CHAPTER VII

COMPUTATION OF DYNAMIC HEIGHT ANOMALY

In the preceding chapter we have found that 3000 d bar surface is an ideal surface to be used as a zero surface in the Arabian sea for the purpose of computation of the derived quantities, namely, anomalies of dynamic height of isobaric surfaces and geostrophic currents. Equation (5.17) has shown that the error in the dynamic height anomaly of an isobaric surface increases with increase in depth of the reference surface. It can further be shown, that the maximum error in the dynamic height anomaly of the zero isobaric surface with reference to 3000 d bar surface is 20 dyn. mm., two and a half times more than the maximum error calculated with 1500 d bar surface as a reference surface. This increased error in the computation of dynamic height anomaly of the sea surface will make the results on the surface circulation pattern more undependable. To reduce the error caused by the selection of a deep isobaric surface as a zero surface, a method is used in which the dynamic height anomaly of the different isobaric surfaces are computed using 1500 d bar surface as a reference surface and then the computed geostrophic current velocities are reduced to the value relative to the 3000 d bar surface using Shtokman's density model. The 1500 d bar surface is selected for the following reasons:

i) 1500 d bar surface is a surface where the density variation in the horizontal is very small. The dynamic topography of the different isobaric surfaces presented with the 1500 d bar surface as a reference surface will not be very different, for practical purpose, from that presented with 3000 d bar surface as the reference surface.

ii) According to the NODC accepted standard depths, there are frequent sampling points upto 1500 m depth which will help to reduce the error in the computed dynamic height anomaly.

iii) The mass field in the oceanic region below 1500 d bar surface is suitable for the application of Shtokman's density model so that the geostrophic currents computed with reference to 1500 d bar surface can be reduced to the value relative to 3000 d bar surface using this model.

7.1. Extending the selected zero reference surface into shallow regions.

Once the reference surface for the purpose of computation is selected, we must extend the computations into shallow regions of the ocean where the depth is less than the depth of selected reference surface. Different methods available for this purpose were critically examined by Fomin (1964) which may be summarised as follows:

7.1.1. Helland-Hansen's method

In this method proposed by Helland-Hansen (1934), the block of solid earth in the form of a triangle formed by the reference line, the bottom line and the vertical at the shallow station is replaced by an imaginary water mass. If it is assumed that the gradient current velocity and the horizontal pressure gradient are zero along the bottom line, then the isobaric and isosteric surfaces in the imaginary water mass must be horizontal. This implies a motionless water mass. If the points of intersection of the isosteric lines with the bottom line are projected horizontally into the vertical at the shallow station, we get the vertical distribution of specific volume anomaly at the shallow station upto the reference surface and these values may be used for the computation of currents with reference to the selected zero surface.

The above method is based on the assumption that gradient current velocity and hence the horizontal pressure gradient are zero near the bottom. According to Fomin (1964) this assumption is not justified because the velocity of total current at a solid boundary becomes zero due to friction and the consequent appearance of a compensating current. This compensating current cannot be determined by dynamic methods. Another disadvantage of the method is that its application requires graphical construction.

7.1.2. <u>Jacobsen and Jensen method</u>

Jacobsen and Jensen (1926) proposed a method which is also based on the assumption that the current velocity and the horizontal pressure gradient along the bottom line are zero. Here also the solid earth formed by the reference line, the bottom line and the vertical at the shallow station is replaced by an imaginary motionless water mass. But this method has two more additional assumptions.

a) The bottom line between the two stations, one of which is shallow, is rectilinear.

b) The isosteres are equidistant near the bottom.

These two assumptions result in the isosteres in the imaginary water mass being equidistant and parallel.

The practical computation is done in the following manner. Let A and B are two stations of which A is a shallow station and B a deep station through the bottom of which passes the zero reference surface which is horizontal. Now assume a horizontal reference surface passing through the bottom of the shallow station A and compute the differences in dynamic height anomalies between the two stations with reference to this assumed reference level. Then add to this the correction

$$\Delta = \frac{1}{2}\Delta p \ (\delta_{B_1} - \delta_{A_1}) \qquad (7.1)$$

where Δp is the pressure difference between the assumed reference surface and the zero reference surface and δ_{B_1} and δ_{A_1} are the specific volume anomalies at the assumed reference level for the two stations B and A respectively. The sum will then be the difference in dynamic height anomalies between the two stations with reference to the zero reference surface.

We have already seen in section 7.1.1. that the assumption of zero gradient current velocity and zero pressure gradient near the bottom is not justified. Eventhough this method has an advantage over the Helland-Hansen method in that its application does not require any graphical constructions, the additional assumptions concerning the structure of the density field near the bottom is not justified because under actual conditions water density field rarely has such a structure (Fomin, 1964).

7.1.3. Goren's method

Goren (1948) proposed a method in which he suggested that the density field be extrapolated in the imaginary water mass in such a manner that all the isosteres on each horizontal level in the imaginary water mass have a constant slope equal to the slope of the isostere at that level on the bottom line. This construction will give the required vertical distribution of the specific volume anomaly at the shallow station with reference to the zero reference surface.

The advantage of this method over the two methods already discussed is that here the solid block of earth along the profile located above the zero reference surface is replaced with an imaginary moving baroclinic water mass. This eliminates the unjustified assumptions made in the former two methods that the geostrophic current velocity and the pressure gradient are zero near the bottom. But this method has also some short comings, the most objectionable one being the requirement that the slope of all the isosteres should be constant at each horizontal in the imaginary water mass, a requirement very difficult to justify (Fomin, 1964). Further, the application of this method requires graphical construction.

Another method suggested by Fomin (1964) is th simple extrapolation of the specific volume anomaly of water along the profile in the imaginary water mass which will provide the vertical distribution of the specific volume anomaly at the shallow station upto the zero reference level. In this case also, solid block of earth along the profile located above the zero reference surface is replaced with a moving water mass. The subjective errors inherent in the method, however, make it most unsuitable, particularly if the shallow station is located at the boundary of the ocean under study.

7.2. A new method suggested for the extension of computation into shallow regions

The foregoing discussion on the different methods used for the extension of computation into the shallow regions of the ocean has brought out the fact that none of them are without short comings. Hence a new method is suggested for this purpose in which most of the objection raised in the preceding pages are avoided.

In this method, the dynamic relief along a profile of the isobaric surface corresponding to the deepest sampling depth at the shallow station is linearly extrapolated along the profile in the shallow region. This gives the dynamic height anomaly of the isobaric surface at the shallow station with reference to the zero surface. If A, B and C are three stations in a line, of which C is a shallow station, then the required dynamic height anomaly at the shallow station is given by

$$\Delta D_{C'} = \left[\frac{\Delta D_{A'} - \Delta D_{B'}}{AB}\right] BC + \Delta D_{B'} \qquad (7.2)$$

where $\Delta D_{A'}$, $\Delta D_{B'}$ and $\Delta D_{C'}$ are dynamic height anomalies of the isobaric surface passing through the deepest sampling depth at station C, and AB and BC are distances between stations A and B and stations B and C respectively.

The following are some of the advantages of this method:

a) In this method the section of the solid earth along the profile located above the zero reference surface is replaced with a moving baroclinic water mass.

b) Since it is a linear extrapolation, its application does not require graphical construction.

c) The linear extrapolation done only at one depth avoids accumulation of subjective errors.

If the values of the independent oceanographic parameters are missing at one depth at a particular station and if their values are known for the neighbouring stations on either side, the dynamic height anomaly at that depth may be obtained by linear interpolation. If A_1, B_1 and C_1 are three stations in a line in that order and if the values of the independent oceanographic parameters are missing at some particular depth at station B_1, then the dynamic depth anomaly at the depth where the values are missing is obtained as

$$\Delta D_{B_1'} = \left[\frac{\Delta D_{A_1'} - \Delta D_{C_1'}}{A_1C_1}\right] B_1C_1 + \Delta D_{C_1'} \qquad (7.3)$$

where $\Delta D_{A_1'}$, $\Delta D_{B_1'}$ and $\Delta D_{C_1'}$ are dynamic height anomalies of the isobaric surface passing through the depth at station B_1 where the independent oceanographic parameters are missing and A_1C_1 and B_1C_1 are distances between station A_1 and C_1 and stations B_1 and C_1 respectively.

Assuming 1500 d bar surface as the reference surface and then extending the same into the shallow regions using the above method for the purpose of computation, the dynamic height anomalies of the different isobaric surfaces, corresponding to the standard depths above 1500 d bar surface, were computed for stations along the profile approximately 15° latitude in the Arabian sea. The station positions are shown in Fig.3.

7.3. Smoothening the dynamic relief in a profile of an isobaric surface

In section 5.1 we have seen that the computed dynamic height anomaly of an isobaric surface will be in error by an amount which can be calculated using the method described in that section. Table VI of the same section gives the magnitudes of errors in the computed dynamic height anomalies of the different isobaric surfaces with reference to the 1500 d bar surface. The computed dynamic relief of an isobaric surface in a profile, so, will be in error by an amount depending on the isobaric surface selected. The actual dynamic relief of the isobaric surface will be one among the infinite number of possible reliefs that can be drawn within the error limits. In this section, the selection of a dynamic relief is done by a method of smoothening suggested by Fomin (1964) which will provide a more dependable picture of the dynamic topography of the isobaric surface as well as the vertical distribution of geostrophic current.

The dynamic height anomalies of the different isobaric surfaces are computed, as explained in section 7.2, for the stations which lie approximately along 15°N latitude in the Arabian sea. The computed dynamic reliefs of the different isobaric surfaces are then drawn and shown with dashed lines in Figs. 5-8. The lines on both sides of the computed dynamic profile are the limits of the error interval. The error limits taken were $1/\sqrt{2}$ times the maximum error for the concerned isobaric surface because the dynamic relief of an isobaric surface in a profile highlights the differences in dynamic height anomalies between adjacent stations and, as we have seen earlier (section 5.2), the total error in the difference in dynamic height anomalies is not the sum of the errors but the sum divided by $\sqrt{2}$*. The actual dynamic relief of an isobaric surface will be one among the many that are possible between the error limits. Those that are selected for the different isobaric surfaces are shown by thick lines in the figures and are the smoothest possible curves between the error limits. The smoothest

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*Fomin (1964) took the error limits as equal to the maximum error itself which, in the light of the above, should be considered as incorrect.

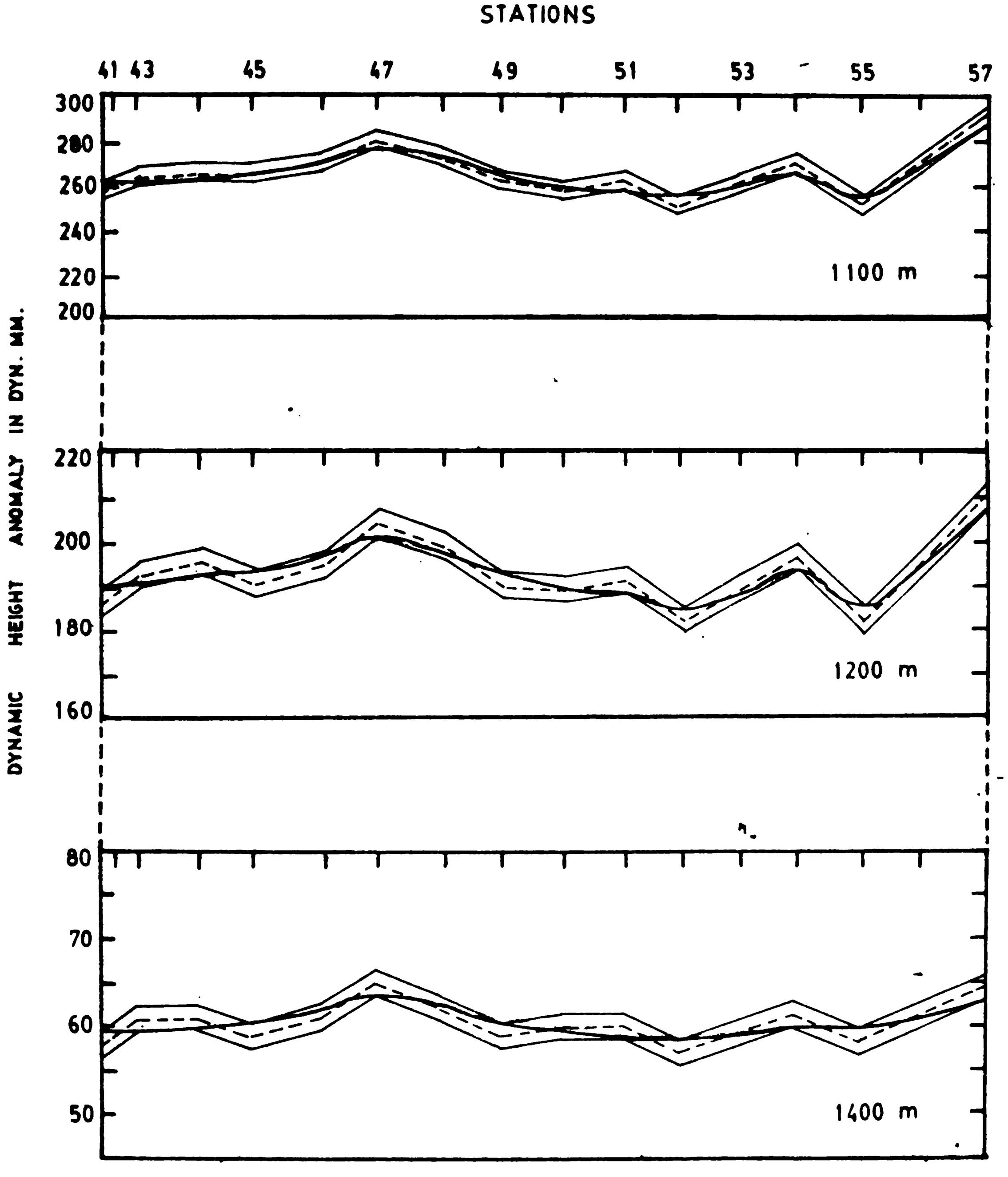

Fig. 5: Dynamic relief of different isobaric surfaces along approximately 15°N Latitude in the Arabian Sea.

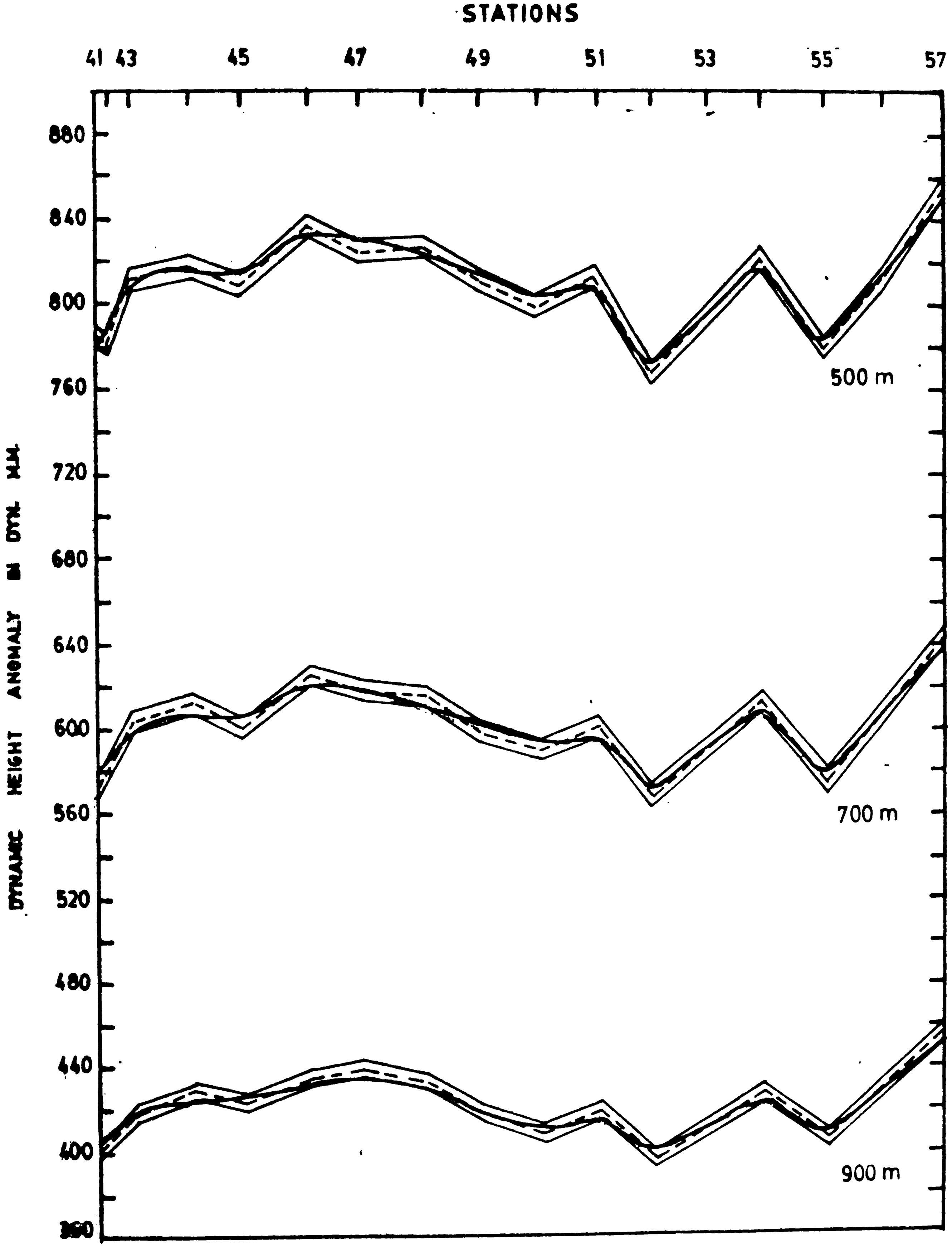

Fig. 6: Dynamic relief of different isobaric surfaces along approximately 15° N Latitude in the Arabian Sea.

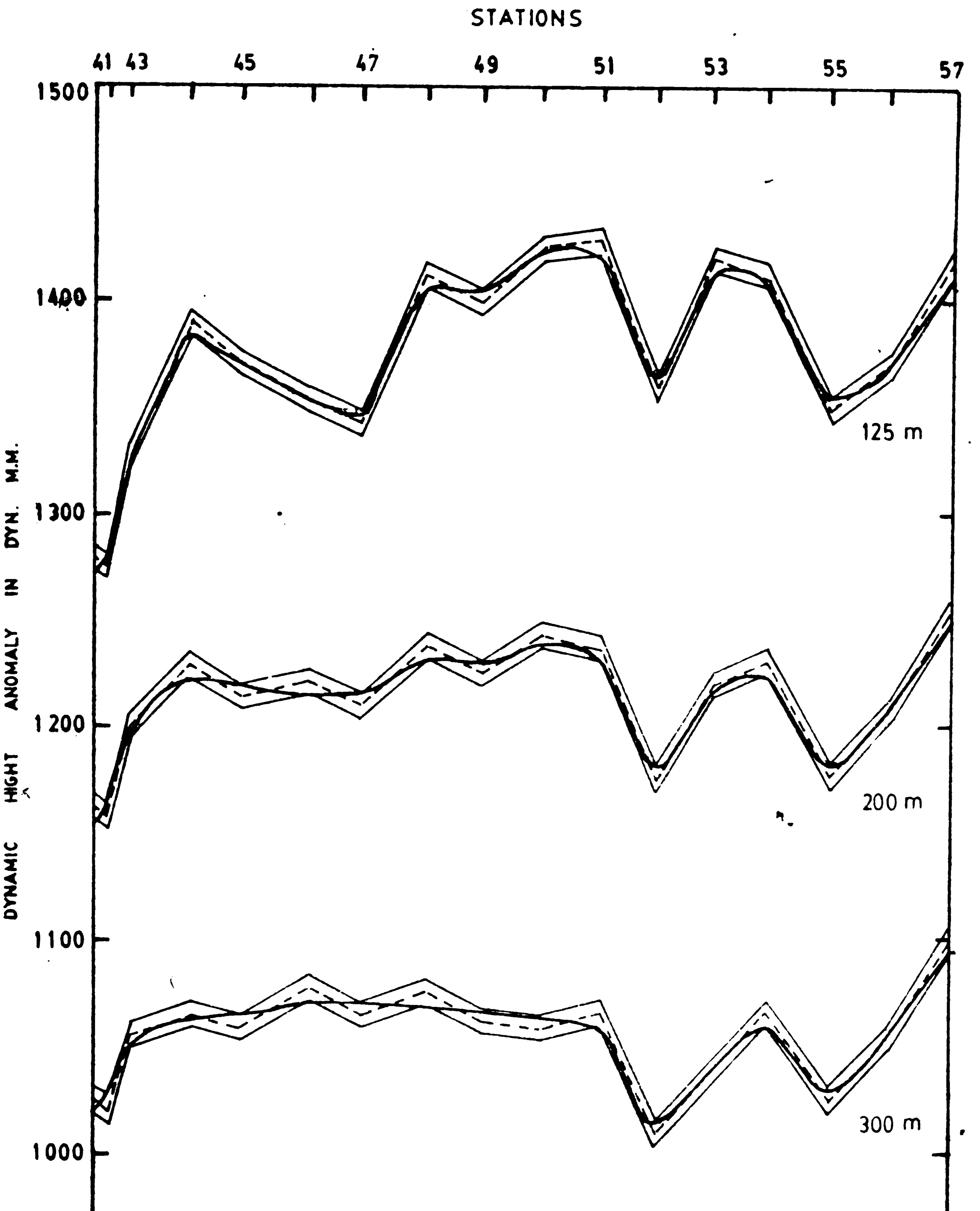

Fig. 7: Dynamic relief of different isobaric surfaces along approximately 15° N Latitude in the Arabian Sea.

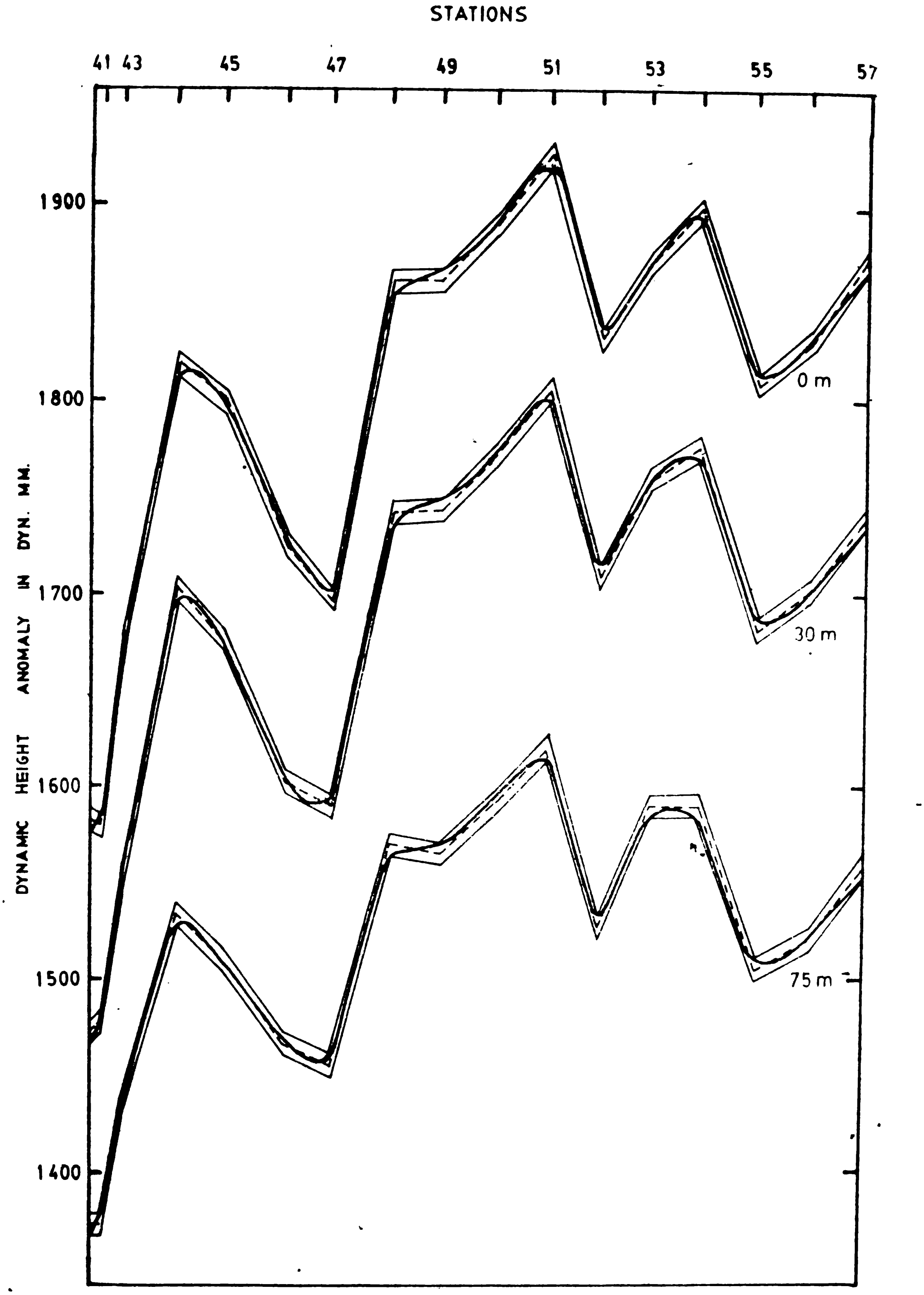

Fig. 8: Dynamic relief of different isobaric surfaces along approximately 15° Latitude in the Arabian Sea.

possible curve is selected because under oceanic condition, in general, large horizontal gradient of any parameter should be considered as unnatural and because any distortion to the curve between the error limits should be considered as unjustified*.

From the smoothened curves, obtained as above, the new values of the dynamic height anomalies of different isobaric surfaces for all the stations in the profile are obtained.

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*Smoothening is a process very commonly employed in Physical Oceanography in the processing and analysis of oceanographic data. For example, Montgomery (1954) and Stroup (1954) recommended a method of analysis of serial oceanographic data in which the shape of the station curves for any particular station is influenced by the data from the nearby stations and this procedure, they claimed, ensure meridional continuity of features of distribution. This is nothing but smoothening of data in-between stations. Again, oceanographers generally 'follow the trend' when they draw isolines of any parameter in sections and are not very particular to draw the lines through the exact plotted points.