SCYLLA AND CHARYBDIS AND THE TIDAL CURRENTS IN THE STRAITS OF MESSINA

by

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(Extract from the "*Annalen der Hydrographie*" of 15 May 1940, pamphlet V, p. 145 to 157).

No other natural phenomenon attained such popularity in ancient times as the phenomenon of the tidal currents which occur with a regular rhythm in the Straits of Messina, and which Homer in his description associated with the redoutable Scylla and Charybdis. Scylla, a monster and horrible object, residing in a dark cave at the southern end of the Italian Peninsula; and Charybdis an insatiable woman, who, immersed in the coastal-waters of the Sicilian beach ceaselessly swallows and violently throws up the masses of sea-water. These are the damned daughters of Neptune, which in the mythological symbolism of Homer represent in the ancient legend the grave dangers which threaten navigation in the Straits of Messina between the Ionian and the Tyrrhenian Seas. In the twelth canto Homer has described in a vividly impressive manner these monsters of the Straits of Messina as well as the dangers involved in the passage through these Straits. In an analogous manner, undoubtedly influenced by the description of Homer, Virgil painted the dangers of Scylla and Charybdis in his Aeneide. We find them also mentioned in the Metamorphosis of Ovid. The following verse is well-known :—

"*Incidis in Scillam cupiens vitare Charybdim*"

In the Pharsalia of Lucan and also in other work of antiquity Scylla and Charybdis always appear. We find that when the ancient Greeks began to regard the objects of nature in a scientific manner, it was again Aristotle who foresaw, and then explained the relation between the phenomenon of the currents and that of the ebb and flood of the tide in the Ionian Sea and in the Tyrrhenian Sea. The ancient legends, which perhaps exaggerated the dangers to navigation in the Straits and sought to conceal under the fantastic myths the prevailing ignorance of the phenomena, have endured to the middle ages. Thus we find in the seventh canto of the Divine Comedy of Dante an indication of the phenomenon in these words :— "Like the billows which alas on Charybdis, break on the others into foam". These words furnish the true explanation of the phenomenon; nevertheless what Homer and later Virgil stated, that every day, three times a day there was an aspiration and expulsion of masses of water at Charybdis, is not a poetical embellishment, but the truth.

At each reversal of the current the phenomenon is produced, and these reversals occur four times during the lunar day of 24 hours and 25 minutes, and three times during the solar day.

The first study of the nature and causes of the currents of irregular and turbulent appearance in the Straits of Messina is due to the french Vice-Consul at Messina, P. Ribaud. The results were published in 1824. In 1907, L. Marini, basing his research on this work gave a detailed account of the reversal of current in these Straits; he was the first to give for each lunar hour a representation of the characteristics of the current in 12 tables, of which 4 have geen reproduced in Krümmel's Manual of Geography. In the following years it was rather the maritime geologists who interested themselves in these features of the Straits of Messina. Lohmann (Hamburg) and Mazzarelli (Messina), through a very complete study of animal life at great depths, especially of those animals whose life is generally passed at depths of 1000 meters and more, and which are passively thrown up on the surface and from thence on the shores of the Straits of Messina in a dying or semi-dying condition, have shown the state of affairs resulting from these abnormal submarine currents, particularly at the time of syzigies, (full and new moon) and that it is necessary to count on powerful vertical displacements of water in the region between Ganzirri and Point Pezzo.

As early as 1922, Professor F. VERCELLI (1) of the Italian Committee on Thalassography, had been delegated to undertake comprehensive research on the oceanographic features in the Straits of Messina. These were conducted between 1922 and 1923 with the research vessel "*Marsigli*" of the Royal Italian Navy both from the point of view of currents and that of the oceanic structure of the masses of water in the Straits. An exhaustive analysis made by VERCELLI of the observations resulting from this research constitutes the basis of the geophysical explanation of the phenomena of the Straits of Messina. We shall have occasion to refer frequently to these important results. Finally, in 1938, Gustavo MAZZARELLI, the son of the one cited above (2), has published the observations which he made on the eddies, convergences of currents, tide ripples and other manifestations of the current in these Straits. While it is true that these are not founded upon numerous measurements, they are very important in describing the phenomena in the Straits and in showing their course.

Querschnitt	Längs-koordinate km	Oberfläche zwischen zwei Querschnitten km²	Breite km	Querschnitts-fläche km²	Mittlere Tiefe m
0	0.0	62.78	23.10	20.11	870
1	3.05	50.53	18.63	14.91	800
2	6.11	46.08	14.86	11.48	775
3	9.16	41.54	14.86	9.41	635
4	12.22	33.20	12.11	6 64	550
5	15.27	32.51	10.28	4.93	480
6	18.32	30.56	10.48	3.86	370
7	21.38	12.26	9.06	2.54	280
7a	22.90	10.12	6.92	1.82	260
8	24.43	11.97	5.90	1.20	220
8a	25.96	9.73	6.41	1.28	200
9	27.49	8.16	6.01	0.78	130
9a	29.01	6.78	5.19	0.42	80
10	30.54	5.49	3.97	0.33	85
10a	32.07	5.37	3.87	0.52	130
11	33.59	5.13	3.87	0.45	120
11a	35.12	9.84	3.97	0.56	140
12	36.65	18.25	8.55	1.23	140
12a	38.18	25.12	16.80	2.92	175
13	39.70	69.68	19.65	4.20	215
14	42.76	85.83	23.92	6.17	260
15	45.81		30.13	8.52	285

TABLE I. — *Morphological Elements in the Straits of Messina.*

A few words will suffice for the morphology of the Straits of Messina. As is shown in Table 1 and Fig. 1 the shoalest water between Calabre and Sicily is found along the profile Point Pezzo-Ganzirri. This profile, with a width of lightly less than 4 kilometers has a cross section of only 1/3 square kilometers, so that the average depth is not more than 80 meters; the greatest depths lie in two trenches of about 120 meters depth.

Starting from this rise the ocean floor sinks rapidly towards the north and the south in the form of a valley, to about the same extent in both cases. We find even in the axis of the Straits depths greater than 300 meters near Messina, about 700 meters near Reggio, then 1200 meters between Cape Ali and Point Pellaro. The axis of this southern part almost follows the meridian, while that of the northern part, having a smaller section,

(1) *Cruise for the study of the phenomenon in the Straits of Messina* (R.N. Marsigli 1922-23), *International Mediterranean Commission, Venice* 1925 *and* 26. — F. VERCELLI : I. *The flow of currents and the tides in the Straits of Messina.* - F. VERCELLI and M. PICOTTI : II. *The physico-chemical regimen of waters in the Straits of Messina. There is given in the special list by* VERCELLI *the bibliography of the previous work antedating this geophysical research.*

(2) G. MAZZARELLI : *I vortici, i tagli e altri fenomeni delle correnti dello stretto di Messina.* Atti Real. Acc. Peloritana. Vol. XI, Messina, 1938.

bends sharply to the N.E. There also, the depths quickly reach 200 meters and then level off to the isobath of 300 meters on the axis between Cape Peloro and Scilla. Table 1 shows how the sections and also the mean depths of the profiles normal to the axis of the Straits are modified progressively from the South to the North. Between the rise located on the profile Point Pezzo-Ganzirri the variation in mean depth to the South as well as towards the N.E. is almost linear, although in the first case it is much more rapid than towards the N.E. The appearance of the surface of the sections shows how in the central part (between sections 9 and 12) soon after the bending of the axis towards the N.E., the narrowing of the Strait is particularly pronounced and almost uniform for nearly 7 kilometers. There, like a barrier, it separates the Ionian Sea from the Tyrrhenian Sea.

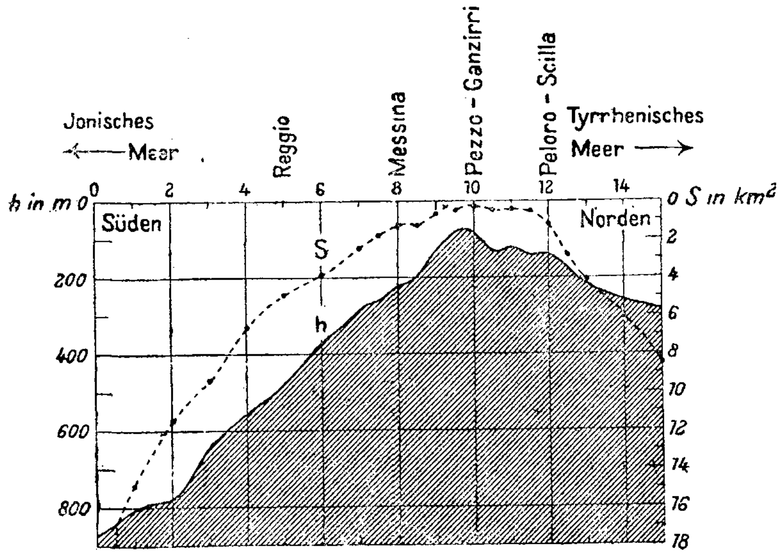

FIG. 1. — *Morphology of the Straits of Messina.*

h = *mean depth derived from 15 cross-sections normal to central axis.*
s = *Cross-sectional areas for the same sections.*

In order to understand the tidal relations in the Straits of Messina it is necessary to know the tides in the adjacent seas, the Ionian Sea to the southward and the Tyrrhenian Sea to the northward, outside the entrances to the Straits. In these two seas, as in general in the Mediterranean, the tides are of the so-called semi-diurnal type. It will suffice therefore to consider one of the principal waves, or, at the time of the greatest development of the phenomenon, i.e. at the time of full or new moon, the sum of the two principal waves M_2 and S_2. In the Ionian Sea, just before the Straits, the phase of this wave is 266°, that is, high water occurs 8.9 hours and low water 2.9 hours after the meridian transit of the moon. The amplitude is about 17 cm. In the Tyrrhenian Sea, just before the Straits the phase of this wave is, on the contrary, 92°; that is to say, high water occurs about 3.1 hours and low water 9.1 hours while the amplitude is about 10 cm. The opposition between these characteristics at the northern and southern extremities of the Straits is shown distinctly in fig. 2.

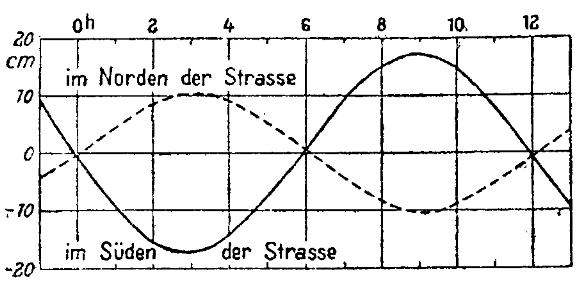

FIG. 2. — *Tidal relations at the North and South entrances to the Straits of Messina.*

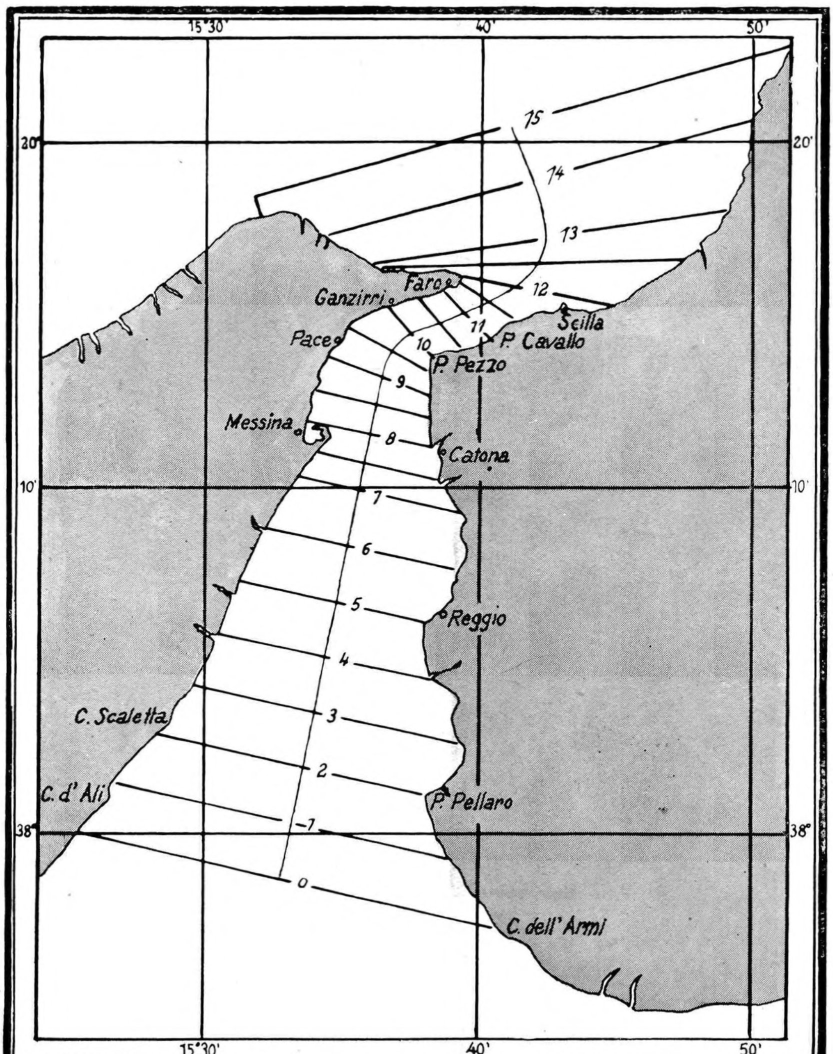

FIG. 3. — *Location and arrangement of the 15 sections normal to the mean axis of the Straits of Messina.*
The morphological data necessary for the calculation are given in table 1.

We see from this that the two seas act in quite a contrary manner from the point of view of the beginning of the ebb and the flood. When the water is high in the Ionian Sea at the entrance to the Straits of Messina it is at low to the north in the Tyrrhenian Sea and vice versa.

The water masses in the Straits of Messina, which constitute the connection between the two seas, then oscillate in accordance with the impulses furnished by the tides of the Ionian and Tyrrhenian Seas. It is in conjunction with and because of these tides that the phenomena of ebb and flood, as well as the relation between the tidal currents, occur in the interior of the Straits. By certain methods which I developped very completely at the time, it is possible to calculate these relations with close approximation from the limiting conditions existing at the north and south, while taking into consideration the morphology of the Straits and the friction encountered by the water masses in movement at the bottom of the sea.

Table 2 gives the results of the calculations, based on 22 sections, the location and direction of which are shown in fig. 3. Their separation along the central axis is 3.054 kilometers. However, between each of the sections from 7 to 13 an intermediary section has been introduced which reduces the separation to 1.527 kilometers.

The Ionian wave oscillates in accordance with the tides of the Ionian Sea just off the southern entrance to the Straits. There, the constants for the tide (amplitude and phase) have been taken as 10 cm. and 90°, corresponding to the actual values for the Ionian Sea. The Tyrrhenian waves oscillates in accordance with the tides to the northward in the Tyrrhenian Sea; the constants are 17.0 cm. and 265°. Table 2 gives the vertical amplitude of the tide μ and the horizontal displacement ξ (positive towards the North) for the two waves. On one side is given their composition, which constitutes the theoretical tides in the Straits joining the two seas, i.e.: the amplitude and the phase of the vertical tide; 2° the amplitude of the horizontal displacement ξ, of which the phase is practically constant throughout the entire Straits and equal to 267°. 3°) the current calculated in accordance with these results (positive towards the north) and the amplitudes in cm/sec.; the phase everywhere is 177°.

This calculation takes into full account all the morphological features of the Straits as shown in table 1, but neglects entirely the influence of friction.

Fig. 4 shows graphically, the distribution of amplitude and phase of the vertical tide along the Straits.

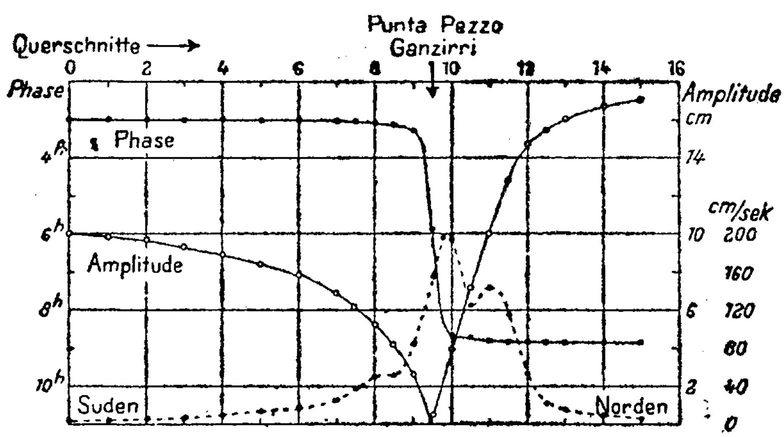

FIG. 4. — *Phase and Amplitude of the Tide in the Straits of Messina and the strenght of the corresponding tidal currents. (Calculations made without considering friction).*

In that part of the Straits to the southward of the profile Punta Pezzo-Ganzirri; i.e. the narrowest section of the Straits, the tidal relations are essentially the same as

(3) See in particular: A. DEFANT. "*Gezeitenprobleme des Meeres in Landnähe*". Vol. IV der Probl. der Kosm. Physik, Hamburg, 1925, or "*Dynamische Ozeanographie*", Berlin, 1919.

those in the Ionian Sea, except that the magnitude of the tidal variation gradually falls off to zero as it approaches this vicinity, while the phase remains the same as in the Ionian Sea until just off the narrowest part. On the other hand, in the part to the northward of the narrowest section, the tides act the same as in the Tyrrhenian Sea, except that here the amplitude falls off very rapidly as the narrowest section is approached while the phase remains practically the same as in the Tyrrhenian Sea until immediately off the narrowest section.

In a very short space of slightly over 3 kilometers the phase of the tide therefore changes by almost 6 hours, such that, when high water occurs in the southern portion of the Straits, it is low water in the northern part, and vice versa. Although the differences in height of water are not very great in the course of the tidal changes, they are, on account of the narrowness of the Straits, sufficient to give rise to very considerable current oscillations. Fig. 5 shows the form of the surface of the sea along the Straits during several characteristic hours of the tidal period. At o h. the surface of the sea is almost horizontal;

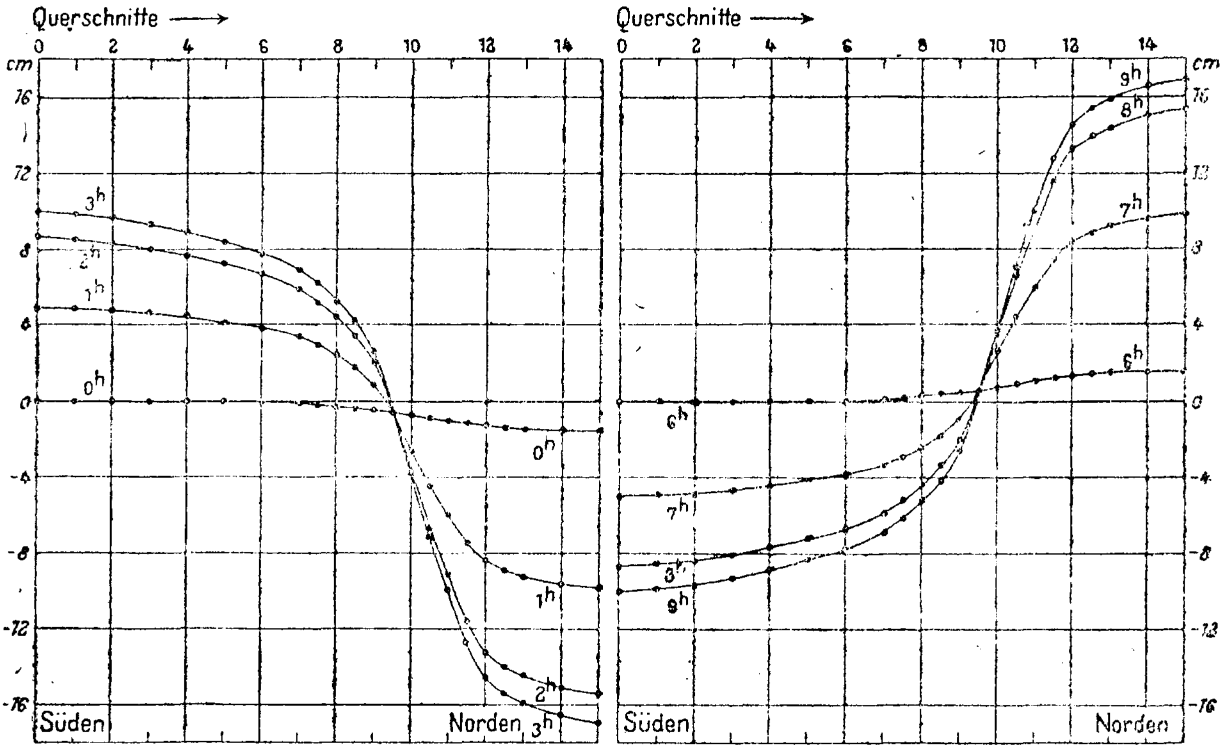

FIG. 5. — *Form of the surface of the sea along the central axis of the Straits of Messina for the various tidal intervals.*

there is almost no difference in level. At 3 h., on the contrary; there is, at the northern entrance of the Straits, a difference in level of 27 cm. The slope of the surface descends from South to North. At 9 h. the difference in surface level is still relatively great, but the slope descends from North to South. The slope is confined to the inner parts of the Straits, almost in the region between sections 8 and 12, which are separated by a distance of 12.2 kilometers. The maximum difference in level for this stretch is 20 cm. or about 1.7 cm. per km. This difference in level is sufficient to impress a very great velocity on the masses of water.

The speeds of the current and their variations along the Straits of Messina are of particular interest to us, especially in their relation to the phenomena of turbulence, which occur principally at the northern exit and in the narrowest sections of the Straits, phenomena which are associated with the turbulence of Charybdis and Scylla. In accordance with the values ξ of the horizontal displacement of the current and its phase, we may easily calculate the tidal current resulting from the vertical tide; the amplitude of which is $u = \frac{2\pi}{\tau}\xi$ and the phase which is 180° in advance of that of ξ. We find also in Table 2 the values relating to the tidal currents. According to these calculations the current sets to the North between 3 h. and 9 h.; this is called the *rema montante*. The greatest velocities are encountered throughout the entire Straits shortly before 6 h. The greatest value occurs at the narrowest place in the Straits and amounts to nearly 2 m/sec. Between 9 h. and 3 h. the current sets to the South; the *rema scendente*. The greatest values are found near 0 h.; the maximum value attained again being about 2 m/sec. in the narrowest place.

We may still verify these results, obtained chiefly by calculation, although based upon observations at the northern and southern exits of the Straits. With regard to the vertical tide, they are in complete agreement with the data obtained from the records of the tide-gauges located at certain places along the Straits. In particular, the fact that the amplitude is almost zero in the region of the narrowest section has been definitely proven by observations. The research vessel *Marsigli* was anchored for 15 days in a depth of 106 meters on the section Point Pezzo-Ganzirri in order to measure currents at depths of 5, 10, 20, 30, 50 and 90 meters. These measurements are of exceptional value in throwing light on the current features in the narrowest portion of the Straits of Messina. Professor F. VERCELLI has made an harmonic analysis of these measurements of current and has utilized the results to determine the totality of characteristics of the current in the Straits. We are interested here above all in the current components of the wave $M_2 + S_2$; which are, moreover, the most important. The action of the components is reproduced in a synoptic manner in fig. 6.

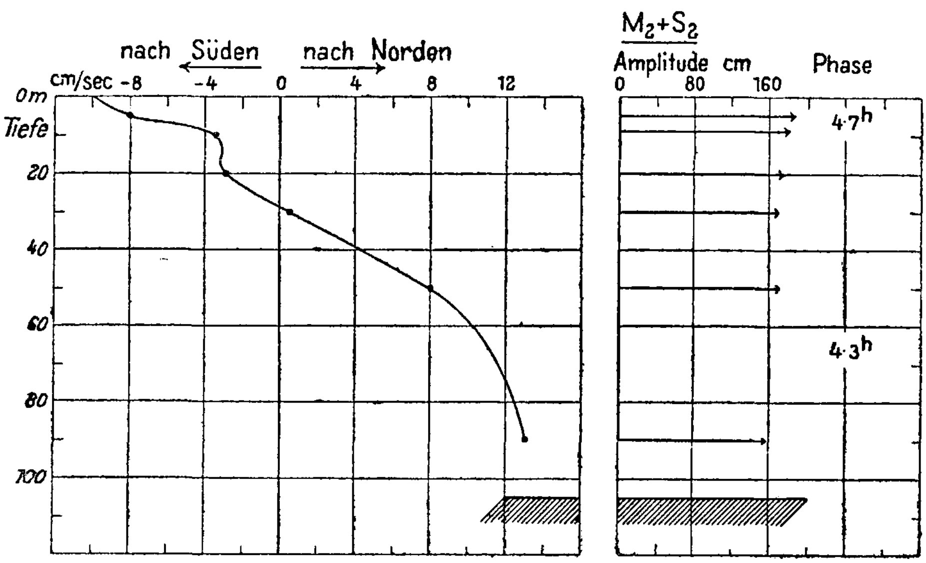

FIG. 6. — *Current relations in the Straits of Messina.*
According to observations by the R.N. "Marsigli" at anchor.
On the right: "Residual Current"; left; amplitude and phase of the $M_2 + S_2$ wave.

It should be noted at first that on the average, up to about 30 meters depth, the current sets to the southward, and from that depth to the bottom, to the north. This could have been foreseen moreover from the distribution of densities in the adjacent seas. But the velocities of the current are low, of the order of 10 cm/sec. at most on the surface and at the greatest depths. These were the conditions obtaining at the time when the *Marsigli* made the observations, but these conditions do not necessarily exist always. On the contrary, as Vercelli has already pointed out, these velocities may reach as much as 50 cm/sec. in certain states of weather and under the influence of certain winds. The periodical tidal currents are very much stronger. We may say that the same characteristics hold for the entire column of water; the tidal current acts upon the entire mass of water at the same time. At the station the tidal current had a phase of about 140°. As a consequence the strongest set of current towards the north occured at 4.7 h., and towards the South at 10.7 h.: the greatest velocities were about 160 m/sec.

In accordance with the previous theoretical study, the times of the strongest currents to the North and towards the South should be exactly 5.9 hours and 11.9 hours. The observations show an advance of 1.2 hours in the time of occurance of these phenomena. This fact must certainly be attributed to the influence of the friction to which the masses of water are subjected in the course of their movements in the two directions. However, it is necessary to take into consideration not only the considerable friction resulting from the flow of water over the very uneven bottom of the sea and through the narrow and shoal passages of the Straits, but also the internal friction due to the turbulence, which is certainly very great, as shown by the existence of the very irregular currents revealed by observations. This friction is also particularly increased by the fact that in the narrowest portion of the Straits there is produced an eddy of two different kinds of water. Since the waters of the Ionian Sea are heavier than those of the Tyrrhenian Sea, as a result of their density and temperature, and the fact that these waters are continually thrown against one another in the narrowest portion of the Straits, considerably increases the turbulence.

It is difficult, without the assumption of some particular hypothesis, to translate into figures the action of the powerful frictional influences, and also because these effects act over a very short stretch (nearly between sections 7 and 12) of about 15 kilometers, while outside this region, the frictional resistance disappears almost completely. But we may easily evaluate its mode of action by the following considerations which are of interest in relation to the drift of the current at the narrowest portion of the Straits.

If the Straits of Messina were closed off from the South at about section 9 (to the southward of Pace — to the south of S. Giovanni) the tides of this bay of the Ionian Sea would be similar to those of that sea; a short calculation shows that the amplitude and phase of the tide would not be different in the extremity of this interior bay from those which occur at the southern entrance of the Straits.

Querschnitte	Ionische Welle		Tyrrhenische Welle		Zusammensetzung				
					η		ξ	u	
	η cm	ξ m	η cm	ξ m	Ampl. cm	Phase °	m	cm	angenommene Phase
0	10.0	80	0.0	145	10.0	90°	224	3.2	180°
1	9.9	110	0.1	195	9.8	90°	305	4.3	180°
2	9.9	145	0.2	255	9.7	90°	399	5.7	180°
3	9.7	175	0.4	310	9.3	90°	484	6.9	180°
4	9.6	250	0.7	440	8.9	90°	690	9.8	180°
5	9.4	340	1.0	590	8.4	91°	929	13.2	180°
6	9.2	435	1.4	750	7.8	91°	1 184	16.8	180°
7	8.9	655	2.0	1150	6.9	91°	1 603	25.6	180°
7a	8.6	920	2.4	1600	6.2	92°	2 517	35.7	171°
8	8.3	1300	3.1	2260	5.2	93°	3 556	50.5	165°
8a	7.9	1310	3.7	2280	4.2	95°	3 586	50.9	159°
9	7.3	2140	4.7	3810	2.6	99°	5 948	84.4	153°
9a	6.4	4010	6.4	6970	0.5	177°	10 968	155.8	145°
10	4.9	5040	8.8	8750	3.9	259°	13 776	195.6	140°
10a	3.6	3255	11.1	5640	7.2	262°	8 881	126.1	138°
11	2.6	3700	12.6	6420	10.0	264°	10 109	143.5	136°
11a	1.5	2995	14.4	5190	12.8	265°	8 176	116.1	135°
12	0.8	1365	15.6	2370	14.7	265°	3 731	53.0	135°
12a	0.5	575	16.1	1000	15.5	265°	1 573	22.3	135°
13	0.4	400	16.4	690	16.0	265°	1 088	15.5	135°
14	0.1	270	16.8	470	16.7	265°	739	10.5	135°
15	0.0	197	17.0	336	17.0	265°	532	7.6	135°
Phase	90°	270°	265°	265°			266.8 266.9	177°	

TABLE II.

Let us suppose, on the other hand that the Straits were to be closed off from the North at section 11a (Cape Peloro-Torre Cavallo). The tides, as well in amplitude as in phase would then be in agreement with those of the Tyrrhenian Sea, of which it forms at part. On each side of the middle of the Straits, which we must assume to be represented by an earthen barrier of about 6 kilometers length, the tides occur in the opposite sense. To the north High Water would occur at 2.9 hours, to the South at 8.9 hours; the times of Low Water would occur respectively at 8.9 hours and 2.9 hours.

If we then cut a narrow channel through this middle ground, joining the two seas, the differences in level on each side would tend to equalize by the effect of the currents. The greatest velocities would occur at the moment when the greatest differences in level existed; while, for the rest, the friction alone would determine the velocity of the current. Under these conditions the phase of the speed of the current in the narrow channel would be 2.9 hours; i.e. apprpoximately 90°. This represents an extreme value. If, on the contrary, the connection between the two seas is so large and deep that frictional influences disappear, the phase of the tidal currents would then attain the value which we can take from Table 2, or about 180°. This is a second extreme case. In the first case the inertia is completely dominated by the friction, while in the second the friction is dominated by the inertia. All the intermediate cases can occur by successive progression between the Ionian and Tyrrhenian seas. In the case presented by nature in the Straits of Messina, having a width and depth increasing constantly, but with a turbulence (friction increased by the exchange of different kinds of waters), there will undoubtedly be produced a mean between the above mentioned extremes. The phase of the periodical current will then be about $(90° + 180°) : 2 = 135°$. Therefore it is not by mere chance that the phase of the component wave $M_2 + S_2$, furnished by harmonic analysis of the current measurements should work out to about this value, i.e. 140°. We conclude therefore, that in the Straits of Messina, the friction is the cause of the phase obtained for the tidal current and that it cannot be understood if this is not taken into consideration.

It is clear, that in order to obtain an insight into the characteristics of the currents in the Straits over the various lunar periods, they should be calculated along the axis of the

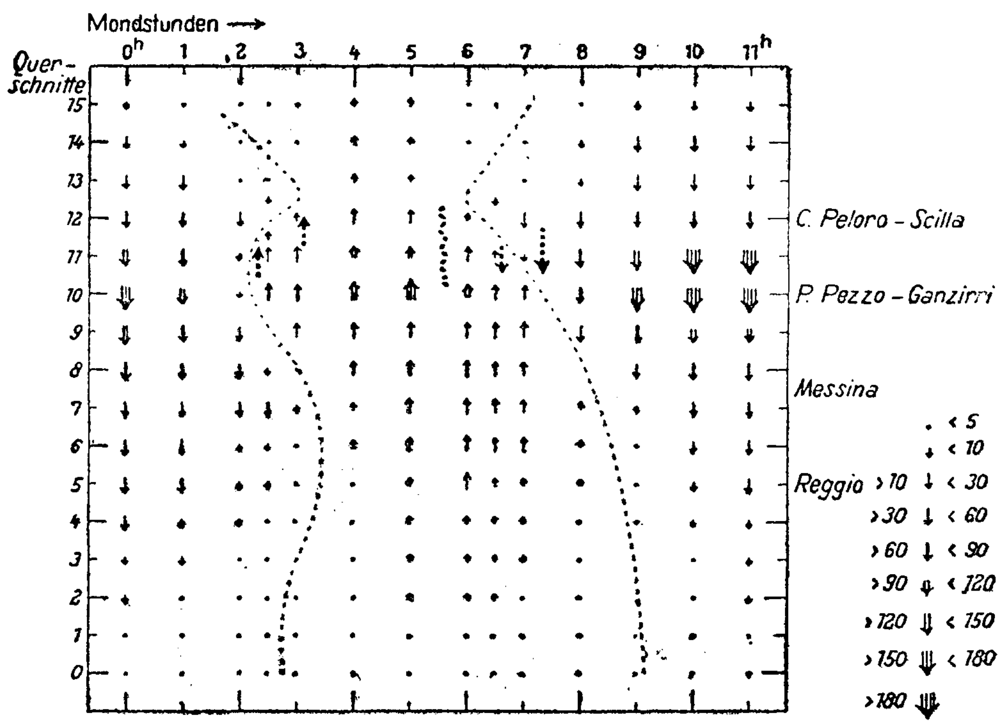

FIG. 7. — *Current relations along the central axis of the Straits of Messina for each lunar hour.*

channel by means of the values given in Table 2 for each lunar hour, taking from them for each section, in order to keep in agreement with the reality, the phase which is given in the last column of Table 2. For the rest the general surface current must be assumed in such manner that there will be, in general, a transfer of water from the Tyrrhenian Sea to the southward. The results of this calculation are given in Table 3 and are represented graphically in fig. 7.

We see directly from this that the great velocities and strong modifications are restricted to the region of the Straits between Messina and Peloro-Scilla and that up to the northern exit, during the flood of the tidal wave, very complicated current phenomena occur, even if we consider only the mean characteristics on all the sections. How much greater the complications if we undertake to consider their distribution in space along the entire Strait. In particular in the section of the Straits which follows the great bend towards the N.E. between Point Pezzo-Ganzirri and Peloro-Scilla, we note the apparition of convergence currents; for the first time between 2 1/2 h. and 4 h.; the second time between 6 1/2 h. and 8 h.; the first time when the current reverses from north to south; the second time when it reverses from south to north. These current reversals have their origin in the fact that the tidal current does not reverse at the same time along the entire length of the Straits, it reverses sooner in the north than in the south. They are the seat and the origin of the characteristic disturbance of the current, which, at least in part, occurs very regularly in spite of its very turbulent character. This characteristic arises particularly from the circumstance that two kinds of water of different kinds, as has been mentioned before, are brought into immediate contact, without ever regaining their equilibrium with respect to each other. The water which comes from the Ionian Sea to the southward is colder and has a higher salinity than that of the Tyrrhenian Sea which comes from the North; the first is therefore heavier than the second and tends to pass under the lighter water from the Tyrrhenian Sea. The result of this is the formation of eddies with vertical and horizontal axis which may, on occasion, attain very considerable proportions.

The fact, alone, that in the general current of the Straits, the upper layers (extending down to about 30 meters) move towards the south, while the lower layers move towards the north, is in itself a reason for the production in the interior of the section Peloro-Scilla and of Messina-Catona of current features in the vertical plane which give rise to dynamic instability. But even though the tidal current has nearly the same strength and direction throughout the entire column of water, its superposition on the general movement in the Straits between the upper and lower layers, causes differences in speed, the result of which is a considerable increase in the turbulence (4). At the time of the strongest "rema scendente" the current strength in the upper layers is appreciably greater than in the lower, and the Tyrrhenian waters flow in a powerful current towards the southward. At the time of the strongest "rema montante", on the other hand, the lower layers show greater movement than the upper and a great mass of the Ionian waters is displaced to the northward. At the reversals, between 2 h. and 4 h. on the one hand, and between 6 h. and 8 h. on the other, the speeds above and below are opposed, a fact which is particularly liable to produce here an advance of the waters which are essentially lighter over the heavier water. It is not surprising therefore, that just at this moment disturbances in the current should occur, particularly those in the form of eddies with horizontal and vertical axes. At first about 3 h. there is formed, by the inversion of the first mass of the rema montante, a disturbance in the current in the form of a surging wave ("bore") (primo taglio della rema montante) near Ganzirri, which progresses to Cape Peloro about 45 minutes later. Towards 4 h. there is formed a second surging wave similar to that in the region of Torre Faro: this reaches the other side, just off Scilla 35 minutes later; it is the second taglio. These tidal waves are, as Vercelli has already explained, of the same nature as the "bore" at the mouths of some rivers; the heavier waters from the Ionian Sea strike violently, so to speak, with a head-wave against the slowly retiring lighter waters of the Tyrrhenian Sea. It is followed by a strip of very turbent and agitated water.

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(4) *A rough calculation shows, that with the given relations (density difference between upper and lower of* 10-3, *velocity difference about* 100 *cm/sec.) there is a dynamic instability in the perturbations of the short waves up to about* 500 *m. length. This indicates that occasional disturbances of the same dimensions may occur which in time become vortices and eddies of considerable importance; the character of the current becomes turbulent and disorganized.*

The counter-part of these "tagli della rema montante" are those of the "rema scendente"; the first, the weaker, originates near Pezzo at about 6 1/2 to 7 h. and reaches Messina; the second, which is much the stronger of the taglio grande, is formed near Peloro and traverses the entire Straits towards the southward.

The lighter waters of the Tyrrhenian Sea, advancing rapidly, slide along in the form of a head-wave, over the heavier water of the Ionian Sea. This is the moment when, in the lower layers, the waters of the Ionian Sea have reached their farthest advance to the north, while above, the waters of the Tyrrhenian Sea are already pushing to the southward at high speed. These are the most favorable conditions permitting the two different kinds of waters to slide over each other and for the formation of the tidal waves.

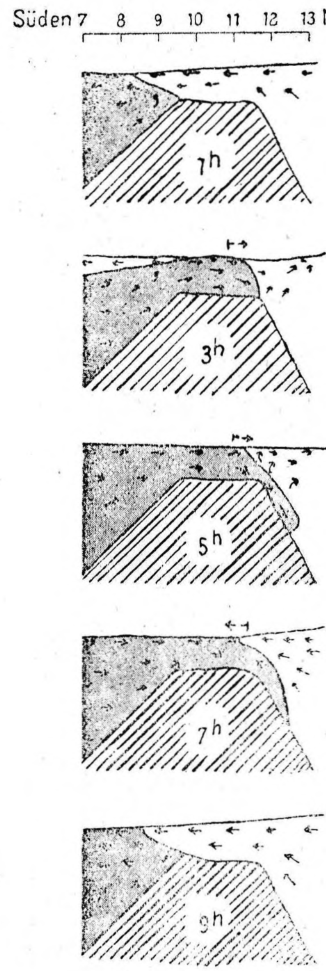

Fig. 8. — *Schematic representation of the position of the two kinds of water on the longitudinal section through the Straits of Messina during the period of the tidal changes.*

Of all these "tagli", Vercelli and Mazzarelli have given detailed descriptions. The former has also given, for certain typical cases, graphical representations of the spatial distribution and the temporal propagation of the individual tidal waves. All of these representations are very instructive and I wish to make special reference to them.

In fig. 8 I have undertaken to demonstrate how one may picture the relations of the two kinds of waters with respect to each other, in a longitudinal section, during the course of a tide, at two hour intervals. I wish to emphasize the fact that this representation is entirely schematic for any average section along the Straits and has no further significance than to show the complicated current relations in a more comprehensible manner. One notices at once the two time intervals when the tidal wave with the characteristics of the "bore" can be produced; i.e. about 3 h. and 7 h., and these times also coincide with the observed times of the greatest turbulence of the current in the northern exit of the Straits. At the time of the "rema montante" there appears something similar to tagli, the so-called "refolo della Calabria", which starts from Point Pezzo towards 5 1/2 h., at the time of the strongest current towards the north, and arrives at Torre Faro about 1/2 hour later. This "refolo" is characterized by a very strong agitation on the surface of the sea and may well be connected with the advance of the unmixed heavy waters as far as the northern exit, which must here show a tendency to sink on account of their greater density with respect to the lighter waters of the Tyrrhenian Sea. I believe that the "refolo" has a different character and origin from that of the "tagli".

All of these *tagli* or *scale di mare* (gradations of the tide) as they are also called, are particularly developped at the time of the syzygy; but it is especially the winds which give them their imposing aspect. Thus it is, as shown by G. MAZZARELLI, that the tidal wave of the "rema montante" attains, when the north wind is blowing, a height of 1 1/2 meters near Pezzo; this being due to the heaping up of the waters violently forced against the lighter waters of the Tyrrhenian Sea, which do not give way before the north wind. With the south wind, its height scarcely attains 1/2 meter. The "rema scendente" also reaches the same order of magnitude when the piling up is due to the south wind. The influence of the wind in augmenting the dimensions of the phenomena is readily appreciated from a theoretical standpoint and proves that the controlling factor is the general exchange of waters between the Ionian and Tyrrhenian Seas, independent of the tides, which, superposed on the tidal currents produce the disturbances to the current known as "tagli". One might, for instance, picture the conditions, such that, with a north wind, the piling up of the waters in the southern Tyrrhenian Sea near the entrance to the Straits of Messina could became so great, that it would act like a barrier to hold back the waters advancing from the south with the tide from the Ionian Sea. Then there would be realized one of the extreme cases noted above and the result would be a particularly turbulent equalization of the differences in level thus brought about.

There is also a connection between the current convergences and the vortices with vertical axis. There are three localities where the morphological formation of the ground seems particularly favorable to their development. These are the following :— 1) at Peloro, i.e. the Charybdis, 2) at Scilla, the Scylla-vortex, and 3) the vortex at Punta San Ranieri before the bar of the port of Messina. Of these the eddies of Charybdis and off Messina are the most important; they consist of opposed eddies formed by the two kinds of waters at the convergence surface; whereby the heavier kind of water sinks and the lighter shoves itself above in the vortex. In general these vortices turn in the cyclonic direction. There are some however of anti-cyclonic character :— these are recognizable by the rise of the water in the central part. The surface of the sea then presents a smooth, rather oily appearance from which it derives the name "macchie d'oglio" (5).

The vortices off Scilla are, on the otherland, of slight importance today, but it appears this was not the case in former times. Thus G. MAZZARELLI reports that at the time of the earthquake in February 1783 the rocks of Scilla sank into the sea over a wide horizontal area and that these extensive pits disappeared below the surface of the sea. These, when half filled with water in stormy weather gave rise to the roaring noise which Homer likened to the howling and whining of dogs. This morphological modification would have doubtless diminished the vortices of Ccilla both in intensity and extent.

This certain diminution in the violence of the vortices off Scilla leads one to believe that perhaps formerly, in antiquity or even pre-historic times, the manifestations of Scylla and Charybdis, which are pictured by Homer as being so terrible, were then actually more powerful and consequently much more dangerous. From the geophysical point of view, one might conceive a simple augmentation in the intensity of manifestation of the tidal currents, such as a reinforcement of the tidal wave and the vortices which result from them, if we

(5) *For the tagli and the vortices,* VERCELLI and G. MAZZARELLI *have reproduced excellent photographs in the above-cited works, to which attention is especially invited.*

(Allgemeiner Strom an der Oberfläche + Gezeitenstrom, cm/sec, + nach Norden.)

Ungefähre Lage	Querschnitt	Mondstunden 0h	1h	2h	2 1/2h	3h	4h	5h	6h	6 1/2h	7h	8h	9h	10h	11h
	15	− 8	− 4	0	+ 2	+ 4	+ 6	+ 6	+ 4	+ 2	0	− 4	− 8	− 10	− 10
	14	− 13	− 8	− 2	+ 1	+ 3	+ 6	+ 6	+ 3	+ 1	− 2	− 8	− 13	− 16	− 16
	13	− 19	− 12	− 4	0	+ 3	+ 7	+ 7	+ 3	0	− 4	− 12	− 19	− 23	− 23
	12a	− 36	− 26	− 13	− 9	− 4	+ 2	+ 2	− 4	− 9	− 14	− 26	− 36	− 42	− 42
C. Peloro—Scilla....	12	− 67	− 44	− 16	− 3	+ 7	+ 21	+ 21	+ 7	− 3	− 16	− 44	− 67	− 81	− 81
	11a	− 122	− 70	− 10	+ 15	+ 42	+ 72	+ 72	+ 42	+ 18	− 10	− 70	− 122	− 152	− 152
	11	− 149	− 85	− 10	+ 25	+ 55	+ 93	+ 95	+ 59	+ 23	− 5	− 80	− 145	− 183	− 185
	10a	− 142	− 87	− 22	+ 9	+ 36	+ 72	+ 75	+ 46	+ 21	− 9	− 74	− 132	− 168	− 171
P. Pezzo—Ganzirri..	10	− 190	− 107	− 6	+ 43	+ 86	+ 144	+ 153	+ 110	+ 72	+ 27	− 74	− 166	− 224	− 233
	9a	− 158	− 96	− 16	+ 23	+ 60	+ 111	+ 125	+ 98	+ 70	+ 36	− 44	− 120	− 171	− 185
	9	− 98	− 69	− 27	− 5	+ 15	+ 47	+ 61	+ 52	+ 39	+ 13	− 19	− 61	− 93	− 107
	8a	− 62	− 56	− 22	− 6	+ 4	+ 26	+ 36	+ 34	+ 27	+ 18	− 6	− 32	− 54	− 64
Messina............	8	− 57	− 44	− 22	− 9	+ 4	+ 26	+ 39	+ 39	+ 34	+ 26	+ 4	− 22	− 44	− 57
	7a	− 42	− 35	− 20	− 11	− 1	+ 16	+ 27	+ 29	+ 26	+ 21	+ 6	− 13	− 30	− 41
	7	− 31	− 27	− 18	− 11	− 5	+ 8	+ 17	+ 21	+ 20	+ 17	+ 8	− 5	− 18	− 27
	6	− 20	− 17	− 11	− 7	− 3	+ 5	+ 11	+ 14	+ 13	+ 11	+ 5	− 3	− 11	− 17
Reggio.............	5	− 15	− 13	− 9	− 5	− 2	+ 5	+ 9	+ 11	+ 10	+ 9	+ 5	− 2	− 9	− 13
	4	− 11	− 9	− 6	− 4	− 1	+ 4	+ 7	+ 9	+ 9	+ 7	+ 4	− 1	− 6	− 9
	3	− 7	− 6	− 3	− 2	0	+ 3	+ 6	+ 7	+ 7	+ 6	+ 3	0	− 3	− 6
	2	− 6	− 5	− 3	− 2	0	+ 3	+ 5	+ 6	+ 6	+ 5	+ 3	0	− 3	− 5
	1	− 4	− 4	− 2	− 1	0	+ 2	+ 4	+ 4	+ 4	+ 4	+ 2	0	− 2	− 4
	0	− 3	− 3	− 2	− 1	0	+ 2	+ 3	+ 3	+ 3	+ 3	+ 2	0	− 2	− 3
Stromvorgänge in der Meeresstraße		rema scendente			rema montante									r scendente	
					2 1/2h bis 3h 1. taglio	3 3/4h bis 4 1/2h 2. taglio		5 1/2h bis 6h refolo della Calabria			6 1/2h 1. taglio	7 1/4h bis 8h taglio grande			
Ausgangsort:					Ganzirri	Torre Faro		Punta Pezzo			P. Pezzo	C. Peloro			
in der Richtung gegen:					C. Peloro	Torre Cavallo		Torre Faro			S. Ranieri	gegen Süden			

TABLE 3.

Mean particulars of the currents along the Straits of Messina for the various lunar hours after the meridian transit of the moon.

(General surface current + tidal current cm./sec. + towards North).

admit that formerly the Straits of Messina were marrower and shall ower. In fact, the diminution of the area of the sections, through which the masses of water must flow from the Ionian Sea to the Tyrrhenian Sea and vice versa during the period of the tides, causes an appreciable augmentation in the speed, and also, as a result of the diminution in the mean depth, of the turbulence of the tidal current. Both of these factors reinforce the intensity of the vortices and the tidal waves (bore) at the northern exit of the Straits. If the section of the Straits shrinks in size, we then approach the first of the extreme cases noted above, where the inertia of the movement of the water diminishes with respect to the frictional influence. If therefore the communication between the Ionian and Tyrrhenian Seas was formerly less deep and prehaps also narrower, account must be taken of the special features which correspond more nearly to the extreme case, with violent currents and with more strongly developped eddies.

If, in the future, the communication between the two seas becomes wider and deeper, the inertia of the water movements will predominate over the friction and the tides will then correspond to the second extreme case of a truly undisturbed passage through the Straits. The present seems to us to be a period of transition between the two extremes and we have seen also that the phase of the tidal currents in the narrowest section of the Straits is influenced in consequence. The intensity of the disturbances to the currents, the tidal waves and the eddies should therefore become less than formerly and this diminution appears to have already occured in the eddies off Scilla. For the rest, one should expect a further diminution in the disturbances if the depth and width of the Straits should be further increased.

Whether or not such a deepening and widening of the Straits of Messina from prehistoric times to the present could have occured is a purely tectonic question. It seems to me that such a possibility should not be rejected, when we consider that just the region near the Straits of Messina is a particularly unstable tectonic area, which is often shaken by violent earthquakes and is in the process of constant change. A deepening and eventually also a widening of the breach between Calabria and Sicilly during the past 3000 years — as the first mention of Charybdis and Scylla dates back to about that epoch — is certainly within the range of possibility, since it is not a question of large vertical displacements or of horizontal displacements either. A mean depth of about 50 meters as opposed to the nearly hundred meters at present would well suffice to give to the eddies of Scylla and Charybdis that intensity which would render them exceedingly dangerous for navigation in those days— a danger which Homer so well expressed in the poetical language of the Odyssee.

Berlin, "*Institut für Meereskunde*", April 1940.