The problem of the tide of Euripus. By *D. Eginitis.*

Since ancient times several philosophers, scientists, travellers and authors have studied the complex problem of Euripus. Some of the questions associated with this subject have been correctly explained, but not always with completeness and the required scientific proofs; others were given a bad solution or misunderstood, while others have been quite ignored, owing to the lack of the neccessary tidal data and some had not been studied at all. So the whole problem has not yet been given a general and complete solution.

In a long paper which is to be shortly published in the Memoirs of the Academy of Athens we give the general solution of this famous problem with all the proofs provided by the theory and the observations. The respective tables, diagrams and other tidal data deduced by means of the theory of tides on the basis of the laws of Celestial Mechanics and Hydrodynamics and the respective rules of Hydraulics are to be found appended there. In our study we have taken into consideration the tide observations made by *A. Mansell* and *Miaoulis* as well as those of the Hydrographic Service of the Ministry of Marine who following an approval of the Minister of Marine placed at our disposal their tidal records and other observations carried out by their Station at Chalkis, together with a note containing some elements in connection with this tide. Moreover we have had under our consideration the respective work of *F. A. Forel*, *A. Miaoulis*, *O. Krümmel*, *A. Endros*, and *R. v. Sterneck* (jun.).

The conclusions we reached in this investigation are briefly summarized as follows:

1. As stated above, the problem of the tide of Euripus is associated with several questions, the principal of which are: a) the origin of the tide, b) the cause of the regular current which near the syzygies of the Moon during 23–24 days of the lunar month is streaming in the channel of Euripus regularly: during about 6^h towards N from about the middle of the flood to about the middle of the ebb and during about 6^h towards S from the middle of ebb to the middle of flood, c) the cause of the irregular current which during the remaining 5–6 days of the lunar month near the quadratures of the Moon is streaming irregularly, changing direction many times in the day without obeying any law or rule whatever, d) the shortness of the daily period of the tide amounting to $24^h22^m2^s$ only near the syzygies of the Moon, e) the inversion of the times of the tide, the first flood observed immediately after the end of the irregular period corresponding to the time of an ebb, as if one ebb had been omitted, f) the great difference in the times of establishment of the two ports of Chalkis situated on either side of the channel of Euripus at a distance of a few metres only from each other, g) the place of the mean level of the two ports, h) the difference of the height of the level at which the N and S currents change direction, i) the difference in the duration of these two currents, j) the difference in the influence which the wind has from time to time on the duration, the velocity and the height of the current, k) the continuously multiple fluctuation of the two ports of Chalkis and especially of the S one, and l) the fact that the durations of the flood and ebb are nearly equal with a small excess of the flood, which is contrary to the phenomenon of the very marked excess of the duration of the ebb, as it is generally observed near the coasts.

2. The tide observed in the gulf of Euboea is nearly exclusively derivative, and it is produced not only by a local tide of the Aegean Sea as up to this time it was erroneously thought to be, but it comes from the Eastern basin of the Mediterranean Sea which is simultaneously fluctuating with the Western Mediterranean; on this latter there is a slight influence of the tides of the Atlantic Ocean. So the Aegean Sea is to be considered as a gulf of the Eastern Mediterranean through which its tide is transmitted to the gulf of Euboea entering it through its two ends and so reaching Euripus. Without this tide coming from the Eastern basin of the Mediterranean the great difference of the times of establishment of the two ports of Chalkis, situated at a distance of a few metres only remains in suspense and it is quite inexplicable, while by this theory it is fully and accurately explained and it constitutes in the same time a strong proof of our hypothesis, coming out from the observations. On the other hand no serious contradictions might be put forth against this theory nor could it be supported that derivative tides cannot come from neighbouring basins. Moreover the ratio of the harmonic waves $S_2 : M_2$ of the Aegean Sea exactly coinciding with that of the Eastern Mediterranean as well as with that of the two ports, after a respective increase in the two gulfs ratify on the contrary the exactness of such an origin of the tide of Euripus. The identity of this ratio, as it is well known constitutes the most important and indispensable characteristic of the derivative tides. Also, the time of establishment of different points of the Aegean Sea and particularly of the Skiathos port, according to the simultaneous observations made there and at Chalkis by *Mansell* and *Miaoulis* pleads very strongly in favour of the correctness of this theory. In fact this time differing by 1^h25^m from the time of establishment of the S end of Euboea, viz. exactly by an interval of time required for the tidal wave coming from the Eastern Mediterranean to travel the distance between that point and Skiathos, proves the correctness of such an origin. While, if this wave came from the Aegean Sea, it would be perpendicular to the S end of Euboea and Skiathos and consequently the times of establishment of these two points would be equal. This origin is one of the fundamental questions of the problem of the tide of Euripus and also one of the principal bases for the solution of some of the most important questions associated with it.

3. As we have shown, the nature and the causes of the regular current of Euripus have been erroneously explained by *Forel*, who supposed, without giving any proof, that the S current is produced by the flood in the Aegean Sea and the N one by its ebb. This current may be produced either owing to uniform fluctuation in the whole gulf of Euboea, in accordance with the theory of the channel tides, as *Krümmel* simply and without any proof supposed, or in consequence of the difference in the level of the two ports of Chalkis as for the first time was supposed by *Eratosthenes* in ancient times and some years ago by *Endros*, but also without any proof. We have theoretically proved, as already *Sterneck* also did, that this current is the result of the second of the

above cases, because a uniform fluctuation of the whole of the gulf of Euboea is impossible owing to friction in general and the narrowness of the channel of Euripus. Consequently the two ports are fluctuating independently from each other and therefore the difference in their levels is the cause producing the regular current.

Up to this time no proof supported by the observations has ever been given to the above negative conclusion of the theory of uniform fluctuation. Similarly no proof either theoretical or observational has ever been given of the positive conclusion that the current is due to the difference in levels. Such a safe certification founded on the very facts, viz. on the tidal phenomena observed in Euripus, as much necessary as indispensable for the completion of the first conclusion and the adoption of the second, is deduced from several proofs given by the observations as follows: a) from the great difference of the time of establishment of the two ports of Chalkis a few metres only apart from each other; this difference would be impossible in the case of uniform fluctuation. b) from the fact that immediately after the N current stops, two simultaneous currents stream in the S port in opposite directions. This shows that the regular current is obviously produced only by the difference of the levels of the two ports, c) from the fact that the change of the direction of the current occurs at heights much differing from that of the mean level and at times much diverging from that of the mean tide in contradiction with the facts required by the theory of the channel tides, d) from the fact, shown also by the observations, that the duration of the flood surpasses slightly that of the ebb, instead of having the duration of the ebb exceeding that of the flood, as it is required by the theory of channel tides, and e) from the coincidence of the times of the maximum velocity of the flood and ebb instead of a marked difference between them, owing to friction effect, as required also by the same theory.

According to *Strabo* (*A'*, 3, 12), *Eratosthenes* also considered that the difference of the sea level on either side of the straits is the cause of the tides observed therein »ὅτι ἡ ἐφ' ἑκάτερα θάλαττα ἄλλην καὶ ἄλλην ἐπιφάνειαν ἔχει«. Therefore in connection with Euripus he had already guessed the true cause not only of the regular, but, as we shall see later on, also that of the irregular currents. Moreover, *Eratosthenes* suggested that the currents of the Messina straits are also due to the same cause. There, as well as in Euripus, a great difference of the sea levels is really observed within a small distance. This is in conformity with the theory according to which the two basins of the Mediterranean, separated by the straights of Messina and that between Sicily and Tunis, are fluctuating simultaneously and therefore the difference in the times of establishment on either side of these straits amounts to many hours.

4. The great difference of the levels of the two ports sometimes observed near the syzygies of the Moon is principally and nearly exclusively due to the great difference of the quantities of water which according to our calculations is running through the Aegean Sea and the two mouths of the gulf of Euboea in the two ports of Chalkis during the flood. In fact, if we compute by means of the respective differential equations of Hydrodynamics the quantities of water which at that time reach there, we see that the theoretical values so found of the height of the high water in these two ports and in the harbour of Aedipsos are in fair agreement with those given by the observations and they do not, except slightly only, differ from those found by *Sterneck* through similar calculations. Another reason which partially, but in a considerably smaller degree, contributes to this difference and consequently to the production of the regular current is the topographic configuration of the two ports. Except these two systematic causes there are of course many others such as the wind, the difference of the barometric pressure, and generally the irregular fluctuations or seiches produced by such local or other effects; these however are taking place only in exceptional cases; however the duration, the height and the velocity of the regular current are very sensibly influenced by them and particularly by the wind.

5. Although there is an ancient tradition mentioned also by some ancient and modern authors stating that *Aristotle* committed suicide in Euripus because he could not solve its problem, nevertheless as it is shewn from his Meteorologicals he has been the first among the ancients who solved this problem but only with regard to the question to which the whole problem of Euripus tide was limited from the early times up to the middle of the 19th century, viz. its irregular current. As it is clearly understood from a passage of his Meteorologicals (Lib. *B*, *A*) mentioned by *Endros* in his paper, *Aristotle* gave the explanation of the irregular currents not only of Euripus, but generally of all the sea straits, by the seiches or »διὰ τῶν δεῦρο καχεῖσε τοῦ πορθμοῦ ταλαντώσεων τῆς θαλάσσης«. The same correct solution as we have seen above had been given by *Eratosthenes*, and in a more general manner. Two thousand years later the same solution has been suggested in the last century by the distinguished Swiss scientist *F. A. Forel*, although he started from erroneous observations and computations and inexactly supposed the N instead of the S port as the source of these currents. As it is evident from other ancient passages *Aristotle* knew also some of the most important causes of the seiches, such as the wind and the earthquakes. But *Forel* also, as we have shown, did not find all their causes, neither distinguished that except the seiches there are more other causes, systematic or accidental, giving birth to the irregular current. In the passage quoted above *Aristotle* in order to explain the great width of the tide in the straits, formulated quite correctly the hydraulic law of the increase of the height of the current in the gulfs, by the entrance of the waters in a narrower and shallower space, viz. exactly as this law is given nowadays.

The calculation of the principal harmonic waves of the N port gives values for M_2 and S_2, the ratio of which $S_2/M_2 =$ 0.68 is much bigger than 0.46 as obtained by the static theory of the tides. The excessive value of the principal solar wave S_2 in comparison with the principal lunar wave M_2, being added near syzygies to M_2 renders at that time the flood in the N port more than double that of the S port, while on the contrary at quadratures and especially when K_2 also is combined with S_2, it renders it then much smaller and about equal to that of the S port. Thence the seiches and the other irregular fluctuations near quadratures, when there is no great difference in the level of the two ports, succeed in overcoming the

regular lunar tide which is very weak at that time, they surpass and sometimes they cover the tidal currents and therefore they produce the irregular current. These seiches do not come only from the gulf of Euboea through the influence of meteorological and other mechanical causes, as it was supposed by *Forel*, but also from the same influences on the outer seas and especially as a result of interferences and reflections on the numerous gulfs and straits of the Mediterranean and particularly of the Aegean Sea.

6. The times of establishment of the N and S port are 5^h30^m and 4^h15^m respectively. The great difference of the times of establishment of these two ports situated at a distance of only 40 metres from each other and connected by the Euripus channel, would be quite strange and even inexplicable if their tide came from the Aegean Sea only. In such a case the tidal waves coming from this Sea, notwithstanding the different distances they would travel between the two mouths of the gulf of Euboea and each of these ports, would reach them in the same time owing to the difference of the depths in the N and S gulf of Euboea, and therefore the times of establishment would then be exactly the same. While, if we accept that the tide observed there is mainly coming from the Eastern Mediterranean, then this difference is fully explained as being a result of the difference of the distances of the two mouths of the Euboean gulf, through which the tidal wave of the Eastern Mediterranean reaches separately each one of these two ports. Really, the computation made on the basis of this difference of distances and the mean depths of the sea, being in full agreement with the difference of times given by the observations, ratifies the correctness of this theory, while the interpretation proposed by *Endros* to the effect that the difference of the times of establishment of the two ports is due to the prevalence of the diurnal tidal type in the S port and of the semidiurnal in the N being not in agreement with the observational data, is not correct. Similarly, the suggestion of *Sterneck* that this difference is due to different friction in the N and S Euboean gulfs is quite contrary to the facts and therefore quite unfounded. Furthermore the correctness of our hypothesis is shown also from the ratio $S_2 : M_2$ of the N and especially of the S port. This ratio being exactly equal to that found on the basis of the tide of the Eastern Mediterranean shows in an obvious way that the tidal fluctuation observed in Euripus originates from that Sea. The identity of this ratio constitutes, as it is well known, the principal characteristic of the origin of any tide.

A natural consequence of this difference in the times of establishment of the two ports which may be easily explained by this difference is the phenomenon of having simultaneously flood in the one port and ebb in the other, which was characterized by *Forel* and *Mansell* as strange and inexplicable.

7. The mean difference from 24^h of the daily period of the tide which on the average must be equal to the mean period of the upper transit of the Moon, viz. about 50^m6^s, in Euripus is near syzygies much shorter amounting to 22^m2^s on the average. This shortness has been considered by some to be an exceptional phenomenon of Euripus, and by others as an impossible one. For such a reason all the observations leading to that result have been characterized by *Krümmel* as inexact. But neither is true, and all observations, the old ones as well as those made recently, are of an accuracy which is beyond any doubt and certify the phenomenon in question which is a general one and not special only for Euripus, but it occurs there on a comparatively smaller scale than usually observed elsewhere. In fact, not only in accordance with the said observations but also in conformity with the theory of tides this is a natural phenomenon and an immediate consequence of the value of the harmonic waves in Euripus, and must be observed on the same scale as in this channel wherever the values of the harmonic waves are such as are found near Chalkis. As a matter of fact, if we compute by the respective formulae of the theory of tides the daily period of the tide of Euripus on the basis of its data, we find that it must be small near syzygies, but very great 2–3 days near quadratures. So its average value within half a lunar month is equal to its normal mean value ($24^h50^m.6$). This result is gathered also from the tidal records of the N port and it is obvious at a glance from the respective curves. The erroneous conclusion as above arrived at by *Krümmel* as to the impossibility of the phenomenon and therefore to the inexactness of the *Miaoulis* observations, as well as the idea of this latter of an exceptional and quite peculiar phenomenon, are due to the fact that they both supposed the daily period of the tide to be the same during the whole month, and they did not take into consideration that also in conformity with the theory it is small near syzygies and great near quadratures.

8. The phenomenon observed by *Miaoulis* of the reversal of the times of high and low water near the third day after the quadratures of the Moon as well as of the reversal of the direction of the current is simply an arithmetical result of the daily period of the Euripus tide which near syzygies is short and much greater near quadratures. Therefore this phenomenon is also an immediate and natural consequence of the values of the main harmonic waves M_2 and S_2 and it does not contain any irregular or peculiar feature, since as we have stated it must be observed wherever the waves in question have these values. Consequently the same reasons lead *Miaoulis* and *Krümmel* to the same erroneous conclusions as above.

9. The great difference of the height of the water levels at which the change of the directions of the two currents occurs amounting to 0.203m is an obvious consequence of the great differences in the times of establishment of the two ports; as a result of this, the tidal phases of the two ports not coinciding, the heights at which their levels meet at the moment of the current's standstill are necessarily much different. This difference, as we have already seen, constitutes the proof of the cause to which the regular current is due.

10. The mean level as it is accurately found from the recent and more complete tidal records and other observations is the same in both ports of Chalkis, being nearly in the middle of the two heights at which the change of the direction of the two currents of Euripus occurs. Therefore the opinion supported by *Endros* and *Sterneck*, without even a founded justification, that the mean level of the N port is sensibly exceeding in height that of the S one is not correct.

11. The mean duration of the N current exceeds that of the S by 27^m1. This difference is a result of the difference of the mean depth of the low water from the mean height of the

high water in the N port, the later exceeding the former by 0.021 m. Thence the current corresponds to a height of level smaller by 0.042 m than that of the N one and consequently to a difference in time which computed on the basis of the mean velocity of the change of height of its level is equal to that given by the observations. The theory suggested by *Endros* that the excess of the duration of the N current is due to the excess of pressure owing to a greater level difference is unfounded as such an excess is not testified by the observations.

12. The influence of the wind on the duration, the height and the velocity of the current in Euripus which is different from time to time is explained as follows: When for instance a S wind is blowing the waters of the Aegean Sea are gathered towards the N coasts of this Sea, while in the same time the height, the duration and the velocity of the S current as a result of their action are naturally increasing. But when on the next day, the S wind continuing to blow over the Aegean Sea, the waters already gathered near its N coasts enter the N gulf of Euboea, then the N current must run, as it really does, longer than usually, with greater velocity and height, but in a direction opposite to that of the blowing wind. So the same wind produces, as it should do here, for the reasons mentioned different results. On the contrary, when a strong N wind is blowing the level of the waters in the Aegean Sea must be low, as it is really, owing to their being pushed by this wind. As a result of this the level of the Euboean gulf as well as that of the Euripus currents is somewhat lower than usually by half a meter approximately, notwithstanding the action of the wind blowing in an opposite direction. Therefore this wind also produces in Euripus a result which is opposite to the natural action of the direction of the wind on the currents of the channel, owing to its influence on the Aegean Sea.

13. The unceasing fluctuation of the S port as well as that of the N port which is less frequent and less wider, is a result of the seiches occurring in the Euboean gulf as well as those coming in from outside. As it results from the respective theoretical investigations and the study of the curves of these two ports, the seiches observed in them as well as the lunisolar tide are not common to these ports but quite individual and independent. If we compute their periods on this basis, the values found are fairly in accordance with those given by the most usual forms of the curves. But the seiches of the S port must be wider and more numerous than those of the N port, as is really the case, for two reasons: firstly, because those of the S port are simple, while in the N port owing to the irregular shape of the N Euboean gulf, its different parts produce individual seiches and from such multiplicity of seiches we have a diminution of their width; secondly, and principally, because the S port is much smaller and shallower than this gulf with which the N port constitutes a single basin. On the other hand the tidal fluctuation in the N port is much stronger than that in the S and therefore it causes the disappearance of many irregular fluctuations which are very marked in the S port owing to the smallness of the width of its regular tide. For this reason the S port looks to be in an unceasing movement much more frequent and wider than the N port. But the unceasing fluctuation of the S port must not be considered to be due only to accidental causes such as the meteorological and other similar phenomena, as supposed by *Forel*, but also to many others more systematic and more numerous coming especially from outside from other seas and not only from the consecutive terms of the harmonic development in to series, but also and principally, as we have already told, from the interference, reflection and other various hydraulic results of the multiform coast of the Mediterranean and more especially of the Aegean Sea.

14. According to the theory of the tide in the channels, the velocity of the current in the channel is a function of the height of the tide, and the different phases of the tide are transmitted with the velocity of the current. Therefore the duration of the flood and ebb depends upon the height of the tide. But in Euripus the velocity of the current as well as the duration of the flood and ebb are a function of the difference of the height of the two ports. For this reason they do not present the difference usually observed at the coasts, as they are not controlled by the law of the change of the height of the tide.

15. As a general conclusion from our study it follows that: the problem of the tide of Euripus is associated with several questions; some of them are peculiar and others, in the majority, common to all tidal problems, but none of them is surpassing the power of the theory of tides; all these questions may be explained and solved by this theory on the basis of adequate and accurate tidal records and meteorological observations carried out methodically and systematically.

Athens, June 1929. *D. Eginitis.*

Die Verteilung der Spektren in zwei offenen Sternhaufen.

Auf der Klassifizierungs-Platte des Eichfeldes 193 (Objektivprismen-Aufnahme der La Paz-Station) finden sich die beiden Sternhaufen

NGC 3532 $11^h\,0^m.6$ $-57°\,55'$ (1860.0)
und NGC 3766 11 29.7 −60 50 »

Ich habe, soweit die gegenseitige Überdeckung der Spektren es zuließ, die relative Häufigkeit der einzelnen Spektralklassen in den beiden Sternhaufen bestimmt und teile die Zahlen als Nebenergebnis der Durchmusterung dieses Feldes hier mit. In NGC 3532 sind 131 Spektren auf einem Raume von $68' \times 68'$, in NGC 3766 43 Spektren auf einem Gebiete von $20' \times 20'$ klassifiziert worden. Die Sterne liegen fast alle zwischen der 7. und 10. Größe. Eine Trennung von Haufen- und Vordergrund-Sternen war allerdings nicht möglich; doch dürfte der weitaus größte Teil der klassifizierten Objekte dem Haufen angehören.

Die Verteilung der Spektralklassen ergibt folgendes Bild:

	B0–B7	B8–A4	A5–A8	K0	K4
NGC 3532	3.8 %	86.3 %	1.5 %	8.4 %	0 %
NGC 3766	44.2	39.5	4.7	0	11.6

Mit Rücksicht darauf, daß bei dieser Zählung wohl nur die Giganten erfaßt werden, kann man NGC 3532 der *Trümpler*schen Gruppe 2a zurechnen, während NGC 3766 anscheinend einen der Sonderfälle der Gruppe 1b darstellt, in denen außer den frühen Typen vereinzelte rote Giganten auftreten.

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