trapolations of existing Hugoniot and thermodynamic data, yielded the values enclosed in parentheses.

Our results support the suggestion of McQueen *et al.* that the phase transition inferred from dynamic studies is the transformation of quartz to a dense phase containing silicon in sixfold coordination. Reconstructive phase transformations between crystalline silica phases are notoriously sluggish (*7*), and one would expect an SRO phase to form under shock conditions. The small quantities of stishovite we have recovered represent regions in which sufficient long-range order had developed during peak pressure to permit survival of stishovite as a metastable phase during cooling from the rarefaction temperature, after pressure decrease, and during the hydrofluoric acid treatment. The bulk of the dense phase in which long-range order had not been attained would be unstable on release of pressure and should invert rapidly to a fourfold coordinated SRO structure.

Examinations of recovered specimens confirm the results of dynamic studies which indicate that the transformation to a sixfold coordinated structure either has a lower threshold pressure or is more complete at a given pressure above threshold for samples of initially lower densities. This would appear to be related to the greater energy content at a given pressure for shocks in materials of initial low density. This may be seen on inspection of the Rankine-Hugoniot relationship derived from the fundamental conservation laws:

$$E_1 - E_0 = 1/2\,[(P_1 + P_0)(V_0 - V_1)]$$

where E, P, and V are specific energy, pressure, and specific volume, respectively, and the subscripts 0 and 1 refer to states before and behind the shock (*8*).

Although stishovite-bearing specimens of the impact-metamorphosed sandstone at Meteor Crater, Arizona, generally contain about ten times as much coesite as stishovite, we found no coesite in the experimentally shocked materials despite carefully monitored extractions in dilute hydrofluoric acid. The greater thermal stability of coesite relative to stishovite, as determined at 1 atm, makes it highly unlikely that any coesite could have formed and then inverted to SRO phases or to quartz during the cooling of the samples from rarefaction temperatures (*9*); we can only conclude that detectable coesite was not formed.

Coesite has been found by Milton *et al.* in partially fused alluvium ejected from the Scooter crater produced by the detonation of 500 tons of TNT (*10*); the peak pressure to which the specimens had been subjected was close to 150 kb. On the other hand, prepared quartzose specimens have been subjected to the long-lived shock pressures of nuclear explosions; the peak pressures were within the stability field of coesite and below the stability field of stishovite and, presumably, of the six-coordinated SRO phase. We and other workers have examined these specimens diligently without finding a trace of coesite (*11*). We suggest that under shock coesite forms from the dense six-coordinated SRO phase after the shock pressure attenuates below the stability field of the six-coordinated phase. In addition to a peak pressure higher than that required for direct equilibrium synthesis, formation of detectable coesite would seem to require a protracted pressure pulse. The total time from initial shock to decrease of pressure to 1 atm for the Meteor Crater impact at the level of the Coconino sandstone was of the order of 0.1 second (*12*). The Scooter and nuclear explosions would give comparably long pulses. In our experiments, however, the corresponding time was less than 10 μsec.

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13. We thank E. C. T. Chao for discussions of his unpublished research on impact-metamorphosed minerals, T. J. Ahrens and V. G. Gregson for use of their unpublished Hugoniot data, G. E. Duvall and G. M. Muller for assistance with shock wave theory, E. M. Shoemaker for discussions of cratering, and J. C. Jamieson for discussions of phase transformations in general. Publication authorized by the director, U.S. Geological Survey.

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Precipitous Continental Slopes and Considerations on the Transitional Crust

Abstract. *The continental slope bordering the Bahamian Platform to the east descends precipitously from a shallow edge to oceanic depths. Sustained slopes of at least 40 degrees have been found east of San Salvador. Considerations based on isostatic equilibrium suggest that in this area the oceanic crust may approach the edge of the shelf within a distance as short as 8.5 km. If so, it may be possible to drill and sample a substantial portion of the transitional crust by means of directional drilling techniques from a rig located at the edge of the shelf. It may even be possible, at some future time, to cross the entire crust, pierce the Mohorovičić discontinuity, and penetrate the mantle.*

As is well known, the continental crust of the earth averages about 34 km in thickness and the oceanic crust about 7 km. Intermediate crustal thicknesses are known to occur in many areas, such as portions of the Gulf of Mexico; the Caribbean, Okhotsk, and Bering seas; beneath the Campbell Plateau (and probably other submarine plateaus); and beneath portions of oceanic ridges and deep-sea trenches (*1, 2*). When the continental margin is free of such features as basins, trenches, and submarine deltas, the continental crust tends to grade geometrically into the oceanic crust through a continuous, tapered transitional zone (see *3*), the topographic expression of which is the continental slope. Because isostatic equilibrium generally prevails, the under-

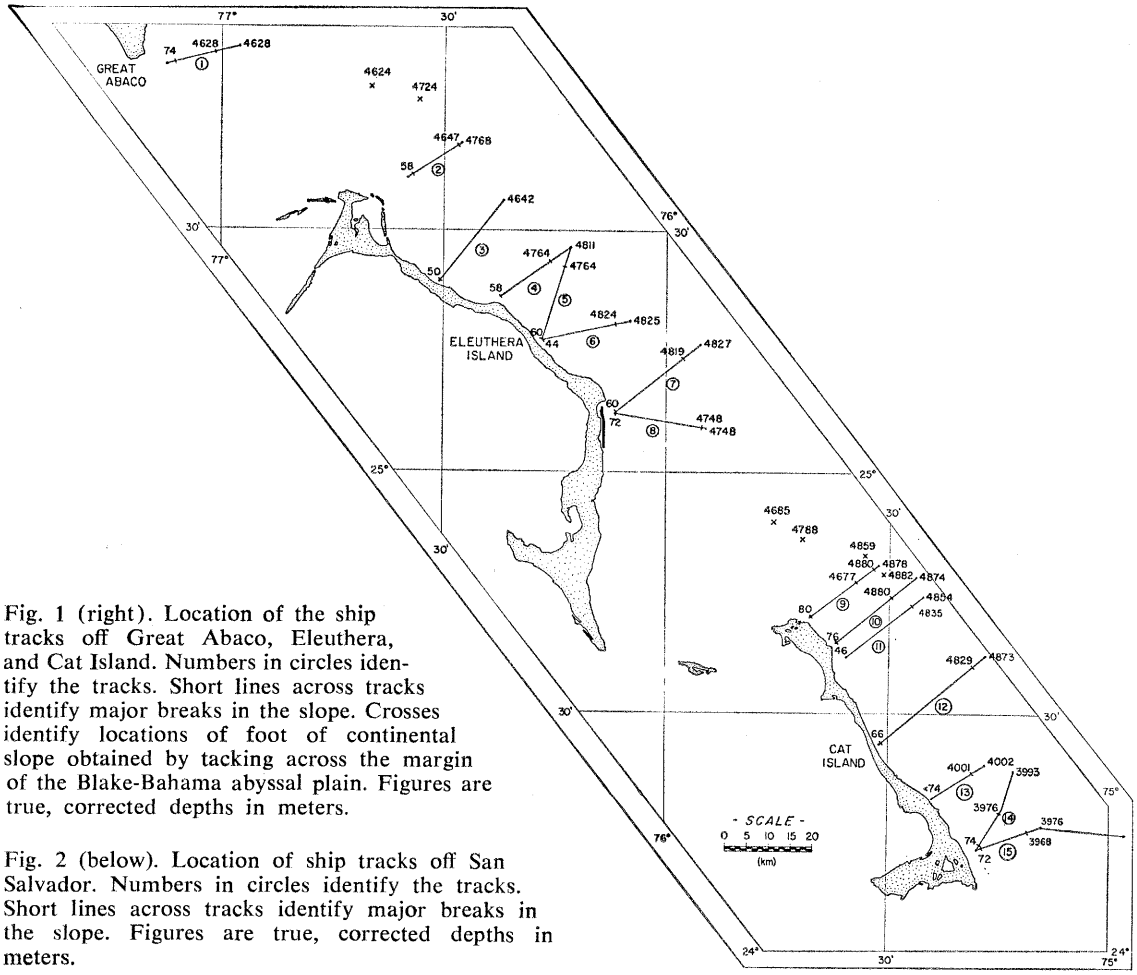
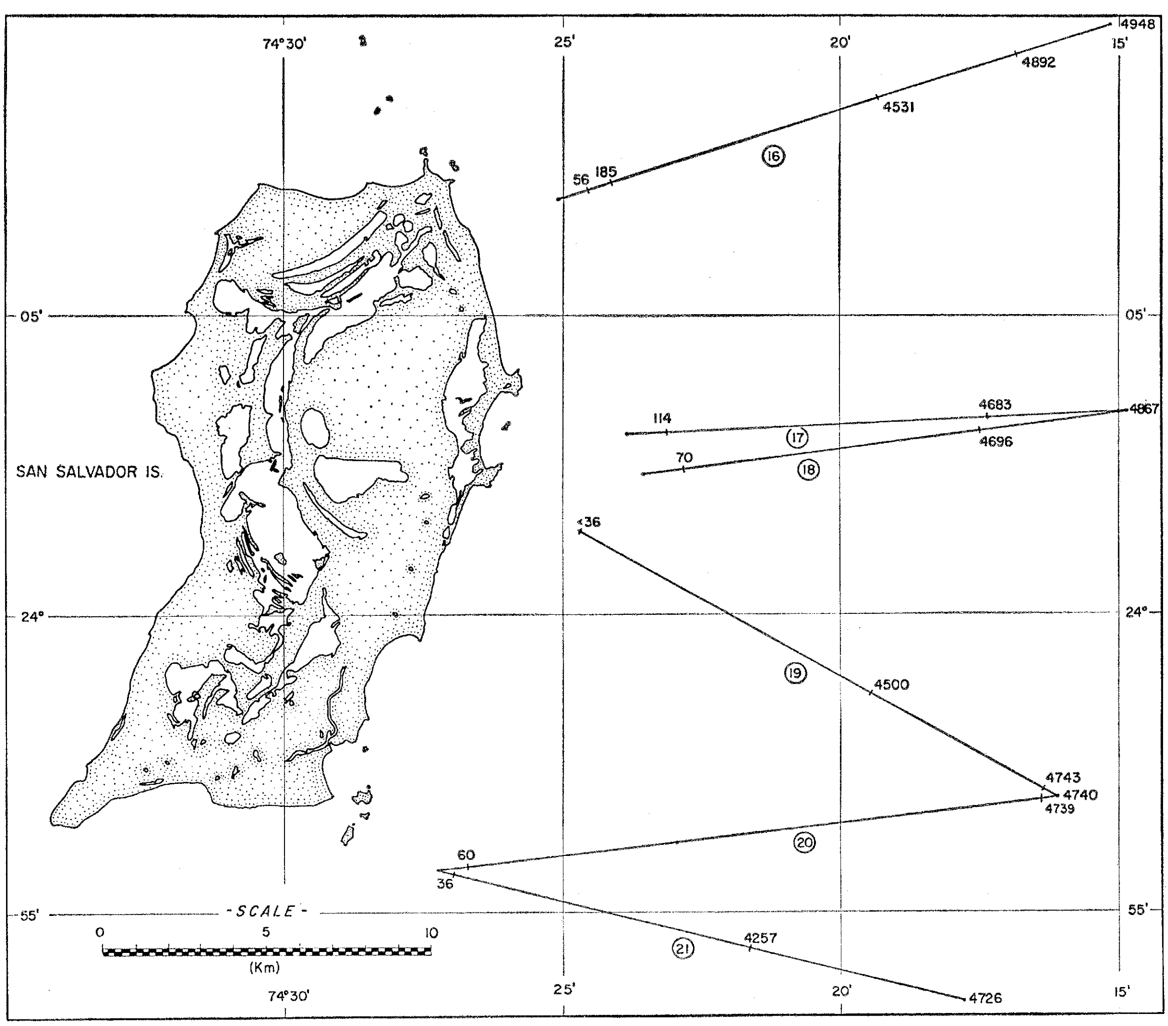


Fig. 1 (right). Location of the ship tracks off Great Abaco, Eleuthera, and Cat Island. Numbers in circles identify the tracks. Short lines across tracks identify major breaks in the slope. Crosses identify locations of foot of continental slope obtained by tacking across the margin of the Blake-Bahama abyssal plain. Figures are true, corrected depths in meters.

Fig. 2 (below). Location of ship tracks off San Salvador. Numbers in circles identify the tracks. Short lines across tracks identify major breaks in the slope. Figures are true, corrected depths in meters.



side of the crust (Mohorovičić discontinuity) has a trend opposite to that of the continental slope. For instance, the outer slope of the continental borderland off southern California descends from −1.0 to −3.5 km (relative to sea level) within a distance of about 20 km, while the Mohorovičić discontinuity shoals from −18 to −12 km within the same distance (*4*, Fig. 2). In this particular case, the inclination of the slope is about 7 degrees, while that of the Mohorovičić discontinuity is about 17 degrees.

The average inclination of most continental slopes is less than 10 degrees. In areas of the continental margin where reef-building has been active for a long time, however, average continental slopes of more than 10 degrees predominate. A classical example is the Florida-Bahamas platform, bound toward both the west (Gulf of Mexico) (*5*) and the east (Atlantic Ocean) by steep slopes. The eastern slope is not only particularly steep but also descends to truly oceanic depths, suggesting that the underlying transitional crust may be very narrow.

The entire Florida-Bahamas platform, with an area of some three-quarters of a million square kilometers, has been subsiding since at least Early Cretaceous time. This is clearly shown by the lithology and stratigraphy encountered by numerous exploratory and production oil wells drilled in the area. In particular, the famous Andros 1 well at Stafford Creek, Andros Island (24°52′37.2″N, 78°01′54.7″W), crossed a thick section of Tertiary and Cretaceous shallow-water carbonates and was bottomed at 4446 m in shallow water carbonates of Lower Cretaceous age without reaching the "basement" upon which the carbonate sediments must rest (Spencer, quoted by Eardley, *6*). Although subsidence appears to have been interrupted a number of times and probably proceeded at different rates at different times and in different portions of the platform, an average subsidence rate of about 4 cm per 1000 years may be calculated from the approximate age of the Early Cretaceous and the thickness of the overlying deposits.

The thickness of the crust within the Bahamian platform proper decreases from about 30 km under the western edge to about 23 km under the eastern edge (*7*), and oceanic thicknesses have been reported for the adjacent Blake-Bahama abyssal plain (*2*, *8*). While the actual trend of the Mohorovičić discontinuity across the eastern margin of the platform remains unknown, the low rate of regional subsidence (an expression of the velocity of subcrustal motions or phase changes ultimately responsible for the subsidence itself) suggests that isostatic equilibrium probably prevailed throughout the time of deposition of the carbonate sediments. Thus, the shoaling of the Mohorovičić discontinuity may be as abrupt as the drop of the topographic surface.

To study the trend of the continental slope bordering the Bahamian platform to the east, 21 bottom profiles were obtained by means of a Precision Depth Recorder operated from the *Gerda*. The ship tracks, distributed from Great Abaco to San Salvador, are shown in Figs. 1 and 2. The short lines across the tracks mark the positions of major slope breaks. Usually, only two such breaks appear, the first showing the position of the edge of the shelf, and the second showing the position of the foot of the slope. Secondary breaks may occur along the steeper positions of the slopes, but are not resolved because of the dispersion of the return signal. The bottom profiles are shown in Fig. 3.

The shelf consists of a narrow platform floored with carbonate sand and rock and supporting small but numerous, actively growing patch reefs. The width of the shelf is generally about 2 km, but it decreases sometimes to less than 1 km or increases to as much as 10 km (off the northeastern end of Eleuthera). The edge of the shelf is usually sharp and well-defined and is located, in the area studied, at an average depth of −65 m.

Precipitous slopes, apparently consisting of hard carbonate rock, begin at the edge of the shelf and generally terminate at the margin of the Blake-Bahama abyssal plain. Their lower portions often appear covered with

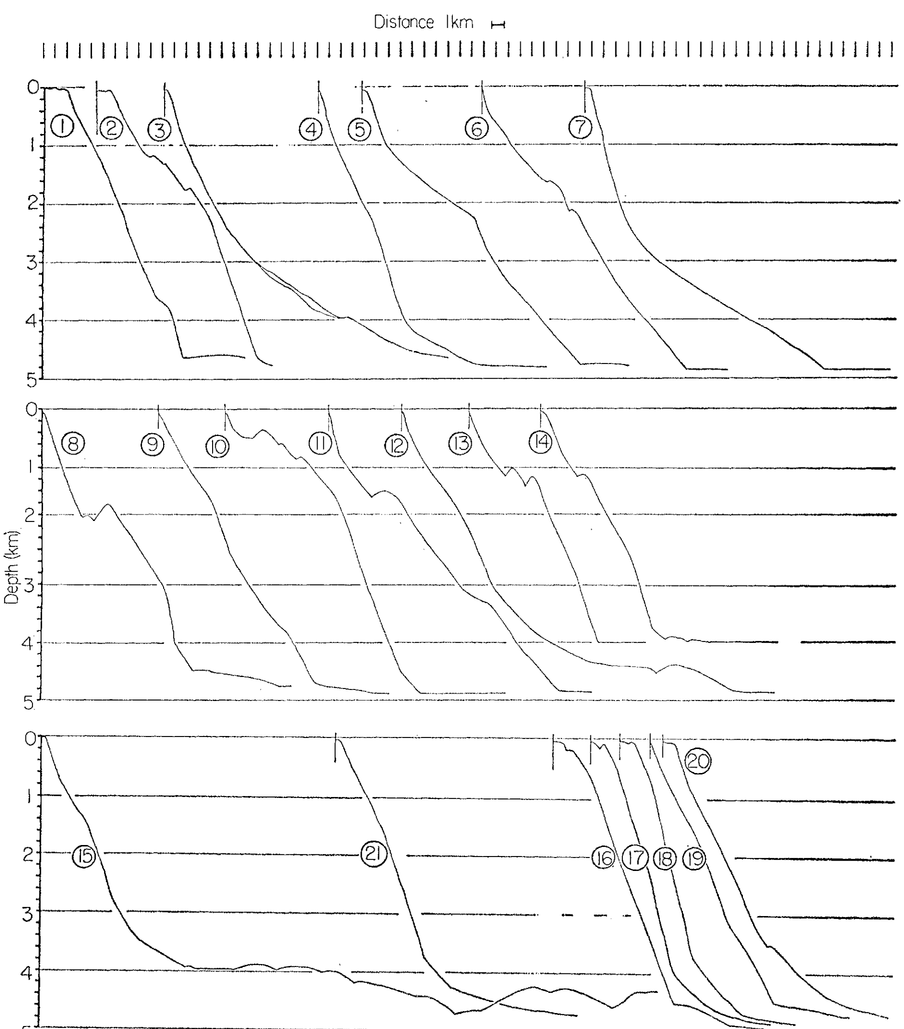


Fig. 3. Bottom profiles. Numbers in circles refer to the tracks shown in Figs. 1 and 2. Depths are true and corrected. Vertical exaggeration 5:1.

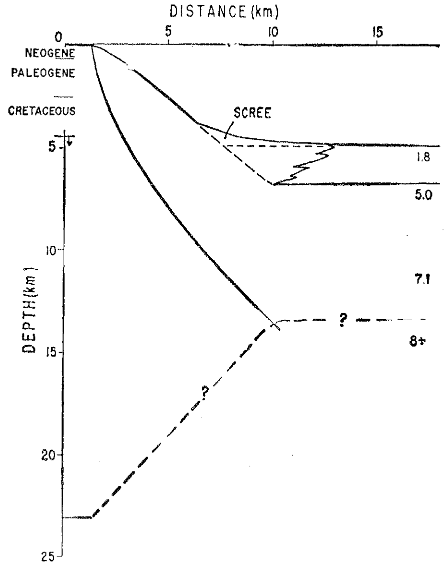


Fig. 4. Hypothetical and schematic reconstruction of the transitional crust east of San Salvador. Stratigraphic column (upper left) inferred from the Andros 1 well. Figures to the right are velocities of P waves in km/sec. These velocities and the thicknesses of the oceanic layers are inferred from data presented in (*8*). Crustal thickness under continental edge is inferred from (*7*). No vertical exaggeration.

scree. The average inclination from the edge of the shelf to the foot of the slope ranges from 14 to 28 degrees, but sustained slopes of more than 30 degrees are common. Thus, in profile 18, the slope drops 3 km (−0.75 to −3.76 km) within a distance of 3.6 km, showing an inclination of 39.7 degrees. This is probably one of the steepest sustained submarine slopes known. It should be noticed that the slope inclinations shown in Fig. 3 are minimal because of the unknown angle between ship track and surface projection of the line of maximum declivity. The hard rock surfaces probably continue beneath the scree to a "basement" perhaps a kilometer below the depth of the Blake-Bahama abyssal plain. The transition between the surface of the slope (including scree if present) and that of the abyssal plain is very sharp in many profiles, but in others is more gradual. Wherever it is sharp, the depth of the margin of the abyssal plain is sharply defined. This depth increases irregularly by about 260 m from northwest to southeast. The crosses in Fig. 1 show the position of the foot of the slope determined by tacking across the margin of the abyssal plain.

The plain visible along the eastern parts of profiles 13 and 14, also seen in profile 15 between 13 and 16.2 km from the western end of the profile, is more than 800 m higher than the adjacent Blake-Bahama abyssal plain. This plain is apparently perched and dammed toward the east by the submarine mounts visible along the eastern portion of profile 15. It slopes slightly (33 m in 20 km) to the north, indicating a southern source for the sediments. The mounts themselves, 600 to 800 m high, pose an interesting problem. On the basis of the single profile available, they could be scree deposits suitably intersected by the ship track, abyssal hills of rather unusual dimensions, or, perhaps more likely, the topographic expression of an outer portion of the basement upon which the entire Bahamian platform was built. If the Atlantic Ocean came into being because the Americas pulled away from Europe and Africa, these features may even be ancient folded mountains deeply eroded by subaerial processes and subsequently depressed to their present depth by subcrustal events. We hope to clarify these structures in the course of future expeditions.

The horizontal distance between edge and foot of the slope ranges from more than 20 km to less than 10 km. The steepest slopes occur off Great Abaco and off San Salvador, in front of the monument to Christopher Columbus (profiles 17 and 18). Here, the average slope (disregarding that of presumed scree deposits) is at least 40 degrees and appears to intersect the landward projection of the surface of the abyssal plain within a horizontal distance of about 6.5 km from the edge of the shelf (Fig. 4). If projected downward, the slope would intersect the surface of the second oceanic layer within a horizontal distance of less than 9 km, suggesting that the oceanic crust may approach the continental crust within this short distance (the oceanward jutting of San Salvador from the regional rim of the Bahamian platform may be relevant here). If this suggestion is substantiated by suitable geophysical investigations, it may be possible to drill and sample a substantial portion of the transitional crust by means of directional drilling techniques from a rig placed at the edge of the shelf (Fig. 4). It may even be possible, at some future time, to cross the entire crust at this location, to pierce the Mohorovičić discontinuity, and to penetrate the mantle.

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Tritiated Water as a Tool for Ecological Field Studies

Abstract. *Tritium was used to investigate the withdrawal by small trees of water from soil at three depths. Within 4 hours of placement at each depth, tritium was detected in the transpired water from nearby trees. On the 3rd day after application, 38 times more tritium (per unit volume) was present in transpired water drawn from soil at a depth of 0 to 30.5 centimeters than in water drawn from the 61- to 91.5-centimeter level.*

Tritium is frequently used to trace water movement in soil but has seldom been used for such studies in plants. Its use in ecological field studies also has been almost totally neglected. Here we report the use of tritium to study water uptake by trees growing naturally in the sandhills of South Carolina.

Five curies of tritium in 500 ml of water were introduced to the soil at each of three locations through pipes which had been driven to depths of 66 cm, 35.5 cm, and 5 cm in order to distribute the water to the soil at depths of 61 to 91.5, 30.5 to 61, and 0 to 30.5 cm, respectively. Upward capillary movement necessitated driving the pipes to a greater depth than the minimum level desired for the tritiated water. Although soil moisture was never deficient during the study, the sandy soil permitted complete infiltration within 5 minutes at all depths. For application to the 0- to 30.5-cm depth, the soil