SUBSURFACE GEOLOGY OF THE ST. CROIX CARBONATE SYSTEM
PHASE II

Ivan P. Gill
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May, 1987

Agreement No. 14-08-0001-G1258

Technical Report No. 28
Caribbean Research Institute
University of the Virgin Islands
St. Thomas, U.S.V.I. 00802

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ABSTRACT

Seven new test holes were drilled into St. Croix's central carbonate plain with a rotary drill rig. Cumulative drilling for this phase of the project exceeded 750 feet, and brought the total number of test holes for the project to fourteen. These test holes allow lithologic and biostratigraphic correlation in a north to south transect from Krausses Lagoon to Estate St. John and in a west to east transect from Estate Hesselberg to Estate Pearl.

The drilling establishes the existence of a probable Pliocene reef and shallow-water facies trend that rims the western and southern coastlines of the central plain. The greatest thickness of Pliocene sediments occurs in a subsidiary graben block in the south coast industrial area. The northern and western boundaries of the Pliocene graben can be inferred from core data. The Pliocene post-Kingshill carbonates are less extensive than the Miocene Kingshill Limestone, but are generally more permeable.

Dolomitization in the Pliocene carbonates rims what was the coastline of Krausses Lagoon before industrial development modified the shoreline in the 1960s. The geographical distribution of the dolomite suggests a hydrologic correlation between Krausses Lagoon and the formation of dolomite. The stable isotopic composition of the dolomite suggests the possibility of a dolomitizing fluid with elevated salinity.

Structural mapping on the upper surface of the Miocene Jealousy Formation indicates marked upwarping under the carbonate highlands. This structural upwarping coincides with the greatest isopach thickness of the Kingshill Limestone. The patterns suggest a basin opening to the south, but with a depocenter located under the present position of the carbonate highlands. There is a greater degree of structural complexity in the central plains region than was previously supposed.

Micropaleontological evidence suggests that the Jealousy Formation / Kingshill Limestone contact is time-transgressive within the Miocene. Both units were deposited in deep water, perhaps at depths greater than 1000 m. Despite the marked color change, there are surprisingly few mineralogic or paleontological differences between the Jealousy Formation and the Kingshill Limestone, and the contact between the two formations does not imply significant paleobathymetric change.

ACKNOWLEDGEMENTS

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Access to exposures and drill sites for this phase of the project was freely given by the staff of Martin Marietta Corporation, in particular G. Bennewith and J. Savage, as well as H. Kerr, O. Schjang and the Women's Coalition of St. Croix. Cooperation during this phase of work was extended by several agencies of the Virgin Islands and Federal Governments: the Department of Public Works, the V. I. Planning Office, the Department of Natural Resources, and Mr. H. Rodrigues and the manbucket crew of the V. I. Water and Power Authority (St. Croix).

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We appreciate the support and advice of the staff of the U. S. Geological Survey, Puerto Rico, in particular Mr. F. Gomez-Gomez and Mr. A. Zack. Logistical support and management was provided by the staff of the West Indies Laboratory, and the program was administered by Dr. H. Smith of the Water Resources Research Center of the University of the Virgin Islands. One of the authors, Gill, is supported on a fellowship from the Louisiana State University Alumni Federation and the Department of Geology, and his lab work is supported by Dr. C. H. Moore and the staffs of the Applied Carbonate Research Program, the Basin Research Institute and the Department of Geology of Louisiana State University. The staffs of the Applied Carbonate Research Program and Department of Geology of Louisiana State University, and the staff of the West Indies Laboratory were invaluable in providing both field and laboratory assistance throughout the project.

TABLE OF CONTENTS

LIST OF FIGURES

information on previous work is contained in the first report (Gill and Hubbard, 1986a) and the reader is referred to that report for additional detail. Complementary information on groundwater chemistry is contained within a second report (Gill and Hubbard, 1986b). Since this project is part of an on-going doctoral research effort, results of longer-term analyses are expected to add to or modify the conclusions given in this report. As further data become available, every effort will be made to contribute this information to the public domain.

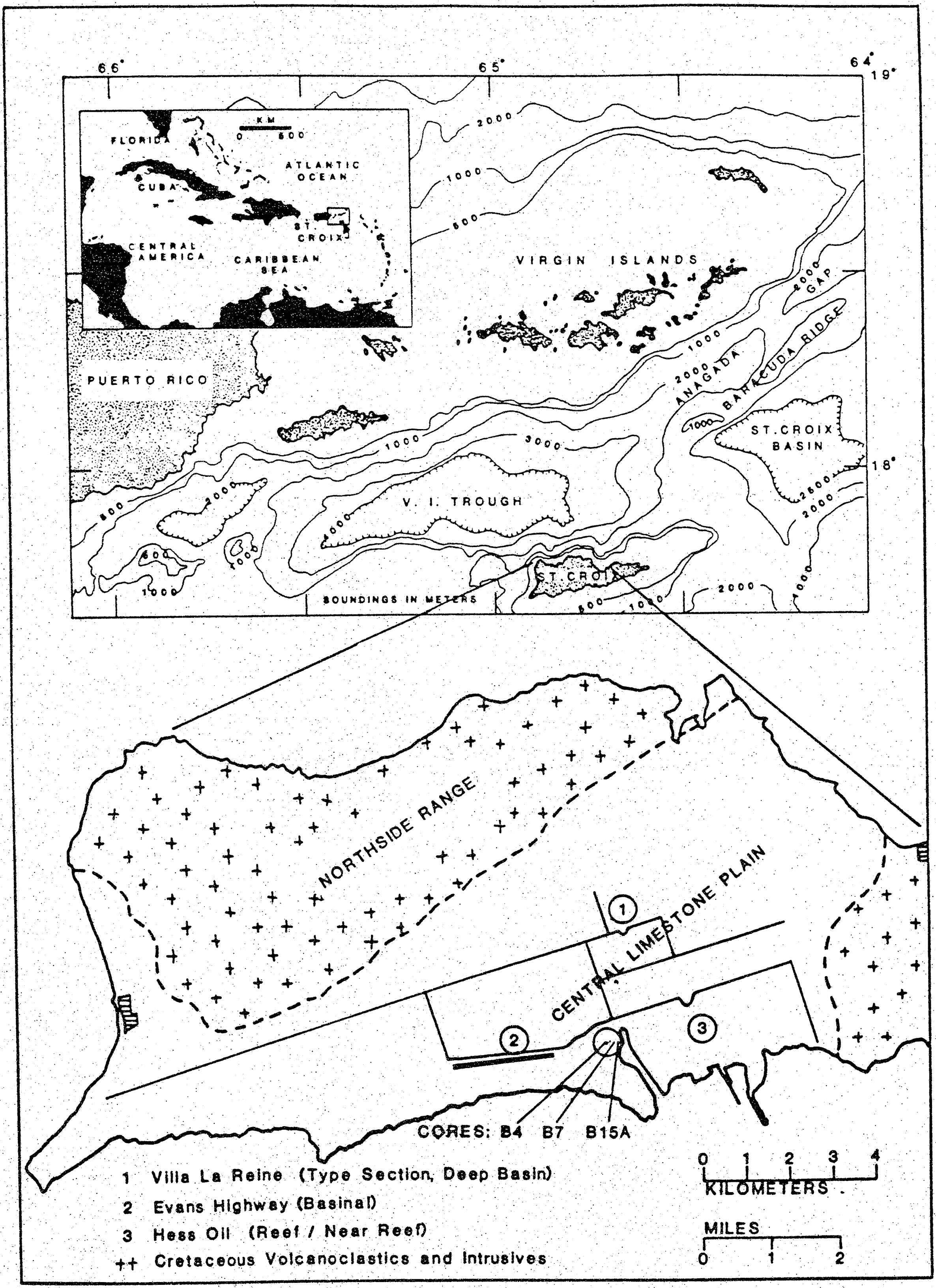

Figure 1. St. Croix: location map and study area.

background geology and the other lithologic units are discussed in the previous report on subsurface geology (Gill and Hubbard, 1986a) and in the references cited therein.

PREVIOUS WORK

Hydrogeology

Early geologic interpretation and groundwater data are found in a publication by Cederstrom (1950), which contains the results and interpretations of the exploratory drilling program of the Civilian Conservation Corps and others in 1939. More recent work and recommendations are found in U.S. Geologic Survey publications by Robison (1972), Hendrickson (1963) and a detailed publication by Jordan (1975).

More recent publications dealing specifically with groundwater issues are Buros (1976), Black, Crow and Eidsness, Inc. (1976), and the recent reports by Geraghty and Miller Inc. (1983a and b). Buros (1976) deals primarily with a wastewater treatment and recharge project in the Golden Grove section of the island. Black, Crow and Eidsness (1976) deal with the entire island water system, including surface runoff, water catchment and desalination. Geraghty and Miller (1983a and b) address strictly groundwater issues, and make specific recommendations regarding maintenance of the public well fields, governmental organization and aquisition of geologic data.

Geology

The overall geology of St. Croix is summarized in a doctoral dissertation and later publications by Whetten (e.g. 1966, 1974). More detailed work on the depositional environments and petrology of the carbonate rocks in particular was done by Gerhard et al. (1978) and Multer et al. (1977). These papers outline the deposition of the carbonate units in a fault-bounded seaway and define the type section of the Kingshill Limestone at Villa La Reine. Biostratigraphic work commenced in the 1920s with Kemp (1926). More recent work is that of van den Bold (1970), Todd and Low (1976), Multer et al. (1977) and Lidz (1982).

The nomenclature of the carbonate units on St. Croix has changed over the years and a short note will help to clarify matters. The name "Kingshill Series" was used by Kemp (1926) to describe the entire Tertiary section of St. Croix. Cederstrom (1950) used the terms "Kingshill Marl" to differentiate the carbonates from the underlying clays of the Jealousy Formation discovered during the deep drilling of 1938-39. Whetten (1966, 1974) followed the usage of Cederstrom (1950, above) as did Multer et al. (1977), whereas van den Bold (1970) referred to the unit as the "Kingshill Formation".

Gerhard et al. (1978) suggested formalizing the name to "Kingshill Limestone" to include the variety of facies included in the unit, and suggested the type section at Villa La Reine (Outcrop 1, Fig. 1). This usage has been adopted for this report, and in the publications since Gerhard et al. (1978).

The depositional models suggested by Multer et al. (1977) and Gerhard et al. (1978) are accepted as the basis for this report. Our findings differ from or add to the papers cited above in the following ways:

1) We discuss the post-Kingshill limestones as a distinct unit, and are concerned primarily with the rocks found in the southeastern section of the central plains area.

2) For the purpose of this report, we chose the boundary between the basinal hemipelagic carbonates and the floods of benthic foraminifera as the formation break between the Kingshill Limestone and the post-Kingshill carbonates. This break is recognizable in core samples and can be seen in Outcrop 2 (Fig. 1). It occurs at approximately the Miocene-Pliocene boundary, and is described in detail by Lidz (1982). The benthic packstones and grainstones are included in the Kingshill Limestone by Gerhard et al. (1978).

3) The Jealousy Formation is a deep basinal unit, containing almost entirely planktic forams, rather than the estuarine and shallow-water unit proposed in the reports listed above. The Jealousy Formation was deposited in water depths comparable to the pelagic portions of the Kingshill Limestone.

4) The Jealousy Formation exposed in outcrop along the Northside Range (Whetten, 1966) does not correspond to the lithologies encountered in the subsurface (Fig. 2). We suggest that these exposures be mapped as Kingshill Limestone.

5) The Jealousy Formation / Kingshill Limestone contact is abrupt, but does not imply sudden deepening to basinal conditions as suggested by Gerhard and others (1978). We suggest that the basin floor was already at least 1000 meters deep before the onset of Kingshill Limestone deposition.

6) The age of the Jealousy Formation is commonly listed as Oligocene, based on work by Cushman (1946). However, Todd and Low (1976) and this report (van den Bold, pers. comm., 1986) show no evidence of sediments older than early Middle

Miocene. Due to the great thickness of Jealousy Formation sediments, however, there is little doubt that the Jealousy Formation clays extend into the Oligocene. Part of the discrepancy is due to the revision of the Miocene / Oligocene boundary after Cushman's (1946) report, and misinterpretation of Todd and Low (1976).

7) The fault boundaries of the Kingshill basin were probably active prior to, and spanned through the time of Kingshill Limestone deposition.

8) Faulting in the southeastern section of the carbonate plain cuts through post-Kingshill deposits and thus implies significant faulting in the carbonate section at least into the Pliocene.

9) The geometric and structural relationships of the Kingshill Limestone and Jealousy Formation units may imply Tertiary-age compressional stress in the northern part of the Kingshill basin. The timing and cause of this deformation is still conjectural, and it must be reconciled with the primarily tensional nature of the normal fault systems in the Kingshill basin.

10) Reefal and lagoonal limestones rim the southern and western coastlines of St. Croix, and

overlie the Kingshill Limestone. These imply significant shallowing of the depositional basin and the establishment of Pliocene coral reefs along its southern and western margins.

11) The greatest thickness of the post-Kingshill limestones occurs in the south coast industrial area. The faulting in this area served:

a) to allow the area to serve as a depocenter during the Pliocene; or

b) to preserve the shallow-water deposits from erosion during the subsequent uplift of St. Croix; or both.

METHODS

The cross-sections in this report are based on test holes drilled both in Phase I and Phase II of the drilling program, as well as water-well drilling logs and records from previous reports and governmental files. Records from other reports and drilling logs are summarized and described in Gill and Hubbard (1986a). The contact between the Kingshill Limestone and the underlying blue clay of the Jealousy Formation was selected as a stratigraphic marker due to its abruptness, geologic importance, and unmistakability to untrained observers.

Eight test holes were drilled with a rotary drilling rig capable of sampling to several hundred feet; the total drilling footage for Phase II exceeded 750 ft. Friable or unconsolidated sediments were sampled at five or ten foot intervals with a split-spoon sampler; well-lithified material was collected with a diamond-bit core barrel. An additional seven cores drilled in 1981 for Martin Marietta Alumina were donated to the project during Phase I by Caribbean Drilling Services, and provided data on the carbonate units underlying the southeastern portion of the central plain. Several test holes drilled in 1983 for Tippetts, Abbott, McCarthy and

Stratton Inc. in the Limetree Bay area provided information on the submarine geology seaward of the Hess and Martin Marietta industrial plants. Samples from one of these test holes was donated to the project during Phase I.

Unconsolidated sediments were sieved into gravel-, sand- and mud-range size fractions. Further size analysis was not undertaken due to significant aggregation of carbonate grains and other diagenetic alteration. Whole-grain counts and mineralogical analysis by X-ray diffraction provided data on grain origin and composition. Thin sections were prepared from consolidated material and loose grain mounts, and were used for mineralogical and facies analysis. Biostratigraphic work was undertaken on the sand-size fraction (> 63 um) of unaltered or little altered foram-rich material.

As in Phase I, test holes were geophysically logged with a portable gamma logging unit; in cases where hole collapse did not interfere, the test holes were also logged with a portable spontaneous potential and resistivity unit. The gamma logging was done through the steel auger that served as casing during the drilling process.

Well log records have been combined with sample logs and data from test holes drilled during this project to produce the cross sections and structural information in this report.

RESULTS

Summary of Test Hole Sampling

In this report, the terms "test hole", "test well" and "boring" are considered synonymous, and refer to a drilled hole from which geologic samples or information has been retrieved. These terms are distinguished from wells drilled specifically for water.

A total of seven test holes were drilled during Phase II. In addition to the data gathered from these test holes, map locations are shown for a water well drilled during this project, an engineering boring taken north of Fredericksted, and several engineering borings taken west of the present Alexander Hamilton Airport runway (Fig. 3). Material from the latter holes was donated by Caribbean Drilling Services.

All test holes drilled during Phase II are located on Figure 3; the complete data base including information aquired during Phase I is shown on Figure 4. Detailed sample logs of Phase II test holes are listed in the Appendix.

Test hole M7 is located on the southernmost extension of Martin Marietta property (Fig. 4). The boring reached 270 feet subsurface (-265 ft msl), penetrating carbonate lagoonal sediments, alluvium, and

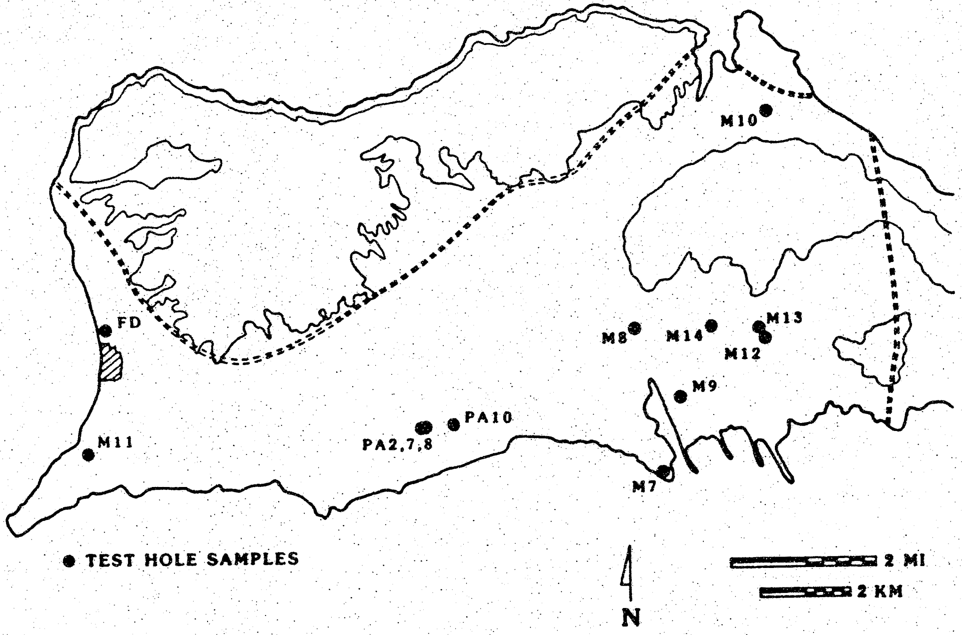

Figure 3. Locations of Phase II test holes.

post-Kingshill carbonates. Split-spoon samples were taken at 5 foot intervals to 160 ft subsurface, then at 10 foot intervals to 230 ft subsurface (-225 ft msl). Due to hole collapse, no sampling was possible past 230 ft subsurface, but the hole was extended with a rock bit to 270 ft subsurface (-265 ft msl) to determine whether any indurated carbonate layers were present.

The upper 170 feet of sediment consists of alluvium and lagoonal carbonates, from top to bottom: shallow-water carbonate lagoonal sands and silts, fluvially derived estuarine sediments, mangrove muds,

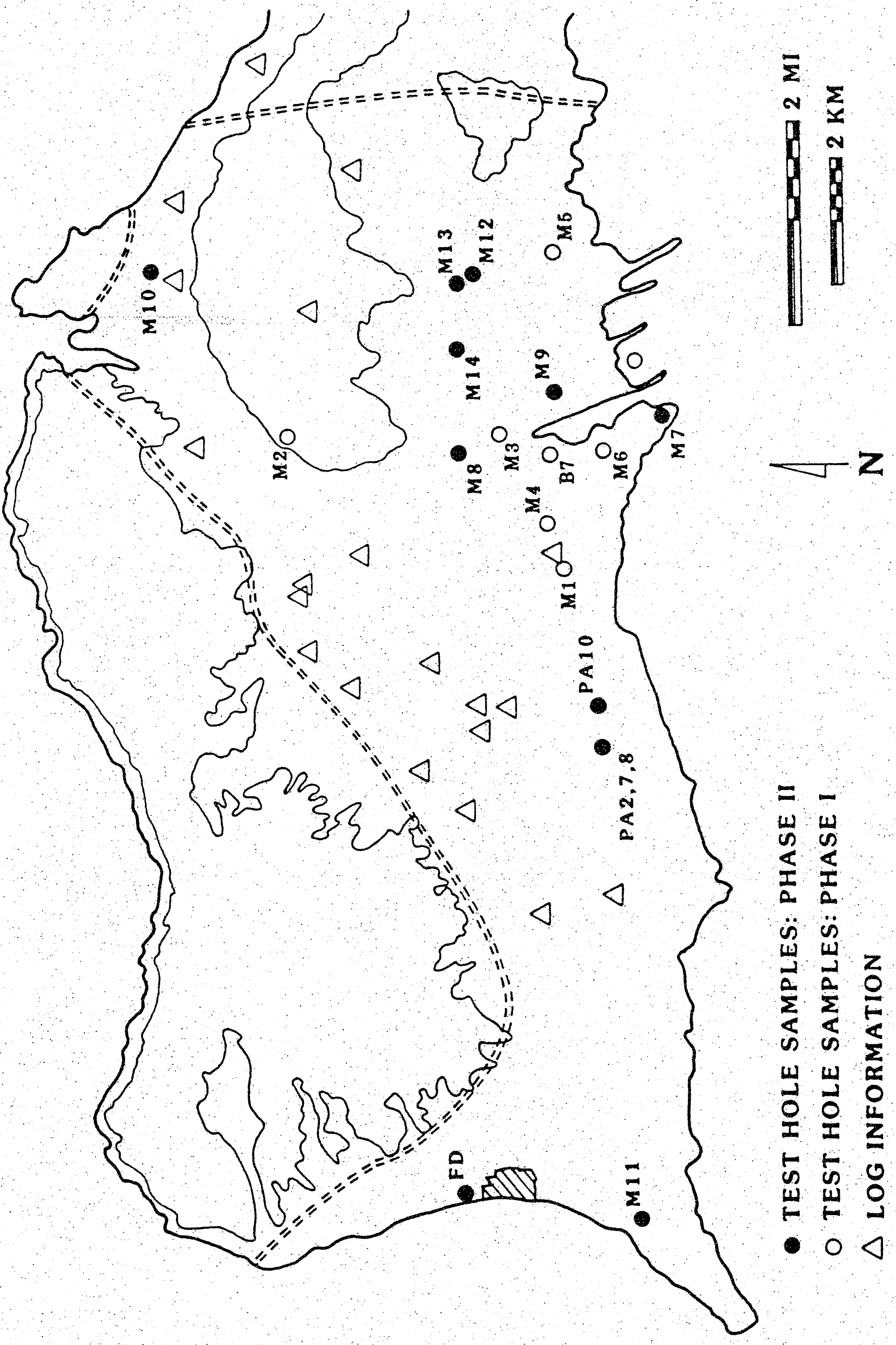

Figure 4. Locations of test holes and data points for Phases I and II.

and alluvium derived both from terrigenous siliciclastics and reworked Pliocene carbonates. Below the alluvium, friable post-Kingshill carbonates extend from 170 ft to 230 ft subsurface (-165 to -225 ft msl) and are pervasively dolomitized past 200 ft subsurface (-195 ft msl).

No zones of extensively indurated carbonates were encountered in this hole despite the presence of a 30 to 40 ft thick cemented layer present in Holes M6 and B7 to the north. The post-Kingshill carbonates presumably extend to the end of the boring at 270 ft subsurface, but sampling was impossible past 230 feet subsurface (-225 ft msl) due to hole collapse (Appendix).

Test hole M8 is located on Estate Spanish Town northeast of the Annaberg ruins at Martin Marietta, with a maximum depth of 95 ft (+70 ft msl, Fig. 4). Test Hole M8 penetrated 65 feet of Pliocene carbonate strata consisting of friable shallow-derived bioclastic packstones representing a benthic foraminiferal, coralline algal and coral assemblage.

Past 65 ft subsurface (40 ft msl), the drilling was characterized by 30 ft of alternating layers of cemented and non-cemented limestone representing the

Kingshill Limestone deep-water facies. Petrographically, the Kingshill Limestone in this well is characterized by a lithic clast, planktic foraminiferal packstone facies. The transition from the post-Kingshill to the Kingshill Limestone was also detectable on the gamma logs. Split-spoon samples were taken at five-foot intervals, with the indurated layers of the Kingshill Limestone being difficult to penetrate with the split-spoon sampler (Appendix).

Test Hole M9 was drilled on the south coast of St. Croix directly south of the Amerada Hess oil refinery. The hole lies in the Krausses Lagoon area within the extension of the borders of Blessing Estate (Fig. 4). This location, as well as the M6 and M7 locations, would have been seaward of the pre-industrial development shoreline, and the top several feet of material is composed of artificial fill from the alumina plant and oil refinery development. Split-spoon samples were taken at five-foot intervals from 0 to 110 ft subsurface (10 to -190 ft msl), and at ten ft intervals from 110 to 180 ft subsurface (-100 to -170 ft msl). Diamond bit core samples were taken from an indurated limestone and dolomitic layer from 182 to 194 ft subsurface, and split-spoon samples were retrieved below this layer from 194 ft to the end of the hole at 200 ft subsurface (-190 ft msl).

The upper 150 feet of M9 were composed of alternating alluvium, organic-rich mangrove swamp muds, and carbonate lagoonal sands and silts. The alluvial material in the upper 150 feet subsurface were composed primarily of muds, sands and gravels of terrigenous material weathered from the Cretaceous siliciclastics, and were presumably deposited by ephemeral fluvial activity. In several intervals within the alluvium, individual or aggregated planktic foraminifera form a significant component of an otherwise siliciclastic sand fraction. We interpret these forams as being cemented in-situ within the Kingshill Limestone, and then eroded from Kingshill Limestone exposures inland of the lagoon. The cementation within the foram tests evidently provides enough strength for the tests to survive the weathering and transport processes.

From 160 ft subsurface to the end of Test Hole M9 at 200 ft subsurface (-150 to -190 ft msl), the boring penetrated post-Kingshill carbonate material composed of moderately cemented, benthic foram/coralline algal dominated packstones. At 160 ft subsurface, the equant calcite spar cement is rounded, and the preservation is poor, implying leaching. Similar textures are observed in modern exposure surfaces on St. Croix, suggesting that the upper surface of the post-Kingshill carbonates in this boring have been exposed to subaerial processes or meteoric waters.

Samples from the diamond bit coring samples at 182 ft subsurface (-172 ft msl) show excellent textural preservation, and geopetal structures that are consistent with the present orientation of the core. The geopetal structures imply that the micrite fill of the foram tests has not been disturbed since burial, and that the tests have not been redeposited since cementation. Nummulitid foram tests and other flattened bioclasts are oriented sub-horizontally in several cases, suggesting either that the tests were reworked by currents or that they remain in a depositional position of highest initial stability.

Core recovery from 182 to 187 ft subsurface (-172 to -177 ft msl) was greater than 90%. Past 187 ft subsurface, core recovery was poor, and the samples were extremely friable due to dolomitization. Split-spoon samples beneath the dolomitic layer contain dolomitic material as well as rounded lithic sand and gravel. The lithic sand and gravel in this case are contamination caused by hole collapse. Dolomitic strata extend from ca. 186 ft subsurface to the bottom of the hole at 200 ft subsurface (-176 to -190 ft msl, Appendix).

<u>Test hole M10</u> is located in Estate St. John on the site of the old airfield south of Judiths Fancy (Fig. 4). Drilling reached a maximum depth of 105 feet subsurface (-190 ft msl), penetrating alluvium, Kingshill Limestone and Jealousy Formation clays. The top 30 feet of material consists of weathered alluvium, with the Kingshill Limestone acting as primary source for alluvial material. Much of the alluvial sand-size material consists of cemented spherical planktic forams presumably reworked from surrounding Kingshill limestone exposures.

Below 30 ft subsurface (55 ft msl) the boring penetrated Kingshill Limestone facies consisting of pelagic foraminiferal packstones alternating with lithic pebble conglomerates. The lithic pebbles appear to be reworked Cretaceous Mount Eagle Group material such as the Judiths Fancy Formation exposed in the neighboring Northside Range. The lithic rounded pebble conglomerate facies of the Kingshill Limestone appears mainly in neighboring outcrops in the north portion of St. Croix. Below the conglomerate facies, the Kingshill Limestone consists of a planktic foram wacke-packstone.

The Kingshill Limestone / Jealousy Formation contact occurs within a 2 ft split-spoon sample and occurs at 86 ft subsurface (-1 ft msl). The Jealousy Formation clays at this location consist of uniform grey-blue, planktic foram-rich clays. Neither the Kingshill Limestone nor the Jealousy Formation clays are indurated close to the formation contact, and foraminifera washed from the samples are clean and show little to no alteration. The total thickness of Jealousy Formation in this area, as in the rest of St. Croix, is unknown due to lack of penetration by drilling (Appendix).

Test Hole 11 is located in Estate Hesselberg close to Westend Saltpond (Fig. 4). This hole, although geographically removed from the rest of the borings, establishes the existence of shallow reef and near-reef facies on the western side of the island. Split-spoon samples were taken at 5 ft intervals to a total depth of 55 ft subsurface (-45 ft msl).

The upper samples show leached and micritized bioclasts, rounded equant spar, and in some cases, algal(?) tubules indicating subaerial weathering. Samples from 10 to 15 feet contain abundant coral-derived bioclasts and coral binding of reef material. Below 20 feet subsurface (-10 ft msl) the fossil bioclast assemblage is very similar to the post-Kingshill facies along the southern coast of the central plain, containing dominantly benthic foram and coralline algal assemblage. In this area, shallow carbonate banks and near-reef deposits were succeeded by scleractinian reef growth.

Chronological correlation between strata penetrated by M11 and the shallow-water deposits elsewhere in the post-Kingshill carbonates is speculative. However, samples from test holes to the west of the Airport runway (PA2, 7, 8 and 10; Fig. 4) and reports in Gerhard et al. (1978) indicate that shallow-water deposits extend at least as far west as Estate Carlton. Shallow-marine facies outcrop in Fredericksted, and are found in test borings drilled to the north of Fredericksted (this report). It is likely that these facies are time-correlative with the post-Kingshill facies on the south coast, and that reef growth extended around the perimeter of the island during the Pliocene.

Test Holes 12, 13 and 14 were drilled in Estates Cassava Garden, Castle Coakley and Cottage, respectively. Sampling was done by split spoon at 5 ft intervals and extended to a maximum depth of 15 ft (Fig. 4). Elevations of the tops of these borings are

90, 110 and 100 ft msl for M12, M13 and M14, respectively. The purpose of these test holes was to investigate the mineralogy and distribution of shallow facies in areas of poor outcrop control. All three borings showed the effects of subaerial exposure and calichification in the shallowest samples, and contained bioclastic packstones dominated by benthic foraminifera and coralline algae. The strata penetrated by these borings correspond to the post-Kingshill facies. No dolomitization has occurred in any of these samples.

Test Holes PA7, 8 and 10 are located to the west of the existing airport runway and were drilled to a maximum depth of 15 ft subsurface (Fig. 4). Despite their shallow depth, these holes confirm the existence of post-Kingshill carbonate deposition along the southern margin of the island to the west of the airport. Samples from these wells contain a foram-algal dominated bioclastic packstone facies typical of the post-Kingshill.

Test Hole FD was drilled just north of the town of Fredericksted (Fig. 4). The samples available were collected by diamond bit drilling from 43.5 to 45 ft subsurface (ca. -38.5 to -40 ft msl). Bioclasts within the core pieces are dominated by external molds of gastropods and pelecypods, and include external molds of fragmented solitary mussid corals similar to Antillea bilobata. If the coral identification is correct, it would place these strata within the Pliocene (S. Frost, pers. comm. 1986). The nature of the biofacies implies a shallow lagoon system and confirms the presence of a Pliocene shallow-water carbonate system extending to the north of Fredericksted.

In addition to the holes listed above, from which sample data are available, well logs and records from the VI Dept of Public Works, Cederstrom (1950) and Hendrickson (1963) provided data on the depth of the Kingshill Limestone / Jealousy Formation contact. Information on the depth to the underlying Jealousy Formation clay and general rock lithology were used to construct geologic cross-sections, isopach and structure maps in areas where rock samples are not available.

Jealousy Formation (Oligocene-Miocene)

The Jealousy Formation underlies the entire central plain of the island, and can be considered the hydrologic basement. The transition from yellowish marls of the Kingshill Limestone to bluish clays of the

Jealousy Formation is marked and abrupt. Well drillers almost invariably stop after reaching the clays, and the boundary is well marked on their drill logs. The Jealousy Formation contains a rich planktic foraminiferal assemblage that allows for paleoenvironmental analysis and biostratigraphic correlation.

The type section for the Jealousy Formation is considered to be the deepest penetrating test well drilled by the Civilian Conservation Corps in 1939. This well penetrated more than 1400 ft of Jealousy Formation sediments with a maximum depth of penetration of 1506 ft subsurface (Cederstrom, 1950). The formation exceeds the 1506 foot depth of penetration of their deepest well, and gravity surveys indicate that it may be as much as 6600 ft (2000 m) thick (Shurbet et al., 1956).

Conglomeratic deposits are noted at various depths in the deepest hole drilled by the CCC, but were not encountered in the holes drilled for this project. None of the test holes drilled for this project in either Phase I or Phase II penetrated more than 25 ft of Jealousy Formation clays. More information on the Jealousy Formation is contained in the report for Phase

I of this project and the references cited therein (Gill and Hubbard 1986a).

Biostratigraphic Age. Descriptions and drill logs from the 1939 test wells are contained in Cederstrom, 1950). Attempts to stratigraphically date the Jealousy Formation date back to Cushman (1946) who was updated by Todd and Low (1976). Todd and Low (1976) placed the age of the Jealousy Formation between early and middle Middle Miocene, or approximately between 13 and 15.5 million years before present. The age determined by Todd and Low (1976) depended on the location of the well and the position of the sample within the well. Uncertainties in interpretation arise from the fact that the samples used were well cuttings, which are subject to potential contamination and uncertainties of depth, particularly in deep wells.

Biostratigraphic determinations of the Jealousy Formation done at Louisiana State University, however, give similar results. P. McLaughlin and W. van den Bold analysed several samples of Jealousy Formation taken for this project (P. Mclaughlin and W. van den Bold, pers. comm., 1987):

Test Hole M1, Sample 12, 105 ft: late N9 - early N10; ca. 15.5 ma.

Test Hole M1, Sample 16, 147 ft: late N8; ca. 16.3 ma.

Test Hole M2, Sample 24.4, 167 ft: N11 - N12; ca 14 - 14.6 ma.

Test Hole M10, Sample HS, 105 ft: early N10; ca. 15.4 ma.

The Kingshill Limestone / Jealousy Formation boundary lies between samples 12 and 16 in Test Hole M1, 15-20 cm above sample 24.4 in Test Hole M2, and ca. 20 ft above sample HS in Test Hole M10 (Appendix). These findings imply that the Jealousy Formation / Kingshill Limestone boundary is time-transgressive, and that the Jealousy Formation should be considered a Miocene stratigraphic unit. Due to the thickness of this unit, there is little doubt that the Jealousy Formation extends into the Oligocene. However, as stated in the Phase I report, labeling the Jealousy Formation as Oligocene in age is misleading (Gill and Hubbard, 1986a).

<u>Structure</u>. The nature of the Jealousy Formation / Kingshill Limestone contact is abrupt and unambiguous, and is used in this report as a subsurface datum for that reason. It is used similarly by well drillers on St. Croix as a marker of the lower boundary

of potable water recovery. Cross-section maps and a structure map of the upper Jealousy Formation surface were prepared for this report using the Jealousy Formation as a datum.

The surface of the Jealousy Formation is characterized by three general trends (Fig. 5):

1) deepening toward the north and south coasts of St. Croix;

2) a marked upbowing of the surface beneath the highlands in the northern section of the central plain;

3) a pronounced rise in the Jealousy Formation close to the fault boundary imposed by the Northside Range (Fig. 5).

Behavior of the Jealousy Formation surface close to the eastern fault boundary is unknown because of poor well control. Similarly, behavior of the Jealousy Formation surface in the southeastern coastal section is not known due to faulting in the area, which places the upper surface of the Jealousy Formation beyond the reach of drilling. Depth to the Jealousy Formation in this region is deeper than -260 ft msl, the deepest penetration of drilling in the area (Fig. 5).

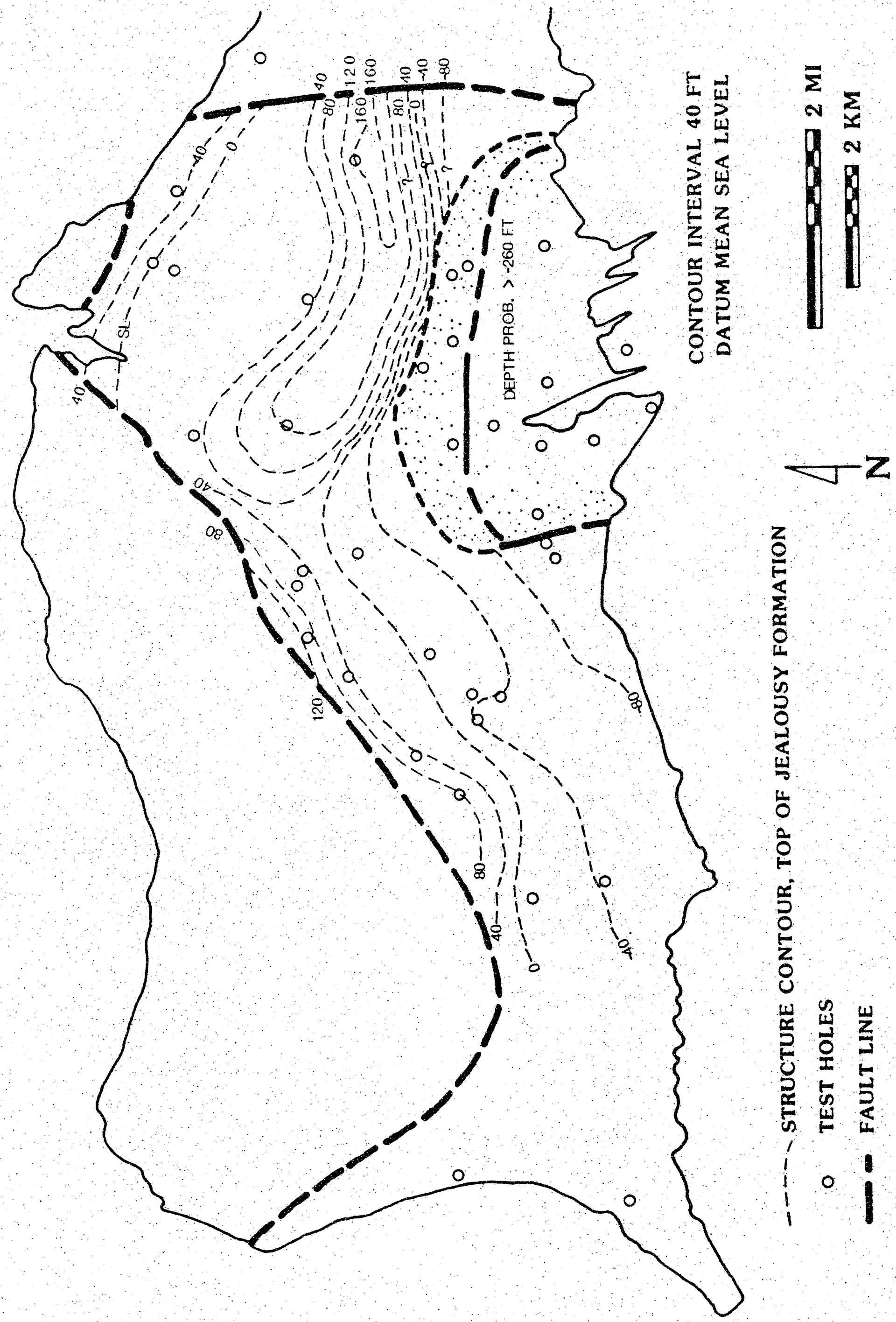

Figure 5. Structure map: top of the Jealousy Formation.

The topography of the Jealousy Formation surface can be explained by:

1) an erosional unconformity between the Kingshill Limestone and the Jealousy Formation;

2) basement topography;

3) tectonic deformation;

4) differential compaction of the thick clay sequence.

A final possibility is that the marked color contrast between the Jealousy Formation and the Kingshill Limestone does not reflect any significant change in age, deposition or mineralogy. In this case, the two units would represent a continuous record of deposition, and the cause and significance of the color change is unknown. The strongest evidence supports the notion that the contact represents a time-transgressive or erosional boundary that has been deformed by tectonic compression.

Depositional Environment. In contrast to earlier work, we suggest that the Jealousy Formation represents a deep-water pelagic unit. Benthic foraminifera in test hole samples from both phases of drilling imply depths comparable to continental slope conditions.

Benthic foraminiferal assemblages with large components of Cassidulina subglobosa and Cibicites wuellersdorfi occur in several upper Jealousy Formation samples and imply depths exceeding 1000 m, and possibly approaching 2000 m (P. McLaughlin, pers. comm. 1987). Although tentative at this point, these depths are three to six times greater than previous estimates (Multer et al., 1977; Gerhard et al., 1978; Lidz, 1982; Gill and Hubbard, 1986a). The foraminiferal assemblages in the Jealousy Formation are similar to the Kingshill Limestone assemblages in immediately overlying samples.

Mineralogy. The mineralogy of the Jealousy Formation is dominated by calcite, with significant components of quartz, feldspars and clay minerals. Based on semi-quantitative estimates by powder mount X-ray diffraction, calcite comprises almost 90 percent of the sample, with six to seven percent of the sample being composed of quartz and feldspar and the remaining four percent composed of clays and other minerals.

However, these components are not largely different either quantitatively or qualitatively than the overlying Kingshill Limestone. Surprisingly, it is apparent that despite the marked color and textural contrasts, the transition from the Jealousy Formation to the Kingshill Limestone does not entail a large change in either mineralogy or depositional environment.

Kingshill Limestone

Referred to as the Kingshill Marl when described by Cederstrom (1950), the unit was renamed the Kingshill Limestone by Gerhard et al. (1978). The more recent label recognizes the existence of a wide variety of lithologies within the unit, and will be used here.

The geologic setting of the Kingshill Limestone is one of deep basinal deposition. The lithologies within the unit consist of alternating layers of planktonic deposits and beds of shallow-derived debris brought by sediment-gravity flows. The appearance of the unit in outcrop is one of rhythmic bedding with individual beds alternating between positive and negative relief. Individual beds are generally packstones and wackestones, and contain clasts of sand- through boulder-sized material. Boulder-sized clasts are generally transported coral heads mixed with finer debris. The type section for the Kingshill Limestone is the Villa La Reine outcrop (Outcrop 1, Fig. 1; and Gerhard et al., 1978).

The Kingshill Limestone is hydrologically important due to the large number of water wells drilled into it, and its wide lateral extent. Water yield from the Kingshill Limestone is highly variable (Cederstrom, 1950; Jordan, 1975). The Kingshill Limestone is bounded on the east and west by normal faults contacting the Cretaceous siliciclastic units.

Structure. The contact between the Kingshill Limestone and the Cretaceous rocks is described as a fault by Whetten (1966) and Multer et al. (1977), a conclusion we follow here. Evidence from the eastern Kingshill Limestone / Cretaceous rock contact in the hills at Estate Work and Rest implies that basin faulting has occurred during or after Kingshill Limestone deposition, in addition to the faulting that presumably formed the depositional basin (Gill and Hubbard, 1986a). The contact against the Northside Range is less obvious due to alluvial cover (Fig. 2). Gerhard et al. (1978) suggest with some evidence that there was less displacement along this northern fault boundary than along the eastern margin just discussed.

Locations of cross-sections drawn through the central plain are mapped in Fig. 6. Cross section A - A′ (Fig. 7) shows the marked upbowing of the Jealousy Formation and Kingshill Limestone strata under the

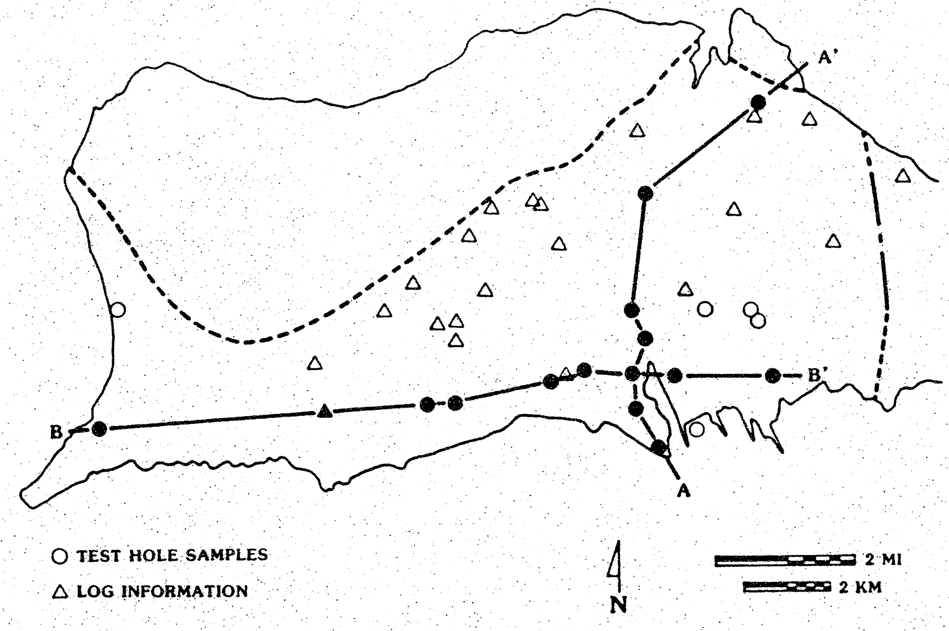

Figure 6. Locations of cross sections A-A', B-B'.

highlands close to the northern coast.

The Jealousy Formation / Kingshill Limestone contact was reached in two test holes: M2 and M10, the latter drilled during Phase II of this project. The Jealousy Formation contact has not been reached by the drill bit along the south coast due to normal faulting within the carbonate section there (Gill and Hubbard, 1986a).

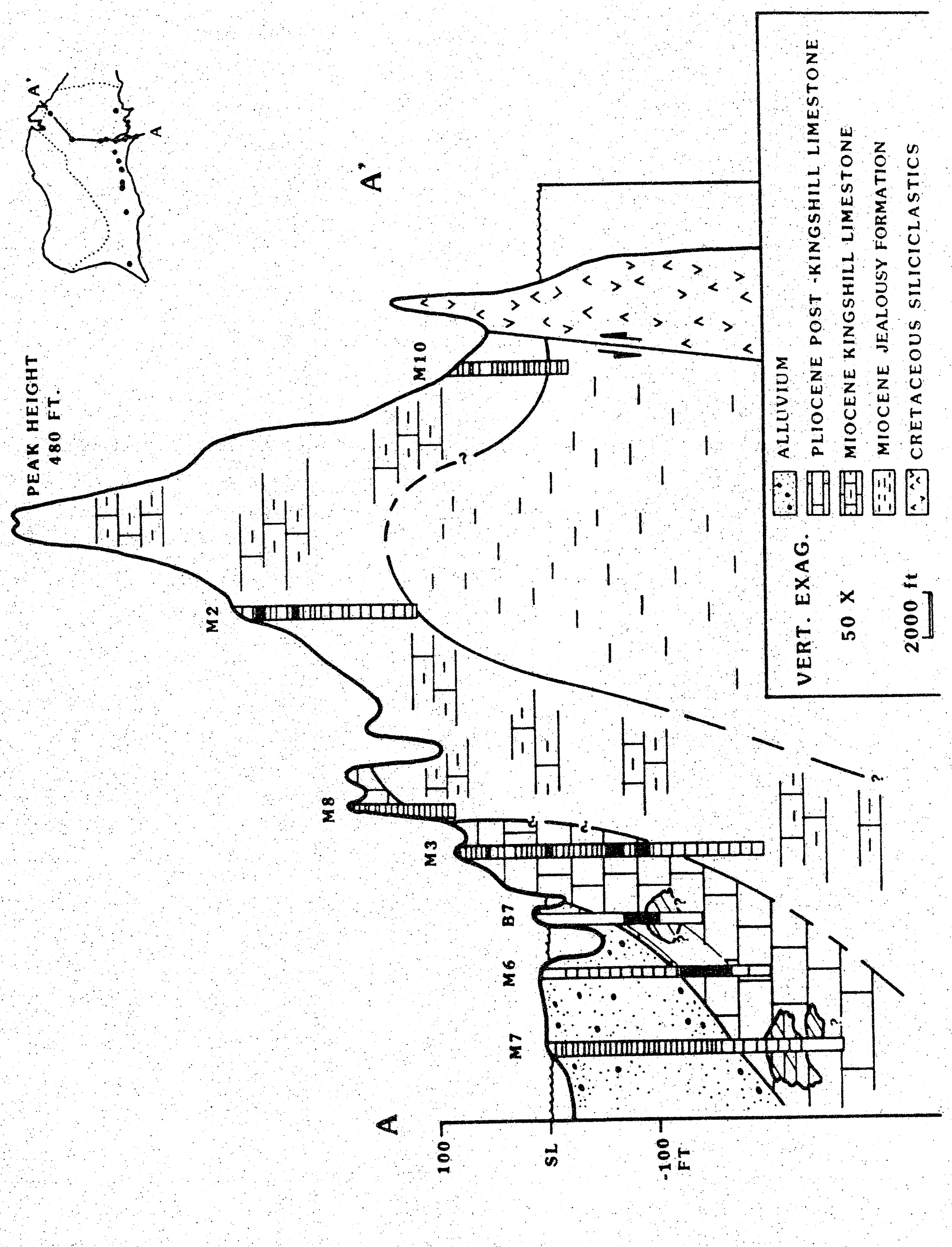

Figure 7. Cross Section A-A': Krausses Lagoon to Judiths Fancy.

The Kingshill Limestone is unconformably overlain by Pliocene carbonates along the southern coast of the island. The contact is erosional as expressed in outcrop (Lidz, 1982; Gill and Hubbard, 1986a), and may parallel a fault boundary between Test Holes M3 and M8 (Fig. 7). If the contact between Holes M3 and M8 is fault controlled, this boundary would delineate the northern hingeline of the fault block whose western border is the normal fault that runs northward between Test Holes M1 and M4 (Fig. 4).

Cross section B - B′ (Fig. 8) is drawn on a west to east transect from Estate Hesselberg to Estate Pearl. The Jealousy Formation underlies the Kingshill Limestone across most of the south coast of St. Croix. The position of the Kingshill Limestone / Jealousy Formation contact is unknown west of Estate Williams Delight due to poor core control, and east of Estate Anguilla due to faulting within the Tertiary section between Test Holes M1 and M4. Similarly, the thickness and geometry of the Kingshill Limestone west of Williams Delight is speculative due to poor core control.

<u>Stratigraphy</u>. The thickness of the Kingshill Limestone is reported by Cederstrom (1950) to range

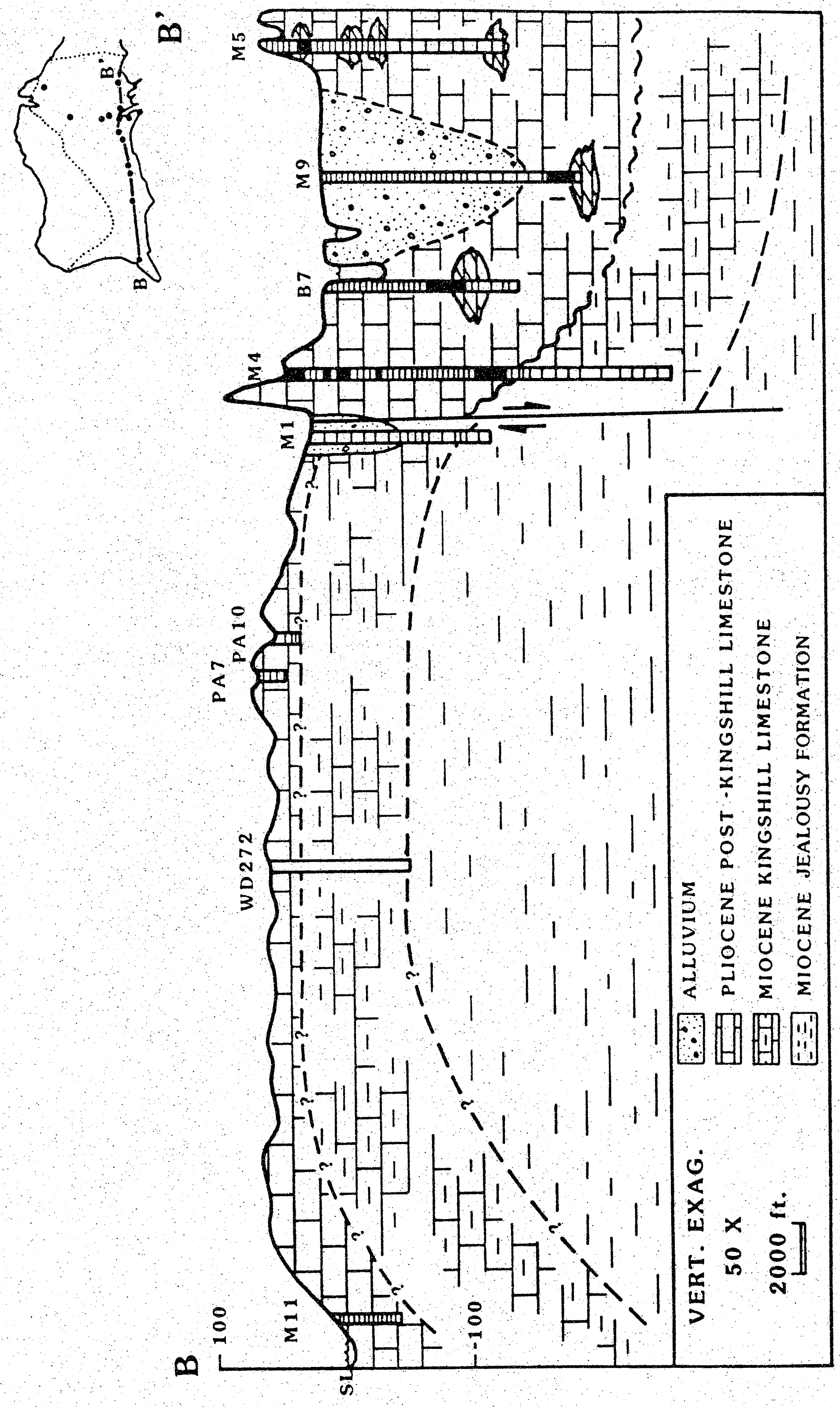

Figure 8. Cross Section B-B': Hesselberg to Pearl.

from 0 to 600 feet, the larger figure referring to extrapolated thickness in the carbonate highlands of the Rattan Hill area. In fact, actual maximum thickness of the Kingshill Limestone is between 400 and 500 ft in the carbonate highlands due to upwarping of the underlying Jealousy Formation (Fig. 7). Thickness patterns of the Kingshill Limestone are shown on an isopach map in Figure 9, and reveal three major trends:

1) pinching out toward the north and northwest margins of the basin;

2) pronounced thickening in the carbonate highlands close to the northern coast of St. Croix;

3) gentle thickening toward the south of the basin, interupted by post-depositional faulting along the south coast (Fig. 9).

Well control for thickness of the Kingshill Limestone section is poorest within the faulted section of post-Kingshill carbonates on the south coast, and to the west of Estate Williams Delight. In general, Kingshill Limestone thickness patterns follow the trends shown by the Jealousy Formation structure map (Fig. 5). If deformation is ignored, the Kingshill Limestone isopach patterns imply a basin opening to the

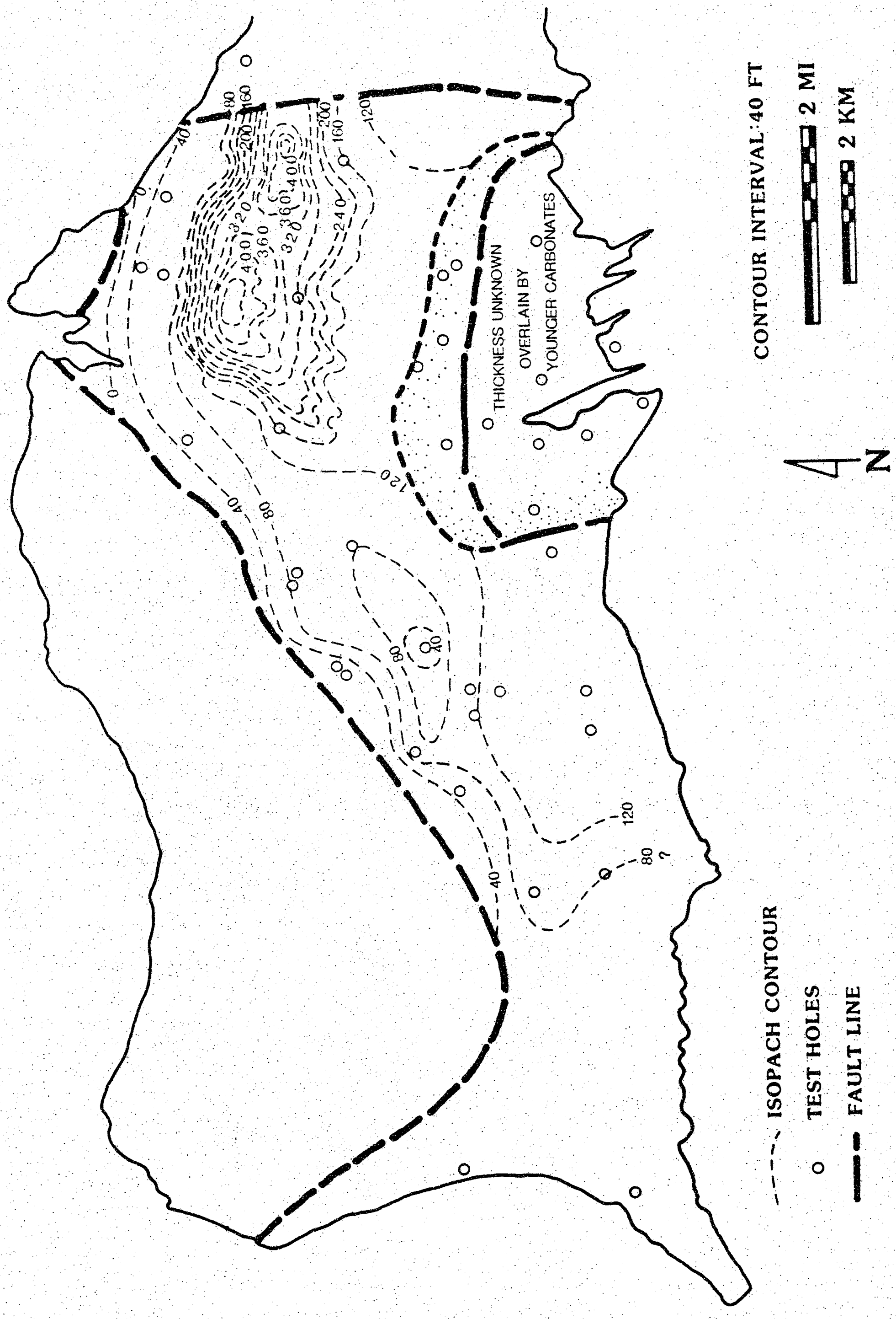

Figure 9. Isopach map: Kingshill Limestone.

south but deepest in the section occupied by the carbonate highlands.

It should be noted that only three of the 14 test holes drilled specifically for this project contact Jealousy Formation clays: Test Holes M1, M2 and M10 at Fairplain, Bonne Esperance and St. John respectively (Fig. 4). The other holes, drilled for the most part on the southern coast, penetrate extensive thicknesses of limestone. The majority of this material is Pliocene carbonate deposition and the total thickness of Kingshill Limestone in the southeastern region is still unknown. Based on extrapolation in our cross-section, though, we estimate a Kingshill Limestone thickness in the southern coast industrial area of 140 to 180 feet (Fig. 8).

Biostratigraphy and paleobathymetry. Samples of Kingshill Limestone material from Test Hole M1 yield planktic foram assemblages corresponding to the base of the N10 zone (P. McLaughlin, W. van den Bold, pers. comm., 1987). This places the base of the Kingshill Limestone in the early Middle Miocene (ca. 15.5 ma), in good agreement with the outcrops studied by Lidz (1982). Benthic foram assemblages close to the Kingshill Limestone / Jealousy Formation boundary are very similar to the assemblages found in the upper Jealousy Formation, implying two points:

1) water depth at the time of Kingshill Limestone deposition may have been on the order of 1000 - 2000 m rather than 600 - 700 m (Multer et al., 1977; Lidz, 1982).

2) the Jealousy Formation / Kingshill Limestone transition does not represent a major change in paleoenvironment or paleobathymetry.

Post-Kingshill Carbonates (Pliocene)

In most early reports, Pliocene sediments are lumped together with the rest of the St. Croix carbonates as the Kingshill Marl, and are treated similarly by Lidz (1982). Gerhard et al. (1978) mentioned a possible younger age for this part of the section, but did not separate it from the Kingshill Limestone. Behrens (1976) and Frost (pers. comm., 1986) suggested two formations, the Annaberg and Blessing formations. We feel the Pliocene rocks are different enough to be segregated from the Kingshill Limestone, but should be treated as one unit for this report. These strata will be referred to here as the post-Kingshill or Pliocene carbonates, prior to formalization of formation names.

The post-Kingshill carbonates are the most consistently permeable and porous of central plain sedimentary units. They are extensively utilized as an aquifer by commercial and industrial concerns and are the source of water for at least one public well field (Barren Spot). Despite this, the geometry of the unit, its facies and diagenesis are the least understood, partly due to the lack of the well logs and exposures. The age of this unit is based on unpublished work by G. Behrens (1976) and S. Frost (pers. comm., 1986), using scleractinian fossils; on correlation to Lidz' (1982) Miocene-Pliocene boundary determinaton in the Evan's Highway outcrop (Fig. 1); and on field work carried out for this report.

Sedimentology. In most hydrogeological reports and some well logs, the post-Kingshill is referred to as a calcarenite. While adequately descriptive for visual inspection and general well logging, the term can also be applied to many parts of the Kingshill Limestone, and should not be inferred to be unique to this unit. Sediments in the post-Kingshill range from sandy muds to the more common silty sands with gravel generally referred to as a calcarenite.

Petrographically, the post-Kingshill carbonates are dominantly a benthic foraminiferal, coralline algal packstone, with significant quantities of reef and skeletal clasts. The dominance of material derived from shallow water distinguishes this unit from the underlying Kingshill Limestone facies of deep-water foraminiferal debris.

Stratigraphy. The Pliocene carbonates are bounded below and laterally by the Kingshill Limestone. The presumed lateral extent of both the Pliocene carbonates and the Kingshill Limestone is shown in map view in Figure 10 with the greatest thickness of Pliocene accumulation occurring within a subsidiary fault block. Based on samples from test holes west of the airport runway, north of Fredericksted, and from Test Hole M11 (Fig. 10), shallow-water carbonate environments stretched along the south coast of St. Croix, wrapped around the Southwest Point area, and extended north of Fredericksted (Fig. 10).

The lower boundary and lateral extent of the Pliocene carbonates is poorly controlled west of Test Hole M1 (Fig. 4). For this reason, unit thicknesses of the Pliocene carbonates west of Test Hole M1 are speculative (Fig. 8). Within the fault-bounded

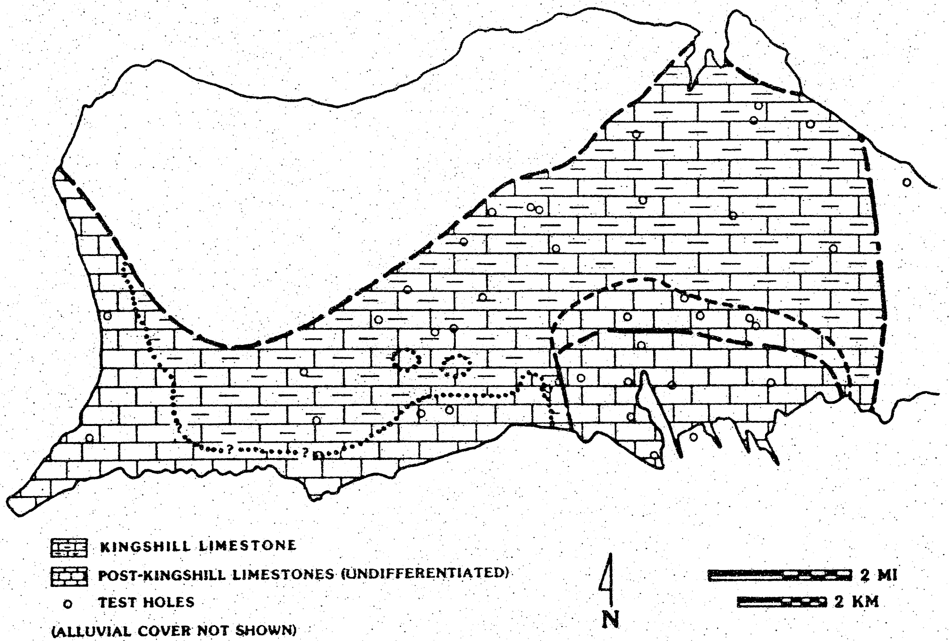

Figure 10. Distribution of carbonate lithofacies, St. Croix central plain.

industrial area on the southern coast, core control is far more extensive.

We place the lower boundary of the post-Kingshill carbonates at the transition between the plankton-dominated sediments of the Kingshill Limestone and the onset of floods of benthic foraminifera and skeletal debris. This boundary is one that is detectable in the subsurface and can be seen in outcrop. In outcrop, the transition can be seen in the Evans Highway exposure less than one mile to the west of Test Hole M4 (Fig. 1). The erosional unconformity in this outcrop was placed at approximately the Mio-Pliocene boundary by Lidz (1982), and corresponds to our Kingshill Limestone / post-Kingshill carbonate contact.

Based on our core material, we assign the lower boundary of the post-Kingshill facies to 145 feet below sea level in Test Hole M4 (Fig. 8). The transition is marked by a change in dominance from the deep-water planktic fauna of the Kingshill Limestone to the shallow-derived benthic fauna of the post-Kingshill facies. The core material from Test Hole M4 indicates that in most of the area studied on the south coast, the post-Kingshill facies extend for at least 185 feet subsurface.

Subunits within the Pliocene carbonates generally correspond to three catagories:

1) benthic foram, coralline algal, bioclastic packstones;

2) scleractinian, bioclastic packstones and grainstones;

3) molluscan, coralline algal, solitary coral packstones.

These correspond to bank, reef and lagoon deposits; all three types exist in the southeastern section of the basin and on the western coast near Fredericksted (Fig. 10).

Structure. Cross-section locations for the southeastern basin area are shown in Figure 11. The western margin of the greatest thickness of post-Kingshill carbonates lies against a fault contact near Fairplain. Test Hole M1 reaches Jealousy Formation clays at -95 ft msl (Fig. 12). Test hole M4, less than 600 ft to the east, does not contact Jealousy Formation material despite penetration to -262 ft below sea level. Similarly, W45a, drilled 200 ft to the east of M1 in 1939 (Gill and Hubbard, 1986a), strikes Jealousy Formation sediments more than 80 feet deeper than the contact in Test Hole M1, indicating a steeply dipping fault zone.

The presence of a fault at this location is supported by the Miocene-Pliocene contact in the Evans Highway outcrop to the west (Lidz, 1982; Fig. 1, this report). In this outcrop, the Kingshill / post-Kingshill contact is elevated 80 ft above sea

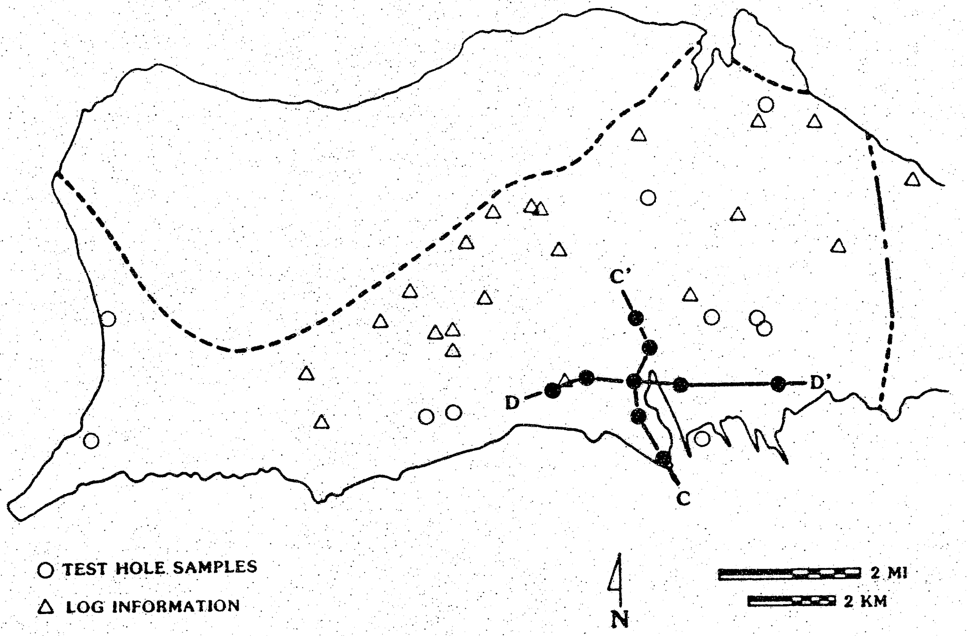

Figure 11. Cross section locations: C-C', D-D'.

level. In the cores drilled on Martin Marietta property, this contact is not reached until approximately 180 ft below sea level, setting a minimum fault displacement of 260 feet. The Evan's Highway outcrop mentioned above displays a noticably anticlinal form dipping into the fault zone. Faulting through these strata implies significant tectonic activity <u>after</u> deposition of both the Kingshill Limestone

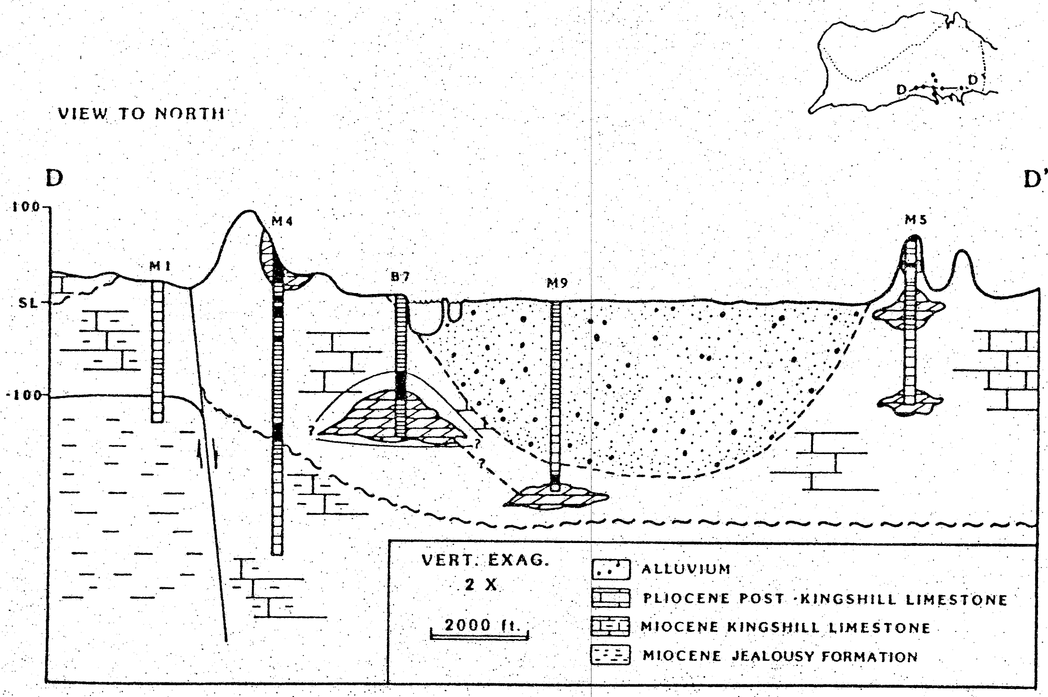

Figure 12. Cross section D-D': Estate Fairplain to Pearl.

and post-Kingshill carbonates, and therefore extends the time of fault activity into the Pliocene.

The Kingshill Limestone and the Pliocene carbonates dip seaward in the southeastern area of the basin (Fig. 13) and are overlain by lagoonal muds and alluvium of Krausses Lagoon and Limetree Bay. The Kingshill Limestone / Pliocene contact dips steeply

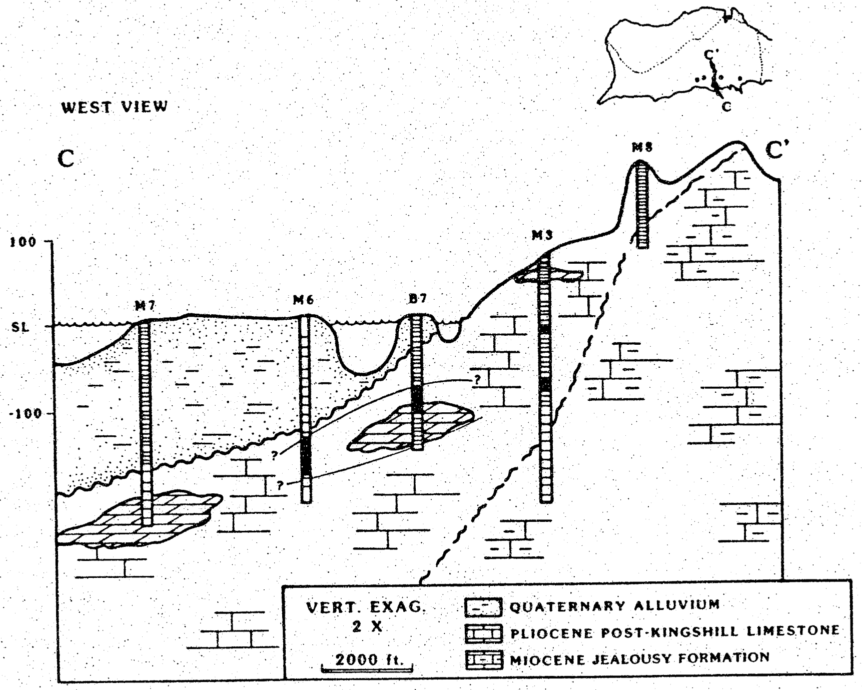

Figure 13. Cross section C-C': Krausses Lagoon to Spanish Town.

between the M3 and M8 test holes. The topography and drainage in an east-west line are interupted. and the area of interuption corresponds to the lateral extent of the reefal facies (Fig. 14). We suggest that the northern boundary of the reefal facies in this area corresponds to the extension of the post-Kingshill Limestone fault found between Test Holes M1 and M4 (Fig. 14).

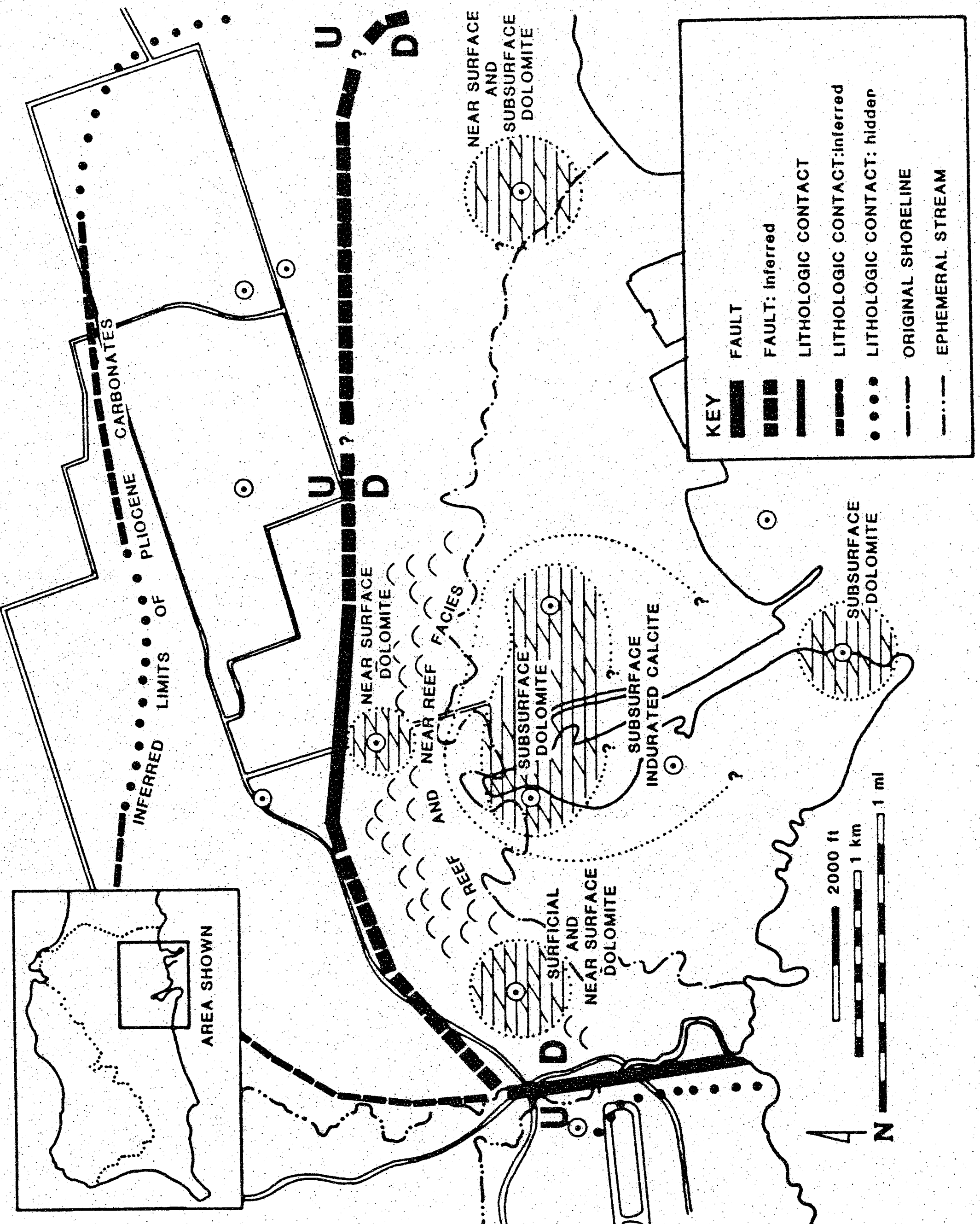

Figure 14. Facies map: south coast industrial area.

Biostratigraphy. The Pliocene carbonates are generally highly porous and recrystallized, and do not yield recognizable forams for biostratigraphic correlation. The biostratigraphic age of the Post-Kingshill carbonates is inferred from:

1) stratigraphic correlation to the post-Kingshill / Kingshill Limestone contact in the Airport-Penetentiary outcrop (Fig. 1) determined by Lidz (1982) to lie close to the Mio-Pliocene boundary;

2) the presence of solitary Mussid corals such as Antillea bilobata and Teliophyllia grandis that went extinct close to the Plio-Pleistocene boundary (S. Frost, pers. comm., 1986).

Dolomitization and diagenesis. The Pliocene carbonates show patchy areas of alteration to dolomite, with Test Holes M3, M4, M5, M7, M9 and B7 intersecting subsurface areas of dolomitization (Fig. 14). The geographic distribution of dolomitization follows the pre-development shoreline of Krausses Lagoon (Fig. 14) and the subsurface trend follows the alluvium / post-Kingshill carbonate contact (Fig. 13). No dolomite has been detected elsewhere in the areas drilled for this project, or elsewhere on St. Croix.

The dolomitization, as indicated by strontium isotopic techniques, most likely occurred during the Pliocene. Stable isotopic analyses suggest that meteoric processes are unlikely culprits for the dolomitization. We suggest that hypersaline conditions could have been responsible for the dolomitization, and that Krausses Lagoon may be a remnant Tertiary feature.

Subsurface dissolution, as evidenced by voids during drilling, do occur in the Pliocene carbonates. Voids have not been identified in the Kingshill Limestone. Adequate water flow for significant dissolution probably does exist today, as evidenced by flowing artesian conditions encountered during the drilling of Test Hole M7 (Fig. 4).

CONCLUSIONS

1. The south shore and western end of St. Croix are underlain by carbonates that represent significantly different facies than the Kingshill Limestone and are Pliocene in age. These deposits represent considerable shallowing of the basin, and range from in-place reefs to transported benthic foraminiferal sands. These deposits, classified simply as post-Kingshill carbonate in this report, should be split from the Kingshill Limestone and put into one or two separate formations.

2. The post-Kingshill carbonates represent three major facies: lagoon, bank and reef. All three facies are represented on the westend as well as the south-central coast.

3. An area extending from Estate Judith's Fancy to Estate Colquehoun was mapped by Whetten (1966) as the Jealousy Formation (Fig. 2). Exposures in this area are completely unlike the Jealousy Formation sampled in the subsurface and are similar to Kingshill Limestone exposures in neighboring areas. We suggest that these exposures be mapped as the Kingshill Limestone.

4. The northern section of Kingshill Limestone deposition is characterized by extensive deposition of

rounded-pebble conglomerate facies. This facies is found both in outcrop and subsurface in Test Hole M10.

5. The contact between the Kingshill Limestone and the underlying Jealousy Formation clays is unambiguous and abrupt. However, analyses undertaken in Phase II of this project show that despite the color change between the formations, the mineralogic content and foraminiferal fauna of the two formations are very similar.

6. The Kingshill Limestone / Jealousy Formation contact forms an undulating surface that upwarps and crudely follows the present island topography. The Kingshill Limestone does not thin over these upwarps, and there is some evidence for folding in the carbonate section over Jealousy Formation topographic highs. We submit that this is evidence for deformation during Kingshill or post-Kingshill time.

7. The Cretaceous rock / Kingshill Limestone contact on the eastern margin of the basin shows evidence of fault brecciation, structural dip and abrupt, nondepositional contact. If true, this suggests that activity along the basin margin fault blocks was not completed prior to Kingshill Limestone

deposition and continued at least through Kingshill time.

8. A fault of 260 feet minimum displacement cuts through the post-Kingshill carbonates on the south shore extending the range of tectonic deformation well into the Pliocene. A curvilinear extension of this fault runs east - west between Test Holes M3 and M8, segregating facies of the post-Kingshill carbonates and rimming the outline of both Krausses Lagoon and the Pliocene reef tract. Evidence for this fault includes disrupted drainage, disrupted topography and lateral facies transition.

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APPENDIX

Key to Well Log Abbreviations

Texture (after Folk, 1974)

s, S = sandy, Sand
z, Z = silty, Silt
g. G = gravelly, Gravel
m, M = muddy, Mud
c, C = clayey, Clay

e.g.: (g)sM = slightly gravelly sandy Mud

e.g.: sG = sandy Gravel

mdst = mudstone
wkst = wackestone
pkst = packstone
grst = grainstone

Sample Designation

(12) = sample no. 12
ss = split spoon sample
db = diamond bit sample
hs = hollow stem auger sample
TS = thin section made from this sample

Color

bk = black
br = brown
bu = blue
gn = green
gy = grey
or = orange
re = red
tn = tan
wh = white
ye = yellow

lt = light
dk = dark

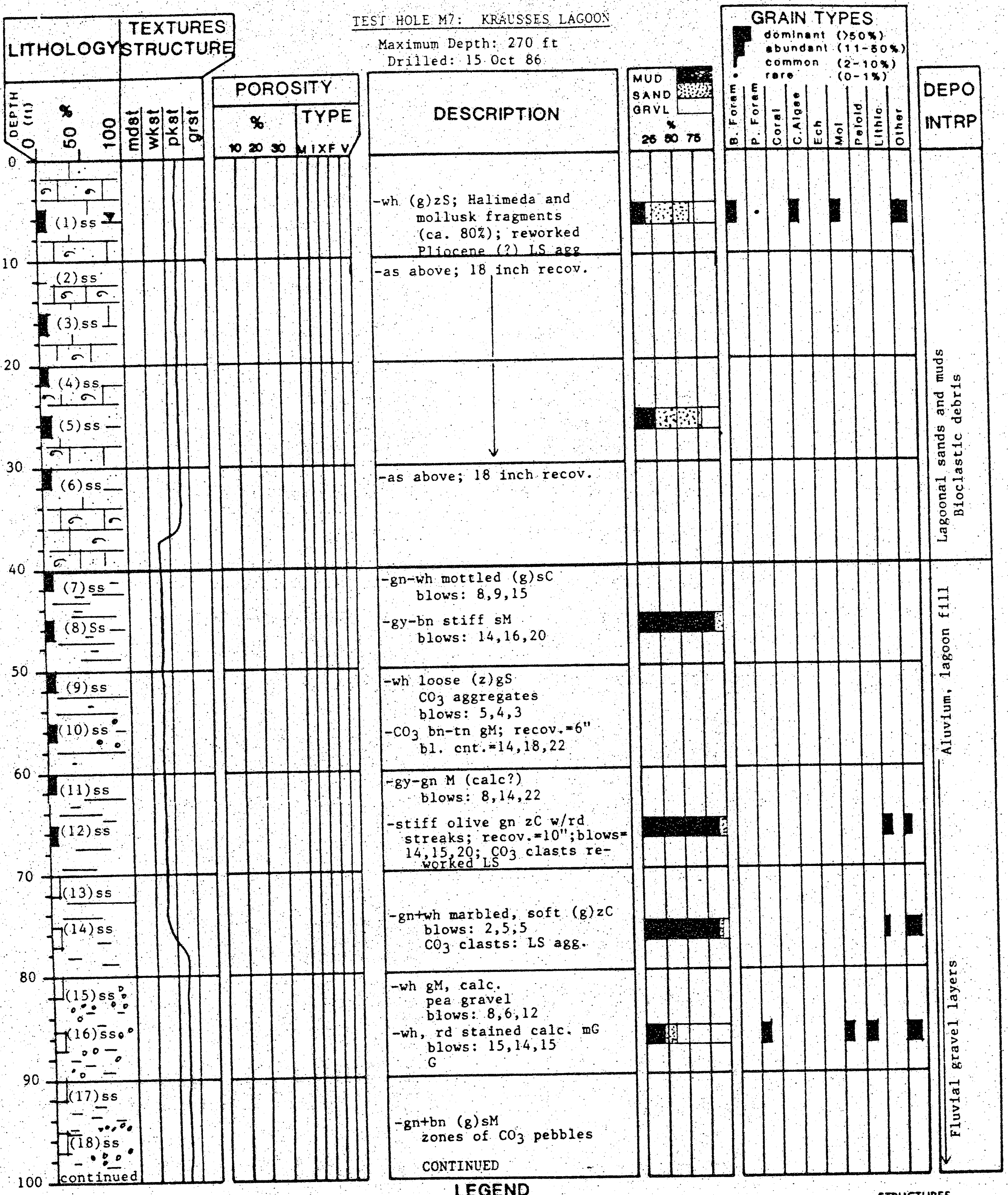
Key to Well Log Abbreviations, (continued)

Lithology

b. foram = benthic foraminifera
calc = calcareous
cmtd = cemented
CO3 = carbonate
frags = fragments
lith = lithic
LS = limestone
Mn = Manganese
p. foram = planktic foraminifera
rbl = rubble
recov = recovery (core recovery)
rk = rock
skel = skeletal
spl = sample

TEST HOLE M7: KRAUSSES LAGOON

Maximum Depth: 270 ft
Drilled: 15 Oct 86



-wh (g)zS; Halimeda and mollusk fragments (ca. 80%); reworked Pliocene (?) LS agg

-as above; 18 inch recov.

-as above; 18 inch recov.

-gn-wh mottled (g)sC
blows: 8,9,15

-gy-bn stiff sM
blows: 14,16,20

-wh loose (z)gS
CO_3 aggregates
blows: 5,4,3

-CO_3 bn-tn gM; recov.=6"
bl. cnt.=14,18,22

-gy-gn M (calc?)
blows: 8,14,22

-stiff olive gn zC w/rd streaks; recov.=10";blows=14,15,20; CO_3 clasts reworked LS

-gn+wh marbled, soft (g)zC
blows: 2,5,5
CO_3 clasts: LS agg.

-wh gM, calc.
pea gravel
blows: 8,6,12

-wh, rd stained calc. mG
blows: 15,14,15
G

-gn+bn (g)sM
zones of CO_3 pebbles

CONTINUED

LEGEND

LITHOLOGY

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

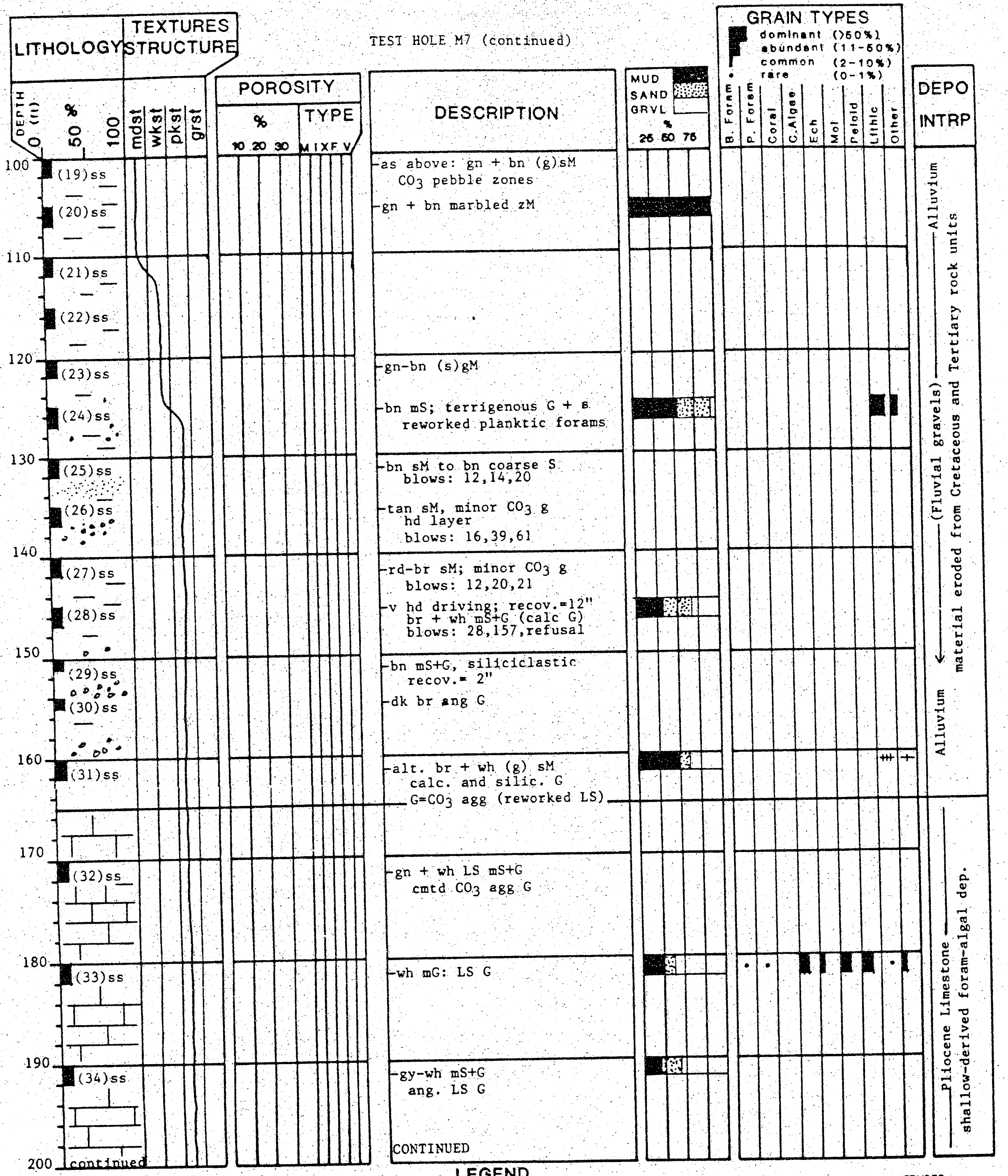
M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

TEST HOLE M7 (continued)



-as above: gn + bn (g)sM
CO$_3$ pebble zones

-gn + bn marbled zM

-gn-bn (s)gM

-bn mS; terrigenous G + s
reworked planktic forams

-bn sM to bn coarse S
blows: 12,14,20

-tan sM, minor CO$_3$ g
hd layer
blows: 16,39,61

-rd-br sM; minor CO$_3$ g
blows: 12,20,21

-v hd driving; recov.=12"
br + wh mS+G (calc G)
blows: 28,157,refusal

-bn mS+G, siliciclastic
recov.= 2"

-dk br ang G

-alt. br + wh (g) sM
calc. and silic. G
G=CO$_3$ agg (reworked LS)

-gn + wh LS mS+G
cmtd CO$_3$ agg G

-wh mG: LS G

-gy-wh mS+G
ang. LS G

CONTINUED

LEGEND

LITHOLOGY

- limestone
- dolomite
- marl
- sand
- clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

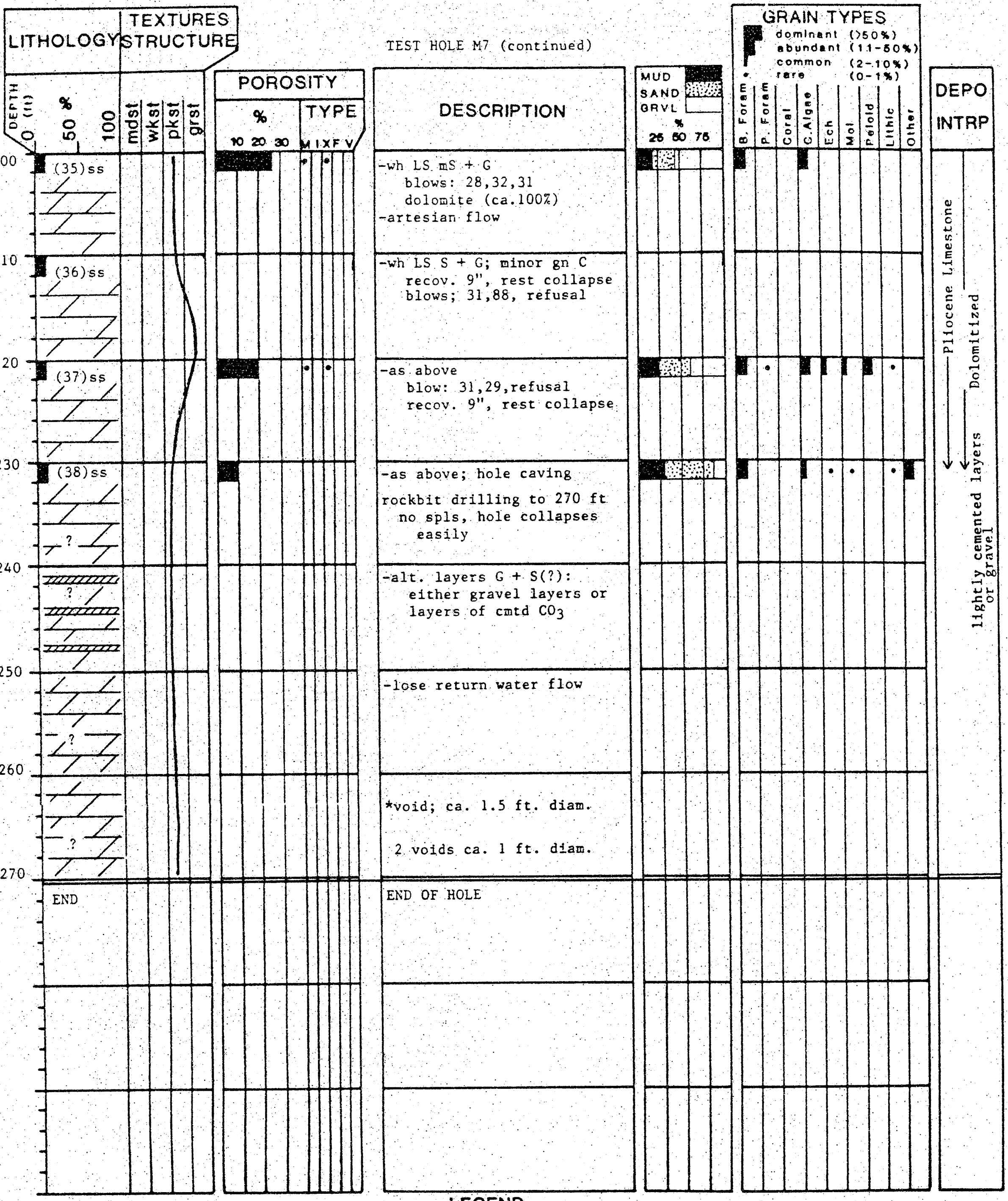
GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated

TEST HOLE M7 (continued)



-wh LS mS + G
blows: 28,32,31
dolomite (ca.100%)
-artesian flow

-wh LS S + G; minor gn C
recov. 9", rest collapse
blows; 31,88, refusal

-as above
blow: 31,29,refusal
recov. 9", rest collapse

-as above; hole caving
rockbit drilling to 270 ft
no spls, hole collapses
easily

-alt. layers G + S(?):
either gravel layers or
layers of cmtd CO_3

-lose return water flow

*void; ca. 1.5 ft. diam.

2 voids ca. 1 ft. diam.

END OF HOLE

LEGEND

LITHOLOGY

- ▦ limestone
- ▦ dolomite
- ▦ marl
- ▨ sand
- ▨ clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

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X=Intercrystalline
V=Vuggy
F=Fracture

GRAIN TYPES

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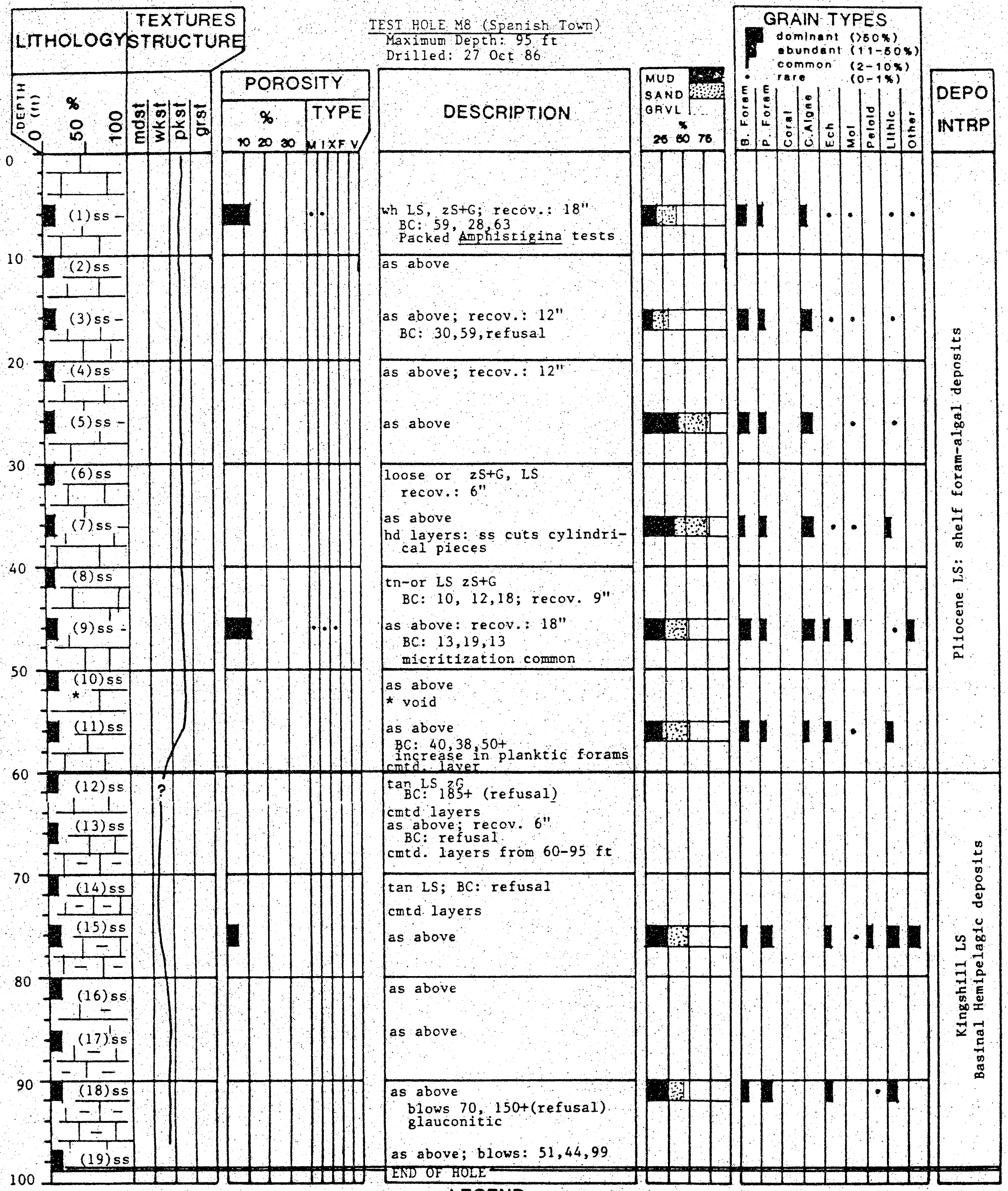
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

cross-bedding
horizontal beds
wavy laminations
graded bedding
fracture
bioturbated

TEST HOLE M8 (Spanish Town)
Maximum Depth: 95 ft
Drilled: 27 Oct 86



wh LS, zS+G; recov.: 18"
BC: 59, 28,63
Packed Amphisrigina tests

as above

as above; recov.: 12"
BC: 30,59,refusal

as above; recov.: 12"

as above

loose or zS+G, LS
recov.: 6"

as above
hd layers: ss cuts cylindrical pieces

tn-or LS zS+G
BC: 10, 12,18; recov. 9"

as above: recov.: 18"
BC: 13,19,13
micritization common

as above
* void

as above
BC: 40,38,50+
increase in planktic forams
cmtd. layer

tan LS zG
BC: 185+ (refusal)

cmtd layers
as above; recov. 6"
BC: refusal
cmtd. layers from 60-95 ft

tan LS; BC: refusal

cmtd layers

as above

as above

as above

as above
blows 70, 150+(refusal)
glauconitic

as above; blows: 51,44,99

END OF HOLE

LEGEND

LITHOLOGY

▦ limestone
▦ dolomite
▤ marl
▒ sand
▒ clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

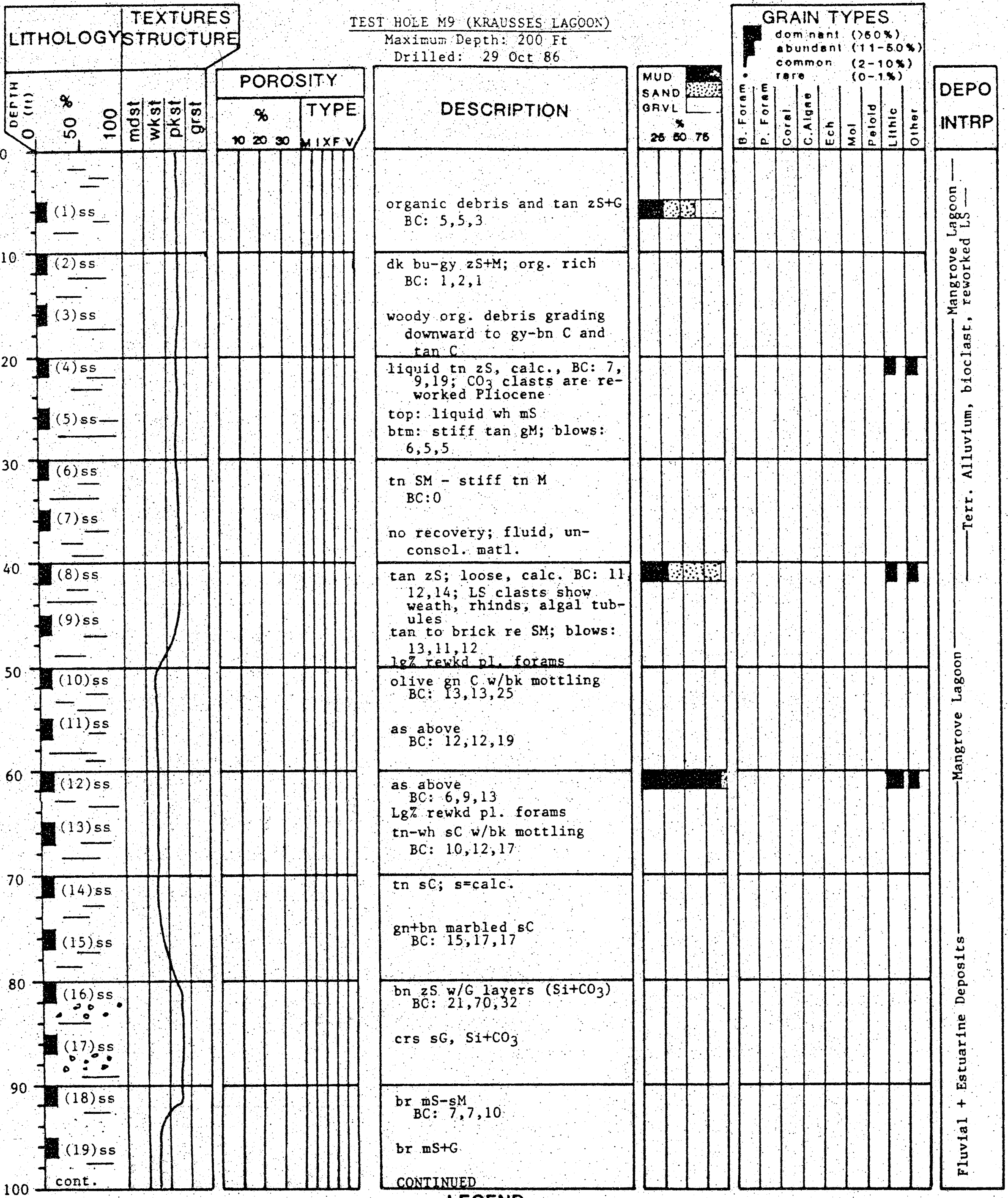
GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

cross-bedding
horizontal beds
wavy laminations
graded bedding
fracture
bioturbated

TEST HOLE M9 (KRAUSSES LAGOON)
Maximum Depth: 200 Ft
Drilled: 29 Oct 86



organic debris and tan zS+G
BC: 5,5,3

dk bu-gy zS+M; org. rich
BC: 1,2,1

woody org. debris grading downward to gy-bn C and tan C

liquid tn zS, calc., BC: 7, 9,19; CO_3 clasts are reworked Pliocene

top: liquid wh mS
btm: stiff tan gM; blows: 6,5,5

tn SM - stiff tn M
BC:0

no recovery; fluid, unconsol. matl.

tan zS; loose, calc. BC: 11, 12,14; LS clasts show weath, rhinds, algal tubules
tan to brick re SM; blows: 13,11,12
Lg% rewkd pl. forams

olive gn C w/bk mottling
BC: 13,13,25

as above
BC: 12,12,19

as above
BC: 6,9,13
Lg% rewkd pl. forams
tn-wh sC w/bk mottling
BC: 10,12,17

tn sC; s=calc.

gn+bn marbled sC
BC: 15,17,17

bn zS w/G layers ($Si+CO_3$)
BC: 21,70,32

crs sG, $Si+CO_3$

br mS-sM
BC: 7,7,10

br mS+G

CONTINUED

LEGEND

LITHOLOGY

- limestone
- dolomite
- marl
- sand
- clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

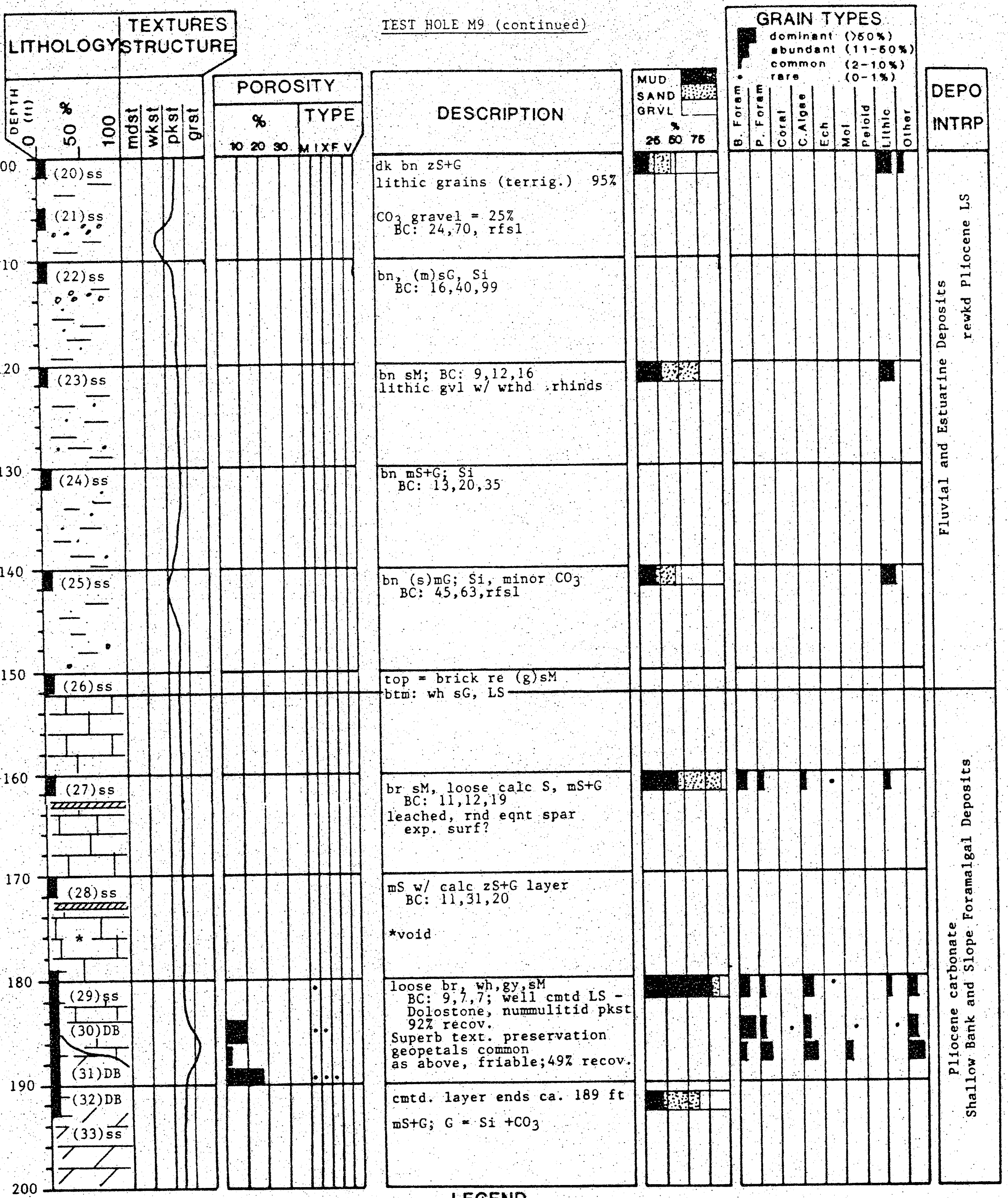
GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated

TEST HOLE M9 (continued)



dk bn zS+G
lithic grains (terrig.) 95%

CO_3 gravel = 25%
BC: 24,70, rfsl

bn, (m)sG, Si
BC: 16,40,99

bn sM; BC: 9,12,16
lithic gvl w/ wthd .rhinds

bn mS+G; Si
BC: 13,20,35

bn (s)mG; Si, minor CO_3
BC: 45,63,rfsl

top = brick re (g)sM
btm: wh sG, LS

br sM, loose calc S, mS+G
BC: 11,12,19
leached, rnd eqnt spar
exp. surf?

mS w/ calc zS+G layer
BC: 11,31,20

*void

loose br, wh,gy,sM
BC: 9,7,7; well cmtd LS -
Dolostone, nummulitid pkst
92% recov.
Superb text. preservation
geopetals common
as above, friable;49% recov.

cmtd. layer ends ca. 189 ft

mS+G; G = Si $+CO_3$

LEGEND

LITHOLOGY

- ▦ limestone
- ▦ dolomite
- ▦ marl
- ▨ sand
- ▨ clay

FABRICS

grst-grainstone
pkst-packstone
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mkst-mudstone

POROSITY TYPES

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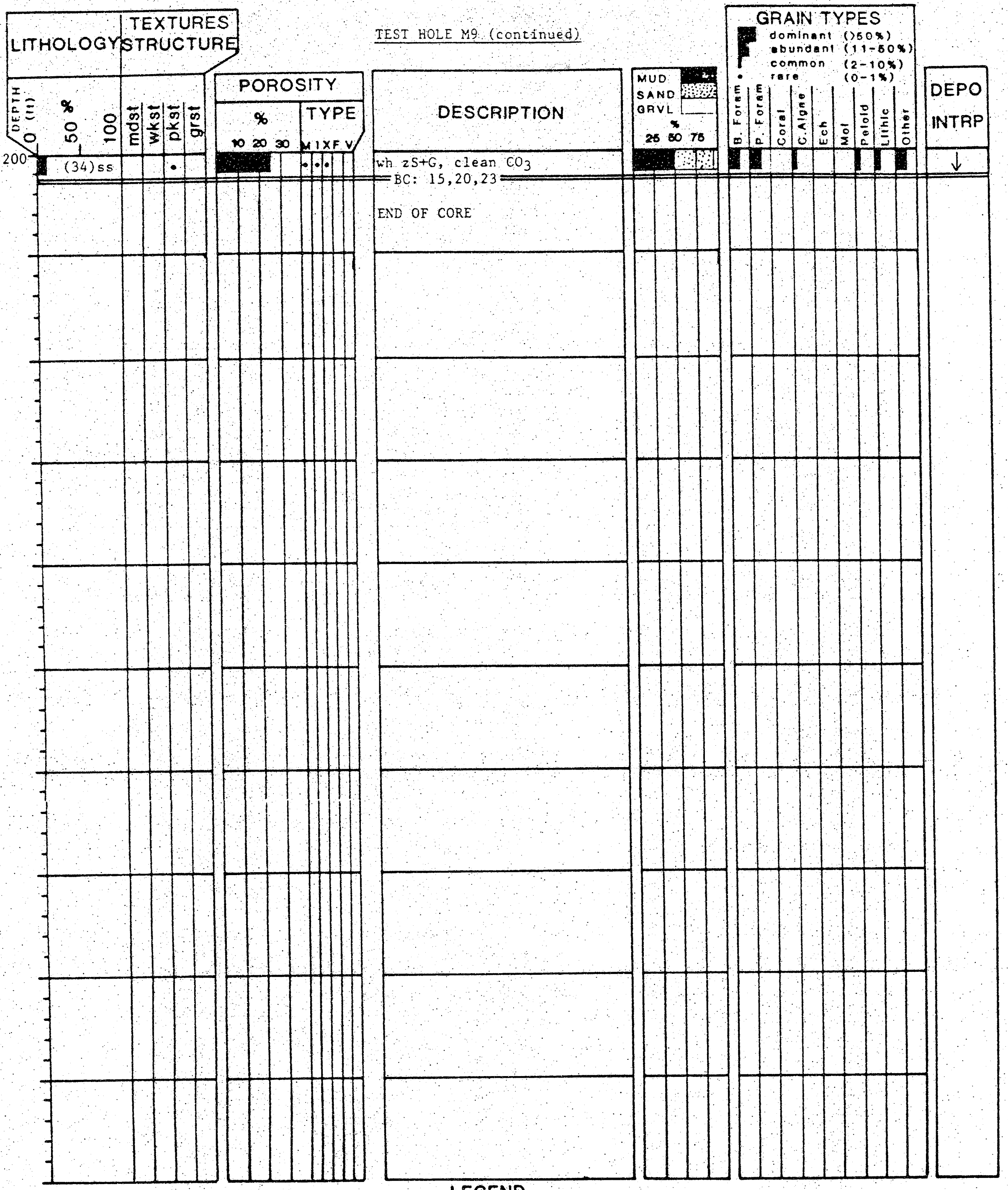
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated

TEST HOLE M9 (continued)



wh zS+G, clean CO_3

BC: 15,20,23

END OF CORE

LEGEND

LITHOLOGY

- limestone
- dolomite
- marl
- sand
- clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

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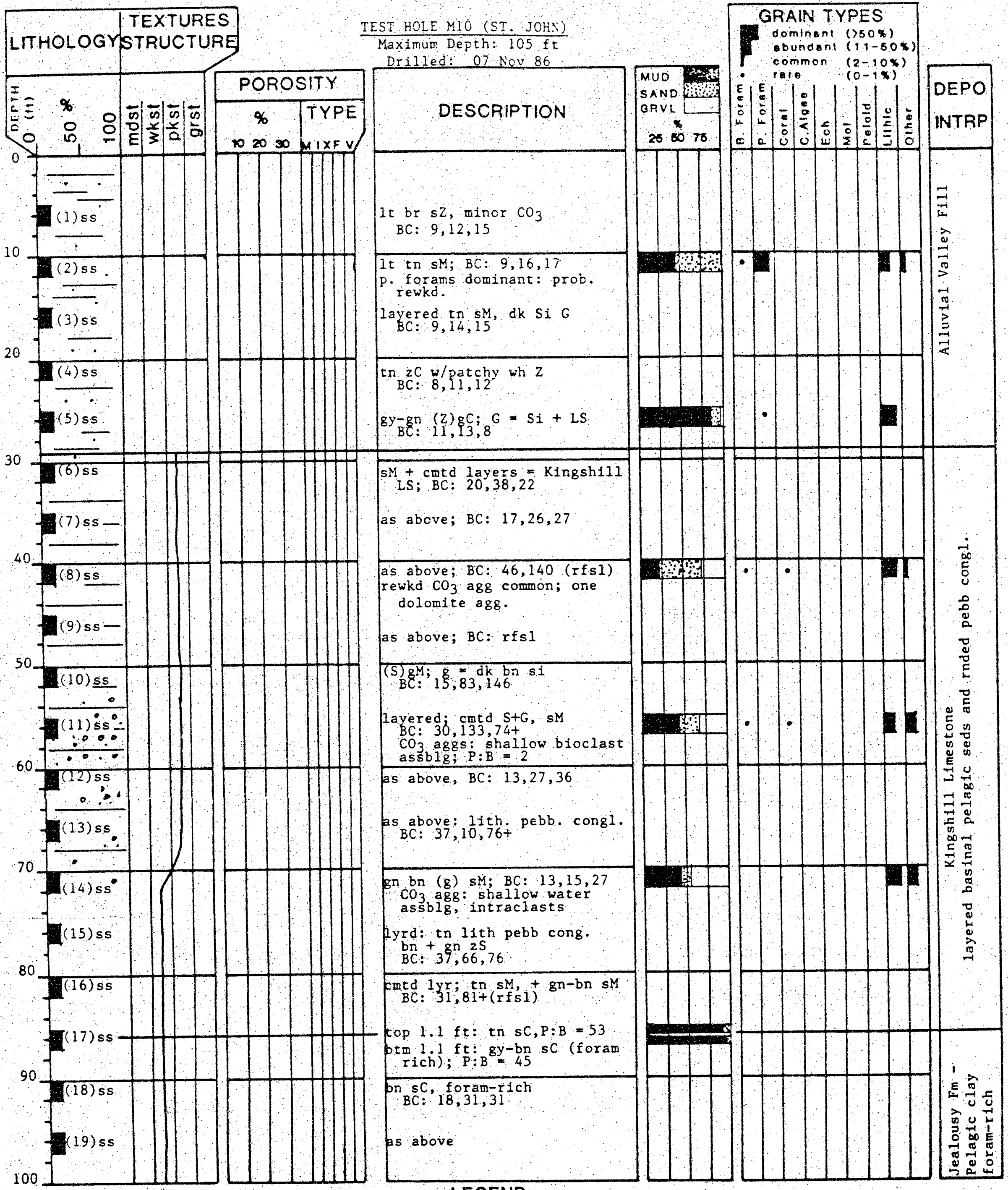
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated

TEST HOLE M10 (ST. JOHN)
Maximum Depth: 105 ft
Drilled: 07 Nov 86



lt br sZ, minor CO_3
BC: 9,12,15

lt tn sM; BC: 9,16,17
p. forams dominant: prob. rewkd.

layered tn sM, dk Si G
BC: 9,14,15

tn zC w/patchy wh Z
BC: 8,11,12

gy-gn (Z)gC; G = Si + LS
BC: 11,13,8

sM + cmtd layers = Kingshill LS; BC: 20,38,22

as above; BC: 17,26,27

as above; BC: 46,140 (rfsl)
rewkd CO_3 agg common; one dolomite agg.

as above; BC: rfsl

(S)gM; g = dk bn si
BC: 15,83,146

layered; cmtd S+G, sM
BC: 30,133,74+
CO_3 aggs: shallow bioclast assblg; P:B = 2

as above, BC: 13,27,36

as above: lith. pebb. congl.
BC: 37,10,76+

gn bn (g) sM; BC: 13,15,27
CO_3 agg: shallow water assblg, intraclasts

lyrd: tn lith pebb cong.
bn + gn zS
BC: 37,66,76

cmtd lyr; tn sM, + gn-bn sM
BC: 31,81+(rfsl)

top 1.1 ft: tn sC, P:B = 53
btm 1.1 ft: gy-bn sC (foram rich); P:B = 45

bn sC, foram-rich
BC: 18,31,31

as above

Alluvial Valley Fill

Kingshill Limestone
layered basinal pelagic seds and rnded pebb congl.

Jealousy Fm -
Pelagic clay
foram-rich

LEGEND

LITHOLOGY

limestone
dolomite
marl
sand
clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

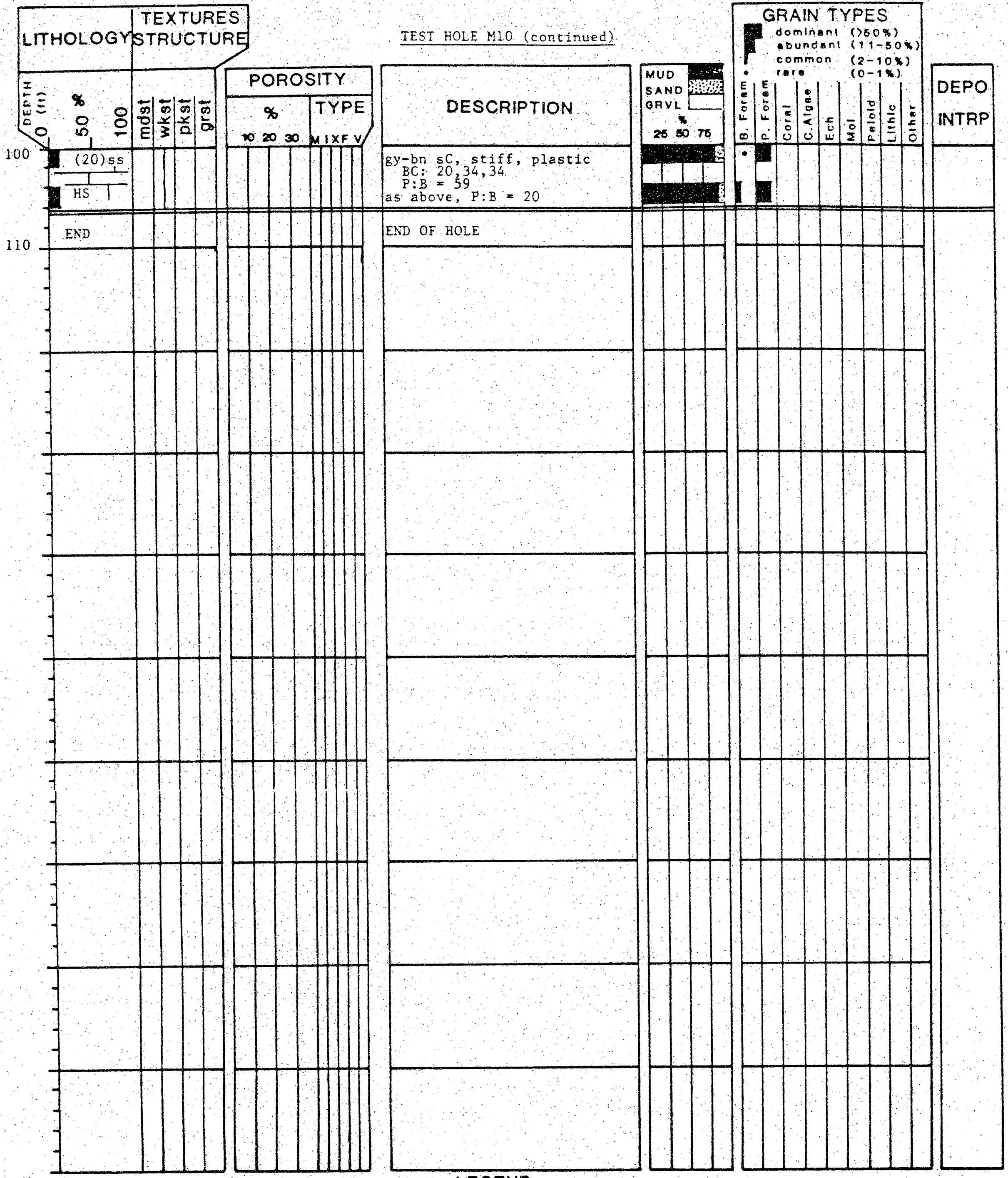
GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

cross-bedding
horizontal beds
wavy laminations
graded bedding
fracture
bioturbated

TEST HOLE M10 (continued)



gy-bn sC, stiff, plastic
BC: 20,34,34
P:B = 59
as above, P:B = 20

END OF HOLE

LEGEND

LITHOLOGY

- ▦ limestone
- ▦ dolomite
- ▦ marl
- ▦ sand
- ▦ clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

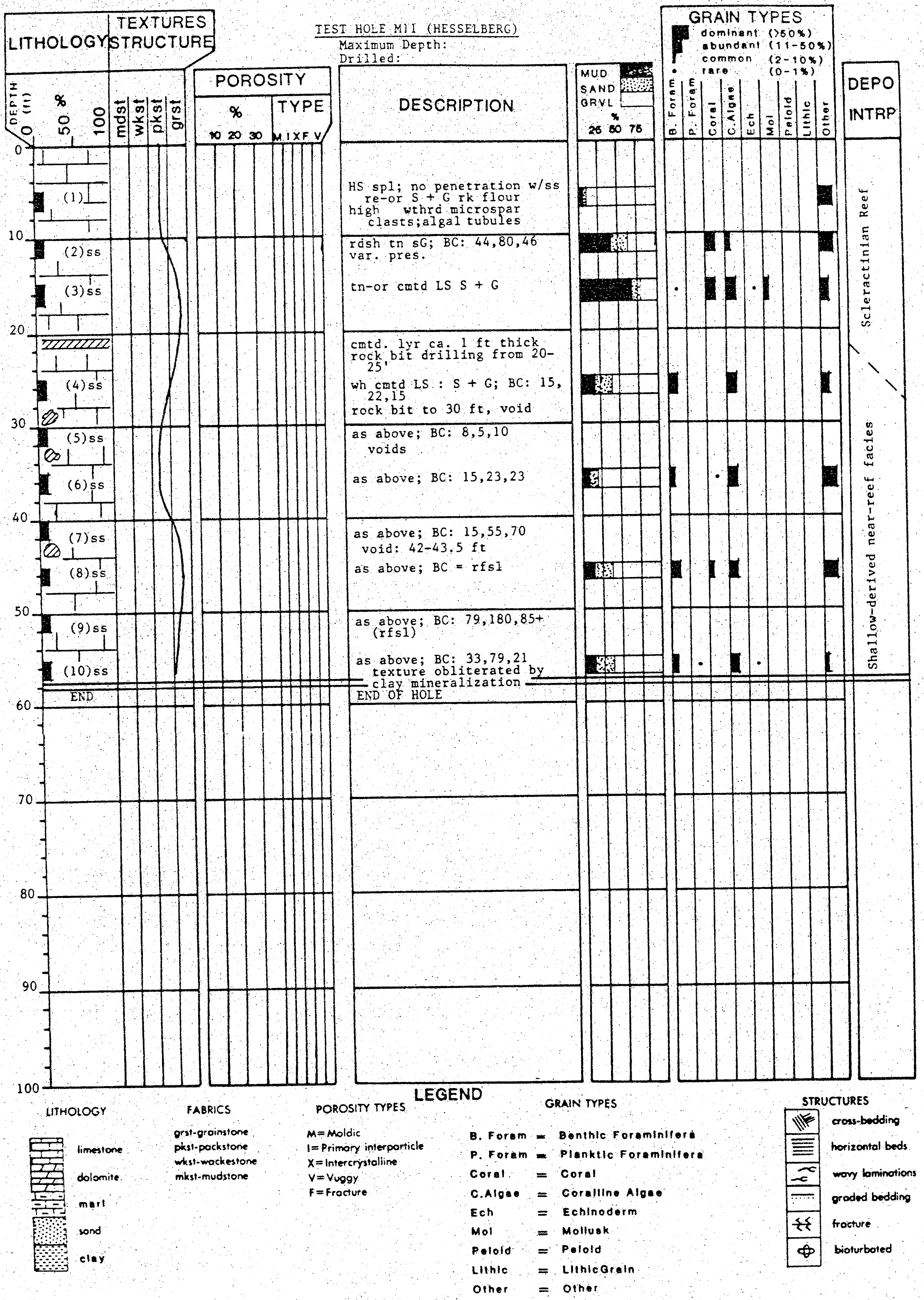
GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- ▦ cross-bedding
- ☰ horizontal beds
- ▦ wavy laminations
- ▦ graded bedding
- ▦ fracture
- ⊕ bioturbated

TEST HOLE M11 (HESSELBERG)
Maximum Depth:
Drilled:



HS spl; no penetration w/ss re-or S + G rk flour high wthrd microspar clasts;algal tubules

rdsh tn sG; BC: 44,80,46 var. pres.

tn-or cmtd LS S + G

cmtd. lyr ca. 1 ft thick rock bit drilling from 20-25'

wh cmtd LS : S + G; BC: 15, 22,15

rock bit to 30 ft, void

as above; BC: 8,5,10 voids

as above; BC: 15,23,23

as above; BC: 15,55,70 void: 42-43.5 ft

as above; BC = rfsl

as above; BC: 79,180,85+ (rfsl)

as above; BC: 33,79,21 texture obliterated by clay mineralization

END OF HOLE

LEGEND

LITHOLOGY
limestone
dolomite
marl
sand
clay

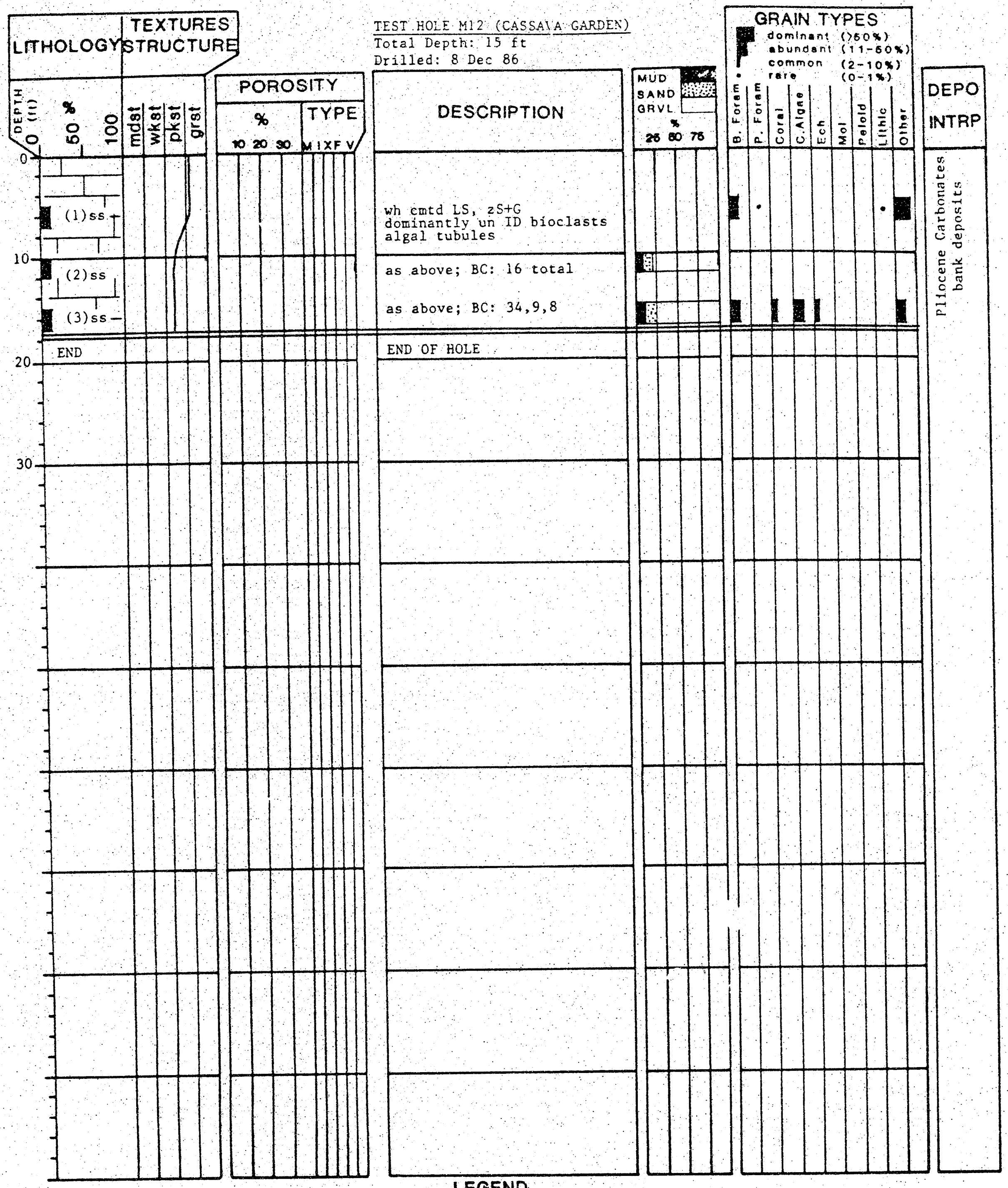
FABRICS
grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES
M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

GRAIN TYPES
B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES
cross-bedding
horizontal beds
wavy laminations
graded bedding
fracture
bioturbated

TEST HOLE M12 (CASSAVA GARDEN)
Total Depth: 15 ft
Drilled: 8 Dec 86



wh cmtd LS, zS+G
dominantly un ID bioclasts
algal tubules

as above; BC: 16 total

as above; BC: 34,9,8

END OF HOLE

LEGEND

LITHOLOGY
- limestone
- dolomite
- marl
- sand
- clay

FABRICS
grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES
M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
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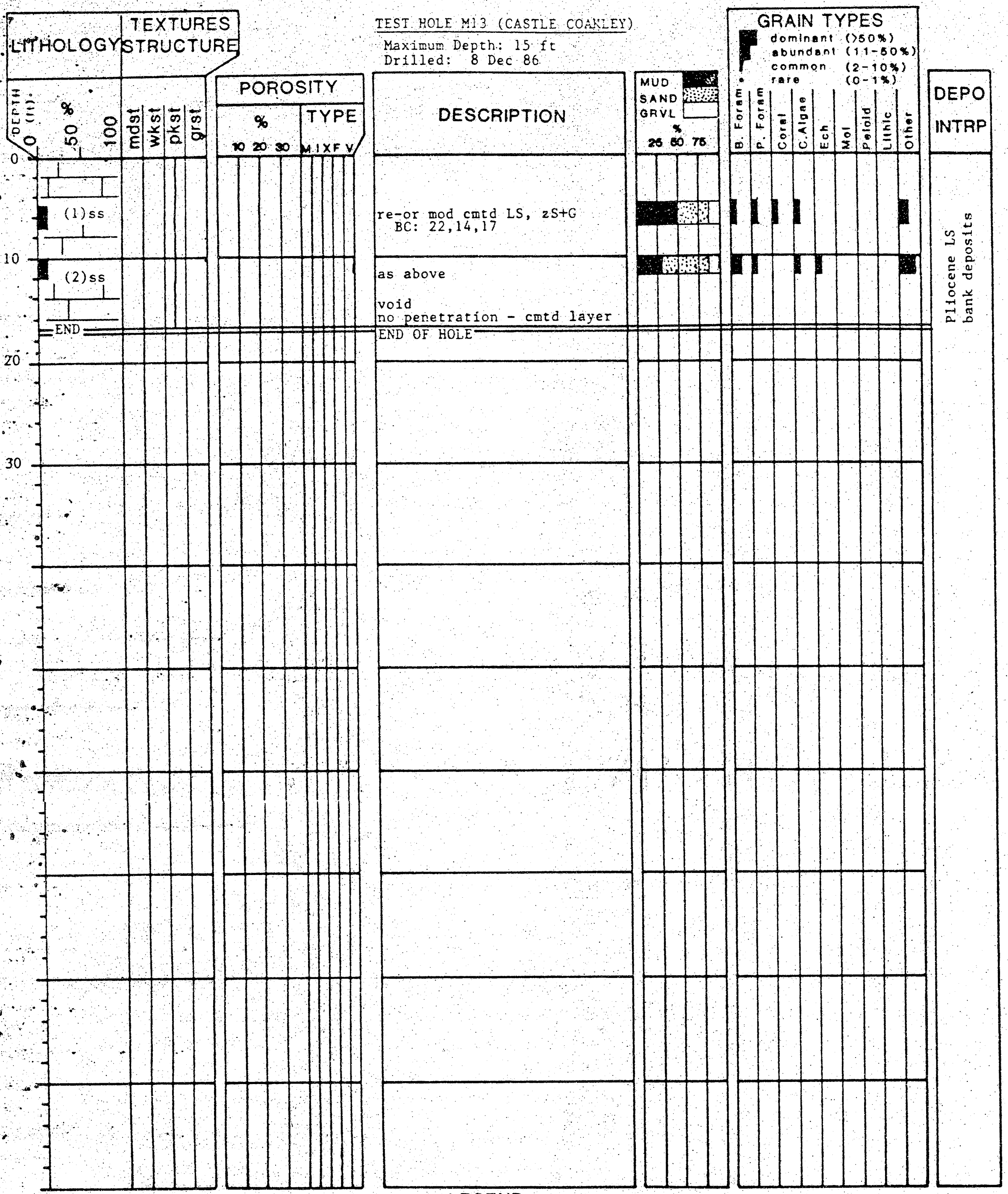
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES
- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated

TEST HOLE M13 (CASTLE COAKLEY)

Maximum Depth: 15 ft
Drilled: 8 Dec 86



re-or mod cmtd LS, zS+G
BC: 22,14,17

as above

void
no penetration - cmtd layer
END OF HOLE

Pliocene LS
bank deposits

LEGEND

LITHOLOGY

- limestone
- dolomite
- marl
- sand
- clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

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I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

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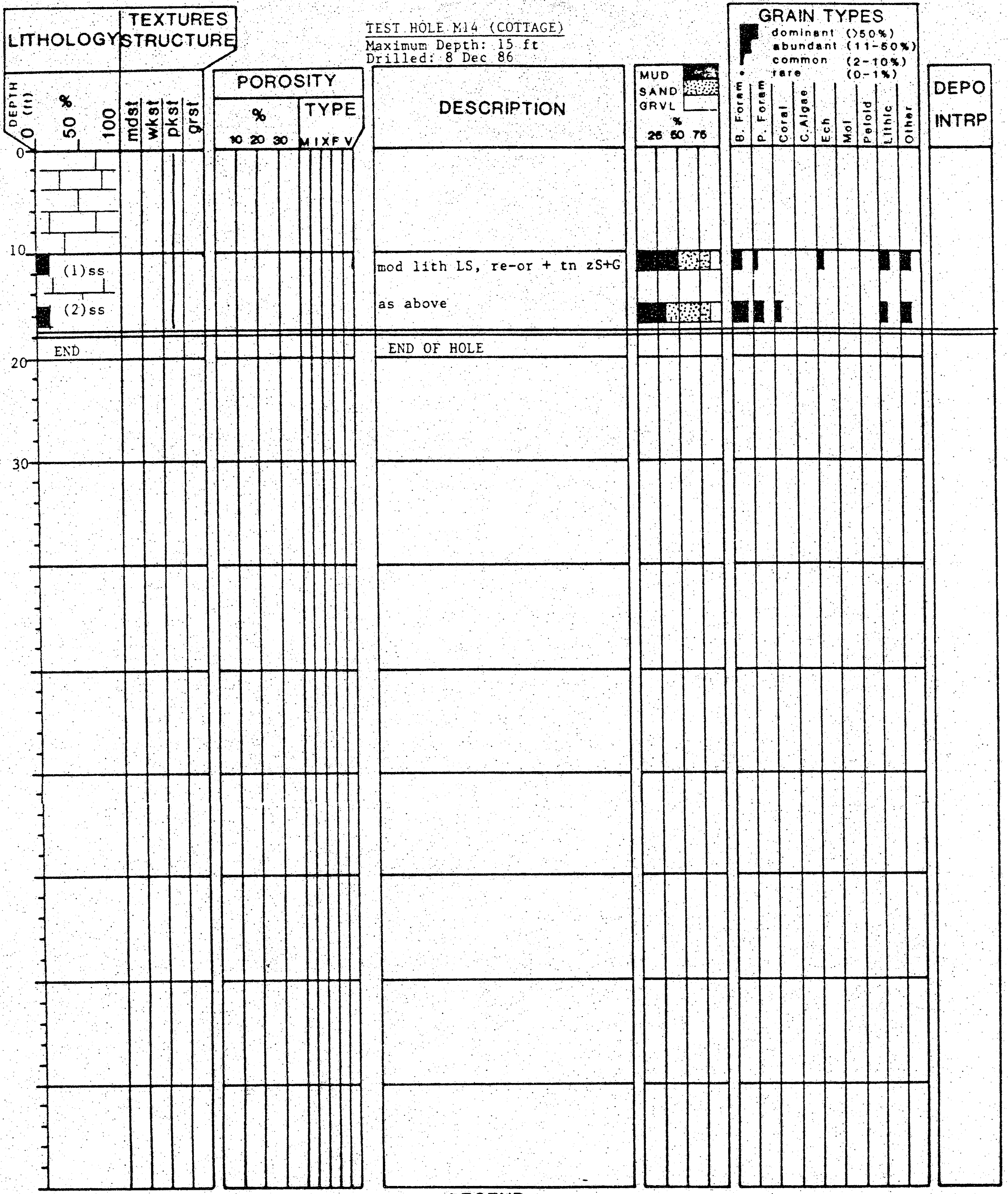
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated

TEST HOLE M14 (COTTAGE)
Maximum Depth: 15 ft
Drilled: 8 Dec 86



mod lith LS, re-or + tn zS+G

as above

END OF HOLE

LEGEND

LITHOLOGY

- limestone
- dolomite
- marl
- sand
- clay

FABRICS

grst-grainstone
pkst-packstone
wkst-wackestone
mkst-mudstone

POROSITY TYPES

M=Moldic
I=Primary interparticle
X=Intercrystalline
V=Vuggy
F=Fracture

GRAIN TYPES

B. Foram = Benthic Foraminifera
P. Foram = Planktic Foraminifera
Coral = Coral
C.Algae = Coralline Algae
Ech = Echinoderm
Mol = Mollusk
Peloid = Peloid
Lithic = LithicGrain
Other = Other

STRUCTURES

- cross-bedding
- horizontal beds
- wavy laminations
- graded bedding
- fracture
- bioturbated