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GEOLOGY OF THE KONAKPINAR--SARICA AREA, SİVAS PROVINCE, TURKEY

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ABSTRACT

The junction of several major structures and stratigraphic sequences is in the Konakpinar-Sarica area of central Turkey. Most of the area is underlain by Upper Jurassic to Cretaceous limestone and siltstone, early Tertiary sedimentary rock, and remnants of younger volcanic rocks and lacustrine deposits. The northeastern part of the area, however, is formed of serpentinite, of possible Cretaceous age, unconformably overlain by Upper Cretaceous conglomerate and siltstone that crop out extensively east of the area.

The regional structure changes direction in the area. Folds and faults change across a northerly striking hinge line from northeast trends on the west to northwest trends on the east. A north-trending regional fault zone is a little east of the hinge line. The northern part of this fault zone and a northwest-striking fault, a possible thrust, east of it form the boundary between the two stratigraphic provinces. The area northeast of this boundary is cut by a series of vertical northwest-trending faults that are downdropped on the southwest. A large northeast-trending fault that is part of a broad fault zone that extends from the Mediterranean Sea northeastward to Divriği is in the northwest corner of the area. Some thrust faults cut the Cretaceous rocks in the western part of the area; the Upper Jurassic limestone may be allochthonous.

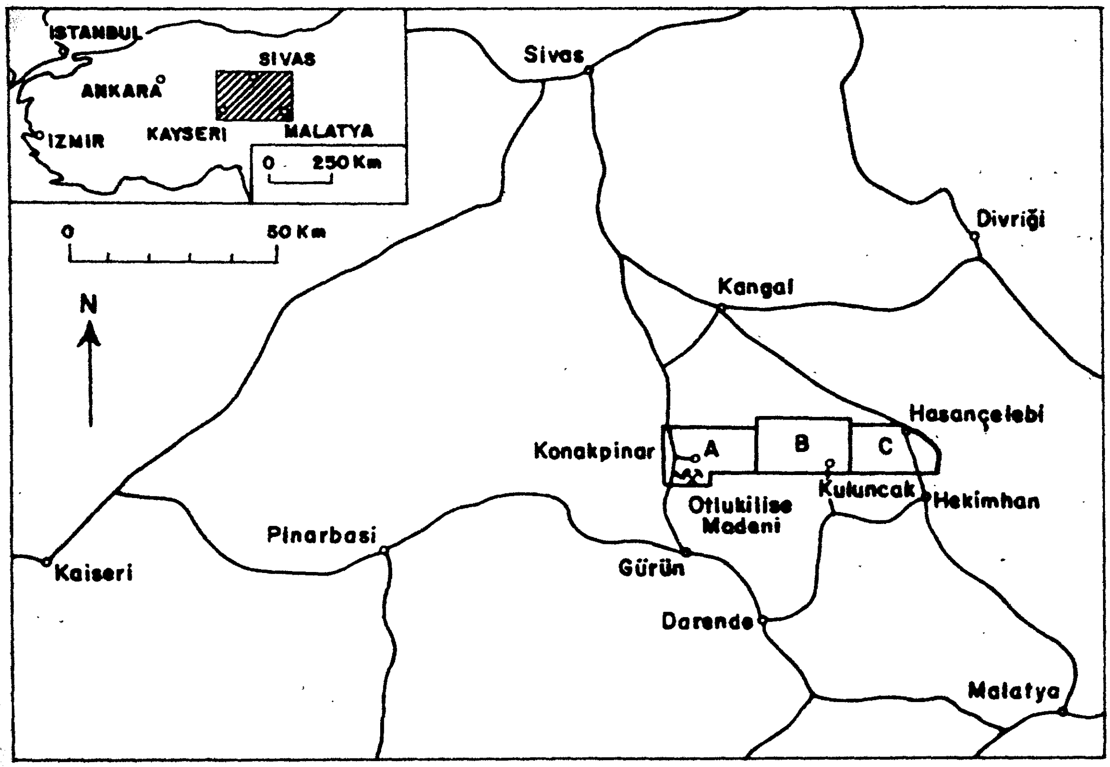
The only economic deposit known in the area is at the Otlukilise Iron Mine where iron is present in a sedimentary filling of sinkholes and as secondary replacement deposits in limestone at their borders. Minor deposits of chrome, copper, and coal also occur in the area.

INTRODUCTION

The Konakpinar-Sarica area covers most of the Elbistan K38-b1 and b2 and the northern part of the b4, 1:25,000-scale quadrangles in Sivas Province, central Turkey(fig. 1). It is 20 km north of Gürün on the Gürün-Sivas road which crosses the western part of the area. The area is moderately rolling to hilly, contains a few mountains, and is crossed in the northeast by the Tohma River canyon. The country is barren and the rocks are moderately to well exposed.

The investigation of the Konakpinar-Sarica area represents part of a general study of the geology and mineral resources bewteen the Otlukilise Iron Mine and Hasançelebi(fig. 1). This study was undertaken as part of a cooperative program of mineral resource appraisal and training by the Maden Tetkik ve Arama Enstitüsü(MTA) and the U. S. Geological Survey(USGS) sponsored by the Government of Turkey and the Agency for International Development, U. S. Department of State. The field investigation was carried out between May and September 1969. The geologic map of the K38-b2 quadrangle represents the combined efforts of all the authors; that of the K38-b1 and b4 quadrangles was done by Barosh.

SEKIL I
Figure- I



Endeks haritasi, Konakpinar-Sarica sahasinin lokasyonunu, (A) ve Leo ve arkadaşlari (1971) (B) ve Jacobson ve diğerleri (1970) (C) tarafindan etüd edilen sahalari gosterir

Index map showing location of the Konakpinar-Sarica area (A) and areas investigated by Leo and others (1971) (B) and Jacobson and others (1970) (C)

Three general reconnaissance maps of the region have been made by MTA: the 1:500,000-scale Sivas sheet of the geological map of Turkey, 1961; and unpublished map at 1:100,000-scale of the Malatya-Gürün Basin by the Petroleum Section, 1968; and an unpublished and untitled map at 1:100,000-scale of the same area by the Geologic Section, 1964. The latter was compiled from 1:25,000-scale reconnaissance maps of which the maps by Dr. Fikret Kurtman(1963) and Tamer Ayan(1969) cover the Konakpinar-Sarica area. The Otlukilise iron mine, which is in the southwest part of the area has been discussed previously in unpublished MTA reports. It was mapped in detail during the course of this study and is described separately (Barosh, 1972b).

GENERAL GEOLOGY

The Konakpinar-Sarica area is situated at the junction of several major structural and stratigraphic elements of central Turkey. The area is formed of two lithologically distinct provinces. In the western and southeastern three quarters of the area massive Upper Jurassic and Cretaceous limestone is the dominant rock type, whereas in the northeast part of the area a serpentinite basement complex overlain by Upper Cretaceous conglomerate and siltstone is dominant.

The regional structure changes direction within the area about a northerly striking hinge line. The general structural trend of faults and fold axes west of this hinge line is to the northeast, whereas east of it the trend is to the northwest(fig. 2). Farther east, outside the mapped area, the trend gradually changes through west-northwest to west (Leo and others, in press; Jacobson and others, 1972). Three major faults

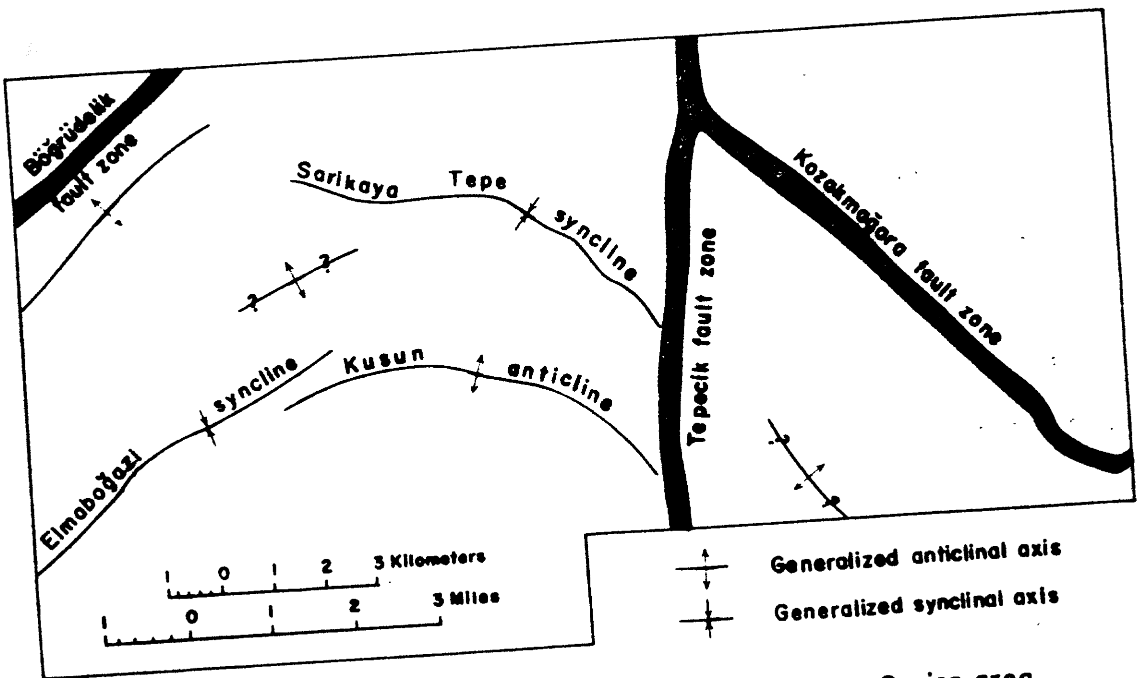


Figure 2.- Major faults and folds of the Konakpinar-Sarica area

converge in the area(fig. 2). A northeast-trending fault that cuts the northwest corner of the area is part of a zone of faulting which extends from the Mediterranean northeastward to Divriği. A northerly trending fault that is a little east of the hinge line passes through or alongside several volcanic centers south of the area. A northwest-trending fault in the eastern part of the area bounds the southwest side of the serpentinite complex.

STRATIGRAPHY

The Konakpinar-Sarica area is formed of two lithologically distinct provinces whose relations are not entirely clear. The western and southeastern three quarters of the area is composed of massive Upper Jurassic and Cretaceous limestone overlain by Upper Cretaceous siltstone and limestone, lower Tertiary marl, siltstone, sandstone, limestone, and conglomerate, and scattered outcrops of younger volcanic and lacustrine rocks(fig. 3). These rocks progressively change upward from marine to continental deposits. The northeast part of the area is underlain by serpentinite and mafic intrusive rocks of Cretaceous(?) age unconformably overlain by Upper Cretaceous conglomerates and siltstones which are cut by trachyte sills(figs. 3 and 4).

Many parts of the stratigraphic column are missing or poorly understood owing to complex structure, poor exposures, or recrystallization; hence, the relationships of several units are only tentative. No special stratigraphic study was undertaken in the region. However, a regional stratigraphic study is necessary to fully understand the area.

Jurassic-Cretaceous

Massive limestone

Hills of massive limestone are very conspicuous in the western two thirds of the area. The limestone is well jointed, slightly dolomitic, light gray, and weathers about the same color. It is generally a fine-grained recrystallized rock which commonly appears to be very fine grained on fresh fractures. Coarser grained bioclastic limestone is present at the top of the unit. The limestone is massive and the only bedding seen is at the top, except for a bedded sequence at Baltaci Sirti on the west edge of the map. A sequence of light- to medium-brownish-gray lithographic limestone at Baltaci Sirti forms beds averaging about 50 cm in thickness. This distinctive sequence appears to grade north, south, and east into massive light-gray limestone.

Bedded limestone at the top of the formation forms a sequence gradational into the overlying siltstone of Kuz. This bedded portion is only about 10 meters thick in the central part of the area, but is considerably thicker west of the Gürün-Sivas road where it is widely exposed in a series of faulted dip slopes and folds. The lowest bed west of the road is 3 or 4 meters thick and the overlying ones are 40 to 200 cm thick. East of the road the bedded limestone generally appears to grade downward into massive limestone. The bedded sequence is composed of light-gray bioclastic limestone at most places; however, west of the Gürün-Sivas road some light-gray and light-pinkish-gray lithographic limestone and pinkish marly limestone is present. An obscured unconformity may underlie the bedded sequence.

The upper contact of the massive limestone unit is placed at the base of the first siltstone bed. This is easy to map where the exposures are good, but it can be difficult elsewhere. Small isolated outcrops of limestone near the contact are not readily identifiable; the cluster of outcrops north and northeast of Akpinar labeled siltstone of Kuz, could be the uppermost beds of the massive limestone.

The limestone is generally very well exposed and forms smoothly rounded hills commonly pockmarked along their higher parts by sinkholes. The outcrops are grooved and fluted by solution and locally contain small solution cavities. The limestone gives the impression of having been weathered by solution beneath a scil cover.

All the massive light-gray recrystallized limestone is assigned to this formation, except that in the limestone of Çakşan Tepe and the bedded limestone sequence on Sarikaya Tepe. Many of the isolated outcrops included with the massive limestone, particularly in the east, might very well belong to lithologically similar, but different stratigraphic units. The massive limestone may be the product of recrystallization of various limestone units and not represent a single stratigraphic unit. A thorough study of the stratigraphy of this region is needed to unravel this problem. The massive limestone was included in both the Etyemez Daği Limestone and the limestone member of the Hekimhan Formation by Ayan (1969).

The base of the formation is not exposed and the lack of bedding prevents working out the minimum thickness; however a minimum thickness of 500 meters for the broad exposures in the northwest is probably not excessive.

No fossils were found in the massive limestone except fragments in the bioclastic limestone at the top. Ayan (1969, p. 12-13), however, collected the following microfossils from the massive limestone west and south of Aşaği Çatkara (fig. 3):

Protopeneroplis striata Weyhs

Pseudocyclamina sp.

Clypeina jurassica Favre

Valvulinirae

Textularidae

Ophthalmididae

Trocholina sp.

Ventrolammina sp.

Lituolidae

Miliolidae

These indicate a Late Jurassic-Early Cretaceous age. These fossils and the Maestrichtian fossils at the base of the overlying formation suggest that the massive limestone could range from Late Jurassic to Late Cretaceous in age.

Cretaceous(?)

Limestone of Çakşan Tepe

The limestone of Çakşan Tepe crops out in the southeast corner of the area, notably northeast of Eskihamal, where it is exposed in a narrow canyon, and at the summit of Çakşan Tepe (fig. 3). The limestone is fine-grained, light to medium gray, and weathers the same or lighter gray. It appears massive from a distance, but close inspection reveals beds between 20 and 50 cm in the narrow canyon and thinner beds southwest of Diksakal Tepe and just east of the extreme southeast corner of the area. The beds near Diksakal Tepe contain a few light-gray chert lenses and locally have a petroliferous odor.

The limestone of Çakşan Tepe is distinguished from the massive limestone by the presence of bedding and slightly darker gray colors. However, as the massive character of the limestone may be due to alteration, the limestone of Çakşan Tepe may be merely an unaltered equivalent to some part of the massive limestone. The limestone of Çakşan Tepe appears to grade upward into light-gray massive limestone similar to the massive limestone unit, and much of the limestone exposed east of Eskihamal appears massive. Massive limestone, which crops out between Çakşan Tepe and Kozakmağara, has been included with the limestone of Çakşan Tepe, as the massive limestone grades from the bedded limestone and appears to be part of the same structural block.

A thin unit of light to medium-red-brown or red slightly calcareous chert is east of Çakşan Tepe and southwest of Diksakal Tepe along the basal contact over the variant of the Tökler Formation. The contact appears normal at these locations, but elsewhere it is faulted or is poorly exposed and the entire contact is probably faulted. No upper contact is exposed.

No fossils were found in the limestone of Çakşan Tepe, but similar limestone just east of the extreme southeast corner of the area contained rudistid fragments (G. W. Lee, personal commun., 1970). This indicates a Cretaceous, probably Maestrichtian, age for the rocks.

Cretaceous

Siltstone of Kuz

The poorly exposed siltstone of Kuz underlies almost all of the low-lying areas in the western part of the mapped area. The edge of the formation is the edge of a valley in many places. The formation is composed of interbedded siltstone, clastic limestone, marl, and minor sandstone and claystone. The unit has been informally named after the hamlet of Kuz which is located on the formation a little east of some of its best exposures. This unit corresponds to Ayan's (1969) marl member of the Hekimhan Formation.

Siltstone is medium to dark greenish gray and is the dominant lithologic type in the formation. The clastic limestone is light gray to light yellowish gray and weathers about the same. It is composed of angular to subangular fragments of limestone, calcite, and fossils with 2 to 10 percent of subangular to rounded varicolored chert grains. The limestone beds are moderately to well sorted and range in grain size from granule to medium-grained sandstone. The chert grains are generally smaller than the carbonate fragments. A few of the finer-grained beds are faintly laminated and many of the coarser-grained beds are graded. A few beds of slightly brownish, medium-gray, very fine grained limestone which weathers the same or lighter are present. The marl and marly limestone are massive, very light gray, and generally highly fractured. The claystone ranges from dark greenish gray through light gray and buff to reddish brown and pink. The few sandstone beds seen are medium gray and are composed of medium-grained subangular varicolored grains of chert, quartz, calcite, and mafic minerals.

The lower half of the formation consists of beds of clastic limestone 10 cm to 2 meters thick and some marl beds separated by 1 to 40 meters of siltstone. The upper part of the formation is composed of siltstone and claystone with minor sandstone and limestone.

The uppermost beds of siltstone and claystone are very light to medium gray or light buff along the eastern edge of the K38-b1 quadrangle and pink to red brown farther west. These uppermost beds underlie the extensive areas of pinkish soil south of Konakpinar. The beds in the upper part are very thin in places, but some of the siltstone and claystone beds near the top are over 3 meters thick.

A peculiar fossiliferous, silty to marly limestone bed appears to cap the formation, but it may be the basal bed of the limestone conglomerate unit. It is red brown with light-gray mottling, generally highly fractured and 1 to 1.5 metersthick. This bed contains a very abundant fauna consisting of one type of turbanate gastropod and an olive-shaped fossil that could be a sponge. This bed is exposed northwest of Karadoruk, southwest of Boztaş, 1 km east of Boztaş, on the south slope of Sari Tepe, and across the valley southwest of it.

The siltstone of Kuz appears to be conformably overlain by the bedded limestone unit northwest at Yukari Çatkara, although the attitude of the siltstone near the contact is not known. The contact southeast of Yukari Çatkara is faulted.

The formation is poorly exposed and extremely contorted, so that only a general estimate of thickness can be made. The thickness is estimated to be 300 to 500 meters.

Limestone near the base of the formation south of Kuz contained microfossils identified by M. Serdaroğlu, MTA, as:

Orbitoides media d'Archiac

Siderolites vidali Douville

Dicyclina schlumbergeri Mun.-Chal.

Globigerina sp.

These fossils along with the Maestrichtian age of the overlying rocks demonstrate a Maestrichtian age for the entire formation.

Bedded limestone

The bedded limestone forms a synclinal body extending southeastward from Eskibektaşli to Sincan Tepe. The unit is composed of generally well bedded, light yellowish brown to light-gray limestone, which weathers about the same, and some interbeds of silty limestone. The lower 15 meters north of Gürle Tepe are composed of medium-grained limestone in beds 10 to 30 cm thick, which contains some bioclastic material and minor dark chert grains, and a few reddish-weathering silty limestone beds about 10 cm thick. Above this the beds are 20 cm to 2 meters thick and the silty limestone weathers pinkish, buff, or very light gray. This part of the section tends to form a bluff. Upward in the section the beds thicken and lose their brownish color, and the uppermost exposures along the ridge top near Sari Kaya Tepe resemble the massive limestone.

A distinct, thin, fossiliferous, light brownish gray, clastic limestone unit which weathers light tan is exposed at the base of the bedded limestone east of Yukari Çatkara in a narrow band along the southwest flank of Sincan Tepe. The limestone is composed of well sorted, medium-grained, sand-size angular to subangular grains of limestone, calcite, and a few fossil fragments plus 2 to 8 percent of smaller varicolored chert(?) grains. It is well bedded in beds ranging from 20 cm to 1 meter in thickness. This limestone is very similar to some of the beds in the lower part of the siltstone of Kuz. Its contacts appear to be faulted at many places and its limited extent may be due to being cut out by near-bedding plane faults that developed during folding.

The bedded limestone along with much of the nearby massive limestone was designated the limestone member of the Hekimhan Formation by Ayan (1969).

The formation overlies the siltstone of Kuz with a contact that is faulted in places. South of Eskibektaşli it is overlain by a pebble limestone unit along a contact which probably is a thrust fault, although the exposures are very poor. The bedded limestone is estimated to have a minimum thickness of about 150 meters at the center of the syncline on the northwest side of the Sarikaya Dere Canyon.

The lower half of the unit contains rudistid fragments, large echinoids, corals, pelecypod casts, and rare ammonites.

The following fossils were identified by Atinç Atillâ, Necdet Karacabey, Yüsel Sezginman, and C. Öztemür of MTA, and Ralph Imlay, USGS:

<u>Orbitoides media</u> (d'Archiac)

<u>Siderolites</u> sp.

<u>Pseudotextularia</u> sp.

<u>Globigerina</u> sp.

<u>Campanile inauguratum</u> Stol.

<u>Hippuritella</u> sp.

<u>Jonfia</u> sp.

<u>Durania</u> sp.

<u>Phylloceras</u>?

<u>Echinocorys</u> sp.

<u>Shizaster</u> sp.

<u>Echinolampas</u> cf <u>leymeriei</u> Cotteau

<u>Neithea</u> sp.

Lamellibranch indet.

The rudistids in this collection indicate a Maestrichtian age for the unit.

Pebbly limestone

Pebbly limestone crops out on three hill tops: Kale Tepe northeast of Boztaş, Yildirim Tepe and Kücük Yildirim Tepe west and southwest, respectively, from Eskibektaşli.

The formation is made up of two members. The lower, thinner, member consists of brownish-gray clastic limestone composed of well sorted, fine to medium sand-sized grains. It is well bedded in 20- to 40-cm thick beds. The upper member consists of light-gray, pebbly limestone which weathers light tan to pinkish. The limestone consists of slightly recrystallized sand to granule size bioclastic grains with very few angular to subangular silicic grains. Numerous subrounded to rounded, light- to dark-gray or brown pebbles of chert, silicic rock, and a few pieces of orange, limy siltstone are scattered through the limestone. The beds are 1 to 3 meters thick and generally form a low bluff.

The beds dip into the basal contact at all three localities and the formation is broken up locally. The formation thus appears to rest on a thrust fault above the siltstone of Kuz and the bedded limestone; neither base nor top is exposed. This formation may be as much as 50 meters thick on Yildirim Tepe.

The lower member contains a few rudistid-like fragments and the upper member contains a few small gastropods and many large Foraminifera. Fossils collected from this unit were identified by Zeki Dağer and Necdet Karacabey, MTA, as:

Loftusia morgani Douville

Loftusia sp.

Siderolites cf. *calsitropoides* Lamark

Omphalocyclus macroporus (Lamark)

Orbitoides sp.

Lepidorbitoides sp.

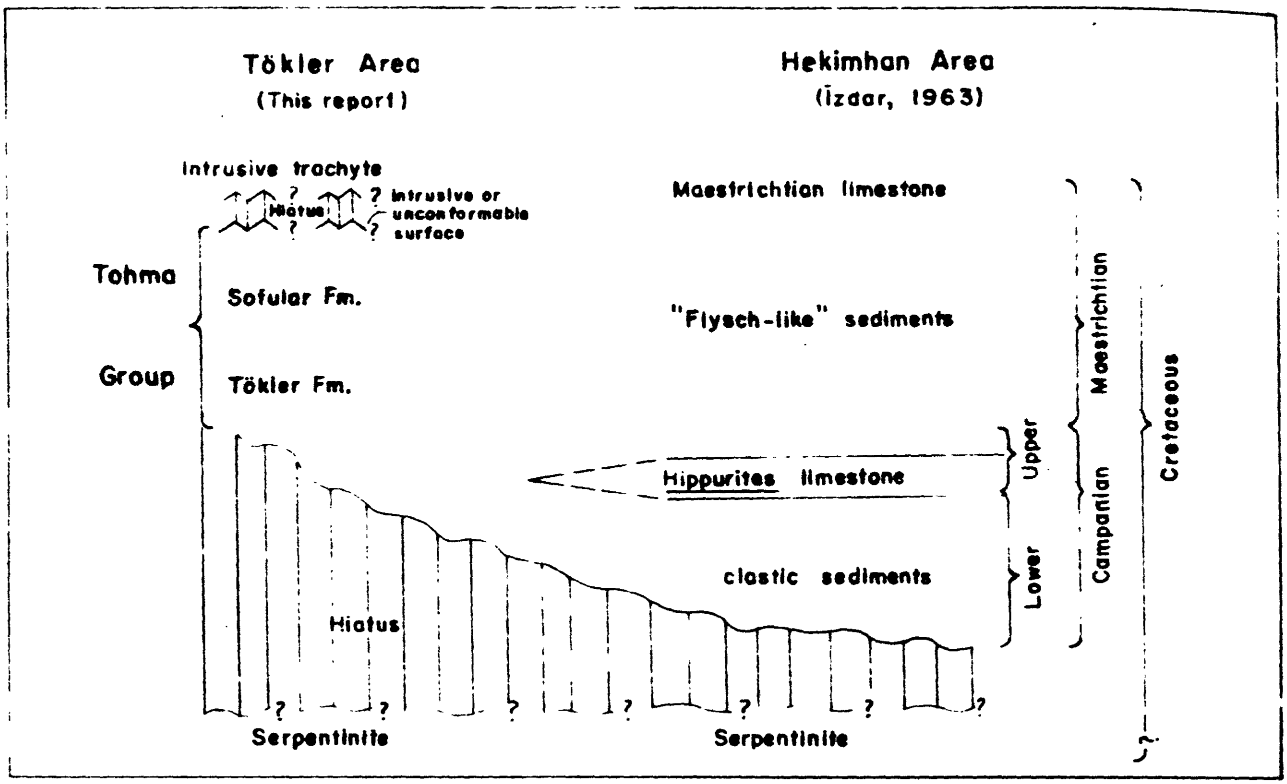
Durania sp.

These fossils indicate that the pebbly limestone is Maestrichtian.

Tohma Group

The Tohma Group consists of a thick Upper Cretaceous clastic sequence that unconformably overlies the serpentinite. It ranges from boulder conglomerate to claystone and includes a few limestone beds, commonly formed of rudistids. The lower, coarser part of the sequence is herein designated the Tokler Formation and the upper, finer part, the Sofular Formation. These rocks were described by Ayan(1969) as the conglomeratic part of the Hekimhan Formation. The upper contact is covered; where exposed, the upper part is in contact with a trachyte intrusive; however, farther east Maestrichtian limestone overlies the group(Izdar, 1963, p. 11). The group is named herein after the Tohma River which flows across the main area of exposure.

The Tohma Group crops out in a belt which extends east-southeastward from the area to at least as far as Hekimhan. The sequence forming the group in the area apparently corresponds in lithology and age to the "flysch-like" sediments of İzdar (1963, p. 10-11) near Hekimhan, but the older rocks which he describes as tonguing in between the "flysch-like" sediments and the serpentinite near Hekimhan should also be included, as they are part of the same clastic transgressive sequence (fig. 5).



Sekil 5 .– Tökler'e ait Tohma grubu ile Hekimhan sahasi arasindaki ilgiyi gösteren tecrübi korölasyon diagrami

Figure 5.– Tentative correlation diagram showing relations between the Tohma Group of the Tökler and Hekimhan areas

The Tohma Group then can be defined as comprising the sequence of Upper Cretaceous clastic rocks and intercalated rudistid limestone unconformably overlying the serpentinite and underlying the Maestrichtian limestone. The group ranges from nearly 3,000 meters in the Konakpinar-Sarica area to 700 to 800 meters thick near Hekimhan (İzdar, 1963, p. 8-11).

<u>Tökler Formation</u>.--The Tökler Formation crops out in the eastern part of the area, principally within the Tohma River canyon. It is also exposed extensively to the east in the western and southwestern parts of the K39-a1 quadrangle. The formation consists of interbedded conglomerate, sandstone, siltstone, tuffaceous siltstone, and some limestone (fig. 6). The formation is generally medium to dark gray or greenish gray with some light gray to tan units. The average grain size decreases upward through the formation, although many local reversals occur. Conglomerate dominates the basal portion of the formation and the siltstone is mainly found in the upper part. The formation is here named after the village of Tökler, which is situated near the upper contact.

The formation rests unconformably on the serpentinite, and the basal conglomerate contains serpentine pebbles and cobbles. However, the great majority of clasts in the conglomerate beds are very dark gray gabbro similar to the gabbro cropping out west of Kozakmağara (see p. 42). Samples also contain fragments of albite diabase, spilite, hornblende-albite diorite, micrographic granite, quartzite, quartzitic sandstone, amphibolite and actinolite schist (Dr. A. Kraeff, written commun.). The clasts are generally subangular to subrounded and the beds range from pebble to boulder conglomerate. The conglomerate beds are medium to dark gray, greenish gray, and reddish brown.

The sandstone is generally medium to dark greenish gray and is composed mainly of quartz and grains from mafic rocks. The grains are mainly subangular and range in size from fine to coarse. Siltstone beds are generally medium to dark greenish or brownish gray in the lower part and light gray to tan in the upper part of the formation where they are generally tuffaceous.

Several light-gray limestone beds are present near the top of the formation, one in the village of Tökler, and a few thin lenses are in the lower part, north of Gökyurdu Tepe. The lenses, which are less than 100 meters in length and 1 to 2 meters thick, are bioherms composed predominantly of 0.3 to 1.0 meter long rudistids in growth position.

Striking changes in lithology take place over short distances laterally in the formation. For example, a thick conglomerate unit interfingers with and is replaced by a siltstone unit along a strike length of only 200 meters.

The beds range from less than a meter to over 10 meters in thickness and are commonly grouped into sequences of one of two alternating lithologic types to form thicker lithologic units.

The conglomerate is generally medium bedded to massive and the sandstone thin to medium bedded. Bedding is hard to distinguish in the siltstone due to slope cover, but some conglomerate is laminated, as are some sandstone beds.

The formation is cut by several diabase dikes south of the Tohma River and by numeraous sills north of it. Much of the rock near the sills is altered to hornfels and is bleached or baked to orange tan at places adjacent to the dikes. Dikes also cut the formation east of Eskihamal. Most, if not all, of the diabase in the measured section is in dikes. East of the area the contact of the formation with the conformably overlying Sofular Formation was mapped at the top of the uppermost limestone bed by G. W. Leo(personal commun., 1970). The same horizon was used in this area, although much of it is covered. A nearly complete section was measured southeast of Tokler from the serpentinite contact on the ridge crest 450 meters north of Gokyurdu Tepe north-northeastward down the top of the ridge west of Gurunyolu dere to 250 meters north of Camsa Koyak Tepe(fig. 6). The measured section is 1,370 meters thick and the remainder of the formation is estimated to be about 100 meters thick to give a total thickness of approximately 1,470 meters (fig. 6). This figure can be considered a maximum, as there is a possibility that the section is faulted and the faults in the canyon repeat section.

An apparent variant of the Tökler Formation composed of fossiliferous conglomerate, breccia, and siltstone is exposed east of Eskihamal. The beds contain more angular fragments and more fine-grained igneous rock than the formation does to the north. The cobble conglomerate and breccia are generally medium to dark greenish gray and are composed of a great variety of fine-grained igneous rock and some silicified rock fragments in a limy siltstone matrix. Fragments of rudistids and other fossils are very abundant in places. The fossils occur as clasts, but have not been transported far, as they are large and only slightly worn. The conglomerate and breccia are interlayered with thin-bedded, probably tuffaceous siltstone. This unit underlies the limestone of Çakşan Tepe below a contact that is at least in part faulted. The Tökler is also cut by numerous fine-grained dikes.

Most of the Tökler Formation is unfossiliferous, but locally it contains abundant rudistids and a few corals.

A limestone lens, a bioherm, in the lower part of the measured section contains fossils identified by Necdet Karacabey, MTA, as:

Vaccinites cf. braciensis Milevastrifunovic

Hippuritella sp.

Radiolitinae

Pironaea polystylus var. slavonica (Hilber) Kühn

and were assigned a Maestrichtian age.

Fossils from near the top of the measured section are identified by M. Serdaroğlu, MTA, as:

Orbitoides sp.

Miliolidae

Microfossil fragments

and were assigned an Upper Campanian or Maestrichtian age.

Limestone at the top of the formation contained:

Orbitoides media d'Archiac

Algae

Bryozoa

Fossils from probably the middle part of the formation collected by Ayan(1969) a little east of the area include:

Cyclolites ellipticus subcircularis Oppenheim

Cyclolites fenuiradiatus de Form

Cyclolites sp.

Plascosmilie sp.

A biothermal limestone that probably lies close to the top of the formation near Tökler contains *Hippurites* (*Vaccinites*) *ultimus* Milanovich (Ayan, 1969), indicating a Maestrichtian age for the formation.

Sofular Formation.--The Sofular Formation was named by G. W. Leo (Leo and others, in press) after the village of Sofular, which is built upon the formation a few kilometers east of Sarica. The Sofular Formation is poorly exposed north of the Tohma River, but crops out extensively to the east in the K39-al quadrangle. It is composed of interbedded sandstone, siltstone, tuff, and minor claystone and pebble conglomerate that conformably overlie the Tökler Formation. The formation is extensively intruded and altered by trachyte sills north of the Tohma River and the mapped area of the formation(fig. 3) includes many small sills. The stratigraphic top of the formation is not exposed in the area; in other areas nearby it is overlain by a trachyte intrusive; in the vicinity of Hekimhan the apparent correlative sequence is overlain by Maestrichtian limestone. An incomplete section east of Sarica is estimated to be 1,500 meters thick (G. W. Leo, personal commun., 1970).

Fossils collected from north of Sarica were identified by Necdet Karacabey and M. Serdaroğlu, MTA, as:

Joufia reticulata Boehm

Orbitoides media a'Archiac

Orbitoides apiculata Schlumberger

Siderolites calcitrapoides Lamark

Lepidorbitoides socialis (Leymerie)

Omphalocyclus macroporus (Lamark)

Textulariella sp.

Globotruncana sp.

Rotalia sp.

These indicate a Maestrichtian age for the Sofular Formation.

Relationships between the Cretaceous rocks

The Cretaceous rocks in the area form two distinct and separate sequences: the Tohma Group above the serpentinite in the northeast and the massive limestone, limestone of Çakşan Tepe, siltstone of Kuz, bedded limestone, and pebbly limestone sequence to the west and southwest. These two sequences apparently overlap in time and their relationships are critical in unraveling the stratigraphic and tectonic history of the area. The two main problems are 1) whether the Maestrichtian strata comprising the siltstone of Kuz to pebbly limestone formations is slightly older, younger, or contemporaneous with the Maestrichtian Tohma Group; and 2) the age relationship between the serpentinite and the massive limestone and limestone of Çakşan Tepe.

The massive limestone unit may range from Late Jurassic to Maestrichtian in age, with only minor stratigraphic breaks, or an obscured unconformity may lie between the bedded, possibly Maestrichtian, limestone of the top of the unit and the underlying massive limestone of possible Late Jurassic-Early Cretaceous age. It is perhaps also possible that the Upper Jurassic-Lower Cretaceous rocks have been thrust over Upper Cretaceous massive limestone, as the known Upper Jurassic-Lower Cretaceous rocks are part of a thrust plate. The limestone of Çakşan Tepe is probably Maestrichtian in age. The serpentinite is considered by Ayan (1969) to have intruded these limestone formations; however, if these limestones are Maestrichtian in part, as suggested by field relationships, the serpentinite would be older than that. Also if exposures of the intruded limestones were as close as they are now to the serpentinite when it was being eroded during the Maestrichtian, then the lack of limestone clasts in the basal conglomerates unconformably over the serpentinite requires an explanation.

Ayan (1969) believes the sequence of siltstone of Kuz and bedded and pebbly limestones and the Tohma Group were contemporaneous and represent different facies of a single unit that was deposited on opposite sides of a limestone ridge, essentially represented by the band of outcrops of the limestone of Çakşan Tepe. However, the lithologic differences between these sequences are too great to be explained by facies changes over such short distances. Also, why would clastic limestone be deposited in the sequence southwest of the limestone ridge and not northeast of it? If, on the other hand, the southwestern sequence were older or younger than the Tohma Group, special circumstances are required to explain the lack of any trace of the group to the southwest.

A Lower Jurassic to Maestrichtian carbonate section is present to the southeast in the vicinity of Darende (fig. 1) (MTA unpub. well-log data), and time equivalents of the massive limestone and some of the younger units are represented. This section demonstrates that while Campanian and Maestrichtian clastic rocks of the Tohma Group were being deposited near Hekimhan (İzdar, 1963) carbonate was being deposited to the southwest.

An explanation that agrees with the available evidence is that the siltstone of Kuz-pebbly limestone strata were contemporaneous with all or part of the Tohma Group and that the serpentinite may have intruded the older part of the massive limestone or its equivalent, but that the two sequences were more widely separated in the Maestrichtian and have been subsequently juxtaposed. The juxtaposition could have been accomplished by movement along the Kozakmağara fault and to a lesser extent along the Tepecik fault. The siltstone of Kuz might then represent a distant tongue of the Tohma clastic sequence.

Tertiary

Eskihamal sequence

The Eskihamal sequence crops out extensively around and west of the villages of Aşagi Çatkara and Eskihamal, after which it is informally named. These rocks were described by Ayan (1969, p. 23 to 25) in two parts: the Eskihamal Eocene and the Aşagi Çatkara Eocene. The sequence is composed of interbedded siltstone, marl, claystone, sandstone, conglomerate, and limestone. The different lithologies alternate in units which are less than 1 meter to perhaps as much as 10 meters thick.

The marl, siltstone, and claystone are generally very light gray, light gray, or yellowish gray. Some siltstone is medium to dark greenish gray and one claystone unit is red brown with dark greenish gray mottlings and some deep red bands. Most limestone is light to medium gray, light tan weathering silty bioclastic limestone in beds about 1 meter thick, that grade in places to marly limestone. Also a few beds of fine-grained limestone 10 to 20 cm thick are present. The sandstone is calcareous and varies from a light brownish gray, well sorted, medium-grained rock to a medium greenish gray, poorly sorted rock composed of varicolored chert and rock fragments. The conglomerate is mainly light brown to gray pebbly conglomerate with lenses of cobble and boulder conglomerate. It is composed mainly of subrounded to rounded clasts of limestone with lesser amounts of various dark fine-grained igneous rocks, including fragments of basalt, diorite porphyry, and albite tonalite porphyry (Dr. A. Kraeff, MTA, written commun.), and chert in a gray sandy matrix. The conglomerate occurs as lentils and beds 1 meter thick or less, generally in the upper part of the formation. Some beds may truncate the underlying ones.

The base of the Eskihamel sequence is only exposed at the north edge of the area where massive limestone underlies it. A similar sequence on the north side of the Tohma River canyon is described by Ayan(1969) as overlying a probable Paleocene unit of conglomerate, limestone, and marl which in turn unconformably overlies the Tohma Group. The upper contact is exposed north of Eskihamal where the sequence grades upward into the conformably overlying Incecigin Dere Formation. The Eskihamal sequence has a minimum thickness of 2,000 meters southwest of the exposed upper contact, unless it is repeated by faulting.

Parts of the sequence are extremely fossiliferous and contain various types of Foraminifera, especially Nummulites, pelecypods, gastropods, echinoids, and corals. Fossils from several collections made in the vicinity of Eskihamal were identified by Özcan Aksoy, Ayhan Güngör, Yunus Pekmen, and Yüksel Secginman, MTA, as:

Nummulities perforatus Denys de Montfort

Nummulities uroniensis A. Heim

Nummulities millecaput Boubee

Nummulities cf. lucasi d'Archiac

Nummulities cf. laevigatus Bruguiere

Nummulities cf. irregularis Deshayes

Discocyclina sp.

Asterocyclina sp.

Orbitolithes sp.

Fabiania sp.

Rupertia sp.

Sphaerogypsina sp.

Rotalia sp.

Alveolina sp.

Orbitoides sp.

Textularia sp.

Miliolidae

Assilina sp.

Lucina *corbaricus* Leymerie

Lucina aff. *immanis* Oppenheim

Velates *schmideli* Chemnitz

Spondylus sp.

Cardium sp.

Echinolampas sp.

Macropneustes sp.

Gastropods indet.

In addition to many of these same fossils Ayan (1969, p. 24) collected in the same area:

Nummulities *lucasi* d'Archiac

Nummulities *quettardi* d'Archiac

Nummulities *globulus* Leymerie

Nummulities *partschi* de la Harpe

Nummulities *irregularis* Deshayes

Amphistegina sp.

Miscellanea sp.

Globorotalia sp.

Globigerina sp.

algae

Collections around Aşagi Çatkara and to the west yielded:

Nummulities millecaput Boubee

Nummulities perforatus Denys de Montfort

Nummulities laevigatus Brugueier

Nummulities uroniensis A. Heim

Nummulities atacicus Leymerie

Nummulities lucasi d'Archiac

Discocyclina sp.

Amphistegina sp.

Alveolina sp.

Assilina exponens Sowerby

Assilina cf. granulosa d'Archiac

Miliolidae

Operculina sp.

Lucina aff. immanis Oppenheim

Lucina aff. nokbahensis Oppenheim

Spondylus sp.

Cardium sp.

Pecten sp.

Chlamys sp.

Chama sp.

Modiola acuminata Deshayes

Ampullina or Naticu

Echinolampas cf. almerae Cotteau

lamellibranche

Collections by Ayan (1969, p. 25) in the Aşaği Çatkara area contained the following besides several of the above.

Nummulities brogmiarti d'Archiac and Heim

Nummulites cf. *granifera* H. Douville

Vermetus sp.

Lucina corbaricus Leymerie

All of these fossils indicate a Lutetian age and many of them point to an early Lutetian age for the formation. An Ypresian to early Lutetian age was assigned to a collection from a limestone bed a little east of Dolamaç, in the northwest corner of the area, by Yunus Pekmen, MTA, who identified:

Nummulities lucasi d'Archiac

Nummulities globulus Leymerie

Assilina cf. *douvillei*

This limestone appears to lie near the base of the formation and therefore represents the oldest part.

Similar Eocene rocks are described by Ayan (1969, p. 25-28) as being north and east of the area. The described units, however, probably also include rocks of the overlying Inceciğin Dere Formation in this area. Eocene limestones that crop out to the southeast at Darende may also correlate with part of the formation.

Inceciğin Dere Formation

The Inceciğin Dere Formation is poorly exposed in a small area north of Eskihamal. The formation crops out extensively northeast of Kuluncak, east of Yunnuk, where it was informally named by Leo and others press) after a nearby stream. Ayan (1969, p. 26-27) earlier included these rocks in the Darili Eocene.

The formation is a light brown, moderately to poorly sorted, pebble to cobble conglomerate with a few coarse-grained sandstone lentils. The conglomerate is composed of angular to rounded limestone, fine-grained igneous and silicic rock fragments. The conglomerate is poorly bedded and the few beds seen had gradational contacts. This conglomerate is very similar to the conglomerates in the Inceciğin Dere sequence northeast of Kuluncak and has therefore been correlated with it.

The conglomerate appears to be either a fluviatile deposit or a near-shore portion of a deltaic deposit that has been reworked by marine processe

The conglomerate lies conformably on the Eskihamal sequence. Its upper beds are faulted against the limestone of Çakşan Tepe. Approximately 500 meters of conglomerate is present, but the unit is much thicker east of the area. Mapping by Leo and others (in press) north of Kuluncak indicates a minimum thickness of 2,000 meters.

Fossils from Inceciğin Dere sequence indicate a middle to upper Eocene age (Leo and others, in press).

Limestone conglomerate

Limestone conglomerate crops out northwest of Karadoruk, in small scattered localities along the western edge of the area and near Yukari-Çatkara. The conglomerate is light gray to light reddish brown and weathers the same to buff. It is composed of subrounded to rounded, light- to medium-gray and subordinate dark-gray and red-brown limestone pebbles to boulders and a few clasts of silicic rocks. A few limestone blocks 0.5 to 1 meter across are present near the base west of Karadoruk. The coarse-grained, sand-size matrix forms 10 to 15 percent of the rock. In exposures near the southwest corner of the area the matrix has locally been replaced by hematite and limonite. A dark-brown chert layer 5 to 10 cm wide lies just above the base northwest of Karadoruk near Kanyurdu Pinar and a thin, very light gray limestone bed containing chert and possibly limestone fragments is found at the base east of Gölbaşi Tepe, at the west edge of the area. The fossiliferous limestone tentatively included at the top of the siltstone of Kuz might possibly be the basal bed of this conglomerate unit.

The conglomerate appears to grade both laterally and upward into a unit of interbedded conglomerate and red-brown siltstone near Kanyurdu Pinar.

The limestone conglomerate unconformably overlies both the siltstone of Kuz and the massive limestone. It appears to be overlain by the Karadağ Andesite. The limestone conglomerate is probably at least 5 meters thick on the flanks of Gölbasi Tepe and probably a little more north of Karadoruk.

The formation is unfossiliferous and is tentatively assigned a late Tertiary Neogene age.

Ayranca Formation

A nearly flat lying sequence of fresh-water limestone and marl with a basal conglomerate crops out widely in the area around the hamlet of Ayranca, after which it is informally named. The base of the formation is formed by conglomerate several meters thick which consists of light-gray limestone cobbles and boulders and caps the serpentinite along Kirmizikuz Dere. The clasts include rounded Nummulities-bearing light-gray limestone and very few pebbles of mafic intrusive and silicic rocks. Overlying the basal conglomerate are alternating layers of light-gray fine-grained freshwater limestone, which is pisolitic in places, and very light gray marl. These rocks, along with terrace gravels and alluvium, are included in the Akdere Formation of Ayan (1969). The formation is not covered and appears to have a minimum thickness of about 100 meters.

The limestone conglomerate at the base of the formation differs from that near Karadoruk and to the west in the kind of limestone forming the clasts and matrix, and also in that the conglomerate near Karadoruk is associated with reddish silstone. Because of these differences and the lack of conglomerate beneath similar marls in the intervening areas, they are treated separately. However, it is possible that these differences are merely the result of vagaries of local source material and deposition.

The formation is unfossiliferous, except for some gastropod casts and the Nummulites-bearing clasts in the conglomerate; it can only be dated as post-Eocene. However, as it is much less deformed than the Eocene formations, it is thought to be of Neogene age. The formation may correlate with the wide-spread flat-lying limestone and marl formation exposed west of Kangal and with the nearly flat lying freshwater limestone capping hills north of Kuluncak.

Marl

Marl with some interbedded limestone is poorly exposed on the hills west and southeast of Kozakmağara and around Dürmepinar. The marl is light to very light gray and is slightly vuggy in places. The limestone is a thin- to medium-bedded, light to medium brownish gray, fine-grained rock. Some of the limestone appeared to be lacustrine, but most is indeterminate in mode of origin.

The unit generally is gently dipping and is unconformably draped over and around massive limestone and probably over the Eskihamal sequence as well. It appears to be about 50 meters thick on Bozyokuş Tepe.

No fossils were found, except Lymnaea sp. assigned a Paleocene-Holocene age, and the rocks are tentatively assigned a Neogene age.

The unit appears to be a lacustrine deposit that probably correlates with some portion of the upper part of the Ayranca Formation that has fewer and less distinct limestone beds.

Volcanic breccia and dacite(?)

Two very small exposures of volcanic breccia occur in the area; one in a depression northwest of the Otlukilise mine and the other on the northwest side of Koyunluhoca. The volcanic breccia northwest of the Otlukilise mine is a gray unit composed of generally angular fragments of light-gray sanidine-bearing dacite(?), medium pinkish gray andesite(?), very light gray altered volcanic rock, and other types in a light-gray to medium brownish gray coarse, sand-size matrix. The fragments range from grit to blocks 1 meter in diameter and faint bedding is present locally. The breccia is in fault contact with the iron-bearing sedimentary rocks. Nearby is a light- to medium-gray dacite(?) porphyry which weathers the same to tan. Small phenocrysts, which form 20 to 50 percent of the rock, appear to be composed of plagioclase, hornblende, and sanidine in order of abundance. The groundmass is light gray and very fine grained with denser medium-gray lentils and streaks. The rock appears to be near the dacite-andesite boundary in composition. The porphyry appears massive locally, but generally shows steep but variably dipping laminae which probably represent flow banding. Similar rock fragments are present in the volcanic breccia and the dacite(?) is apparently part of the same volcanic series. A drill hole revealed massive limestone a few meters below the east edge of the area of dacite(?).

The breccia on the northeast side of Koyunluhoca contains light-gray to dark-brown, angular and subangular, pebble- and cobble-sized porphyritic fragments in a gray matrix. No bedding is exposed. The breccia is faulted against the massive limestone and overlies either the massive limestone or the Eskihamal sequence, which is exposed nearby.

The volcanic agglomerate and flow-rock described in drill logs at the Otlukilise mine are probably similar to the volcanic rocks to the northwest. The volcanic rocks at the mine are not exposed, but lie beneath the iron-bearing sedimentary rocks, and above the massive limestone The exposed volcanic rocks are only a few meters thick, but a vertical thickness of 50+ meters is reported present at depth in the mine (Gümüş, 1964).

These volcanic rocks are very tentatively assigned a Neogene or Pleistocene age.

Karadağ Andesite

Andesite caps Karadağ and forms as an outlier on Kepez Tepe. The andesite is a medium-gray to purplish-gray fine-grained flow rock which weathers darker to grayish brown. It contains very few tiny glassy phenocrysts and pyroxene crystals and is near the andesite-basalt boundary in composition; a very minor amount is amygdaloidal near the base. The andesite is massive and very well jointed into noncolumnar joint patterns that might be the result of spreading above a conduit.

The andesite overlies the massive limestone, limestone conglomerate, siltstone of Kuz, and gravel. The gravels are in float on the southeast side of Karadağ and include volcanic and gabbroic cobbles. Between 200 and 250 meters of andesite is present on Karadağ.

The andesite is probably Neogene or possibly Pleistocene in age, and may be younger than the volcanic breccia and dacite(?), as they did not contain any fragments of it. It is probably contemporaneous with some of the Tertiary basalts and andesites that crop out extensively to the east (Ayan, 1969; İzdar, 1963; Leo and others, in press) and to the basalt conduit and flows exposed several kilometers east of Gürün, at Suçat. The basalt at Suçat appears to be interbedded with Neogene sedimentary rocks. The Karadağ Andesite is probably also related to the basalt or andesite that rose up a conduit at the intersection of a west-trending fault with the Tepecik fault zone 6 km southeast of Karadağ.

Quaternary

Iron-bearing sedimentary rock

Small bodies of iron-bearing sedimentary rock cropout at and near the Otlukilise Mine. The unit is composed of reddish-brown conglomerate, sandstone, siltstone, and claystone, in ascending order. The conglomerate contains hematite and magnetite clasts and all the rock types contain fine hematitic material. The conglomerate also contains clasts of quartzite and phyllite, rock types which are not seen anywhere else in the area. The unit overlies both the volcanic breccia and flows and the massive limestone. The iron-bearing rock is described in detail in a report on the Otlukilise mine(Barosh, 1972b).

These sedimentary rocks are unfossiliferous and cannot be dated closely. They occur in bowl-shaped deposits that appear to be fillings of sinkholes in the massive limestone. Sinkholes, which are common in the area, were formed in an erosional period earlier than the present. Therefore, the iron-bearing rocks were probably deposited during the late Neogene or, more likely, the Pleistocene.

Terrace gravel

Terrace gravel is very widespread in the eastern part of the area and well represented in the western part, where it is mapped separately, but in the central part of the area the gravel is less well exposed and is not everywhere separated from alluvium. The gravel generally consists of rounded limestone and a few silicic cobbles and boulders as much as a meter in diameter plus a few clasts of silicic rocks. Very large sub-angular boulders are present north of Baltaci Tepe at the west edge of the area angular and subangular clasts are found locally, as on Kücük Yildirim Tepe. The basal gravels overlying the serpentinite near Tavşan Tepe contain serpentine and jasper clasts in addition to limestone clasts and are cemented by sandy caliche.

Most of the gravel deposits are a few meters thick, but they reach a thickness of about 40 meters on Kücük Yildirim Tepe and Sari Tepe.

The terrace gravel occurs on different levels and was deposited at different times during the very complex erosional history of the area. The majority of deposits are thought to be Pleistocene in age, but a few may be Holocene.

Travertine

Travertine and freshwater limestone covers part of a large terrace 3 km northeast of Konakpinar. The travertine is light brownish gray and forms contorted, porous layers. It grades locally into similar, but non-porous fine-grained limestone.

The travertine overlies the terrace gravels and is only a few meters thick. It appears to have extended eastward to the west end of Çaltepe and therefore predates the formation of the valley south of Sari Tepe. Similar travertine crops out farther north, north of Gurtüzaka Tepe.

The travertine is probably Pleistocene in age although it could be of Holocene age.

Alluvium

The areas mapped as alluvium include undifferentiated Holocene stream deposits, colluvium, thin soil cover over terrace gravels and, in places, terrace gravels. Landslide blocks and debris and mine dumps are distinguished from the rest (fig. 3).

INTRUSIVE ROCKS

Cretaceous(?)

Serpentinite basement complex

Serpentinite.--Serpentinite is found in the eastern part of the area northeast of a line extending through Eskihamal and Kozakmağara and south of the Tohma River. This is the western end of a belt of serpentinite that crops out very extensively to the east.

The serpentinite is a dark-green slickensided rock that generally weathers lighter; it may also be gray or light to dark brown. Some weathered slopes, however, are very colorful with shades of bluish gray, greenish gray, red, light and very light gray, brown, and very dark gray. The serpentinite is altered in places and is locally silicified to white jasper on the south slope of Bozyokuş Tepe.

The serpentinite is highly altered beneath an ancient weathered surface underlying terrace gravels on the ridge crest south of the Tohma River (fig. 4, section A-A'). The weathered serpentinite forms a cap rock 2 to 5 meters thick. Fresh serpentinite beneath the cap grades upward into a highly fractured rock which becomes progressively more altered upward, changing into a light-tan porous material cut by veinlets of calcite or, in places, silica. The veinlets widen and become more numerous toward the ancient surface. The altered serpentinite fragments commonly weather out, leaving a vuggy boxwork-like brownish calcareous rock which may resemble a highly altered limestone and which indeed has locally been mapped as limestone. In the mapped area this cap rock is locally siliceous and it is very siliceous farther east.

Much of the serpentinite is poorly exposed and forms gentle slopes covered with sparse vegetation in a dark olive brown soil.

The age of the serpentinite complex in the area can only be stated as pre-Maestrichtian from the age of the overlying strata. To the east, in the Hekimhan area, however, lower Campanian rocks unconformably overlie the serpentinite (İzdar, 1963, p. 8-9) and establish a minimum age.

The serpentinite in the region is most closely associated with Upper Cretaceous strata (Baykal and Erentöz, 1966, p. 87) and most workers have assigned it a Late Cretaceous age (İlker, 1964). However, the exact age of intrusion of the serpentinite is not known in this region due to confusion among earlier workers in distinguishing features caused by intrusion from those due to later movements or weathering.

Small intrusive rock bodies.--The serpentinite is intruded by a number of dikes and small pipe-like bodies ranging in composition from quartz monzonite to gabbro. Most of these are small and have not been mapped separately. Large areas of gabbroic rock were exposed here or nearby to erosion in the past as attested by the very numerous clasts in the overlying conglomerate; however, only small amounts of gabbro are presently exposed in the area.

Several small diorite dikes occur along the ridge east of Kozakmağara and a few very small pipe-like bodies and dikes of quartz monzonite crop out along the contact north of Gökyurdu Tepe. Various types of gabbroic rocks are exposed west of Kozakmağara and east of Tavşan Tepe and a very fine-grained black basaltic rock appears to intrude the serpentinite on Diksankal Tepe in the southeast corner of the map. The intrusives west of Kozakmağara were identified as hornblende gabbro, hornblende-diopside gabbro, olivine-diallage gabbro, albite tonalite and albite granite by Dr. A. Kraeff, MTA. In addition, other small intrusive bodies crop out at scattered localities in the serpentinite.

Most of these igneous rocks are represented in the overlying conglomerate as clasts and are Campanian or older in age. A few of the very fine grained rocks may be equivalent to the very fine grained trachyte dikes and sills and diabase dikes that cut the overlying Tökler and Sofular Formations and thus may be Maestrichtian or younger in age.

Cretaceous or Tertiary

Dikes, sills, and small intrusive bodies

Numerous dikes, sills, and small intrusive bodies cut the Tokler and Sofular Formations in the Tohma River Canyon and a few similar intrusive rocks cut these formations and the serpentinite elsewhere in the area.

These small fine-grained intrusive bodies do not appear to cut any rocks younger than the Sofular Formation and are considered to be Maestrichtian or Paleocene in age.

Diabase.--Several fine-grained dark-gray diabase dikes and sills(?) 0.5 to 2 meters thick cut the Tokler Formation southeast of Tokler. These dikes have locally baked the adjacent sediments and are identified by the growth of green lichen.

Trachyte.--Numerous medium to dark gray fine-grained trachyte sills cut the Sofular Formation north of the Tohma River, baking the adjacent sediments to hornfels. Only the large ones are shown on the map(fig. 3). South of the river few sills are present and the large dike-like trachyte intrusion is partially mapped from data by Ayan(1969).

The fine-grained dark-gray to brown weathered mafic dikes that cut the Tökler Formation and serpentinite east of Eskihamal are presumed to be related to those farther north. Dark greenish gray, altered porphyritic rock included in the Tökler Formation just north of Eskihamal may be also.

STRUCTURE

The area is part of one of the most structurally critical localities in the region. The structure is extremely complex and unfortunately the incomplete stratigraphic information and poor exposures in critical areas result in many unresolved problems.

The regional structural trend changes from west to east across the area, about a northerly striking hinge line, from northeast-trending fault and fold axes on the west, to northwest-trending structures on the east(figs. 2 and 3). Superimposed on these curving structures are three converging major faults: the northeast-striking Boğrüdelik fault which cuts the northwest corner of the area; the northerly striking Tepecik fault zone which passes just east of the hinge line, and the northwest-striking Kozakmağara fault which crosses the eastern part of the area(fig. 2).

The structure is quite diverse in detail and can best be described by subdividing the area into three parts that have similar structural characteristics and discuss them separately. The area east of the Tepecik fault zone is characterized by northwest-striking faults and beds which dip northeast; it is referred to as the east complex. The central complex which is between the Tepecik fault zone and the Gürün-Sivas road straddles the structural bend and shows many structural complications. The central complex is bounded on the west by the southeast-to-east-inclined dip slopes of the west complex which is mainly formed of a faulted northeast-trending anticline. The Böğrüdelik fault zone cuts the northwest limb of this anticline.

East complex

The east complex is characterized by northwest-striking, northeast-dipping rocks, cut by northwest-striking faults. The northeast part of it is a block composed of serpentinite and the Tökler and Sofular Forma-tions with a veneer of younger sediments. Within the block, rocks of the Tökler Formation are repeated several times by vertical northwest-striking faults whose southwest sides are relatively down (fig. 3, sections A-A' and B-B'). The block is bounded on the west by the Tepecik fault zone and on the southwest by the Kozakmağara fault. A narrow northwest-trending block formed of the limestone of Çakşan Tepe is southwest of the Kozakmağara fault zone. The southwest boundary of this block is formed by vertical faults near Eskihamal and is probably faulted elsewhere along the generally unexposed border. Here again, the southwest side is relatively down.

The area southwest of the block consists mainly of northwest-striking, northeast-dipping beds of the Eskihamal sequence and the Inceciğin Dere Formation, which may be cut by a few small northwest-trending faults (fig. 4, section A-A'). The southwest contact between the Eskihamal sequence and the siltstone of Kuz is probably also a northwest-trending fault. The massive limestone in the southwest corner could be either a fault-bounded block, an anticline, or both, as shown.

Kozakmağara fault zone

The Kozakmağara fault is near vertical where it is well exposed at Kozakmağara and just east of the southeast corner of the area (G.W. Leo, personal commun., 1970) (fig. 4, section A-A' and B-B'). Northeast of Eskihamal the evidence for faulting is not as clear, but the fault plane would dip moderately southwestward. The fault has a large displacement and may be of regional significance. Stratigraphic considerations (see p. 24 - 26) suggest that large horizontal movement (thrust or strike-slip) along the fault has juxtaposed different Upper Cretaceous facies. If the present positions of these Upper Cretaceous rocks could be somehow reconciled without calling for horizontal movement, then a large vertical displacement, southwest side relatively down, would be required. The fault is apparently cut by the Tepecik fault zone.

Tepecik fault zone

The Tepecik fault zone is the least exposed and understood part of the area. A north-trending vertical fault is exposed along its west edge and other faults probably extend through other parts of the zone, as suggested by alignments of the limited exposures and north-trending topographic features, to form a broad fault zone (fig. 4, section B-B').

The fault zone terminates the southeastward extensions of folds on the west, forms the western boundary of the serpentinite west of Ayranca north to at least the Tohma River and forms a break between the exposures of the Eskihamal sequence in the eastern and central complexes.

The Tepecik fault is named on a map by the Petroleum Section of MTA (1968) after a village northwest of Darende. This map shows that the fault zone continues about 24 km southward, bends, and continues at least another 35 km southeastward. North of the area, the Tepecik fault zone is shown to be cut off at the Tohma River by a northwest-trending fault. However, the discontinuities of geologic features on the map by the Geologic Section of MTA(1964) suggest that the fault continues northward at least 10 km beyond the presently mapped area. The fault zone appears as a slightly discontinuous series of single breaks on the map by the Petroleum Section (MTA, 1968); but the mapping for this report and the width of the zone of geologic discontinuities on the map by the Geologic Section(1964) indicate that the fault zone is commonly about 1 km wide.

The Tepecik fault zone has apparent right-lateral offset. The Eskihamal sequence-siltstone of Kuz contact has an apparent offset of 1 to 2 km across the zone. An apparent right-lateral offset of about 5 km for the contacts of the massive Cretaceous limestone, Eocene sedimentary rocks, and volcanic rocks is shown just south of the area on the map by the Geologic Section (MTA, 1964). Vertical movement may be more important farther south as both maps show younger rocks on the east side.

The fault probably extends to great depth, because Neogene volcanic centers are along or adjacent to the fault zone at several places and the fault disappears southward beneath a Neogene volcanic complex. Six kilometers south of the area a small volcanic center is located where the Tepecik fault is joined on the east by a westerly trending fault.

Central complex

A major bend in the regional structure is in the central complex area. Faults and folds change direction across the complex from predominantly northwest trends on the east to northeast trends on the west side. However, considerable structural differences exist between the south, central, and northern portions of this complex.

The central part of the central complex is composed mainly of highly contorted siltstone of Kuz between hills of massive limestone within which little structure can be discerned. These characteristics of the main rock units make it very difficult to decipher much of the structure, except along their contacts. Several large and innumerable small folds are present. The Kuzun anticline which passes through Kuzun Tepe and Kuzun Sirti south of Yukari Çatkara is highly variable(fig. 4, sections C-C' and D-D'). Attitudes along both flanks are steeply dipping to overturned, although the northeast flank shows a more general overturning toward the south. The axis of this faulted anticline apparently bends from a northwest trend south of Yukari Çatkara to a west-southwest trend north of Karadag. The anticline cannot be followed farther westward, but the southwest trend of the adjacent Elmaboğazi syncline south of Konakpinar completes the general bending of the structures. This syncline is revealed by bedding attitudes only in the vicinity of Konakpinar; but it probably continues farther southwestward as indicated by the uppermost reddish beds of the siltstone of Kuz in the valley. This syncline is cut by several small transverse faults and its southeast flank is faulted. The syncline might continue northeastward as far as Sari Tepe before dying out.

The north and northeast flanks of the Kuzun anticline continue northward into the Sarikaya Tepe syncline, which is strikingly displayed in the canyon northeast of Yukari Çatkara(fig. 4, section C-C'). The axis of this syncline bends from a northwest trend near Yukari Çatkara to a west trend near Eskibektaşli. The syncline probably extends farther west as indicated by the U-shaped bend of the contact between the buried massive limestone-and siltstone of Kuz around the west side of Yildirim Tepe(fig. 4, section D-D'). The faulting along the southwest flank of the syncline along Sincan Tepe may possibly be due to a thrust fault beneath the bedded limestone. The massive limestone on Büyükburun Tepe may form an anticline between the Elmaboğazi and Sarikaya Tepe synclines, although attitudes are difficult to ascertain.

Numerous small folds are indicated by clastic limestone and marl beds in the siltstone of Kuz. These generally parallel the larger folds, but west of Yukari Çatkara there are several tight little folds which diverge about 30° from the axes of the larger folds.

Many northwest- and northeast-trending faults cut the folds. The fault of both trends appear to be contemporaneous in age. These are irregular and form a confused pattern, although northwest-trending faults are more prominent on the east side and northeast-trending ones on the west side.

The pebbly limestone formation appears to represent remenants of a thrust plate. At all three localities on the map the beds dip into the lower contact of the formation that is locally broken into jumbled blocks, as shown along the west crest of Kale Tepe. The locations of the remnants of this thrust fault are near the axes of synclines in the siltstone of Kuz (fig. 4, sections D-D' and E-E') and possibly the thrust faults developed as a slippage plane during folding.

North of the Sarikaya Tepe syncline the area is composed mainly of Eskihamal sequence and massive limestone (fig. 4, section C-C' and D-D'). These rocks bend from northwest strikes on the east to westerly strikes on the west. The Eocene rocks generally dip northward, but are locally tightly folded, such as near Gürtüzaka Tepe and east of Durmepinar. The high-angle faulting in this area appears simpler than farther south; a few northwest-trending faults are exposed on the east side of the bend and several northeast-trending ones on the west side.

The Eocene rocks overlie massive limestone with an apparent unconformable relationship near the northern edge of the mapped area (fig. 4, section D-D'). They may also be unconformable over the siltstone of Kuz along the north side of the Sarikaya Tepe syncline, although a faulted contact is possible. Massive limestone overlies the Eocene rocks at the north edge of the area and in the vicinity of Aşagi Çatkara. The limestone is Late Jurassic-Early Cretaceous in age around Aşagi Çatkara (Ayan, 1969) and may be to the north also. Thus, it appears to represent remnants of a thrust plate. The thrust plate, however, is not simple in structure. At the west end of Hacikelik Tepe the massive limestone lies with a nearly horizontal contact over very steeply dipping beds of the Eskihamal sequence, whereas along the southwest side the contact is highly brecciated and appears to be a steeply dipping fault, as it also does on the northeast side(fig. 4, section C-C').

The southern part of the central complex is composed essentially of massive limestone and the Karadağ andesite(fig. 4, section C-C'). It is cut by numerous, probably small, faults which are expressed as narrow covered breaks that resemble small roads or paths in the otherwise very well exposed rock. Most of the faults trend northwestward but a few northeast-trending faults are along the northwest side of the block. The Karadag andesite trends northwestward on line with a few northwest-trending faults that strike into the southeast part of the outcrop and thus it is probably fault controlled to some extent(fig. 4, section C-C').

No folds could be delineated in the southern part owing to lack of bedding, but the massive limestone may form an anticline which bends around parallel to the folds to the north. Beds along the south side of the massive limestone, south of the area, are shown by Kurtman(unpub. data, 1963) as changing from a northwest strike on the east side to a northeast strike on the west side and may represent a south flank of an anticline.

The northern contact of the massive limestone with the area of delineated folds is faulted. The boundary fault along the northeast side of Karadağ is a reverse fault that dips 50° southwest near Kanyurdu Tepe(fig. 4, section C-C'). The northwest side is faulted where exposed and probably elsewhere also. The massive limestone may have been thrust slightly northward against the more plastic rocks, or may have been a buttress around which the plastic rocks folded, or both, because as mentioned above, the unit itself is not effected by the folding.

West complex

The western edge of the area appears to be part of a large northeast-trending anticline formed of massive limestone with siltstone of Kuz dipping from the southeastern limb(fig. 4, section E-E'). The generalized limestone-siltstone contact closely parallels the Gürün-Sivas road north to 1 km south of Böğrüdelik where the contact swings to the west and outlines the northeast-plunging nose of the anticline. In places the anticlinal limb is wrinkled into a series of small faulted north-northeast-trending folds, as shown west of Konakpinar.

The anticline is cut by numerous faults. A branch fault of the Böğrüdelik fault zone, which bounds the anticline on the northwest, cuts the anticlinal axis, as does a large northeast-trending fault that is near Gölbaşi Tepe(fig. 4, section E-E'). A curving fault branches from the fault near Gölbaşi Tepe and bends southeastward and southward toward Boztaş. Another curving southeast-trending fault cuts the complex west of Boztaş. These two curved faults drop the intervening area down relative to the areas to the north and south.

The massive limestone northwest of the Böğrüdelik fault zone continues northward several kilometers to a fault bounding the northwest side of the ranges. No folds or faults were discerned in this limestone.

Böğrüdelik fault zone

The Böğrüdelik fault zone, named after a village in the northwest edge of the area, is part of a zone of faults that extends from the Mediterranean northeastward to Divriği(fig. 4, section E-E'). The unpublished maps of the Geologic and Petroleum Sections of MTA(1968) when used together, show that the Böğrüdelik fault zone extends 65 km southwest of the area. Southeast of Pinarbaşi (fig. 1) the fault merges with a zone of faults that continues southwest to east of Adana and forms a major structural zone of central Turkey (Baykal and Erentöz, 1966; Ternek and Erentöz, 1962). Another branch of this zone of faults passes a few kilometers northwest of the Böğrüdelik fault zone and forms the boundary between hills of massive limestone and a basin of Neogene rocks to the north. This range-front fault zone appears to continue northeastward to Divriği, north of which it is cut off by a major west-trending fault. The Böğrüdelik fault zone itself appears to be cut off by the Tepecik fault zone a short distance north of the area(MTA, 1964).

The amount and direction of displacement along the Böğrüdelik fault zone is unknown. Displacement along some of the breaks on the southeast side of the zone is relatively down on the southeast, or possibly is a right-lateral displacement. However, the displacement along the related range-front fault to the northwest is relatively down on the northwest; at Uzunpinar 45 km west of the area fault patterns in this same zone of faults suggest left-lateral displacement along the faults(Barosh, 1972a).

HISTORICAL GEOLOGY

The geologic history revealed in the area indicates a progression since Late Jurassic from an offshore marine environment to a continental one. This progression was interrupted by Late(?) Cretaceous, Cretaceous-Paleocene, and mid-Tertiary orogenic episodes. Marine limestone deposition continuing from the Late Jurassic was probably interrupted in the early part of the Late Cretaceous by orogenic activity that resulted in the recrystallization of much of the limestone, intrusion of a serpentinite complex, and uplift and erosion. Then followed the deposition of "flysch-like" clastic sediments of the Tohma Group over eroded serpentinite. This transgression sequence began in early Campanian time near Hekimhan and extended into the Konakpinar-Sarica area by latest Campanian or early Maestrichtian time. Short pauses during the deposition enabled patch reefs of rudistids to become established locally, and at times, volcanic activity contributed material to the deposits. To the southwest of this "flysch" basin, offshore marine limestone and fine clastic sediments continued to be deposited, and in very late Maestrichtian time limestone may have again been deposited in the entire region.

During the latest Maestrichtian or early Paleocene, small bodies of trachyte and diabase dikes were intruded into the Tohma Group. The Maestrichtian limestone and fine-grained clastic sequence to the southwest were folded, faulted, and moved north into the "flysch" basin apparently by displacement along the Kozakmagara fault zone. Small bedding-plane thrust faults may have developed within tightly folded synclines. These movements were followed or accompanied by uplift and erosion.

Beginning in the Eocene or perhaps the Paleocene, sediments were deposited unconformably over the older rocks. The environment changed from shallow-water marine conditions when the Eskihamal sequence was deposited to the very near shore conditions prevailing at the time the conglomerates and siltstones of the Inceciğin Dere Formation were deposited.

A break in the stratigraphic record exists in the area from mid-Eocene until the time of deposition of the Neogene, probably Pliocene, lacustrine deposits. The area must have undergone some of the same changes that affected the Sivas region to the north where Oligocene and Miocene clastics, marls, and gypsiferous rocks were deposited in environments that changed from marine in the Oligocene and early Miocene to lagoonal or continental ones in the late Miocene (Baykal and Erentöz, 1966, p. 80-82).

Sometime during the mid-Tertiary another orogeny affected the area during which the Eocene rocks were folded and tilted northward, and Upper Jurassic-Lower Cretaceous limestone was thrust over the Eocene rocks. Movement along the Tepecik and Böğrüdelik fault zones was perhaps initiated soon afterwards. The iron-bearing veinlets in the massive limestone may have formed a short time after the fault movements.

Vertical movements, by which the northeastern part of the area was relatively uplifted, may have taken place in conjunction with the tilting or soon after. Movement along these faults may have been part of the general orogeny that raised and formed basins in the region that received conglomerate and lacustrine limestone, probably during the Pliocene or perhaps even Pliocene to Quaternary time (Baykal and Erentöz, 1966, p. 82). Breccias, andesite, and basalt flows, and intrusions from volcanic activity in the area formed during this same general interval. Subsequent movement along high-angle faults has apparently offset these deposits and may be continuing at the present.

A period of erosion followed in the Pleistocene during which extensive terraces were cut, their surfaces weathered and covered by gravels, and locally, by travertine. The karst topography over areas of massive limestone may have developed at this time. The sinkholes formed near Otlukilise in a topographically low area and began to receive iron-bearing detritus eroded from adjacent hills.

Continued uplift and possible precipitation changes brought about renewed erosion which carved the Tohma River canyon, swept away large areas of gravel, lowered much of the area, and initiated a surface drainage system in the areas of Karst topography. At present erosion actively continues on ridges where remnants of karst topography still exist, and in the Tohma River Canyon.

The area is presently seismically active. A very large spring on the west side of the Gürün-Sivas road 1 km north of Kardeşlergediği is reported to have been activated by an earthquake in 1967; to the south, near Gürün, a large number of small local earthquakes occurred during the summer of 1969. In spite of having been involved in at least three orogenies, the area is still in a youthful stage of development.

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