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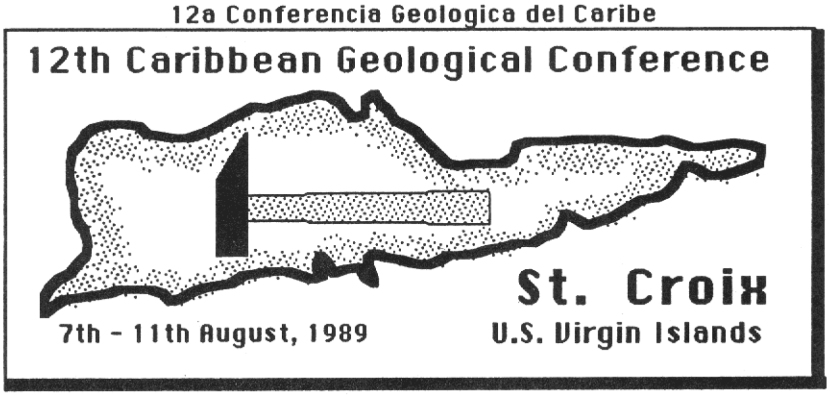

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THE CRETACEOUS AGE SEDIMENTS OF THE SABA BANK AND THEIR PETROLEUM POTENTIAL

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ABSTRACT

The Saba Bank area has been under active exploration for hydrocarbons since the early 70's. There has been 3600 plus km of seismic data acquired over the bank, two wells drilled and numerous reports on the area's petroleum potential published. The work proved the existence of good source and reservoir rocks within the Tertiary section. The well data also proved the Tertiary section to be too immature to have produced the hydrocarbon shows found during the drilling. The available data suggests the existence of a Late Cretaceous sedimentary section underlying the drilled Tertiary section. This section may have provided the source rocks for the hydrocarbons present.

INTRODUCTION

The Saba Bank is 13.5 km (8 mi) southwest of the island of Saba and 135.5 km (84 mi) east-southeast of St. Croix, U.S. Virgin Islands (fig. 1). The bank is a completely submerged carbonate platform raised approximately 1,000 m (3,290 ft) above the general seafloor. The area has had two (2) exploratory wells drilled on the permit since 1977 (fig. 1). Both wells reached total depth in a Paleocene-Eocene Age andesite (Larue, 1988; Warner, 1989).

The Saba Bank area belongs to the very complex tectonic framework of the Caribbean Sea (Case, 1980) and so far no completely satisfactory theory of the tectonic history of the region exists. In discussing the geological history and petroleum potential of the Saba Bank several things must be considered: (1) Is The Saba Bank genetically related to the Greater Antilles, the Lesser Antilles or both? (2) Is the Saba Bank a northern extension of the Aves Ridge (Bouysse, 1985)? (3) Do sediments of Early Eocene age and older exist beneath the platform? Saba Island is usually considered as part of the Tertiary Island Arc system along the Eastern edge of the Caribbean Plate, yet geologically Saba Bank or a part might belong to the Greater Antilles.

STRATIGRAPHY

There were four major stratigraphic units drilled in the two wells (fig. 2). The units range, in age, from Early Eocene through Early Pliocene (Fina, 1982a, 1982b; Marathon 1977a, 1977b). The units from top to bottom are as follows:

Upper Carbonate Unit

This unit is primarily pale yellow to translucent, crystalline to microcrystalline limestone. Age dating and the fossil recoveries suggest this section ranges from Middle Miocene to Early Pliocene in age.

Volcano Clastic Section

This unit in Saba Bank No. 1 consists of conglomerates, sandstones, alternating siltstone and claystone facies. In the Saba Bank No. 2, the central unit is finer grained and contains no conglomerates. The volcano-clastic unit ranges in age from Early Eocene to Middle Miocene. The environment of deposition of the unit is a near-shore deltaic-neritic at S. B. No. 1 and a neritic to deep water submarine fan environment at S.B. No. 2.

Lower Carbonate Unit

In Saba Bank No. 1, a Mid to Late Eocene age limestone was encountered. Marathon (1977a) has described the limestone as being:

> . . . mostly micritic or well cemented clean limestones with little porosity, but includes interbeds of poorly cemented, fine grained carbonate sand that have excellent porosity.

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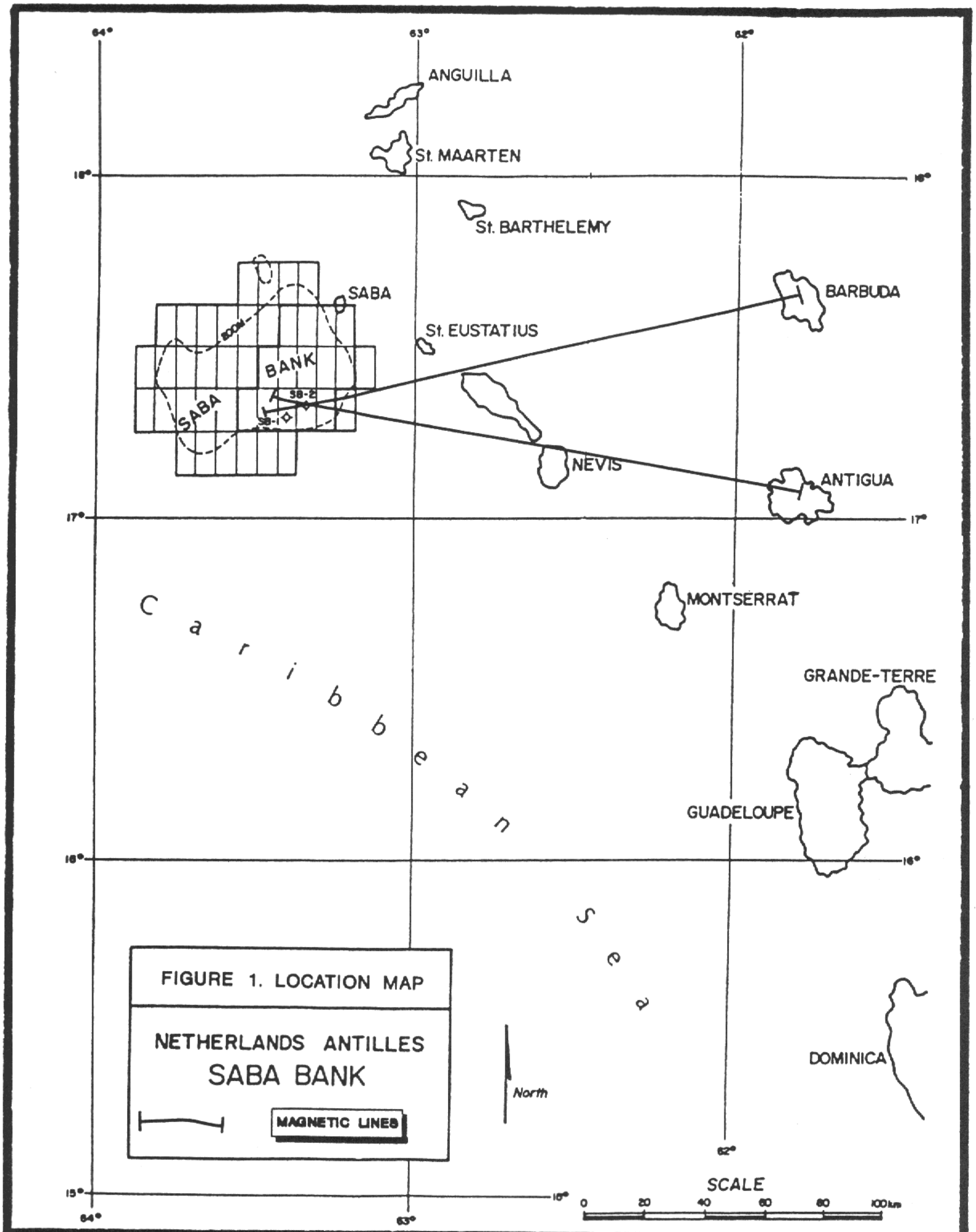


The lower unit in Saba Bank No. 2 is not a carbonate but rather a turbidite. This unit consists mainly of silty claystones and argillaceous siltstones, with several sandstone beds encountered in the lower portion (Fina, 1982a).

Conglomerate Found In S.B. No. 1

In the S.B. No. 1, a basal conglomerate was encountered above the andesite. The conglomerate was not cored. It was described (Marathon, 1977a) as being composed of quartz grains ranging from fine grained to conglomeratic with a

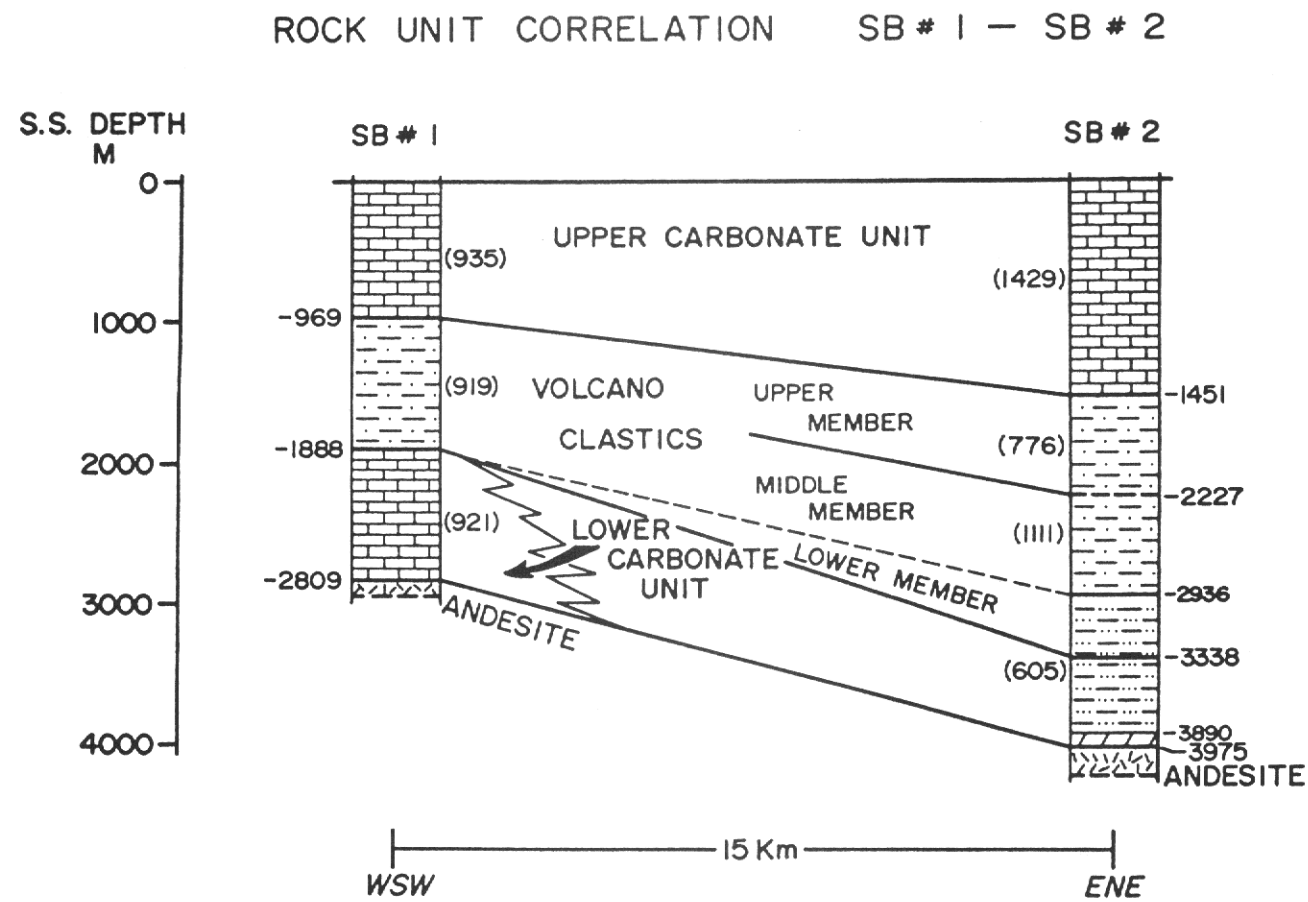


FIGURE 2.

After Fina 1982a.

silica cement in a non calcareous clay matrix with disseminated pyrite. The unit is green-gray with a "weathered Kaolinite appearance. (Marathon, 1977a) It is clear from the interval of altered conglomerate rocks resting on these volcanics that a significant unconformity which may represent part of the Late Paleocene and/or Early Eocene time caps the volcanic sequence. In the S.B. No. 2. this conglomerate was not found Fina described several basal sands that could possibly represent weathered andesite.

Andesite

Both exploratory wells reached total depth in an andesite porphyry that is dated between Early Paleocene to Early Oligocene. See table No. 1. The original dating on the andesite under S.B. No. 1 is a closer approximation of the actual age of the andesite. The dates were recorded from separated hornblende crystals. Whereas the S.B. 2 dates were from whole rock samples. From the samples recovered, the consensus is that the andesite represents either a surface intrusion or a near surface volcanic feeder system. In the Saba Bank No. 1, the top of the andesite is at 2,856 m (9,370 ft). In the Saba Bank No. 2, the unit is at 4,032 m (13,228 ft).

GEOCHEMISTRY

Marathon's S.B. No. 1 Data

Nine composite samples of cuttings were analyzed for total hydrocarbons, saturates and aromatics. The samples yielded total hydrocarbons of 234 to 593 ppm. All the composites gave the appearance of containing good source rocks for oil. (figure 3.) Marathon's stated:

> ...the rocks give the appearance of good but

TABLE 1.
AGES OF ANDESITE

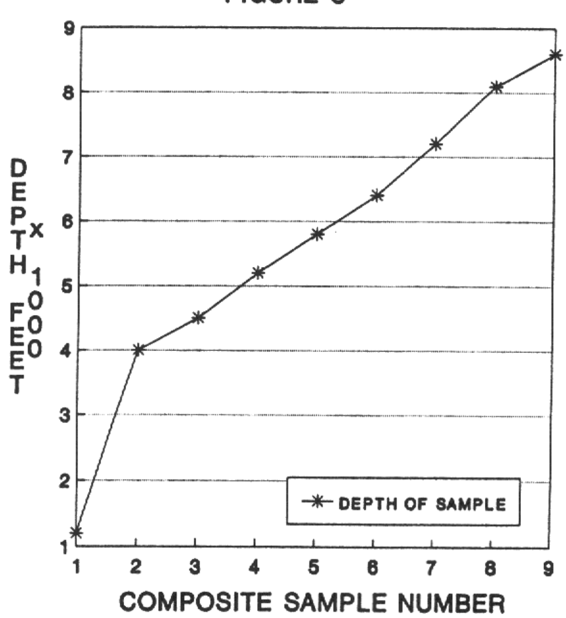
LABORATORY	ROCK TYPE	SB 1	SB 2
GEOCHRON USA	HORNBLENDE	64.5MY	
BRUSSELS UNIV.	WHOLE ROCK	37.3MY	
" "	FELDSPATH		34.4MY
ROBERTSON RESEARCH	WHOLE ROCK		38.4MY
" "	WHOLE ROCK		54.3MY

MARGIN OF ERROR 1.4 TO 3.7 MY

BASED ON K-AR DATING METHODS

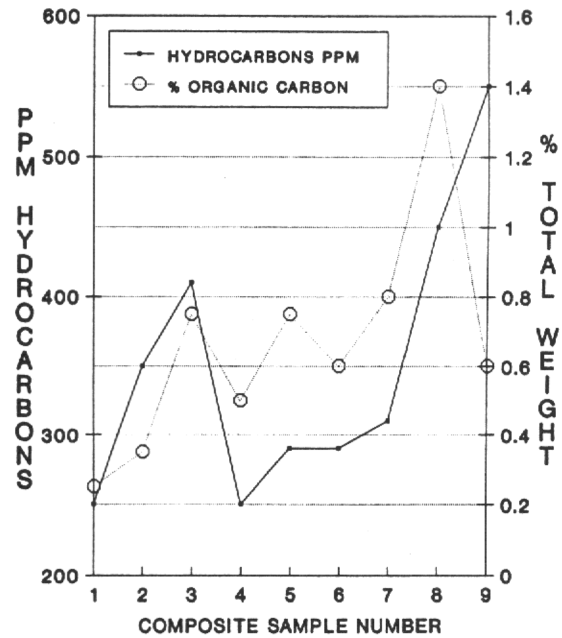
immature source rocks for oil. If similar rocks occur deeper, or if rocks stratigraphically equivalent are more deeply buried elsewhere, they should make excellent source rocks.. (Marathon 1977a) (figures 4 and 5.)

GEOCHEMICAL STUDY OF S.B. NO. 1
FIGURE 3



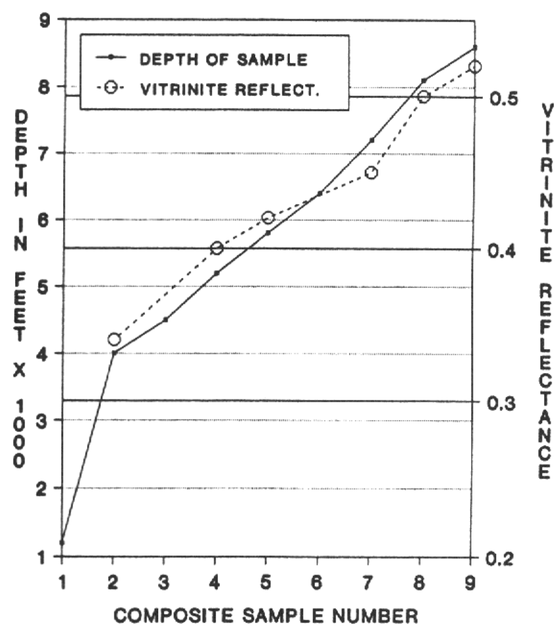
BASED ON MARATHONS DATA

S.B. NO. 1 HYDROCARBONS AND ORGANIC CARBON FIGURE 4.



BASED ON MARATHONS DATA

OIL WINDOW OF S.B. NO. 1
FIGURE 5



BASED ON MARATHONS DATA

Petrofina's S.B. No. 2 Data

Petrofina S.A. contracted Robertson Research U.S. Inc. to conduct the various analyses on the S.B. No. 2 samples. Twelve core samples from 3,422.3 m. (11,190.9 ft.) to 3,795.6 m. (12,411.6 ft.) were analyzed to determine total organic carbon content and vitrinite reflectance. (figure 6.)
Robertson Research concluded that:

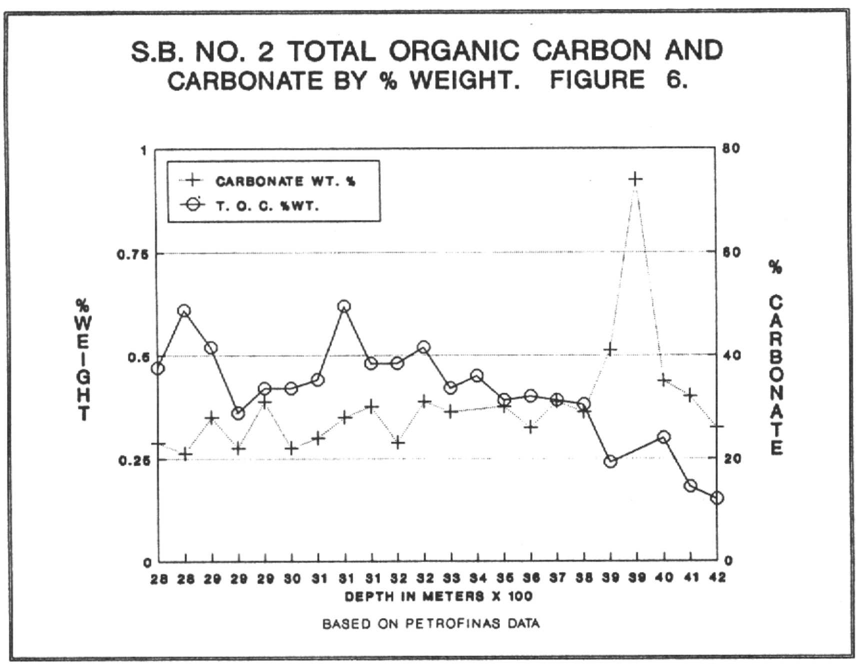
> Geochemical data on representative samples from two cored intervals in the S.B. - 2 well reveal only limited quantity of low yield, gas-generating organic matter is present and the sampled interval, therefore, has very little capacity to generate hydrocarbons. Sufficient burial and thermal maturation for oil generation does exist but the samples are only in the early stages of gas generation.

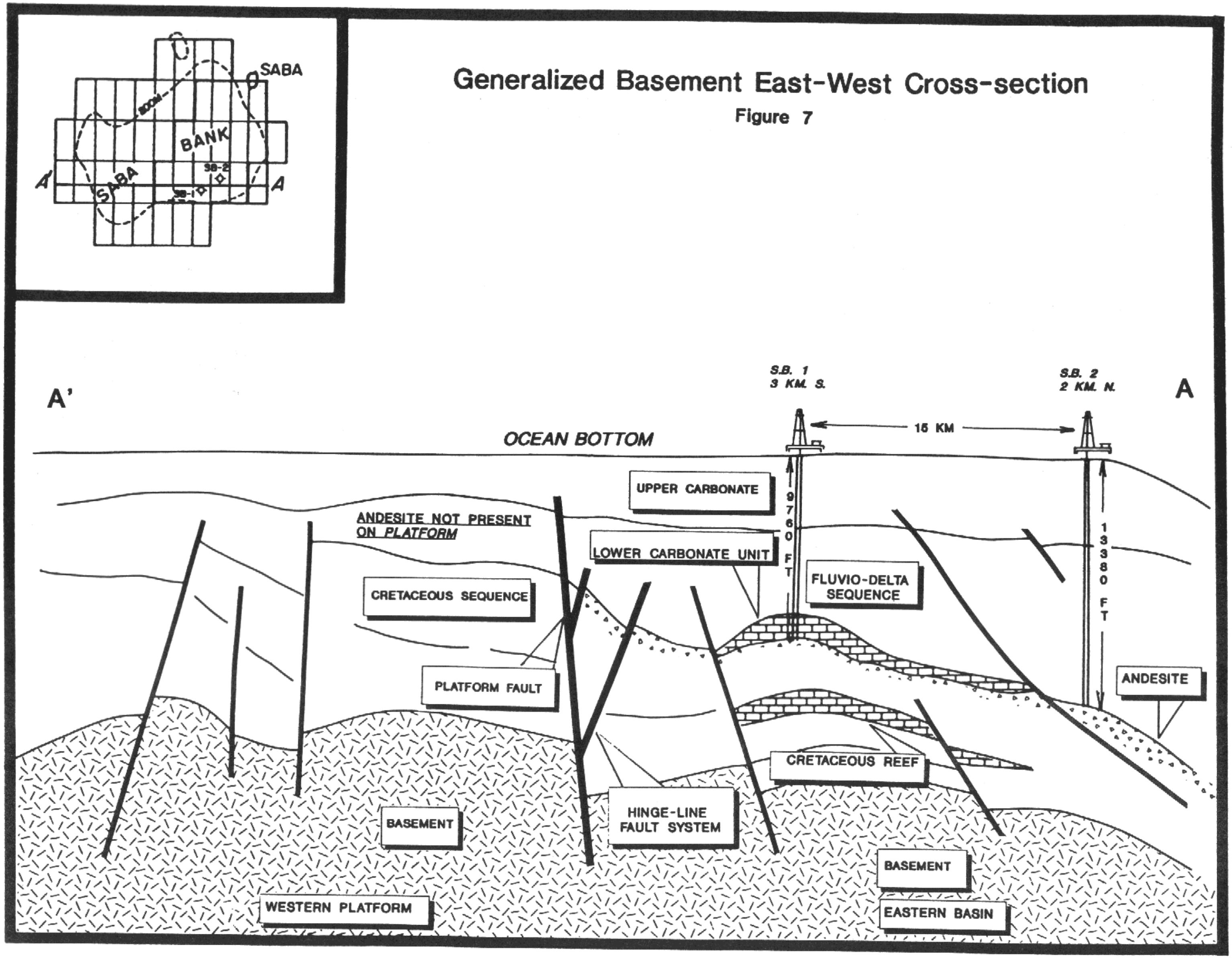
PREANDESITE FORMATIONS

The thesis that there exists pre-Eocene sedimentary rock units rests heavily upon three major facts: (1) the Cretaceous clastic rock samples recovered from the two Saba Bank wells; (2) the deep sedimentary basin beneath Saba Bank revealed by the airborne and surface magnetic; and (3) seismic data which includes an abundant amount of slower velocity seismic reflections that exist below the 64 my andesite (Daly 1983). (figure 7.)

In both the S.B. No. 1 and S.B. No. 2 reworked Cretaceous rocks were found. The samples contained reworked calcareous nannofossils. The nannofossils found in S.B. No. 2 were in the central sedimentary section from 1770 - 1930m (5805 -6330ft) and 2860 - 3994m (9380 -13100ft). (Robertson Research 1982) Marathon in their reports on the S.B. No. 1 discuss the calcareous nannofossils but, like Robertson Research, fail to give a listing of the individual species present. A sidewall core in S.B. No. 1 taken at 1679m (5507ft) contained a very large amount of organic matter including much fungal material, pieces of light brown cuticle, fusinite and wood. (Daly 1989) Joe Guennel of Marathon described the material as " ...Mesozoic in age and I suspect that they are associated with the coaly material, especially the fungal remains. A Cretaceous coal or lignite may thus be one of the sources for some to the allochthonous organic material in this sample". (Marathon 1977b)

A sample in the S.B. No. 2 well at 3,920 m. (10,758 ft.) was dated using K/AR at 90.2 my (Fina 1982a). This date was acquired from what appears to be reworked Cretaceous volcanics. Petrofina failed to give a good description of this sample so its exact composition is unknown. There is no definite





Generalized Basement East-West Cross-section

Figure 7

proof that older sediments exist, but my interpretation of the data infers the existence of an older sedimentary section. Figure 7 is a reconstruction of the sedimentary sequence underlying the Saba Bank based on seismic information and results from the S.B. No. 1 and S.B. No. 2. Both Saba Bank No. 1 and 2 penetrated into the Eocene age Andesite. The magnetic and gravity data suggests volcanic basement at approximately 17,000 ft and 23,000 ft under the Saba Bank No. 1 and 2 respectively. In the Saba Bank area seismic data strongly suggest the presence of a thick pre-Tertiary sedimentary section. The reworked Cretaceous found rocks in the Tertiary sediments on Saba Bank show that the Bank may have been attached or adjacent to St. Croix during Mid to Late Cretaceous (Speed 1974). If this is the case, then the proposed Cretaceous section underlying the andesite at Saba Bank would be similar to that found exposed at St. Croix. Lidz (1988) describes the St. Croix Cretaceous section as follows: " Strongly folded Upper Cretaceous deep water (oceanic) calcareous turbidites and volcaniclastics (>10.6 km. thick; 34,700 ft.)..."

Recent evidence suggests that rocks on St. Croix represent 5 to 7 Cretaceous nappes such that only a structural thickness can be estimated (Speed, 1989; Speed and Joyce, 1989). The Cretaceous layered rocks on St. Croix are mostly volcanogenic strata that accumulated probably at deep-marine sites (Speed, 1989; Speed and Joyce, 1989). Essentially, all of the exposed Cretaceous section on St. Croix has experienced low grade regional and contact metamorphism and would therefore be considered unfavorable for hydrocarbon production. If this is correct, then relating the Saba Bank to the Greater Antilles rules out any hydrocarbon potential in the older Saba Bank sediments. However, if the Saba Bank region is related to the present Lesser Antilles volcanic arc, then the sediments expected in the area would be no older than the Mid Miocene to Oligocene and be primarily volcanic or volcano clastic in origin (Malfait and Dinkelman, 1972; Tomblin, 1975).

Offshore St. Croix along the base of the north insular slope, dives by the Alvin have revealed a thick sedimentary section that might contain some of the oldest exposed sedimentary formations of the Caribbean Region. Lidz (1988) reported that:

> . . . Alvin dives about East End Range showed sedimentary rocks 3.7 km. (12,000 ft.) below sea level dipping gently (10^{o}-20^{o}) westward under the Cretaceous strata. Although not sampled, these sandstones and conglomerate beds indicate a thick sedimentary section under the island. Seismic reflection data collected on the Frederickstedt plateau at the west end of the island and cooperative dives in the DSRV Aluminaut revealed that the plateau is formed by synclinal valley-fill sequence underlain by unknown thickness of stratified, moderately deformed sedimentary and metasedimentary rocks.

Presence of reworked unmetamorphosed mature organic matter (coal fragments?) and calcareous nannofossils of Cretaceous Age, found in the S.B. 1 and S.B. 2 wells, tends to prove the proximity of a Cretaceous section which has not undergone the metamorphism seen in surface exposures on St. Croix. This also suggests that Cretaceous rocks of Saba Bank were not deposited in the same environment as the exposed Cretaceous section on St. Croix.

It is, therefore, incorrect to generalize the idea of an Early Cretaceous economic basement throughout the region. If the above is the case, the Saba Bank being genetically related to the St Croix region would not preclude hydrocarbon production.

STRATIGRAPHIC RECONSTRUCTION

The Platform Fault (figure 7.) appears to have been first activated during the Middle to Upper Cretaceous when the western platform area was uplifted with the eastern Saba Bank slowly subsiding. The eastern area remained at or near sea level long enough to allow for the Cretaceous reef under the Saba Bank No. 1 to grow. (figure 8.) The eastern area continued to drop relative to sea level creating a basin that was receiving sedimentary influx from the uplifted Cretaceous Platform.

Around Mid to Late Paleocene the andesite that was encountered in the two wells was emplaced. The andesite was either a surface flow or a near surface volcanic feeder system emplaced along the platform

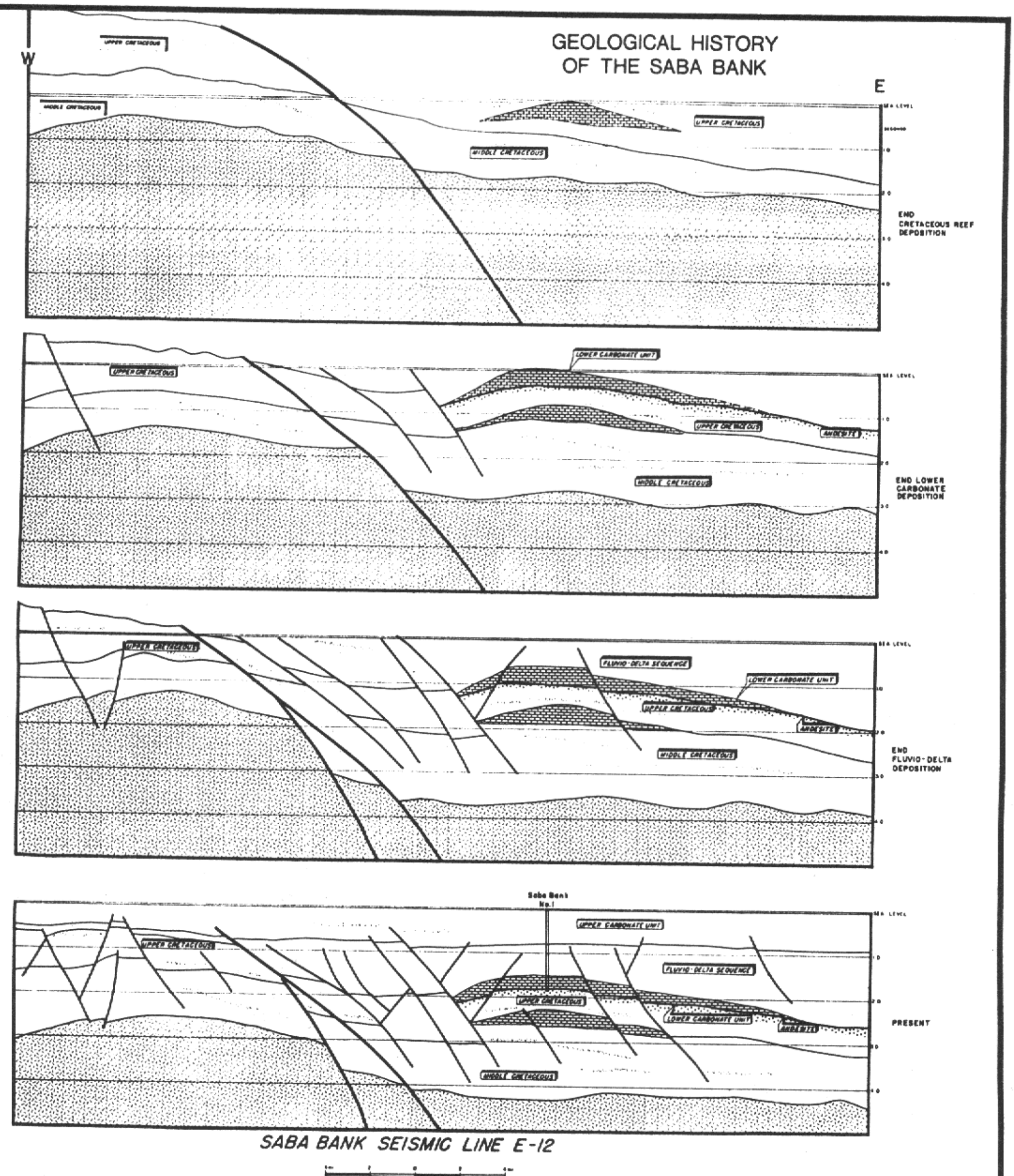


Figure 8.

fault system. The andesite is probably evidence of the final volcanic activity from the Aves Ridge (Pinet, 1985). Neither Marathon nor Petrofina made any comment about finding reworked andesite in the sedimentary sections of the two wells but diagenesis may have destroyed the evidence. In both wells there is no indication of thermal alteration to the sediments overlying the andesite, suggesting that the sedimentary section overlying the andesite was removed before the deposition of the carbonate, or the andesite was a surface extrusion that cooled quickly prior to the western area submerging. As the eastern basin was filling, post andesite emplacement, the basin became shallow enough to allow for the reefal buildup that was tested in S.B. No. 1. This reef continued to build until Late Eocene. The reef created an effective dam stopping what sediments were being eroded from reaching the deep basin found in the S.B. No. 2.

The area north and west of the Platform Fault was a positive during Late Eocene time with the present hinge-line being the shoreline. Carbonates were building in the shallow marine zone east of the hinge-line fault. The slope was narrow with the sea floor plunging rapidly to the east creating the basinal area tested by S.B. No. 2. Sediments found in the S.B. No. 2 are younger than the Lower

Carbonate, suggesting a period of nondeposition during Late Eocene in the deeper basinal areas. The above suggests that the Western Platform area did not have great relief and was not subject to extensive erosion during Late Eocene.

During Oligocene to Middle Miocene time, the Platform Fault was reactivated with the Western Platform being uplifted and the eastern area subsiding rapidly. Seismic data shows progradation from the platform to the east and southeast. In the S.B. No. 1 area, an increase in sandstone and conglomerate deposition is seen where claystones were reported to have been deposited at the S.B. No. 2. This suggests that S.B. No. 1 is closer to the depositional source i.e., the platform.

During the Middle to Late Miocene, the whole Saba Bank area was peneplained preceding the deposition of the Upper Carbonate. This was probably caused by a general uplift of the whole bank area with the eroded sediments being deposited off the bank into the deeper basinal areas. This general uplift may have been brought about by the changes that took place along the Outer Island Arc at this time. During the Middle Miocene to Early Oligocene the outer arc became an inactive volcanic arc and the Inner Island Arc became the active Volcanic Arc.

1988 SEISMIC DATA

Approximate Cretaceous Tertiary Boundary

The Approximate Cretaceous Tertiary Boundary Horizon varies in depth below sea level from 2,850 milliseconds on the downthrown side of the Platform hinge-line to 600 milliseconds on the upthrown side of the Platform hinge-line. The horizon appears to represent seismic anomalies relative to the sedimentary hiatus between Tertiary sediments and the underlying Cretaceous sediments (figure 9).

Site 146 of leg 15 of the D.S.D.P., in the central Caribbean Basin proved the existence of a Late Cretaceous sea level low stand, thus allowing Late Cretaceous carbonate buildups to be generated (Edgar, 1973). At the S. B. No. 1 site, line E-12 shows one such Cretaceous reefal buildup.

One of the questions from previous seismic work was: Did the andesite cover the platform area and if so, does the Approximate Cretaceous Tertiary Boundary Event represent the andesite seismically on the platform? The lack of reworked andesite in the sediments overlying the basal carbonate buildup under S. B. No. 1 suggests that the andesite was not present on the uplifted platform, and if the andesite was emplaced on the platform, all sedimentary evidence has been destroyed. If the andesite is the Approximate Cretaceous Tertiary Boundary Event on the platform, it would have to be older than the dating indicates. This assumption is made because in the central sedimentary sequence penetrated in the S.B. No. 1, reworked Cretaceous was found; therefore, the source for these sediments must be Cretaceous in age. If the Approximate Cretaceous-Tertiary Boundary Event on the platform is the andesite, it would have to be at least Mid to Late Cretaceous (90 my) not Paleocene-Eocene in age. Between the S.B. No.1 site and the uplifted platform, there is a character change in the reflection of the andesite such that it is no longer traceable as a continuous event. The seismic characteristics go from a high amplitude reflection to a lower frequency event.

Mid Cretaceous Event

The Mid Cretaceous Event Horizon varies in depth from 4.0 seconds below sea level under the S.B. No. 1 location to roughly 1.4 seconds on the platform. This reflection is correlative across the platform, and as interpreted, appears to represent a Mid Cretaceous event. The seismic also suggests an additional section below the horizon. From the reflection characteristics, these events are sedimentary in nature. (figure 10.)

PROSPECTS IDENTIFIED ON THE SABA BANK

The prospects on the Saba Bank can be divided into two groups, the Tertiary Prospects proven by the Saba Bank wells and the Cretaceous prospects indicated by the new seismic and the reworked Cretaceous sediments found in both wells. The Tertiary Prospects are limited to the downthrown eastern basins.

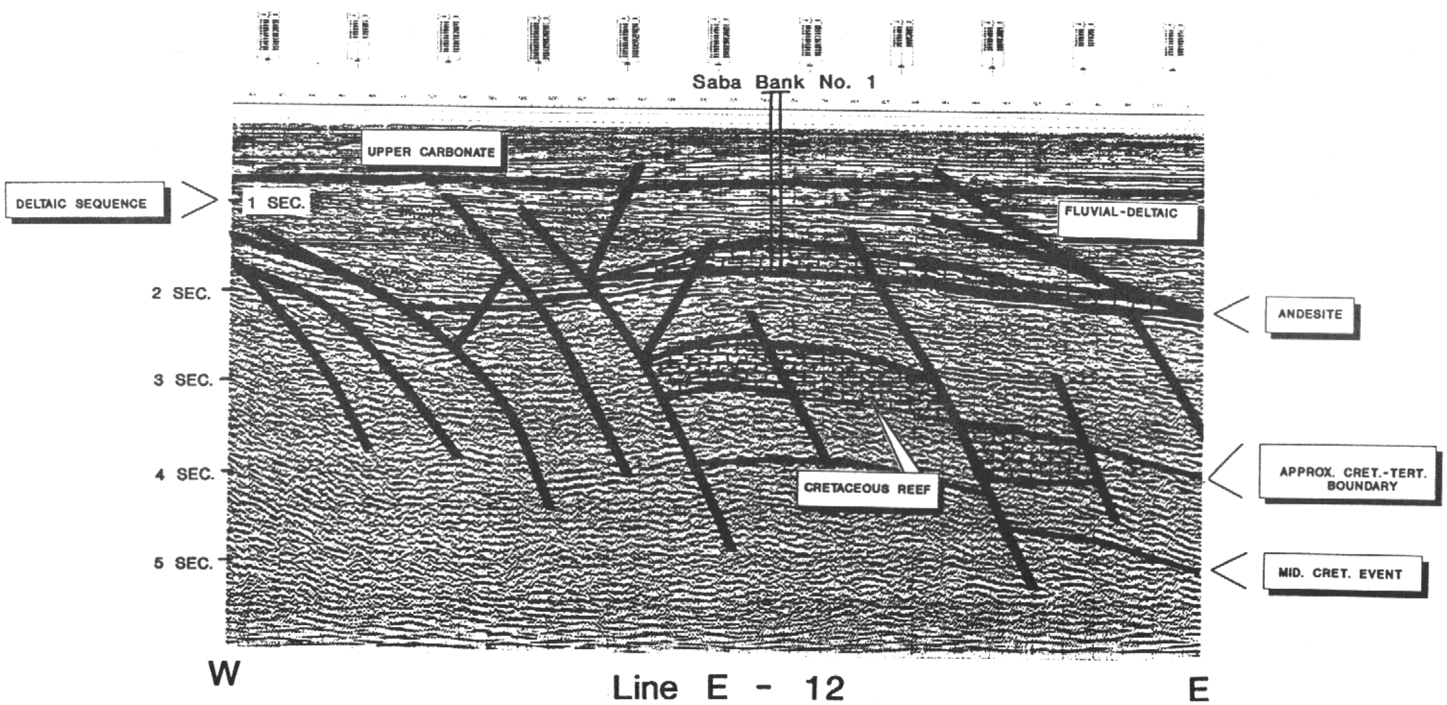
TERTIARY PROSPECTS

Carbonate Buildups

The Saba Bank wells proved that along the platform hinge-line an ancient shelf existed. Carbonate

Drilling Targets on Eastern Saba Bank

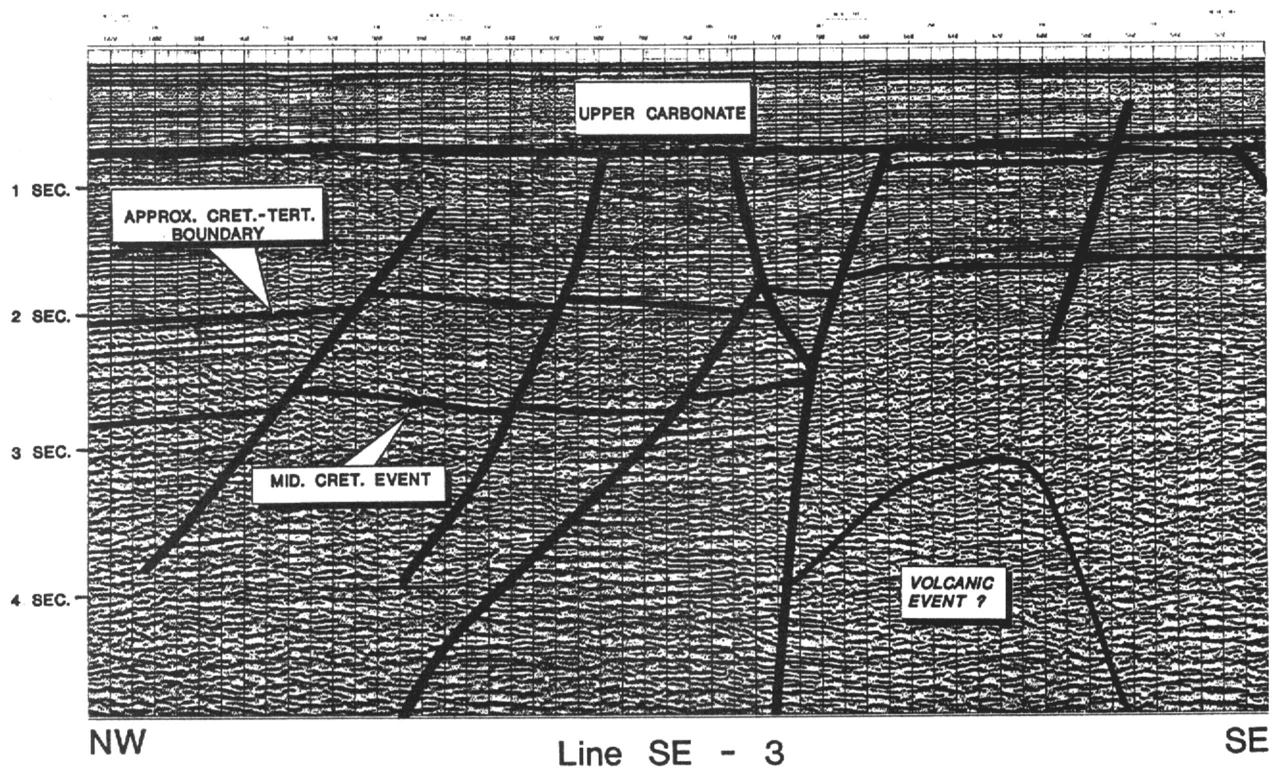
Figure 9.



Line E - 12

Deeper Cretaceous Section on Northwest Platform

FIGURE 10.



Line SE - 3

buildups and associated reef facies have been seismically recognized along this shelf. (Figure 11.) Petrofina described several good drilling targets in the shelf area (Fina 1983). The reservoirs are carbonates similar to that encountered in the Saba Bank No. 1. The fair to good source rocks encountered in the S.B. No. 1 & 2 should be developed within the area of this prospect. The reef drilled under the S.B. No. 1 location showed some asphalt in the basal portion. This unit had TOC values that ranged from 732 to 434 ppm and % organic carbon values of 1.33 to .64% of total weight. The analysis of the carbonate samples showed it to be a good to superior source for oil yet, immature. (Marathon 1977a) The analysis of the depositional history of these prospects indicates that they lie within the oil window. Furthermore, the faulting that is indicated through the andesite will, in some cases, allow migration from the older Cretaceous sediments. The logs from S.B. No. 1 show the basal carbonate contained adequate porosities to be productive but was immature.

Fluvial-Deltaic Sequence

Seismic line E-12 (figure 9.) from shot point 380 to 700 shows a sedimentary basin 2,137 m. (7,000 ft.) deep. The sedimentary sequence of this basin is expected to be deltaic deposits, i.e., sandstone with interbedded shales. The basin can be traced along the ancient shelf line trending north, northeast, and east. In the S.B. No. 1 the central sequence contained several zones of sandstone and fine grained conglomerates that would make good reservoirs, but immature. This sequence is further from the depositional source than the above described delta systems and should be finer grained than the sediments within the systems. These deltaic systems overlie the platform hinge-line fault system, where the seal of the andesite should be broken, thus allowing the migration of hydrocarbons from the underlying Cretaceous sediments.

Turbidite Prospects

Evaluation of the seismic data revealed that the S.B. No. 2 was drilled on a paleo-ridge and due west of the S.B. No. 2 location is a north-south trending trough. Although poor to fair data quality and limited resolution was experienced, reliable seismic mapping of the prospects was achieved. This early paleo-ridge restricted the eastward flow of the turbidite sequences, resulting in north-south trending sand bodies which form stacked bundles of sands and, in consequence, multiple pay targets. S.B. No. 2 was located in a paleogeographic position not favorable for the buildup of clean sand bodies. Therefore, channel margin facies were encountered with poor reservoir characteristics. The S.B. No. 2 well did, however, have good gas indications. In correlating these shows with the proposed turbiditic sequence, an environment favorable for accumulation of hydrocarbons should be developed west of the well. The C_1 to C_5^+ gas component ratios recovered from the well test indicate that the turbidite sand reservoirs will be liquid hydrocarbon bearing.

Cretaceous Plays

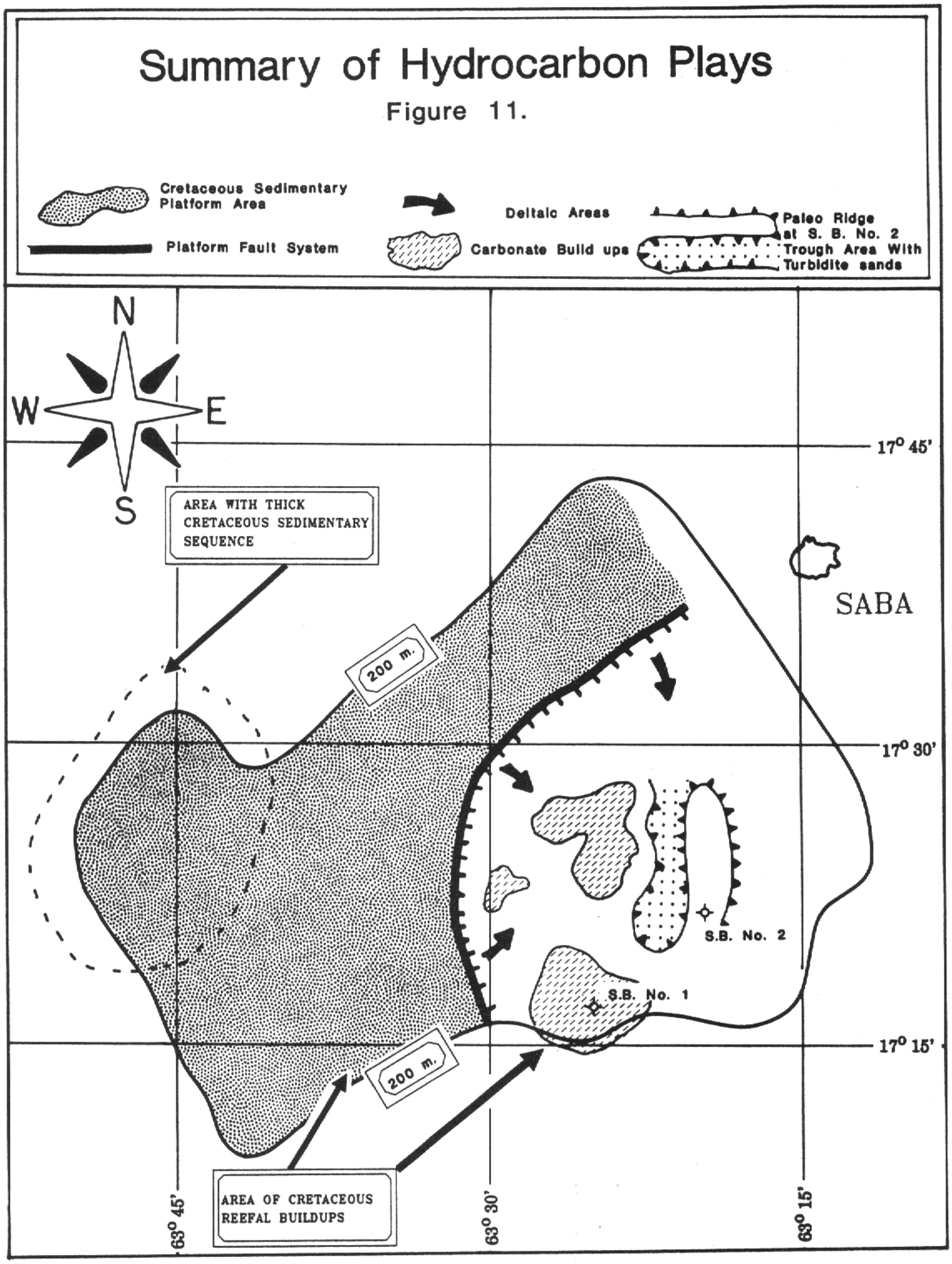
At D.S.D.P. site # 146, in the central Caribbean Basin, is an Upper Cretaceous (90 +/- my.) limestone that varies from reefal to biogenic in nature. This limestone is evidence for a sea level low stand in the Caribbean Basin during this time period. Above the limestones are several bituminous layers with up to 12% total organic carbon. These layers may represent a period of bottom stagnation that was brought about by the lowering of sea level and may be equivalent to the reworked bituminous layers found in the two Saba Bank wells.

Two oil seeps have been reported in Puerto Rico in outcrops of Cretaceous rocks. One consists of drops of oil in calcareous concretions in a shale near Coamo. The other seep consists of oil-impregnated soil in the bottom of Largo No. 1, 8 km. northeast of Ponce. The petroleum apparently comes from the Cretaceous or Eocene rocks beneath the lake.

The seismic survey of the Saba Bank Platform reveals a thick sedimentary section in the Northwestern portion. (figure 11.) The area is either a downdropped block respective to the remainder of the platform, or a piece of the original Cretaceous platform that was not uplifted, but remained stable during the activation of the platform fault system. Regardless of whether the additional section is of Tertiary Age or if the additional section is Cretaceous and is similar to the section that provided sedimentary detritus for the Eastern Bank sediments, good drilling targets should be present.

On the Eastern Saba Bank, the Tertiary sediments proved to be immature for hydrocarbon generation, but both wells proved that good reservoir rock existed. If the andesite acts as an effective seal for the Cretaceous rocks as believed, then where the andesite is not present, i.e., the Platform, the overlying Tertiary sediments should be productive. Reworked Cretaceous detritus, in the sediments, at the two Saba wells suggests that both good source and reservoir rocks exist in the eroded sections. These Cretaceous rocks, when encountered, should be mature for hydrocarbon production as indicated by the migrated hydrocarbons found in both Saba wells. In addition, these Cretaceous sediments would have been within the oil window prior to the uplift of the platform. Both stratigraphic and structural traps are seismically mappable in this thicker sedimentary sequence.

Underlying the andesite at the S.B. No. 1 location, the seismic indicates an additional sedimentary section. Within this section is a thick reefal buildup approximately 4,114 m. (13,475 ft.) below ocean bottom. The seismic reflections indicate an onlapping reefal buildup. The western edge of the buildup appears from the seismic data to have experienced a similar deposition history as the shallower reef. The velocities and the amplitude of the reflectors indicate that the western edge of the buildup is very dense. The upper reef experienced a sedimentary loading which either created conditions of porosity filling or matrix collapse, thereby giving the dense character that the seismic reflections indicate. The S.B. No. 1 well proved that adequate reservoir porosities were present within the penetrated carbonate, but the Tertiary rocks were immature. The lower reefal buildup is within the known oil window, that was 10,000 +/- ft under the S.B. No. 1. Figure 6 shows the location of a Cretaceous age shelf where numerous Cretaceous reefal buildups are suggested by the seismic data. These reefs trend generally east-west beginning in the southwestern Saba Bank and ending under the location of S.B. No. 1. The seismic data suggests that these buildups are considerably larger than the reef found under S.B. No. 1.



Summary of Hydrocarbon Plays

Figure 11.

SUMMARY

The well, seismic, and magnetic data on the Saba Bank all allude to the conclusion that there exists a thick sedimentary section beneath the andesite. The age dating results suggest this section will be younger than Early Eocene and probably as old as Early Cretaceous. The live hydrocarbon shows in Saba Bank No. 2 are from migrating oil that has moved through the zone. The underlying Cretaceous section represents the most logical source for these hydrocarbons. In both Saba Bank No. 1 and Saba Bank No. 2, the oil window was just being entered as total depth was being reached. The Cretaceous section has been buried to a sufficient depth to allow for full maturation of the source rocks. This is based on live oil found in Saba Bank No. 2 that was not in situ but migrated from underlying deposits, i.e., the Cretaceous section. (figure 11.)

The reworked bituminous layers and calcareous nannofossils indicate the Cretaceous rocks should vary from terrestrial to neritic in origin, giving both good reservoir and source rock potential to the section. Evidence suggests that an unmetamorphosed Mid to Late Cretaceous sedimentary section exists beneath the Saba Bank and that the section should not only contain good reservoirs but also the source rocks for the hydrocarbons found in S.B. No. 1 and No. 2

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