ON THE FORMATION OF BARRIER REEFS AND OF THE DIFFERENT TYPES OF ATOLLS.[1]

THE results here presented are based upon observations carried on during the past twenty-five years in Florida, the Bermudas, Bahamas, Cuba, Jamaica, and the West Indies in the Atlantic. They include in the Pacific the Galapagos, the Hawaiian Islands, the Great Barrier Reef of Australia, the Fiji Islands, and the Coral Reefs and Islands of the tropical Pacific, from the Marquesas to the Paumotus, the Society Islands, the Cook Archipelago, Niue, the Tonga, Ellice, Gilbert, and Marshall Islands, the Carolines and Southern Ladrones, and the Maldives, in the Indian Ocean.

Recognising that Darwin's theory did not explain the conditions observed, my reports were limited to descriptions of the different types of Coral Reefs and of the causes to which they probably owed their formation, and no attempt was made to establish any independent general theory.

Beginning with the Barrier Reefs, we find that those of Fiji, the Hawaiian Islands, and the West Indies usually flank volcanic islands and are underlaid by volcanic rocks. Those of New Caledonia, Australia, Florida, Honduras, and the Bahamas are underlaid by outliers of the adjoining land masses, which crop out as islands and islets in the very outer edge of the Barrier Reefs. Some of the Barrier Reefs of the Society Islands, of Fiji, and of the Carolines, show that the wide and deep lagoons, separating them from the land mass, have been formed by erosion, from a broad fringing reef flat. Encircling reefs, such as characterise especially the Society Islands, hold to their central island or islands the same relation which a Barrier Reef holds to the adjoining land mass. Denudation and submarine erosion fully account for the formation of platforms upon which coral reefs and other limestone organisms may build, either barrier or encircling reefs, or even atolls, rising upon a volcanic base, of which the central mass may have disappeared as in Fiji, the Society and Caroline Islands.

We may next take the type of elevated islands of the Paumotus, the Fiji, the Gilbert, and the Ladrones, many composed only of Tertiary limestones, others partly of limestone, and partly volcanic. We can follow the changes from an elevated island, like Niue, or Makatea in the Paumotus, to an island like Niau, through a stage like Rangiroa to that of the great majority of the atolls in the Paumotus. The reef-flats and outer reefs flanking elevated islands hold peculiar relation to them; they are partly those of Barrier Reef and partly of Fringing Reef. We may also trace the passage of elevated plateaux like Tonga, Guam, and islands in Fiji, partly volcanic and partly limestone, to atolls where only a small islet or a larger island of either limestone or volcanic rock is left to indicate its origin. Atolls may also be formed upon the denuded rim of a volcanic crater as at Totoya and Thombia in Fiji, as well as in some of the volcanoes east of Tonga.

In the Ellice and Marshall group and the Line Islands, are a number of atolls, the underlying base of which is not known and where we can only follow the formation of the land rim of the atoll, as far as it is due to the agency of the trades or of the monsoons in constantly shifting the superficial material (prepared by boring organisms) which goes to form its rim. Many of the atolls in the Pacific are merely shallow sinks, formed by high sandbanks, thrown up around a central area.

Throughout the Pacific, the Indian Ocean, and the West Indies the most positive evidence exists of a moderate, recent elevation of the coral reefs. This is shown by the horses, pinnacles, and undermined masses of modern or Tertiary limestone left to attest it. The existence of honeycombed pinnacles of limestone within the lagoons of atolls, as shoals, islands, or islets, shows the extent of the solvent action of the sea upon land areas, having formerly a great extension than at the present day. Signs of this solvent action are to be seen everywhere among coral reefs. Atmospheric denudation has played an important part in reducing elevated limestone islands to the level of the sea by riddling them with caverns and by forming extensive sinks, often taken to be elevated lagoons.

[1] By Alexander Agassiz, For. Mem. R.S. Read at the Royal Society, March 19.

Closed atolls can hardly be said to exist; Niau in the Paumotus is the nearest approach to one, yet its shallow lagoon is fed by the sea through its porous ring. Sea water may pass freely into a lagoon at low tide over extensive shallow reef flats where there are no boat passages. The land area of an atoll is relatively small compared to that of the half-submerged reef flats. This is specially the case in the Marshall Islands and the Maldives where land areas are reduced to a minimum.

The Maldivian plateau with its thousands of small atolls, rings, or lagoon reefs, rising from a depth varying from twenty to thirty fathoms is overwhelming testimony that atolls may rise from a plateau of suitable depth, wherever and however it may have been formed and whatever may be its geological structure. On the Yucatan plateau similar conditions exist regarding the formation of atolls, only on a most limited scale.

The great coral reef regions are within the limits of the trades and monsoons and areas of elevation, with the exception of the Ellice and Marshall Islands and some of the Line Islands. The extent of the elevation is shown by the terraces of the elevated islands of the Paumotus, Fiji, Tonga, Ladrones, Gilbert, and West Indies, or by the lines of cliff caverns indicating levels of marine erosion.

In the regions I have examined the modern reef rock is of very moderate thickness, within the limits of depth at which reef builders begin to grow and within which the land rims of atolls or of Barrier Reefs are affected by mechanical causes. This does not affect the existence of solitary deep sea corals, of extensive growths of Oculina or Lophohelia at great depths, or in any way challenge the formation of thick beds of coraliferous limestone during periods of subsidence.

The Marquesas, Galapagos, and a few islands in the Society and West Indies have no corals, although they are within the limits of coral areas. Their absence is due to the steepness of their shores and to the absence or crumbling nature of their submarine platforms. Coral reefs also cannot grow off the steep cliff faces of elevated, coraliferous limestone islands.

Corals take their fullest development on the sea faces of reefs; they grow sparingly in lagoons where coralline algæ grow most luxuriantly. Nullipores and corallines form an important part of the reef-building material.

UNDERGROUND WATERS.

"THE Motions of Underground Waters" is the title of an essay by Mr. Charles S. Slichter, and it is issued as No. 67 of the Water Supply and Irrigation Papers of the United States Geological Survey. The author, in the first place, discusses the origin and extent of underground waters, remarking that these are included only in the zone of saturated rocks, the surface of which is known as the *water table* or *water plane*. The lowest depth at which ground waters can exist is regarded as approximately six miles. The region above this limit is distinguished as the zone of fracture, for in it pressures and stresses result in the breaking of the rocks. Below, all cavities and pores in the rock are completely closed. The amount of ground water within the crust of the earth is estimated to be nearly one-third the amount of the oceanic water, and to be sufficient to cover the entire surface of the earth to a uniform depth of from 3000 to 3500 feet. But these "waters under the earth" are, of course, only recoverable in useful quantities at limited depths; even the thermal springs arise from a level much above the geologic limit of depth.

Attention is directed to the fact that water is found in notable quantities in crevices of schists and gneisses, as in the St. Gothard tunnel; but the greater part met with in rocks is stored up in the minute pores and openings between the rock particles themselves, In sands, sandstones and limestones, in clay loams, while even the strongest rocks, such as the Montello granite, are measurably porous.

The author then discusses the cause and rate of movement of water through the strata, according to the size of the pores, the pressure and the temperature, the flow being noticeably greater for high than for low temperatures. This subject is illustrated by microscopic sections of rocks, and the author then passes on to the laws of flow, as determined by the length, shape and number of the openings between particles. In the mechanical analysis of soils, the mean diameter of the grains is known as the *effective size*, and is such that if all grains were of that diameter, the soil would have the same transmission capacity that it actually has. The effective size is determined from the dimensions of the mesh of a sieve which will permit 10 per cent. of the sample to pass through it, but will retain the other 90 per cent. That is, in any soil, 10 per cent. of the grains are smaller than the effective size and 90 per cent. are larger. It is remarked that the velocity of flow through porous strata is much less than might at first be supposed. In the sands of the Dakota formation, from which remarkable artesian wells draw their supply, the flow does not exceed a mile or two a year.

Underground waters are divided into three principal zones:—(1) The unsaturated zone, (2) the surface zone of flow, and (3) the deeper zones of flow. The motion of water in the unsaturated zone is essentially vertical—downward in supplying the saturated sheet below, and upward in supplying the surface evaporation and the requirements of vegetation by means of the capillary action of the soil during rainless periods.

The surface or upper zone of flow extends from the level of the water table to the first impervious rock floor. The deeper zones of flow are those that lie below the first impervious stratum, and the direction and character of the flow are usually quite independent of the surface topography, being controlled by large regional and geologic conditions.

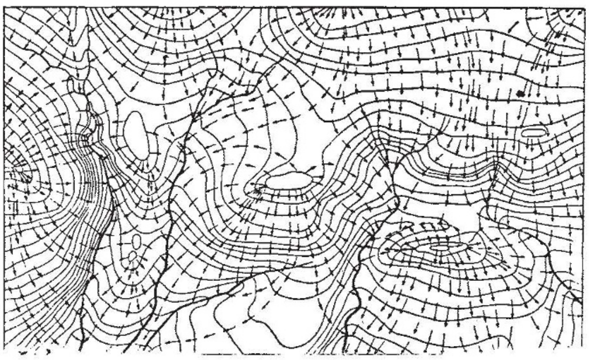

FIG. 1.—Contour Map showing position of water table (continuous lines), supposed lines of motion of ground water (arrowed lines), and the thalwegs or drainage lines (heavy lines).

The author points out that the unit of the surface zone of flow of ground waters is the river valley, and the rate and direction of motion conform primarily to the slopes and grades of the land surface. The underground flow, in fact, follows the trend and direction of the surface drainage. The water table has a slope which is essentially similar to the slope of the surface of the ground, though less steep. The motion of the underground seepage into the streams and rivers is similar to the lines followed by the surface drainage into the same streams.

The lowest line of drainage of the valley is known technically as the *thalweg*. Topographically, it is a line upon a contour map which is a natural water-course (Fig. 1). Beneath the thalweg there is usually a similar drainage line for the underground current, in general coincident with the thalweg. For other parts of the valley the actual lines of motion of the underground water are represented by a set of curves which cut the contour lines of the water table at right angles. The similarity of the contours of the water table to those of the land surface enables one to sketch approximately the lines of underground seepage from a contour map of the surface. For the most part the lines of flow run into the surface streams or thalwegs, but between A and B, and X and Y, there is indication of an underflow or general movement in the direction of the surface streams and independent of the same.

These views are worthy of attentive consideration and study in connection with the geological structure, for, as the author justly remarks, they must not be taken too literally. The surface topography is only one, and often not the most important, element in the control of the underground current. He points out how irregularities in the form of the first impervious layer and the amount of rainfall will influence the distribution and motion of the ground water. He directs attention also to the fact that much ground water returns to the surface in the form of seepage which is more important, though less obvious, than the springs. Much ground water, moreover, may not find its way immediately into open channels, but may even take a general course down the thalweg and flow through coarse materials toward the sea in large underground streams or moving sheets of water. This underflow is well known in the Great Plains of America, although the movement is excessively slow. Sometimes the underflows appear to be independent of the surface streams, as indicated by chemical analyses.

The deep zones of flow and artesian wells are finally discussed by the author; he deals also with common dug wells and the influence of pumping on contiguous wells, as well as the mutual interference of artesian wells. H. B. W.

LONDON FOG INQUIRY, 1901–02.[1]

IN November, 1901, the Meteorological Council appointed Captain Carpenter, R.N., D.S.O., a member of the council of the Royal Meteorological Society, to conduct an inquiry into the occurrence and distribution of fog in London, initiated, with the assistance of a grant from the County Council, in response to requests for more detailed forecasts of the occurrence of fog. Captain Carpenter at once put himself into communication with Captain Wells, R.N., the chief officer of the Metropolitan Fire Brigade, and made arrangements for the systematic observation of fogs at some of the river stations and at other stations of the Metropolitan Fire Brigade. He also arranged for supplementary observations to be taken at certain of the Metropolitan Police stations, at Battersea Park and Regent's Park, at a number of coast-guard stations in the Thames estuary, and by one or two private persons. Observations of temperature and other meteorological conditions were obtained from a number of the stations and from the parks; self-recording thermometers were installed on the Victoria Tower at Westminster, the Golden Gallery at St. Paul's, on the roof of the Meteorological Office and at a private house at Banstead. Regular records of fog in accordance with a conventional scale distinguishing the kind and intensity of the fog were thus obtained from a series of points in or round London. By arrangement with Captain Wells, special observations were made during fog or when fog was anticipated by the forecast branch of the Meteorological Office.

Attention may be called to the following points in Captain Carpenter's report, which is now issued:—

(1) The first result of the inquiry is the suggestion of a scale of fog intensity, arranged according to the interference with traffic upon road, rail, river, or sea, and represented by the serial numbers 0 to 5.

(2) Next it appears that on account of smoke the extreme limit of visibility in winter from an elevated position in London, in most favourable circumstances, is set at 1½ miles. That limit is diminished as the tendency to form fog is developed until the well-known effects of dense fog are reached.

(3) No evidence has been obtained of any special connection between fogs and geological conditions.

(4) The commencement of a fog is not identified with any particular locality; it seems to be a general process depending upon general atmospheric conditions. There is no evidence that fogs formed outside invade or drift into London. The London fogs are produced in London; they do not come from the country.

(5) The meteorological conditions for the formation of fog are set forth and illustrated by charts and diagrams. An interesting point brought out is a tendency to indraught

[1] Report to the Meteorological Council by Captain Alfred Carpenter, R.N., D.S.O.