SUBMARINE CANYONS

(Extract from *Geographical Review*, New York, October 1937, p. 681).

The attention that is being given to submarine canyons of the continental shelf has probably raised a question in the minds of many of those interested concerning the nature and accuracy of the material available for this study. The reasonable accuracy of methods recently developed by the United States Coast and Geodetic Survey has been outlined by Paul A. SMITH (The Accuracy of Soundings and Positions Obtained by Methods Used in the United States Coast and Geodetic Survey, *Trans. Amer. Geophys. Union, Sixteenth Ann. Meeting*, April 25 and 26, 1935, Washington, 1935, Part I, pp. 9-14). He states that the error of soundings may be within 1 per cent in depths of 10 to 200 fathoms and within 3 per cent in depths greater than 200 fathoms. For position, where visual-fix ranging near the shore is feasible, the error ranges from 1:500 to 1:1000; out of sight of land, where radioacoustic ranging is used, the error may range from 1:200 to 1:500. Such accuracy is remarkable. Privately conducted surveys in which a hand reel was used have been described by F.-P. SHEPARD (Detailed Surveys of Submarine Canyons *Science*, Vol. 80 (N. S.), 1934, pp. 410-411; see also his "Canyons off the New England Coast", *Amer. Journ. of Sci.*, Ser. 5, Vol. 27, 1934, pp. 23-36). There is therefore the beginning of an accurate base map on which submarine geology can be delineated (see also pp. 625-636 of this number of the *Review*).

Successful dredging has been carried on in the canyons of the Atlantic coastal plain by H.-C. STETSON (Geology and Paleontology of the Georges Bank Canyons, Part I, Geology, *Bull. Geol. Soc. of America*, Vol. 47, 1936, pp. 339-366) and off the California coast by SHEPARD. Both succeeded in breaking fragments of rock from the canyon walls. In 1934 STETSON obtained samples of coarse sandstone, greensand, and indurated silt ranging from Upper Cretaceous to late Tertiary in age from the steeper walls of Georges Bank canyons. In the summer of 1935 SHEPARD (Geological Mapping of the Ocean Bottom, *Science*, Vol. 82 (N. S.), 1935, pp. 614-615), using similar dredging equipment, obtained fragments of rock ranging probably from Eocene to Pleistocene in age from five canyons off the California coast. Of 15 canyons examined up to this year, 12 showed rocky walls, some even granite. The presence of fossils in many of the samples means that identification need not rest on purely lithological grounds.

A radical improvement in methods of sampling the softer bottom deposits, whereby cores more than eight feet long can be obtained in deep water, has been developed by PIGGOT (C.-H. PIGGOT: Apparatus to Secure Core Samples from the Ocean-Bottom, *Bull. Geol. Soc. of America*, Vol. 47, 1936, pp. 675-684; "Core Samples of the Ocean Bottom", *Carnegie Instn. News Service Bull.*, Vol. 4, 1936, pp. 83-87). It should furnish results of great importance. The refraction seismograph has been adapted to work at sea down to 100 fathoms (Maurice EWING, A.-P. CRARY, and H.-M. RUTHERFORD: Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain, Part I, Methods and Results, *Bull. Geod. Soc. of America*, Vol. 48, 1937, pp. 753-802). The surface of the crystalline basement beneath the Atlantic coastal plain (presumably corresponding in part to the Fall Zone peneplane) has been traced from the inner margin of the coastal plain to the edge of the continental shelf. Near the edge the crystalline basement lies beneath 12,000 feet of less consolidated material; the abyssal slopes of the ocean are some 4,000 feet higher. As a result of this work, according to MILLER (B.-L. MILLER: Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain, Part II, Geological Significance of the Geographical Data, *ibid.*, pp. 803-812), we can be fairly certain that the submarine canyons of the Atlantic coastal plain are entirely incised in rocks of Mesozoic or Cenozoic age.

A rather full statement of the canyon problem and its historical background up to 1933 was made by SHEPARD (F.-P. SHEPARD: Submarine Valleys, *Geogr. Rev.* Vol. 23, 1933, pp. 77-89). He has, however, as a result of later data (see below), apparently partly abandoned the theory developed there. More recently SMITH has enumerated field studies and theories suggested (P.-A. SMITH: Submarine Valleys, *U. S. Coast and Geodetic Survey Field Engineers Bull.* N° 10, 1936, pp. 150-155)*. At the risk of repetition, some of the major theories advanced in the last four years are reviewed here.

In 1934 DAVIS (W.-M. DAVIS: Submarine Mock Valleys, *Geogr. Rev.* Vol. 24, 1934, pp. 297-308) proposed that, where shore-line topography is favorable for localized ocean currents, outward-flowing bottom currents compensating inward drift of surface water might

(*) See above, page 61.

develop or keep open submarine valleys. "It is possible that the shore waters, made turbid... (at times of severe onshore winds) by wave action, would thus gain an increased specific gravity that would facilitate their descent into the colder water of the depths". Whereas DAVIS made no point of this increased density and treated it as an accessory circumstance, there is a similarity here to the density current later suggested by DALY.

Whereas DAVIS considered processes going on to-day, DALY (R.-A. DALY: Origin of Submarine "Canyons", *Amer. Journ. of Sci.* Ser. 5, Vol. 31, 1936, pp. 401-420) suggests canyon cutting under special conditions during the Pleistocene. The theory, in brief, demands a 300-foot eustatic drop of sea level during formation of the ice-caps. Most of the continental shelves were then exposed. The waters, weighted with sediment from the mud banks on the outer margins of the shelves and from rivers, slid down the continental slope, thus producing a density current. Concentration of current action in preëxistent irregularities of the slope led to excavation of the canyons. DALY'S theroy has received the support of KUENEN (P.-H. KUENEN: Experiments in Connection with DALY'S Hypothesis on the Formation of Submarine Canyons, *Leidsche Geol. Mededeelingen*, Vol. 8, 1937, pp. 327-351). SHEPARD discusses aspects unfavorable to this theory (F.-P. SHEPARD: DALY'S Submarine Canyon Hypothesis, *Amer. Journ. of Sci.* Ser. 5, Vol. 33, 1937, pp. 369-379).

STETSON has reviewed the problem of subaerial and submarine origin of the canyons, discussing subaerial processes in greater detail, but at the time of writing did not consider the evidence warranted complete rejection of either view. He has tested current in the Georges Bank canyons and demonstrated that normal tidal currents are not significant as an erosive agent.

HESS and MACCLINTOCK (H.-H. HESS and Paul MACCLINTOCK: Submerged Valleys on Continental Slopes and Changes of Sea Level, *Science*, Vol. 83 (N. S.), 1936, pp. 332-334) have put forward the hypothesis that, possibly under the influence of some stellar body, the rotation of the earth was suddenly decreased and a rapid change in the shape of the hydrosphere resulted, depressing sea level in low latitudes and raising it in high latitudes, though the authors themselves point out that a sudden change in the speed of rotation is a formidable objection to overcome. SHEPARD has raised additional objections (F.-P. SHEPARD: Submerged Valleys on Continental Slopes and Changes of Sea Level, *ibid.*, pp. 620-621). A.-C. VEATCH also has considered a theory taking into account the influence of a stellar body (see SMITH, Submarine Valleys, p. 154), in which a change in the lithosphere may have taken place.

In 1936, on the basis of recent Russian investigations, SHEPARD (F.-P. SHEPARD: The Underlying Causes of Submarine Canyons, *Proc. Natl. Acad. of Sci.* Vol. 22, 1936, pp. 496-502) suggested the formation of an enormous dome-shaped icecap about four miles thick over the entire Polar Regions and a greatly extended Antarctic icecap. This, according to his figures, would lower sea level some 3000 feet. Before glaciation there were depressions of the continental slope resulting partly from diastrophism, landslide, and the submergence of true river valleys by diastrophism in an earlier period. Recession of the sea by 3000 feet during formation of the icecap allowed rivers to flow out over the exposed shelf into preëxistent depressions of the slope and excavate canyons to the level of the sea.

The problem is surrounded with difficulties. Objections have been raised regarding the efficacy of submarine currents. For the most part the submarine canyons do not suggest faulting or collapse of solution channels. If the canyons are entirely of subaerial origin, the shelves of the world may have been uplifted some 8000 feet or more sometime since late Tertiary, maintained temporarily during stream cutting, and again depressed. In the light of existing knowledge this is hard to accept. The ocean bottom may have been depressed. FIELD (R.-M. FIELD: Structure of Continents and Ocean Basins. *Journ. Washington Acad. of Sci.* Vol. 27, 1937, pp. 181-195) suggests that "there may have been profound, local, Quaternary movements in the basin itself; and that these movements may have affected ocean level, especially if there were coincident movements in the floor of the Pacific". We are then faced with the necessity of reëlevating the ocean bottom in order that sea level may again resume approximately its former position. Water may have been removed from the ocean to form great icecaps. The recent suggestion of a 3000-foot eustatic drop in this way does not account for the lower 3000 to 5000 feet of canyon. But we have greatly improved techniques for obtaining information, and considerable enthusiasm is being shown by workers in this comparatively new field.