NATIONAL INSTITUTE OF OCEANOGRAPHY
WORMLEY, GODALMING, SURREY

# Revision of Matthews Tables

(PUBLICATION HD. 282)

## Pilot Study of The Gulf Stream Region

by

J. CREASE and PAMELA EDWARDS

N.I.O. Internal Report No. A. 56

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## Introduction

An earlier study of Matthews tables for the Mediterranean (NIO Internal Report A26) concluded that in that area errors in depth correction were not more than 3m. Allowance for variations in surface temperature due to the annual cycle made it feasible to reduce the errors to 1m. To achieve this accuracy new methods of data presentation were proposed.

It was also proposed that a study be made of a region of greater variability where Matthews areas become so close as to become difficult to use and indeed uncertain in their usefulness. In this paper we take up this study and have chosen to work in perhaps the most difficult region for interpretation: the area of Gulf Stream meanders north of Cape Hatteras.

This area encompasses Matthews areas 5, 6, 7, 8, 9, 12, 13 and 14 in the space of some 120 n. m. including water masses identifiable with the slope, Gulf Stream and Sargasso sea. The meander structure of the Gulf Stream is well known and results in the displacement of parts of the Stream some 300 n. m. southwards thus invalidating the 'climatological mean' corrections given by Matthews, possibly by as much as 25m. Table 1 shows the corrections for the areas covered.

## The Data

There are a vast number of observations of varying quality available for the Gulf Stream region at different seasons of the year. We have however chosen to use some 200 stations from a detailed high quality survey carried out in April to June 1960 by Fuglister. It spans the region 33° to 43°N, 57° to 69°W. As in the previous study the basic data are temperature and salinity as a function of depth.

Sound velocity is computed using Wilson's formula (1960). There have been suggestions that this may be in error by 65cm/sec but this is not really significant for our purposes and in any case the formula is widely accepted at the present time. Depth corrections using a nominal sound velocity of 1500m/sec ($\delta$1500) have been calculated for all stations individually both as a function of true depth and uncorrected depth observed on an echo-sounder.

Corrections using a nominal sound velocity of 1463m/sec are not discussed in this paper as they can readily be extracted from $\delta$1500 by a single table lookup (NIO I. R. /A26, P. 5). The computational procedures are discussed in more detail in our earlier report.

Matthews Areas 13 and 14

Certain of our data are clearly identifiable as being south east of the Stream and lying in Matthews areas 13 or 14. A comparison of our corrections and Matthews' is made in table 2. It is apparent that differences of 10m are present at depths of 1000m. in area 13. These are not related to the meander pattern and are presumably due to improvements in the data, primarily, and in the sound velocity formula. Area 14 is much more closely in agreement with our data and more-over is oceanographically consistent with the presence of '18° water', as it is called, to the south of the Stream at a depth of 400m or so.

Revision of the tables in their present form in this area would therefore amount to an extension of area 14 over the whole region and the elimination of area 13.

The Meander Region and Cold Wall

The cold wall is a frontal zone in which the surface temperature can drop some 10°C in 20n. m. From the point of view of the present study a complicating factor is that the 'cold wall' slopes down to the SW across the Stream below the surface.

We first examine the accuracy obtainable from a mean correction table for the area. Tables 3, 4, and 5 make it abundantly clear that in the vicinity of the cold wall variations of 20m or more in $\delta$1500 can occur at one location. Therefore any 'climatological' table can only be accurate to this extent. It then follows, on examination of the whole area under study, that one table would probably suffice for the region at present covered by areas 7, 8, 9, 12. Rather than generate an entirely new set of tables the area 9 table as it exists at present could be adopted as the mean table for areas 7, 8, 9, 12 with an uncertainty of $\pm$ 12m. Any further subdivision of a mean 'climatological' table is meaningless.

Turning to the possibility of synoptic corrections of greater accuracy we examine as before the correlation of correction with surface temperature on the grounds that this latter variable is the only one likely to be both of some use and available synoptically. Figure 1 shows all the $\delta$ 1500 corrections at a depth of 2500m as a function of surface temperature. The different symbols indicate the relationship of the observations to existing Matthews areas. The correlation is apparent and interesting. Below about 18°C there is a strong correlation between the two variables- above 18° there is wide scatter. This is related directly to the emergence at the surface of '18° water'. First we examine and account for the scatter. The reason is most simply illustrated by the vertical temperature profiles at 39°N, 64°W, in figure 2. The surface layer is typical of profiles to the south of the Stream whilst the main thermocline can be typical of water to the north, within, or to the south. The station positions are in the immediate vicinity of the surface 'cold wall'.

The point of immediate practical importance is that within a short distance to the south of the 'cold wall' it will be impossible to make corrections with any great improvement on the mean table.

Turning to the correlation below 18°, i. e., in the areas:- 7, 8, 9, 12, it can be seen from figure 1 that it can be used to reduce the error in $\delta$1500 to $\pm$ 3m.

In other words in the area we have defined above as the mean area

$$\delta\, 1500\ (\text{synoptic}) = \delta\, 1500\ (\text{mean}) + 0.6\ (T - 19°)$$

The temperature correction vanishes of course as one approaches shallow depths and the formula is appropriate to depths greater than 500m. At lesser depths the coefficient of 0. 6 would decrease proportionately to zero.

## Canadian Study of the Gulf Stream Region

Greenberg and Sweers (CODS unpublished) have made a somewhat similar study of the area 40° - 50°N and 40° - 60°W, (Marsden Squares 149 and 150). They used all the data available to the data centre for areas 149 and 150 and established mean values of $\delta$1463 for various levels by 1° square. They also looked for and found a surface temperature correlation. For Marsden square 149 at a depth of 2000m they found

$$\delta 1463 = 22.2 + 1.03T$$
$$= 41.8 + 1.03\ (T-19)$$

which may be converted by table lookup (NIO I. R. /A26, table 6) to

$$\delta 1500 = -8.2 + 1.03\ (T-19)$$

This is to be compared with our correction in the previous paragraph

$$\delta 1500\ (\text{synoptic}) = -9 + 0.6\ (T-19)$$

The significant difference between these two expressions is in the change of correction/ °C. One possible explanation is that in a statistical fit of all the data to a straight line the slope of the line would be biassed if the data above 18°C were included (see fig. 1). This could be the case in the CODC treatment. If not, CODC's larger sample may provide a more precise estimate of this parameter.

## Conclusions

1. That in areas of strong horizontal temperature gradient such as the Gulf Stream the sub-division into many closely spaced Matthews areas is inappropriate and misleading.
2. That variations of ± 12m can be expected in the Gulf Stream area at any one place.
3. That the errors are inherent in the instability of the Gulf Stream.
4. That to the south of the Gulf Stream there is clear evidence that redefinition of Matthews areas 13 and 14 would improve the accuracy of the corrections.

## Possible Proposals

1. That in the region of the Gulf Stream the present conglomeration of areas 7-12 be replaced by a single 'mean' one (area 9 has been suggested in the text) with an accurancy of ± 12m.

2. That for higher accuracy synoptic corrections for surface temperature are possible in the Gulf Stream region with an accuracy of $\pm$ 3m or better with some provisos as to accuracy when close to the cold wall.

3. That a revision of Matthews areas outside regions of strong gradients could significantly improve their accuracy. The new methods of presentation discussed in NIO I. R. /A26 may be the appropriate basis for this revision.

TABLE 1

MATTHEWS CORRECTIONS REFERRED TO NOMINAL SOUND VELOCITY OF 1500m/sec

CORRECTIONS IN METRES

| Depth m | AREA 5 | 6 | 7 | 8 | 9 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|
| 200 | - 2 | - 3 | - 2 | - 1 | 2 | 3 | 2 | 4 |
| 400 | - 5 | - 7 | - 4 | - 2 | 1 | 4 | 2 | 6 |
| 600 | - 9 | - 10 | - 8 | - 4 | 1 | 6 | 3 | 8 |
| 800 | - 13 | - 13 | - 11 | - 6 | - 2 | 4 | 3 | 9 |
| 1000 | - 16 | - 17 | - 13 | - 9 | - 3 | 4 | 3 | 9 |
| 1200 | - 20 | - 19 | - 15 | - 10 | - 4 | 3 | 3 | 8 |
| 1400 | - 23 | - 21 | - 18 | - 13 | - 7 | 2 | 3 | 6 |
| 1600 | - 26 | - 23 | - 19 | - 15 | - 7 | 1 | 4 | 6 |
| 1800 | - 26 | - 24 | - 20 | - 16 | - 8 | 0 | 4 | 5 |
| 2000 | - 27 | - 26 | - 21 | - 16 | - 9 | 0 | 4 | 4 |
| 2200 | - 28 | - 26 | - 22 | - 16 | - 10 | 0 | 4 | 3 |
| 2400 | - 28 | - 26 | - 22 | - 16 | - 10 | 0 | 5 | 6 |
| 2600 | - 28 | - 26 | - 21 | - 16 | - 9 | 1 | 5 | 7 |
| 2800 | - 27 | - 26 | - 21 | - 15 | - 9 | 2 | 6 | 7 |
| 3000 | - 26 | - 25 | - 18 | - 14 | - 8 | 4 | 8 | 10 |
| 3200 | - 24 | - 22 | - 17 | - 10 | - 6 | 6 | 8 | 11 |
| 3400 | - 23 | - 19 | - 16 | - 9 | - 5 | 7 | 11 | 14 |
| 3600 | - 20 | - 16 | - 12 | - 7 | 0 | 10 | 15 | 17 |
| 3800 | - 18 | - 13 | - 9 | - 5 | 3 | 13 | 18 | 18 |
| 4000 | - 14 | - 9 | - 6 | 0 | 8 | 16 | 22 | 22 |
| 4200 | - 12 | | - 2 | 3 | 12 | 20 | 26 | 26 |
| 4400 | - 6 | | | 8 | 16 | 27 | 30 | 33 |
| 4600 | - 4 | | | 13 | 22 | 32 | 36 | 38 |
| 4800 | 0 | | | 19 | 27 | 36 | 40 | 42 |
| 5000 | 5 | | | 25 | 34 | 44 | 46 | 48 |

TABLE 2

COMPARISON OF CORRECTIONS FOR AREAS 13 AND 14 (METRES)

| DEPTH m | AREA 13 NIO MEAN CORRECTION, δ | AREA 13 NIO δ — MATTHEWS' δ | AREA 14 NIO MEAN CORRECTION, δ | AREA 14 NIO δ — MATTHEWS' δ |
|---|---|---|---|---|
| 200 | 3 | 1 | 3 | -1 |
| 400 | 6 | 4 | 6 | 0 |
| 600 | 9 | 6 | 9 | 1 |
| 800 | 12 | 9 | 11 | 2 |
| 1000 | 13 | 10 | 11 | 2 |
| 1200 | 12 | 9 | 10 | 2 |
| 1400 | 11 | 8 | 9 | 3 |
| 1600 | 10 | 6 | 8 | 2 |
| 1800 | 9 | 5 | 7 | 2 |
| 2000 | 9 | 5 | 7 | 3 |
| 2200 | 9 | 5 | 7 | 4 |
| 2400 | 9 | 4 | 8 | 2 |
| 2600 | 10 | 5 | 9 | 2 |
| 2800 | 11 | 5 | 10 | 3 |
| 3000 | 13 | 5 | 11 | 1 |
| 3200 | 15 | 7 | 13 | 2 |
| 3400 | 17 | 6 | 15 | 1 |
| 3600 | 19 | 4 | 18 | 1 |
| 3800 | 22 | 4 | 21 | 3 |
| 4000 | 26 | 4 | 25 | 3 |
| 4200 | 30 | 4 | 29 | 3 |
| 4400 | 34 | 4 | 33 | 0 |
| 4600 | | | 38 | 0 |
| 4800 | | | 43 | 1 |
| 5000 | | | 49 | 1 |

NOMINAL SOUND VELOCITY 1500m/sec.

**TABLE 3**

RANGE OF CORRECTIONS AT **500** METRES AND SURFACE TEMPERATURES

| LAT.°N \ LONG°W | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | LAT.°N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | | | | | | | | | | -7/-2 6/11 2 | -7/0 4/13 2 | -1 10 1 | | 43 |
| 42 | | | | | -7/-5 3/5 2 | -7 4 1 | -7 6 1 | -4/-3 5/10 2 | -3 9 1 | -5/-3 6/9 2 | 0 16 1 | 0 14/15 2 | | 42 |
| 41 | | | -4 6 1 | | -5 3/5 2 | | | -2/3 12/19 3 | | -3/6 7/22 2 | 0 6 1 | 0 15 1 | | 41 |
| 40 | -6 4 1 | | | -2/-1 8/13 3 | -3/-2 12/13 2 | | 4 19 1 | 0 16 1 | | 7 22 1 | | 0 10 1 | | 40 |
| 39 | -4 7/9 3 | | -3/-2 13/15 2 | -3/-2 14/18 4 | -3/7 13/23 4 | -2/8 12/24 9 | | 8 21 1 | 1/7 17/22 4 | 1 20 1 | 0/7 18/20 4 | 1/7 18/23 3 | 3 23 1 | 39 |
| 38 | -4 8 1 | 3/8 23 2 | | 3/7 23/26 2 | 7/8 19/23 6 | 8 21 3 | 8 18/19 2 | 8/9 22/23 3 | 4/9 18/26 8 | 9 26 1 | | 8 20 2 | | 38 |
| 37 | 8 21 1 | 8 20 1 | 8 22 2 | 8/9 24/25 2 | 3/8 19/25 9 | 4/8 21/25 5 | 7/8 19/20 2 | 8 19/22 2 | 8 20/22 2 | 2/9 16/26 6 | 8 23 1 | 8 19 1 | | 37 |
| 36 | 7 18 1 | 7 18 1 | 7 22 1 | 6/8 20/23 4 | 2/9 18/25 7 | 8 21/22 2 | 6 19 1 | 7/8 21 2 | 7 19 1 | | 7 19 1 | 8 19 1 | | 36 |
| 35 | | 7/8 18 2 | 7 19 1 | 8 20 1 | 8 23 2 | 7/8 19/22 4 | 5 18 1 | 7/8 21 3 | 8 19 1 | | | 7 18 1 | | 35 |
| 34 | | 7 18 1 | | 8 18 1 | | 8 20/23 2 | | 8 19/21 2 | 7 19 1 | | | 7 19 1 | | 34 |
| 33 | 7 19 1 | | 8 19 1 | | | 8 20/22 3 | | 8 20/21 3 | 7 19 1 | | | 8 20 1 | | 33 |
| | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | |

**1st Column** ---- RANGE OF CORRECTIONS AT **500** M. (UNCORRECTED DEPTH)
**2nd** ,, ---- RANGE OF SURFACE TEMPERATURES
**3rd** ,, ---- NUMBER OF OBSERVATIONS USED.

NB. READ VERTICALLY.

**TABLE. 4.**

RANGE OF CORRECTIONS AT **1500** METRES AND SURFACE TEMPERATURES

| LAT.° N \ LONG.° W | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | LAT° N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 — | | | | | | | | | | -17/-12 6/11 2 | -18/-10 4/13 2 | -8 10 1 | | 43 |
| 42 — | | | | | -17/-16 3/5 2 | -18 4 1 | -17 6 1 | -15/-12 5/10 2 | -13 9 1 | -15/-13 6/9 2 | -10 16 1 | -10 14/15 2 | | 42 |
| 41 — | | | -15 6 1 | | -15 3/5 2 | | | -11/-6 12/19 3 | | -13/-2 7/22 2 | -9 16 1 | -9 15 1 | | 41 |
| 40 — | -17 4 1 | | | -12/-11 8/13 3 | -13/-12 12/13 2 | | -5 19 1 | -8 16 1 | | 3 22 1 | | -9 10 1 | | 40 |
| 39 — | -15/-14 7/9 3 | | -13 13/15 2 | -14/-13 14/18 4 | -13/2 13/23 4 | -13/7 12/24 9 | | 7 21 1 | -8/5 17/22 4 | -8 20 1 | -9/9 18/20 4 | -8/6 18/23 3 | 7 23 1 | 39 |
| 38 — | -15 8 1 | -6/6 23 2 | | -5/0 23/26 2 | 4/9 19/23 6 | 7/11 21 3 | 11 18/19 2 | 10/12 22/23 3 | -2/10 18/26 8 | 4 26 1 | | 7/9 20 2 | | 38 |
| 37 — | 10 21 1 | 13 20 1 | 9/10 22 2 | 9/10 24/25 2 | -5/11 19/25 9 | -2/9 21/25 5 | 5/10 19/20 2 | 10/11 19/22 2 | 7/11 20/22 2 | -6/9 16/26 6 | 8 23 1 | 8 19 1 | | 37 |
| 36 — | 12 18 1 | 9 18 1 | 6 22 1 | 1/10 20/23 4 | -6/11 18/25 7 | 8/13 21/22 2 | 2 19 1 | 5/7 21 2 | 7 19 1 | | 8 19 1 | 10 19 1 | | 36 |
| 35 — | | 11/12 18 2 | 10 19 1 | 11 20 1 | 11/14 23 2 | 3/15 19/22 4 | -2 18 1 | 4/7 21 3 | 9 19 1 | | | 8 18 1 | | 35 |
| 34 — | | 9 18 1 | | 11 18 1 | | 13 20/23 2 | | 7 19/21 2 | 9 19 1 | | | 5 19 1 | | 34 |
| 33 — | 9 19 1 | | 9 19 1 | | | 10/11 20/22 3 | | 9/11 20/21 3 | 7 19 1 | | | 9 20 1 | | 33 |
| | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | |

**1st Column** ----- RANGE OF CORRECTIONS AT **1500** METRES (UNCORRECTED DEPTH)
**2nd** " ----- RANGE OF SURFACE TEMPERATURES.
**3rd** " ---- NUMBER OF OBSERVATIONS USED.
NB. READ VERTICALLY.

**TABLE 5**

RANGE OF CORRECTIONS AT **2500** METRES AND SURFACE TEMPERATURES.

| LAT° N \ LONG° W | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | LAT° N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | | | | | | | | | | -14 11 1 | -20/-11 4/13 2 | -10 10 1 | | 43 |
| 42 | | | | | -18 3 1 | | | -17 5 1 | -15 9 1 | -17/-15 6/9 2 | -11 16 | -11 14/15 2 | | 42 |
| 41 | | | | | -17/-16 3/5 2 | | | -13/-7 12/19 3 | | -15/-3 7/22 2 | -11 16 1 | -11 15 1 | | 41 |
| 40 | -18 4 1 | | | -14/-13 8/13 3 | -15/-14 12/13 2 | | -6 19 1 | -9 16 1 | | 2 22 1 | | -10 10 1 | | 40 |
| 39 | -17/-16 7/9 3 | | -15/-14 13/15 2 | -16/-14 14/18 4 | -15/1 13/23 4 | -14/7 12/24 9 | | 7 21 1 | -9/4 17/22 4 | -10 20 1 | -11/9 18/20 4 | -9/5 18/23 3 | 6 23 1 | 39 |
| 38 | -16 8 1 | -7/5 23 2 | | -7/-1 23/26 2 | 3/9 19/23 6 | 7/11 21 3 | 11 18/19 2 | 10/12 22/23 3 | -3/9 18/26 8 | 3 26 1 | | 7/9 20 2 | | 38 |
| 37 | 10 21 1 | 13 20 1 | 9 22 2 | 8/9 24/25 2 | -6/10 19/25 9 | -3/8 21/25 5 | 4/9 19/20 2 | 9/11 19/22 2 | 6/11 20/22 2 | -7/8 16/26 6 | 8 23 1 | 7 19 1 | | 37 |
| 36 | 12 18 1 | 9 18 1 | 6 22 1 | 0/9 20/23 4 | -7/11 18/25 7 | 7/12 21/22 2 | 1 19 1 | 5/6 21 2 | 7 19 1 | | 8 19 1 | 10 19 1 | | 36 |
| 35 | | 11/12 18 2 | 10 19 1 | 11 20 1 | 10/14 23 2 | 2/15 19/22 4 | -3 18 1 | 3/7 21 3 | 8 19 1 | | | 8 18 1 | | 35 |
| 34 | | 9 18 1 | | 11 18 1 | | 13 23 1 | | 6 19/21 2 | 8 19 1 | | | 5 19 1 | | 34 |
| 33 | 8 19 1 | | 9 19 1 | | | 10 20/22 3 | | 8/10 20/21 3 | 6 19 1 | | | 9 20 1 | | 33 |
| | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | |

**1st Column** ---- RANGE OF CORRECTIONS AT **2500** METRES (UNCORRECTED DEPTH)

**2nd** ,, ------- RANGE OF SURFACE TEMPERATURES.

**3rd** ,, ------- NUMBER OF OBSERVATIONS USED.

NB. READ VERTICALLY.

Figure. 1.

CORRECTION AT 2500m. PLOTTED AGAINST SURFACE TEMPERATURE

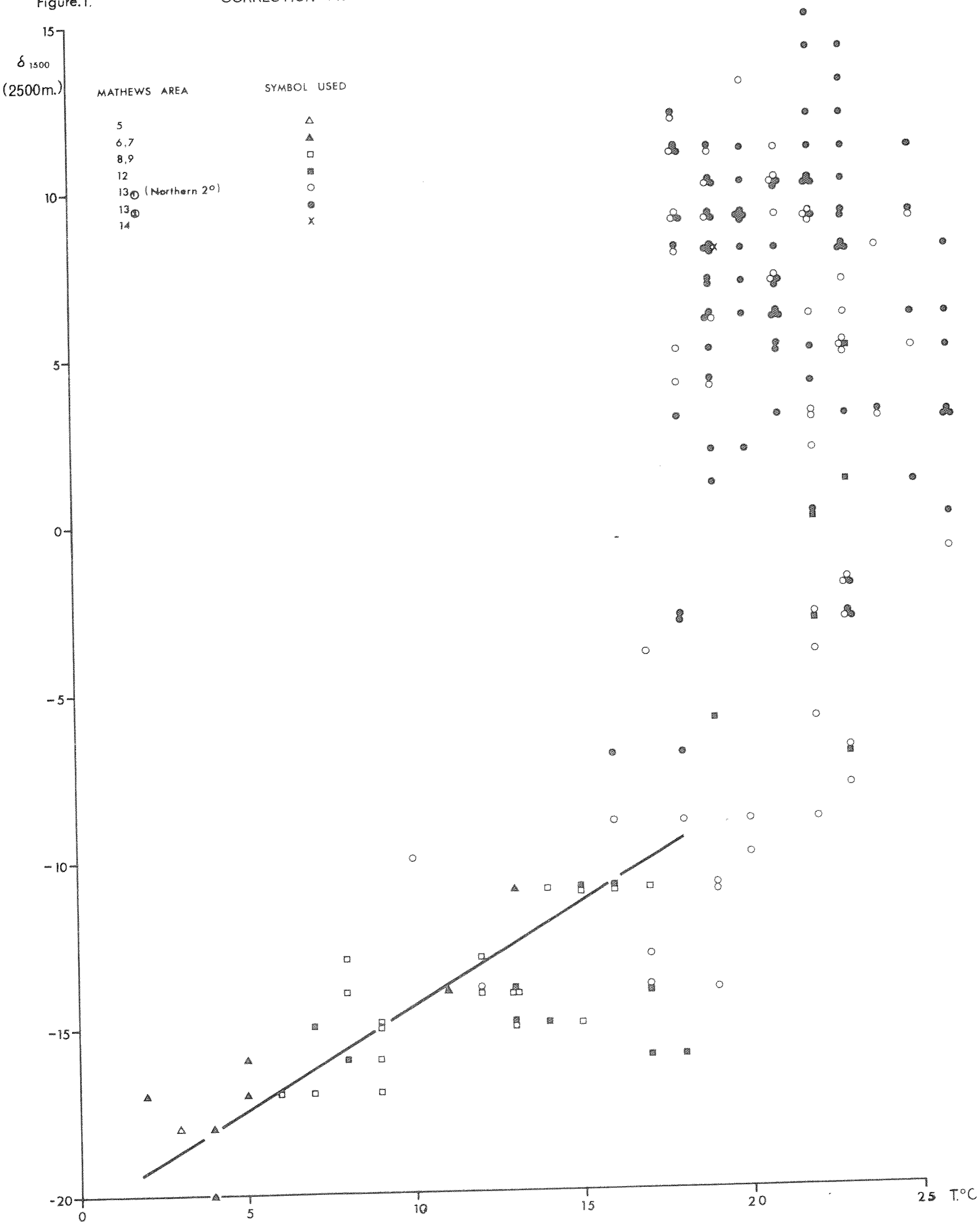

Figure. 2. TEMPERATURE PROFILES AT 39°N, 64°W