THE GEOLOGY OF THE AMASRA REGION WITH SPECIAL REFERENCE TO SOME CARBONIFEROUS GRAVITATIONAL GLIDING PHENOMENA

Melih TOKAY

Mineral Research and Exploration Institute of Turkey

ABSTRACT. — While conducting some geological studies in 1952 the author had noticed, at Süzek Creek near Bartın, some overturned Upper Visean strata which had been overlain unconformably by transgressive Upper Cretaceous formations of Turonian age. This pointed to the presence of some hercynian horizontal movements in this region. It was highly probable that these movements had also affected the coal-bearing formations at Amasra. Bearing this point in mind, a number of boreholes have been drilled at Amasra to explore the coal deposits and the geological structure. In our interpretation of the borehole data, it appears that, beside a block-faulted structure of the Carboniferous strata which had been postulated by the earlier workers, we are dealing with numerous coal-bearing *slabs,* which had traveled eastwards by free gliding from their positions above the uplifted Devonian - Lower Carboniferous foundation, during the hercynian orogenic cycle.

Under this new light of interpretation, which is new for Zonguldak as well as for Turkey, the coal mining possibilities of this region have been examined. It is estimated that in Westphalian D and C, in a limited area and down to —600-meter level, there is a reserve of 42 million tons of coal.

INTRODUCTION

In agreement with the Ereğli Coal Exploitation Enterprise (E.K.İ.) geological investigations have been carried out in recent years by the Mineral Research and Exploration Institute (M.T.A.), in order to assess the economic value of the coal seams in the Carboniferous formations around Amasra and Tarlaağzı. A revision of the previous work on the historical and structural geology of the region was supported by borehole drillings, arranged on the basis of prior geological and sporological studies. The information derived from the boreholes has been invaluable in increasing our knowledge of the geological structure of the region, by providing such details as the types of coal seams, their thickness, depth, and arrangement on the stratigraphical scale.

The Amasra-Tarlaağzı coalfield is part of the coal-bearing Carboniferous of northern Anatolia. It is situated on the Black Sea coast in between two — Eastern and Western — coalfields. The Carboniferous formations of the western coalfield outcrop at Çamlı-Kandilli-Armutçuk, and further east form the Zonguldak coalfield, parts of which are named Kozlu, Çaydamar, Üzülmez, Kilimli, Karadon and Gelik. Eastwards these formations are covered by younger formations, but appear again to the east of the mouths of Filyos and Bartınsuyu rivers, forming the visible part of the Amasra coalfield. Further east, the coal-bearing formations outcrop at Pelitovası, south of Söğütözü, Azdavay, Karafasıl, Suğla Yaylası, forming the eastern coalfield.

The Carboniferous rocks of the coalfield are exposed in ah area having a SW-NE diameter of 5.5 km. and a NW-SE diameter of 2.5 km. At a number of localities they are overlain by Cretaceous rocks. Previous exploitations have been carried out at Tarlaağzı, at Çınarlı and at Dökük. However, the potentially productive coalfield is much larger and extends south and south-eastwards under what are probably Permian and Cretaceous rocks.

The coast—as it is generally the case for the northern Anatolia—is an open type consisting of cliffs, few narrow beaches and—as at Amasra—small bays. The undulating hillocky topography extends southwards and is bordered by an approximately SW-NE extending escarpment of Upper Cretaceous volcanic rocks. The highest hills of the region (Dinlence Hill 489 m., Meşelik Hill 422 m., Kuşkayası 446 m.) are situated almost to the south of this escarpment. Further southwards, the elevations decrease on account of the general southward dip of the strata and the accompanying erosion. The region is bordered in the west by hills formed by the Devonian and Lower Carboniferous formations.

The important river, Bartınsuyu (old Parthenius), of this region flows to the west and outside the coalfield, reaching the Black Sea after passing over some Devonian formations.

Amasra is connected to Bartın by a 18-km. long road. Bartın, in turn, is connected to the steel industry center at Karabük by a south-traveling road which passes through Safranbolu, while Zonguldak and other towns in the west can be reached by road and railway via Kokaksu. Old Amasra has been built on a peninsula. On both sides of the isthmus there are two harbors, the eastern one having artificial breakwaters.

On account of the slightly hillocky relief, there is no great agricultural activity present. Locally, wheat and corn are grown in small fields, vegetables and fruit trees in gardens. No important forests are present.

HISTORY OF PREVIOUS RESEARCH

The coal seams of the Tarlaağzı-Amasra region have been the object of attention for more than a century. Towards the end of the first half of the last century, A. Schlehan (17) visited this region and published the results of his geological and mining studies conducted around Tarlaağzı, Gömü and Çınarlıdere, southward to Dinlence Hill and Kuşkayası. Some of his information is still considered valid today. In the following years, mining firms explored the region from time to time. During that period, G. Ralli (15-16) mentioned Amasra in his work; F. Charles (5-7) conducted a series of studies between Amasra and the İnkum anticline, situated to the west of the mouth of Bartınsuyu River, and collected a number of fossils. Other geologists, such as P. de Tchihatcheff and E. Nowack, have also carried out some investigations in the region. These have been followed by the activities of the Mineral Research and Exploration Institute. The following scientists are some of the important contributors : P. Ami (geologist) (1-4); Professor J. Jongmans (phytopaleontologist, adviser to the M.T.A. Institute) (1, 12); S. Pekmezciler and R. Egemen (8), who concluded the studies carried out during the final years of World War II; J. Louis (13), who did some revisions during the years 1955-1956; K. Yahşıman (19-21) and Y. Ergönül (9, 10, 21) whose works—geological and sporological studies on cores drilled according to the information supplied by the geological maps started in 1955—are partly published.

The author (18) has studied the area between Amasra and the mouth of Filyos River, and its southward extension. Later, he closely followed the drilling operations, started in 1956, as part of his job.

The Ereğli Coal Exploitation Enterprise, which has shown a great interest in this region, has carried out a number of exploration activities in the east, in the form of galleries—one at Tarlaağzı and the other at a locality near to the Bedesten borehole (No. 21).

The M.T.A. drilling program, which has been in operation since 1956, includes the determination of depths of the coal seams within the exposed Carboniferous formations, as well as assessing their probable south and southeastward extension under the cover rocks.

STRATIGRAPHY

Basal series

Formations, which constitute the base of the coal-bearing rocks, are probably of Upper Silurian, Devonian and Lower Carboniferous age, and are exposed in large areas to the west and southwest of our region. Considering the total thickness of the coal-bearing series and the overlying Cretaceous rocks, it is apparent that these basement formations have been uplifted from considerable depths.

The oldest formations are exposed at the center of the İnkum anticline, to the west of the outcrops of the coal-bearing beds. Away from the axis, on both limbs of this faulted structure, Lower, Middle, Upper Devonian and Lower Carboniferous formations can be seen (18).

Lower Devonian .

In the core of the İnkum anticline, a section of which can be seen on the beach to the west of the mouth of Bartınsuyu River, a formation with a thickness of more than 250 meters' consisting of green-red colored ferruginous shales can be ascribed to Lower Devonian or even to Upper Silurian.

Formations stratigraphically higher up include more and more quartzitic intercalations. These are followed by microconglomeratic or cherty quartzites of light violet, gray, brown and white colors, and gray, fine to medium-grained, even brecciated limestones, all with a probable thickness of 400 meters. Among other fossils, the presence of *Spirifer crassifulcitus* Spriesterbach indicates the Coblentzian (Lower Devonian) age of this formation.

Middle Devonian

These consist of light or dark-colored crystalline, sometimes cherty, bedded and fractured limestones and dolomitic limestones. Their 360-meter thickness in the west appears to increase to 1,200 meters in the east.

Upper Devonian

These consist of limestones and dolomites, containing Upper Devonian fauna *(Spirifer verneuili* Murchison, *Productella subaculeata* Murchison, *Athyris communis* Goss) and 325 - 900 meters thick. The upper parts are probably of Tournaisian (Lower Dinantian) age, though no fossil evidence has been found to confirm this, as yet.

Yisean

The lower formations consisting of cherty, dolomitised marine limestones (approximately 1,250 meters thick), contain the D_1 zone of *Dibunophyllum.* The upper formations, which are argillaceous shales of Culm facies with marine limestone intercalations (180-320 meters thick), contain the D_2 zone of *Dibunophyllum.*

Namurian A-B-C (Alacaağzı stage)

They consist of sandstones and shales containing thin coal seams and overlie the Upper Viscan shales which have at least two limestone intercalations.

The most important fossils are :

Cardiopteridium ivaldenburgense Zimm.
Diplotmena bermudensiforme Schloth.
Pecopteris aspera Bgt.
Mesocalamites
Amongst the characteristic megaspores, there are :
Lagenicula crassiaculeata (Zerndt) Pot. & Kr.
Lagenicula subpilosa (İbrahim) Pot. & Kr.
Rotatisporiies rotatus (Bartlett) Pot. & Kr.
Zonalesporites brasserli (Stach & Z rndt) Pot. & Kr. forma *minor* Dijkstra
Setosisporites praetextus (Zerndt) Pot. & Kr. forma *minor* Dijkstra

Namurian (especially Namurian A and B) formations have been seen in Tarlaağzı in the open-cast and underground works and in the boreholes Nos. 22 and 28; also in Amasra at the surface, and to the south of Dökük (Namurian C), as well as in the No. 23 borehole. The Kestane (0.80-1.05 meters) Upper and Lower Karaali seams are found within this series. Of those only the Kestane seam has a workable thickness.

Two types of Namurian formations more than 300 meters thick are found : a much-disturbed, slab-like occurrence and a less disturbed, autochthonous occurrence.

Westphalian A (Kozlu stage)

This consists of conglomerates, sandstones and shales. Occasionally coal remains can be found.

The characteristic fossils are :

Neuropteris schlehani Stur.
Neuropteris gigantea Bgt.
Sphenopteris hoeninghausi Bgt.
Mariopteris acuta Bgt.
Sphenophyllum cuneifolium Sternb.
etc..

Amongst the characteristic megaspores there are :

Zonalesporites brasserti (Stach & Zerndt). Pot. & Kr.
Setosisporites praetextus (Zerndt). Pot. & Kr.
Setosisporites hirsutus (Loose) Ibrahim
Cystosporiles varius (Wicher) Dijkstra
Tuberculatisporites tuberosits Ibrahim
Lagenoisporites rugosus (Loose) Pot. & Kr.

The Westphalian A is seen at the surface in the upper reaches of Çınarlı Creek, and at the Dökük area. On the other hand, it has been penetrated by the boreholes (Nos. 21, 22, 23, 25, 26, 27, 29, 31, 32, 41, 44) and at various depths found to be either autochthonous or disturbed slabs. Generally the thickness of the disturbed slab-like Westphalian A is in the region of 200-300 meters, though this increases where successive slabs are found overlying each other. Prior to the latest drilling operations, few coal seams had been attributed to the Westphalian A in the Çınarlı faulted region. These were mainly the Büyük Dökük seam (3-10 m. thick) at Dökük, another seam (1 meter thick) stratigraphically 10 meters above the former, and two doubtful seams (1-1.20 m. thick) at the base. However, as we shall see later, boreholes sunk into the Westphalian A have penetrated at various depths many coal seams with thicknesses between 1-9 meters. Studies are continuing for the determination of the stratigraphical position and correlation of these seams.

Leaving exploitation problems aside and considering only the geological point of view, it appears that the Westphalian A offers some rich coal seams.

Karadon stage

In the Zonguldak Coalfield, the Westphalian B-C-D are named altogether as the Karadon stage. Although not well developed in the western coalfield, it carries a great importance in the Amasra coalfield because of its thickness, number of coal seams and ease with which stratigraphical subdivisions can be made. For this reason its subdivisions will be considered separately.

a. Westphalian B

It appears to be an upward continuity from the Westphalian A, but it can be distinguished from the latter by phytopaleontological evidence. The upper limit is considered to be a refractory clay horizon which forms the base of the Westphalian C coal group (8). It generally consists of dark-gray fine-grained sandstones, sandy shales, shales and rarely microconglomerates.

The fossils are :

Alethopteris lonchitica Schl.
Discopteris vullersi Stur.
Lonchopteris

which are common to Westphalian B and Westphalian A.

There are also :

Neuropteris rarinervis Burb.
Sphenophyllum emarginatium Br.
Linopteris sp.

which are especially developed later, in Westphalian C (8, 13)

Amongst the characteristic megaspores there are :

Superbisporites superbus (Bartlett) Pot. & Kr.
Colisporites pekmezcileri Ergönül 1961
Cystosporites giganteus Zerndt

Recognizable Westphalian B is found at Tarlaağzı, Çınarlı and Amasra in the boreholes Nos. 21, 23, 26, 27, 29, 32, 33, 34, 35, 36, 42, 45, 47. The real thickness of this formation is not definitely known, because many boreholes did not completely penetrate it. The thickest bore is about 320 meters (borehole No. 29), but, considering the possible thickening effects of duplication of slabs here, a more reasonable figure is in the order of 100-200 meters.

Westphalian B generally contains only thin coal seams; however, at a cutting in the Dökük area, a seam with a 0.85 meter thickness has been observed (13). Only in borehole No. 29, two coal seams (or parts of the same) on both sides of a fault have been met, with thicknes5es of 1.25 and 0.95 meters.

6. *Westphalian C*

It consists of dark-gray very fine-grained sandy argillaceous shales, with coal seam intercalations, bounded by a refractory clay horizon below, and sandstones and conglomerates above. It can be seen exposed on the surface in many places, at Tarlaağzı, Gömü and Çınarlı, and has been penetrated by a number of recent boreholes.

It includes abundant

Neuropteris rarinervis Bunb.
Neuropteris scheuchzeri Hoffm.
Neuropteris tenuifolia Schl.
Linopteris münsteri Eichw.
Linopteris obliqua Bunb.

Amongst the characteristic megaspores, there are :

Laevigatisporiles glabratus (Zerndt) Pot. & Kr.
Valvisisporites auritus (Zerndt) Pot. & Kr.
Tuberculaloisporites regliensis (Dijkstra) Pierart
Tuberculatoisporites egemeni Yahşıman 1961
Bentzisporites bentzii Pot. & Kr.
Knoxisporites tokayi Ergönül 1961

It can be stratigraphically subdivided into two natural divisions. The lower division, known as the Tarlaağzı (or Schlehan) series, is about 50 meters thick, comprising seven coal seams. The upper division is about 100 meters thick and consists of sandstones and conglomerates.

Westphalian C, which includes the most worked coal seams up to now, can be found as autochthonous bodies, as well as glided slabs. It has been penetrated by many boreholes (Nos. 21, 22, 23, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 40, 41, 45, 47), generally ranging in thickness from 0 to 125 meters, occasionally reaching 230 meters.

The succession of the coal seams, either in the autochthonous or disturbed slab-like Westphalian C, agrees with the information given by Schlehan. However, in both types of tectonic occurrences of this formation, there are some lateral thinning and thickening of the coal seams which could be observed in the boreholes. Westphalian G is considered to be an important formation because of its abundant coal seams, great area coverage and nearness to the surface.

c. *Westphalian D*

It can be observed to the east of Tarlaağzı, at Yılanlı, Çapakdere, Çınarlı and Gömü, at the surface and underground workings. Also in the recent boreholes (Nos. 22, 25, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 40, 44, 47).

The characteristic fossils are :

Mixoneura ovata Hoffm.
Mariopteris nervosa **Br.**
Odontopteris **sp.**
Pecopieris unita **Br.** (continues into Stephanian)

Also, there are :

Triletisporites tuberculatus (Zerndt) Pot. & Kr.
Triletisporites distinctus Ergönül 1960
Superbisporites dentatus (Zerndt) Pot. & Kr.
Valvisisporites auritus var. *grandis* (Zerndt) Pot. & Kr.
Bentzisporites tricollinus (Zerndt) Pot. & Kr.
Cystosporites. striatus Yahşıman 1959
Laevigatisporites dijkstrai Yahşıman 1959

The series consisting of sandstones and conglomerates which overlie the Tavan coal seam of Westphalian C, forms the base of the Westphalian D. Stratigraphically upwards they are followed by Kurudere coal seam group consisting of three closely-spaced seams. These are followed by greenish argillaceous sandstones, a coal seam which could not be located in the boreholes with any certainty, more argillaceous sandstones of a lighter green color, and local occurrences of red beds. The usual, Westphalian D thickness found in the boreholes ranges from 40 to 180 meters; but occasionally it may be up to 300 meters thick. Mainly because of tectonic causes these thicknesses are frequently reduced to 15-20 meters, or even to zero.

Stephanian (Westphalian E)

These formations, following Westphalian D, are devoid of fossils and coal seams. They are similar to the underlying rocks, though slightly limy in the upper parts. Lower parts are gray-green-colored, while the upper parts exhibit green and wine-red colors.

The separation of the two similar series—Westphalian D and the Stephanian—is based on the following criteria by Y. Ergönül, who has closely followed the drilling operations :

a. The appearance of certain spore species of *Pollenites* and *Bentzisporites* at the base of the Stephanian.

b. Locally, the presence of a small amount of limestone in the Stephanian, as opposed to Westphalian D which does not contain any limestones.

Stephanian has been found between Tarlaağzı and Çınarlı, around Çapakdere, to the west of Yılanlıdere, near Gömü, and in the recent boreholes (Nos. 33, 34, 35, 36, 37, 38, 44). According to the measurements made on the drilling profiles, to the south and east of Kuşkayası, the thickness of Stephanian can be more than 150 meters. At the borehole No. 44, situated between Ahatlar and İnpiri, the thickness was found to be 190 meters. On the other hand, the formation is much thinner (less than 100 meters) on the NW of the region.

Permian (Arıtdere formation)

This formation consists of wine-red, green, gray-colored, medium to fine-grained, laminated and banded, unfossiliferous sandy shales and marls, devoid of coal seams. It appears to be conformable over the underlying Carboniferous formations. On the other hand, it has been unconformably overlain by the Lower Cretaceous limestones. Especially in the west it appears to be discontinued. The small thicknesses teen in the west increase east and southeastwards, reaching a maximum of 110 meters.

Sometimes the lower beds contain conglomerates including rounded pebbles of chert, green quartz, olive-green sandstone, etc.

These supposedly Permian beds are known as the Antdere formation in the eastern coalfield.

Cover rocks

The lowest member of the Cretaceous, which transgresses over the coal-bearing Carboniferous and older Paleozoic formations, is a 0-100-meter thick (400 meters in the east) Barrernian of Urgonian (reef) facies. The overlapping Albian and Cenomanian present a facies consisting of blue marls with thin limestone and sandstone intercalations, and a variable thickness which can reach up to 700 meters, where basins have developed (borehole No. 42). Turonian consists of thinly-bedded white and pink-colored limestones and argillaceous limestones, comprising a thickness of 30-80 meters. This is followed by an extrusive formation consisting of volcanic breccias, tuffs, andesitic and dacitic lavas (230-300 meters thick), overlain by marls and tuffs, all of Senonian age. The following Campanian volcanic rocks are mainly basaltic. The Maestrichtian (100-400 meters) consists of white, gray, red-colored argillaceous limestones and — outside the map area to the south of Kozcağız — contains spilitic pillow lavas.

In order to complete the stratigraphical succession of the cover rocks, we may mention the transgressive Danian-Paleocene (125 meters) which consists of white-gray limestones, Ypresian (125-200 meters) consisting of marls and sandy argillaceous shales, and Lutetian consisting of hard sandstones, limestones and shales.

TECTONICS

As shown on the geological sections (Pl. IV, V, Va) there are four distinct successive groups in the area. At top there are alpine formations (Cretaceous) which overlie the Paleozoic basement rocks with an angular unconformity and have a different style and direction of folding.

The next lower group consists of Permian and the uppermost members of the coal-bearing formation, such as Stephanian, etc., all exhibiting a relatively quiet and regular tectonic form. These are underlain by an allochthonous group, consisting of displaced and mixed slides of Westphalian C, B, A and Namurian. Underneath this group, at depths to which only a few boreholes penetrated, there is an almost autochthonous, relatively less disturbed sequence of Carboniferous formations, consisting of probable Westphalian B and older formations, as well as limestones which are more rigid than the ones in the overlying groups.

Naturally, the, old formations which had suffered deformation and dislocation during the hercynian orogeny, have been re-disturbed by the movements of the alpine orogeny.

Local synclinal bendings in conjunction with thickenings of the cover Westphalian C (see following pages) in the sections between boreholes Nos. 31 and 36, 47 and 41, 32 and 34, and 40, while not neglecting the effects of possible faulting, can be interpreted as the existence of topographical depressions before the sliding and accumulation of Westphalian C. As a matter of fact, the Westphalian A and Namurian slabs did not spread uniformly; they accumulated locally in great vertical thicknesses (as for instance in borehole No. 25), while in other places, where these slabs did not reach, some depressions were formed.

Folds

A. Folds affecting the Paleozoic rocks

1. The İnkum anticline. —The core of the anticline can be seen at the coast, about 10 km. SW of the Carboniferous outcrops of the Tarlaağzı-Amasra region. It involves the whole of the Devonian and the Carboniferous limestone series. The axis of the anticline has an overall plunge towards the SE. At the core, ferruginous argillaceous sandstones, of Lower Devonian age, are seen to be overthrust northeastwards on the limestones with quartzite intercalations, also of Lower Devonian age. The anticline has been dissected by other faults as well. On the northeastern flank of the structure, an outcrop of Lower Devonian

limestones, with quartzite intercalations, appears to be wedged between Carboniferous limestones in the north and Upper Devonian dolomitic limestones in the south (Pl. I, III).

2. The Gavurpınar syncline. — This structure, with a fold axis in an E-W direction, is situated within the limestones of D_1 zone of *Dibunophyllum,* and includes limestones and shales of Culm fades, belonging to the D_2 zone of Dibunophyllum, as well as the Namurian shales. Beyond the disturbed region to the south of Yaylacık Tepe, the structure becomes confused and obscure. The Carboniferous strata are locally overturned. A good example to this can be seen at the Süzek Creek, where limestones of D_1 zone are seen to overlie shales of D_2 zone. This overturned position of the D_1 zone limestones extends as far as Kızılelma in the west. The pinching of the Carboniferous strata, as seen at the Süzek Creek, is the result of the same compressive stresses producing the İnkum and Diştaşlık anticlines to the west.

3. The Diştaşlık anticline. —- This is an irregular fan-shaped structure involving Carboniferous limestones at the center, D_2 zone and Namurian formations on the flanks. The structure may be considered as a subordinate fold, situated between the primary İnkum anticline and the Tarlaağzı-Amasra trough. The flanks of the anticline have been dislocated by downward converging faults.

4. The Tarlaağzı-Amasra trough. — For a long time this structure had been considered as a primary syncline, refolded by secondary folds. The complex nature of this trough has been elucidated as a result of studies conducted since 1952. This is a trough into which, from a certain time in Westphalian B onwards, foimation slides have glided and accumulated, traveling east and northeastwards from the eastern slopes of the high ground composed of İnkum and Diştaşlık anticlines. All formations, from Carboniferous limestone to Permian, are locally found in this trough. The bottom of this trough, which is nearer to surface in the Amasra region, appears to deepen towards east and southeast. A summary of the geological characteristics of this structure is presented further below.

B. Folds affecting the cover rocks

The northernmost fold within the Cretaceous cover rocks in the area between the Black Sea coast and Bartın extends along Tarlaağzı-Gömü-Amasra, in a SW-NE direction, and particularly involves the Lower Cretaceous formations. However, on the southern flank of the structure continuous Upper Cretaceous formations are to be found. Also the volcanic rocks of Lower Senonian age produce a cliff which is peculiar to the dominating hills to the south of Amasra (Pl. II).

Traveling southwards, towards Bartın, a syncline followed by an anticline can be seen to be developed within the Upper Cretaceous strata. These relatively large structures have been separated by a subordinate anticline and syncline. The axes of all these folds, with the exception of some minor local diversions, extend in a SW-NE direction.

Faults

Most of the faults seen in the surface exposures of the rocks of Tarlaağzı-Amasra trough, are normal faults, while the rest constitute reverse faults.

Most of those which could be observed were formed during the late alpine orogeny.

The faults generally appear in certain directions which could be classified under a few groups : (1) the N to NNW-S to SSE group (E Çapakdere, Çeşme-yam, etc.); (2) the E-W group (Kamışlar fault); (3) the N to NE-S to SW group; and (4) the N-S group.

As the studies continue, more evidence comes into light supporting the presence of reverse faults in the Tarlaağzı area.

The amount of throws of faults varies considerably. Without going into any details, we shall just mention the estimated throws of a few important faults:

Throw of reverse fault, W of Tarlaağzı — 700 m.
Throw of fault, W of borehole No. 44 — 350 m.
Throw of fault, E of borehole No. 44 — 500 m.
Throw of fault, W of borehole No. 21 — 230 m.
Throw of fault, around borehole No. 23 (The Kamışlar fault) is more than 120 m. (Here the thinning of the following is seen : cover Westphalian C, Westphalian A slide, and autochthonous Westphalian B.)

The important faults, in the area covered by the boreholes (Nos. 25, 26, 27, 28, 29, 31, and 47), have usually a throw of 20-60 meters. However, some faults, which border the Lower Cretaceous limestone blocks, may have throws as much as 110-150 meters. It is highly probable that a number of faults with smaller amounts of throws will be observed during future mining operations.

PALEOGEOGRAPHY AND TECTONIC DEVELOPMENT OF THE REGION (Pl. III, IV, V, Va)

Since the nature of the formations which form the base and cover of the coal-bearing series has been published elsewhere (18), I shall confine these lines to information obtained from additional studies and to my views on the tectonic disturbances from which the coal-bearing series have suffered.

Until 1951, the coal-bearing formations of the Tarlaağzı-Amasra coalfield were believed to be controlled only by bloc faulting. However, the following points indicate the presence of different tectonics of a pre-alpine (hercynian) age :

- The presence of an upthrust at the core of the İnkum anticline, not extending into the Cretaceous cover rocks to the south.
- The wedge-like appearance of Lower Devonian rocks in between Carboniferous limestones and Upper Devonian, to the east of the mouth of the Bartınsuyu River, and the discontinuity of the faults bounding it in the overlying Upper Cretaceous formations to the south.

— At Gavurpınar and Süzek Creek, the overturned and pinched position of the incompetent top Visean (D_2) and Namurian strata, together with the adjacent competent limestones (D_1).

— The existence of an angular unconformity between Carboniferous rocks and the overlying Turonian conglomerates (E and W of Süzek Creek) and, to the south of Tarlaağzı, the difference of nearly 75° between the strikes of the Turonian and the N-S striking Carboniferous (in this locality the Cretaceous limestone has the same strike as the Turonian), etc. go to show that the overturning is definitely of pre-alpine origin.[1]

Such movements of hercynian age would obviously affect the Carboniferous formations. Thus, since 1952 the following points have been noted during the drilling operations in the coal-bearing Carboniferous series:

— The occurrence of squeezing, contortions and sliding parallel to bedding planes, in certain (especially shale) formations.

— Horizontal or sub-horizontal mechanical contacts showing brecciation or squeezing.

— Sudden pitch alterations in the drilling profiles, where no evidence for faulting exists. This might be indicative of disharmonic folding.

— The apparent non-conformity of the profiles of closely-spaced boreholes.

— The non-uniform sequence of various strata.

— In certain boreholes, the disappearance of some formations, thus upsetting the stratigraphical sequence. At those levels where these formations are normally expected to occur, horizontal or sub-horizontal mechanical contact surfaces are found which can also be traced in the adjacent boreholes.

— Lack of horizontal continuity in some formations bounded by mechanical contact planes, above and below.

— Repetition of the same formation on one drilling profile (none of those investigated have been found to be overturned) and the presence of mechanical contact boundaries, above and below such repeated formations.

—- The existence of a recumbent fold which involves Westphalian C and Namurian formations, to be seen in the galleries at Tarlaağzı (21).

Considering the surface and subsurface evidence, the following interpretations and conclusions have been derived as far as the coal-measures are concerned :

1. Block-faulting is not the sole type of structure present in the Tarlaağzı -Amasra coalfield, but it is only superimposed on some more important tectonic structures. In any case, the inter-stratal and inter-formational gliding, observed in the coal-bearing Carboniferous rocks, can not be explained simply by presuming the existence of faults in this area.

2. This is a realm of horizontal movements. Although the possibility of the reversed limb of a recumbent fold can not be ignored, the simplest way to join the drilling profiles, in accordance with a number of observations, is only possible with the acceptance of the existence of free gliding tectonics.

3. Either in the case of the reversed limb of a recumbent fold or glided slabs this fold or at least part of the slabs should have had formed prior to Westphalian C. Apart from that, after Westphalian C, before Stephanian and also towards the end of Permian, there must have been horizontal movements taking place.

4. It is our opinion that in this region we are dealing with epidermic movements of free gliding type.

GRAVITATIONAL GLIDING AFFECTING PART OF THE COAL-BEARING CARBONIFEROUS

The sequence of the gliding events have been diagrammatically presented in Plate VIII, which has been constructed without a scale.

Pl. VIII, Fig. 1 (end of Westphalian B)

The normal sedimentation of Upper Visean (D_1) limestones, D_2 formations of Culm facies, Namurian, Westphalian A and B formations have taken place in a depression between Tarlaağzı and Amasra. The same strata have also been deposited in the Diştaşlık-İnkum area, here the Westphalian B being probably thinner. At the Amasra area, a subsurface rise of unknown origin[2] has caused the D_1 limestones to come near the surface, thus cutting off the connection between these old Carboniferous strata and the Westphalian B in the depression to the east; there the denudated Carboniferous limestone is directly overlain by Westphalian B (borehole No. 45).

Pl. VIII, Fig. 2

Either by ordinary epirogenic movements, or as a result of lateral compression, in any case due to deep-reated forces, a vertical uplift takes place in the area including the İnkum and Diştaşlık anticlines, to the west, outside the horizontal section. Although the shape and dimensions of this uplifted area are unknown, it may be thought to be extending under the Black Sea. A succession of thick Devonian and Lower Carboniferous limestones, overlain by coal-bearing Carboniferous formations, in turn overlain by Westphalian B, which probably thinned towards west, must have been present in this uplifted area.

Under favorable conditions, with the.development of a shearing plane near the base[3] of Westphalian A, on the eastern slopes of the uplifted mass, Westphalian A and part of the overlying Westphalian B (WBkl) have glided towards the east.

The factors, which make such a glide possible, are : the existence of an inclined plane, the gravitational action on the detached slab masses, the presence of shale beds, and the existence of a trough in the Tarlaağzı-Amasra region.

Pl. VIII, Fig. 3

At this stage the autochthonous Namurian, which had been uncovered by the gliding away of the Westphalian A and B, has by similar causes glided eastwards, partly covering the glided slabs of Westphalian A and B (Fig. 3a). It may be said that the Namurian has divided into several portions, some of which have traveled even greater distances, during these movements (Nkl, Nk2).

Pl. VIII, Fig. 4 (Deposition of Westphalian C in the west)

The deposition of Westphalian C formations took place in such a manner as to cover only the western part of the accumulated slabs.

Pl. VIII, Fig. 5

Two possible interpretations can be put forward according to the time of emplacement of the Namurian (Nk2) slab, met in the No. 42 borehole.

(1) Fig. 5a : The emplacement of the Namurian happens prior to this stage. Following an uplift in the west, two separate masses of Westphalian C detach themselves and glide eastwards. One of them travels only a limited distance in the south (WCkl), while the other mass reaches as far as the area where the present No. 41 borehole is located, coming into contact with the Namurian slab which had already arrived there.

(2) Figs. 56 and 5c : Nk2 reaches the area, where No. 42 borehole is located, not before, but during this stage.

Fig. 56 : According to this hypothesis : the future Nk2 is situated to the east of Westphalian C. Following an uplift in the west a mass detaches itself from the southern portion of Westphalian G and travels over the future Nk2, forming WCkl and reaching the then eastern border of the previously detached Westphalian A.

Fig. 5c : Here, the Namurian Nk2 slab is supposed to have been emplaced in the borehole No. 42 area, during this stage.

Slightly to the north of the area, where events shown at Fig. 56 are observed, Westphalian G formations are seen to cover Westphalian A and the future Nk2. As a result of uplift in the west, a mass detaches itself from the eastern portion of the Westphalian C, traveling eastwards (I).

At the same time, a sub-horizontal basal shearing plane develops in the Westphalian A, detaching a portion of Westphalian A (WAk2) and the future Nk2, situated to the east of the former. This mass (II) also travels eastwards and reaches the place of accumulation after mass I. Thus, in the area, where now the boreholes No. 41 and 42 are located, a sequence forms with WCk2 at the bottom and part of WAk2 together with Nk2 at top.

PI. VIII, Fig. 6

In these figures, two possible modes of development are shown, based on the two possible interpretations discussed at stage 5 (Figs. 5a and 5c).

1. The thick Westphalian A is split into two by a horizontal shearing-plane, forming WAkl and WAk2 (Fig. 6a). The WAk2, carrying the Westphalian C cover on its back, travels further east. Also, during this period, various gliding movements take place within the Westphalian C cover, which can be seen covering some pre-accumulated slabs, in the east, around the location of borehole No. 41.

2. The same sequence of movements as stated above occurs, only the accumulation of Nk2, WCk2 and WAk2 in the area of boreholes No. 41 and 42 is the result of stage 56.

PI. VIII, Fig. 7

Westphalian D is deposited after the gliding and accumulation of Westphalian C. The overlying Stephanian extends further south. Permian covers even greater areas than Stephanian, in the west.

Pl. VIII, Fig. 8

The compressive forces increase towards the end of Permian in the area of İnkum and Diştaşlık anticlines. During this stage a reverse fault develops on the eastern flank of the Diştaşlık anticline, west of Tarlaağzı. Along this upthrust fault, the western block is pushed over the Carboniferous strata of the Amasra trough. Also, the formation of reverse faults, the development of the small recumbent fold seen in the Nkl Namurian of the Tarlaağzı mine, upthrow of the western portion of the Nkl Namurian slab, are all thought to have taken place at this stage. At the same time, strong compression, partly due to the eastward movement, of the Tarlaağzı upthrust, narrowed the Tarlaağzı-Amasra trough. In our opinion, the steeply dipping Namurian strata, seen at the surface to the west of Tarlaağzı, was brought up by the above-mentioned upthrust, from the autochthonous Namurian at the basement. Also, we think that the western extension of the Namurian slab (Nkl), seen in boreholes and mines to the east of the upthrust, was eroded away.

The region was kept above sea level until the Lower Cretaceous transgression. No further analysis will be carried out here on the later developments; however, we may add, for the sake of completion, that the area of İnkum anticline and the Tarlaağzı-Amasra region both of which had been gradually covered by the Lower Cretaceous sea, were once again lifted above the sea level following the alpine orogeny, and eroded into-their present state (18).

POSITIONS AND BOUNDARIES OF SOME FORMATIONS AND GLIDED MASSES

Plate VI indicates the following points :[4]

The eastern limit of the autochthonous Namurian, starting from a point to the south of Amasra, extends northwards, passing between boreholes No. 45 and 41, and to the north of borehole No.- 38, later possibly turning eastwards. The Namurian formations are also seen as glided masses. The eastern limit of such a glided mass, observed in the mines at Tarlaağzı, forms the sides of an angle whose apex is situated somewhere between the boreholes. No. 26 and 27. Another less important eastern mass is found around borehole No. 42.

Westphalian A occurs as two glided masses. The lower, relatively less important slab (Pl. VI, WA, Slab I) is limited in the east by a line joining the boreholes Nos. 27, 31 and 32. The eastern limit of the western portion of the overlying glided mass (Pl. VI, WA, Slab II), which extends over a larger area, is closely traced by the line joining the boreholes Nos. 33, 34, 47, 45; only around borehole No. 41 there seems to be an eastward stretching tongue of thin mass. On the other hand, it is possible that the Westphalian A formation observed in the area of the borehole No. 44 is part of this Slab II of the Westphalian A, both joining along a free gliding plane which extends under the sea.

In the area where boreholes No. 26 and 27 have been drilled, the Westphalian B is found as a glided mass. Due to lack of sufficient number of boreholes to the south, the southern boundaries of this mass have not been traced.

The glided mass of the cover-like Westphalian C is restricted to the area south of a curve which begins from Tarlaağzı, crosses over the sea and passes near the boreholes Nos. 23, 45, 41, and 38. The Westphalian C formations are also found, in deeper levels, as two separate glided masses, in the borehole No. 41 and borehole No. 32 areas, respectively.

Westphalian D extends from Tarlaağzı eastwards; it follows the coast for awhile under water, then swings to the south of boreholes Nos. 21, 41 and 42, joining the sea again and continuing in an E or NE direction.

The Stephanian is mainly restricted to the SE of the drilled area, its NW border not reaching the boreholes Nos. 31, 32, 40 and 42.

Widespread Permian formations, which had been protected from erosion, extend over the area where boreholes Nos. 37, 36 and 44 have been drilled. They are also found as separate masses in the areas of No. 22 and No. 29 boreholes.

The southern edge of the transgressive sea, which deposited the Lower Cretaceous limestones (Barremian, etc.), begins at the west of Tarlaağzı, following a short southward extension, swings towards borehole No. 32, passes to the east of boreholes Nos. 31, 41 and 23 in irregular curvatures, follows the coast from the south of Amasra onwards and turns southwards at a point near borehole No. 44.

The western border of the formation group of Albian-Cenomanian age is located probably in the Tarlaağzı area. It is almost certain that this transgressive group had once completely covered the drilled area, parts of which have later been removed by erosion.

Coal measures

The earliest coal-bearing formations in the stratigraphical succession are found in the Upper Visean of Culm facies. The following Namurian (including A, B, C sub-stages), Westphalian (including A, B, C, D sub-stages) and Stephanian (Westphalian E) are coal-bearing formations, except the last one. Conformably overlying the uppermost rocks there are local remains of unfossiliferous red sandstones and marls of Stephanian or Permian age, which are unconformably overlain by Lower Cretaceous limestones of reef facies (Urgonian).

There are coal seams of various thickness present in all formations from the Visean D_2 zone up to and including Westphalian D. These coal seams had been known to exist from the older studies and explorations, but due to the lack of deep-reaching borehole information, their exact distribution remained obscure. As a result of the latest drilling operations and parallel sporological and geological studies, many questions have been clarified about these seams.

The seams within Westphalian D (partly) and Westphalian C appear to be the most geologically continuous ones, capable of being easily correlated. On the other hand, the seams in Westphalian B, Westphalian A and Namurian can not be correlated because of gliding, disharmonic folding and faulting. The existence of important coal seams may be expected in the probably relatively less disturbed autochthonous Westphalian B, which underlie the glided slabs, and especially in Westphalian A. However, these formations, which are found in great depths, have been reached so far by only a few boreholes.

The coal seam group of Westphalian C and D, which have been correlated and found to offer more favorable possibilities relative to other areas, are located approximately within the area bordered by the boreholes Nos. 21, 29, 33 and 37, south of Amasra. The calculation of reserves has been limited to this area. The isopachous maps of the four out of seven important seams (Tavan, Kalın, Ara, Taşlı) of the Schlehan group of Westphalian C have been shown together in PL VII.

The upper one of the Kurudere coal seams in Westphalian D, reaches a thickness[3] of 1.75 meters. Within the area bordered by boreholes Nos. 37, 47 and 32 its thickness may exceed 1.00 meter.

The maximum thickness exhibited by the Tavan seam, which is the top seam of Westphalian C, is 2.20 meters. It shows a thickness of only 1.30 meters at Tarlaağzı. Within the area bordered by the boreholes Nos. 47, 29 and 31, its thickness varies from 0.5 to 2.20 meters.

The thickness of the Kalın seam; 2.00 meters at Tarlaağzı, varies from 0.5 to 2.10 meter's (maximum) in the area falling within the boreholes Nos. 21, 29, 33, 35 and 41.

The thickness of the Ara seam, varying between 0.70 and 1.00 meter at Tarlaağzı, presents a maximum thickness of three meters in this region. Within the area bordered by boreholes Nos. 41, 27, 33 and 35 the thickness is found to be always more than 0.5 meter.

The Taşlı seam, which is locally found to be one meter thick at Tarlaağzı, has been established during drillings to be the thickest seam within Westphalian G. This seam, which shows a maximum thickness of seven meters (borehole No. 34), is found to be always thicker than 0.5 meter within the area bordered by boreholes Nos. 41, 27, 33 and 35.

Another group of three seams appear in the lower parts of Westphalian C. These seams, known from top to bottom as Üçüncü, İkinci, Birinci, are generally less than one meter thick. In places, the Üçüncü seani is so close to the Taşlı seam (borehole No. 29) and sometimes to the İkinci seam (borehole No. 31) that they might be considered as a single seam. However, its thickness varies irregularly between the boreholes.

The results of the up-to-date analyses (giving the maximum and minimum values), carried out on samples of the above-mentioned coal seams of Westphalian G and *D,* are summarized in the table below :

Table

Stage	*Westphalian D*		*Westphalian C*		
Seam	Üst Kurudere	Tavan	Kalın	Ara	Taşlı
Moisture content (%)	4.0-5.2	4.30	3.6-8.6	1.3-6.5	2.0-5.0
Ash content (%)	19.1-47.1	19.63	15.0-32.0	31.0-38.0	23.0-49.8
Volatile matter (%)	19.4-30.8	33.26	28.2-32.0	26 0-31.6	22.8-32.6
Fixed carbon (%)	29.5-44.8	42.81	36.0-45.0	30.0-37.0	22.12-42.0
Lower calorific value (moisture-ash-free) Kcal/kg.	6700-7300	7300	6900-7000	7000-7300	6100-7500

The total sulphur content is low, less than 2 %. The coal does not have good coking ability in its run-of-the-mine form. It does riot generally show a good caking ability during coking, exhibiting a sand-like appearance.

COAL RESERVES

The following reserves have been estimated on the isopachous maps based on net thicknesses of coal seams belonging to the Westphalian D and C, which have been penetrated by the boreholes in the coalfield under study :

Formation	*Name of seam*	*Probable reserve*[6] *(tons)*
Westphalian D	Upper Kurudere	2,900,000
Westphalian C	Tavan	900,000
Westphalian C	Kalın	7,650,000
Westphalian C	Ara	9,900,000
Westphalian C	Taşlı	20,900,000
	Total	**42,250,000**

The 0.5 meters isopachous for each coal seam has been taken as its reserve limit. Goal seams in the NW, within the area beyond the fault known as Mezarlik Doğusu Basamağı, have not been taken into account, because of the greatly faulted and locally exploited nature of this area. The northwestern reserve limit for the Westphalian C coal seams is the Westphalian C formation boundary as shown in the Plate VI.

The maximum depth, within which the reserves of the coal seams have been considered, is — 600 meters.

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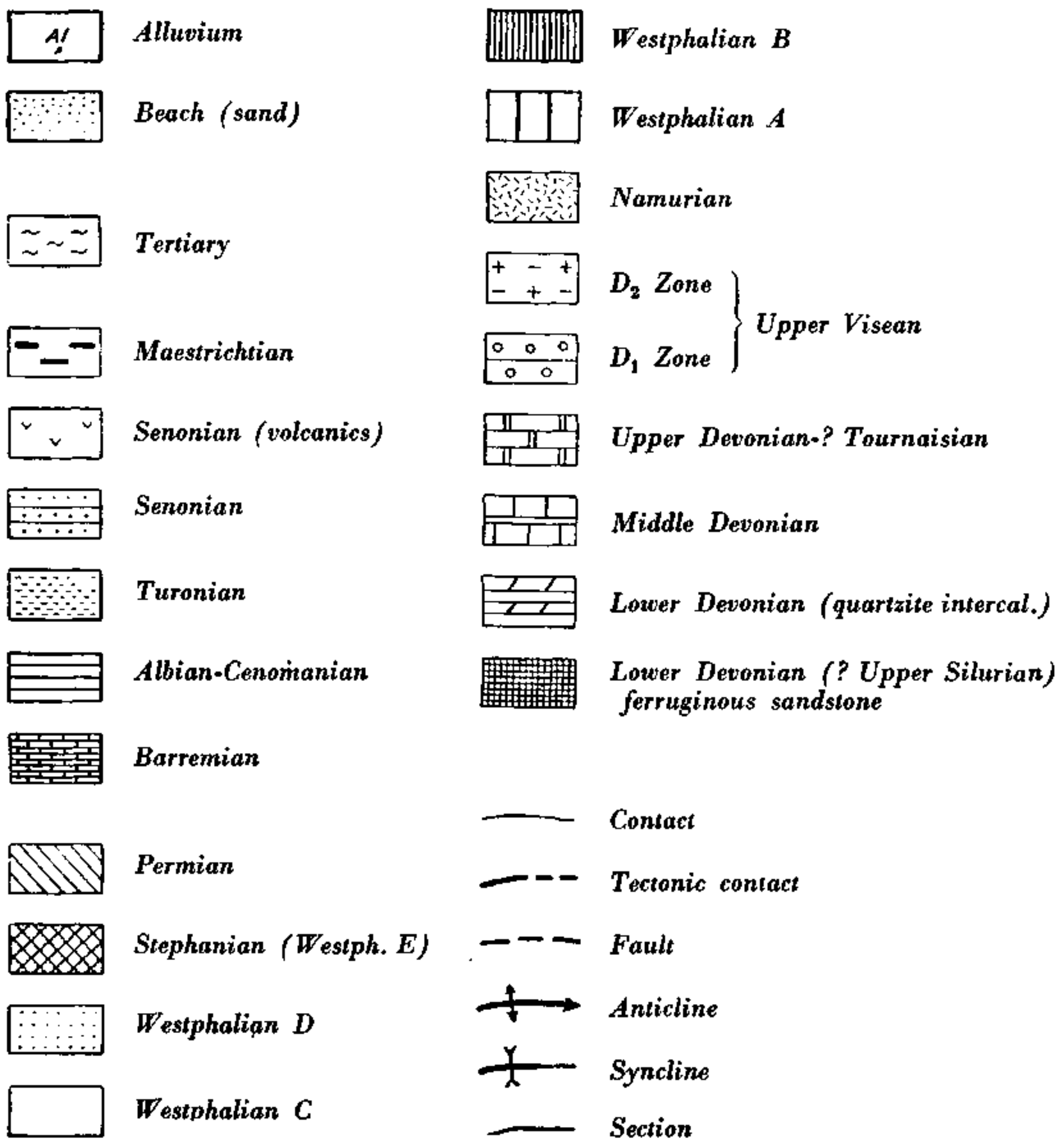
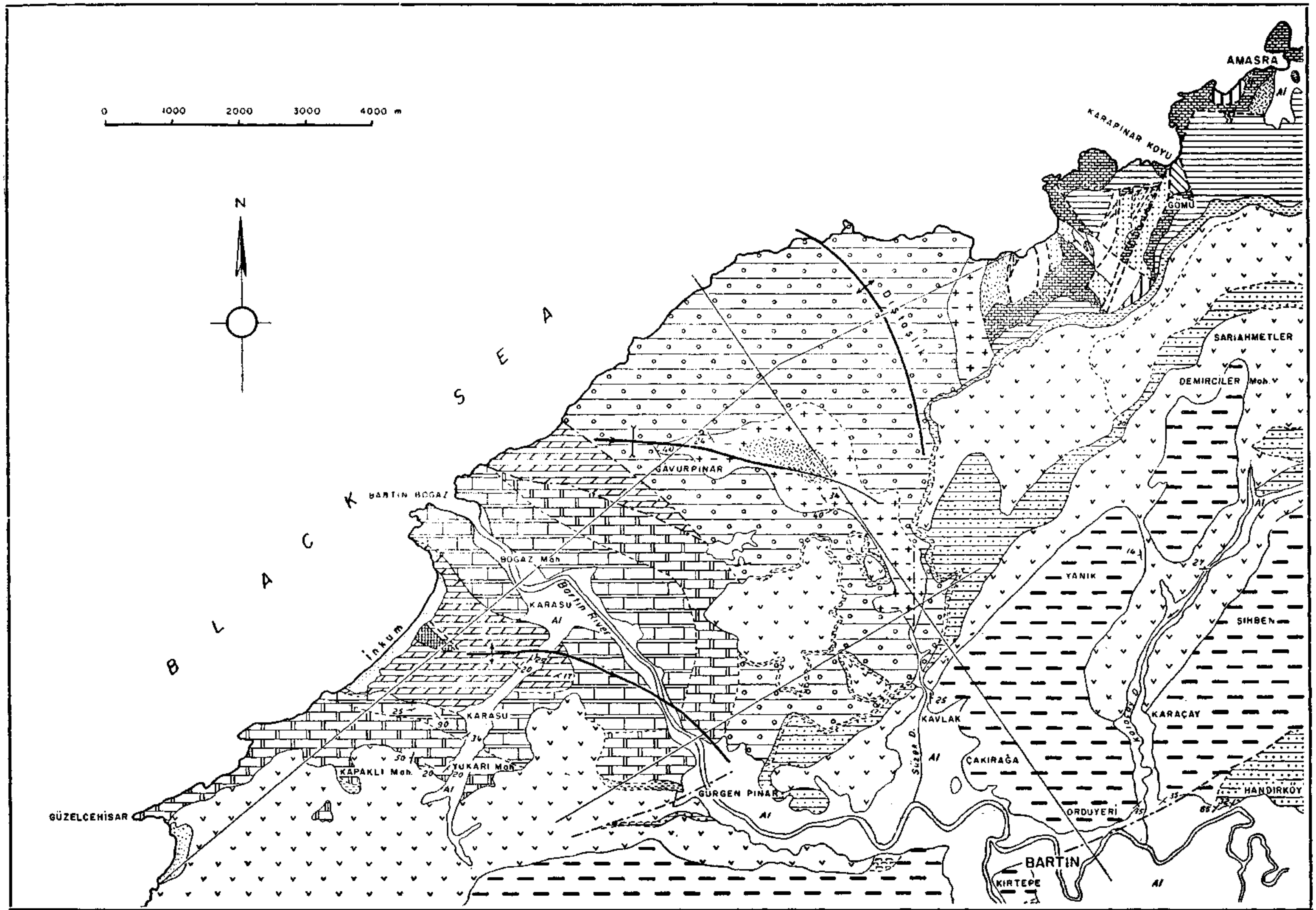
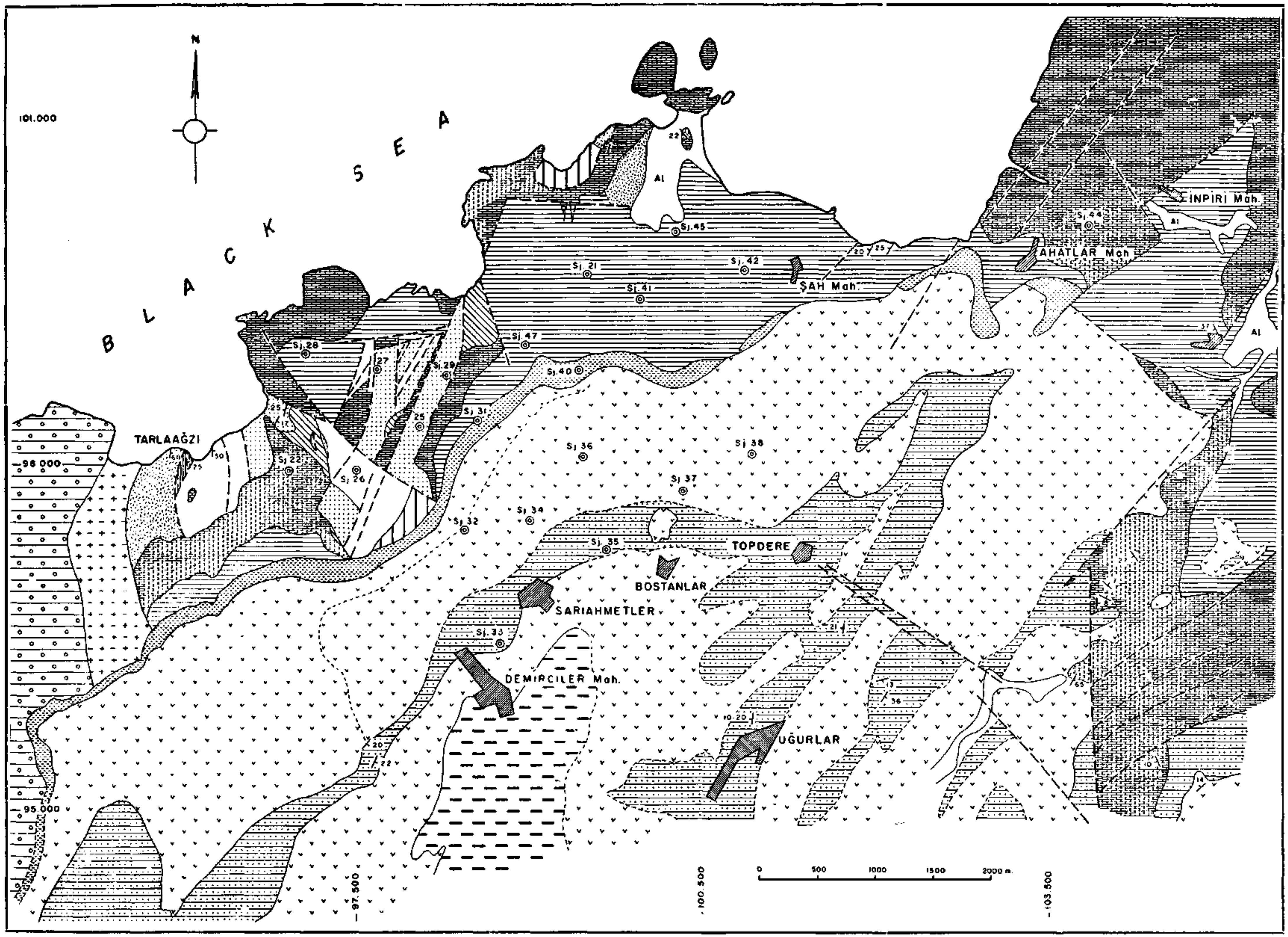
LEGEND FOR MAPS AND SECTIONS





GEOLOGICAL MAP OF İNKUM-AMASRA AREA



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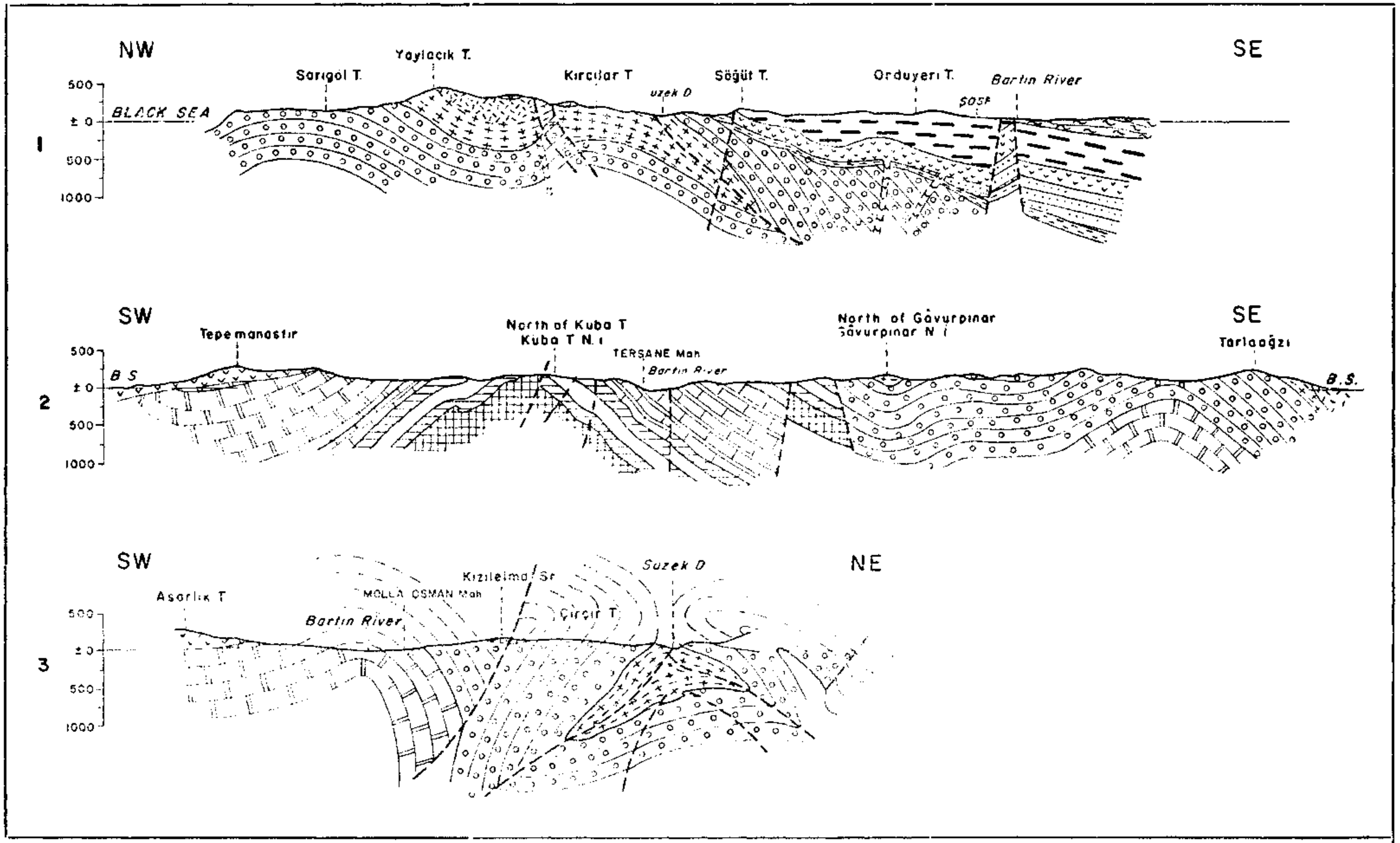
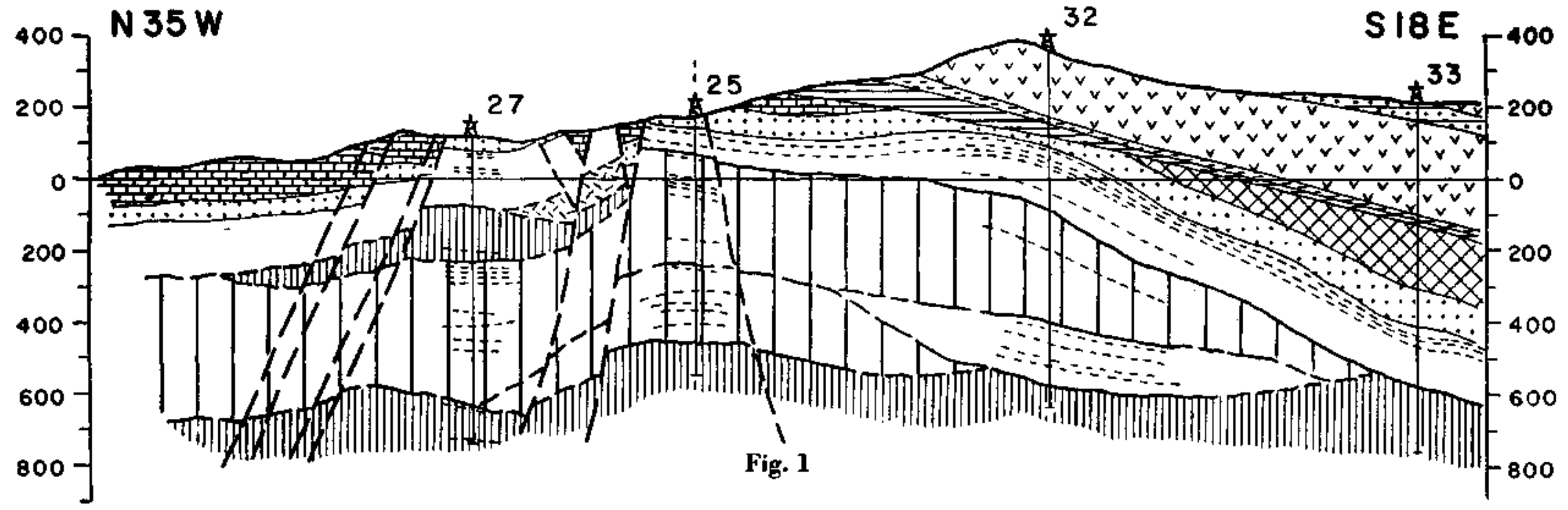


SECTIONS OF PLATE I



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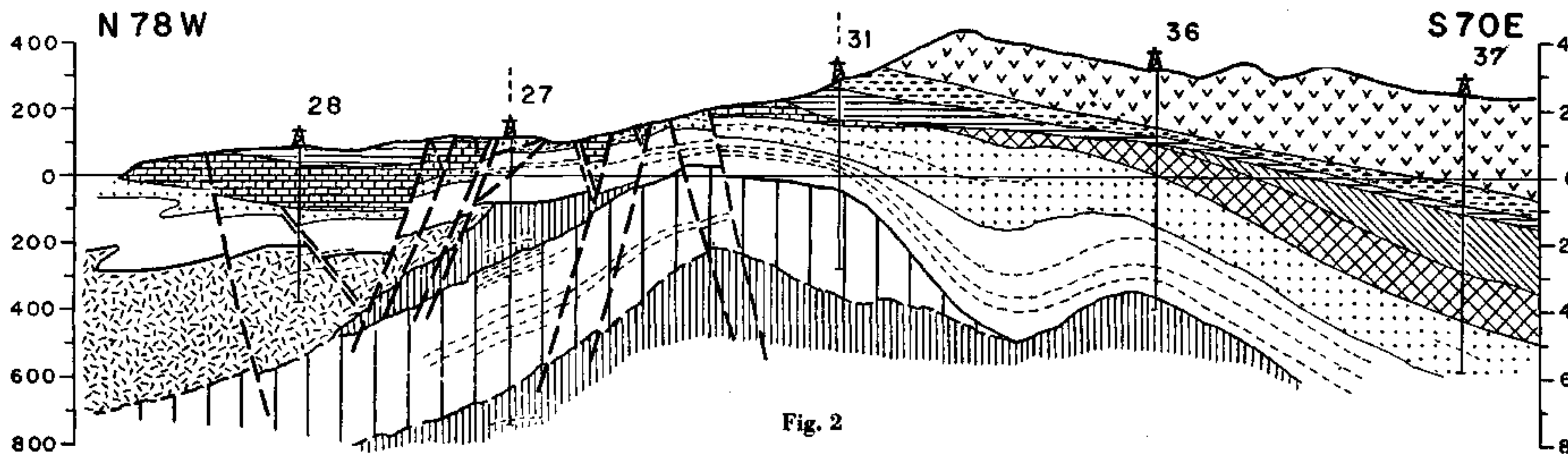

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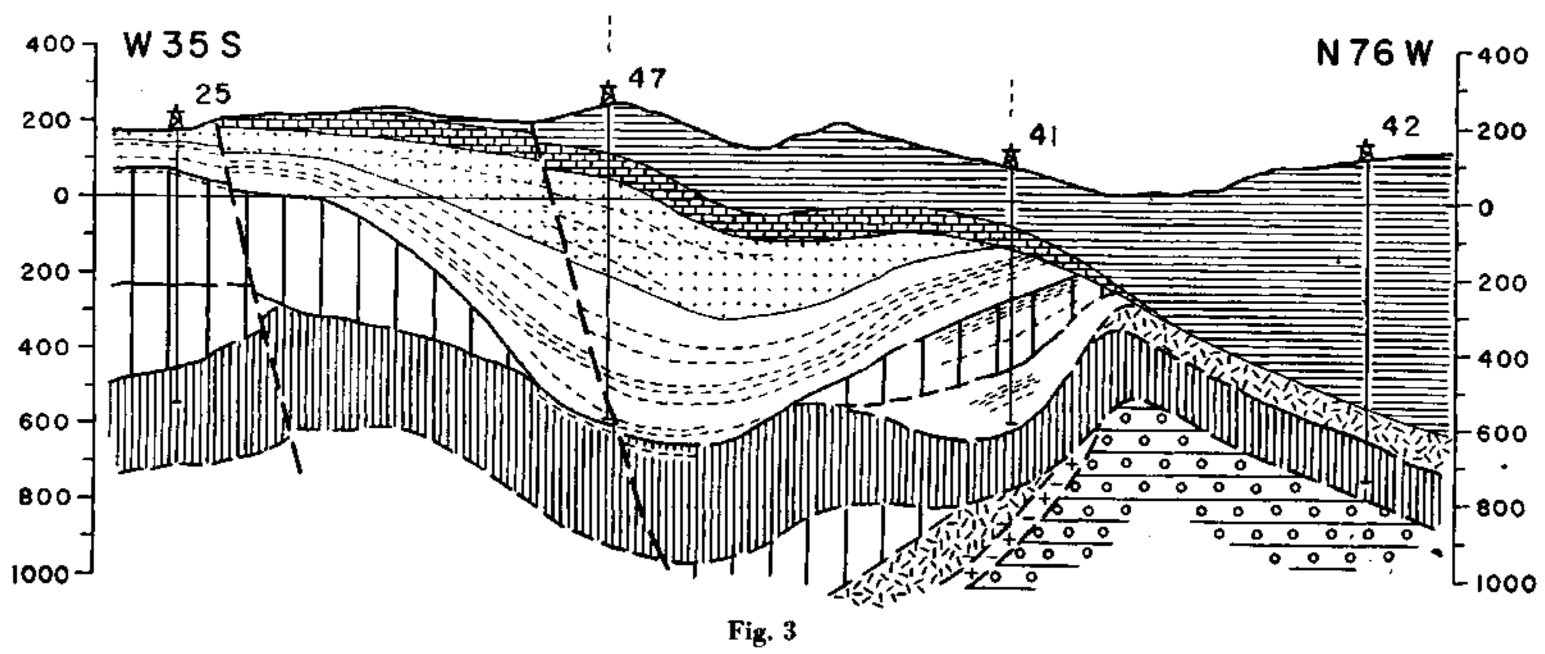
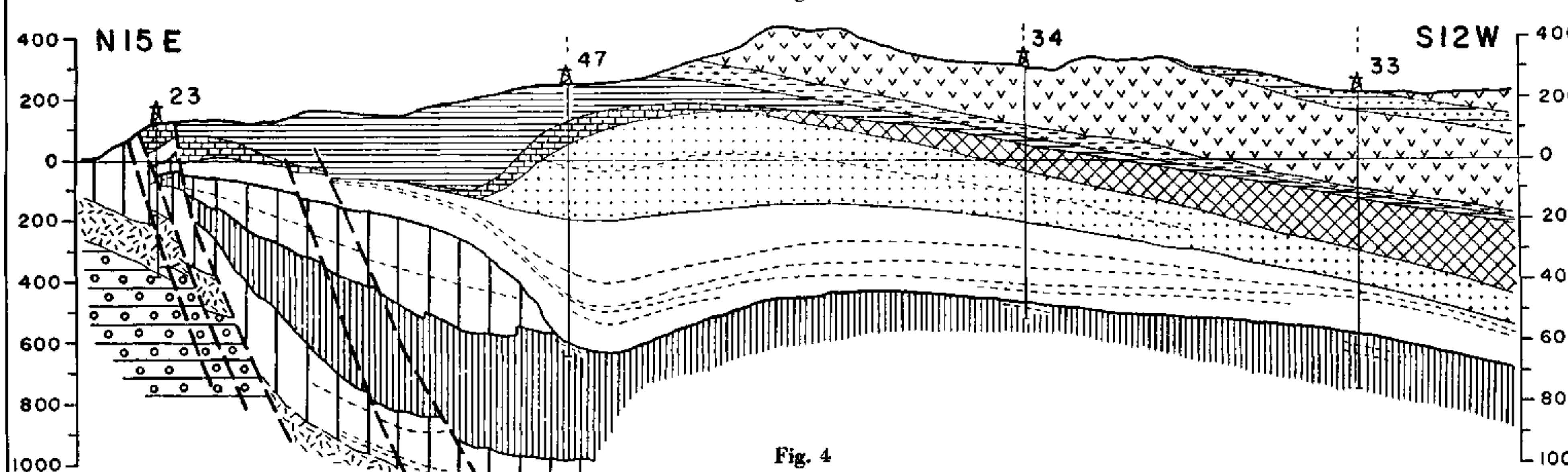


Fig. 3



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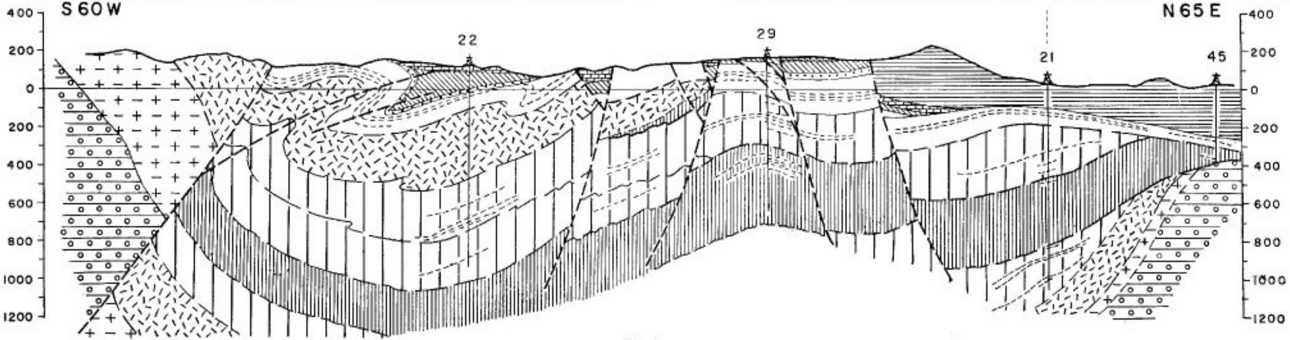
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Fig. 1

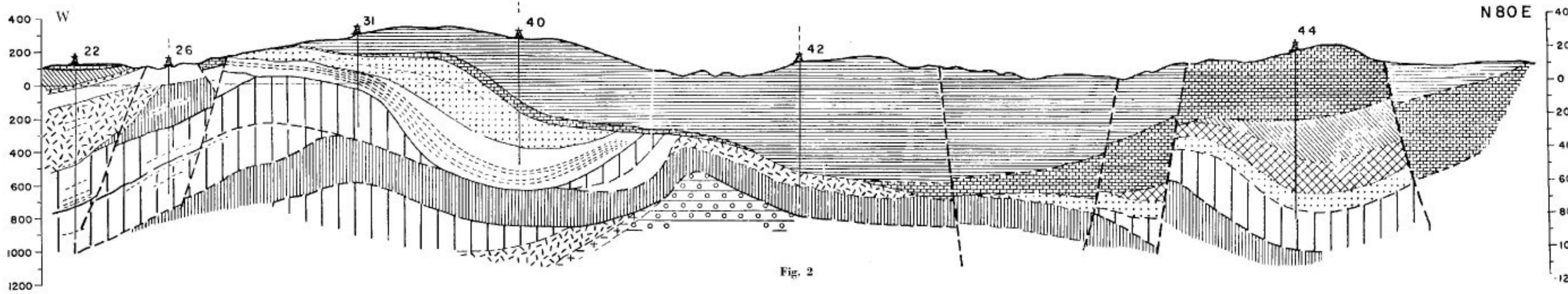
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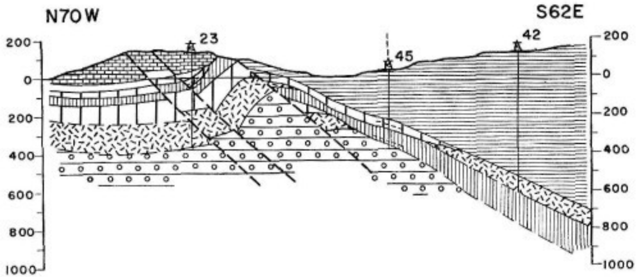
Fig. 2



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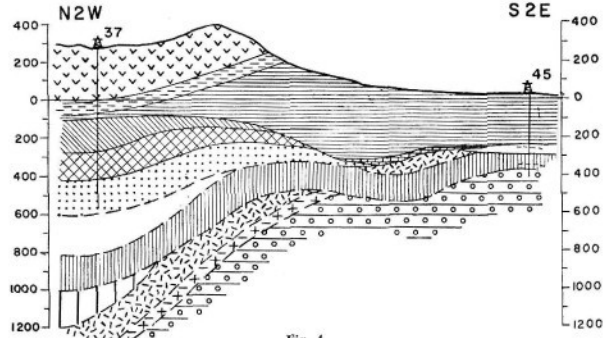

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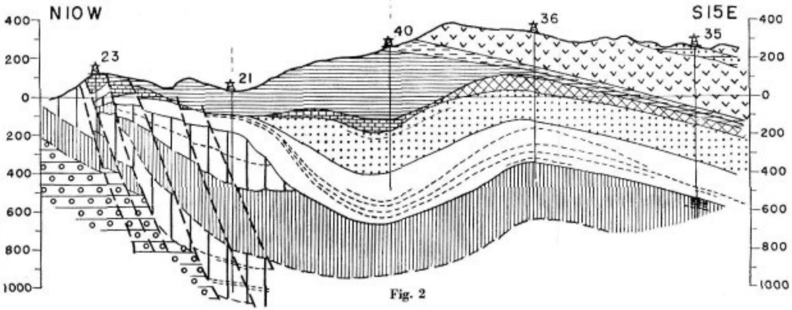

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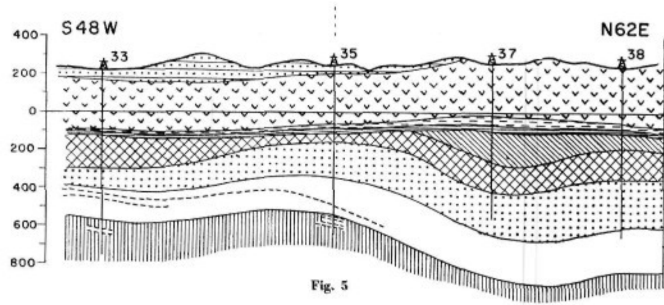


Fig. 5

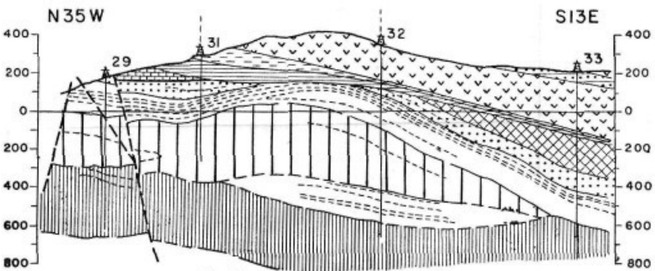


Fig. 3

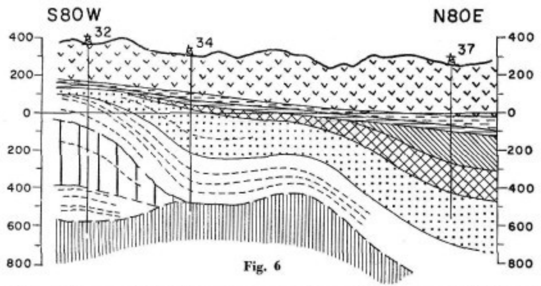


Fig. 6

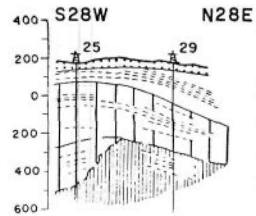
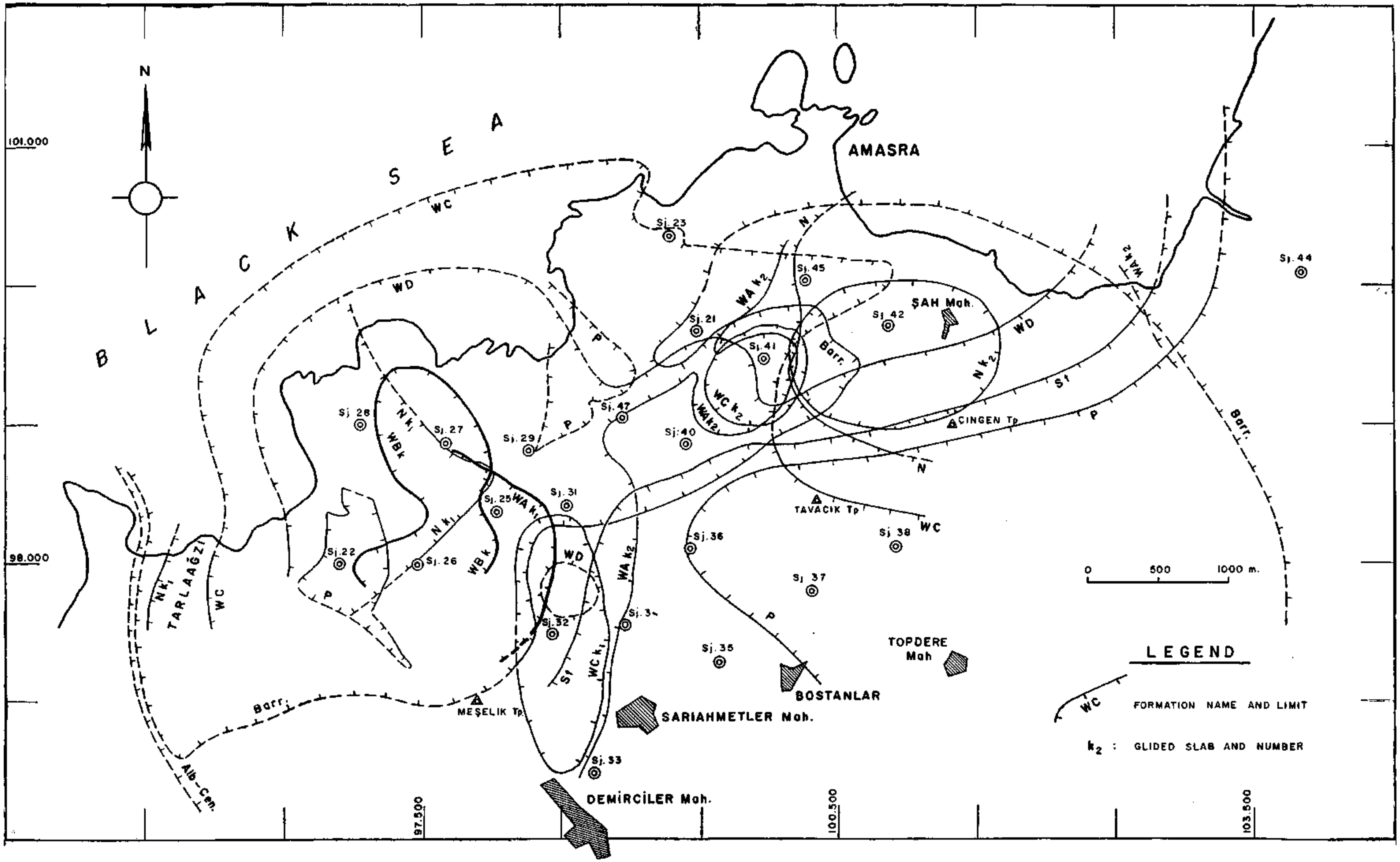
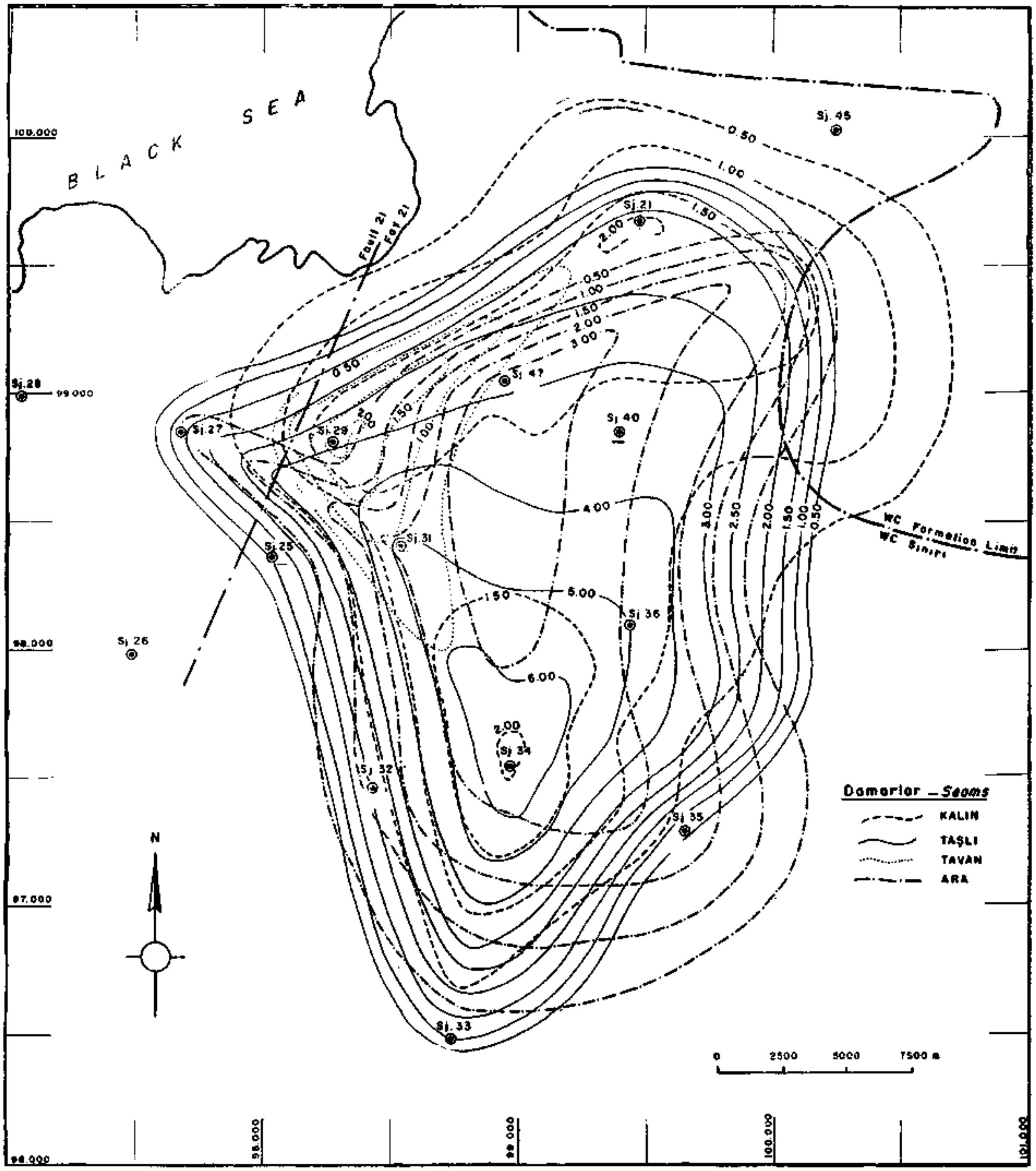


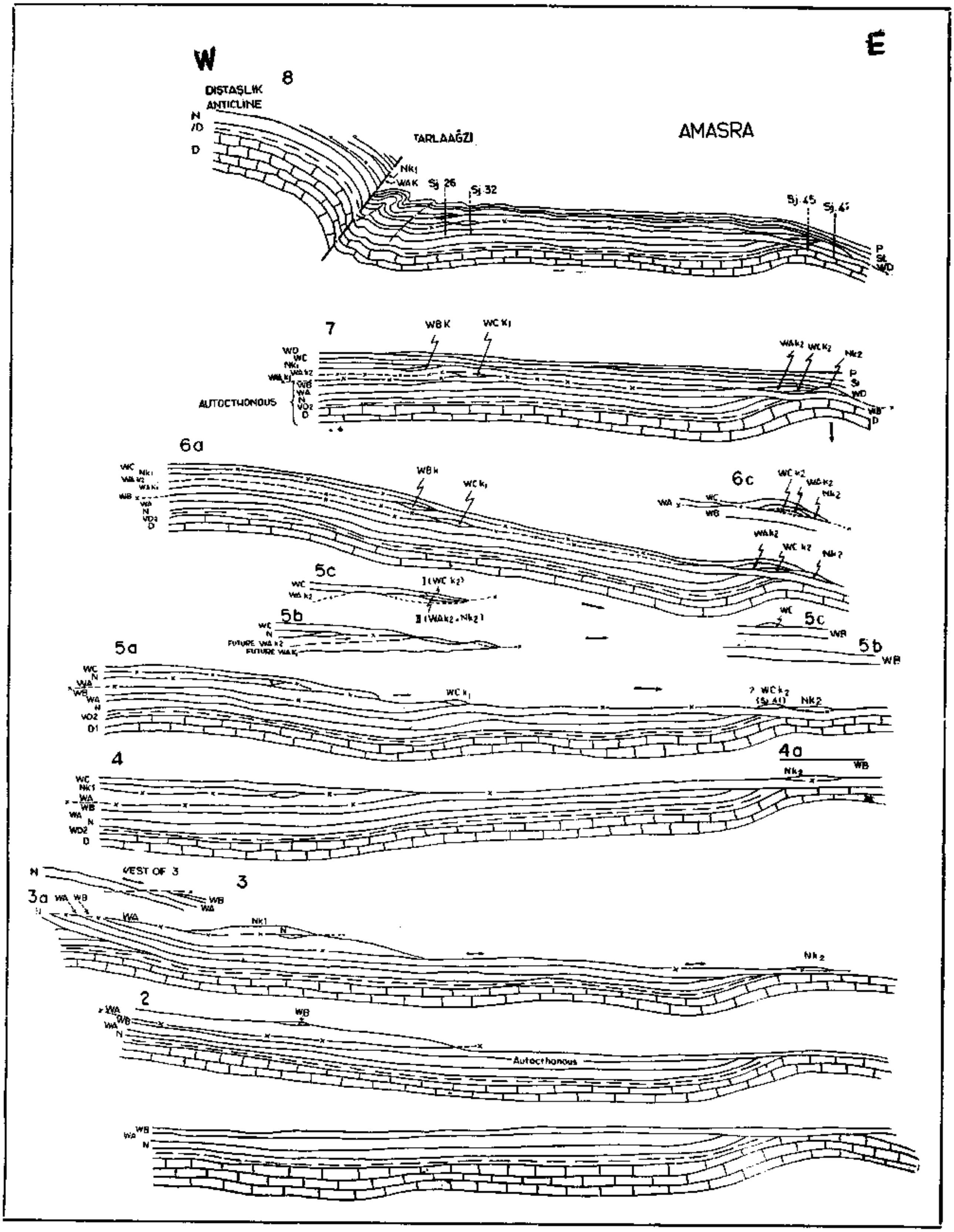
Fig. 7



MAP SHOWING THE BOUNDARIES OF SOME FORMATIONS AND THE POSITION OF THE GLIDED SLABS



ISOPACHOUS MAP OF FOUR COAL SEAMS



SKETCH SHOWING THE TECTONIC DEVELOPMENT OF THE UPPER CARBONIFEROUS IN AMASRA