47. BLACK SEA GEOPHYSICAL FRAMEWORK[1]

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INTRODUCTION

The Black Sea is one of the largest enclosed marine seas, occupying an area of 432,000 km^2 and having depths greater than 2 km. This basin, which has sediment thicknesses in excess of 15 km, has been in existence for perhaps 200 million years. Prior to then it was a topographic high that supplied sediments to adjacent basins that were eventually folded into the surrounding Caucasus and Pontic mountains.

The Black Sea has long been of interest to oceanographers because of its unusual history and environment. It is believed to be a remnant of the Tethys Sea which existed prior to the major splitting and separation of continents some 200 million years ago. The environment of the Black Sea is also unique in that it is the largest body of anoxic water in the world. From about 100 meters depth to the bottom at 2200 meters, the water contains hydrogen sulfide which is deadly to all forms of life except anaerobic bacteria.

At present the Black Sea has only one opening to the ocean—the Bosporus (sill depth about 50 m). Thus when the ocean level dropped during Pleistocene glacial interludes, the Black Sea became disconnected from the Mediterranean, and in due course changed from marine to lacustrine conditions. Earlier, another link existed, i.e., via the Caspian Sea. Still earlier, other, poorly documented, links occurred with the Carpathian basins. These openings had a decisive influence on the water chemistry, biological population, and sediment composition of the Black Sea. Since they are climatically controlled, the paleontological record and geochemistry of the sediments can supply information about regional paleoecology and paleoclimatology.

The main objective of drilling in the Black Sea was to continuously core the upper 500 meters or more of sediment at two or three selected localities. The sediments obtained have yielded one of the most complete Pleistocene records yet obtained from the ocean. Because the Black Sea has a relatively high sedimentation rate (about 10 cm/1000 yr) and is sensitive to sea level changes (because of the shallow sill at the Bosporus), changes in the level of the sea had a dramatic influence on the sediments and environment of the Black Sea (see following papers in this volume). An indication of this influence was noted from short piston cores, which showed that the Black Sea was a fresh-water lake from 22,000 to 9000 years B.P. when worldwide sea level dropped and isolated it from the Mediterranean Sea. The numerous rivers entering the Black Sea at that time were sufficient to turn it into a lake.

The purpose of this paper is to present some background data on the geophysical, and to a lesser extent geological, setting of the Black Sea.

GEOLOGICAL SETTING

The Black Sea basin is surrounded to the north, northeast, south, and southwest by the Alpine folded systems of Crimea, Caucasus, Asia Minor, and southern Balkans. In the northwest it is bordered by the epihercynian platform, located between the Balkans and the Crimea (Muratov, 1972). Geological and geophysical studies have shown that parts of these tectonic structures are now located under nearshore areas of the present basin. The time and origin of the Black Sea deep basin are still debatable. For example, Muratov (1975) has suggested that its history can be divided into three different periods. In the Mesozoic and Paleogene, a relatively shallow basin was located in the Black Sea area bordered by deep geosynclinal depressions to the north and south. The second period was characterized by several deep basins in the central, northern, western, and eastern parts of the Black Sea, which were filled with sediments during the Oligocene and Miocene. In the third period, the Pliocene and Pleistocene, the present deep basin of the Black Sea was formed.

PHYSIOGRAPHY

A detailed study of the bottom relief of the Black Sea was carried out by V. P. Goncharov of the Soviet Institute of Oceanology in 1956-1958. A result of his studies was a bathymetric chart (Figure 1) and a detailed description of bottom geomorphology (Goncharov et al., 1972). In 1969, additional echo-soundings were made from *Atlantis* II of the Woods Hole Oceanographic Institution (Ross et al., 1974a) and another bathymetric map was made (Figure 2). These two maps have some minor differences, a portion of which appears to be due to the use of different sound corrections. According to the Soviet data, the maximum depth is 2212 meters.

Based on the bathymetric data, the Black Sea can be divided into four principal physiographic provinces (Figure 3):

1) Shelf—generally delineated by the 100-meter isobath except off the Crimean peninsula and Sea of Azov where it extends to 130 meters.

2) Basin slope—two subtypes are possible: (a) steep gradients of 1:40 or so, highly dissected by canyons, and (b) relatively smooth slopes.

3) Basin apron—generally smooth and gently sloping (1:40 to 1:1000) area at base of basin slope that is similar to a continental rise.

[1]Contribution 3975 of the Woods Hole Oceanographic Institution.

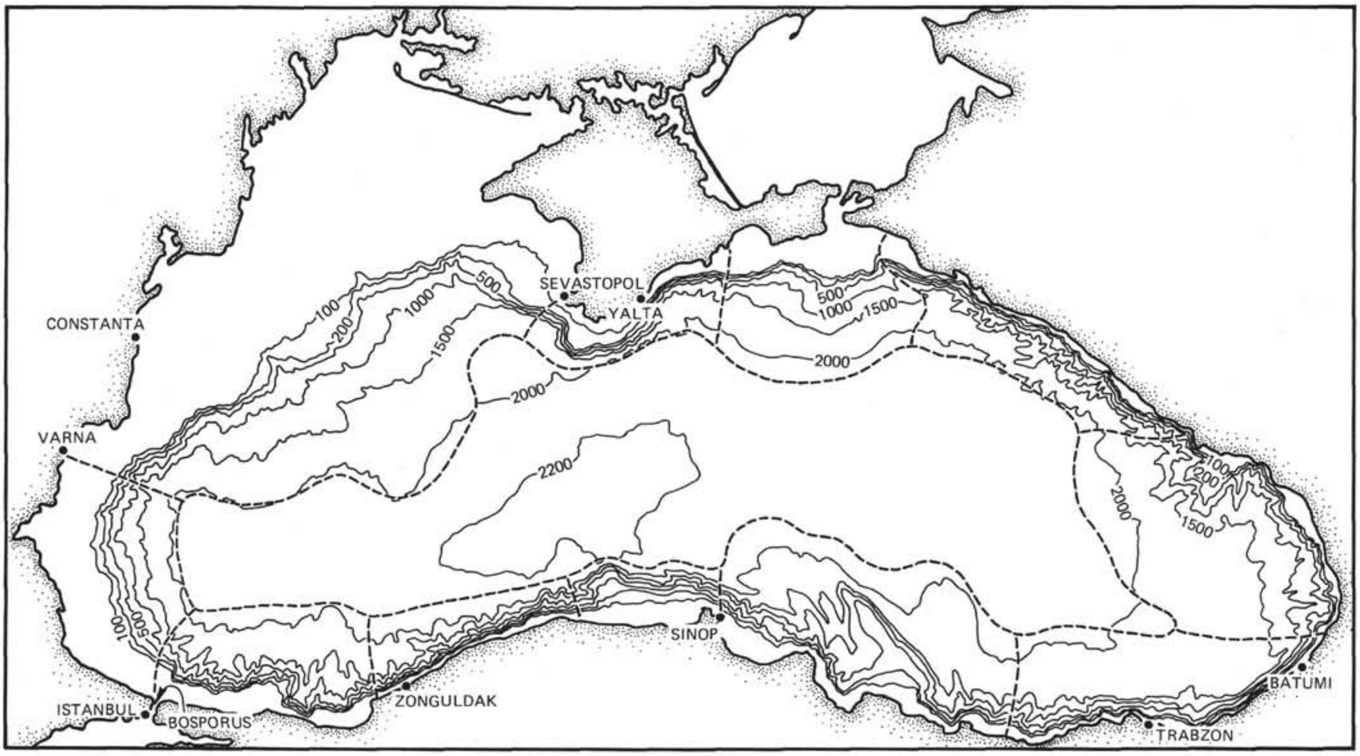

Figure 1. *Bathymetric map of the Black Sea made by Soviet scientists of the Institute Oceanology, USSR (Goncharov et al., 1972). Contour interval in corrected meters.*

4) Abyssal plain—very flat area (gradient of less than 1:1000) similar to a deep-sea abyssal plain.

The relative percentage area of these four physiographic provinces is shown in Table 1.

TABLE 1
Percentage Area of Black Sea Physiographic Provinces

Physiographic Province	Percentage Area
Shelf	29.9
Basin Slope	27.3
Basin Apron	30.6
Abyssal Plain	12.2

STRUCTURE

Many seismic sounding profiles (Figures 4a and 4b) have been collected in the Black Sea by Soviet (Neprochnov, 1962; Goncharov et al., 1972; Neprochnov et al., 1975) and U. S. (Ross et al., 1974b; Letouzey et al., this volume) scientists. Soviet deep seismic sounding (DSS) has shown that the crust in the central part of the Black Sea consists of two main layers (Figure 5). The upper sedimentary layer with a mean seismic velocity of about 3 to 3.5 km/sec is between 8 to 16 km thick. The second layer is between 5 to 10 km thick and has a seismic velocity of about 6.6 to 7.0 km/sec, a velocity comparable to layer 3 of the ocean. The continental areas surrounding the Black Sea commonly have deep layers with velocities of about 6.0 km/sec to 6.4 km/sec, velocities, typical of granite. No such velocities were found in the deep basin of the Black Sea (Figure 6). The total thickness of the crust in the Black Sea is between 18 to 24 km.

Sediment fill in the basin is composed of three units having, respectively, seismic velocities of 1.6-1.8, 3.0, and 4.0-5.0 km/sec (Neprochnova, 1975). The upper unit is to 2 km thick (Figure 7), and is assumed to consist of Pleistocene and Pliocene sediments (Muratov and Neprochnov, 1967). The second unit is thought to be Miocene in age, and the lower or third unit probably Paleogene, Cretaceous, and older sediments.

Studies by Ross et al. (1974b) have shown that slumping and downfaulting is fairly common along most of the margin of the Black Sea except for the western margin. Seaward of the slope, much of the basin apron and low velocity upper unit are characterized by distinct horizontal reflectors that can be traced for several hundred kilometers (Figure 8). In some places, such as south of the Crimea, these layers are interrupted by small, steep, normal faults that may be related to a northeast-southwest structural zone running across the Black Sea Basin. In the central portion of the sea the strata are folded, a structure that may be the consequence of the Caucasus orogeny.

GRAVITY

The Bouguer gravity anomaly tends to follow the general topography with the strongest anomalies found in the central parts of the Black Sea (Figure 9). Free air anomalies are usually negative and can be divided into two principal types: (1) those where the anomaly is correlatable with topographic or subsurface structure (as detected from CSP records); or (2) those where no relationship occurs. The first type is typical of the shelf and slope areas; the second occurs

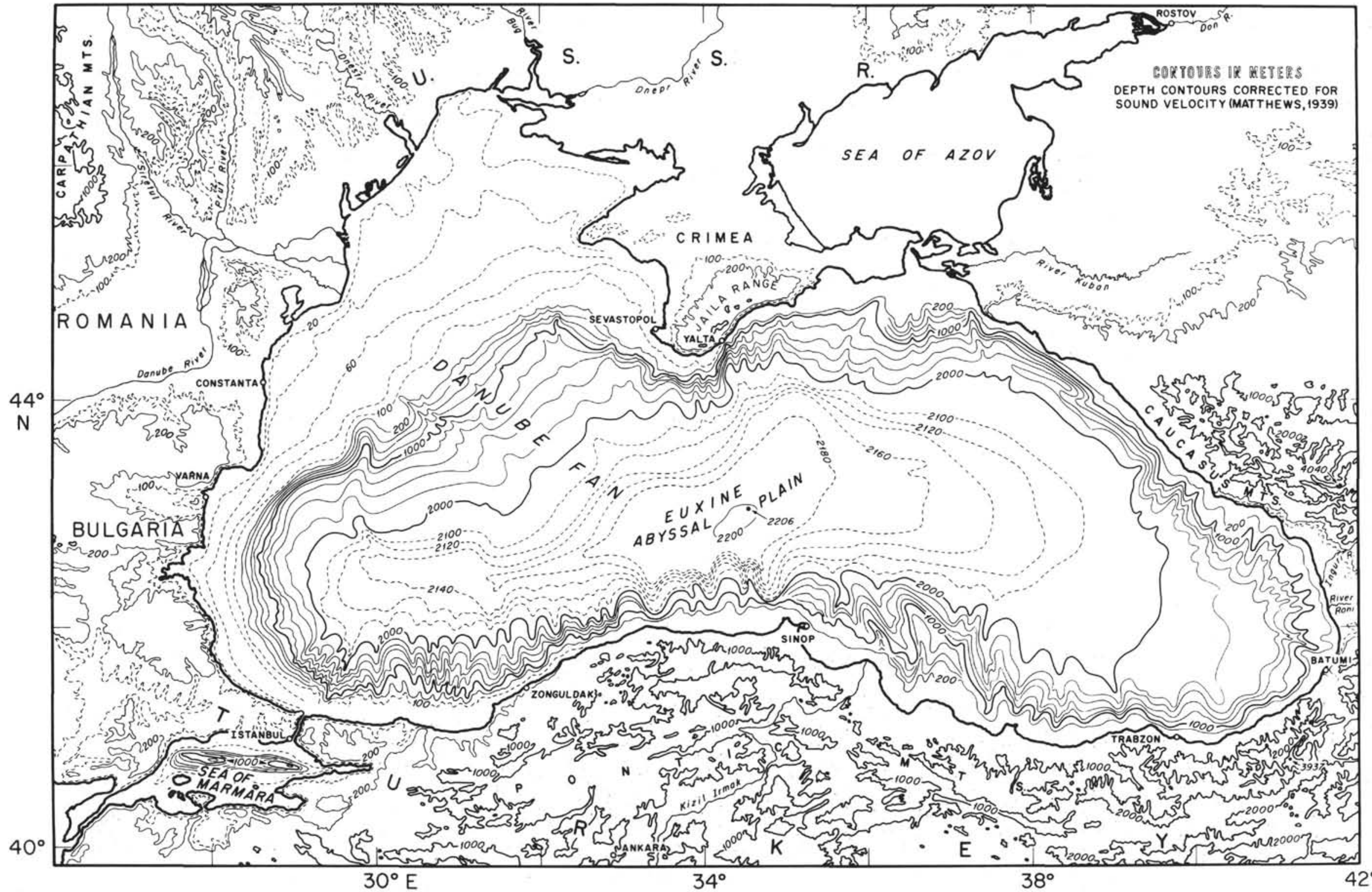

Figure 2. *Bathymetric map of the Black Sea made by U.S. scientists (Ross et al., 1974a). Note the change in contour interval at 200 and 2000 meters. Data from the 1969* Atlantis II *cruise, a Russian chart supplied by Pavel Kuprin of the University of Moscow, and U.S. Plotting Sheets 108N and 3408N. Land topography is from the Morskoi Atlas, Tom I, Navigatsionne-Geographicheski Izdanie Morskogogeneralnogo Shtaba. The map was contoured by Elazar Uchupi of the Woods Hole Oceanographic Institution.*

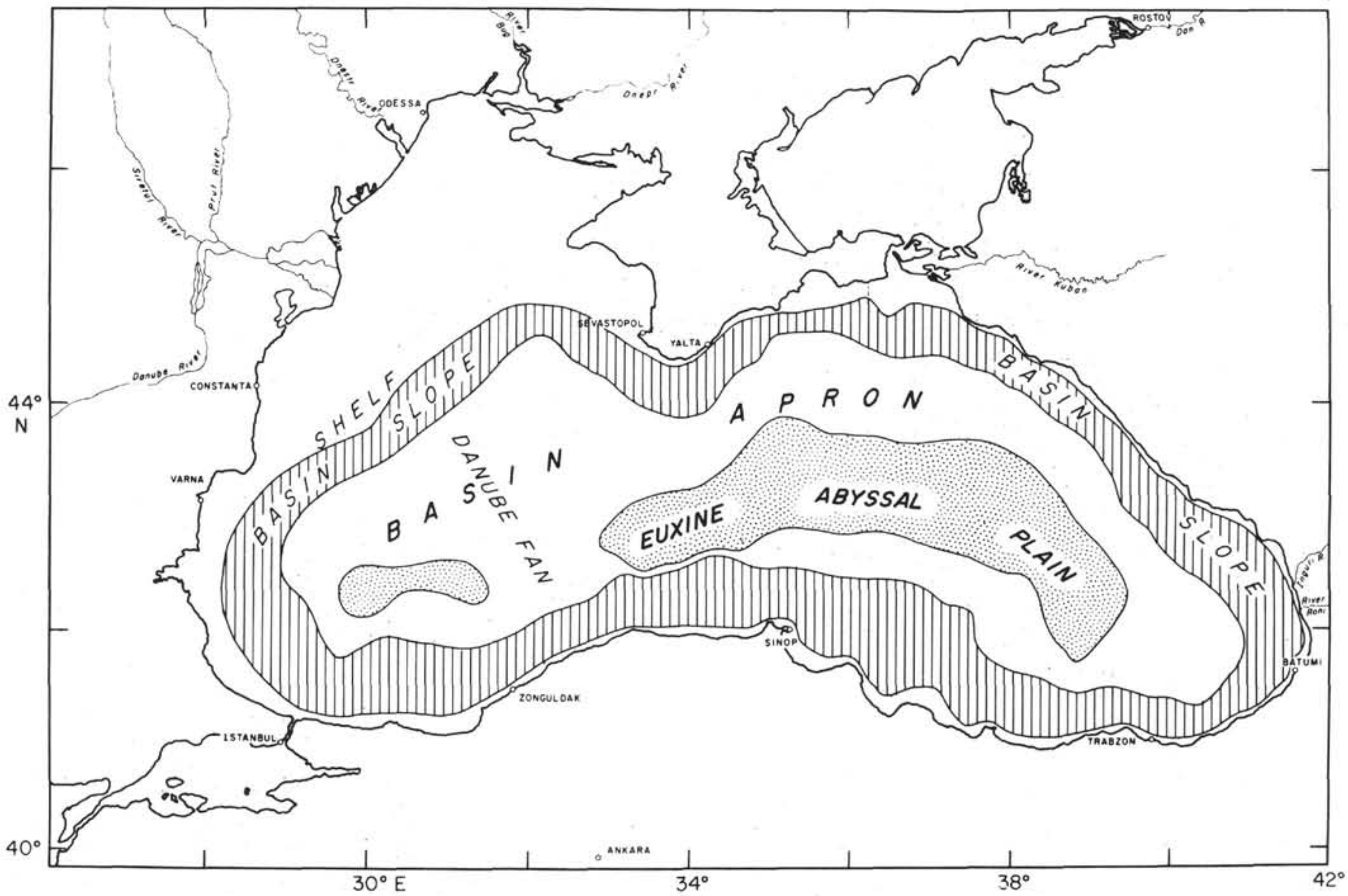

Figure 3. *Main physiographic provinces of the Black Sea (from Ross et al., 1974a).*

mainly in the deeper parts of the basin (Figure 10). The rapid change from one type to another suggests that the basement deepens abruptly near the basin slope (Ross et al., 1974b). This conclusion is similar to that of Malovitsky and Neprochnov (1966) who conclude that the lower parts of the crust exercise the major influence on the gravity pattern.

SEISMIC ACTIVITY

Present-day seismic activity is relatively shallow and is generally restricted to the marginal portions of the sea. A strong marginal seismic zone extends along the Anatolian Fault which is somewhat parallel to the southern part of the Black Sea (Figure 11). Focal depths in this area are generally less than 30 km (Canitez and Toksöz, 1970). Another shallow seismic zone trends southeastward from the eastern Black Sea across the Caucasus Mountains into the Caspian Sea and south-central Asia (Nowroozi, 1971).

MAGNETICS

The residual magnetic field along the margin area tends to mirror that of the surrounding Caucasus and Pontic mountains, which suggests that these features may trend into the present Black Sea (Figures 12 and 13). Within the deep basin the anomalies trend northwest-southeast and are several hundred gammas in amplitude. The source of the anomalies in the abyssal plain and basin apron area probably lies below the thick sediment section. Assuming a tabular magnetic body, the calculated depth to the magnetic source ranges from 3 to 19 km below sea level (C. Bowin, personal communication).

HEAT FLOW

In general the heat flow values are relatively low. Erickson and Simmons (1974) determined an average of 0.92 ±0.23 μcal/cm²/sec for 16 observations; Lyubimova et al. (1975) found an average of 0.9 μcal/cm²/sec, with some higher values in the fracture zones south of the Crimea and the Caucasus. Erickson and Simmons (1974) believe that much of the geothermal flux was being absorbed by the rapidly accumulating sediment, and that the heat flow they determined was only about 50% of the geophysically relevant heat flow. In addition, they suggest that the lower thermal conductivity of the sediments may also have a blanketing effect and reduce the flux by as much as 50%. They conclude that after correcting for these effects, the actual heat flow may be on the order of 2.2 μcal/cm²/sec.

ORIGIN OF THE BLACK SEA

The Black Sea is a very unusual geological feature, situated as it is between two Alpine-like mountain systems. Its origin is somewhat controversial. Estimates of the age of the basin have ranged from Precambrian (Milanovskiy, 1967) to early Quaternary (Nalivkin, 1960), but a middle to late Mesozoic age seems to be the consensus (Brinkmann, 1974).

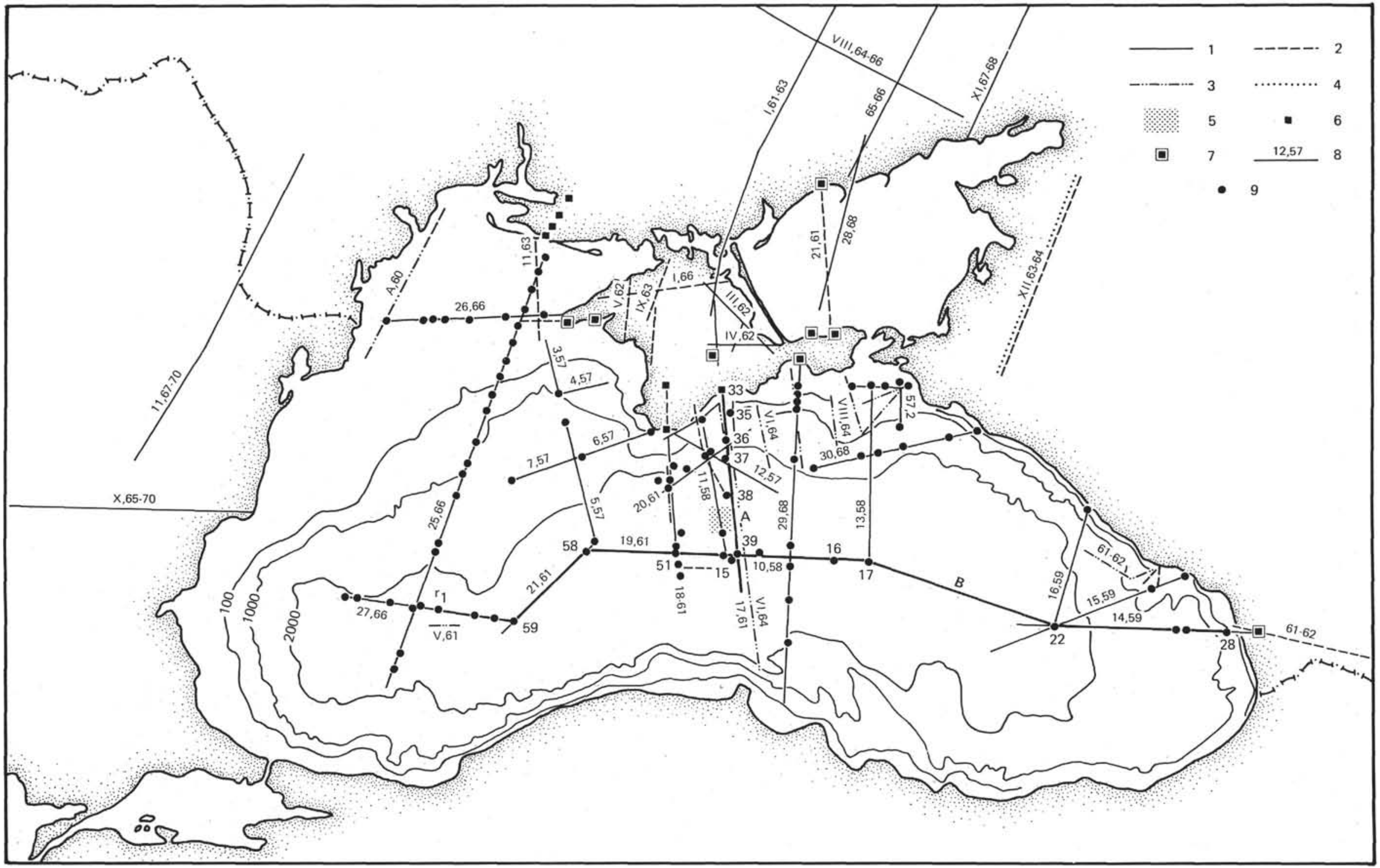

Figure 4a. *Location of Soviet seismic profiles: (1) DDS profiles, (2) more detailed refraction work, (3) regional reflection profiles, (4) profile of study of waves from earthquakes, (5) detailed reflection work, (6) multichannel seismic stations made on land during DSS, (7) location of the shots on land, (8) number of profile, and year, (9) seismic stations made at sea during DSS. Profiles labeled A and B shown in Figure 5.*

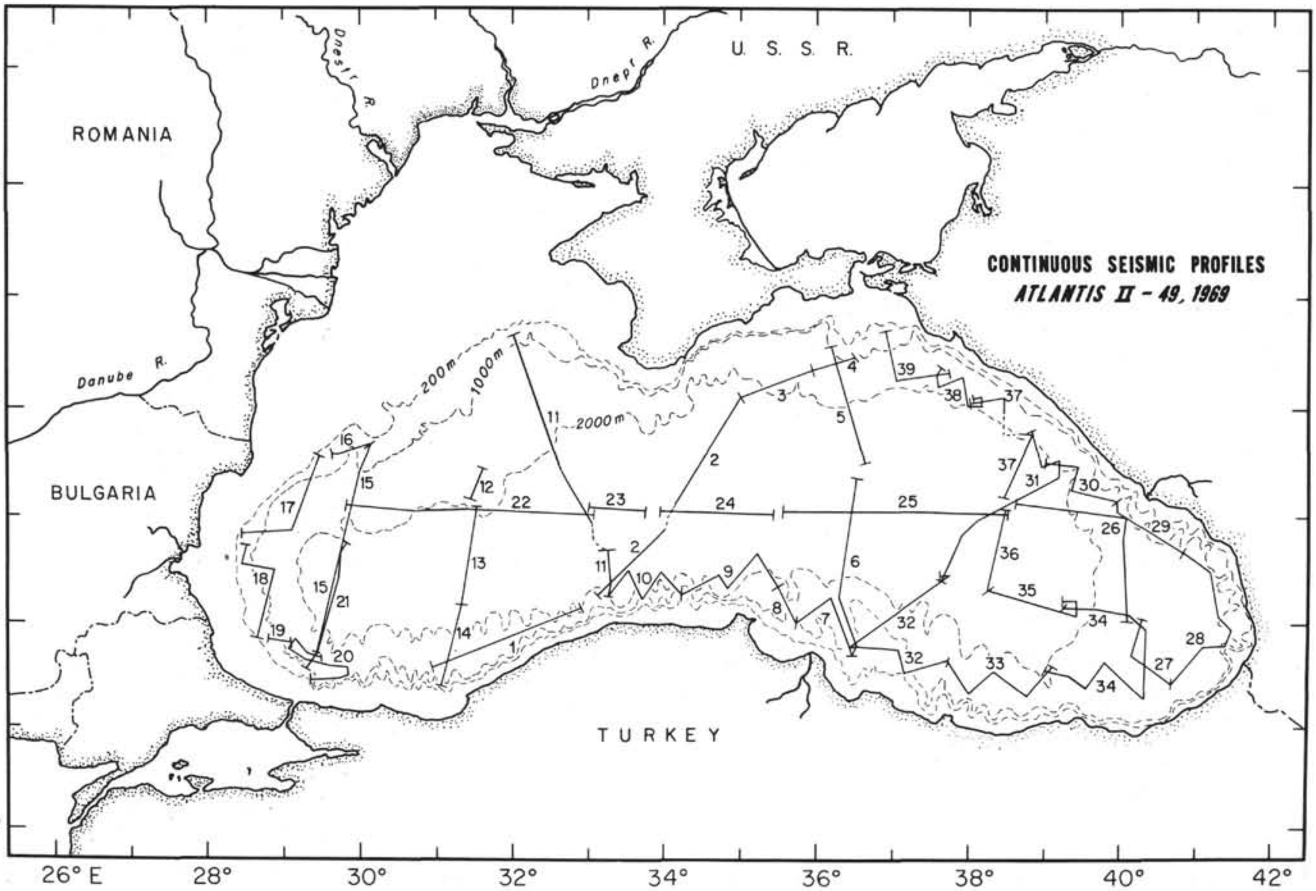

Figure 4b. *Continuous seismic profiles made in Black Sea during 1969 expedition of* Atlantis II *(see Ross et al. for actual records).*

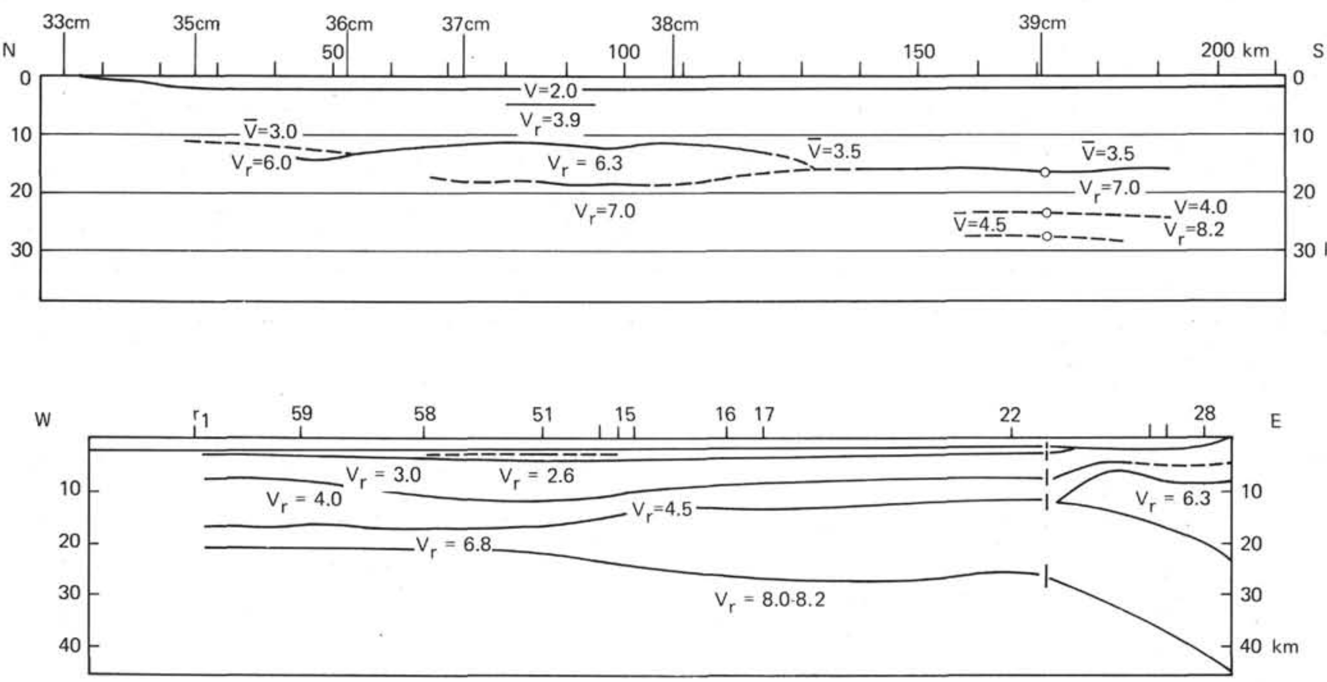

Figure 5 (A, B). *Composite Black Sea seismic sections based on Soviet DSS data (from Neprochnov et al., 1974). See Figure 4a for location of profiles.*

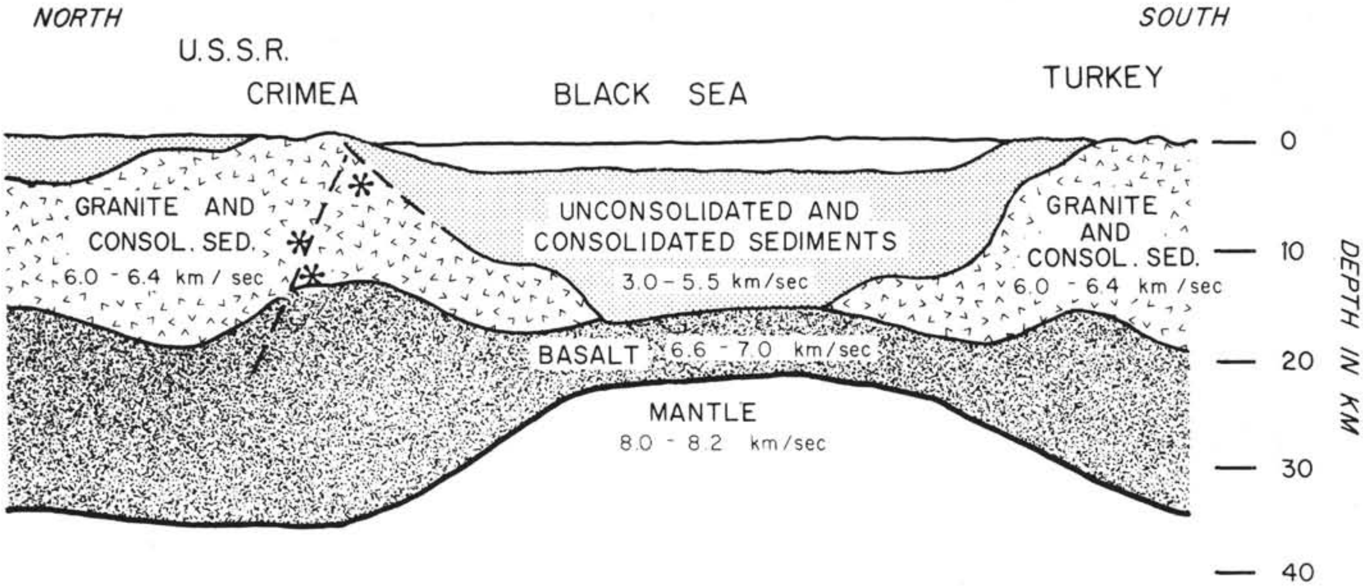

Figure 6. *Crustal north-south cross-section across Black Sea (adapted from Subbotin et al., 1968; Neprochnov, 1968; Neprochnov et al., 1970).*

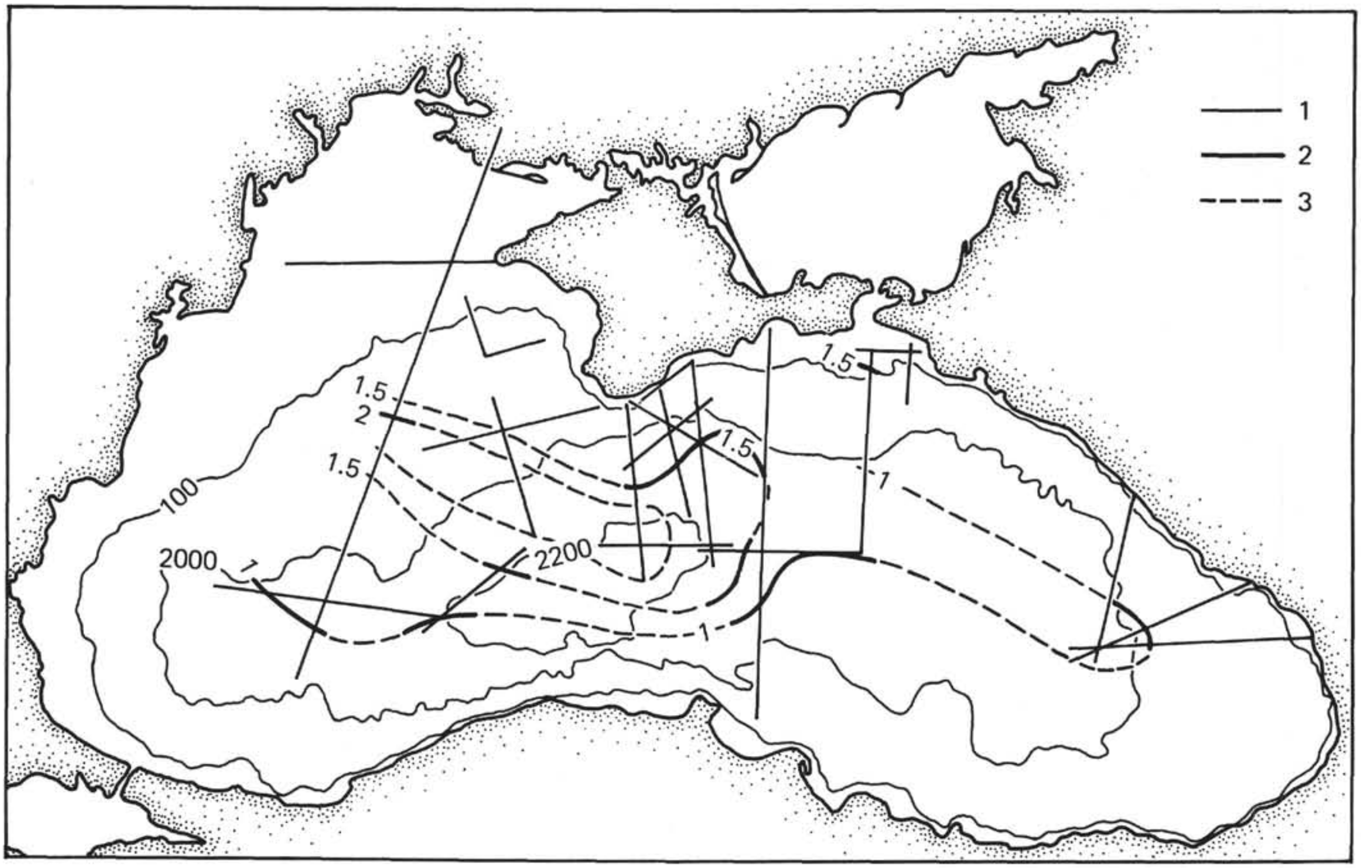

Figure 7. *Map of sediment thickness between sea floor and seismic unit having a velocity of 3.0 km/sec. (Neprochnov, 1975).*

Magnetic data strongly suggest regional subsidence along the marginal areas. Seismic profiles show numerous examples of slumping on the basin slope and upper basin apron, especially in the southern and eastern areas. The central portion of the sea is in isostatic equilibrium, although the Bouguer anomalies in the western and eastern areas suggest that they may be raised above isostatic conditions (C. Bowin, personal communication). If this point is correct, it suggests that further deformation of the basin may be in progress. The present east-west alignment of the surround-

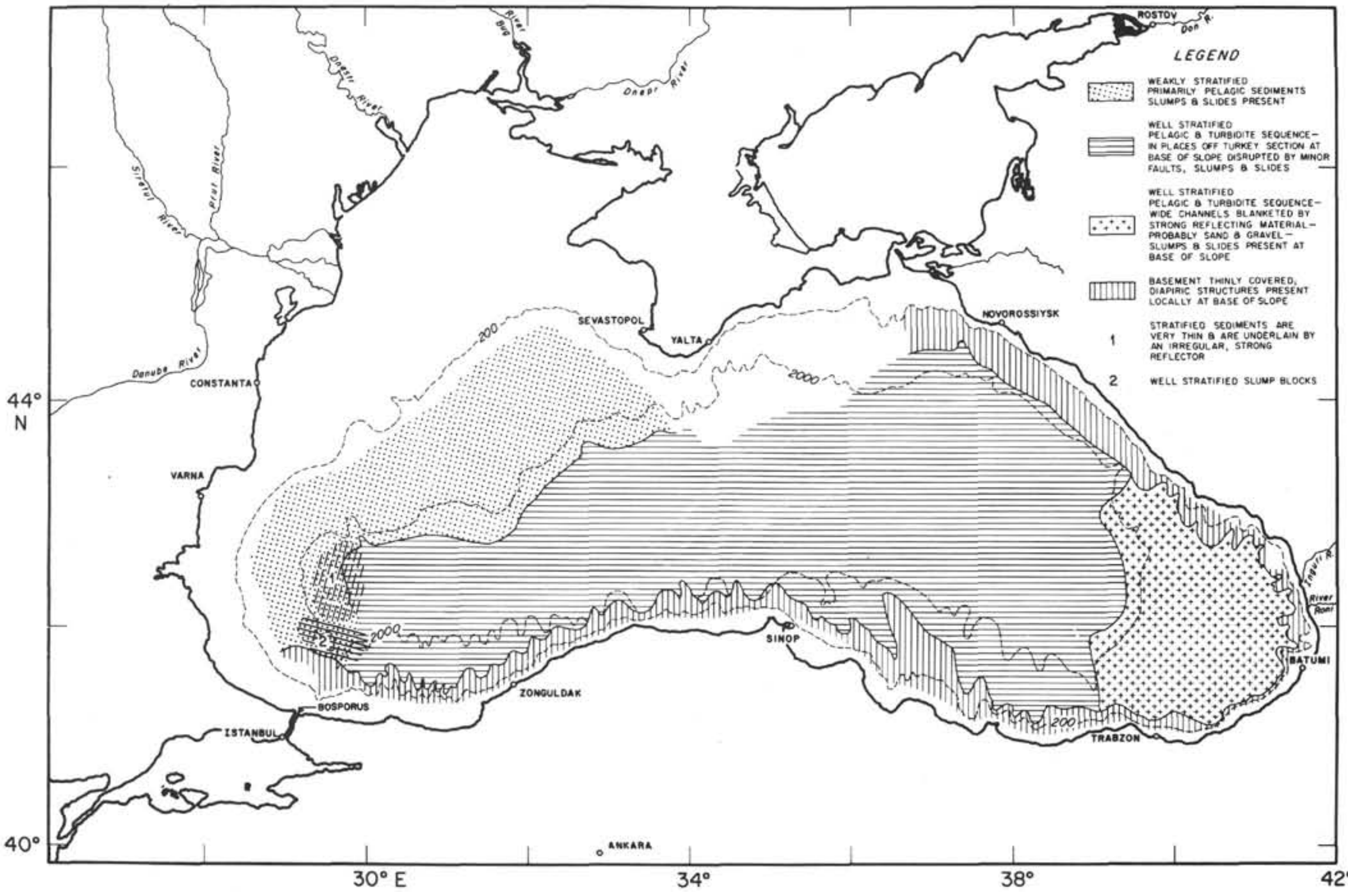

Figure 8. *Main structural features of the Black Sea as determined from seismic profiles made during 1969 cruise of* Atlantis II *(from Ross et al., 1974b).*

ing mountains suggests that at least during the Cenozoic and Mesozoic the Black Sea area was a zone of compression, although subsidence is prevalent now.

Neprochnov et al. (1970) noted a similarity in the crustal structures and sediment thickness of the Mediterranean, Black, and Caspian seas (in both cases the Black Sea is intermediate to the other two). These authors thus suggest a regional sequence of subsidence and sediment accumulation for these areas.

One especially interesting aspect of the Black Sea is the presence of material having a "granitic" seismic velocity underlying the marginal parts of the basin. This could mean a past period of intense erosion of continental crust (when the Black Sea area was topographically higher), followed by subsidence and sediment accumulation. On the other hand, this "granitic" layer does not seem to be magnetic and thus, instead, could be metamorphosed sedimentary rocks (Borisov, 1967; Sollogub, 1968; Neprochnov et al., 1974). Within the Black Sea the so-called "granite-free" area has a velocity of 6.6-7.0 cm/sec and could be gabbroic in nature.

There are two intriguing possibilities for the origin of this "granite-free" area: either it is a relict ocean crust, or it has formed in place. It should be noted that the thickness of the oceanic (14-18 km) portions of the deep basin is considerably greater than that of a typical oceanic crust (Milanovskiy, 1967). The interested reader should consult the papers listed above for further discussion about the origin of the Black Sea. The relatively shallow drilling of Leg 42B (slightly over 1 km) did not provide much new information on its origin. Very deep penetration into the sediment, of about 10 km, is necessary to resolve some of the problems concerning the nature and origin of the Black Sea Basin. We hope therefore that Leg 42B is but the first stage of drilling in this interesting area.

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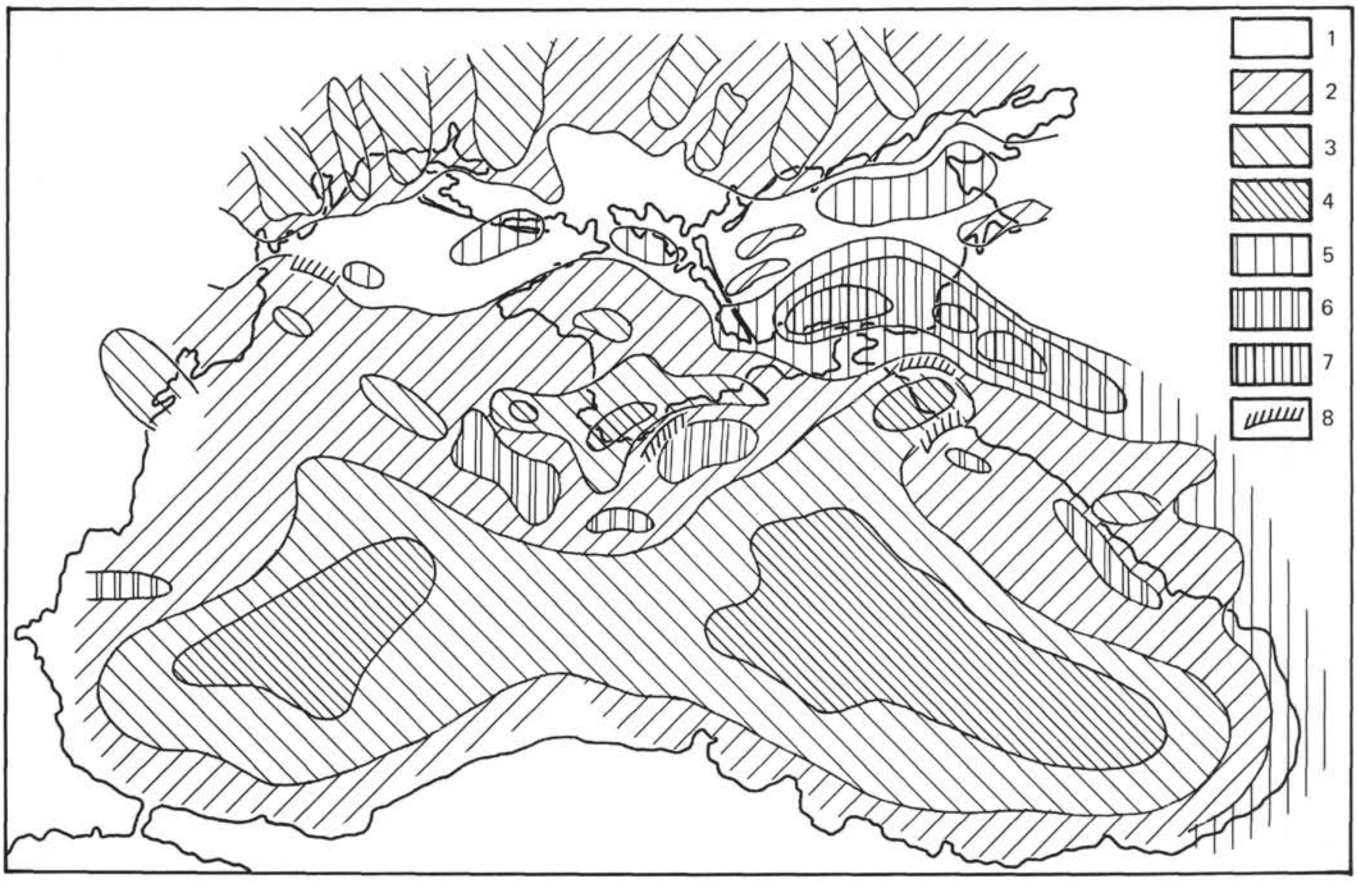

Figure 9. *Bouguer anomalies based on Soviet data (Goncharov et al., 1972). (1) variable field, (2) weak positive anomalies, (3) relative maximum, (4) great positive anomalies, (5) weak negative anomalies, (6) relative minimum, (7) great negative anomalies, (8) gravity steps.*

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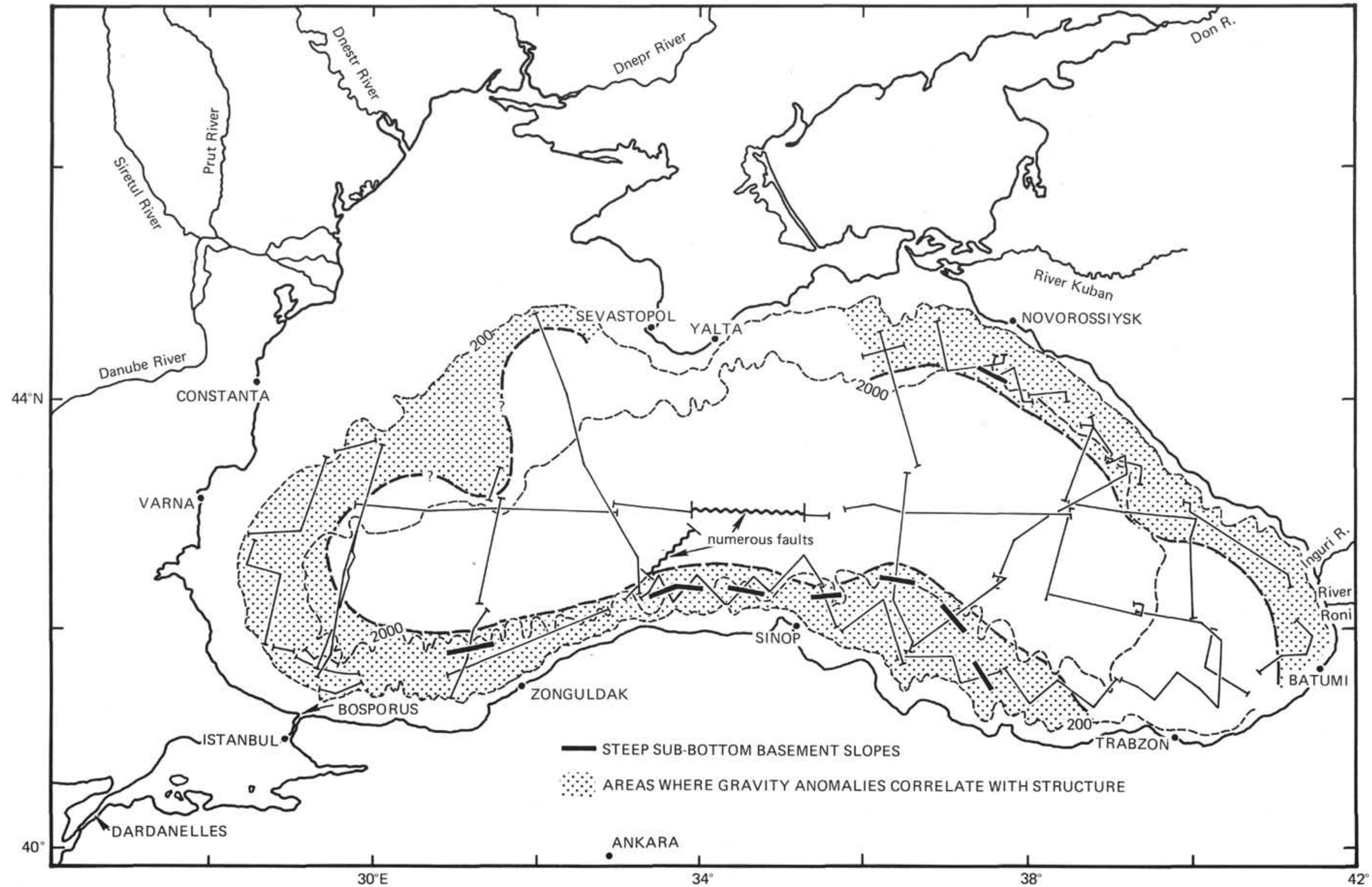

Figure 10. *Summary of gravity observations, location of steeply dipping basement, and location of small faults in Black Sea, based on data of 1969* Atlantis II *cruise (from Ross et al., 1974b).*

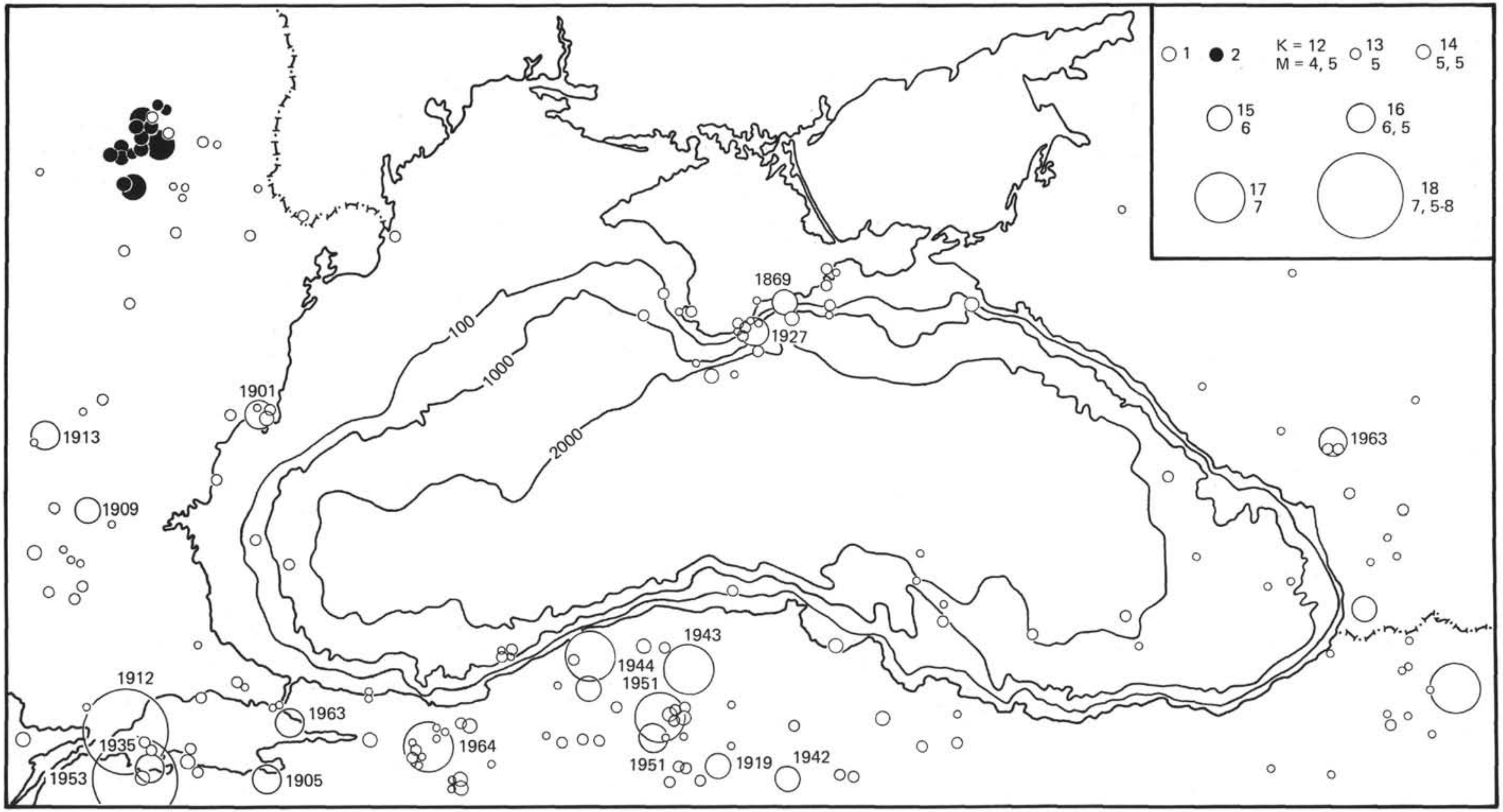

Figure 11. *Seismicity of the Black Sea area (Riznichenko et al., 1975). (1) epicenters inside of crust, (2) epicenters under crust. Different size of circles shows magnitude M of earthquake.*

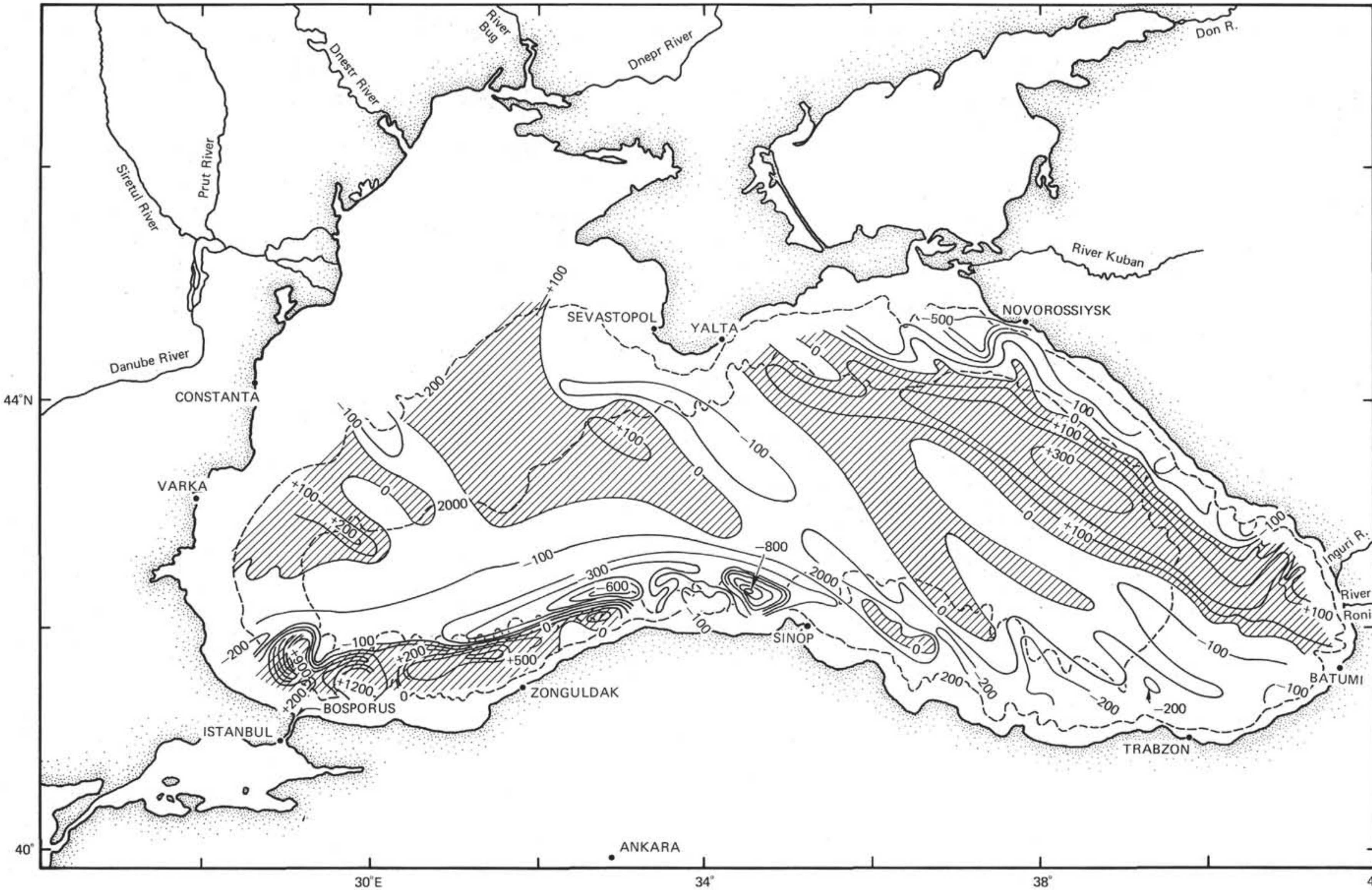

Figure 12. *Magnetic anomalies in the Black Sea based on measurements made from* Atlantis II. *Anomalies calculated by removal of a reference field (Cain et al., 1968) from measurements of total intensity. Contour interval is 100 gammas. Positive anomaly areas are cross-hatched (from Ross et al., 1974b).*

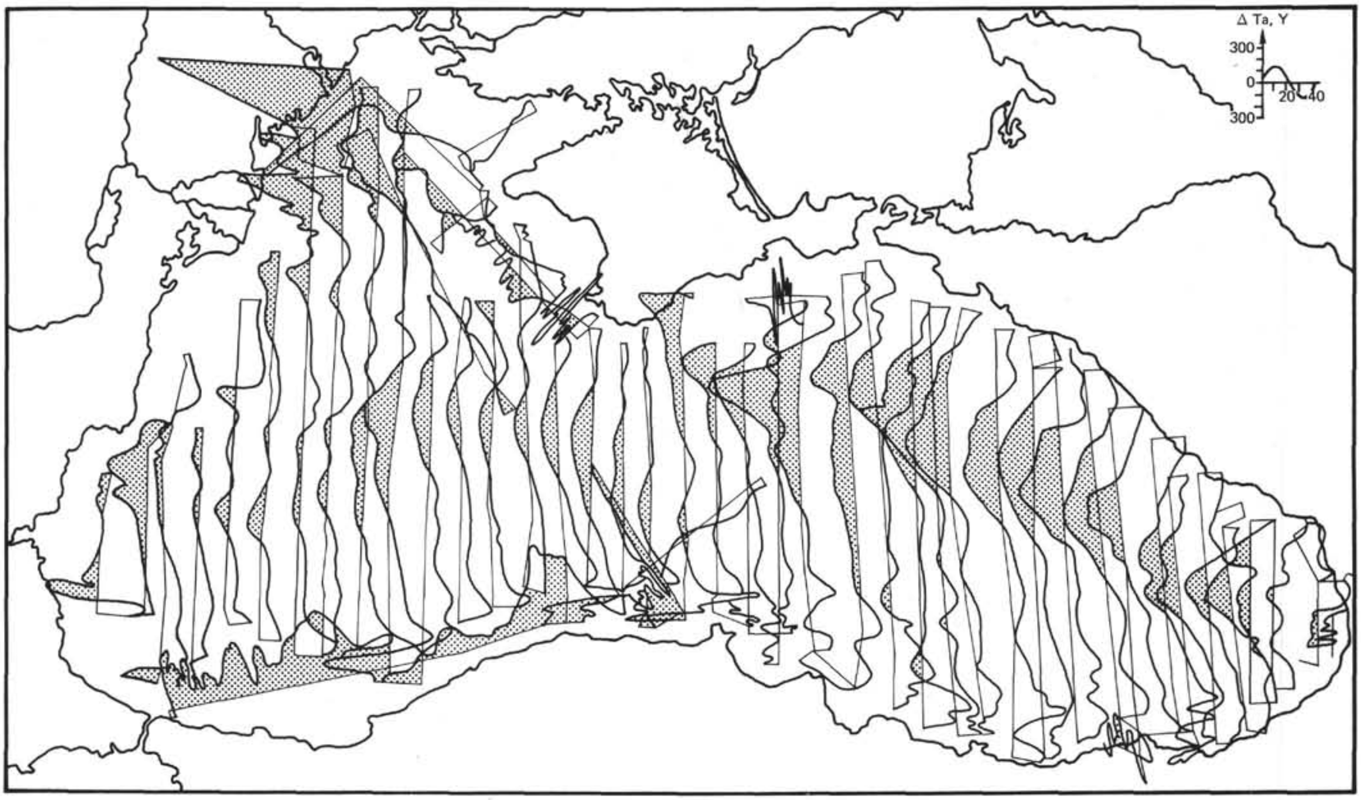

Figure 13. *Plot of the magnetic anomalies along profiles across the Black Sea (Malovitsky et al., 1975). Dotted areas show the positive magnetic field.*

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