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from the Bahamas

Megabank found? Flanks record sea level

On Leg 101, the first international voyage for the Ocean Drilling Program, the deep-sea drilling ship *JOIDES Resolution* (SEDCO/BP 471) left Miami, Fla., on Jan. 31 to investigate the geology of the Bahamas. (Leg 100 tested the *Resolution*'s readiness. See July *Geotimes*.) Before returning to Miami on March 14, the crew had drilled 19 holes at 11 sites and recovered 46.2% of the cored section (about 1.5 of 3.1 km cored).

The scientific party wanted to test conflicting hypotheses about the development of the modern shallow-water carbonate banks and intervening deep-water troughs in the Bahamas, and to study the growth patterns of carbonate slopes and their response to sea-level fluctuations. Those objectives (the 'deep' and the 'shallow') were selected because recent advances in interpreting the micropaleontology of shallow-water carbonate platforms, coupled with data from previous sedimentological investigations and regional and site-specific seismic surveys, now permit consistent stratigraphic comparisons in the Bahamas.

2 hypotheses describe the patterns of banks and basins of the Bahamas; the deep objective was to acquire from older strata the data to test them. The 'megabank' hypothesis holds that the modern archipelago is underlain by a drowned shallow-water platform in which ocean currents have eroded deep troughs. The 'graben' hypothesis suggests that the present topography faithfully reflects underlying horsts and grabens formed during the rifting in the Mesozoic Era that opened the Atlantic Ocean and separated North America from Africa.

A reflection that coincides with a pronounced compressional wave-velocity increase on regional multichannel seismic reflection profiles was inferred to be the flat top of the old shallow-water carbonate platform (the megabank). Drilling at 6 sites attempted to sample the layer, but succeeded only once.

At Site 626, in the Straits of Florida beneath the axis of the Gulf Stream, the inferred platform-top appeared at 1,200 m below the sea floor on seismic profiles. Unstable sediments forced the crew to abandon the hole at 447 m. Although the deep target went unreached, 3 important findings emerged: Winnowed, unconsolidated carbonate sands throughout the section indicate that the Florida Current part of the Gulf Stream has been a pervasive erosional and depositional agent since at least late Oligocene time (about 28 million years ago). Debris flows and turbidites dated middle Miocene by their fossils (about 16 to 10.5 million years ago) are of the same age as similar deposits in the Blake-Bahama Basin to the north and may have a common cause. Great Bahama Bank appears to have grown seaward (prograded) substantially since late Miocene time.

Correlation of strata at Site 626 with strata at Great Isaac-1 exploration well, 60 km northeast of Great Bahama Bank, suggests the progradation. Shallow-water dolomites about 1,900 m below sea level that mark the Albian-Cenomanian boundary (mid-Cretaceous, about 100 million years ago) in Great Isaac-1 are believed to correspond to the velocity-increase layer (inferred platform-top) identified on seismic profiles in the vicinity of Site 626. That layer is about 2,000 m below sea level at Site 626. Sediments above the layer are all deep-water at Site 626, but show transition from deep- to shallow-water deposition at Great Isaac-1.

(Chevron drilled the Great Isaac-1 well in 1971, and recently supplied to the University of Miami the geophysical logs and side-wall samples that provided new, more certain dates for the sedimentary section on the northwest corner of Great Bahama Bank.)

Drilling at Site 627, on the north side of Little Bahama Bank, succeeded in sampling the velocity-increase layer and established that it is the top of a buried shallow-water carbonate platform. The sediments are late Albian in age (103 to 100 million years old) and are interbedded layers of dolomitized limestone and gypsum, from 468 to 536 m below the sea floor (about 1,500 m below sea level). Shows of hydrocarbon gas and oil in the sediments at the bottom of the hole forced the crew to abandon the site.

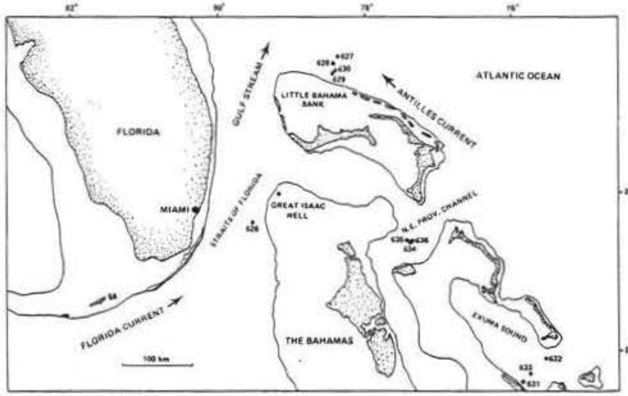
The scientists wanted to compare the sedimentary section they hoped to recover at Site 632 in Exuma Sound to that from Site 626 beneath the Straits of Florida. But the hole at Site 632 did not penetrate the deeper strata or reach the inferred platform-top (about 1,300 m below the sea floor). Drilling had to be halted because marginally mature bitumen was in the pore spaces of upper Miocene deposits. However, the 283 m of younger sediments sampled were important for the shallow objective.

Poor hole conditions at Site 634 prevented reaching the inferred platform-top about 800 m below the sea floor on the east flank of Northeast Providence Channel. Drilling stopped at 480 m in turbidites and debris flows of loosely cemented coarse-grained reef material of Late Cretaceous age (Campanian, 78 to 70 million years ago). Compensated Neutron and Gamma Spectroscopy logs taken through the drill string did provide a measure of porosity and an estimate of mineralogy of sediments poorly recovered in the drilling, and the available data allowed re-dating of 2 regionally correlated, acoustically identified horizons. Both were substantially older than previously assumed. (Site 634 is a re-occupation of Deep Sea Drilling Project Site 98. See September 1970 *Geotimes*, DSDP Leg 11.)

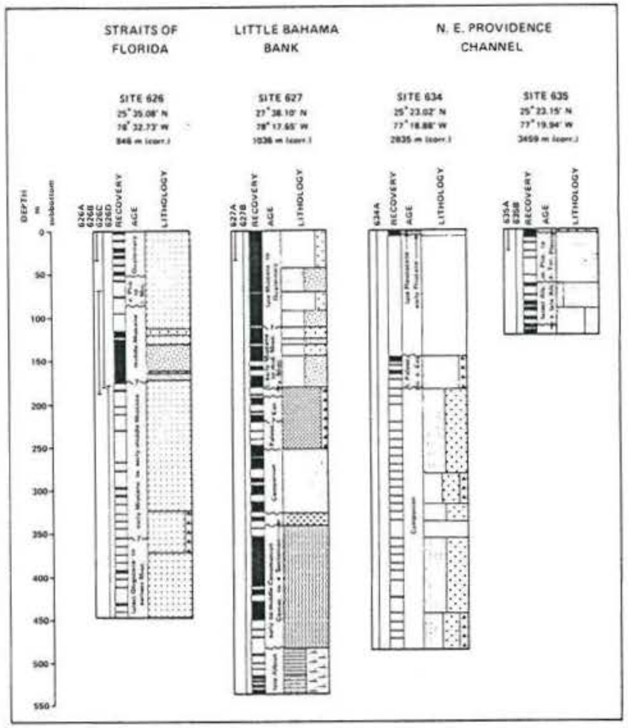
The seismically estimated depth of the inferred platform-top at Site 635, on the west flank of Northeast Providence Channel, was only 200 m below the sea floor, but once again unconsolidated calcareous sand forced drilling to stop, at 118 m, before reaching it. (The sands are primarily Pleistocene in age, younger than 2 million years, and are probably recent fill in the canyon system of which the Channel is a part.) The slightly silty limestones recovered from 61 to 118 m are dated mid-Cretaceous (early late Albian to earliest Cenomanian, about 104 to 100 million years old), slightly older than the marls directly overlying the top of the old shallow-water carbonate platform at Site 627. At Site 635 the fossil fauna have open-ocean affinities, compared to the shallow-shelf fauna at Site 627. This suggests both differential drowning and subsequent subsidence of parts of the old carbonate platform.

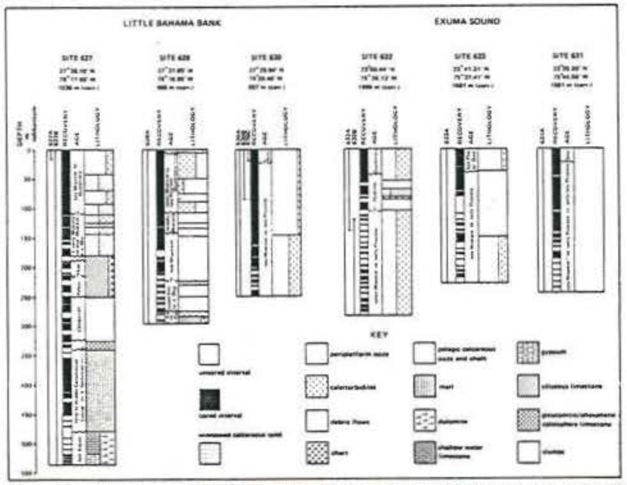
Of special interest are dark-colored laminated zones in the Site 635 limestones that have high organic-carbon content, occasionally more than 6%. Microfossils indicate that these zones are the same age as some of the dark shales found in the western North Atlantic Ocean—additional support for intermittent oxygen deficiency in the world's oceans during Cretaceous time.

At Site 636 the inferred platform top was about 100 m below the sea floor, in the axis of Northeast Providence Channel, but time permitted drilling



These sites were drilled on ODP Leg 101. Carbonate banks are outlined; land is stippled. (Map from the Ocean Drilling Program, Texas A&M University)





Top, deep objective: columns depict sediments encountered at sites 626, 627, 634 and 635—drilled to test hypotheses about the origin and development of the modern shallow-water carbonate banks and intervening deep-water troughs in the Bahamas. (Diagram from the Ocean Drilling Program, Texas A&M University)

Bottom, shallow objective: lithologic columns at sites 627, 628, 630, 632, 633 and 631—drilled to learn how modern carbonate banks grow and respond to sea-level change. (Diagram from the Ocean Drilling Program, Texas A&M University) only to 21 m. However, fragments of shallow-water carbonate material inferred to be from the platform were recovered from a young debris flow in unconsolidated fill.

The shallow objective of studying how carbonate banks grow and respond to sea-level changes required drilling a cross section of sites from the upper slope of a bank to its foot. Evidence from previous seismic surveys, dredge samples and piston cores suggests that the banks become steeper as they become older and larger, that belts of sediment types parallel water-depth contours and that the response of a Bahamian carbonate bank to worldwide sea-level changes is different from the response of slopes composed of clastic (non-carbonate) materials.

2 areas were chosen: the north side of Little Bahama Bank—a gentle slope of modest height, open to the ocean, and the southeastern margin of Exuma Sound—a steeper, higher slope completely sheltered from ocean action. Samples acquired on these transects reveal the 3-dimensional development of the banks. Both areas have gullied upper slopes and patterns of deposition indicating that coarser materials are transported along the gullies to the basin, bypassing the upper slopes. Pelagic periplatform ooze collects on the interfluves between gullies. Accumulation rates on the slopes have been rapid, even during postulated high sea levels when large quantities of debris were shed from adjacent banks, a response apparently opposite to that of clastic-dominated slopes.

The north slope of Little Bahama Bank is 800 to 900 m high and inclines 2 to 3°. It is characterized by slumps, gravity flows and turbidites that have built the bank seaward through time. The slope was sampled at 3 places with the hydraulic piston corer and the extended core barrel.

Site 627 (the only hole to reach the inferred platform-top) is at the deep-water end of the transect. Sediments overlying the mid-Cretaceous platform deposits show how the modern bank has developed. As the old shallow-water carbonate platform was buried, it became first a shelf with sediments that are a mixture of carbonate and continent-derived (terrigenous) materials (late Albian to early Cenomanian), then a marginal oceanic plateau with sediments that show frequent erosional episodes (Campanian to Oligocene, about 75 to 24 million years ago), and finally an apron of carbonate material coming from the bank as it has prograded.

Site 628 is at the bank's toe-of-slope. The samples show the transition from a marginal plateau where pelagic ooze was deposited to an environment at the base of the carbonate slope that received frequent turbidites during late Oligocene time (30 to 23.7 million years ago). The upper Oligocene sediments are at least 75 m thick, indicating accumulation rates as high as 27 m in a million years. Seismic evidence reveals downslope movement along faults and bedding-plane shears that are steeply dipping, nearly parallel and overlapping (imbricate). Such movement may be an important process on gentle carbonate slopes where accumulation rates are high.

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Site 630 is on one of the interfluves between gullies on the upper part of the slope. The cored section shows undisturbed deposition for at least the last 6 million years (since late Miocene time). 124 m of periplatform ooze containing abundant bank-derived aragonite indicate a depositional rate of 28 m or more in a million years. 2 or more holes were drilled at this site to obtain a complete record of perennial pelagic sedimentation since the onset of Northern Hemisphere glaciation, one that contains the Pliocene-Pleistocene boundary.

At all 3 Little Bahama Bank sites, cementation in Tertiary and younger sediments was minor and decreased downward. This may indicate that little organic material was deposited, thereby allowing complete aerobic destruction of organic material before burial on this slope.

The southwestern margin of Exuma Sound is steeper (10-12°) and higher (about 1,600 m) than the north side of Little Bahama Bank. 3 sites were drilled, again using the hydraulic piston corer and the extended core barrel. Scientists expected to find that accumulation rates had been lower and that more material derived from the carbonate bank had bypassed the upper slopes by moving down the gullies into the deep basin. They found instead that accumulation rates were high everywhere, even on the steep upper slopes.

At Site 632, the basinward end of the transect, they sampled about 283 m of upper Miocene and younger periplatform ooze, chalk and limestone interlayered with turbidites. Extensive lithification in sediments less than 100 m below the surface implies rapid chemical, physical and biological changes (diagenesis) as the material was accumulating. Aragonite is present throughout the sampled section and indicates rapid deposition via turbidites. (Otherwise, the aragonite would have dissolved in the water column before being incorporated in the sediments.) Accumulation rates were very high, up to 120 m in a million years during the late Miocene and early Pliocene. Fluctuations in accumulation appear to vary with the kind of sediment. The turbidites shed from the margins of the bank were deposited more rapidly than the periplatform oozes. The maximum rates of deposition seem to correspond to high sea levels, a correlation based on oxygen-isotope and other evidence

from the adjacent bank. Elsewhere, slopes made of non-carbonate materials generally show lower rates of deposition during high sea levels.

Drilling at Site 633, just a few km beyond the toe-of-slope, sampled 227 m of upper Miocene (?) and younger sediments that can be subdivided into 3 lithologic units. The basal sediments are basin-floor deposits of interbedded chalks and turbidites similar to those at Site 632. The middle unit, of homogeneous ooze and occasional debris flows, is tentatively interpreted as a series of slumps. Seismic data support the presence of at least 3 generations of slumps within the upper 300 m. The topmost unit is 52 m of ooze containing thin turbidites that drape the topographically high area created by the middle unit. Abundant aragonite again is present, indicating very high deposition rates (up to 115 m in a million years in late Miocene and early Pliocene time).

Site 631 is on the steepest part of the gullied upper slope. In the 244 m of ooze and chalk sampled, little coarse material from the bank was found, indicating that the turbidites have been bypassing the upper slopes on their way basinward. A major surprise was the high accumulation rate of the periplatform ooze (the perennial, fine-grained 'background' sediment)—up to 75 m in a million years. Seismic data and the nature of the samples suggest that that part of the slope is prograding slowly, probably as a result of slow creep and small-scale slumping.

Within the Miocene and younger sediments at all 3 Exuma Sound sites, the organic content (presumably derived from the sea grass *Thalassia*) is higher than at other Bahama locations, probably from anaerobic oxidation by both sulfate reduction and methanogenesis. Byproducts of those reactions are responsible for the noticeable lithification of the shallow subsurface sediments, but they have not altered the composition of the water that surrounds the sediment grains (interstitial pore water) enough to dissolve all the aragonite, which is present throughout the sampled sediments.

Leg 101 accomplished parts of both deep and shallow objectives. Scientists answered many questions, but left others open for further study.

The presence of a drowned mid-Cretaceous 'megabank' in the northern Straits of Florida and southern Blake Plateau seems reasonable from the results of drilling at sites 626 and 627, but the origin of the present topography of the rest of the Bahamas remains uncertain. The evidence from sites 627 and 635 indicates that the drowning of the megabank may not have occurred everywhere at the same time. Faulting probably influenced the subsidence patterns, as suggested by the more than 2 km difference in elevation between the sampled sediments from the top of the old carbonate platform at Site 627 and the inferred platform-top at sites 635 and 636. However, the lateral migration of the margins of the carbonate banks by at least tens of kilometers through time (correlation of Site 626 and Great Isaac-I well) argues against significant fault control of the modern bank-and-trough configuration.

How carbonate banks develop is better understood. Coarser material bypassing the upper slopes of a bank through the gullies is an important process on both gentle and steep slopes. However, rates of deposition are high everywhere on the interfluves. Those high rates promote quick burial of organic matter and rapid lithification of the sediments. The highest rates of turbidite deposition in the basin generally appear to correlate with postulated high sea levels.

Drilling encountered hydrocarbons at sites 626, 627 and 632. Rock-Eval and gas chromatography tests showed they were catagenic, formed by the action of increasing temperature and pressure as the sediments containing the organic source material were buried. They probably migrated from deeper unsampled parts of the sedimentary section. (The holes were plugged using special cement that sets when mixed with sea water, in accordance with Ocean Drilling Program practice for dealing with hydrocarbon shows.)

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Poetry of the Earth

A few weeks ago, 20 minutes after reading Robinson Jeffers's poem, 'Oh lovely rock', I picked up the telephone and asked Marvin E. Kauffman if I might write a bimonthly column on poetry for *Geotimes*. That was impetuous and presumptuous, even for one who wrote rhymes in his teens and had several verses accepted by Miss Billings for publication in *The Washakie Warrior*. The willingness of the executive director of the American Geological Institute and the managing editor of *Geotimes* to take a chance on an unaccredited poet was gratifying and, I hope, not foolhardy.

The middle part of Jeffers's poem goes this way:

Across the stream. Light leaves overhead
danced in the fire's breath, tree-trunks
were seen: it was the rock wall
That fascinated my eyes and mind. Nothing strange: light-gray diorite with two or
three slanting seams in it,
Smooth-polished by the endless alteration
of slides and floods; no fern nor lichen,
pure naked rock . . . as if I were
Seeing rock for the first time. As if I were
seeing through the flame-lit surface into
the real and bodily
And living rock. Nothing strange. . .

Jeffers was a poet who disliked humans. He wrote generously and often eloquently about rocks, animals, and plants. His affection for diorite parallels mine for siltstone. When I was 4, I picked up a small piece of ripple-marked red siltstone from the Chug-