ART. X.—*On recent Soundings in the Gulf Stream.*—Abstract of a paper read before the National Academy of Sciences; by HENRY MITCHELL, Assistant U. S. Coast Survey.

EARLY in the spring of the present year an application was made to the Coast Survey by the International Ocean Telegraph Company for information relative to the form and character of the bottom of the Straits of Florida between Key West and Havana along the proposed track of the submarine telegraph cable which is to connect the United States with the West India Islands. It was clearly the province of the Coast Survey to supply information of this sort, and a special survey was therefore ordered under instructions from Mr. J. E. Hilgard who, during the illness of Prof. Bache, conducts the work of this bureau. These instructions were carried out carefully and under favoring circumstances, so that the results are entitled to confidence.

The distance from Sand Key, on the extreme southern point of the Florida reef to El Moro rock at the entrance to Havana, is but a trifle over 82 miles. To lay a cable over this short distance would seem to be an easy task and one that should long since have been executed. In fact, however, the locality offers a new problem to the engineer, viz: *to lay a cable nearly at right angles to a strong stream, or system of streams, flowing through a rocky pass of great depth.* The new survey, if it does not, as is hoped, supply the elements for the solution of this problem, at

least develops and gauges the difficulties of the task, and incidentally adds a few items of interest to physical inquiry.

The line of maximum depression was struck at a point 24 miles north of the Moro, and followed some distance to the northeast with depths of 858, 845 and 794 fathoms. The direction of this line does not correspond to that of the Gulf Stream in this neighborhood; but a glance at the map will show that a S.W. course would be a natural one for the *Polar Current*, as it is called, which runs near the bottom.

The numerous soundings of this survey make it possible to develop a profile of section from Sand Key to the Moro, and the subjoined table gives the numerical data for such a profile.

Section of Soundings across the Straits of Florida, from Sand Key to El Moro.

Position on profile.		Distances from Sand Key.	Distances from El Moro.	Depths. By indicator.	Depths. By outrun of line.	No. of stations sounded.	Kind of bottom.	Remarks.
Northern approach to channel.	A	2¾	79½		65		rock.	Coral strewn over with shells.
	B	7½ to 8½	74½	111	125	5	"	Specimen of coral debris obtained.
	C	11	714	129	132	1	"	
	D	14½	67½	289	309	2	"	Specimen of coral debris.
	E	18½	64	369	397	1	mud.	Specimen of gray mud.
	F	24½	58	432	466	1	"	Specimen of mud nearly white.
	G	29⅓	53⅓	504	553	2	"	Specimen nearly white with dashes of red.
	H	34	48½	687		1	"	Specimen of stiff mud, nearly white.
	I	38	44½	794		1	"	Specimen gray and granular mud.
Southern approach to channel.	i	45½	36½	845	No indication of depth by the outrun of line.	1	"	Specimen nearly white with red tinge.
	h	51½	31	842		3	"	Specimen same as above.
	g	55½	26½	818		2	"	Specimen same as above.
	f	60	22½	455		2	"	Specimen of mud with drab color.
	e	61½	20½	380		1	"	No specimen—some doubt of cast.
	d	67½	15	710		1	hard.	
	c	73½	9	748		1	mud.	
	b	78½	3½	583	620	1	sand.	Sand or mud of reddish brown hue.
	a	80½	1½	243	244	1	rock.	A small shell obtained.

In this profile, which is, strictly speaking, that of a diagonal section, the point of maximum depression is found 37 miles from the Moro, and is 843 fathoms. The approaches to the great valley from the two coasts are dissimilar in general features. From the northward the bottom falls away in *terraces* whose intervening slopes are nowhere abrupt; while from the southward an irregular and hilly approach is found with indications of abrupt if not precipitous changes of elevation. Above the terraces of the north shore the sea lies almost motionless, while among the cañons of the southern half of the Straits flow the Gulf Stream and its counter currents.

These natural distinctions authorize us in taking up separately the descriptions of these approaches, and we shall proceed to do so briefly, commencing at Sand Key and following the profile southward from A to I: then commencing at the Moro and following northward from *a* to *i* (see table).

Northern Approach.—Leaving Sand Key, the water deepens rapidly to 18 fathoms, then shoals again to 7 fathoms upon a coast bar or ridge parallel to the reef, and scarcely ⅘ths of a mile distant from it. Seen from the deck of a ship upon a fine day this bar is marked by a narrow belt of pale blue-green water in beautiful contrast with the dark blue-black of the ocean. The bottom can be seen on crossing it and appears to be a pure white rock *in situ*, strewn sparsely over with fragments of the weathered and brown reef rock. Two miles farther out carries us to the point A, where our table for the profile commences with sixty five fathoms of water on a slope of one foot in thirty seven. The next points B and C lie upon a nearly level plain which terminates about twelve miles from the reef in a slope of one foot to twenty-two. Upon this terrace numerous soundings were made covering about eight miles of longitude, which show that the formation belongs to the reef system and lies parallel to it. Chips of white coral rock were brought up in one of the casts—in all of them the hard bottom was felt by the hand. At what appears to be the foot of the fore slope of this terrace (point E) the bottom is found to be soft mud, and a specimen procured proved to be of a grey color quite in contrast both as regards color and consistency, with that obtained above or beyond. It differed from the white muds beyond, of which we shall hereafter speak, in possessing a granular character and retaining the same when dry. It is conceived that this terrace was once a dry reef covered over like Sand Key with dark fragments of agglomerated reef rock, and that a subsequent submergence has caused all this loose and weathered material to be swept down to the foot of the fore slope.

Between D and E, in about 800 fathoms, the *swept* portion of the Florida Reef, if not also the *base* of the formation, is passed. At F, G and H the bottom is of nearly white mud, with dashes of red at the last named point. These muds were found to *set* on drying. The mud with dashes of red is supposed to be the debris of a kind of coral, quite common upon the reef, which is spotted as if with drops of blood. These three stations seem to comprise another grand terrace, because at the 500 fathoms curve there seems to be a considerable belt where a difference of a mile in latitude or longitude scarcely altered the soundings. If this is so, we must suppose that we are not yet beyond the reef and that the rock still underlies the material which the specimen cup procures. *At the foot of the fore slope of this second terrace* (I)

in 794 fathoms, the mud is again grey and *granular* while the next station beyond is of the ordinary white tinged with red.

Do these features belong to the history of the Gulf Stream or to the geology of the coral reef? As these slopes and terraces are now scarcely traversed by the streams, we are inclined to regard them as exhibiting the order in which, through successive ages, the reef has alternately subsided and stood still. As far as the swept portion of the reef apron extends, we see no indications of any caving down of the structure; and in the neighborhood of the second terrace the presence of mud forbids the supposition of long continued abrasion.

Southern Approach.—The Moro Rock is nearly perpendicular at the water line but retreats at points higher up. Its northwest profile is convex with a mean dip of 45° from the castle wall to the sea. Leaving this rock and advancing 1¼ miles northward, the bottom declines 1 foot in 7 to point *a*, where the depth is 243 fathoms and the bottom, *rock*. From *a* to *b* the depth increases very rapidly, 1 foot in 6, and the foot of the Moro Rock is passed. The bottom at *b* is a reddish brown mud which becomes in part granular on drying—*in many respects it resembles the specimens from the foot of the fore slope of the coral terrace on the north bank of the straits.* It is no doubt weathered debris swept down from the Moro.

The dip of the rocky part of this space between *a* and *b* is unquestionably much more precipitious than the mean we have stated, because 1 foot in 6 is altogether too great an inclination for the material found at *b*.

Beyond *b* the slope is gradual, 1 foot in 32, and terminates at *c* in the nearly horizontal bed of a depression which we shall call the Moro Channel. Here at *c* the depth is 748 fathoms. Six miles farther carries us across the Moro Channel and we find the depth a trifle more shallow, 710 fathoms, at *d*.

At *e* and *f* we find ourselves near the summit of a submarine mountain whose height above the bed of the Straits is about twenty four hundred feet. This mountain, lying but a few miles to the northward of the axis of the Gulf Stream, may be claimed as a point of decided interest in this survey. It is scarcely twenty one miles from the shore of Cuba whose hills are in full view if the weather is fine. Six casts were made upon its summit under the greatest difficulties, owing to the current. Only three of these proved successful and but one yielded a specimen of bottom. The depth on the summit was found to be about 400 fathoms. On looking over the work of former years we find that Capt. B. F. Sands in 1858 made deep sea soundings in this locality, and that he struck one sounding of 320 fathoms on the same parallel, but some twelve miles to the westward. He procured a specimen and observed the temperature to be 60°

which is the usual amount for this depth in the Straits of Florida. The Polar current which underlies the stream, following the line of maximum depression, has a temperature of less than 45°. At first thought, it might be supposed that an obstacle in the track of the stream would cause an ascension of the Polar current, but when we consider that this Stream Bank has not the nature of a bar, and that the deep channel way beyond is ample, there would seem to be no reason for an ascension of the cold waters in this neighborhood.

Several other casts, not referred to in our table, because too far to the eastwasd of the section line, furnish some clue as to the form of the Stream Bank. It appears to be triangular in its general figure, presenting at its west angle a bold prow to the stream. As the current is here flowing with an accelerating velocity, a *deposit* is impossible. This bank, it appears to us, must have, like the adjacent reef, a firm constitution. It is an interesting question whether it belongs to the mountain system of Cuba (as its line of least water running E. and S. E. might seem to indicate), or whether it is an ancient reef now wearing and crumbling away. The least depth is about that of the foot of the *swept* portion of the reef apron on the north side of the Straits —it may indicate the true depth of the Gulf Stream itself, and if so, its summit is not now abraded, while its base must be wearing away under the action of the Polar current. A bank so situated must have precipitious slopes.

Observations upon the trend of the lead line, on hauling in, furnish indications that the thickness of the upper moving stratum, i. e., the depth of the Gulf Stream, is scarcely more than one third of the maximum depth of the channel. This stream seems to be an *overflowing* of water, not a profound movement. In the exchange between the Gulf of Mexico and the Atlantic, the office of the Gulf Stream appears to be the *restoration of surface level*, while the office of the counter stream, ("Polar current") below, is the *restoration of equilibrium thus disturbed*, between waters of different specific weights or densities. To illustrate this view of compensating currents, we may be suffered to recall an instance from our experience in observations at the mouth of Hudson River. In the dry season (July) the surface *outflow* (brackish) through the Narrows of New York harbor, occupies nine out of the twelve tidal hours, while in the lowest water stratum the case is more than reversed, the *inflow* (salt) predominates to that extent, that as a general thing it is *continual* along the bottom, although not *constant* in velocity. The same conditions, with variable proportions, were followed some distance up the river. On running a line of levels from New York city to Albany it was found that the bed of the Hudson lies below the *mean level* of the sea for over a hundred miles; but that the sur-

face of the fresh water, even in the dry season, is above this level—not so much above, however, as to *equalize the difference of specific weight between it and the sea water*, so that the latter, during the summer months, flows in along the bed of the stream, while the former *overflows* into the ocean.

In the recent survey, observations upon surface densities were carried over several hundred miles. These show decided contrasts between the ocean and the stream, but no greater than the differences of temperature might lead us to expect.

The Gulf Stream is essentially confined to the southern half of the Strait in the portion crossed by this survey, but no westwardly drift along the north shore was observed except at one time a feeble flood tidal current setting close along the reef. It is not impossible that the widths of the Gulf Stream vary, as its velocities are known to do, and both of these may in many cases depend upon long continued gales of wind. During the period of the recent survey, however, the weather was exceedingly calm in the Gulf, and as far as learned, generally quiet at sea, yet the velocities of the stream altered in a marked manner, and so much so that the changes became a matter of comment among pilots and ship masters arriving at Havana. It would be exceedingly interesting and practically useful to ascertain from systematic inquiry the order of these variations. We would suggest as a reasonable hypothesis that these variations follow those changes of *mean-sea-level* which depend upon the declinations of the sun and moon—more especially the latter. There are no two seas upon the earth whose tidal phenomena differ more essentially than those of the Gulf of Mexico and the Atlantic Ocean; and it is a matter of certainty that the elevations of these two bodies of water are not affected in the same manner and degree by the half-monthly changes of the moon's declination. Professor Bache's paper on the "Tides of Key West," published in the Coast Survey Report of 1853 shows that the *mean level* of this station is one foot higher when the moon is in the equator than when she is at her greatest declination. In the North Atlantic the order is the reverse of this; the mean level is there about three inches higher at the maximum than at the zero declination.* Small as these relative changes of elevation may seem they must bear a large proportion to the total head of the Gulf Stream which suffers exceedingly little resistance in its course.

* From computations of the Coast Survey, and from Phil. Trans. R. S., 1839.