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PRELIMINARY INTERPRETATION OF A SEISMIC SECTION FROM THE NORTH END OF SAN SALVADOR, BAHAMAS

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ABSTRACT

A nearly north-south, 100-meter experimental seismic line was run on the north end of San Salvador using an analog seismic-enhancement seismograph. Over a depth of 130m from the surface, eight apparently good reflectors and a few less definite ones were interpreted. Most of these surfaces can be correlated with exposure horizons or major facies changes observed from the Supko core, less that 2.0km to the west.

The apparent geometry of these surfaces suggests beach-ridge complexes. If this interpreation is correct, most surfaces represent maximum beach-ridge development or offlap, followed by a period of sea-level drop, exposure and erosion, and succeded then by a period of sea-level rise and transgression or onlap. The lower six surfaces show a progressive seaward migration of beach-ridge complexes through time except for an apparent transgressive interval represented by the 45-57m surface. Overall these six surfaces suggest a net lowering of sea level and regression. The uppermost of these surfaces, at a depth of 27 to 41m is extremely prominent and apparently represents a major period of sea-level fall, regression and exposure.

Two overlying surfaces suggest beach-ridge migration of approximately 40-60m shoreward of those underlying the prominent surface at 2-41m, suggesting that major sea-level rise and transgression followed the formation of this surface.

Subsequently, however, sea-level rise and transgression apparently resumed, for a reef complex developed just seaward of the last beach-ridge complex and migrated shoreward to a position atop the beach ridge where it is exposed (Mosquito Marsh reef) along our section. What we have described above are net sea-level rise and fall episodes; each may be represented by several interpreted surfaces. Our data are so preliminary that possible time constraints must be viewed with caution. Nonetheless, possible correlations with the magnetostratigraphic dating from the Supko core, suggest that the 27 to 41m surface reflects a major period of late Pliocene sea-level decline. Thus, most of the overlying sediments, as well as five included reflecting surfaces, apparently represent Pleistocene or Holocene events.

INTRODUCTION

Establishing a stratigraphic framework in the Quaternary sediments of San Salvador has been rather difficult because of the plethora of subtidal, intertidal and supratidal facies, the similarity of any respective carbonate facies in the geologic record despite age, and the effects of multiple erosional events during late Tertiary and Quaternary sea-level fluctuations. Marker beds are essentially absent because of the facies mosaics and erosion, whereas the relatively short time spans involved and abrupt marine-to-nonmarine facies transitions prevent the use of fossils for correlation. Moreover, the relative youth of the sediments, the geochemical mobility of carbonate and organic matter in the present climatic and geologic setting, as well as expense, obviate the large-scale use of absolute dating techniques. Although correlation using unconformities has been attempted, in situations where even ephemeral exposure may produce seemingly major unconformities rapidly, such correlations must remain uncertain.

In view of the problems in trying to establish a stratigraphic framework for the island by traditional means, we decided to experiment with the possibility of using seismic stratigraphy. Our short seismic line shows the type of resolution to be expected as well as some of the necessary constraints and some of the possible ways of interpreting the results.

METHODS

We chose the location of the seismic line

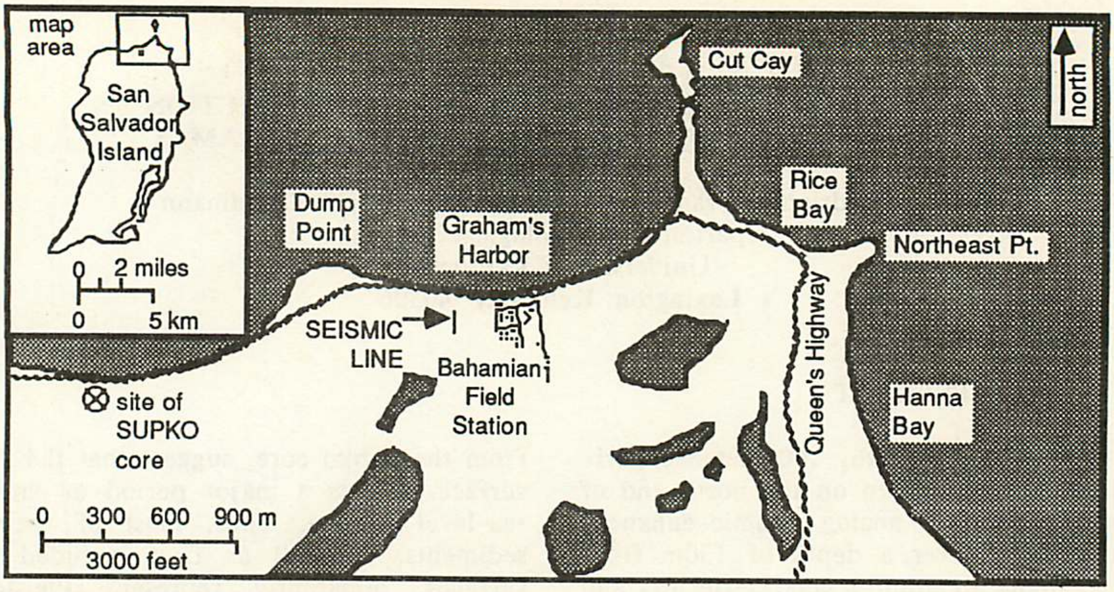

Fig. 1. Location map showing the position of the seismic line relative to the site of the Supko core.

(Fig. 1) to satisfy three criteria: 1) it was close to a core hole (Supko, 1970, 1977) where correlation with known lithologies and surfaces might be possible (Fig. 2); 2) it was in a near-shore area where beach-ridge facies were likely to predominate; and 3) it crossed the outcrop of a unique lithofacies, in this case, a Pleistocene patch reef (Mosquito Marsh reef; see Vierma et al., 1984).

The experimental seismic reflection line was 100m long and oriented N5°W; it is located approximately 250m west of the CCFL Field Station (Fig. 1). Reflections were recorded analogically on an OYO-NIMBUS 1220 seismic signal enhancement seismograph at a rate of 10,000 points per second. Single vertical geophones with a 14 Hz natural frequency were spaced at 10m intervals along the line. Five shots, at geophones 1,4,6,8, and 11, were set off separately in order to stack data using common depth points. The reflections were recorded analogically on light-sensitive Lynagraph paper as shown in Fig. 3. The seismograms obtained were analyzed for reflection arrivals from each geophone for each shot and by plotting the square of the arrival times (t^2 in msec **2). The best straight-line fit of the resulting data points indicates the different reflectors and their slope, as well as the RMS velocity for layers above the reflector. Fig. 4 shows an example of the analysis. The reflection times selected in this way were used to transform the two-way vertical reflections (TWVR) below each geophone by correcting for normal move out and migration. Initial statics corrections were made using refraction velocities from the overlying layers. The TWVR were used to produce the seismic section shown in Fig. 5. The resulting seismic section was tested by comparison with nearby exposures and with a nearby core in order to check for correspondence between reflectors and major geological discontinuities.

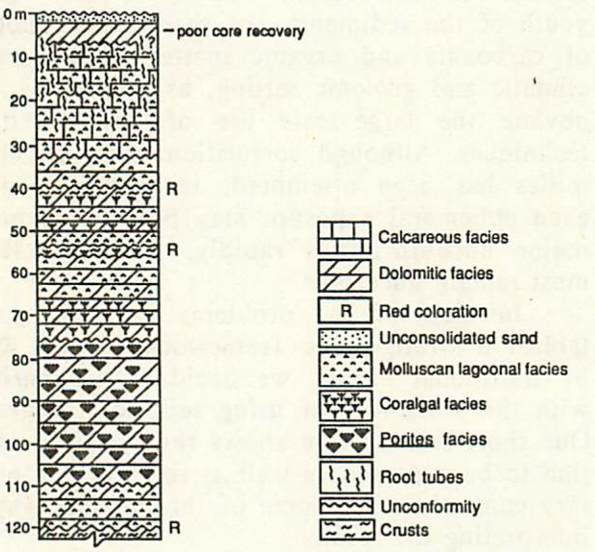

Fig. 2. Schematic stratigraphic column from the Supko core showing the vertical distribution of major facies, sedimentary features and unconformities.

BASES FOR INTERPRETATION

Based on correlations with the Supko core

BAHAMAS RETRACED ORIGINAL RECORDS

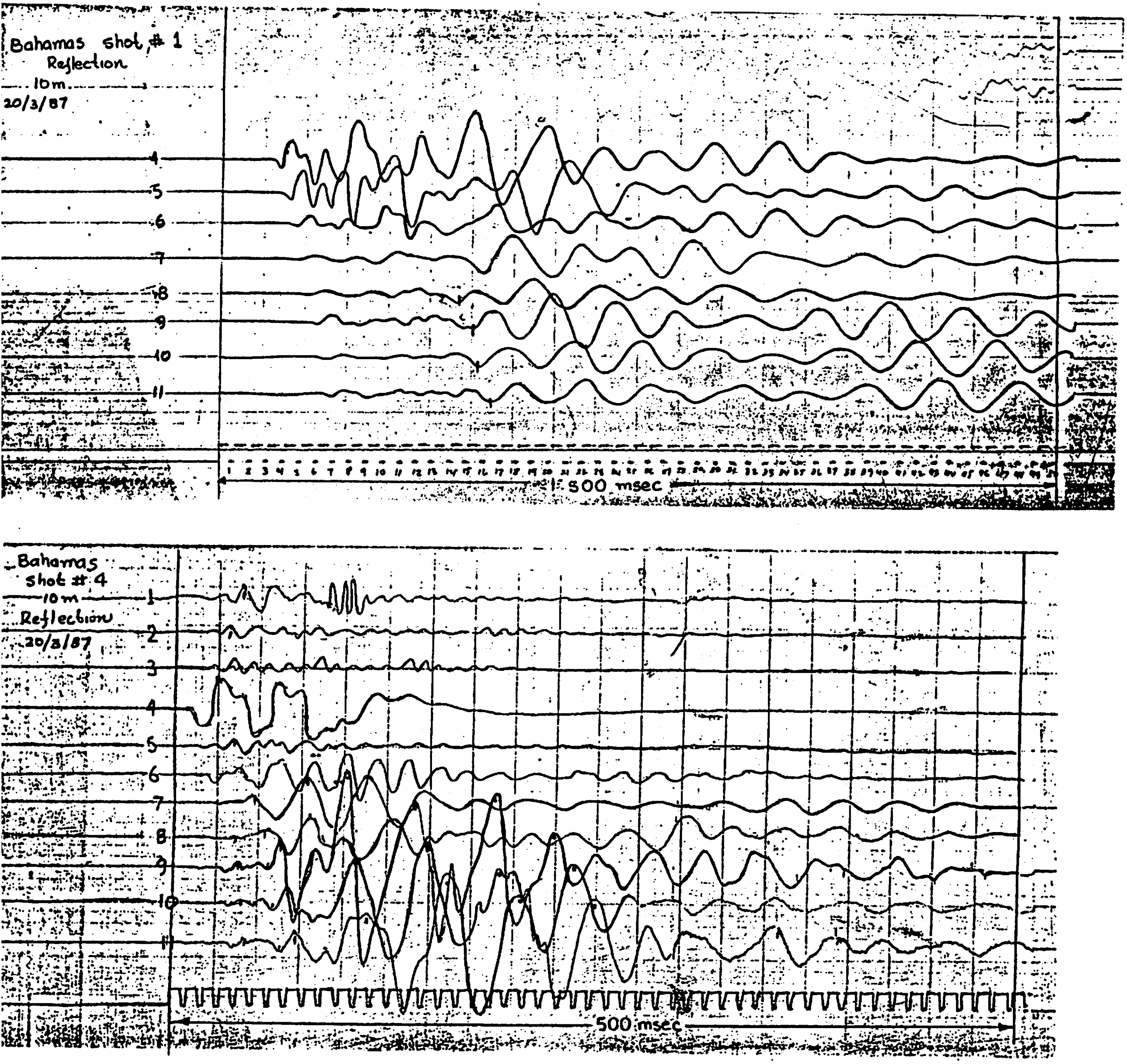

Fig. 3. Examples of two retraced analog seismographs recorded on light-sensitive Lynagraph paper. Individual peaks and troughs were picked and x^2 vs t^2 analysis performed to detect all possible reflectors.

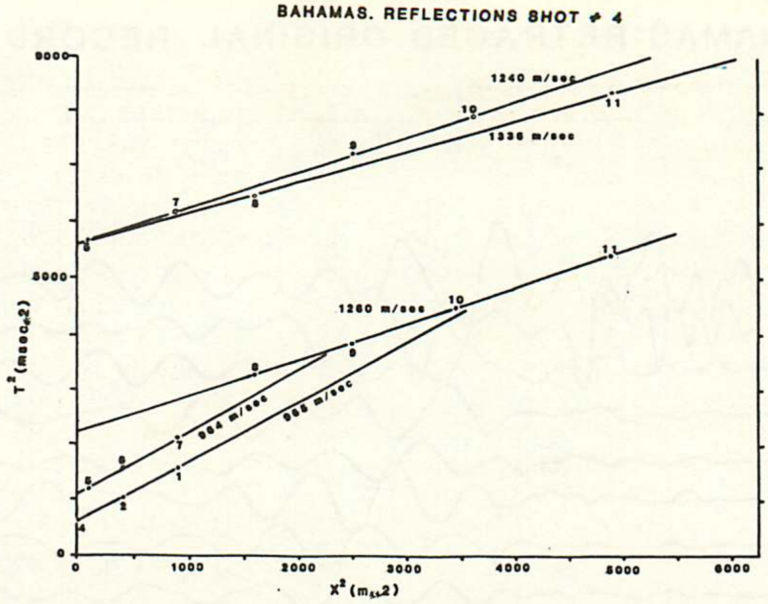

Fig. 4. Example of the straight-line fits resulting from shot #4, showing reflectors, their slopes, and RMS velocities.

(Supko, 1970) (Fig. 2), most of the reflection surfaces shown in Fig. 5 represent discontinuities or unconformities. The surfaces apparently contrast with adjacent lithologies because of thin, but dense, accumulations of micritic, pedogenic carbonates (see Brown, 1984, Hale and Ettensohn, 1984). Each such surface apparently represents regression of seas and exposure, followed at a later time by transgression. In a few other instances, however, the reflections are not so much related to indurated erosion surfaces as they are to contrasting lithosomes. The best example of this is the contrast between the Pleistocene patch reef and the encompassing

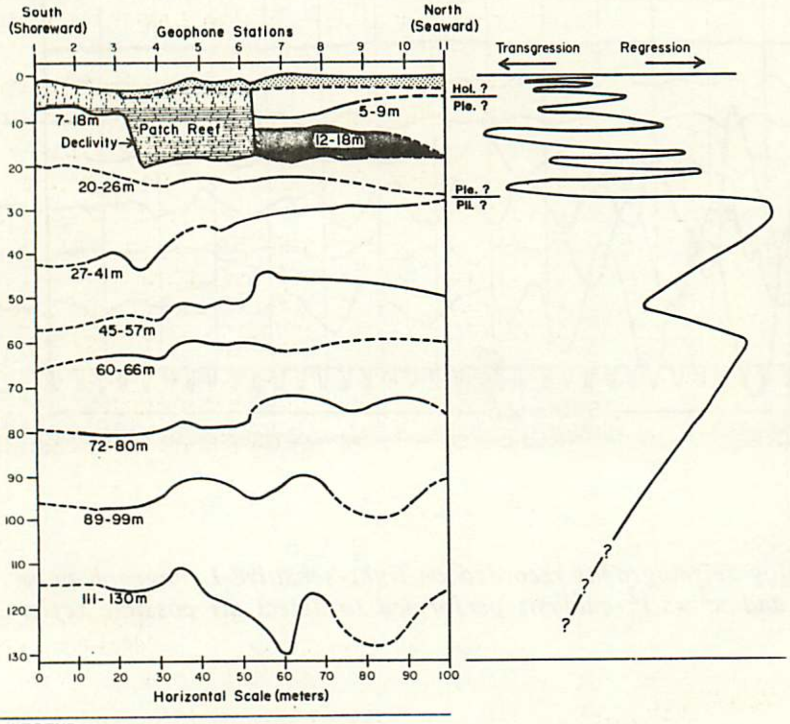

Fig. 5. Seismic section showing major reflectors to a depth of 130m. Curve on the right is interpreted and shows the probable sequence of transgressions and regressions based on coastal onlap and offlap indicated by surface profiles. Parts of the curve below the probable Pliocene-Pleistocene boundary are highly generalized and do not show smaller transgressions or regressions associated with individual surfaces. Numbers below each surface reflect the depth in meters below the surface for each reflector. Hol.=Holocene; Ple.=Pleistocene; and Pli.=Pliocene.

sediments from various beach-ridge complexes. Fortunately, the reef was exposed so that its origin was easily determined (Fig. 5).

Aside from correlating surfaces in the section with surfaces in the nearby core (Fig. 2), interpretations of net sea-level rise and fall were based on the geometry, or shape and slope of the individual surfaces and on the assumption that shoreward-or seaward-dipping parts of successive surfaces reflect parts of a beach-ridge profile (Fig. 6) which shifted either shoreward or sea ward with time. What we are effectively examining in the relative positions of seaward-versus-shoreward parts of the surfaces, are patterns of coastal onlap and offlap, or transgression and regression respectively. Although each surface apparently represents a regressive-transgressive event, a net seaward shift of successive surfaces is assumed to indicate a larger period of overall regression or sea-level fall; an apparent shoreward shift of successive surfaces, in contrast is taken to represent a period of net transgression and sea-level rise. The interpreted pattern of transgression and regression suggested by the apparent migration of the surfaces is shown on the right of Fig. 5. Of course, in light of late Tertiary and Quaternary glaciation, we have assumed that transgressions and regressions are products of glacio-eustatic sea-level rises and falls respectively, but subsidence and uplift could have produced similar results.

SURFACE INTERPRETATION

The deepest reflector observed on our seismic line was an irregular surface occurring at 111-130m. This is probably the same surface noted by Supko (1970) at about 121m (397 ft). Supko indicated that the surface was an unconformity characterized by aphanitic, reddish crusts. The dense, aphanitic crusts apparently indicate pedogenic calcretes or subaerial exposure crusts formed during a time of exposure. Up to 19m of relief is present on this surface in our section, and at least three isolated ridges are apparent (Fig. 5) suggesting extensive erosion of accreted beach ridges or accretion of beach ridges during a series of sea-level drops.

The surface at 89-99m apparently is not represented in the Supko core unless it is equivalent to the unconformity at 110m (Fig. 2). The same depth interval in the Supko core is represented by a shallow subtidal *Porites* facies present throughout an interval over 30m thick. The predominance of this facies over that vertcal distance must indicate that at this time the area of the Supko core was seaward of any beach-ridge complex. In contrast, the surface at 72-80m suggests a seaward shift of the beach-ridge facies and is represented by a possible hiatus and an abrupt change from shallow subtidal to coralgal lagoonal facies in the Supko core. The hiatus, and the change to a more restricted, shallow-water facies may reflect the same regressive event indicated by the apprent seaward shift of beach-ridge facies in the section.

The surface at 60-66m is a very poorly defined reflector. The shoreward dip and low relief on the surface suggest a back-beach-ridge setting and that regression has moved the beach farther seaward beyond the seismic section. No equivalent surface is present in the Supko core, but the interval in the core is represented by a change from a coralgal lagoonal facies to an even more restricted, and possibly shallower, mollusc-algae-dominated lagoonal facies.

The geometry of the overlying 45-57m surface indicates that the surface was the product of a period of transgression, because a seaward-dipping, shoreface-foreshore surface appears to be present (Fig. 5). The same interval in the Supko core is represented by a change to a slightly deeper water facies (molluscan to coralgal), which is truncated by an apparent unconformity with reddish subaerial exposure crusts (Fig. 2). The sequence of events reflected in the core is essentially the same as indicated by the succession of surfaces in the seismic line at this

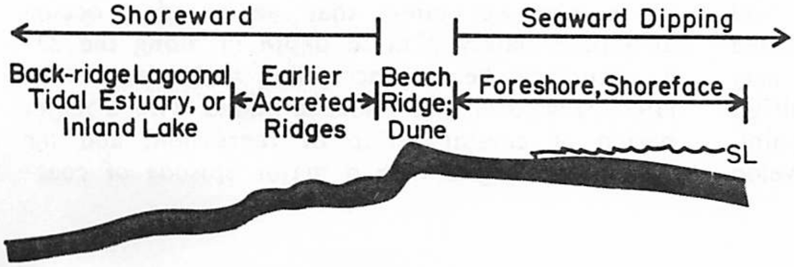

Fig. 6. Generalized beach-ridge profile based on the surface at 45-57m in Figure 5 used to interpret onlap versus offlap relations for successive surfaces. SL=sea-level.

point.

The reflecting surface at 27-41m is one of the most prominent along the line, and its shoreward dip suggests the back side of the beach-ridge complex. If this is the case, then the beach ridge and more marine shoreface environments were much farther seaward compared to the underlying surface, indicating that the 27-41m surface was the product of regression or major sea-level fall. The same vertical interval in the Supko core is very complex. The upper 8m (26-34m) of this core interval exhibits extensive soil features, breccias, and solution pipes and represents a major period of exposure. The middle 6m (34-40m) consists of restrictive lagoonal, intertidal and supratidal facies unconformably overlying a thin, reddish crust zone. Although the core indicates that this regression was somewhat more complicated that the single reflecting surface would suggest, both lines of evidence indicate that this was a major episode of sea-level fall.

The shape and profile position of two overlying seaward-dipping surfaces (20-26m and 7-18m) suggest that subsequent beach ridges migrated 40 to 60m shoreward of their probable position on the 27-41m surface, indicating net sea-level rise and transgression. The lower 20-26m surface is probably represented by an unconformity and soil zone at 18m (60ft.) in the Supko core (Fig. 2). The upper surface (7-18m) exhibits a prominent seaward facing declivity near the southern end of the seismic line (Fig. 5) and seems to reflect seaward progradation of a beach ridge, and hence sea-level fall compared to the underlying surface. However, the declivity and the relatively level seaward part of the surface (at 18m) suggests wave erosion and formation of a wave-cut bench during a succeeding period of sea-level rise and transgression. The modification of this surface by later transgression and erosion makes it difficult to relate this surface to one in the Supko core; the unconformity at 7m (22ft.) in the core (Fig. 2) is a possible equivalent.

The occurrence of sea-level rise at this time is also supported by the presence of a patch reef in front of the declivity (Fig. 5). Although the reef is exposed at the southern end of the seismic line (Fig. 5), its presence seaward of the declivity is indicated by geometry and seismic velocities identical to those for exposed parts of the reef. The apparent declivity may have been part of an older beach ridge modified by wave erosion into a promontory or point, inasmuch as patch reefs will preferentially develop just seaward of such points because wave energy is concentrated here. Nonetheless, as sea-level rise continued, the reef apparently migrated shoreward to a position atop the beach ridge where it is exposed (Mosquito Marsh reef, Vierma et al., 1984) along our section.

The remaining two surfaces (12-18m and 5-9m) are present only seaward of the patch reef and are rather poorly developed. If these are unconformities, the fact that they apparently do not extend into the reef suggests that they developed after reef formation. The 12-18m surface probably developed atop a package of subtidal sediment that was deposited simultaneously with reef formation. Because both surfaces are lower than the top of the reef, reef formation must have been succeeded by a period of sea-level fall of at least 9m, the vertical distance to the lower of the two surfaces. The two surfaces then may represnt periods of sea-level fall and subaerial exposure during Pleistocene sea-level fluctuations. The upper 5-9m surface is at approximately the same elevation as is the unconformity in the "Dump", Barkers Point and Rocky Point. If this is the same unconformity, the 2-6m of limestone above the surface may be the same as what has been called the "Grahams Harbour Formation" (Titus, 1980, 1981, 1983, 1984) or the Rice Bay Formation (Carew and Mylroie, 1985).

One to three meters of unconsolidated carbonate sands veneer these rocks along most of the seismic line and at the Supko core site.

AGE

No reasonable way exists to develop time constraints for the rocks along the seismic line from our data alone. However, possible correlations with the magnetostratigraphic dating from the Supko core (McNeill et al., 1988) suggest that the Pliocene-Pleistocene boundary interval can be approximated. Magnetostratigraphic dating of the Supko core indicates that this boundary occurs at a depth of approximately 25m. If any kind of elevational equivalence is present between the Supko core and our seismic line, then the Pliocene-Pleistocene boundary interval should occur near 25m in depth. More specifically, in our section we believe that the boundary occurs at approximately 27m in depth or along the 27-41m surface, because according to Harland et al. (1982, Fig. 5.1), the Pliocene ended with a major period of coastal offlap or regression, and the Pleistocene began with a major episode of coastal onlap or transgression, which is precisely what the surface at 27-41m on our seismic line indicates. Hence, we believe that the partial coincidence of elevations, as well as the fact that this surface apparently corresponds to a major period of sea-level fall or regression, approximately locates the Pliocene-Pleistocene boundary on our line. Moreover, in the presence of many transgressive-regressive fluctuations above the Pliocene-Pleistocene boundary and in the general transgression or onlapping apparent in the curve below the boundary, our transgressive-regressive curve (Fig. 5) is very similar to the sea-level curves or Harland et al. (1982, Fig. 5.1). If this is the case, then all rocks lower than the 27-41m surface are probably Pliocene in age. McNeill et al. (1988) only reported on rocks to a depth of 90m in the Supko core, but by this depth they were already well into the Lower Pliocene rocks.

As for other ages, Vierma et al. (1984) attributed the patch reef along our line to a Sangamonian high stand of sea level based on amino-acid racemization analysis. Furthermore, if the surface at 5-9m is the same as the unconformity at many of the nearby points (Dump, Barkers and Rocky points), then it may well represent the Pleistocene-Holocene boundary as suggested by Titus (1984) and Carew and Mylroie (1985).

CONCLUSIONS

The present study suggests that it is possible to determine the presence and configuration of reflecting surfaces in late Tertiary and Quaternary carbonates on San Salvador using very simple seismic reflection techniques. The presence of nearby exposure or cores, however, is essential in interpreting such a seismic line. If it is assumed that the configuration of the surfaces approximates some part of the depositional profile of a beach-ridge complex, then it is possible to delimit episodes of coastal onlap and offlap, or transgression and regression respectively, by observing the seaward or shoreward migration of various parts of the surfaces, even on short seismic lines like ours.

Where some surface control is present, these techniques and assumptions may be useful in explicating some of the stratigraphic complexities on San Salvador.

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REFERENCES CITED

Brown, T.W., 1984, Formation and development of caliche profiles in eolian deposits: San Salvador, the Bahamas, in Teeter, J.W. (ed.), Proceedings of the Second Symposium on the Geology of the Bahamas, CCFL Bahamian Field Station, p. 245-264.

Carew, J.L., and Mylroie, J.E., 1985, The Pleistocene and Holocene Stratigraphy of San Salvador Island, Bahamas, with reference to marine and terrestrial lithofacies at French Bay, in Curran, H.A. (ed.), Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas-Guidebook for Geological Society of America, Orlando Annual Meeting Field Trip: Ft. Lauderdale, Florida, CCFL Bahamian Field Station, p. 11-61.

Hale, A.P., and Ettensohn, F.R., 1984, Micromorphological features observed in pedogenic carbonates (caliche) on San Salvador Island, Bahamas, in Teeter, J.W., (ed.), Proceedings of the Second Symposium on the Geology of the Bahamas, CCFL Bahamian Field Station, p. 265-277.

Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, A.G., and Walters, R., 1982, A geologic time scale: Cambridge, Cambridge University Press, 131 p.

NcNiell, D.F., Ginsburg, R.N., Chang, S.B.R., and Kirkschvink, J.L., 1988, Magnetostratigraphic dating of shallow-water carbonates from San Salvador, Bahamas: Geology, v. 16, p. 8-12.

Supko, P.R., 1970, Depositional and diagenetic features in subsurface Bahamian rocks (Ph.D. dissertation): Coral Gables, The University of Miami, 168 p.

Supko, P.R., 1977, Subsurface dolomites, San

Salvador, Bahamas: Journal of Sedimentary Petrology, v. 47, p. 1063-1077.

Titus, R., 1980, Emergent facies patterns on San Salvador Island, Bahamas, in Gerace, D.T. (ed.) Field guide to the geology of San Salvador (First Edition): CCFL Bahamian Field Station, p. 92-105.

Titus, R., 1981, Emergent facies patterns on San Salvador Island, Bahamas, in Gerace, D.T. (ed.) Field guide to the geology of San Salvador (Second Edition): CCFL Bahamian Field Station, p. 92-105.

Titus, R., 1983, Emergent facies patterns on San Salvador Island, Bahamas, in Gerace, D.T. (ed.) Field guide to the geology of San Salvador (Third Edition): CCFL Bahamian Field Station, p. 97-116.

Titus, R. 1984, Physical Stratigraphy of San Salvador Island, Bahamas, in Teeter, J.W. (ed.) Proceedings of the Second Symposium on the Geology of the Bahamas: CCFL Bahamian Field Station, p. 209-228.

Vierma, L., Kwolek, J., Heidt, D.A., Hattin D.E., Hasenmueller, W.A., and Feldman, H.R., 1985, Stratigraphic analysis of a newly discovered Pleistocene reef, San Salvador Island, Bahamas: The Compass, v. 62, p. 16-30.