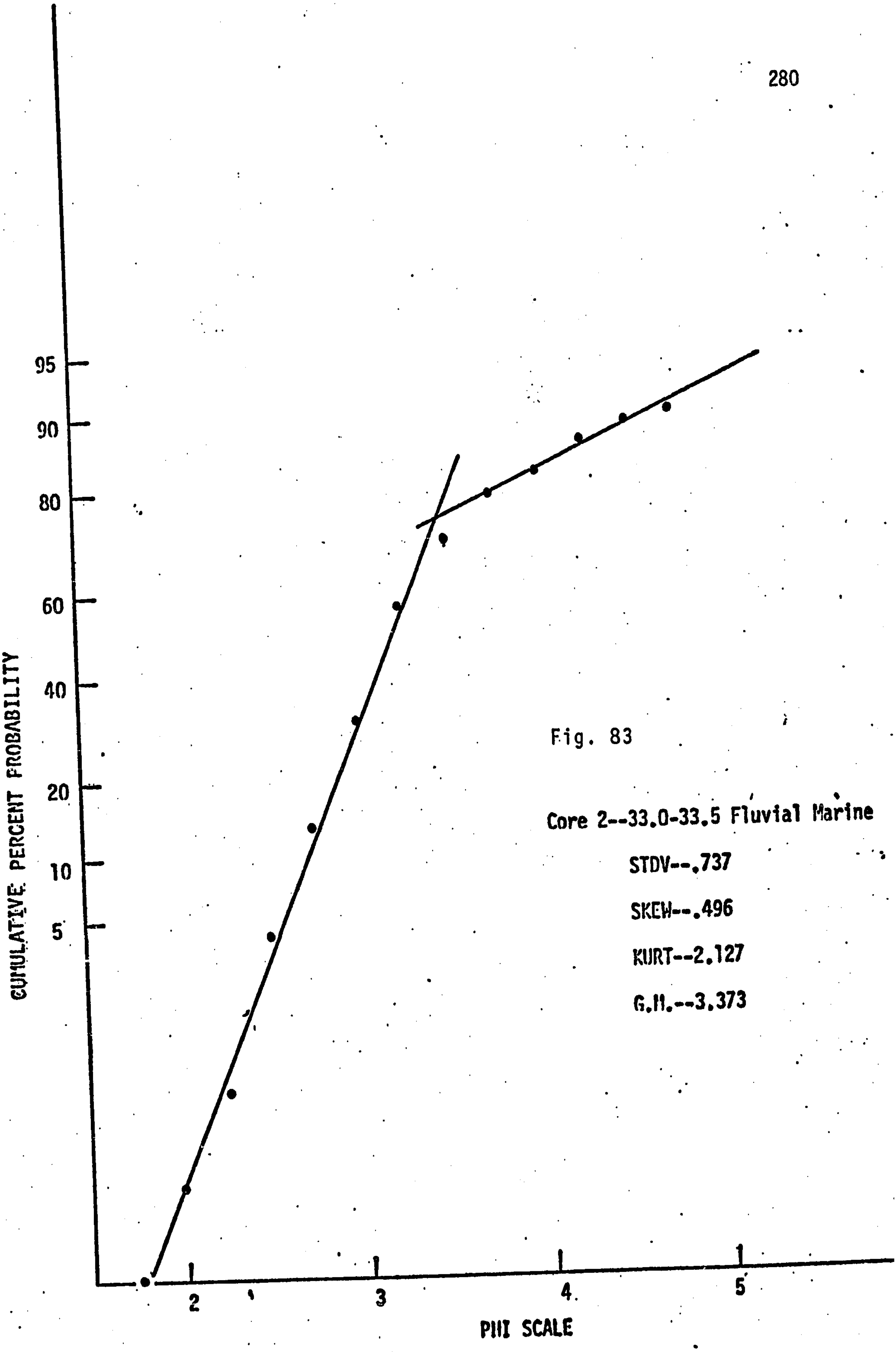


Fig. 83

Core 2--33.0-33.5 Fluvial Marine

STDV--.737

SKEW--.496

KURT--2.127

G.M.--3.373

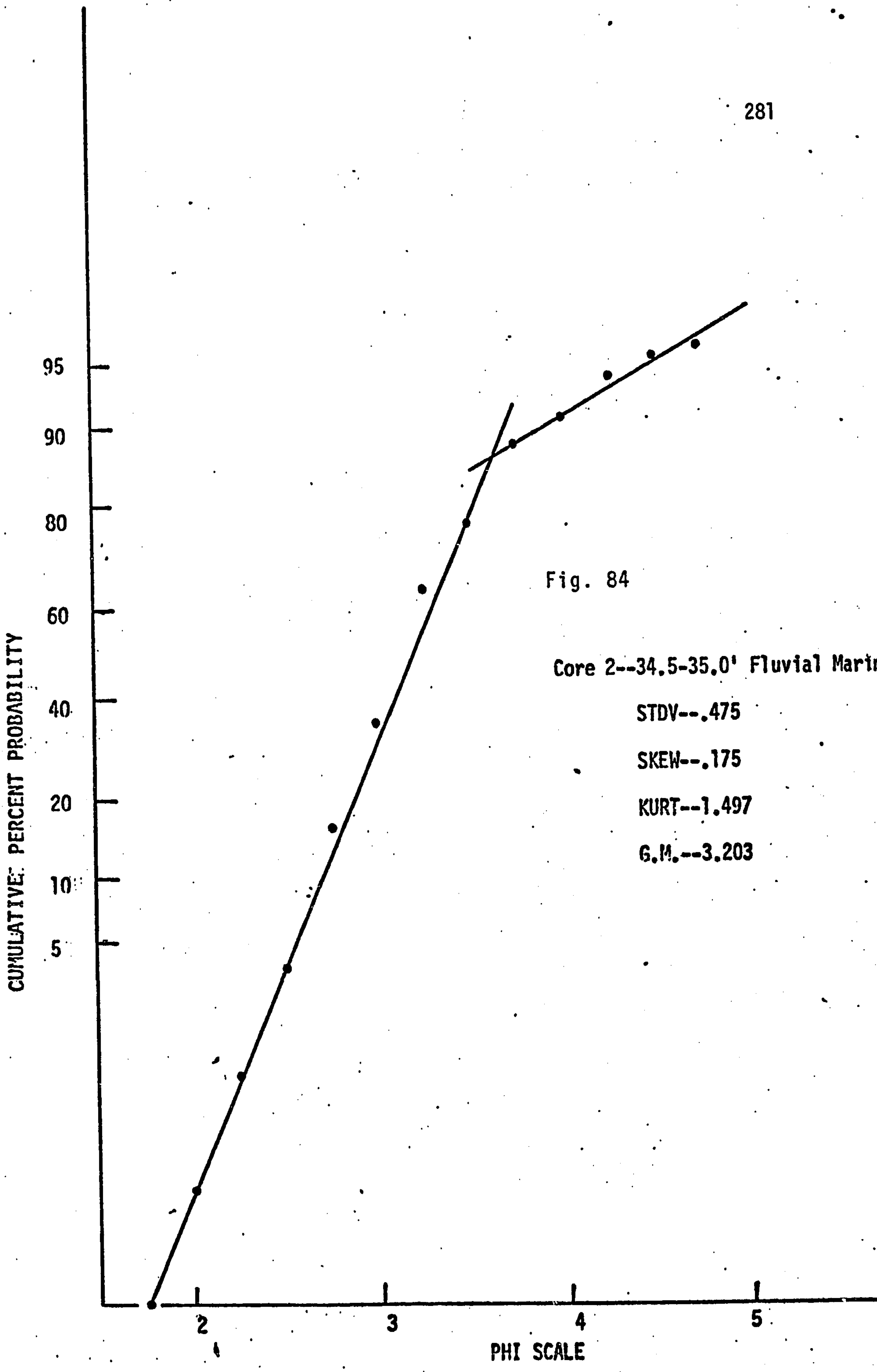

95
90
80
60
40
20
10
5
CUMULATIVE PERCENT PROBABILITY
2
3
4
5
PHI SCALE
Core 2--34.5-35.0' Fluvial Marin
STDV--.475
SKEW--.175
KURT--1.497
G.M.--3.203

Fig. 84

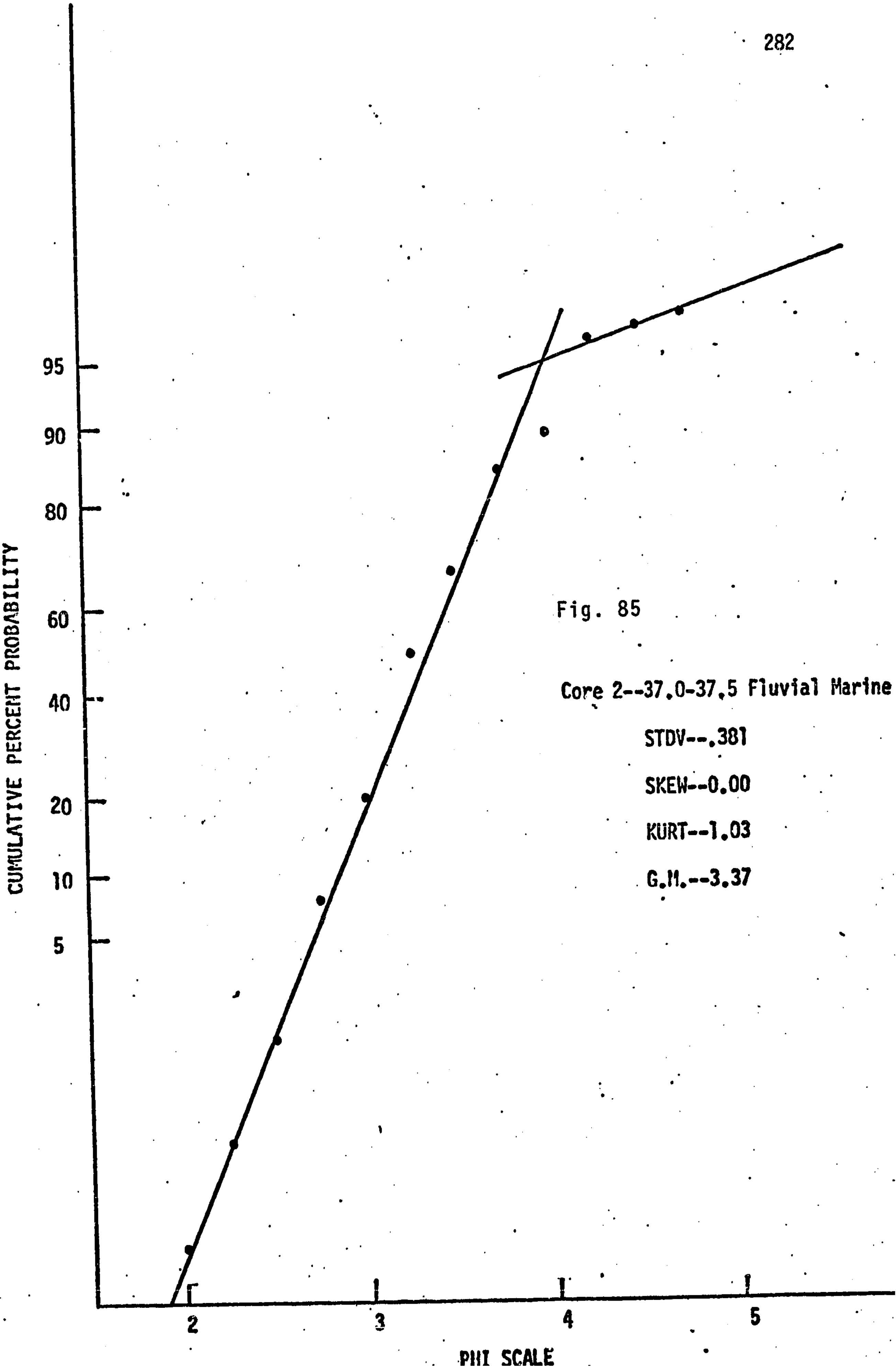


Fig. 85

Core 2--37.0-37.5 Fluvial Marine

STDV--.381

SKEW--0.00

KURT--1.03

G.M.--3.37

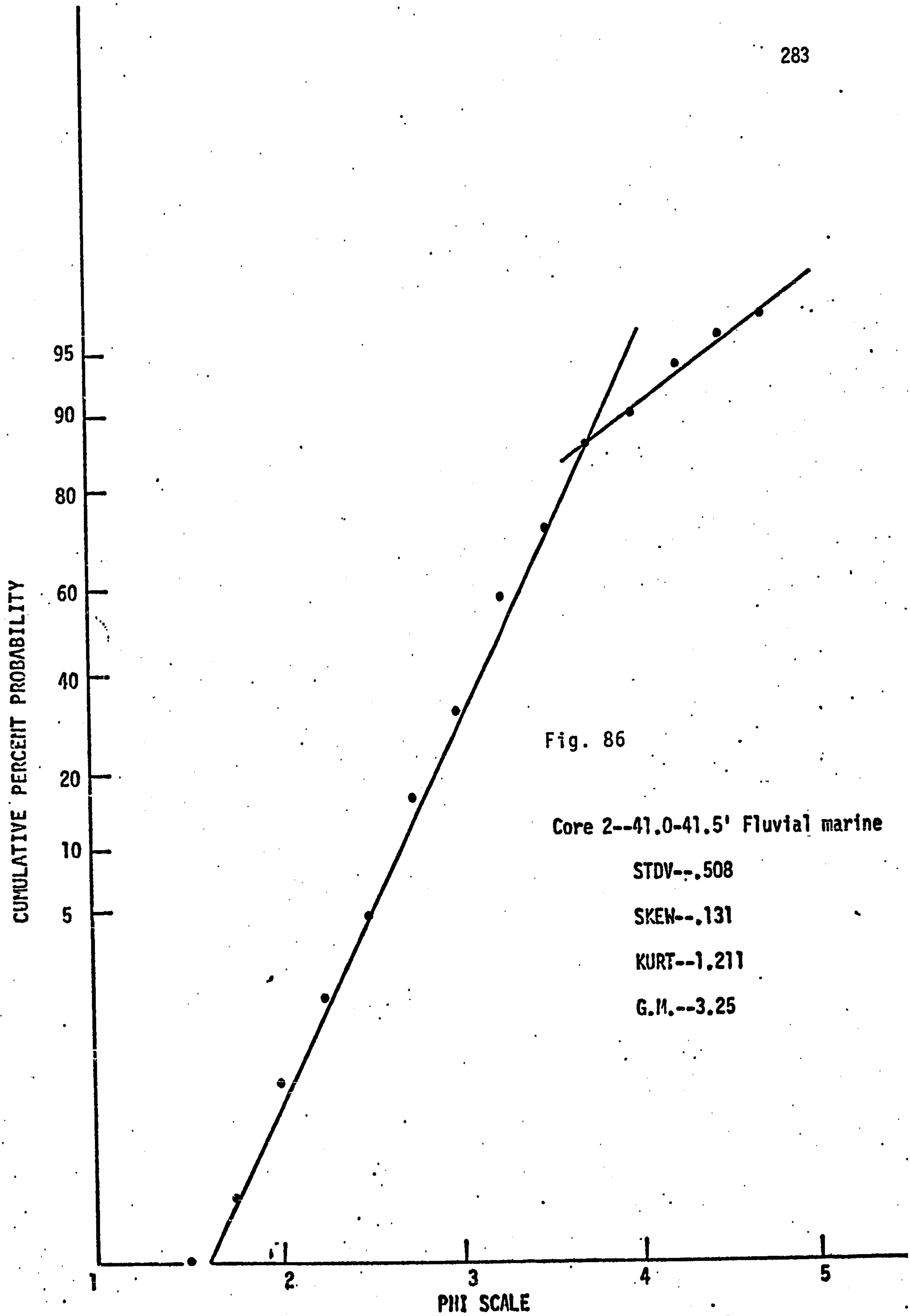


Fig. 86

Core 2--41.0-41.5' Fluvial marine

STDV--.508

SKEW--.131

KURT--1.211

G.M.--3.25

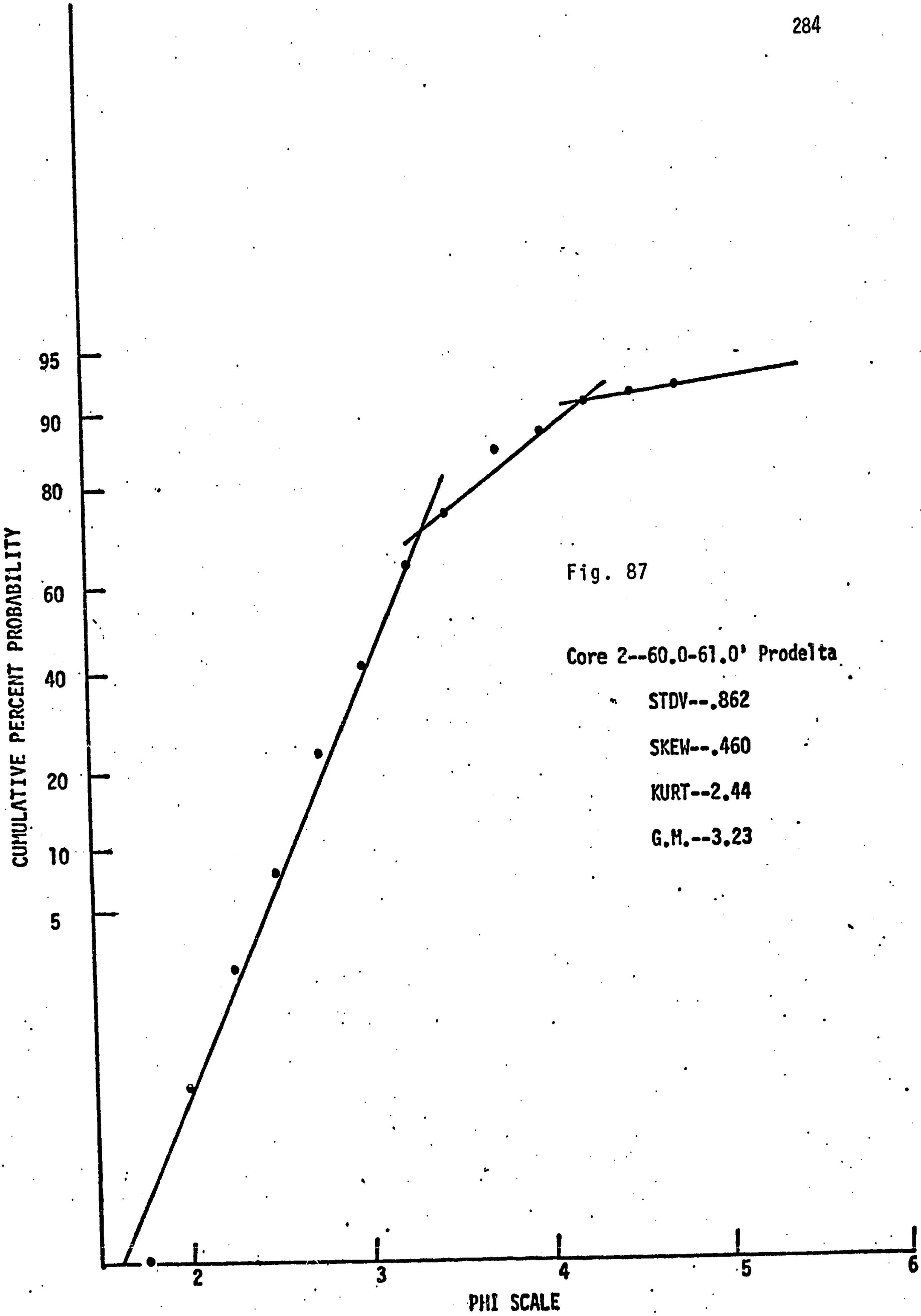


Fig. 87

Core 2--60.0-61.0' Prodelta

STDV--.862

SKEW--.460

KURT--2.44

G.M.--3.23

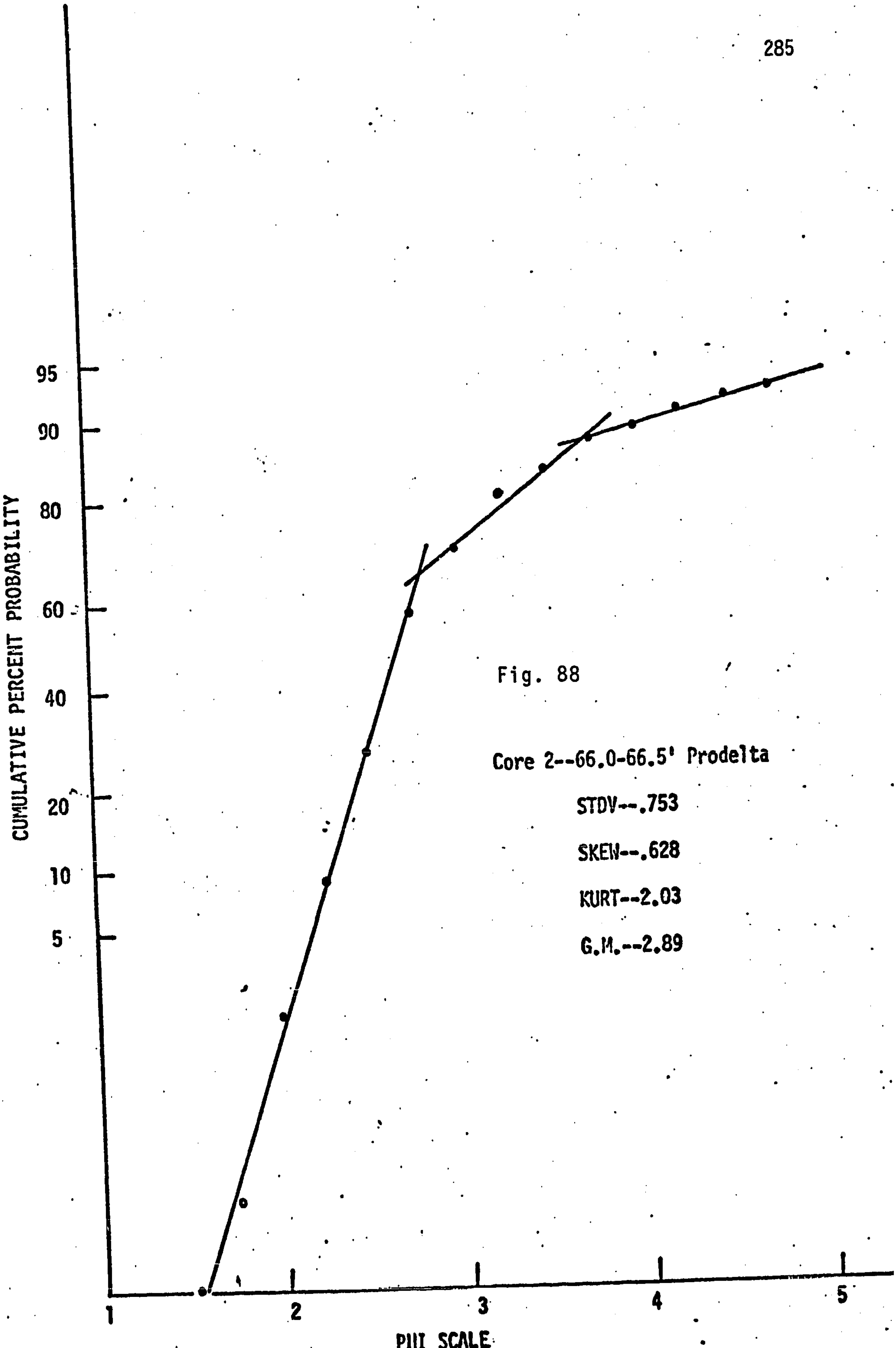

95
90
80
60
40
20
10
5
CUMULATIVE PERCENT PROBABILITY
1
2
3
4
5
PHI SCALE
Core 2--66.0-66.5' Prodelta
STDV--.753
SKEW--.628
KURT--2.03
G.M.--2.89

Fig. 88

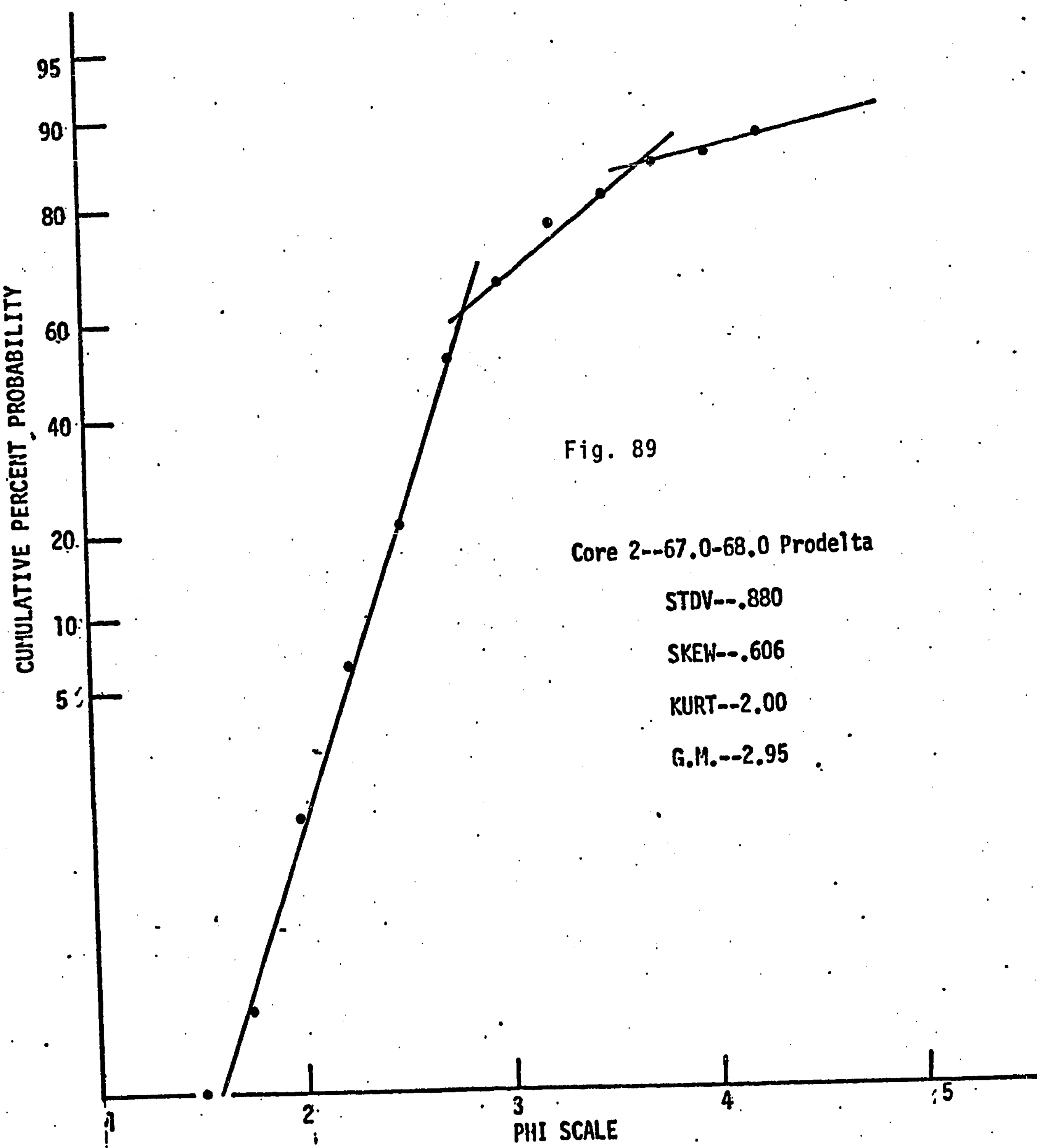


Fig. 89

Core 2--67.0-68.0 Prodelta

STDV--.880

SKEW--.606

KURT--2.00

G.M.--2.95

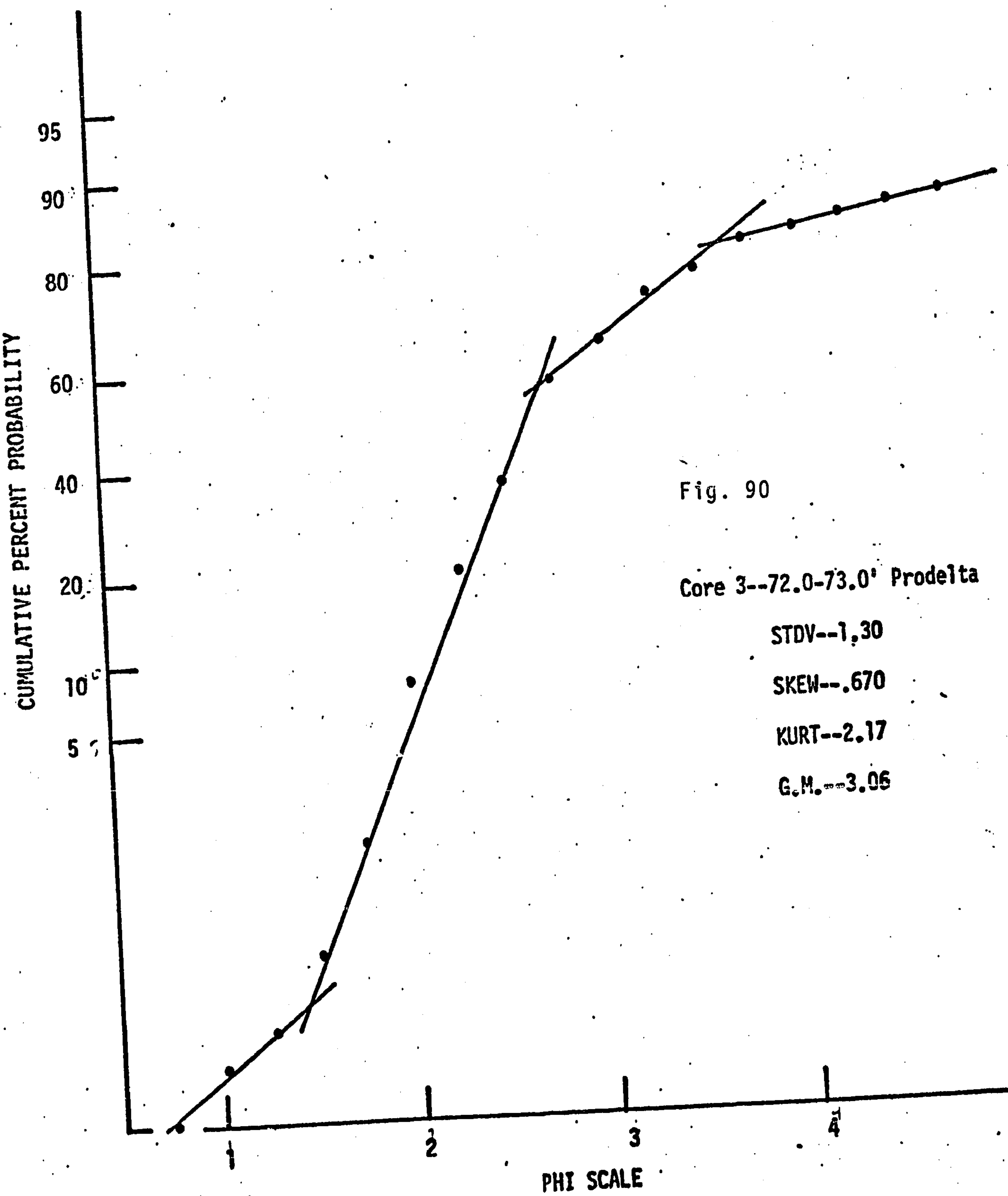


Fig. 90

Core 3--72.0-73.0' Prodelta

STDV--1.30

SKEW--.670

KURT--2.17

G.M.--3.06

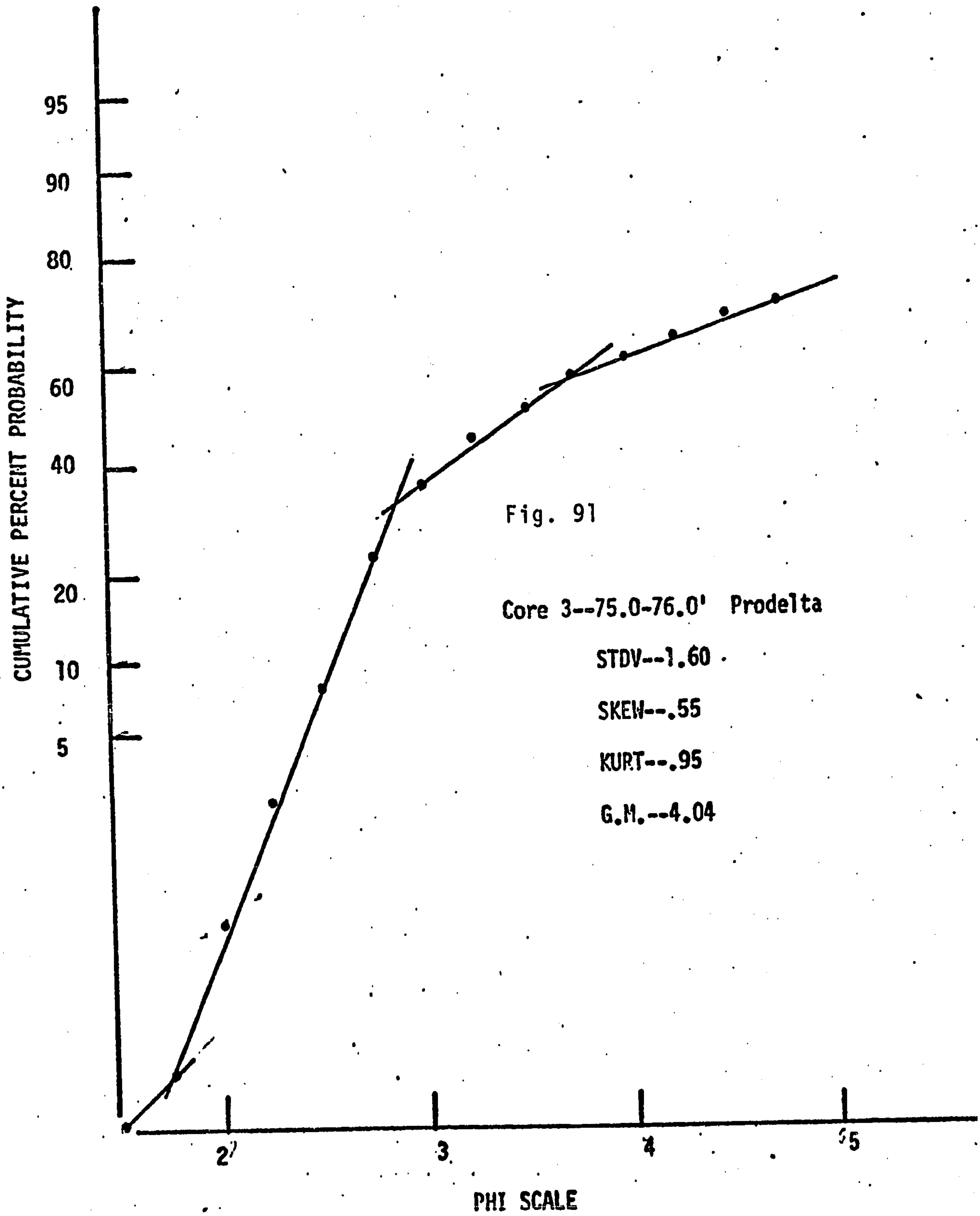


Fig. 91

Core 3--75.0-76.0' Prodelta

STDV--1.60

SKEW--.55

KURT--.95

G.M.--4.04

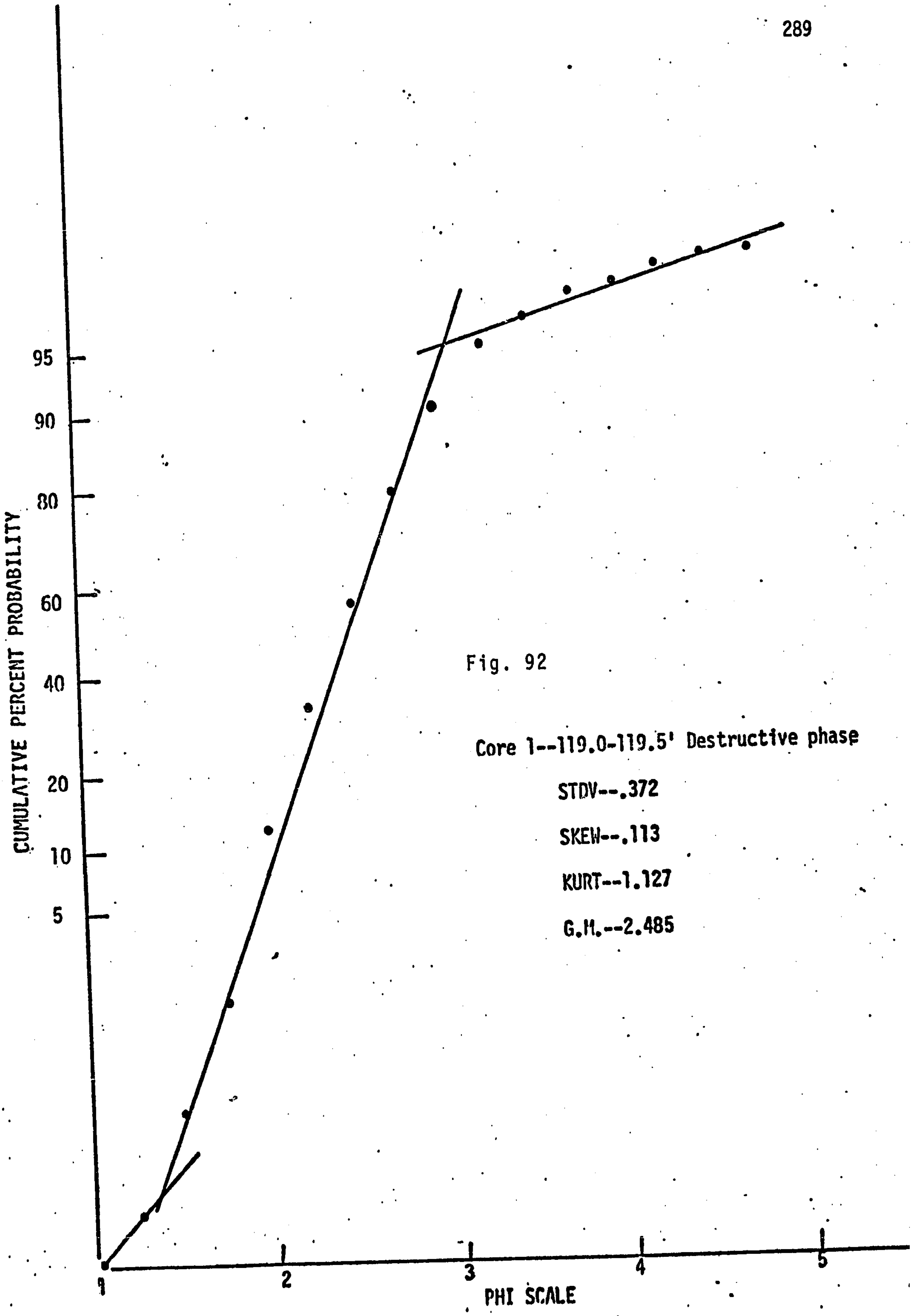


Fig. 92

Core 1--119.0-119.5' Destructive phase

STDV--.372

SKEW--.113

KURT--1.127

G.M.--2.485

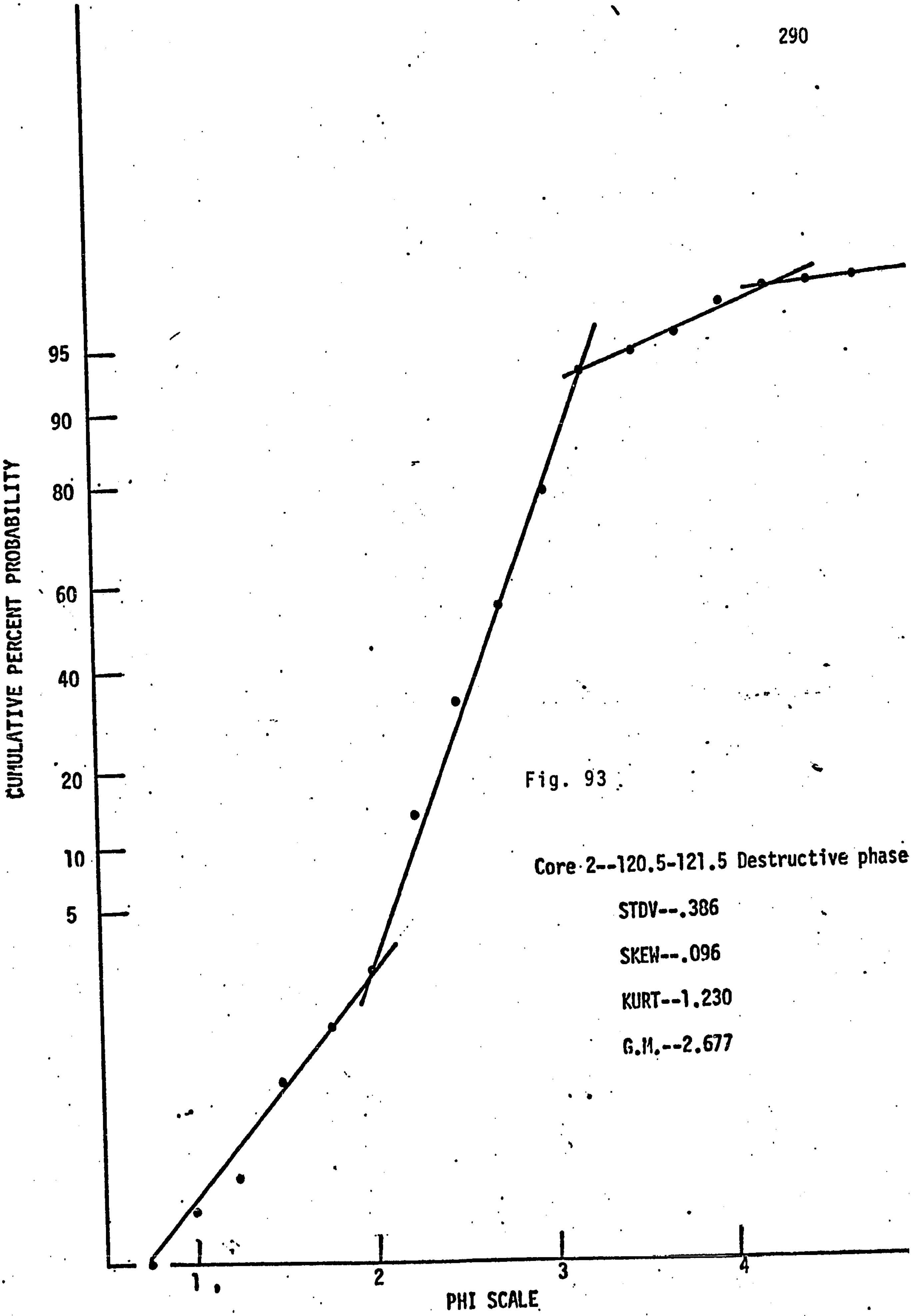

95
90
80
60
40
20
10
5
CUMULATIVE PERCENT PROBABILITY
1
2
3
4
PHI SCALE
Core 2--120.5-121.5 Destructive phase
STDV--.386
SKEW--.096
KURT--1.230
G.M.--2.677

Fig. 93

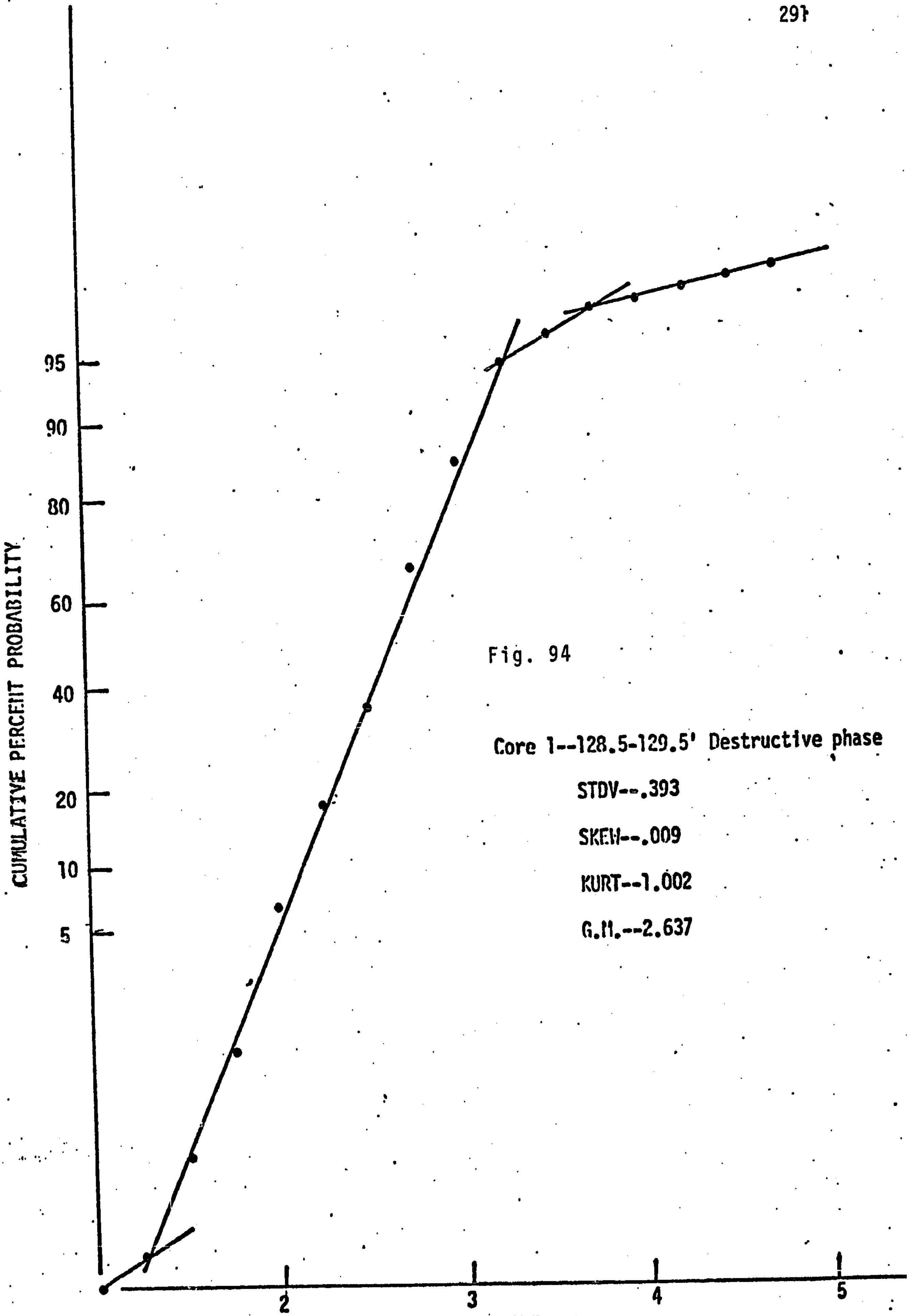


Fig. 94

Core 1--128.5-129.5' Destructive phase

STDV--.393

SKEW--.009

KURT--1.002

G.M.--2.637

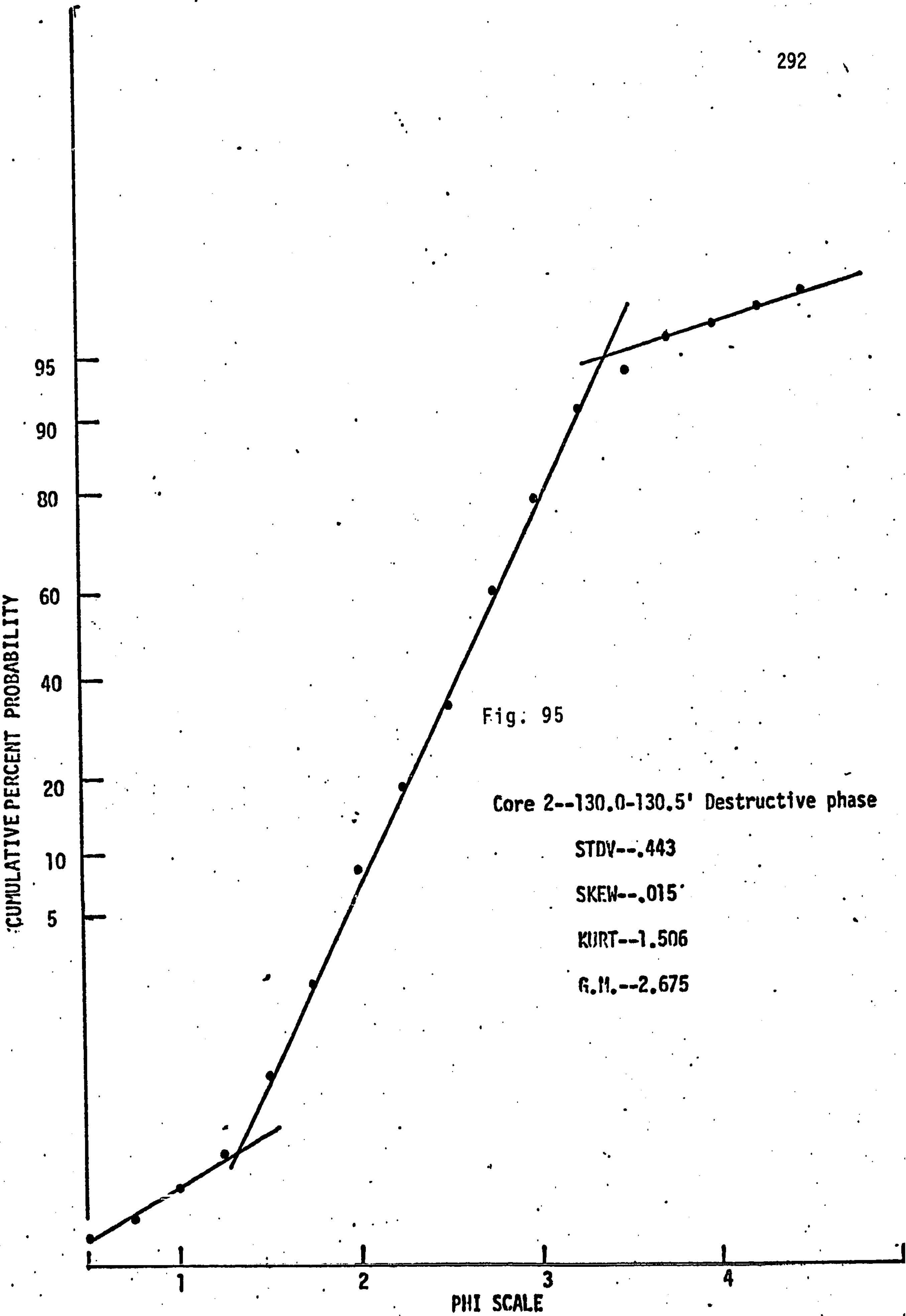

95
90
80
60
40
20
10
5
CUMULATIVE PERCENT PROBABILITY
1
2
3
4
PHI SCALE
Core 2--130.0-130.5' Destructive phase
STDV--.443
SKEW--.015
KURT--1.506
G.M.--2.675

Fig. 95

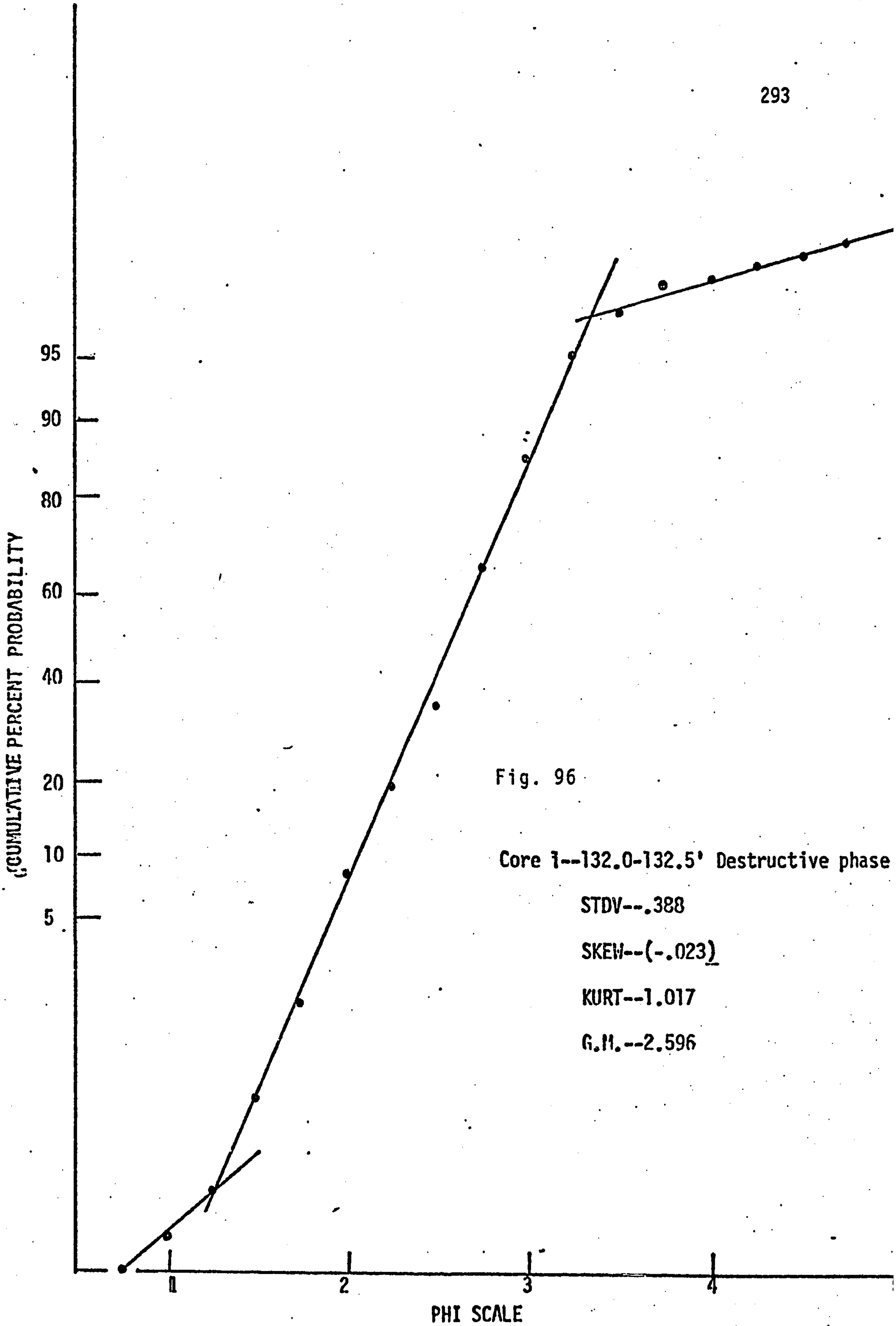


Fig. 96

Core 1--132.0-132.5' Destructive phase

STDV--.388

SKEW--(-.023)

KURT--1.017

G.M.--2.596

APPENDIX III

CLAY MINERAL X-RAY TRACES

(Figs. 97-103)

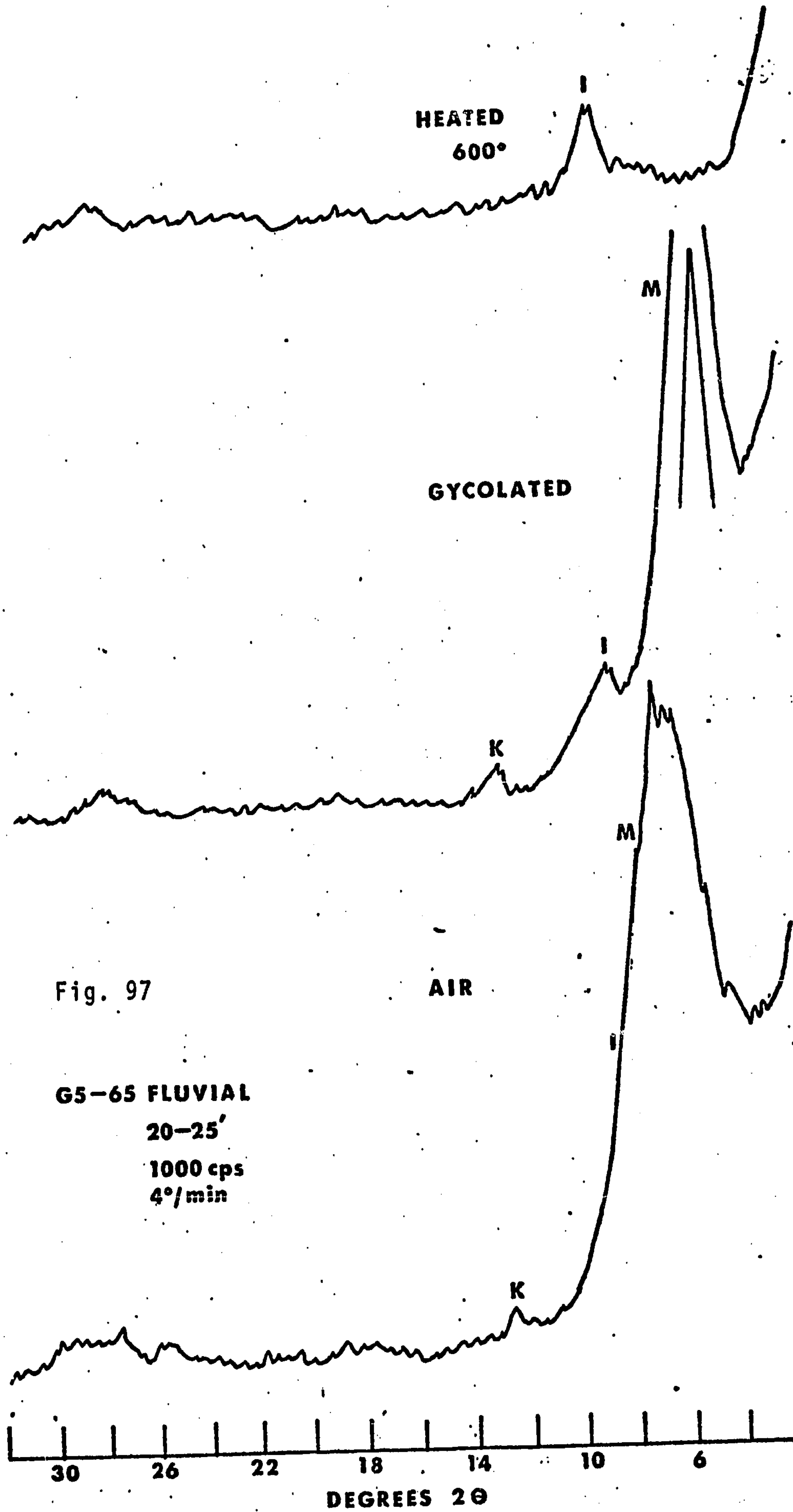
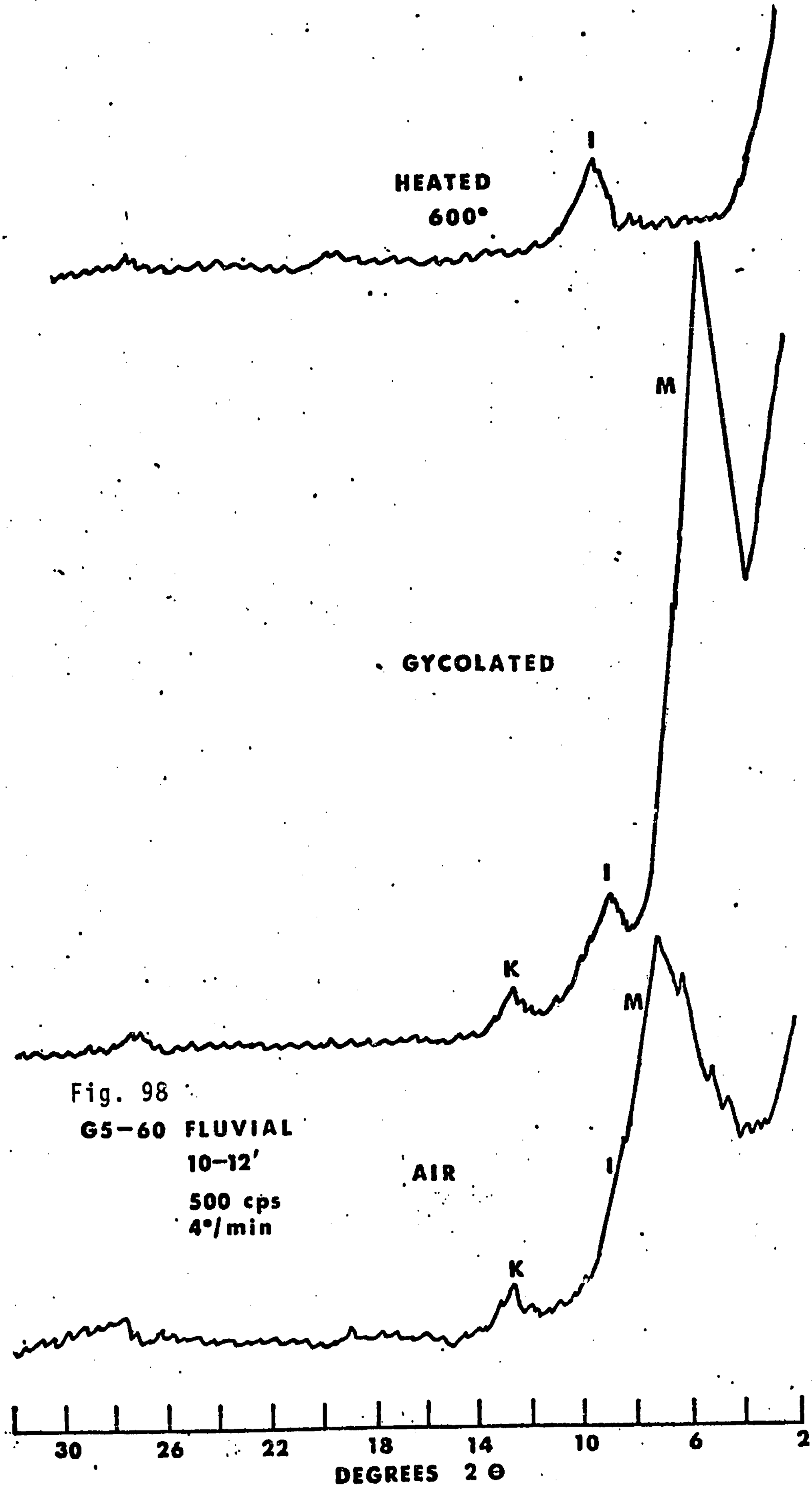

HEATED
600°
I
M
GYCOLATED
I
K
M
AIR
I
G5—65 FLUVIAL
20—25'
1000 cps
4°/min
K
30
26
22
18
14
10
6
2
DEGREES 2Θ

Fig. 97


HEATED
600°
I
M
GYCOLATED
I
K
M
Fig. 98
G5-60 FLUVIAL
10-12'
500 cps
4°/min
AIR
I
K
30
26
22
18
14
10
6
2
DEGREES 2 Θ

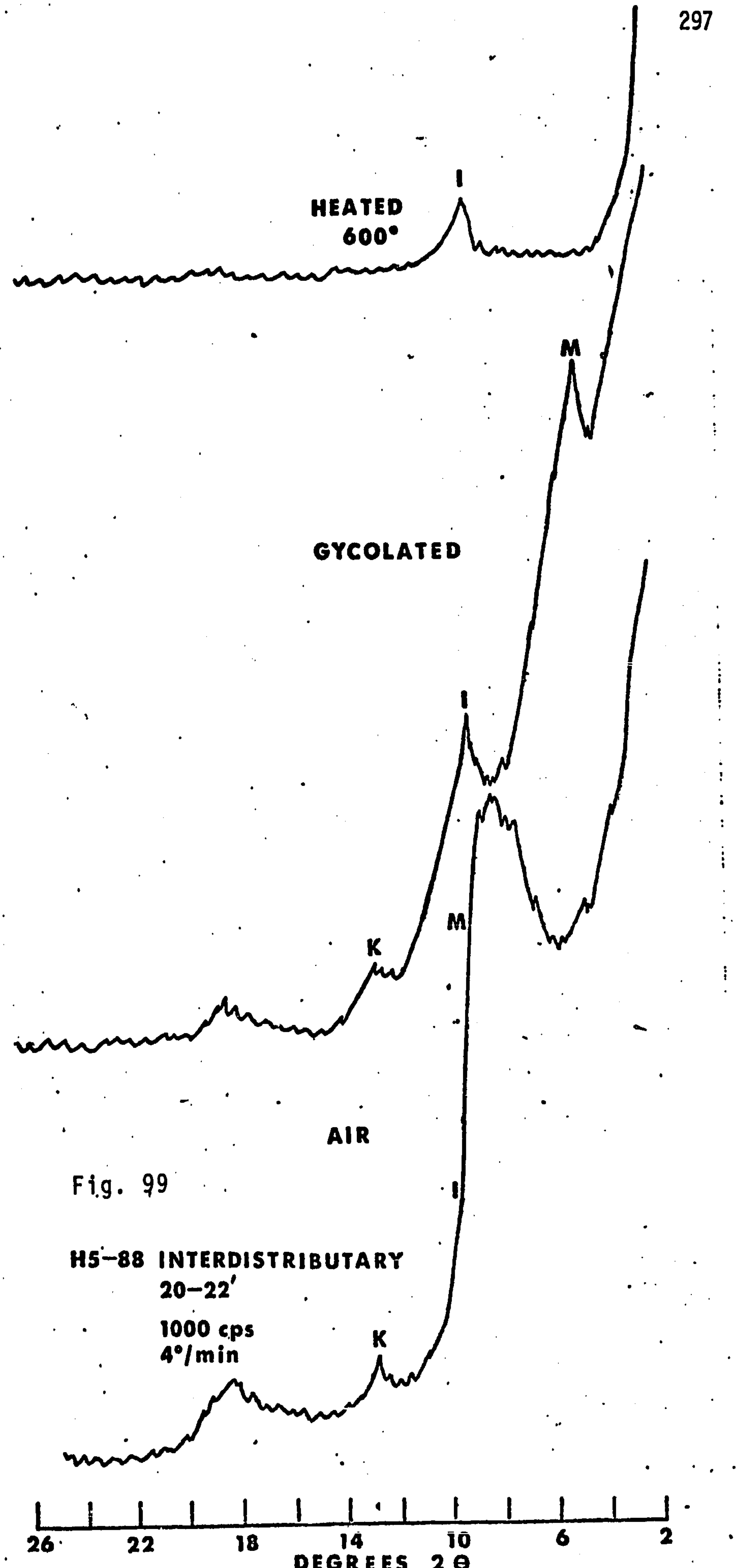

I
HEATED
600°
M
GYCOLATED
I
M
K
AIR
I
H5-88 INTERDISTRIBUTARY
20-22'
1000 cps
4°/min
K
26
22
18
14
10
6
2
DEGREES 2Θ

Fig. 99

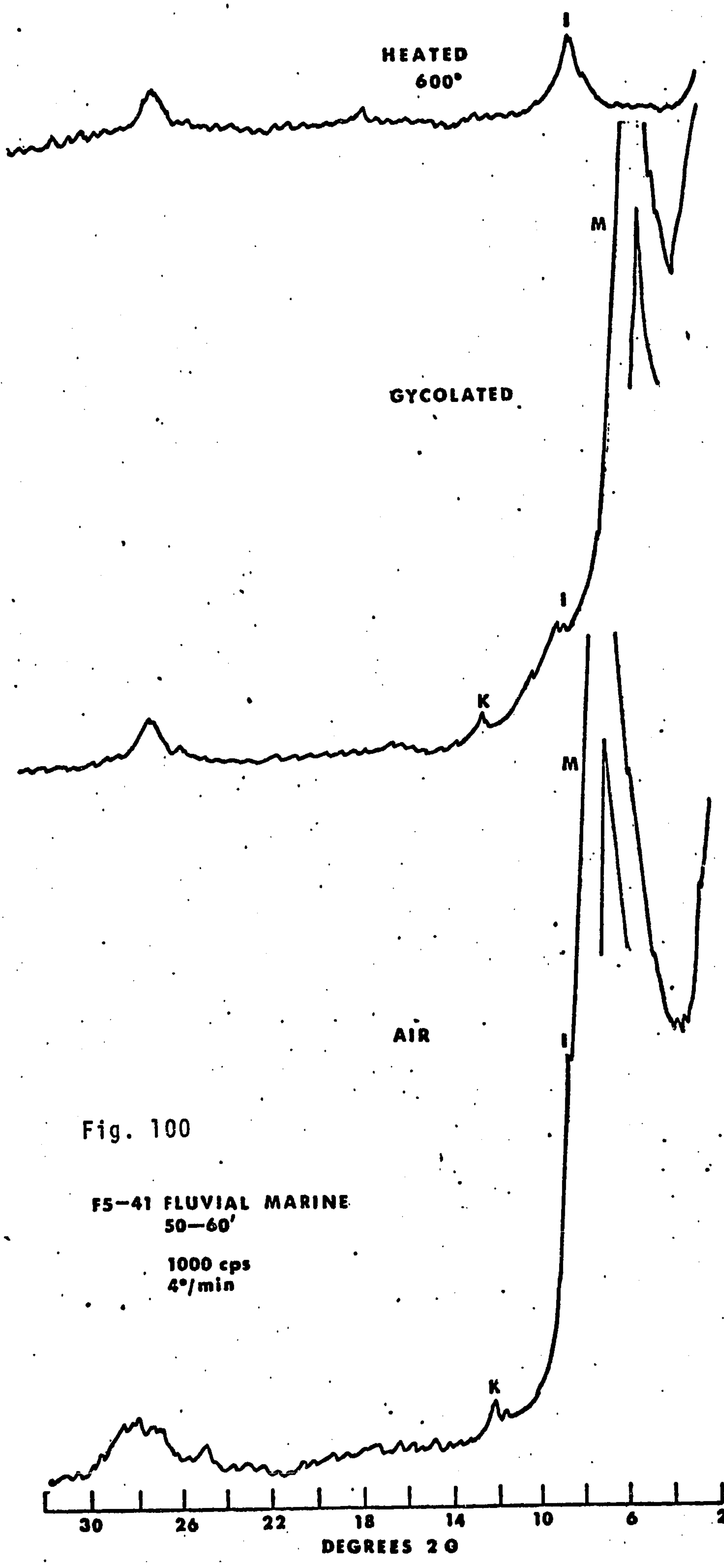


Fig. 100

F5—41 FLUVIAL MARINE
50—60′

1000 cps
4°/min

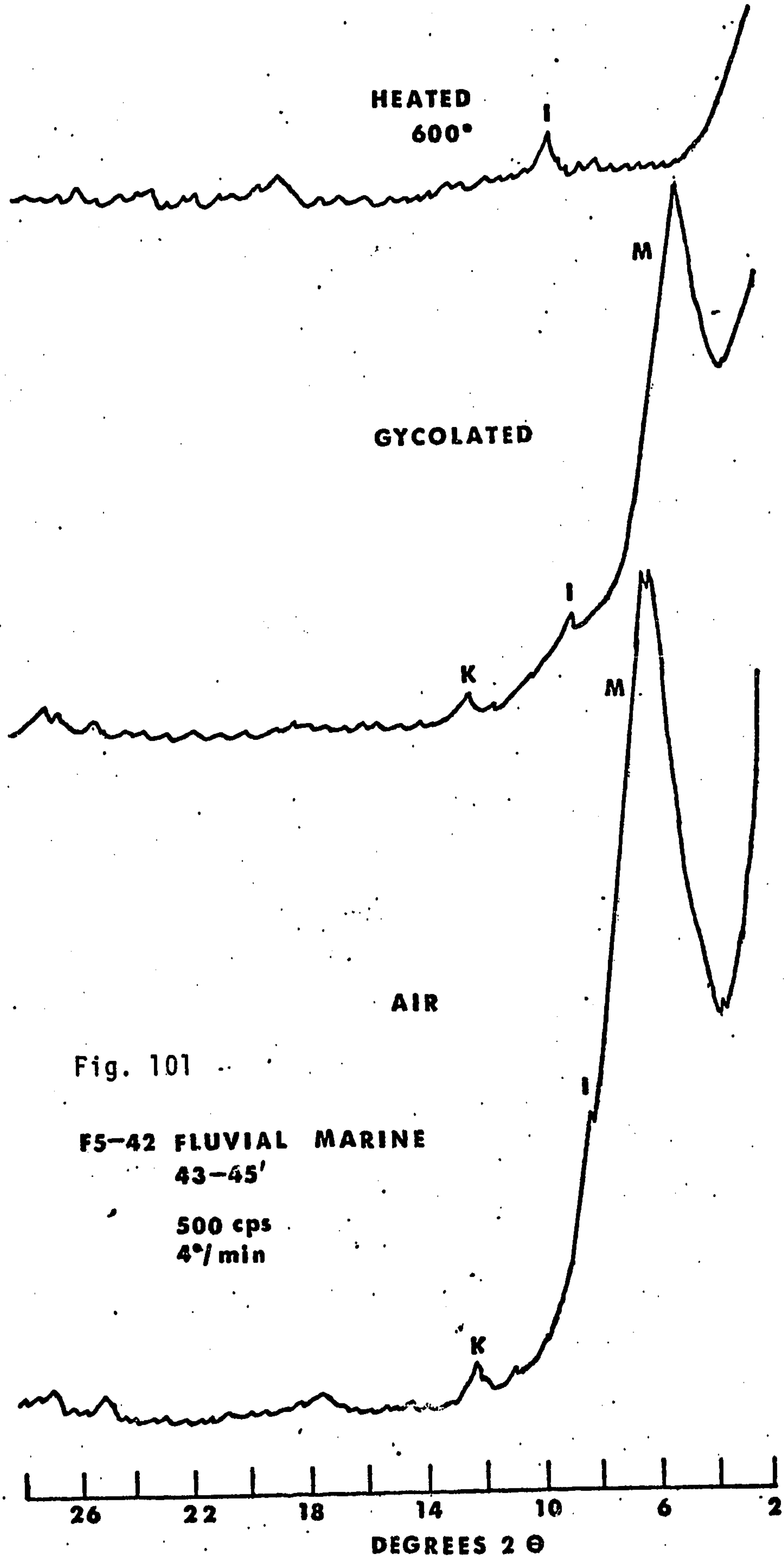


Fig. 101

F5–42 FLUVIAL MARINE
43–45′

500 cps
4°/min

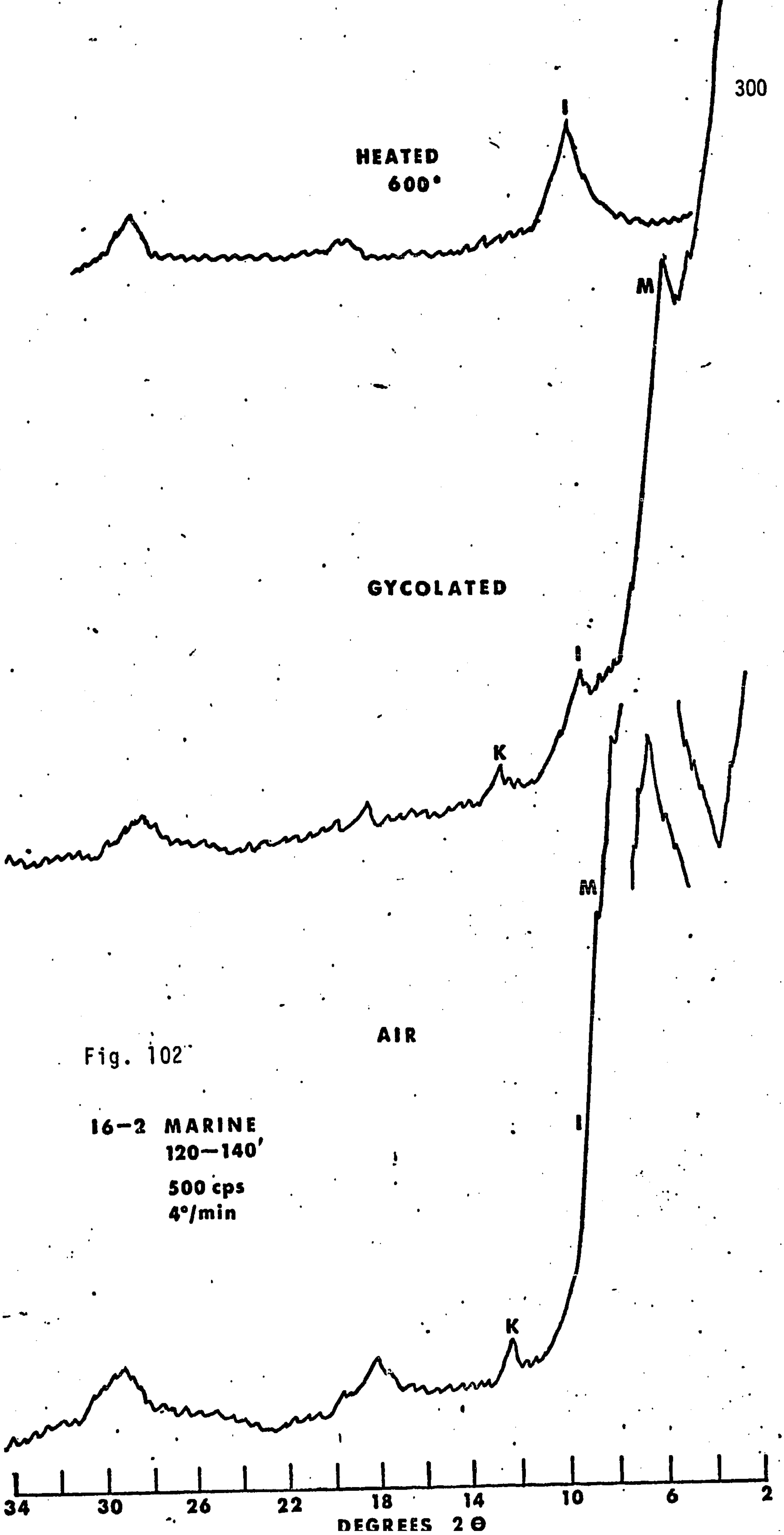

300
I
HEATED
600°
M
GYCOLATED
I
K
M
AIR
16-2 MARINE
120-140'
500 cps
4°/min
I
K
34
30
26
22
18
14
10
6
2
DEGREES 2 Θ

Fig. 102

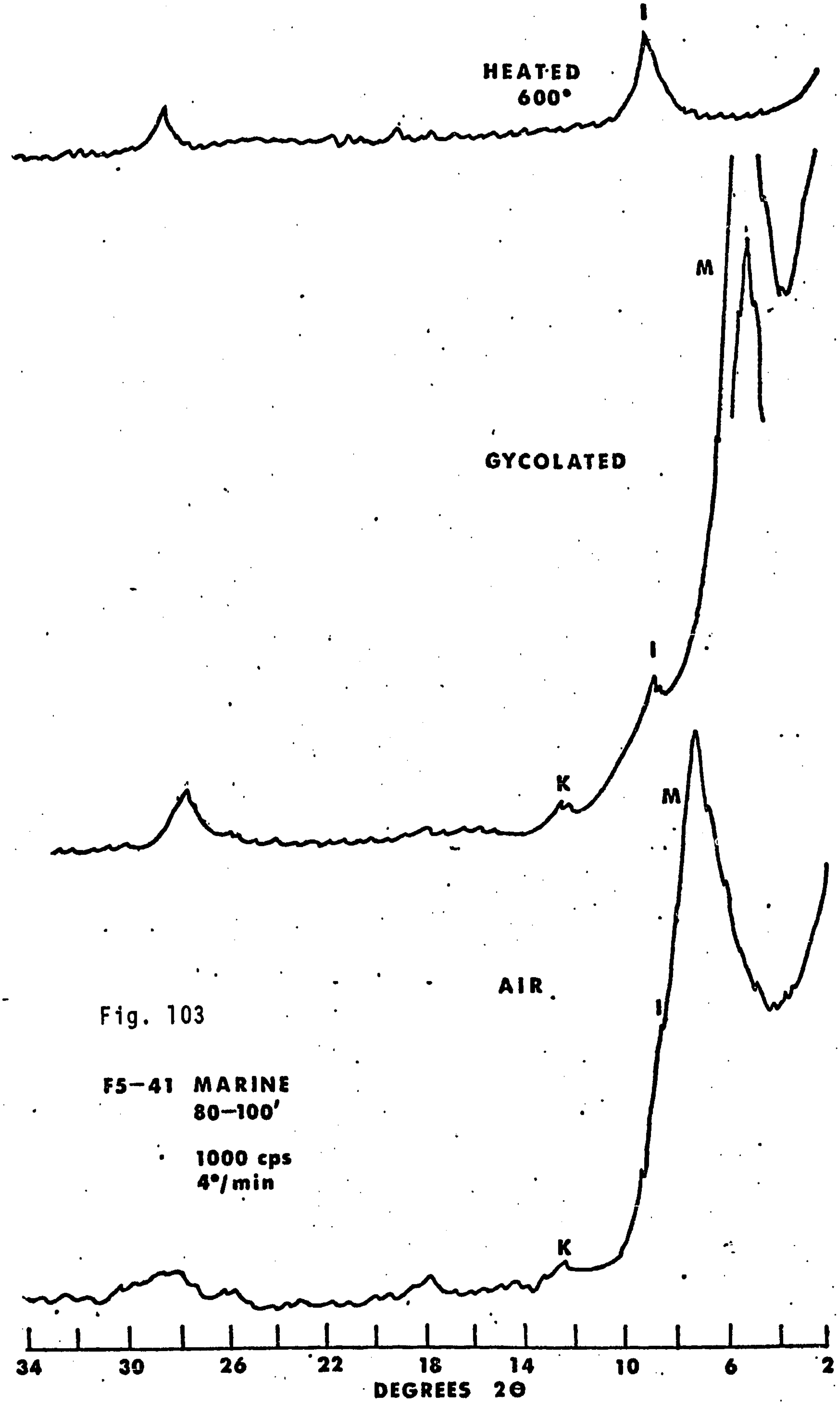


Fig. 103

F5–41 MARINE
80–100'

1000 cps
4°/min

APPENDIX IX

CLAY MINERAL PERCENTAGES

Well	Depth Feet	Percent Mont.	Percent Illite	Percent Kaol.
G5-60	5-6	92	7	1
	10-12	90	7	3
	16-18	92	4	2
	47-48	95	4	1
G5-65	2-4	82	13	5
	4-6	87	8	5
	14-16	84	14	2
	20-25	92	7	1
	27.0	91	7	2
	45.0	87	9	4
	55.0	94	5	1
	62-64	89	9	2
G6-34	4-6	90	8	2
	8-10	92	6	2
	13-15	92	7	1
	21-22	90	8	2
	32-34	93	5	2
	40	95	2	3
H5-35	5-10	85	10	5
	25-30	89	9	2
	35-40	81	15	4
	45-50	74	23	3
	55-60	82	15	3
	65-70	87	16	3
F5-42	2-4	86	13	1
	6-8	92	6	2
	8-10	90	8	2
	10-12	92	8	-
	12-14	89	7	4
	14-16	91	7	3
	16-18	93	6	1
	35-37	90	8	2
	37-39	88	9	3
	39-41	89	8	3
	41-43	91	8	1
	43-45	90	7	3
	45-47	88	9	3
	47-49	88	9	3

Well	Depth Feet	Percent Mont.	Percent Illite	Percent Kaol.
F5-42 con't	53-55	92	6	2
	55-57	89	9	2
	63-65	89	8	3
	65-67	89	7	4
	67-69	90	9	1
F5-41	0-10	89	8	3
	10-20	87	9	4
	20-30	89	9	2
	30-40	88	9	3
	40-50	88	9	3
	50-60	92	6	2
	60-70	90	7	3
	70-80	89	8	3
	80-90	90	8	2
	90-100	93	5	2
	100-120	93	5	2
	120-140	85	13	2
	140-160	91	6	3
	160-180	83	14	3
	180-200	83	15	2
	200-220	84	13	3
	220-240	84	14	2
	240-250	86	13	1
	260-280	88	9	3
	280-300	86	13	1
	300-320	85	13	2
	320-340	89	9	2
	360-380	90	8	2
	380-400	89	9	2
	400-420	81	16	3
	420-440	86	10	4
	440-460	89	9	2
	460-480	87	10	3
	480-500	85	13	2
	500-520	84	13	3
	520-540	86	12	2
	540-560	90	8	2
	560-580	89	9	2
	580-600	89	9	2
	600-620	89	9	2
	620-640	88	10	2

Well	Depth Feet	Mont.	Illite	Kaol.
		Percent		
F5-41 con't	640-660	86	12	2
	660-680	88	9	3
	680-700	87	12	-
	700-720	86	10	4
	720-740	92	7	1
H6-32	0-5	79	17	4
	5-10	84	13	3
	10-15	83	15	2
	15-20	82	16	2
	20-25	82	15	3
	25-30	86	13	1
	30-35	86	12	2
	35-40	82	15	3
	40-45	85	13	2
	45-50	88	9	3
	50-55	87	12	1
	55-60	91	7	3
	60-65	84	12	4
	65-70	80	17	3
	70-75	88	10	2
	75-80	86	11	3
H5-23	0-5	87	9	4
	5-10	87	10	3
	10-15	88	9	3
	15-20	90	7	3
	20-25	88	9	3
	25-30	81	17	2
	30-35	81	15	4
	35-40	79	17	4
	40-45	82	15	3
	45-50	84	13	3
	50-55	82	15	3
	55-60	85	12	3
	60-65	84	14	2
	65-70	83	15	2
H5-89	10-20	90	7	3
	20-30	80	15	5
	30-40	84	12	4
	40-50	92	5	3
	50-60	90	7	3

Well	Depth Feet	Mont.	Illite	Kaol.
		Percent		
H5-89 con't	60-70	86	10	4
	70-80	91	5	4
	80-90	86	10	4
	90-100	82	13	5
	100-120	87	9	4
	120-140	85	12	3
	140-160	92	5	3
	140-160	92	5	3
	160-180	91	6	3
	180-200	87	9	4
	200-220	79	14	7
	220-240	85	12	3
	240-260	86	11	3
	260-280	88	11	1
	280-300	87	10	3
	300-320	85	13	2
	320-340	88	10	2
	340-360	84	13	3
	360-380	84	14	2
	350-400	84	13	3
	420-440	80	16	4
	440-460	84	13	3
	460-480	87	11	2
	480-500	80	17	3
	500-520	84	14	2
	520-540	77	20	3
	540-560	86	12	2
	560-580	83	14	3
	580-600	86	12	2
	600-620	86	12	2
H5-88	10-12	78	19	3
	2-4	85	12	3
	20-22	69	28	3
	28-30	85	12	3
	40.5	78	16	6
	54-56	83	11	6
	58-60	82	15	3
	80-82	52	44	4
	88-90	72	22	6

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