NATIONAL INSTITUTE OF OCEANOGRAPHY

WORMLEY, GODALMING, SURREY

Tel. Wormley 2122

Revision of Matthews Tables

PUBLICATION HD.282

Pilot Study of the Mediterranean Sea

by

H. CHARNOCK and J. CREASE

INTERNAL REPORT NO. A 26

JULY 1966

NATIONAL INSTITUTE OF OCEANOGRAPHY

Wormley, Godalming, Surrey

REVISION OF MATTHEWS TABLES - PUBLICATION HD.282

PILOT STUDY OF THE MEDITERRANEAN SEA

H. Charnock and J. Crease

INTERNAL REPORT No. A.26

July 1966

CONTENTS

	Page
1 - Summary	1
2 - Introduction	1
3 - Existing tables	1
4 - Determination of sound velocity	2
5 - Hydrographic observations	2
6 - Numerical methods	3
7 - Interpolation	4
8 - Interpretation of computed variables	5
9 - General features of sound velocity in the Mediterranean	5
10 - Methods of presentation and results	6
Conclusion	10
Future Work	11
Acknowledgements	11
References	12

Tables
1 - Existing 'Matthews' corrections to depths (in metres) assuming nominal sound velocities of 1463 and 1500 m/sec.
2 - Synopsis of hydrographic stations
3 - Coefficients for calculation of sound velocity
4 - Revised 'Matthews' area for the Mediterranean
5 - Critical Table for revised 'Matthews' area
6 - Critical Table for conversion of D_{1463} to D_{1500}
7 - Depth correction at 500 m.
8 - " " " 1500 m.
9 - " " " 2500 m.
10 - " " " 3500 m.
11 - " " " 4500 m.

Figures
1 - Distribution of hydrographic stations
2 - Sound velocity at 1000 m.
3 - Depth correction at 1000 m.
4 - Sound velocity at 2000 m.
5 - Depth correction at 2000 m.
6 - Variations of depth correction at 500 m. and 1000 m. with surface temperature

1. SUMMARY

Hydrographic observations from the Mediterranean Sea have been used in a preliminary study of the following questions:

a) Whether, in the light of the greatly increased number of hydrographic observations a revision of the areas defined by Matthews (1939) is desirable.

b) Whether new knowledge of the relationship of sound velocity to salinity, temperature and pressure makes a recalculation of sounding velocities and depth corrections desirable.

c) Whether new forms of presentation of the data available can materially improve the accuracy of the published tables.

2. INTRODUCTION

The current edition of Matthews "Tables of the Velocity of Sound in pure water and sea-water" is in wide use throughout the world for the correction of soundings. The main tables give 'depth corrections' to be applied to 'nominal depths' recorded by echo-sounders scaled on on the assumption that the sound velocity in the sea is either 1463 or 1500 $m.sec^{-1}$. The tables are given both in fathoms and metres.

The corrections are given as functions of nominal depth for a total of 52 oceanic areas which are displayed in chartlets at the beginning of the book.

The tables are used variously for producing bathymetric charts and for immediate use on board ship when true depth is required.

Though at the present time there is much discussion as to whether soundings should be recorded on charts as 'nominal' or 'true' depths and whether the standard nominal sound velocity should be 1463 or 1500 $m.sec^{-1}$, we feel that these questions are beyond the scope of this study and we will be concerned only with those questions raised in the summary.

The discussion in this paper is entirely in terms of metric units though it is not intended by this to prejudge any decision on the relative merits of metres and fathoms as units.

The Mediterranean was chosen as a suitable area for a pilot study for various reasons:- a solid body of good hydrographic observations was available - the region was well defined geographically - there were only three existing 'Matthews' areas to be considered.

Oceanographic conditions in the Mediterranean are such, however, that not all the important questions can be examined. Studies of other areas will be needed to extend our conclusions to the oceans in general.

3. EXISTING TABLES

The Mediterranean is covered by the Matthews areas 48, 49, 50. Table 1 lists the depth corrections assuming nominal velocities of both 1463 and 1500 $m.\ sec^{-1}$. The areas tend to separate the Sea into geographical areas characterised by the bottom topography. Area 48 covers the Western basin, area 50 the Eastern and Aegean basins and area 49 includes the Adriatic and Tyrrhenian Seas. This topographic

division is not typical of many of the Matthews areas in other oceans, the boundaries of which represent changes of the physical properties of the water. Thus, while a change in depth correction of several metres is of no consequence in crossing from one area to another if they are separated by a sill, it will be a considerable source of error when there is no topographic separation. For example, in moving from area 2 to 7 at 1000m. depth a spurious jump in topography of 15m. will be introduced into the 'true' depth. We have not therefore been influenced overmuch in considering the general problem by the sub-division of the Mediterranean into distinct basins or by the fact that its three Matthews 'areas' have corrections differing by at most 3m. from each other at all depths.

Another feature of the existing tables is the crowding of areas in certain regions, notably the Gulf Stream. It is impractical to use the tables systematically in such regions. In the case of the Gulf Stream it is known that the crowding is due to the strong horizontal temperature gradient in the upper layers of the sea which accompanies the Stream. It is also known that the Stream meanders considerably from month to month. Time variability of the sound velocity structure can also be produced by the varying energy balance at the surface. In many regions seasonal changes will limit the accuracy of the corrections. We consider possible ways of overcoming these problems of time variability.

Finally the present tables were prepared when there were relatively few observations available. They do not extend to the greatest depth in some areas (e.g. area 13). Other areas are suspect (e.g. area 15 off the Portuguese coast.

4. DETERMINATION OF SOUND VELOCITY

In recent years there has been, on the one hand the development of in situ sound velocimeters by Greenspan and Tscheigg (1957) and others to a claimed accuracy of about 0·3 m/sec. On the other hand notable laboratory work by W.D. Wilson (1960 a, b) and Del Grosso (1952) has provided the functional dependence of sound velocity on salinity, temperature and pressure to the same order of accuracy.

Comparative measurements by Hays (1961) lend support to the claimed accuracy of the two approaches. There is as yet no world-wide set of velocimeter observations to form a basis for the revision of HD. 282. The bulk of the data is in the form of hydrographic observations and we have used these with Wilson's formulae in our work. His original equation was based on measurements over the restricted range 33‰ - 37‰ in salinity. His later equations (1960b) is valid over a stated range 0 - 37‰ in salinity. It can however be used with confidence up to 40‰ as Dr. Wilson kindly carried out additional observations on Red Sea Water supplied by the National Institute of Oceanography and was able to confirm (personal communication) the validity of the formula at these salinities.

5. HYDROGRAPHIC OBSERVATIONS

In common with some other oceanic areas the Mediterranean has been extensively surveyed in the post-war years. We have in this work only used data from systematic surveys, the time involved in searching for isolated observations being out of proportion to the increase in information.

Many of the observations stem from a series of cruises in Woods Hole research vessels in 1961/2 which have been made available by Messrs. Miller, Tchernia and Charnock in advance of complete publication.

As the dependence of sound velocity on salinity is not strong we have considered equally the observations made using modern salinometers and those using titrations. Table 2 lists the stations used together with general information about the area of work and time of year. Some Russian data has only recently been obtained. When analysed it will provide further information on seasonal variations in sound velocity.

6. NUMERICAL METHODS

For each station the following variables were computed at all observations depths.

a) Pressure P

All data used reported depths of observation and not pressure (although the original observation was presumably the pressure obtained from paired protected and unprotected thermometers). The depths were therefore initially converted to pressure by using the following formula appropriate to average conditions in the Mediterranean.

$$P \text{ (decibars)} = 1{\cdot}0076\ D \text{ (metre)} + 2{\cdot}53 \times 10^{-6}\ D^2 (\text{metre})^2 \qquad (1)$$

b) Sound Velocity V

The sound velocity is given by the expression

$$V = \sum_{i,j,k} a_{i,j,k}\ P^i\ (S-35)^j\ T^k \quad \text{m.Sec}^{-1} \qquad (2)$$

where the coefficients $a_{i,j,k}$ are listed in Table 3.

S is salinity in ‰. T is temperature in ^{o}C and P is pressure in kg/cm² above atmospheric pressure.

c) Sounding Velocity W(D)

Sounding velocity to depth D is defined to be the harmonic mean of V from the surface to depth D.

$$\therefore \quad \frac{D}{W(D)} = \int_0^D \frac{1}{V}\, dz = t \qquad (3)$$

where z is the depth co-ordinate and t is the single path travel time of sound from z = 0 to z = D. The integral is approximated numerically by the trapezium formula.

d) Depth Correction δ_{1500}

The depth correction is defined to be

$$\delta_{1500} = D - D_{1500} \qquad (4)$$

where D_{1500} = 1500 t is the nominal depth resulting from a travel time t and an assumed sounding velocity W = 1500 m/sec.

$$\therefore \quad \delta_{1500} = D - 1500\,t$$

$$= D - \frac{1500D}{W(D)} \qquad \text{(from 3)} \qquad (5)$$

$$= D\left(1 - \frac{1500}{W(D)}\right)$$

other depth corrections, e.g. δ_{1463} may be defined in an analgous manner.

e) Potential Temperature and Potential Density

These were computed from standard oceanographic formulae to provide an approximate quality check on the data. Marked inversions in deep water were assumed to be due to errors in observation.

7. INTERPOLATION

Sound velocity, sounding velocity and δ_{1500} were interpolated to standard depths at 100m. intervals down to the deepest observation.

Three point Lagrangian interpolation was employed. Thus, if variable V is required at depth D and it was observed to be V_i, V_{i+1} at depths D_i, D_{i+1} immediately above and below depth D then V is approximated first by

$$V^1 = \frac{(D-D_i)(D-D_{i+1})}{(D_{i-1}-D_i)(D_{i-1}-D_{i+1})} V_{i-1} + \frac{(D-D_{i+1})(D-D_{i-1})}{(D_i-D_{i+1})(D_i-D_{i-1})} V_i + \frac{(D-D_{i-1})(D-D_i)}{(D_{i+1}-D_{i-1})(D_{i+1}-D_i)} V_{i+1} \qquad (6)$$

and then by V^{11} in which i is increased by 1 in all the above formulae. Finally the average $(V^1 + V^{11})/2$ is the accepted estimate for V. $(V^1 - V^{11})/2$ is a measure of the error in interpolation. It rarely exceeds 0·1 m/sec in the case of the sound velocity.

Near the surface and bottom there are insufficient points for carrying out the above process and we then resort to linear interpolation.

8. INTERPRETATION OF COMPUTED VARIABLES

All variables have been interpolated as a function of true depth D at 100m. intervals. For practical application a table of δ_{1500} as a function of D_{1500} (the nominal depth observed on an echo-sounder set to 1500 m/sec) has been produced.

Corrections based on nominal sound velocities other than 1500 m/sec may be found directly from δ_{1500}.

For example, we have

$$D_{1500} \equiv D_{1463} + (\delta_{1463} - \delta_{1500}) \qquad (7)$$

$$\text{and } (\delta_{1463} - \delta_{1500}) = \frac{37D}{W(D)} = \frac{37D_{1463}}{1463} \qquad (8)$$

Thus if we have tables of δ_{1500} against D_{1500} for all areas and our echo-sounder is set to 1463 m/sec we need only add the correction (8) to D_{1463} to find D_{1500} and thence δ_{1500} from the tables.

Alternatively we may write

$$D_{1500} = D_{1463}\ (1 + {}^{37}/_{1463}) \qquad (9)$$

The correction (8) is of course dependent only on D_{1463} and not on the geographical area.

9. GENERAL FEATURES OF SOUND VELOCITY IN THE MEDITERRANEAN

Figure 1 shows the location of all hydrographic stations used so far in the investigation. The Russian stations referred to in the introduction are not included.

There is a lack of data in the Gulf of Sirte but the majority of the area is shallow and errors arising from extrapolation into this region should not be large.

Figure 2 illustrates the sound velocity distribution contoured at 1 m/sec intervals over the entire area at a true depth of 1000m.

Figure 3 is a similar chart for δ_{1500} at 1000m. There is little to comment on here except to say that at nearby stations were reproducible to within 1m. Charts of sounding velocity are of course similar to those of δ.

Figures 4 and 5 are similar to 2 and 3 but at a depth of 2000m. It is clear that the corrections change only slowly over a relatively large area and that the pattern of change is similar at both levels (though this feature is not necessarily common to other areas).

/26

Similar charts have been constructed at intermediate depths but are not here reproduced.

10. METHODS OF PRESENTATION OF RESULTS

It is possible that the sounding corrections (and sound velocity might best be displayed in a form other than that adopted by Matthews.

However there are varying requirements and no one presentation may suit all of them. At sea there is frequently a need to estimate the true depth, when setting instrumented systems in deep water. The accuracy is often limited by variables (ship's drift, wire stretch, etc.) other than sound velocity variations. An estimate of the true depth to 5 to 10m would be adequate.

Ashore, in the study of the true bathymetry and in the preparation of charts the data for sounding corrections should be available to the highest accuracy warranted by the observations.

We now consider how different schemes might meet these varying requirements.

a) 'Matthews' areas

We have indicated earlier some of the problems presented by the existing system of 52 areas. However it appears that any improvement in precision is likely to be gained only by greatly increasing the number of areas. For example our analysis shows that the Mediterranean corrections are reproducible to ± 1m. at all depths. An approximate estimate of the number of areas required to reflect this precision is six as opposed to the present three. It should be emphasised here that the situation will often be worse in other oceanic areas as the Mediterranean is comparatively uniform.

However, Matthews' corrections are straightforward to use, particularly when rearranged (as has been done in many Institutes) in the form either of critical tables or more recently as a direct conversion in a given area from D_{1500} (or D_{1463}) to D in steps of 1m. These last tables are more bulky but they considerably reduce the frequency of arithmetical errors. These points appear to us to be important for the user at sea who may not be interested in extreme accuracy.

It is possible that for use when the highest accuracy is not required, the presentation by areas should be retained, using the following criterra:

1.

1. Differences in corrections between two adjacent areas should generally be less than 5m.

2. An exception to rule 1 can be made where there is a shallow sill between the area. In this case the boundary between the areas should be marked as being a topographical feature.

3. The tables should be either:

i) Critical tables in which only the depths at which the correction increases by 1m. are indicated.

or

ii) Direct metre to metre conversion from nominal to true depth at every metre of depth.

Our preference is for alternative ii) even though the tables are more bulky.

4. In any one set of tables only one nominal sounding velocity should and need be used (e.g. 1500m.sec^{-1}). Duplication of corrections will only lead to confusion and error. The need for both sets is only likely to arise in special circumstances and this possibility is most simply catered for by para. 5 below.

5. With each set of tables at one nominal sound velocity there should be provided a single page table listing the relationship of D_{1500} to D_{1463} in 1m. steps. This may be a critical table or a direct conversion table.

6. Tables should be prepared independently for entry by fathoms. In the case of tables mentioned in 3 ii) above nominal and true depths could be listed in fathoms and metres side by side in four columns though there is some risk of confusion if this is done.

On the basis of these criteria the Mediterranean may be covered by only one area. The critical table for this area is given in table 4.5. Critical points are at intervals of 5m. in in accord with the limited accuracy claimed for the tables. A Direct conversion table from D_{1500} to D for this area at 5m. intervals is given in table 5.4. Finally a critical table for conversion of D_{1463} to D_{1500} is given in table 6.

b) Tables for high accuracy.

In this case we consider it inevitable that some simplicity in use be sacrificed. Significant improvements can be sought in methods which, firstly, overcome the discontinuous horizontal division into areas thus allowing for the smooth transition between water masses, and secondly take account of fluctuations in the sound velocity structure of the upper layers due to seasonal changes and meandering of frontal regions.

We have considered the following possibilities:

1) Sub-division of Matthews area. In this case the chart on which the areas are shown would be sub-divided into sub-areas, e.g. 49•0, 49•1, 49•2 etc., implying that in area 49•0 the basic Matthews correction of area 49 applies whilst in area 49•5 a correction half-way between that of 49 and the area geographically adjacent to it applies. This method soon runs into difficulties in practice both when adjacent geographical areas are not numerically adjacent in the tables and also when the areas are geographically close together.

We are therefore led to abandon the Matthews system of horizontal division into areas and consider the possibility of vertical division into layers.

2) Contours of depth correction at a given level. Examples of this method are shown in figures 3 and 5. The area covered by a single chartlet could well cover for example the North Atlantic. If contours were prepared say at 200m. intervals some 25 chartlets would cover all but the deepest layers. Interpolation at intermediate depths would be required. This method has the advantage that contours at each depth are independent and allow greater freedom in representing the three dimensional sound velocity structure.

It appears to us that this method, while possessing some desirable features is likely to be time consuming in use (interpolation between two charts being involved). There are more general objections to visual methods basically oriented to human rather than machine use. It appears important to us that at a time when the more routine aspects of data analysis are rapidly being automated that new tables should be in a form readily adaptable to an electronic data processing system. It would also be preferable for them to be simple enough for manual use should the need arise.

3) Sub-Division into 1° squares at given levels. To overcome the objections to b) above, we consider at chosen nominal depths the sub-division into 1° squares in each of which the following information is recorded either in tables, chartlets or data files:

1. the depth correction appropriate to that depth and position
2. the increment in correction per 100m upwards from the given depth
3. the increment in correction per 100m. downwards

In the Mediterranean we have found that layers at 1000m. intervals are sufficient with the given linear interpolation to reproduce the observed depth corrections at all depths to within the variability of the observations themselves. The data is given in this form in tables 7, 8, 9, 10 and 11.

The numerical entries in each 1° square are as follows:

a) Centre number - δ_{1500} at the observed depth on which the table is based (i.e. 500, 1500, 2500 3500, 4500m. respectively).

b) Upper number - increment of δ_{1500} per 100m. increase in depth in the 500m. above the depth on which the chart is based.

c) Lower number - increment of δ_{1500} per 100m. increase in depth in the 500m. below depth on which the chart is based.

In some 1° squares our results have been extrapolated below the deepest sounding at present known, primarily to assist in interpolation.

Storage of the depth corrections and increments in a magnetic tape data file for the whole world would raise no great problem.

4) Correction for temperature variation in the surface layer. Suppose that the temperature variations are confined to depths less than D^1 and that the temperature difference from some mean profile is $T(z)$. $(T(z) = 0,\ z > D^1)$.

Then if $\overline{\delta}$ is the correction appropriate to the mean profile and δ to the observed profile and similarly for V and $\overline{V}$

$$\delta_{1500} - \overline{\delta}_{1500} = 1500 \int_0^D \frac{1}{\overline{V}} - \frac{1}{V} \, dz \qquad D > D^1$$

The variation of V with T may be given with sufficient approximation by

$$V = \overline{V} \left(\frac{z}{3}\right) (1 + \alpha T)$$

where α is constant.

$$\therefore \delta - \overline{\delta} = 1500 \int_0^{D^1} \frac{1}{V} \left(1 - \frac{1}{1 + \alpha T}\right) dz$$

$$\simeq 1500\alpha \int_0^{D^1} \frac{T}{V} \, dz$$

$$= 1500\alpha \frac{\overline{\overline{T}}}{\overline{\overline{V}}}$$

where $\overline{\overline{T}}$ is the average value of T over the depth D^1 and $\overline{\overline{V}}$ is the value of V at some depth between 0 and D^1

$\overline{\overline{T}}$ may be available from B/T observations but to make the temperature corrections of more general use it is worth investigating the correlation between $\delta - \overline{\delta}$ and the surface temperature T_s on the supposition that there is a good correlation between T_s and $\overline{\overline{T}}$. T_s is usually available either from log books or intake temperature records.

We assume therefore that

$$\delta - \overline{\delta} = \beta T_s$$

where $\overline{V}$ has been absorbed into the constant β .

1/26

and T_s is the difference between the observed surface temperature and the surface temperature on which the corrections are based. β may possibly vary slowly over a wide area It is suggested that in addition to the three quantities already tabulated in 1^0 squares that two optional items be added as follows:

4) The parameter β

5) The surface temperature T_s on which the basic correction D is based.

The only long time series of hydrographic observations that we have located in the Mediterranean are those made some 50 years ago by the Eidor near Monaco. The maximum depth is only 1000m. but we may use the data to illustrate the method even though the results in this case are only marginally useful.

Figure 6 shows δ_{1500} at 500 and 1000m. plotted against surface temperature. There is clearly a correlation between δ and T, δ increasing by about 1m. for 10^0C change in temperature. This variation is supported by a comparison between Atlantis, A. Mouchez, E. Monier and Calypso stations in the West Mediterranean. As the temperature effect is marginal there being a total seasonal variation of about 1m. in δ (corresponding to a temperature change of 10^0C), items 4 and 5 above have not been included on the present charts, though they may be expected to be of considerable value where there are greater seasonal or short-term changes in the surface water mass (e.g. Gulf Stream). However an attempt was made to adjust δ to a uniform surface temperature of 25^0C. This involved changes of less than a metre and did improve the correlation between observations in different seasons.

CONCLUSION

1. Modern measurements of sound velocity as a function of temperature, salinity and pressure indicate that in the Mediterranean Matthews tables lead to errors in depth correction of not more than 3m.

2. Errors will clearly be larger in other areas. These will arise largely from the discontinuity between areas and may be as much as 15m.

3. In the Mediterranean it is possible to reduce the uncertainty in depth correction to approximately 1m. if allowance is made for temperature variations in the upper layers.

4. To achieve this accuracy on a routine basis new methods of presentation of data are desirable.

Problems requiring a decision.

1. Extreme accuracy and ease of use of tables are to some extent incompatible. It has been suggested in this paper that there is a case for the continuance of Matthews tables in their present form with some revision of areas and with a definite limitation on their stated accuracy. For precise work a new system is proposed which is more suitable for automatic computation of true depths.

The introduction of two sets of tables might be dangerous if they are used indiscriminately. Thus, before proceeding to a general review of the depth corrections in the world ocean it is important to reach a decision on the need for highest possible absolute accuracy.

2. No matter what system is adopted consideration should be given to the extent to which the original observations are recoverable.

   If depths are corrected at all it is essential that the methods used be recorded.

   This is to some extent linked with the previous remarks. For example, charts of oceanic depth based on nominal sound velocities may be of more use navigationally than those based on corrected depths. A decision on this question and related ones will clearly affect a decision to revise Matthews tables.

FUTURE WORK

Assuming that there is a requirement for tables of greater precision the following point arises:

1. The Mediterranean investigation has only given a partial answer to the effectiveness of compensation for temperature variations in the upper layers. A study of a more active region would be very desirbale.

ACKNOWLEDGEMENTS

We are grateful to the Hydrographer of the Navy both for initiating this investigation and for financial support. We also thank members of the data processing section at the National Institute of Oceanography who have borne the main burden of data preparation.

REFERENCES

DEL GROSSO V.A., 1952, Velocity of Sound in Sea Water at zero depth. N.R.L. Report 4002.

GREENSPAN M and TSCHEIGG C.E., 1957, Speed of sound in sea water by a direct method. J. Res. Nat. Bur. Stan. 59, 4.

HAYS E.E., 1961, Comparison of directly measured sound velocities with values calculated from hydrographic data. J. Ac. Soc. Amer. 33, 1.

MATTHEWS D.J., 1939, Tables of the velocity of sound in pure water and sea water for use in echo-sounding and sound-ranging. H.D. 282 (2nd. Ed^{n}.)

WILSON W.D., 1960a, Speed of sound in sea-water as a function of temperature, pressure and salinity. J. Ac. Soc. Amer. 32, 6.

WILSON W.D., 1960b, Equation for speed of sound in sea-water. J. Ac. Soc. Amer. 32, 10.

Area	48		49		50	
Sound Speed	1463	1500	1463	1500	1463	1500
Depth						
200	6	1	6	1	7	2
400	12	2	13	3	14	3
600	18	3	20	4	21	5
800	26	5	27	6	28	7
1000	34	7	36	9	37	11
1200	41	10	42	12	44	15
1400	50	14	52	16	53	18
1600	58	17	60	19	62	21
1800	68	22	70	24	71	25
2000	79	27	80	28	83	31
2200	90	32	92	34	95	37
2400	100	39	102	41	105	42
2600	112	44	116	48	118	50
2800	125	51	129	55	131	57
3000	138	59	140	61	144	64
3200			154	70	157	73
3400			168	78	170	81
3600			182	89	186	91
3800			197	96	201	100
4000			213	106	217	111

TABLE 1. - EXISTING 'MATTHEWS' CORRECTIONS TO DEPTH (IN METRES) ASSUMING NOMINAL SOUND VELOCITIES OF 1463 AND 1500 m/sec.

Ship	Stations	Date	Area
Atlantis	138	Feb/March 1961	All
Atlantis	119	Feb/March 1962	All
Atlantis II	12	July 1963	East, Ligurian
Chain	72	Oct/Nov 1961	East, Aegean, Marmora
Calypso	118	July/August 1955	All
Calypso	97	Sept/Oct 1956	All
Elie Monier	24	December 1953	West
Elie Monier	14	March 1954	West
Am. Mouchez	14	September 1961	Alboran
Eidor	41	All seasons 09-14	Monaco

TABLE 2 - SYNOPSIS OF HYDROGRAPHIC STATIONS

i	j	k	$a_{i,j,k}$
0	0	0	1·44930, 3
0	0	1	4·5721 , 0
0	0	2	-4·4532 , -2
0	0	3	-2·6045 , -4
0	0	4	7·9851 , -6
0	1	3	1·39799, 0
0	2	0	1·69202, -3
1	0	0	1·60272, -1
2	0	0	1·0268 , -5
3	0	0	3·5216 , -9
4	0	0	-3·3603 , -12
1	0	1	-1·8607 , -4
1	0	2	7·4812 , -6
1	0	3	4·5283 , -8
2	0	1	-2·5294 , -7
2	0	2	1·8563 , -9
3	0	1	-1·9646 , -10
0	1	1	-1·1244 , -2
1	1	0	7·7016 , -5
2	1	0	-1·2943 , -7
1	1	1	3·1580 , -8

TABLE 3 - COEFFICIENTS $a_{i,j,k}$ IN EXPRESSION FOR SOUND VELOCITY -

$$V = \Sigma\, a_{i,j,k}\, P^i\, (S-35)^j\, T^k$$

Table 4 REVISED 'MATTHEWS' AREA FOR THE MEDITERRANEAN.

Direct conversion of Observed to True Depth assuming sound velocity of 1500m.sec^{-1} (accuracy ±5m.)

Obs.d	True	Obs'd	True	Obs'd	True	Obs'd	True
0	0	250	252	500	505	750	758
5	5	255	258	505	510	755	763
10	10	260	263	510	515	760	768
15	15	265	268	515	520	765	773
20	20	270	273	520	525	770	778
25	25	275	278	525	530	775	783
30	30	280	283	530	535	780	788
35	35	285	288	535	540	785	793
40	40	290	293	540	545	790	798
45	45	295	298	545	550	795	803
50	50	300	303	550	556	800	808
55	56	305	308	555	561	805	813
60	61	310	313	560	566	810	818
65	66	315	318	565	571	815	823
70	71	320	323	570	576	820	828
75	76	325	328	575	581	825	833
80	81	330	333	580	586	830	838
85	86	335	338	585	591	835	844
90	91	340	343	590	596	840	849
95	96	345	348	595	601	845	854
100	101	350	353	600	606	850	859
105	106	355	359	605	611	855	864
110	111	360	364	610	616	860	869
115	116	365	369	615	621	865	874
120	121	370	374	620	626	870	879
125	126	375	379	625	631	875	884
130	131	380	384	630	636	880	889
135	136	385	389	635	641	885	894
140	141	390	394	640	646	890	899
145	146	395	399	645	651	895	904
150	152	400	404	650	656	900	909
155	157	405	409	655	662	905	915
160	162	410	414	660	667	910	920
165	167	415	419	665	672	915	925
170	172	420	424	670	677	920	930
175	177	425	429	675	682	925	935
180	182	430	434	680	687	930	940
185	187	435	439	685	692	935	945
190	192	440	444	690	697	940	950
195	197	445	449	695	702	945	955
200	202	450	455	700	707	950	960
205	207	455	460	705	712	955	965
210	212	460	465	710	717	960	970
215	217	465	470	715	722	965	975
220	222	470	475	720	727	970	981
225	227	475	480	725	732	975	986
230	232	480	485	730	737	980	991
235	237	485	490	735	742	985	996
240	242	490	495	740	747	990	1001
245	247	495	500	745	752	995	1006

TABLE 4 (continued)

Obs'd	True	Obs'd	True	Obs'd	True	Obs'd	True
1000	1011	1250	1265	1500	1521	1750	1776
1005	1016	1255	1270	1505	1526	1755	1781
1010	1021	1260	1275	1510	1531	1760	1786
1015	1026	1265	1280	1515	1536	1765	1791
1020	1031	1270	1285	1520	1541	1770	1796
1025	1036	1275	1291	1525	1546	1775	1801
1030	1041	1280	1296	1530	1551	1780	1807
1035	1047	1285	1301	1535	1556	1785	1812
1040	1052	1290	1306	1540	1561	1790	1817
1045	1057	1295	1311	1545	1567	1795	1822
1050	1062	1300	1316	1550	1572	1800	1827
1055	1067	1305	1321	1555	1577	1805	1832
1060	1072	1310	1326	1560	1582	1810	1837
1065	1077	1315	1331	1565	1587	1815	1842
1070	1082	1320	1336	1570	1592	1820	1848
1075	1087	1325	1342	1575	1597	1825	1853
1080	1092	1330	1347	1580	1602	1830	1858
1085	1097	1335	1352	1585	1608	1835	1863
1090	1102	1340	1357	1590	1613	1840	1868
1095	1107	1345	1362	1595	1618	1845	1873
1100	1112	1350	1367	1600	1623	1850	1878
1105	1118	1355	1372	1605	1628	1855	1883
1110	1123	1360	1377	1610	1633	1860	1889
1115	1128	1365	1382	1615	1638	1865	1894
1120	1133	1370	1387	1620	1643	1870	1899
1125	1138	1375	1392	1625	1649	1875	1904
1130	1143	1380	1398	1630	1654	1880	1909
1135	1148	1385	1403	1635	1659	1885	1914
1140	1153	1390	1408	1640	1664	1890	1919
1145	1158	1395	1413	1645	1669	1895	1924
1150	1163	1400	1418	1650	1674	1900	1929
1155	1168	1405	1423	1655	1679	1905	1935
1160	1173	1410	1428	1660	1684	1910	1940
1165	1178	1415	1433	1665	1689	1915	1945
1170	1184	1420	1438	1670	1694	1920	1950
1175	1189	1425	1444	1675	1699	1925	1955
1180	1194	1430	1449	1680	1705	1930	1960
1185	1199	1435	1454	1685	1710	1935	1965
1190	1204	1440	1459	1690	1715	1940	1971
1195	1209	1445	1464	1695	1720	1945	1976
1200	1214	1450	1469	1700	1725	1950	1981
1205	1219	1455	1474	1705	1730	1955	1986
1210	1224	1460	1479	1710	1735	1960	1991
1215	1229	1465	1485	1715	1740	1965	1996
1220	1234	1470	1490	1720	1745	1970	2001
1225	1240	1475	1495	1725	1750	1975	2006
1230	1245	1480	1500	1730	1756	1980	2012
1235	1250	1485	1505	1735	1761	1985	2017
1240	1255	1490	1510	1740	1766	1990	2022
1245	1260	1495	1515	1745	1771	1995	2027

TABLE 4 (continued)

Obs'd	True	Obs'd	True	Obs'd	True	Obs'd	True
2000	2032	2250	2289	2500	2547	2750	2805
2005	2037	2255	2295	2505	2552	2755	2810
2010	2042	2260	2300	2510	2557	2760	2816
2015	2047	2265	2305	2515	2562	2765	2821
2020	2053	2270	2310	2520	2568	2770	2826
2025	2058	2275	2315	2525	2573	2775	2831
2030	2063	2280	2320	2530	2578	2780	2836
2035	2068	2285	2326	2535	2583	2785	2841
2040	2073	2290	2331	2540	2588	2790	2847
2045	2078	2295	2336	2545	2593	2795	2852
2050	2083	2300	2341	2550	2599	2800	2857
2055	2089	2305	2346	2555	2604	2805	2862
2060	2094	2310	2351	2560	2609	2810	2867
2065	2099	2315	2356	2565	2614	2815	2873
2070	2104	2320	2362	2570	2619	2820	2878
2075	2109	2325	2367	2575	2624	2825	2883
2080	2114	2330	2372	2580	2629	2830	2888
2085	2120	2335	2377	2585	2635	2835	2893
2090	2125	2340	2382	2590	2640	2840	2899
2095	2130	2345	2387	2595	2645	2845	2904
2100	2135	2350	2392	2600	2650	2850	2909
2105	2140	2355	2398	2605	2655	2855	2914
2110	2145	2360	2403	2610	2660	2860	2919
2115	2150	2365	2408	2615	2666	2865	2925
2120	2156	2370	2413	2620	2671	2870	2930
2125	2161	2375	2418	2625	2676	2875	2935
2130	2166	2380	2423	2630	2681	2880	2940
2135	2171	2385	2429	2635	2686	2885	2945
2140	2176	2390	2434	2640	2691	2890	2951
2145	2181	2395	2439	2645	2697	2895	2956
2150	2186	2400	2444	2650	2702	2900	2961
2155	2192	2405	2449	2655	2707	2905	2966
2160	2197	2410	2454	2660	2712	2910	2971
2165	2202	2415	2459	2665	2717	2915	2977
2170	2207	2420	2465	2670	2722	2920	2982
2175	2212	2425	2470	2675	2728	2925	2987
2180	2217	2430	2475	2680	2733	2930	2992
2185	2223	2435	2480	2685	2738	2935	2997
2190	2228	2440	2485	2690	2743	2940	3003
2195	2233	2445	2490	2695	2748	2945	3008
2200	2238	2450	2495	2700	2754	2950	3013
2205	2243	2455	2501	2705	2759	2955	3018
2210	2248	2460	2506	2710	2764	2960	3023
2215	2253	2465	2511	2715	2769	2965	3029
2220	2259	2470	2516	2720	2774	2970	3034
2225	2264	2475	2521	2725	2779	2975	3039
2230	2269	2480	2526	2730	2785	2980	3044
2235	2274	2485	2532	2735	2790	2985	3049
2240	2279	2490	2537	2740	2795	2990	3055
2245	2284	2495	2542	2745	2800	2995	3060

TABLE 4 (continued)

Obs'd	True	Obs'd	True	Obs'd	True	Obs'd	True
3000	3065	3250	3326	3500	3588	3750	3850
3005	3070	3255	3331	3505	3593	3755	3856
3010	3075	3260	3337	3510	3599	3760	3861
3015	3081	3265	3342	3515	3604	3765	3866
3020	3086	3270	3347	3520	3609	3770	3872
3025	3091	3275	3352	3525	3614	3775	3877
3030	3096	3280	3358	3530	3620	3780	3882
3035	3102	3285	3363	3535	3625	3785	3887
3040	3107	3290	3368	3540	3630	3790	3893
3045	3112	3295	3373	3545	3635	3795	3898
3050	3117	3300	3379	3550	3641	3800	3903
3055	3122	3305	3384	3555	3646	3805	3908
3060	3128	3310	3389	3560	3651	3810	3914
3065	3133	3315	3394	3565	3656	3815	3919
3070	3138	3320	3399	3570	3661	3820	3924
3075	3143	3325	3405	3575	3667	3825	3929
3080	3149	3330	3410	3580	3672	3830	3934
3085	3154	3335	3415	3585	3677	3835	3940
3090	3159	3340	3420	3590	3683	3840	3945
3095	3164	3345	3426	3595	3688	3845	3950
3100	3169	3350	3431	3600	3693	3850	3955
3105	3175	3355	3436	3605	3698	3855	3961
3110	3180	3360	3441	3610	3703	3860	3966
3115	3185	3365	3446	3615	3709	3865	3971
3120	3190	3370	3452	3620	3714	3870	3976
3125	3196	3375	3457	3625	3719	3875	3982
3130	3201	3380	3462	3630	3724	3880	3987
3135	3206	3385	3467	3635	3730	3885	3992
3140	3211	3390	3473	3640	3735	3890	3998
3145	3217	3395	3478	3645	3740	3895	4003
3150	3222	3400	3483	3650	3745	3900	4008
3155	3227	3405	3488	3655	3751	3905	4013
3160	3232	3410	3494	3660	3756	3910	4019
3165	3237	3415	3499	3665	3761	3915	4024
3170	3243	3420	3504	3670	3767	3920	4029
3175	3248	3425	3509	3675	3772	3925	4034
3180	3253	3430	3514	3680	3777	3930	4039
3185	3258	3435	3520	3685	3782	3935	4045
3190	3264	3440	3525	3690	3788	3940	4050
3195	3269	3445	3530	3695	3793	3945	4055
3200	3274	3450	3536	3700	3798	3950	4061
3205	3279	3455	3541	3705	3803	3955	4066
3210	3284	3460	3546	3710	3808	3960	4071
3215	3290	3465	3551	3715	3814	3965	4076
3220	3295	3470	3556	3720	3819	3970	4081
3225	3300	3475	3562	3725	3824	3975	4087
3230	3305	3480	3567	3730	3829	3980	4092
3235	3311	3485	3572	3735	3835	3985	4097
3240	3316	3490	3577	3740	3840	3990	4102
3245	3321	3495	3583	3745	3845	3995	4108

TABLE 4 (continued)

Obs'd	True	Obs'd	True	Obs'd	True	Obs'd	True
4000	4113	4250	4377	4500	4641	4750	4905
4005	4118	4255	4382	4505	4646	4755	4910
4010	4124	4260	4387	4510	4651	4760	4916
4015	4129	4265	4393	4515	4656	4765	4921
4020	4134	4270	4398	4520	4662	4770	4926
4025	4139	4275	4403	4525	4667	4775	4932
4030	4145	4280	4408	4530	4672	4780	4937
4035	4150	4285	4414	4535	4677	4785	4942
4040	4155	4290	4419	4540	4683	4790	4947
4045	4160	4295	4424	4545	4688	4795	4953
4050	4166	4300	4430	4550	4693	4800	4958
4055	4171	4305	4435	4555	4699	4805	4963
4060	4176	4310	4440	4560	4704	4810	4969
4065	4182	4315	4445	4565	4709	4815	4974
4070	4187	4320	4451	4570	4714	4820	4979
4075	4192	4325	4456	4575	4720	4825	4984
4080	4197	4330	4461	4580	4725	4830	4990
4085	4203	4335	4466	4585	4730	4835	4995
4090	4208	4340	4472	4590	4735	4840	5000
4095	4213	4345	4477	4595	4741	4845	5006
4100	4218	4350	4482	4600	4746	4850	5011
4105	4224	4355	4488	4605	4751	4855	5016
4110	4229	4360	4493	4610	4757	4860	5022
4115	4234	4365	4498	4615	4762	4865	5027
4120	4240	4370	4503	4620	4767	4870	5032
4125	4245	4375	4509	4625	4773	4875	5037
4130	4250	4380	4514	4630	4778	4880	5043
4135	4255	4385	4519	4635	4783	4885	5048
4140	4261	4390	4524	4640	4788	4890	5053
4145	4266	4395	4530	4645	4794	4895	5059
4150	4271	4400	4535	4650	4799	4900	5064
4155	4277	4405	4540	4655	4804	4905	5069
4160	4282	4410	4546	4660	4810	4910	5075
4165	4287	4415	4551	4665	4815	4915	5080
4170	4292	4420	4556	4670	4820	4920	5085
4175	4298	4425	4561	4675	4826	4925	5090
4180	4303	4430	4567	4680	4831	4930	5096
4185	4308	4435	4572	4685	4836	4935	5101
4190	4313	4440	4577	4690	4841	4940	5106
4195	4319	4445	4582	4695	4847	4945	5112
4200	4324	4450	4588	4700	4852	4950	5117
4205	4329	4455	4593	4705	4857	4955	5122
4210	4335	4460	4598	4710	4863	4960	5128
4215	4340	4465	4604	4715	4868	4965	5133
4220	4345	4470	4609	4720	4873	4970	5138
4225	4350	4475	4614	4725	4878	4975	5143
4230	4356	4480	4619	4730	4884	4980	5149
4235	4361	4485	4625	4735	4889	4985	5154
4240	4366	4490	4630	4740	4894	4990	5159
4245	4371	4495	4635	4745	4900	4995	5165

Depth (m) Observed	~~True~~ Corrn	Depth (m) Observed	~~True~~ Corrn
280	0	3380	80
730	5	3480	85
1070	10	3590	90
1350	15	3680	95
1600	20	3780	100
1800	25	3880	105
2010	30	3980	110
2180	35	4070	115
2360	40	4170	120
2520	45	4260	125
2670	50	4350	130
2800	55	4430	135
2940	60	4520	140
3050	65	4600	145
3170	70	4690	150
3270	75	4770	155
	80	4860	160
		(4950)	165

TABLE 5 - CRITICAL TABLE FOR REVISED 'MATTHEWS' AREA ASSUMING SOUND VELOCITY OF 1500m.sec^{-1} (accuracy ± 5m.)

TABLE 6 - CRITICAL TABLE FOR CONVERSION OF D_{1463} TO D_{1500}.

(ALWAYS ADD CORRECTION $\delta_{1463}-\delta_{1500}$)

D_{1463}	$\delta_{1463}-\delta_{1500}$	D_{1463}	$\delta_{1463}-\delta_{1500}$	D_{1463}	$\delta_{1463}-\delta_{1500}$	D_{1463}	$\delta_{1463}-\delta_{1500}$
	0		35		70		105
20	1	1404	36	2788	71	4172	106
59	2	1443	37	2827	72	4211	107
99	3	1483	38	2867	73	4251	108
138	4	1522	39	2906	74	4290	109
178	5	1562	40	2946	75	4330	110
217	6	1601	41	2985	76	4369	111
257	7	1641	42	3025	77	4409	112
297	8	1680	43	3064	78	4448	113
336	9	1720	44	3104	79	4488	114
376	10	1760	45	3143	80	4527	115
415	11	1799	46	3183	81	4567	116
455	12	1839	47	3223	82	4606	117
494	13	1878	48	3262	83	4646	118
534	14	1918	49	3302	84	4686	119
573	15	1957	50	3341	85	4725	120
613	16	1997	51	3381	86	4765	121
652	17	2036	52	3420	87	4804	122
692	18	2076	53	3460	88	4844	123
731	19	2115	54	3499	89	4883	124
771	20	2155	55	3539	90	4923	125
811	21	2194	56	3578	91	4962	126
850	22	2234	57	3618	92	5002	127
890	23	2274	58	3657	93	5041	128
929	24	2313	59	3697	94	5081	129
969	25	2353	60	3737	95	5120	130
1008	26	2392	61	3776	96	5160	131
1048	27	2432	62	3816	97	5200	
1087	28	2471	63	3855	98		
1127	29	2511	64	3895	99		
1166	30	2550	65	3934	100		
1206	31	2590	66	3974	101		
1246	32	2629	67	4013	102		
1285	33	2669	68	4053	103		
1325	34	2709	69	4092	104		
1364	35	2748	70	4132	105		

A/

	E. 5	4	3	2	1	0	E. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N. 46																					
45																					
44										0·8 (4·0) 1·1			0·9 4·7 1·1	0·9 4·3 1·2	0·9 4·5 1·2	0·9 4·3 1·2					
43									0·8 (4·1) 1·1	0·8 (4·1) 1·2	0·8 4·0 1·2	0·9 4·4 1·2	0·9 4·5 1·2	0·9 4·4 1·2	0·9 4·5 1·2	0·9 4·7 1·2					
42									0·8 (4·2) 1·1	0·8 (4·2) 1·1	0·8 (4·2) 1·1	0·9 4·3 1·1	0·9 4·3 1·2	0·9 4·5 1·2	0·9 4·6 1·2	1·0 4·9 1·3	1·0 (4·9) 1·3	1·0 (4·9) 1·3			
41							0·8 (4·2) 1·1	0·8 (4·2) 1·1	0·8 4·2 1·2	0·8 (4·2) 1·2	0·9 4·3 1·2	0·9 4·3 1·2	0·8 4·2 1·2	0·9 (4·3) 1·2	0·9 (4·5) 1·2	0·9 4·5 1·2	1·0 5·0 1·3	1·0 (5·0) 1·3	1·0 (5·2) 1·3	1·1 (5·3) 1·3	
40						0·8 (4·2) 1·2	0·8 4·2 1·2	0·9 4·3 1·1	0·9 (4·3) 1·1	0·8 (4·2) 1·1	0·9 (4·3) 1·2	0·9 4·5 1·2	0·9 4·6 1·2	1·0 4·8 1·3	0·9 (4·7) 1·3	0·9 (4·6) 1·3	0·9 (4·8) 1·3	1·0 5·2 1·3	1·1 5·4 1·3	1·1 (5·4) 1·3	1·1 (5·4) 1·3
39						0·9 (4·3) 1·2	0·9 4·4 1·2	0·8 4·2 1·2	0·9 (4·5) 1·2	0·9 (4·5) 1·2	0·9 (4·6) 1·2	0·9 4·6 1·2	0·9 4·6 1·2	1·0 4·8 1·3	1·0 (4·8) 1·3	1·0 (4·8) 1·3	1·0 (4·9) 1·3	1·0 4·9 1·3	1·0 4·9 1·3	1·1 5·4 1·3	1·1 5·4 1·3
38					0·8 (4·1) 1·2	0·8 (4·2) 1·2	0·9 (4·3) 1·2	0·9 (4·5) 1·2	0·9 4·7 1·2	0·9 (4·6) 1·2	0·9 (4·5) 1·2	0·9 4·5 1·2	0·9 (4·6) 1·2	1·0 4·8 1·2	0·9 4·4 1·2	0·9 (4·6) 1·2	1·0 (4·8) 1·2	1·0 5·0 1·2	1·0 (5·0) 1·2	1·0 (5·2) 1·2	1·0 (5·2) 1·2
37	0·8 (4·0) 1·1	0·8 (4·0) 1·1	0·8 (4·0) 1·1	0·8 (4·0) 1·2	0·8 (4·1) 1·2	0·8 4·2 1·2	0·8 (4·2) 1·2	0·9 (4·5) 1·2	1·0 4·8 1·2	0·9 (4·6) 1·2	0·9 (4·5) 1·2	0·9 4·3 1·2	0·9 (4·6) 1·2	**1·0 5·0** 1·2	1·0 (4·8) 1·2	0·9 (4·7) 1·2	1·0 (4·8) 1·2	1·0 (4·9) 1·2	1·0 (5·0) 1·2	1·0 (5·1) 1·2	1·0 (5·1) 1·2
36	0·8 4·0 1·1	0·8 (4·0) 1·1	0·8 4·0 1·1	0·8 4·0 1·1	0·8 (4·1) 1·1	0·8 (4·2) 1·1	0·8 (4·2) 1·2										1·0 (4·8) 1·2	1·0 (4·9) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2
35	0·8 3·8 1·1	0·8 (3·9) 1·1	0·8 (3·9) 1·1	0·8 (3·9) 1·1													1·0 (4·8) 1·2	1·0 (4·9) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2
34																	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2
33																	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2
32																	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2	1·0 (5·0) 1·2
31																					1·0 (5·0) 1·2

TABLE 7 - DEPTH CORRECTION δ_{1500} AT OBSERVED DEPTH OF 500m. (ACCURACY ± 1m.)
Brackets indicate interpolated values.
See text (p. 8)

N. \ E.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
46																					
45																					
44																					
43	1·0 (4·8) 1·2	1·0 (4·8) 1·2	0·9 (4·7) 1·2																		
42	1·0 (4·8) 1·2	1·0 4·8 1·2	0·9 4·7 1·3	0·9 4·7 1·3										-1·8 -9·2 -1·2	-1·7 -8·4 -1·2						
41		1·0 (4·9) 1·2	0·9 4·9 1·2	1·0 5·0 1·2								1·0 (5·0) 1·4	1·0 5·2 1·4	1·0 5·1 1·5							
40		1·0 (5·0) 1·3	1·0 (5·0) 1·3	1·1 5·5 1·3	1·1 (5·7) 1·3			1·0 (4·9) 1·3	1·0 4·9 1·3	1·0 5·0 1·3	1·0 4·9 1·3	1·0 (5·0) 1·3									
39	1·0 4·8 1·3	1·0 5·1 1·3	1·1 5·3 1·3	1·1 5·6 1·4	1·2 6·0 1·4	1·2 (6·0) 1·4			1·1 (5·5) 1·3	1·1 (5·6) 1·3	1·1 (5·5) 1·3	1·1 (5·7) 1·3									
38	1·0 4·9 1·4	1·0 5·1 1·4	1·1 5·4 1·4	1·1 5·6 1·4	1·1 5·5 1·4	1·2 (5·8) 1·4	1·2 (6·0) 1·4	1·2 (6·1) 1·3	1·2 (6·2) 1·3	1·2 6·1 1·3	1·2 6·1 1·2	1·2 6·0 1·2									
37	1·0 5·2 1·4	1·1 (5·3) 1·4	1·1 (5·4) 1·4	1·1 (5·6) 1·4	1·2 5·8 1·4	1·2 (5·8) 1·4	1·2 (6·1) 1·4	1·3 (6·3) 1·4	1·3 6·3 1·4	1·3 (6·4) 1·4	1·3 (6·4) 1·4	1·3 6·7 1·3	1·3 6·6 1·3	1·3 6·6 1·3							
36	1·0 5·2 1·3	1·1 5·5 1·3	1·1 (5·4) 1·3	1·1 (5·7) 1·3	1·2 6·0 1·3	1·2 5·9 1·4	1·3 6·4 1·4	1·3 6·4 1·4	1·3 6·4 1·5	1·3 6·7 1·5	1·3 6·7 1·5	1·3 6·7 1·4	1·3 6·5 1·4	1·3 6·6 1·3	1·4 6·8 1·3	1·3 6·7 1·3	1·3 6·6 1·3	1·4 6·9 1·3	1·4 6·8 1·3	1·3 6·7 1·3	
35	1·0 (5·2) 1·3	1·1 (5·3) 1·3	1·1 5·3 1·3	1·1 5·6 1·3	1·1 5·7 1·3	1·2 (5·8) 1·3	1·2 (6·0) 1·3	1·2 6·0 1·3	1·2 (6·2) 1·3	1·3 (6·5) 1·3	1·3 6·6 1·3	1·3 6·7 1·3	1·3 6·4 1·4	1·3 6·3 1·4	1·3 6·3 1·4	1·3 (6·4) 1·4	1·3 6·5 1·3	1·3 (6·6) 1·3	1·3 6·6 1·3	1·2 6·2 1·3	
34	1·0 (5·2) 1·3	1·1 (5·3) 1·3	1·1 (5·3) 1·4	1·1 5·6 1·4	1·2 5·9 1·3	1·2 5·8 1·3	1·2 5·8 1·3	1·2 5·8 1·3	1·2 5·9 1·3	1·3 (6·3) 1·3	1·4 6·9 1·3	1·4 6·8 1·3	1·3 (6·5) 1·4	1·3 (6·6) 1·4	1·3 (6·5) 1·4	1·4 (6·8) 1·4	1·4 7·1 1·4	1·4 (7·0) 1·4	1·4 (6·8) 1·4	1·3 6·5 1·3	
33	1·1 (5·3) 1·3	1·1 (5·4) 1·3	1·1 (5·5) 1·3	1·1 (5·7) 1·3	1·2 5·8 1·3	1·2 5·9 1·3	1·2 5·8 1·3	1·2 (6·2) 1·3	1·3 6·6 1·4	1·3 6·4 1·4	1·3 (6·3) 1·4	1·2 6·2 1·4	1·3 (6·5) 1·4	1·4 6·9 1·4	1·3 6·3 1·4	1·3 (6·6) 1·4	1·4 6·9 1·4	1·4 (6·9) 1·4	1·3 (6·7) 1·3	1·3 (6·5) 1·3	
32	1·1 (5·4) 1·2	1·1 (5·6) 1·2	1·2 (5·8) 1·3	1·2 (5·9) 1·3	1·2 (6·0) 1·3			1·2 (6·2) 1·3	1·3 (6·4) 1·4	1·2 (6·2) 1·3	1·2 (6·2) 1·3	1·3 6·4 1·4	1·3 (6·4) 1·4	1·3 (6·3) 1·4	1·3 6·3 1·4	1·3 (6·4) 1·4	1·3 6·5 1·4	1·3 (6·5) 1·4	1·3 (6·5) 1·4	
31		1·1 (5·6) 1·2	1·2 (5·8) 1·3	1·2 (5·9) 1·3	1·2 (6·0) 1·3							1·3 (6·4) 1·4	1·3 (6·4) 1·4	1·3 (6·3) 1·4	1·3 (6·3) 1·4	1·3 (6·4) 1·4	1·3 (6·5) 1·4	1·3 (6·5) 1·4	1·3 (6·5) 1·4		

TABLE 7 (Continued)

N.	W. 5	4	3	2	1	0	E. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
46																					
45																					
44														1·7 18·6 2·2	1·7 19·2 2·2						
43											1·6 18·8 2·2	1·7 18·8 2·2	1·7 19·2 2·2	1·7 18·9 2·2	1·7 19·2 2·2						
42										1·6 (18·7) 2·2	1·7 (18·8) 2·2	1·7 18·8 2·2	1·7 18·9 2·2	1·7 19·1 2·2							
41									1·7 18·7 2·2	1·7 (18·7) 2·2	1·7 18·7 2·2	1·7 18·7 2·2	1·7 18·8 2·2	1·7 (18·9) 2·2		1·8 20·3 2·3	1·8 20·5 2·3	1·8 (20·6) 2·3	1·8 (20·6) 2·3		
40							1·6 (18·7) 2·2	1·7 18·8 2·2	1·7 (18·7) 2·2	1·7 18·7 2·2	1·7 18·8 2·2	1·7 19·0 2·2	1·7 19·0 2·2	1·7 19·2 2·2		1·8 (20·3) 2·3	1·8 20·2 2·3	1·8 20·8 2·3	1·8 20·9 2·3	1·8 (20·9) 2·3	1·8 (20·9) 2·3
39							1·7 (18·7) 2·2	1·7 (18·7) 2·2	1·7 (18·8) 2·2	1·7 (18·8) 2·2	1·7 (18·9) 2·2	1·7 19·3 2·2	1·7 19·2 2·2	1·7 19·7 2·2	1·7 (19·3) 2·2	1·7 (19·8) 2·2	1·8 (20·3) 2·3	1·8 20·2 2·3	1·8 (20·3) 2·3	1·8 20·7 2·3	1·8 21·1 2·3
38							1·7 (18·7) 2·2	1·7 (18·9) 2·2	1·7 19·1 2·2	1·7 (19·1) 2·2	1·7 (19·1) 2·2	1·7 19·1 2·2	1·7 (19·3) 2·2	1·7 19·6 2·2	1·7 19·2 2·2	1·7 (19·3) 2·2			1·8 (20·3) 2·3	1·8 (20·3) 2·3	1·8 (20·3) 2·3
37					1·7 18·3 2·2	1·7 (18·5) 2·2	1·7 (18·6) 2·2	1·7 (18·9) 2·2	1·7 19·3 2·2	1·7 (19·2) 2·2	1·7 (19·0) 2·2	1·7 18·8 2·2	1·7 (19·3) 2·2	1·7 19·6 2·2							
36	1·7 18·3 2·2	1·7 18·3 2·2	1·7 18·3 2·2	1·7 (18·2) 2·2	1·7 (18·3) 2·2	1·7 (18·3) 2·2															
35																					
34																					

TABLE 8 - DEPTH CORRECTION δ_{1500} AT OBSERVED DEPTH OF 1500m.

N.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
46																				
45																				
44																				
43																				
42															-0·6 -17·3 -0·1					
41																				
40		1·9 (21·4) 2·4		1·9 (21·4) 2·4	1·9 (21·5) 2·4															
39		1·9 (21·4) 2·4	1·9 (21·4) 2·4	1·9 (21·6) 2·4	1·9 (21·7) 2·4															
38	1·9 21·4 2·4	1·9 21·4 2·4	1·9 21·6 2·4	1·9 21·7 2·4	1·9 21·9 2·4	1·9 (22·0) 2·4														
37	1·9 21·4 2·4	1·9 (21·5) 2·4	1·9 (21·6) 2·4	1·9 (21·8) 2·4	1·9 22·0 2·4	1·9 (22·1) 2·4	1·9 (22·4) 2·4													
36	1·9 21·6 2·4	1·9 21·6 2·4	1·9 (21·7) 2·4	1·9 (21·8) 2·4	1·9 22·0 2·4	1·9 22·1 2·4	1·9 22·4 2·4	1·9 22·7 2·4	1·9 (24·5) 2·5	2·0 24·5 2·6	2·0 24·5 2·6	2·0 24·5 2·6	1·8 22·7 2·4	1·8 22·8 2·4	1·8 23·0 2·4	1·8 (22·7) 2·4	1·8 22·9 2·4	1·8 (22·9) 2·4		
35	1·9 (21·6) 2·4	1·9 (21·6) 2·4	1·9 21·7 2·4	1·9 21·9 2·4	1·9 21·8 2·4	1·9 (21·9) 2·4	1·9 (22·2) 2·4	1·9 22·4 2·4	1·9 (22·4) 2·4	1·9 (23·0) 2·4	2·0 23·5 2·4	1·8 23·0 2·4	1·8 22·9 2·4	1·8 22·6 2·4	1·8 22·5 2·4	1·8 (22·6) 2·4	1·8 22·7 2·4	1·8 (22·9) 2·4	1·8 (22·9) 2·4	1·8 22·9 2·4
34	1·8 (21·6) 2·4	1·8 (21·6) 2·4	1·8 (21·7) 2·4	1·8 21·7 2·4	1·9 21·7 2·4	1·9 21·8 2·4	1·9 (22·0) 2·4	1·9 22·2 2·4	1·9 22·2 2·4	1·9 (22·9) 2·4	1·8 23·6 2·4	1·8 23·5 2·4	1·9 22·9 2·4	1·9 (22·8) 2·4	1·9 (22·6) 2·4	1·9 (23·0) 2·4	1·8 23·4 2·4	1·8 (23·2) 2·4	1·8 (23·0) 2·4	1·8 (22·9) 2·3
33	1·8 (21·6) 2·4	1·8 (21·6) 2·4	1·8 (21·7) 2·4	1·8 (21·7) 2·4	1·8 (21·7) 2·4	1·8 (21·8) 2·4	1·8 (21·9) 2·4	1·8 (22·1) 2·4	1·8 (22·1) 2·4	1·8 (22·3) 2·4	1·8 (22·4) 2·4	1·8 22·5 2·4	1·9 (22·7) 2·4	1·9 23·0 2·4	1·9 22·7 2·4	1·9 (23·0) 2·4	1·8 (23·2) 2·4	1·8 (23·2) 2·4	1·8 (23·1) 2·4	1·8 (23·0) 2·4
32	1·8 (21·6) 2·4	1·8 (21·6) 2·4	1·8 (21·7) 2·4	1·8 (21·7) 2·4	1·8 (21·7) 2·4				1·8 (22·1) 2·4	1·8 (22·3) 2·4	1·8 (22·5) 2·4	1·8 22·8 2·4	1·9 (22·9) 2·4	1·9 (22·9) 2·4	1·9 (22·9) 2·4	1·9 (23·0) 2·4	1·8 (23·0) 2·4	1·8 (23·0) 2·4	1·8 (23·0) 2·4	
31			1·8 (21·7) 2·4	1·8 (21·7) 2·4								1·8 (22·9) 2·4	1·9 (22·9) 2·4	1·9 (22·9) 2·4						

TABLE 8 (Continued)

	W 5	4	3	2	1	0	E 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N 46																					
45																					
44															2·8 44·9 3·3						
43											2·7 (44·7) 3·2	2·7 44·9 3·2	2·8 45·0 3·3	2·8 44·8 3·3	2·8 45·0 3·3						
42										2·7 (44·6) 3·2	2·7 (44·6) 3·2	2·8 44·6 3·3	2·8 44·8 3·3	2·8 44·9 3·3							
41									2·7 (44·6) 3·2	2·7 (44·6) 3·2	2·8 44·6 3·3	2·8 44·6 3·3	2·8 44·7 3·3	2·8 (44·8) 3·3			2·8 (46·8) 3·3	2·8 (47·1) 3·3	2·8 (47·3) 3·3		
40										2·8 44·6 3·3	2·8 44·8 3·3	2·8 44·9 3·3	2·8 45·3 3·3	2·8 (45·2) 3·3		2·8 (46·8) 3·3	2·8 46·8 3·3	2·8 47·2 3·3	2·8 47·5 3·3	2·8 (47·3) 3·3	
39									2·8 (44·9) 3·3	2·8 (44·8) 3·3	2·8 (45·0) 3·3	2·8 45·2 3·3	2·8 45·0 3·3	2·8 (45·2) 3·3		2·8 (46·7) 3·3	2·8 (46·7) 3·3	2·8 46·7 3·3	2·8 (46·6) 3·3	2·8 (47·3) 3·3	2·8 47·2 3·3
38						2·8 (44·5) 3·3	2·8 (44·6) 3·3	2·8 (44·8) 3·3	2·8 45·0 3·3	2·8 (45·0) 3·3	2·8 (44·9) 3·3	2·8 44·9 3·3	2·8 (45·2) 3·3	2·8 45·5 3·3	2·8 (45·5) 3·3	2·8 (46·3) 3·3					
37					2·7 (44·5) 3·2	2·8 44·5 3·3	2·8 (44·7) 3·3	2·8 (44·9) 3·3	2·8 45·2 3·3	2·8 (45·0) 3·3	2·8 (44·8) 3·3	2·8 44·6 3·3	2·8 (45·2) 3·3	2·8 45·3 3·3							
36				2·7 (44·5) 3·2	2·7 (44·5) 3·2	2·8 (44·5) 3·3															

TABLE 9 - DEPTH CORRECTION δ_{1500} AT OBSERVED DEPTH OF 2500m.

N. \ Z	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
46																					
45																					
44																					
43																					
42																					
41																					
40																					
39			2·9 49·2 3·4	2·9 (49·2) 3·4	2·9 (49·3) 3·4																
38	2·9 (48·6) 3·4	2·9 (49·0) 3·4	2·9 49·1 3·4	2·9 49·1 3·4	2·9 49·4 3·4																
37	2·9 48·8 3·4	2·9 (49·0) 3·4	2·9 (49·1) 3·4	2·9 (49·3) 3·4	2·9 49·5 3·4																
36	2·9 49·2 3·4	2·9 49·0 3·4	2·9 (49·2) 3·4	2·9 (49·4) 3·4	2·9 49·6 3·4	2·9 49·6 3·5	3·0 (49·9) 3·5	3·0 (50·1) 3·5			3·1 (50·1) 3·5	3·0 (50·1) 3·5	2·9 50·1 3·5	2·9 50·1 3·5	2·9 (50·1) 3·5	2·9 (50·1) 3·5	2·9 50·1 3·5				
35	2·9 (49·2) 3·4	2·9 (49·2) 3·4	2·9 (49·3) 3·4	2·9 49·4 3·4	2·9 48·8 3·4	2·9 (49·1) 3·5	2·9 (49·6) 3·5	2·9 50·1 3·5	2·9 (50·1) 3·5	3·0 (50·1) 3·5		2·9 50·0 3·5	2·9 (50·1) 3·4	2·9 50·1 3·4	2·9 (50·0) 3·4	2·9 (49·9) 3·4	2·9 49·8 3·4				
34	2·9 (49·2) 3·4	2·9 (49·2) 3·4	2·9 (49·2) 3·4	2·9 49·1 3·4	2·9 48·7 3·4	2·9 (49·1) 3·4	2·9 (49·4) 3·4	2·9 49·7 3·4	2·9 (50·0) 3·4	2·9 (50·2) 3·4	2·9 (50·5) 3·4	2·9 50·9 3·4	2·9 (51·0) 3·4	2·9 (51·0) 3·4	2·9 (51·0) 3·4	2·9 (51·1) 3·4	2·9 51·2 3·4				
33		2·9 (49·2) 3·4	2·9 (49·2) 3·4	2·9 (49·2) 3·4	2·9 (49·2) 3·5	2·9 49·6 3·5	2·9 (49·9) 3·5	2·9 50·2 3·5	2·9 50·5 3·5	2·9 (50·4) 3·5	2·9 (50·2) 3·5	2·9 50·0 3·5	2·9 (50·6) 3·5	2·9 51·1 3·5	2·9 (51·1) 3·4	2·9 (51·1) 3·4	2·9 (51·1) 3·4	2·9 (51·1) 3·4	2·9 (51·1) 3·4	2·9 (51·1) 3·4	
32										2·9 (50·3) 3·4	2·9 (50·2) 3·4	2·9 50·2 3·4	2·9 (50·4) 3·4	2·9 (50·5) 3·4	2·9 (50·7) 3·4						
31																					

TABLE 9 (Continued)

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
N.																										
41		3·7 (82·0) 4·5						3·8 (85·5) 4·5																		
40							3·8 (85·5) 4·5	3·8 85·5 4·5	3·8 (85·5) 4·5																	
39	3·7 (82·0) 4·5	3·7 (82·0) 4·5						3·8 (85·5) 4·5	3·8 (85·5) 4·5	3·8 (85·5) 4·5																
38													3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·4) 4·5											
37											3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·4) 4·5	3·9 (89·3) 4·5	3·9 (89·3) 4·5									
36											3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·4) 4·5	3·9 89·2 4·5	3·9 89·4 4·5						4·0 (89·4) 4·5	4·0 89·5 4·5		
35											3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 89·5 4·5	3·9 (89·4) 4·5	3·9 (89·3) 4·5	3·9 (89·3) 4·5	3·9 (89·3) 4·5	3·9 (89·3) 4·5			4·0 (89·3) 4·5		4·0 (89·5) 4·5	4·0 (89·5) 4·5	4·0 (89·5) 4·5
34													3·9 (89·5) 4·5	3·9 (89·5) 4·5	3·9 (89·4) 4·5								4·0 (89·4) 4·5		4·0 (89·5) 4·5	4·0 (89·5) 4·5
33															3·9 (89·4) 4·5	3·9 (89·3) 4·5					4·0 (89·3) 4·5	4·0 (89·3) 4·5	4·0 (89·4) 4·5	4·0 (89·5) 4·5		
32																						4·0 (89·3) 4·5	4·0 (89·4) 4·5			

TABLE 10 - DEPTH CORRECTION δ_{1500} AT OBSERVED DEPTH OF 3500m.

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
37																5·0 (140·0) 5·6										
36											5·0 (140·0) 5·6		5·0 (140·0) 5·6	5·0 (140·0) 5·6		5·1 140·0 5·6	5·1 (140·0) 5·6							5·0 140·8 5·6		
35													5·0 (140·0) 5·6													

TABLE 11 - DEPTH CORRECTION δ_{1500} AT OBSERVED DEPTH OF 4500m

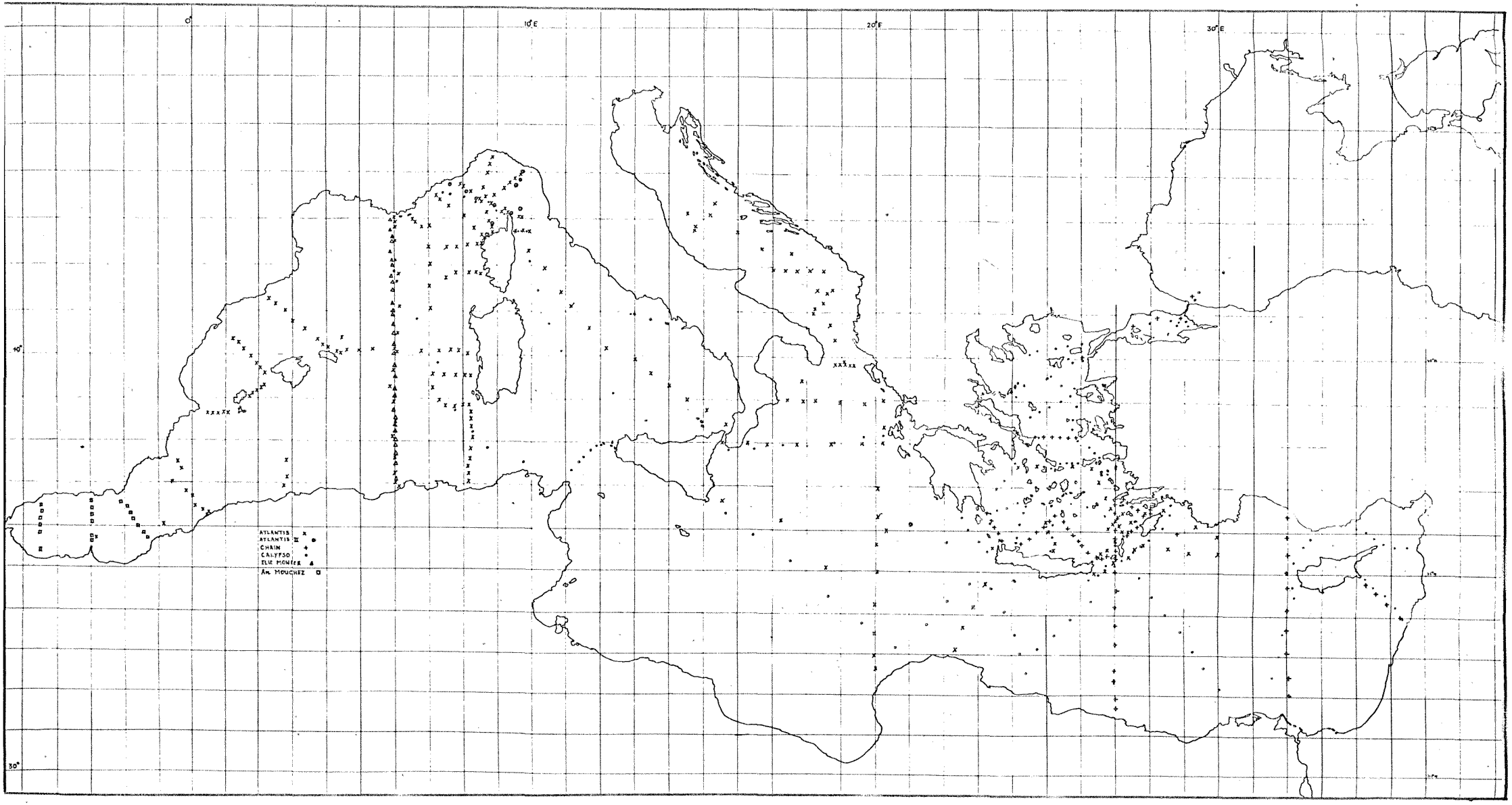


FIG. 1 DISTRIBUTION OF HYDROGRAPHIC STATIONS

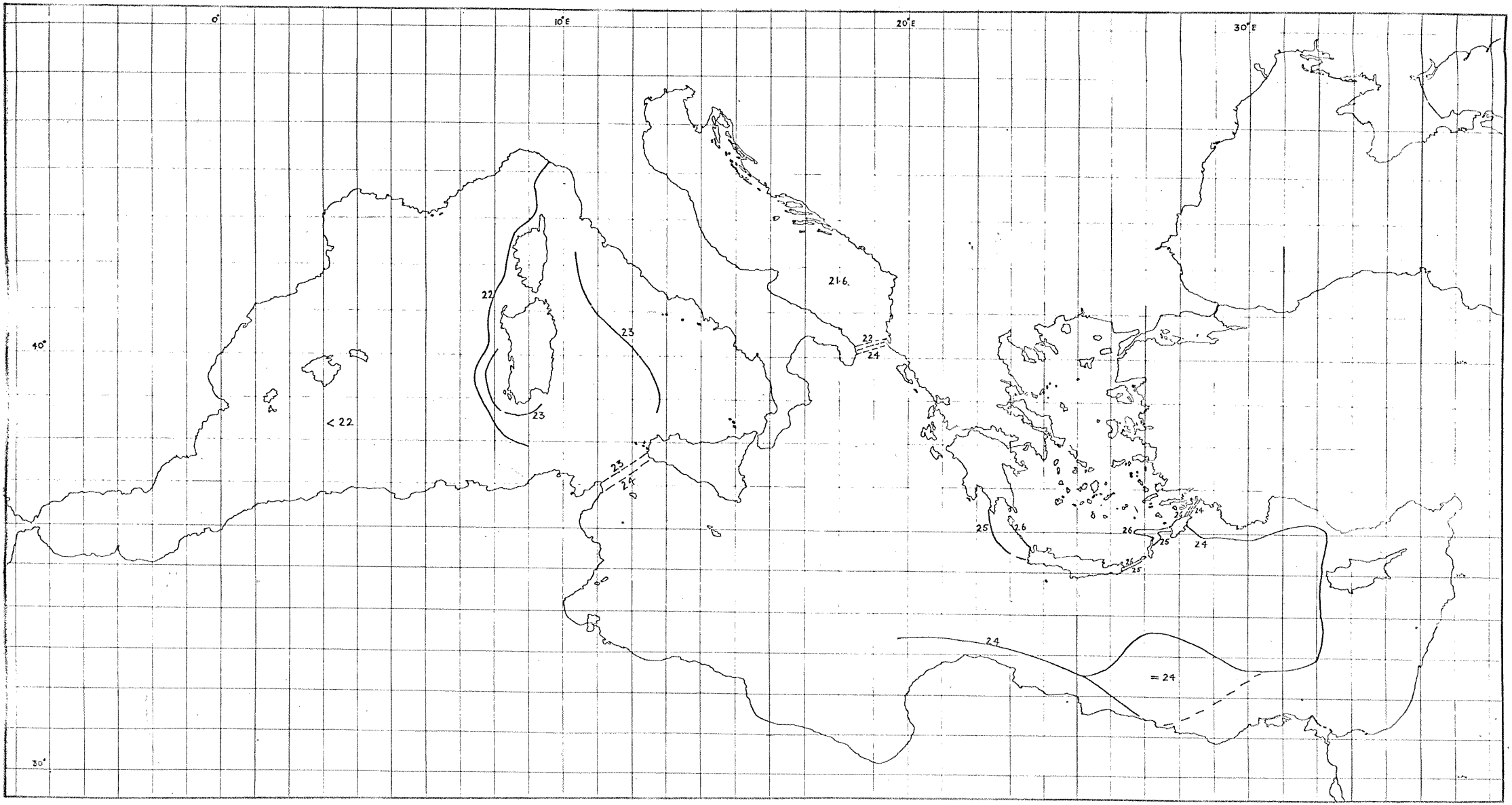


FIG. 2 SOUND VELOCITY AT 1000m.
(units are $m.sec^{-1}$ relative to $1500m.sec^{-1}$)

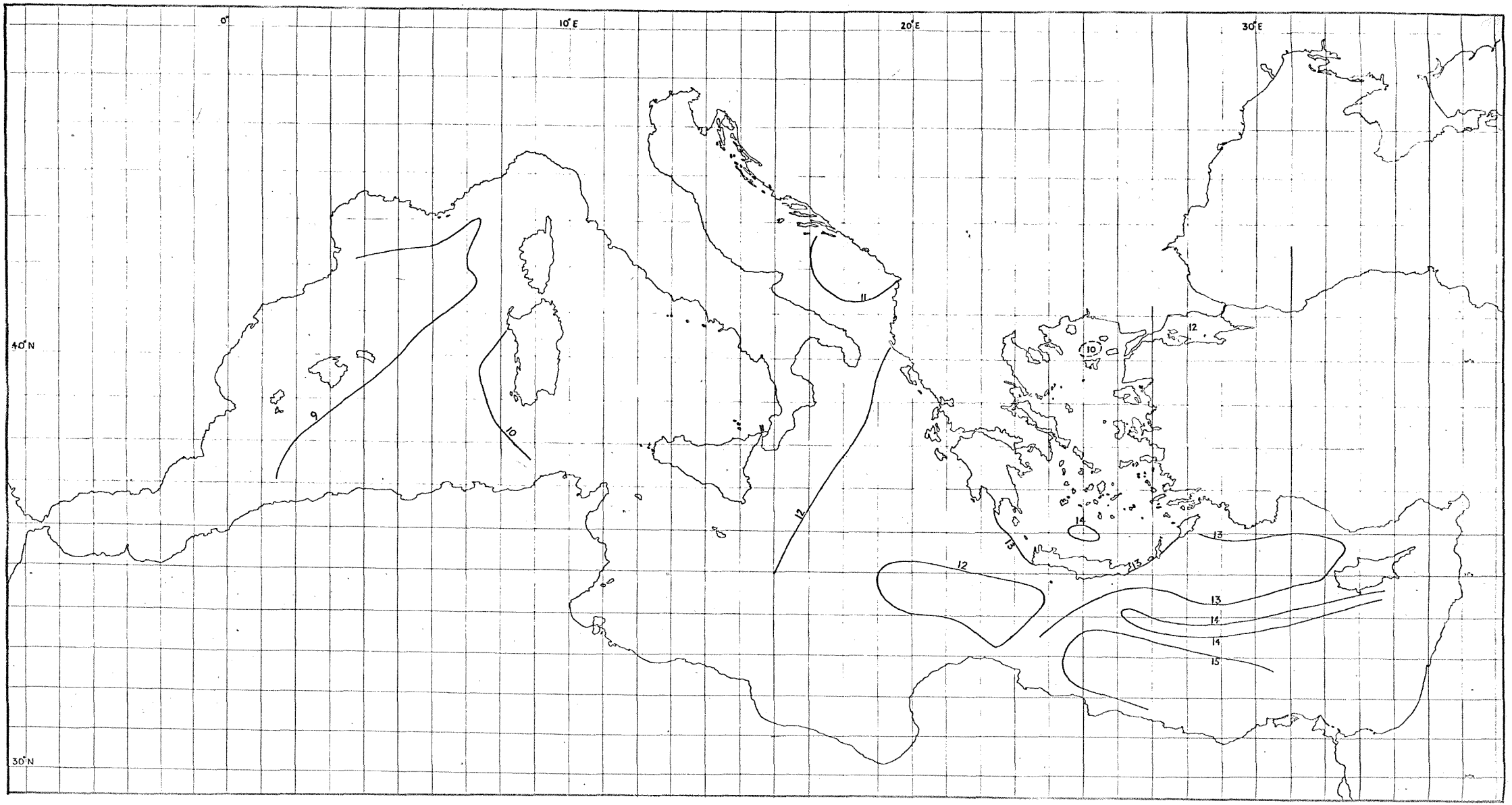


FIG. 3 DEPTH CORRECTION δ_{1500} AT 1000m. TRUE DEPTH
(metres)

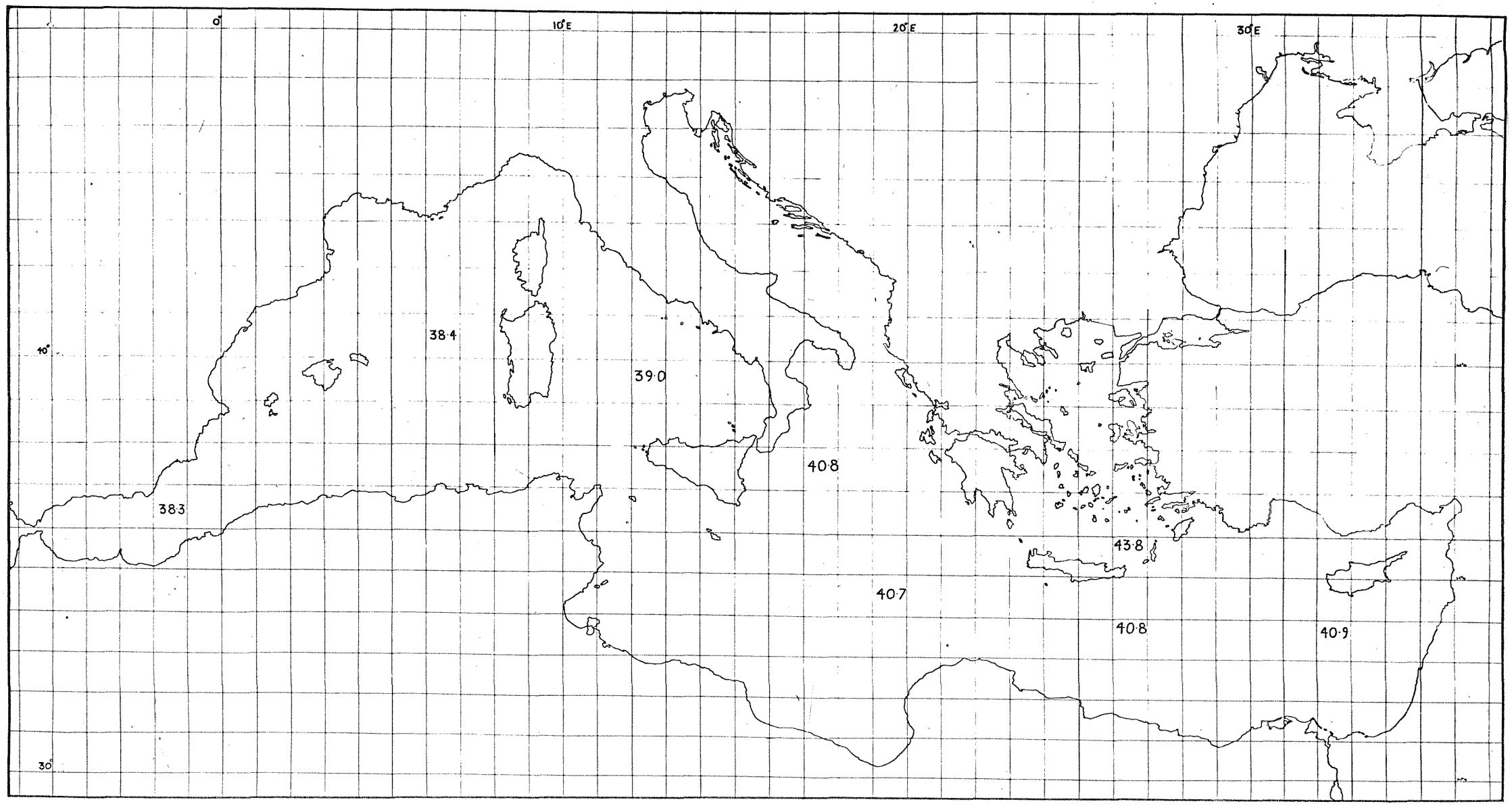


FIG. 4 SOUND VELOCITY AT 2000m. (units are m.sec^{-1} relative to 1500m.sec^{-1}).

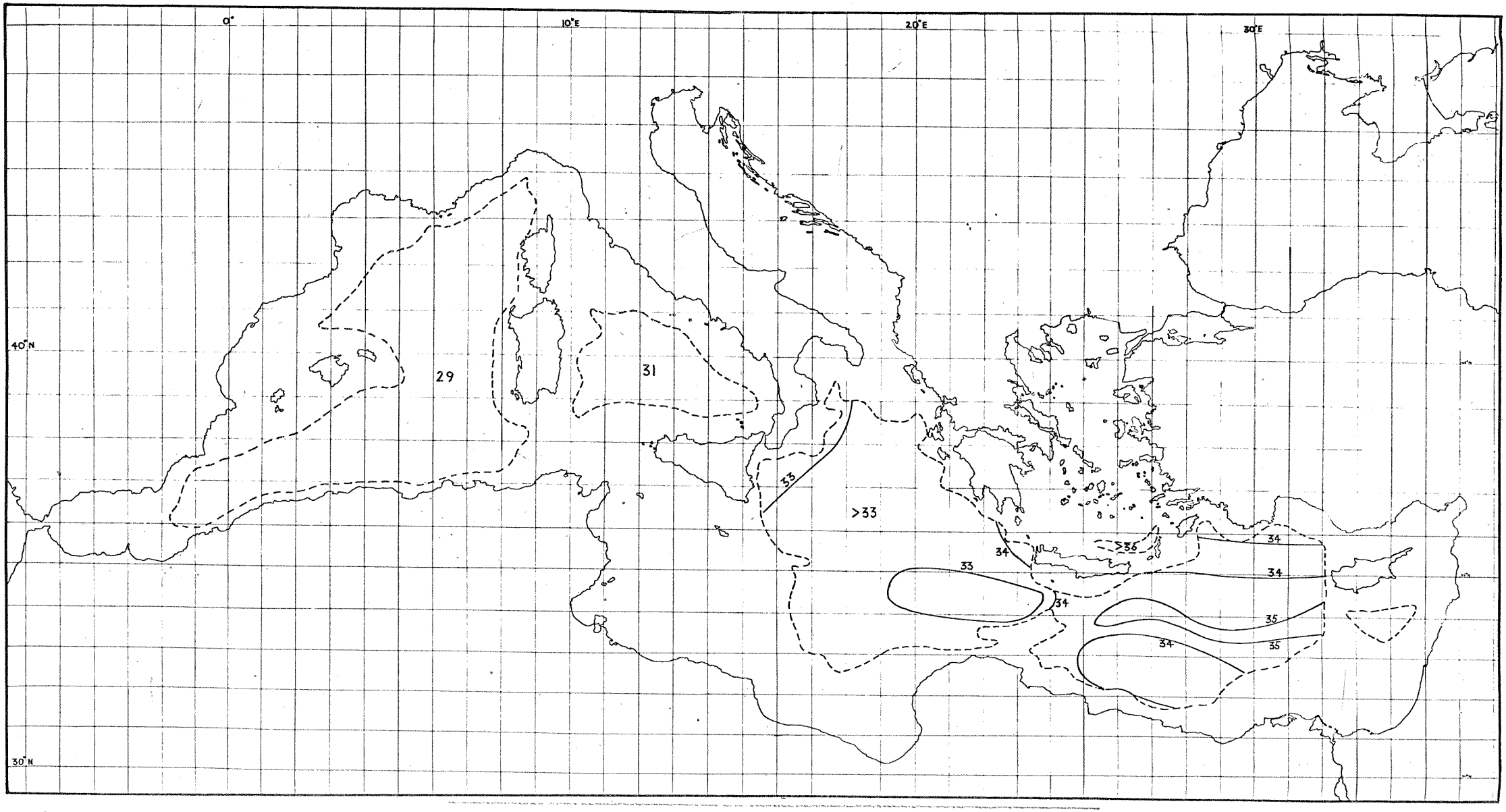
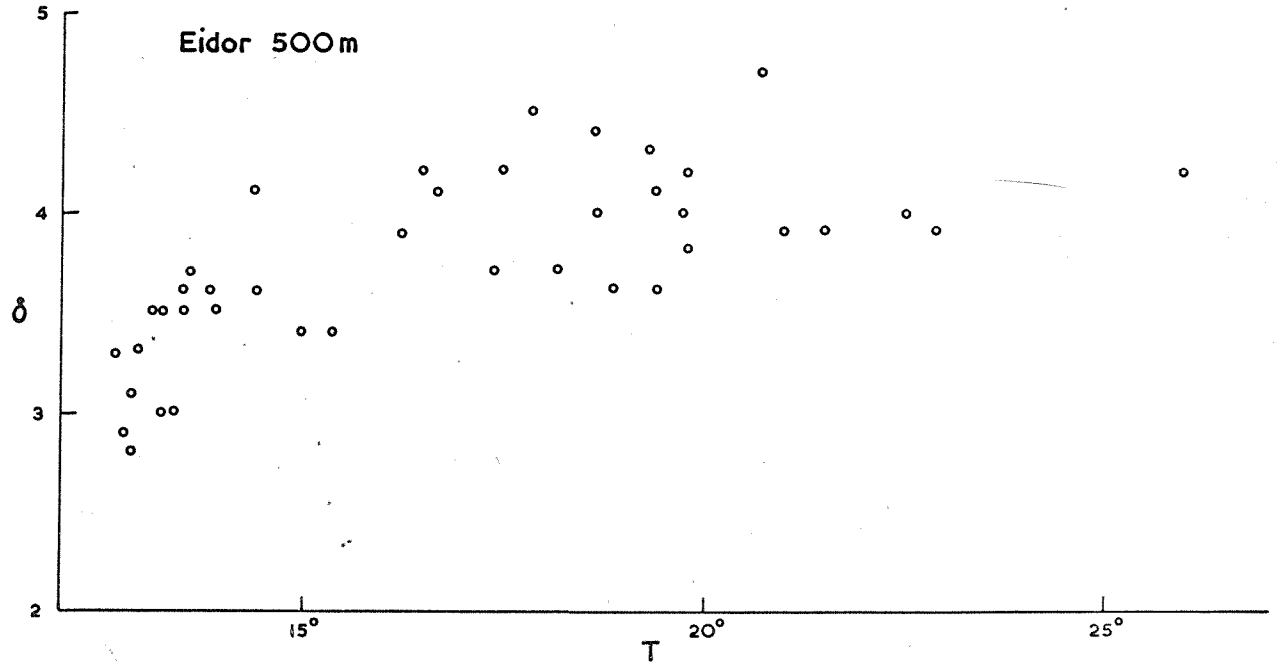


FIG. 5 DEPTH CORRECTION δ_{1500} AT 2000m. TRUE DEPTH (metres)



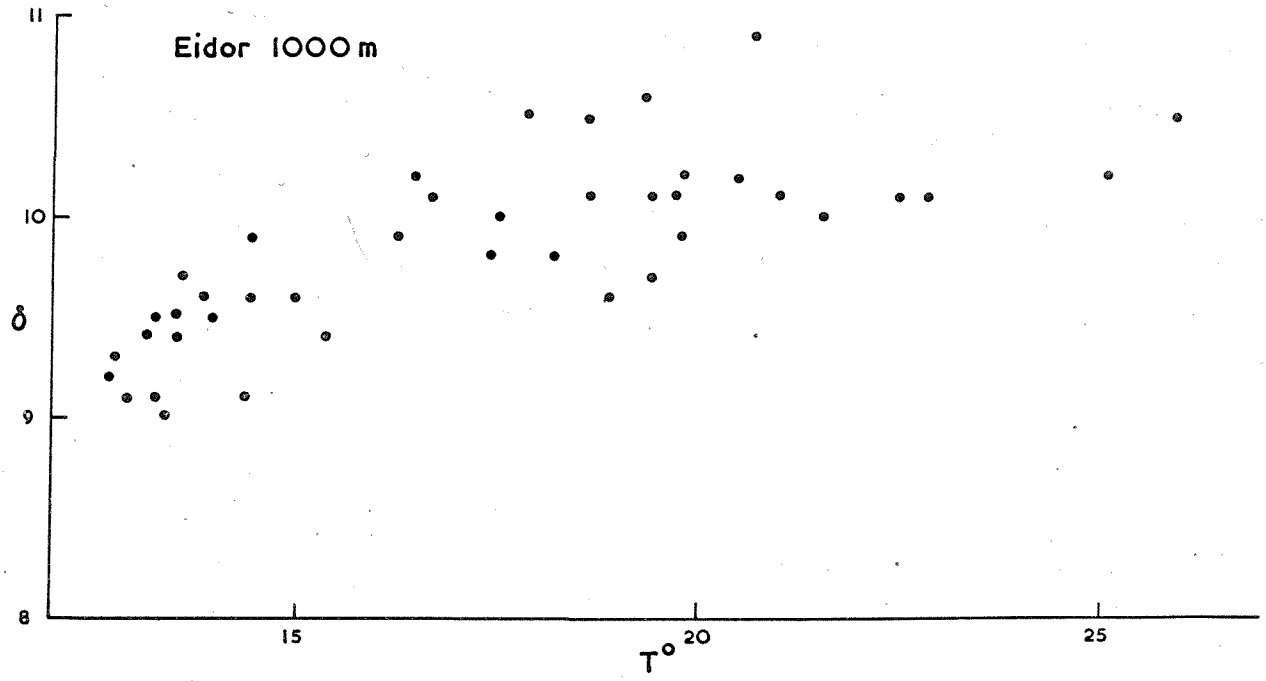


FIG. 6 VARIATION OF δ_{1500} AT 500m. AND 1000m. WITH SURFACE TEMPERATURE.