STRATIGRAPHICAL AND SEDIMENTOLOGICAL STUDIES OF UPPER CARBONIFEROUS ROCKS IN NORTHWESTERN TURKEY

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ABSTRACT

The combined stratigraphical and sedimentological analysis described in the present study permits a general synthesis of the palaeoenvironmental and palaeogeographical evolution recorded in the Upper Carboniferous rocks of northwestern Turkey, which occur in a number of outcrops near the Black Sea coast. It was found possible to assign the Upper Carboniferous rocks to four lithostatigraphic formations, which have been defined and further sub-divided where appropriate. These Namurian-Westphalian age formations comprise approximately 3500 m of clastics overlying Visean platform carbonates and are unconformably of structurally succeeded by younger rocks, mainly Permian red sandstones and Cretaceous limestones or flysch.
The Namurian and Westphalian sequences have yielded significant collections of megaflora, microflora and invertebrate faunas (both marine and non-marine) which enable the chronostratigraphic limits of the formations to be defined with reasonable precision and which demonstrate the strong stratigraphic links of these north Turkish late Palaeozoic sequences with those from Europe and Russia.
As a result of the sedimentological study, eighteen individual lithofacies have been recognised and assigned to two broad facies complexes (coastal and alluvial). These two complexes have been further divided into six Associations, namely i) prodelta, delta front, delta plain, meandering stream, braided stream and lacustrine. The stratigraphic distribution and environmental significance of these associations has been assessed for each of the four major lithostratigraphic units, namely the Alacaağzı, Kozlu, Karadon and Kızıllı Formations.

The Alacaağzı Formation (Uppermost Visean-Namurian C) comprises a broadly coarsening upward deltaic sequence, displaying regionally

variable influence of wave activity and longshore currents. The delta-plain sub-association is usually complete and indicates a fluvially dominated type of delta with southeasterly transport directions. The basal part of the Kozlu Formation (Namurian C - Westphalian A) is characterised by lacustrine deposits while the upper part comprises sequences formed by southeasterly-flowing meandering and low-sinuosity rivers. The thick laterally extensive Kozlu Formation coals are assigned to flood-plain environments and the sedimentary modal closely resembles that for the later Westphalian coals of northwestern Europe. The conglomeratic sequences of the overlying Karadon Formation (Westphalian B - C) represents interfingering of coarse sandy braided streams and humid alluvial fans with south-westerly transport directions. The Karadon Formation coals were formed in situ in braidplain environments and reflect a delicate balance between basin subsidence and alluviation rate, permitting maintainence of a high water table. The sedimentary model for the Karadon coals resembles that developed for the tectonically controlled late Carboniferous basins of Cantabria, Spain. However, some climatic control is indicated by progressive reddening of the Turkish sequences and development fo thick, strongly leached palaeosols (Schieferton units). The alternating coarse sandy and fine silty sequences of the overlying Kızıllı Formation (Westphalian D) contain impersistent coals and are attributed to deposition in an anostomesed stream network formed in intermontane regions.

The petrographic character, and particularly the mineralogical and textured maturity of the sandstones in these Upper Carboniferous successiona appears to be closely controlled by environmental factors, although some positional data can be used to infer the changing nature of the source area. The diagenetic history of the sandstones (including the nature and abundance of the cementing materials) also appears to vary according to the nature of the original site of deposition.

In summary, the stratigraphical, sedimentological and faunal data presented in this study indicate that the various small, structurally separated outcrops of Upper Carboniferous rocks now found in northwestern Turkey were originally deposited within a single, large basin of deposition (with a northerly source). This basin was formed on the southern margin of the Laurasian plate, and was subject to increased marginal fault-activity towards the end of the Carboniferous, prior to the main Variscan deformation and uplift.

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CHAPTER 1

INTRODUCTION

1.1. AIMS OF RESEARCH

This study of the Upper Carboniferous rocks of northwestern Turkey was undertaken to elucidate and refine the stratigraphy and to determine the sedimentary history of these rocks. As a result of the new stratigraphic information obtained during this study it was decided to concentrate attention on the Namurian and Westphalian sequences in northwestern Turkey (Fig. 1).

There is a substantial body of previously published data on these rocks but existing accounts of the stratigraphic successions are confusing and inconsistent. Thus in order to provide the necessary stratigraphic framework for the sedimentological study, reliable lithostratigraphic and biostratigraphic data had to be acquired to form the basis of this study. For that purpose plant fossils were collected and coal seams were correlated utilising previous microfloral studies (Fig 9). In the light of this information it was found possible to assign the Upper Carboniferous rocks to four formations (see Chapter 2), which have been defined and further sub-divided where appropriate. After this general stratigraphical framework had been established, the sedimentary characters of the succession were determined by field logging of sections in several localities. These provide further evidence of the history of sedimentation in the basin in which the Upper Carboniferous formations were laid down, thus permitting a palaeogeographic synthesis to be made for the whole region, during the Late Carboniferous. This study also includes: a detailed analysis of the distribution of lithofacies both vertically and laterally,

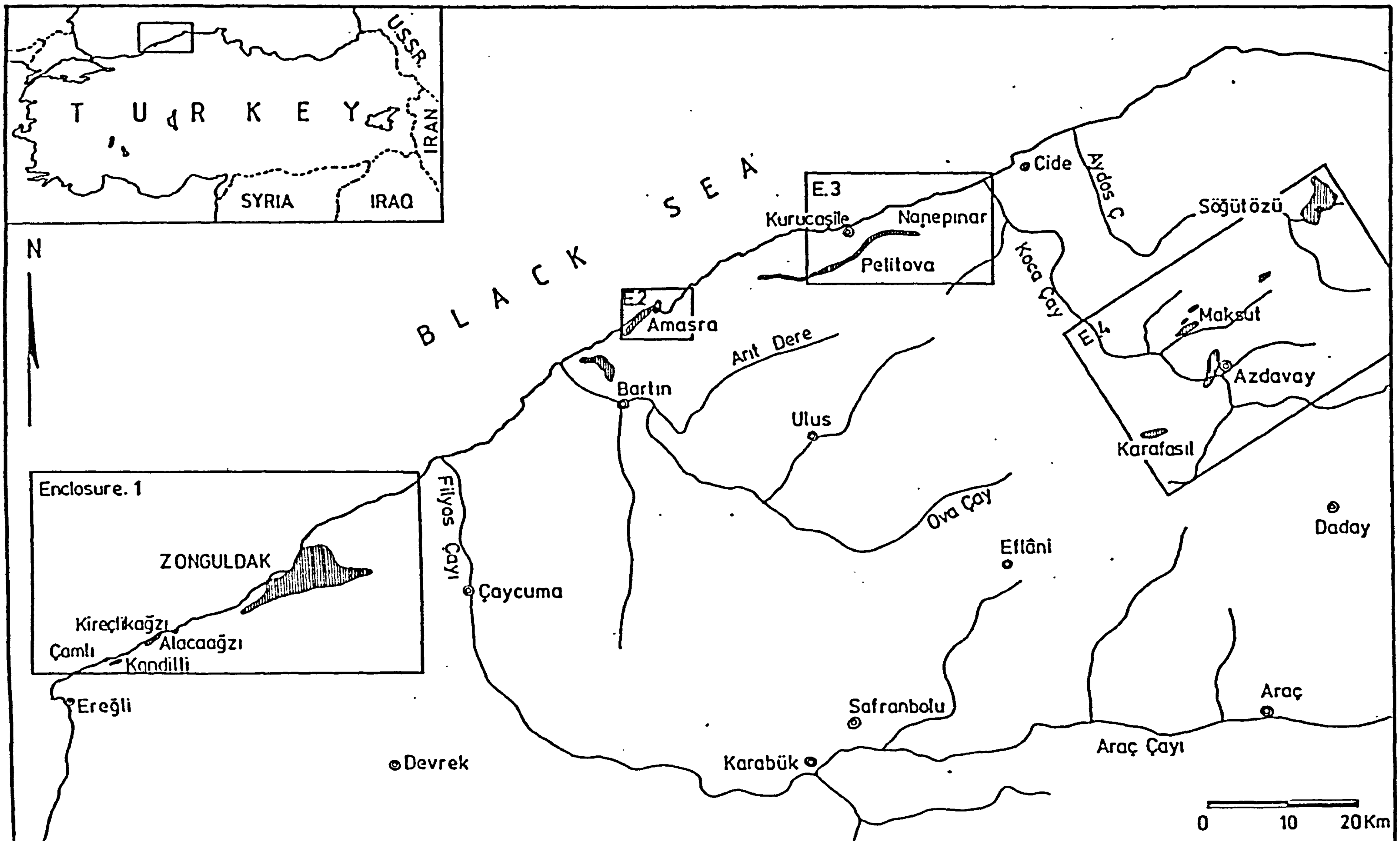


Fig.1.- Distribution of Upper Carboniferous outcrops from northwestern Turkey.

analyses of sediment transport vectors, a preliminary petrological study and the interpretation of palaeoenvironments and depositional mechanisms for each of the formations.

A general correlation and synthesis of stratigraphic, palaeontological, palaeoenvironmental and palaeogeographic data derived from the now-separated areas of Carboniferous rocks also has been made in order to determine the affinities and geotectonic status of these Carboniferous sequences and to test some current models for the plate tectonic evolution of northern Turkey.

1.2. DEFINITION AND NATURE OF THE STUDY AREA

Upper Carboniferous rocks are exposed in a number of relatively small outcrops in the northwestern part of Turkey (Fig. 1), where they have stripped off the unconformable or structurally emplaced cover of Mesozoic sediments. As shown on this locality map (Fig. 1), four main areas have been examined.

Area 1 (Zonguldak): this extends roughly from the village of Kandilli in the west and Göbü in the east (Enclosure 1), covering an area of approximately 110 km^2. The Zonguldak Coal field occurs on the Black Sea coast, which is 180 km east of the Bosphorus. It can be reached either by the asphalt road from Istanbul via Düzce and Ereğli, or by the Ankara-Zonguldak highway. The whole of the coal field is characterised by steep hills and deep, forested valleys. From north to south there are two ranges of hills, and farther south a range of higher (mainly Mesozoic) mountains. Mainly there are good exposures of the Carboniferous rocks on the coast line, such as the Alacaağzı bay and Kireclikağzı bay exposures. Many forest tracks cross the area, revealing a few outcrops in the road cuttings. However, while exposures of this type provide good outcrops when new, they rapidly weather and become covered by vegetation. The general structure of the area is a dome flanking to the east, to the north and to the west. The area has considerable economic importance through the presence of the largest known reserves of hard coal and fine clay (Schieferton) in Turkey. The main collieries still working in this area are from west to east: Armutçuk (Kandilli and Alacaağzı) in the west and Kozlu, Üzülmez (Çaydamar, Asma and Dilaver), and Karadon (Gelik and Kilimli) in the east.

The geological map of the Zonguldak area (1:50 000 scale) compiled by M.T.A. personnel, has been used as a base map and has been modified to potray the stratigraphic results obtained in the present study. (see Enc. 1).

Area 2 (Amasra): This area is situated approximately 110 km east of Zonguldak and can be reached by the paved highway via Bartın town either from Zonguldak or from Ankara. Carboniferous rocks outcrop within an area of approximately 15 km^2 limited to the north by the Black Sea shoreline which provides excellent exposures, most of which are accessible by tracks. Inland exposures, are few and poor, although some information has been gained from boreholes. Coal is currently extracted from Tarlaağzı,Çinarlı and Dökük collieries. The potentially productive coalfield is much larger and extends south and southeastwards under probable Permian and Cretaceous rocks.

The geological map of Konyalı (1: 25 000 scale) has been modified and used as a base map for this area, and the logged dection has been indicated with a red line for the Tarlaagzı section (see Enc. 2).

Area 3 (Kurucaşile): This is situated approximately 60 km east of Amasra (Enclosure 3). The Upper Carboniferous rocks outcropping here occur in a narrow strongly disturbed and some 10.5 km long and 500 metres wide. This area is economically less important, only the Kanepınar mine still operating on the eastern side of this so-called Pelitova zone. The Çardak mine in this area was abandoned several years ago because of mining problems. This area is accessible by the main asphelt road from Amasra towards Cide but from the Çardak road junction the Carboniferous area there are only improved tracks. The noteworthy outcrop (Locality 1) is in the Ilyas Geçidi Dere (stream and road cut combination). This section was logged and studied in detail. The second important locality is situated in Değirmendere (stream cut), approximately 3 km east of Haci Ahmet village. The highly deformed rocks in this outcrop do not reveal any useful sedimentological features.

The geological map of the Kurucaşile area, provided by Senturk (1:50 000 scale) has been used as a base-map and the logged section is indicated by a red line on this map.

Area 4 (Azdavay): This is situated approximately 180 km east of Amasra town (Enclosure 4). The area is accessible by partially paved roads either from Amasra via Kurucaşile and Cide or from Bartın via Eflani. The coast road via Cide is in reasonable condition but beyond Cide the unpaved mountain tracks are in poor condition. The second route is also unpaved beyond Eflani as far as Azdavay. This town lies some 900 metres above sea level. Physically the area of Carboniferous rocks is hilly to mountainous with a relief ranging from 700 m to 1800 m. However, only in the marginal parts of the area are exposures limited by dense forests. Again major attraction for this area is coal. However only the Maksut mine, to the north of Azdavay, is still operating, while others such as Söğütözü mine, were abandoned several years ago. Only a few tracks cross the area and road cuttings therefore provide only a few small exposures. The best exposures occur in natural escarpments but are also on few poor stream sections. Basically scattered, the Upper Carboniferous outcrops are intimately associated with Lower Cretaceous flysch. Locality 1, occurs west of Azdavay town, near the Karafasıl village, and the deformed rocks do not provide any evidence of primary sedimentary structures. Locality 2, is on the Azdavay-Cide road cutting and reveals an undifferentiated sequence of Upper Carboniferous clastics and Permian red sandstones. These strata have been thrust on top of the Upper Cretaceous flysch. Locality 3, is near Maksut mine near Yahyabeş village. Locality 4, track side exposures occurs near Kozluviran village and is not well exposed while locality 5, involves trackside exposures near the Kızıllı village (NE corner of the Enclosure 4). Locality 6, represents a track-side exposure some 500 metres east of Özkem village (see Enclosure 4). Localities 3, 5 and 6 have provided logged sections of the Upper Carboniferous rocks of this area.

The geological map is in 1:50 000 scale compiled by M.T.A. personnel and has been used for this study as a base map.

1.3. IMPORTANT NOTE ON TOPOGRAPHIC MAPS AND LOCALITY REFERENCING

It should be pointed out that the acquisition of reasonably large-scale topographic maps of the study area presented major problems. Two sheets at 1:25 000 scale were made available for the Zonguldak

area by M.T.A. personnel. These are Zonguldak sheets of F27 b1 and F27 b2. In the stratigraphy chapter (2) the grid references given for some important logged sections relate to these topographic maps. However, in later chapters only the logged sections are named and these sections are indicated by red lines drawn at the appropriate location on the relevant map (see Enclosures).
Basically, throughout the study, the topographic base has been derived from prepared geological maps and the individual localities are are numbered and displayed on the Enclosures.

1.4. LAYOUT OF THE THESIS.

This thesis is divided into seven chapters. The first chapter consists of an introduction. In the second chapter, previous geological work on the Carboniferous rocks of northern Turkey is summarised, followed by an account of the stratigraphy and generalised structure of the area. In the third and fourth chapters the various facies present in these sequences are defined, described and interpreted. This facies analysis forms the basis of a new lithostratigraphic division of the Upper Carboniferous rocks of northern Turkey. Petrological data are presented in Chapter 5 and brief accounts of the nature and occurence of palaeocurrent data in Chapter 6. The mutual relationships of all these various stratigraphic and sedimentological attributes are utilized to develop the detailed conclusions offered in Chapter 7. The maps and logged sections are presented in the back pocket. All other figures, tables and plates are incorporated within the text.

CHAPTER 2

STRATIGRAPHY, AND RELATED STRATIGRAPHIC AND TECTONIC PROBLEMS

2.1. INTRODUCTION

A combined stratigraphical and sedimentological study has been undertaken in order to establish the sedimentary history displayed by Upper Carboniferous rocks in the Zonguldak and adjacent areas of north-central Turkey.

As a result of this study, a detailed lithostratigraphical sequence has been established and possible chronostratigraphical correlations have been proposed. The stratigraphical analysis of the Upper Carboniferous succession of the studied areas, proposed in this chapter, is based upon lithological differentiation of the rock units together with analysis of fossil flora and faunas and takes due account of the limited amount of previous work.

Consequently, according to their chronological order four different Formations have been defined and described for the entire basin. These are (in ascending order of relative age):

I - Alacaağzı Formation

II - Kozlu Formation

III - Karadon Formation

IV - Kızıllı Formation

Formations I - III were established and named by previous workers but Formation IV is newly defined in the present study.

2.2. HISTORICAL BACKGROUND OF STRATIGRAPHICAL SUBDIVISIONS

It has consistently proved difficult to fix definite boundaries between the stratigraphical subdivisions of the Upper Carboniferous System on the basis of lithostratigraphy, biostratigraphy or chronostratigraphy. This brief account reviews previous work on various lithostratigraphic, biostratigraphic and chronostratigraphic units recognized in the Upper Carboniferous rock of Northern Turkey.

In a pioneer study Ralli (1896, 1933) subdivided the coal-bearing units into four stages, which he termed Alacaağzı, Kılıç, Kozlu and Karadon. He stated that close links existed between his "Alacaağzı Stage" and the Upper Kulm facies of Waldenburg (Germany), between the "Kılıç and Kozlu Stage" and the middle coal basin of Valenciennes (France), and between the "Karadon Stage" and the Western European Coal Measures. He drew attention to the possibility of a stratigraphic gap between the Kozlu and Karadon stages, because he believed that the conglomerates of the Karadon stage represented a transgressive sequence. He also distinguished the Kozlu stage from the Karadon on the presence of quartz-porphyry pebbles in the conglomerates of the Karadon stage. Thus Ralli's definition was based mainly on lithostratigraphic criteria. However, Bayramgil (1949) demonstrated the existence of quartz-porphyry pebbles in both the Kozlu and Karadon stages, and they are therefore not indicative criteria. According to Bayramgil the only petrographic difference between these rock units is that the upper part of the Karadon stage contains Andesitic pebbles.

Following Ralli's study several other workers such as Zeiller (1896, 1899), Simmerbach (1903), Fliegel (1927), Wilser (1927) and Charles (1931), broadly accepted his stage definitions, although the Kılıç stage was not widely accepted.

According to the Code of Stratigraphic Nomenclature (1961 p.28), "the Stage is an important working unit in time-stratigraphic correlation and classification and bears no lithostratigraphic connotations." Currently recognized stages are variable in time-span, but on average they range from 3 - 10 million years as indicated by isotopic age determinations. The thickness of stages in their type sections may range from a few metres to many thousands of metres. Also a stage should be defined in a single, continuously exposed section, in facies favourable for time correlation (Hedberg, International Stratigraphic Guide, 1976). Unfortunately such single complete sections of strata are not common in the Zonguldak area.

Arni (1931, 1938, 1939, 1941) worked for the M.T.A. in the Zonguldak Coal Measures, and published several maps and brief notes. In 1939 he introduced the term "Series" for these groups of rocks, replacing the earlier "Stages" terminology. His definition was based partly on litho-stratigraphic and partly on biostratigraphic criteria. He distinguished two subdivisions within the "Alacaağzı Series". The lower part is characterised by marine faunas with a few plant remains. The upper part lacks marine faunas, but contains Stigmaria and includes more sandy layers. The Alacaağzı Series also contains three units rich in bivalves indicating fresh-water conditions. On top of the "Ali Molla" coal seams the bivalve Cardiopteridium Waldenburgensis has been recognized. According to Arni the Alacaagzı Series demonstrates laterally continuous facies relations whereas the Kozlu Series displays several discontinuous facies and begins with conglomerates throughout the coal basin. However Arni suggested that there is no well defined boundary between the Alacaağzi and Kozlu beds.

Elsewhere in his major work Arni (1939 p.50) used the term "facies" instead of "series" without giving any reason for doing so. He also disputed the conclusion of Ralli and Zeiller, stating that there is no stratigraphical break between the Kozlu and Karadon Series. Arni suggested that the location of this boundary is not certain and offered a phytopaleontologic solution whereby the presence of Lonchopteris is characteristic of the upper part of Kozlu Series while Lonchopteridium Lonchopteris Chaudescise BETR. indicates the lower part of the Karadon Series.

The stratigraphic studies of Hartung (1937), Grancy (1939), Jongmans (1939, 1955), Tokay (1952,1954), Egemen (1959) and Özkoçak et al. (1978) were based on biostratigraphic criteria. They tried to distinguish "Series" according to their plant fossil content.

In modern terminology a "Series" is a subdivision of a System,and is usually further divided into Stages, thus indicating a chronostratigraphic basis. However the term "Series" frequently has been used in the past as a lithostratigraphic term, more or less equivalent to a "group" in the previous work. Also "Facies" in stratigraphy generally refers to the aspect, nature, or manifestation of character of rock strata or specific constituents of rock strata, (usually reflecting the conditions of origin) (Hedberg 1976, p.15).

Basically these workers have adopted a number of lithostratigraphic sub-divisions whose distinctive lithology was supposed everywhere to characterize the rocks generated during certain intervals of geologic time. This approach using "Series" obviously poses problems when dealing with rocks that are the products of locally restricted environments. Another problem in these studies was the duplication of names, which should be avoided, such as the use of "Lower Karadon Series" by Grancy (1939).

Dijkstra (1952) published some details of the geology and megaspore assemblages of the Turkish Carboniferous. He revealed the sharp boundary between the "Alacaağzı Group" and the "Kozlu Group" and found that the vertical distribution of the spores is very similar to that of the Polish Carboniferous.

considered to be indicators of a different and higher stratigraphical level, with a transitional position between the Kozlu and Karadon Series.

Yahşiman and Ergönül (1950 - 1961) studied the Amasra - Söğütözü basin (Fig. 1). They identified three horizons in the Namurian on the basis of megaspores, and four horizons in the Westphalian (Kozlu Series: Westphalian A, and Karadon Series: Westphalian B - C - D). Also they named the Westphalian C the "Schlehan Series" due to its refractory clay content.

In his palynological studies of the Zonguldak rocks Nakoman (1976, 1977) preferred to use the term "zone" without mentioning their lithologic characteristics and previous names, such as "Alacaağzı". According to his palynologic observations the Namurian may be subdivided into 8 biozones and the Westphalian A into nine biozones. The term which he used was unqualified and has been the source of confusion.

According to International Stratigraphic Guide (1976 p.95), biostratigraphic units are fundamentally different from lithostratigraphic units and are based on different distinguishing criteria. The boundaries of the two may locally coincide, but usually they lie at different stratigraphic horizons or cross each other. Where fossil remains are so abundant that of themselves they become lithologically important, a biostratigraphic unit may also be a lithostratigraphic unit. Also Hedberg (1976, p.48) states "There are frequently overlaps or gaps, both vertically and horizontally, among different kinds of units based on different taxons or different kinds of fossils". Biostratigraphic correlation may coincide with time-correlation, or it may be facies controlled and therefore diachronous. In either case, correlation becomes a matter of judgement. Both lithostratigraphic and biostratigraphic units rather closely reflect the environment of deposition, but biostratigraphic units are much more strongly influenced by, and indicative of, geologic age.

Biron (1961 p.234) was the first to use the term "Formation" for these groups of rocks in his mine-gallery profile (Fig. 2), but without giving any explanation for this use. Yahşiman (1961) and Artüz (1980) have also used the term "Formation" for Upper Carboniferous rocks from northern Turkey.

One of the great problems in drawing boundaries within the strata of the Zonguldak area is that lithologically uniform units are of limited lateral extent. The present study has attempted to provide a more standardised framework using distinctive lithostratigraphical features. According to modern rules of stratigraphic nomenclature (Hedberg, 1976 p.33) "A bed is the smallest unit in the hierarchy of lithostratigraphic units. It is a unit layer in a stratified sequence of rocks which is lithologically distinguishable from other layers above and below". The term "bed" is applied customarily to layers of a centimetre to a few metres in thickness. Therefore it is not a practicable term for the Zonguldak area, where, for example, the Alacaağzı beds may reach up to 700 metres in thickness. The other lithostratigraphic unit is a "member" and it is always part of a "formation", although a formation need not be divided into members. According to Hedberg (1976) the thickness of units of formation rank follows no standard and may range from less than a metre to several thousand metres, depending on the size of the units. Practicability of mapping and delineation on cross sections is an important consideration in the establishment of formations. In the present case, the previous work has demonstrated that the distinctive lithological units of Alacaağzı, Kozlu and Karadon can be mapped separately and they can therefore be considered formations. Moreover it is possible to divide the Alacaağzı Formation into four lithologically distinctive members within suitable vertical successions but the degree of exposure does not permit precise and extensive mapping

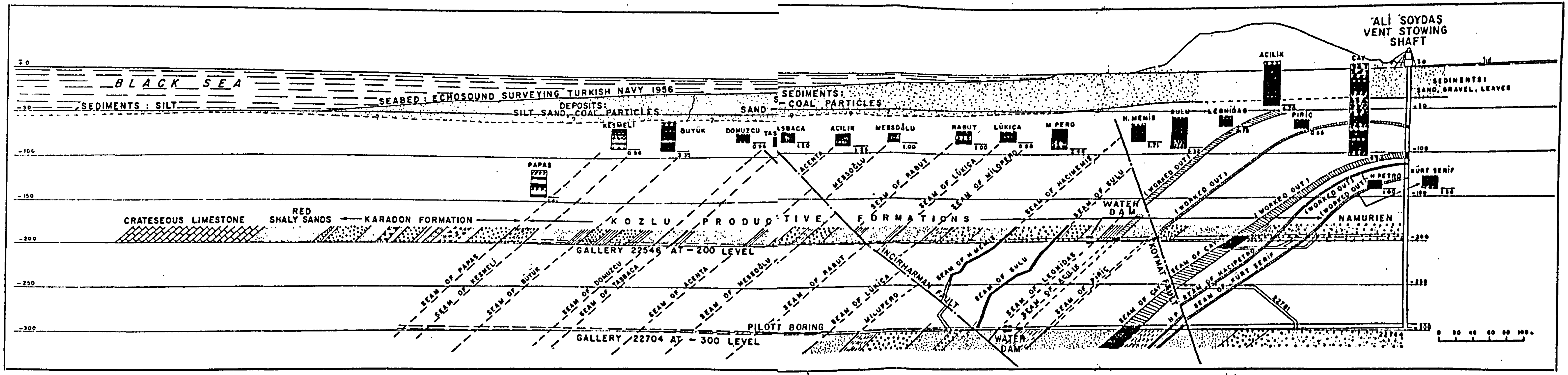


Fig.2.- Gallery profile of Biron's(1961).

UNDERSEA PROFILE OVER GALLERY 22704, KOZLU AREA, ZONGULDAK, TURKEY of these sub-units, and it is therefore considered more appropriate to assign them informal "member" names rather than to erect a formalised formation/member terminology.

The same argument may be applied to the term "Group". Of course formations can be assembled into groups and if it were possible to map these units extensively according to the example given above it might be appropriate, for instance, to refer to the "Kokaksu Formation" the "Gökgöl Formation", the "Tarlaağzı Formation" and the "Asma Formation" under the "Alacaağzı Group" name. Since it is not at present feasible to map constituent units it is again considered more appropriate to adopt formation names such as the Alacaağzı Formation.

In the Zonguldak area the boundaries of formations are placed at positions of marked lithologic change. Most boundaries are indicated by sharp lithologic contacts, but some have been placed arbitrarily within zones of lithologic graduation or they may overlap each other. The boundaries of formations commonly cut across time-horizons, across the limits of fossil ranges and across the boundaries of any other kind of stratigraphic unit. According to Hedberg (1976 p.38) "time equivalence on a local scale can be established by the intertonguing of various strata and by the tracing of marker beds that were deposited more or less synchronously throughout their extents". The only extensive marker beds in the Zonguldak basin are the coal deposits most of which are regarded as broadly synchronous. However, not all coals are necessarily synchronous deposits; if the edges of the coal swamp migrate slowly in one direction through a long time interval, a continuous but non-synchronous layer of coal would be deposited. The lithologic character is commonly influenced more strongly by environment than by age. Even so, a lithostratigraphic unit such as a formation always has some chronostratigraphic connotation and is useful as an approximate guide to chronostratigraphic position (Hedberg, 1976). The analysis of stratigraphic breaks involves the interpretation of several kinds of information in the Zonguldak area. First of all, one seeks to determine how much time elapsed while the local record was being interrupted. More commonly a comparison is made of the strata above and below the postulated break with successions elsewhere that seem to be relatively uninterrupted. Secondly in the case of marine strata it is important to establish whether the interruption of the record resulted from uplift, subaerial exposure and resubmergence. Apart from local penecontemprenous erosion associated with fluvial and deltaic channels, there is little direct field evidence for significant unconformities or breaks in sedimentation in the Upper Carboniferous sequence of the Zonguldak coal field. The most conspicuous periods of non-deposition are those marked by seat-earths.

Normally, where fossils are available, both lithostratigraphic and biostratigraphic analyses are undertaken. In the Zonguldak coal field both types of analysis have contributed to the interpretation of the geological history of the basin. The determination of palaeodepositional environments in sedimentary basins commonly requires a multifaceted approach, in which lithostratigraphic analysis is only one facet.

2.3. PREVIOUS WORK

The Upper Carboniferous rocks of Turkey have been studied by many geologists mainly concerned with the economic importance of these rocks. The existence of the coal beds in these rocks was first brought to general notice by the sailor Uzun Hasan (1829), but they were not systematically exploited by the Turkish Government until the 1930's.

The first systematic geological work in northern Anatolia was done by Tchihatcheff (1850) and the later publications of this worker (1866, 1867) were mainly concerned with Upper Cretaceous fossils found around Ereğli. This last publication mentioned Schlehan's account of the Carboniferous beds at Amasra and also listed fossils sent to him by J. Barkley which had been identified by Brogniart from coal beds or Kozlu, as he had not been able to visit the district.

Schlehan (1852) gave brief descriptions of some patches of Carboniferous near Amasra and provided a list of Carboniferous plants collected in that district.

Admiral Spratt (1877) visited the area to obtain coal for his warship during the Crimean War. His fossil collection was identified by Ethridge and the samples from Kozlu area were assigned a Carboniferous age.

However the most important early contributions concerning the stratigraphy and fossil flora are those of Zeiller and Ralli.

Zeiller (1895, 1896, 1899) compared the fossil flora of the basin of "Heraclee" (= Ereğli, located 70 km west of Zonguldak) with the flora of Upper Silesia. He declared that all the flora is essentially of Euroamerican type. However, Zeiller considered that there was some comparison with the flora of Gondwana through the prescence of Phyllotheca Ralli, (although Jongmans, 1955 later declared that this plant does not indicate a Gondwana flora). Simmersbach (1903) who also worked in the

Zonguldak area, was mainly concerned with mining problems, naming and correlating some of the coal seams. Fliegel (1927) worked in the Carboniferous areas of Pelitova, Azdavay, Söğütözü, Karafasil and Kırmacı, which occur to the east of the Zonguldak basin and indicated the presence of the Upper Carboniferous rocks in these regions.

Wilser (1927) proposed a palaeogeographical reconstruction for Carboniferous times for the Zonguldak basin, suggesting the existence of a peninsular landmass stretching from Northern Turkey to the Donetz basin in order to explain the close relationships between the basins. This land (Pontides) was believed to occupy the Podalya massifs and the Black Sea. Wilser also accepted that the Kılıç beds were equivalent to the lower part of the Kozlu beds. Charles (1933) assingned the Kılıç group to Westphalian A, while the Kozlu group was allocated to the Westphalian A and B. Hartung (1937) re-examined the Zonguldak Carboniferous sequence and put the Kozlu group into the Westphalian B while he assigned the Karadon group to the Westphalian C - D.

Grancy (1939) working on the Bartın-Azdavay area, distinguished some stratigraphical levels according to Jongmans floral determinations, naming the "lower, middle, upper Karadon". Parejas (1941) provided a general interpretation of the palaeogeographical outlines of the Turkish Carboniferous He suggested that the Carboniferous suffered erosion until Hauterivian times in the south, although the Carboniferous was covered by the Rotliegende facies and younger deposits in the north. He claimed that the Jurassic Sea could not have reached south of Amasra otherwise these remnants would have also been eroded.

F. Charles (1947, 1948) defended the idea that the Carboniferous beds of the Ilıksu (Zonguldak) area were emplaced as nappes in the Upper Cenomanian, rather than in exotic blocks, as advocated by Arni.

Later (1948) he suggested that before the Cretaceous Sea covered this area, there were two synclines which he called the Zonguldak and Cide synclines, with an intervering anticline termed the Bartin anticline. Ziljstra (1948, 1950, 1952) produced several maps and sections of the Zonguldak area, and postulated high fluvial energies to account for the coarse nature of sedimentation during Westphalian A times and for the different thickness of coal layers. He also suggested erosion of the Namurian prior to deposition of the Westphalian B - C in the Zonguldak area. McCallien and Tokay (1948) studied sedimentation phenomena of the Cretaceous rocks in the north-central part of Turkey, which contain great exotic blocks of Carboniferous material, up to 600 - 700 metres long and more than 50 metres wide. These authors showed that the boulder beds are accompanied by the usual phenomena of submarine slumping due to earthquake movemnnts. Further articles by Tokay (1952, 1954, 1961) mainly dealt with the 1:100.100 and 1:25 000 scale geological maps of the Ereglı-Alacaagzı and Amasra-Bartin regions and also provided extensive lists of publications condeming the regional geology. His latest publication (1981) basically states the same general conclusions set out in his 1961 papers. Bayramgil (1951) provided petrographic analyses of the rocks of the Zonguldak area. He showed that the Upper Carboniferous rocks are partly composed of arkose and graywacke and partly of conglomerates in which sillimanite bearing quartz grains and pebbles of metamorphic and igneous rocks, such as quartz-porphyry and, more rarely, dacite and andasite, can be found. Fratschner (1952, 1954) suggested that the Namurian beds of Amasra contain more coal than the Zonguldak Namurian. He accepted the Westphalian B - D age of the Pelitovası Series in the Kurucasile area, although Jongmans (1939) placed these beds in the Westphalian D - E. Fratschner also postulated some Carboniferous tectonic windows within the Cretaceous sequences. Patijn (1950, 1953, 1954) published several articles about the Turkish Carboniferous including topographic and geologic maps which showed the location of the various small basins. Gök (1970) gave very brief geological and tectonic descriptions of the coal measures in northern Turkey.

Özkoçak et al. (1978) suggested that Kılıç series belong to lower Westphalian A, Kozlu series to Upper Westphalian A, Karadon series to Westphalian B, C, D. They alos suggested that in the west; Zonguldak, Amasra, Kandilli coal beds are autochthonous, however, in the further east; Pelitova of Kurucaşile, Azdavay, Maksut and Söğütözü exposures are allochthonous inside the Aptien-Albian flysch.

Apart from these general works, several studies concerned largely with plant spores have been published, such as the articles of Artüz (1957, 1963), Okay and Artüz (1964), Yahşiman (1956, 1959, 1960, 1961a, 1961b), Ergönül (1959, 1960, 1961), Ağralı (1963, 1969, 1970), Ağralı and Konyalı (1969), Akyol (1968, 1974) and Nakoman (1976, 1977).

Baykal (1971) gave a general account of the Upper Carboniferous rocks of Turkey in his book entitled "Historical Geology of Turkey", while Brinkmann (1974, 1976) outlined the effects of the Variscan (Hercynian) tectogenesis place during the Carboniferous and Permian in the Black Sea area. According to Brinkmann's map (see Fig. 3), the area roughly north of the North Anatolian fault line is marked by continental deposits during the late Palaeozoic, while south of this line the sediments are of marine eugeosyncline facies, passing gradually to the south into a shelf facies. Bergougnond and Fourquin (1980) suggested that the North Anatolian belt (Pontids) belong to the Eurasiatic continent facing the Tethyan Ocean and are characterised during the Mesozoic by important tectonic and magmatic activity. Şengör et al. (1980, 1981) have suggested that the eastern Pontide tectonic zone consists of two distinct

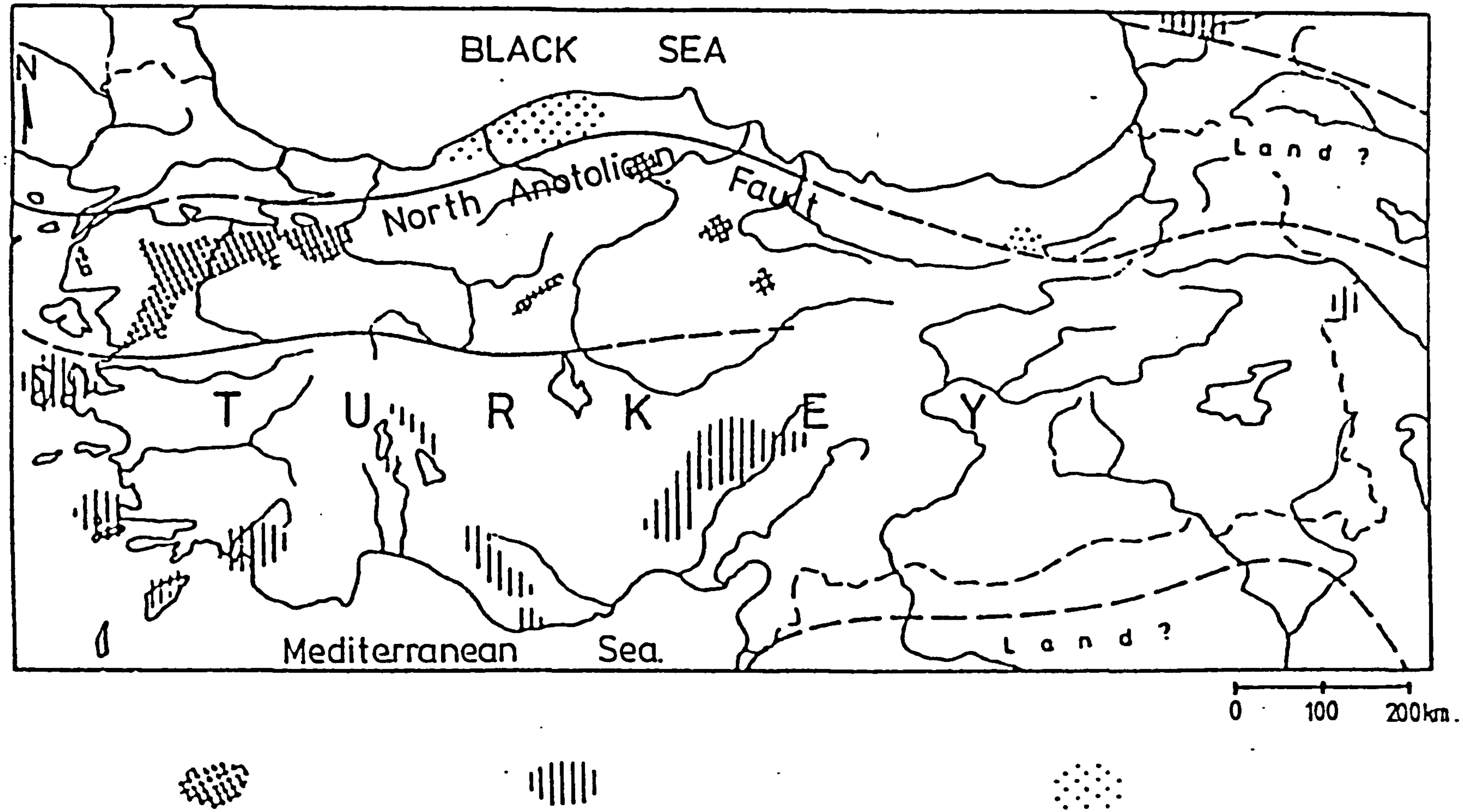


Fig. 3. Distribution, facies and paleogeography of the Upper Carboniferous in Turkey
After Brinkmann, 1976.

lithological associations and add (1980 p. 539) that the first one is "continental assemblage , representing a Permian to early Jurassic north-facing magnetic arc, whereas an oceanic assemblage , including a locally metamorphosed ophiolite suite overlain by deep-sea sediment, is believed to represent the vestiges of an oceanic realm that existed north of the arc during the Permian and Jurassic interval". According to these articles, evidence from the eastern Pontids indicates a Permian-Jurassic ocean with a south-dipping subduction zone. Regional consideration suggests that the suture forms part of an orogenic belt resulting from the closure of the Permo-Triassic Palaeo-Tethys. The oceanic assemblage is viewed as part of a previously formed Cimmerian continent. These suggestions are controversial, and more evidence and detailed work in this part of Turkey is needed to substantiate them.

The M.T.A. (Turkish Geological Survey) have produced several geological and economic maps of different scales concerned with the Turkish Coal Measures and regional geology.Of special importance are the geological maps of the Zonguldak area (1:50 000 scale) which has been modified by several authors, the geological map of Kurucaşile area by Şentürk (1:50 000 scale), the geological map of Amasra by Konyali (1:25 000 scale) and the geological map of Azdavay (1:50 000 scale) by Şentürk and et al..

2.4. LITHOSTRATIGRAPHIC DIVISIONS

2.4.1. INTRODUCTION

The stratigraphic succession of the Zonguldak coalfield can be studied at outcrop, and since the structure consists of rather steeply dipping synclines and anticlines, it is possible to obtain sections of considerable stratigraphic thickness by walking across strike. As discussed above, "Formation" terminology permits the Upper Carboniferous of Northern Turkey to be subdivided into four formations. In accordance with the standards of the Code of Stratigraphic Nomenclature, the main criteria utilised in such a division were "1. definite lithologic composition or a distinctive, interbedded or intergraded succession of lithologic types, 2. observable lithologic separation from adjacent units above and below, and 3. traceability from exposure to exposure", (Krumbein & Sloss 1963, p. 32). All of the formations are, in the field, readily separable into sub-units or "members", some of which are also defined and described here. The members, however, have not been distinguished on the maps because of: 1. time limitation and large size of the area surveyed, 2. the relatively thin nature and almost horizontal position of some members, which make it extremely difficult to realistically project their boundaries on a 1:50 000 scale map. The definition (description) of the formations will be given below, after a brief account of the older formations which lie below the Upper Carboniferous succession.

2.4.2. OLDER FORMATIONS

The oldest formations which are known near the studied area, are the Hamzafakılı sandstone (Silurian) and the Göktepe Schist (Devonian) which occur south of Ereğli. In 1929 Heritsch and Gaertner published the results of palaeontological researches on the Brachiopods, corals, etc., primarily obtained by Nowack, showing the existence of new species and also the presence of the lower Devonian to the south of Göktepeköy. Tokay (1954) showed that the core of the Inkum anticline (which occurs south-west of Amasra) is occupied by Upper Silurian ? - Lower Devonian sandstones (clay and iron-rich), quartzites and fossil-rich limestones (Coblenzian) followed by limestones of middle-upper Devonian age (Charles 1933) and by dolomitic limestone (which is possibly of Tournaisean age) and very thick Visean limestones.

The Visean is well developed throughout the studied areas. These rocks are mainly coral-rich dolomitic limestones interbedded with calcareous shales and sandstones. The Lower Carboniferous as well as the Upper Devonian sedimentation of north-west Turkey occurred under more shallow water conditions and with less detrital influx than is seen in the coeval sequences of Istanbul. These limestones are overlain by dark, fossiliferous mudstones with ostracods, mollusks, goniatites and brachiopods which represent the upper Visean and lowermost Namurian stages (Wagner - Gentis, 1958, Petracheck 1955, Dil and Konyalı 1978). The Tournaisean and Visean deposits of the Zonguldak basin are platform limestones, comparable with the Kohlenkalk (Carboniferous Limestone) of north-western Europe. Similar faunal assemblages are involved and the correlation on the basis of small foraminifers seems well established.

Fine-grained to sandy terrigenous sediments were laid down in some areas, but mostly they are carbonates and were deposited at a fairly low rate of sedimentation.

In the Istanbul area, post-Visean beds are restricted to the western side of the Bosphorus. According to Kaya (1973) possible Namurian shales disconformably overlie the flysch beds and late Visean limestones, but this situation has not been observed in the studied area. A locally exposed unit of reddish shale interbedded with greywackes is the youngest Palaeozoic deposit (Namurian) in the Istanbul area, and represents the first indication in the west of the limnic facies. On the eastern side of the Bosphorus there is no exposure of Carboniferous rocks until the Zonguldak region is reached.

Generally speaking, in the northwestern part of Turkey a series of small Upper Carboniferous exposures appear through a cover of Cretaceous sediments. From west to east these exposures are Kandilli - Alacaağzı - Kireçlikağzı - Zonguldak - Amasra - Pelitovası - Azdavay and Söğütözü (Fig. 1).

The comprehensive study of the Upper Carboniferous formations of this area over the past several years by the Turkish Geological Survey (M.T.A.) and the Eregli Coal Exploitation Enterprise (E.K.I.) on a more intensive scale than has been achieved previously, has yielded a great amount of valuable information, in order to assess the economic value of the coal seams in the Carboniferous formations.

2.4.3. ALACAAGZI FORMATION

The Alacaağzı Formation essentially represents the Namurian sequence of northern Turkey. The name Alacaağzı was given to these beds by Ralli (1896) and he indicated as a type section the Alacaağzı Bay (40 km west of Zonguldak). Rocks of the Alacaağzı Formation are well developed in the Üzülmez Dere, at Zonguldak, (termed in the present work the Gökgöl section, Grid Ref. 188775 - 02500). The Alacaağzı Formation also occurs in the Amasra region. In addition there are a few smaller outcrops at Kandilli, Kireçlikağzı, Çamlı (these three outcrops occur to the west of Zonguldak; see Enclosure I) and Gavurpınarı (west of the Amasra region).

The lower contact of this formation with the older rocks is transitional while the upper contact with the Kozlu Formation is also transitional. The Alacaağzı Formation contains a variety of facies in an almost complete succession of beds dominated by marine fossils but also yielding numerous plant fossils. Lithologically, it is characterized by dark shales and mudstones and fine-grained sandstones. The general thickness of the formation is about 400 metres, and it is laterally traceable from Alacaağzı Bay in the west to the Amasra region in the east. The Alacaağzı Formation can be subdivided into four "members", which may be traced throughout most of the Zonguldak area. Detailed palaeontologic and lithologic aspects of the formation will be given within the description of each member below, together with biostratigraphic data related both to chronostratigraphical boundaries in northern Turkey, and to correlation with the western European successions.

2.4.3.1. Kokaksu "Member"

This lowermost member is limited to the western parts of the basin, being exposed near the South-West margin of the basin. Only the Zonguldak area provides outcrops of the Visean-Namurian transition, especially in the Kokaksu section (Grid Ref. 88000 - 00325), while no other locality is known to show this transition because the Upper Carboniferous basin is generally fault-bounded. The sequence of beds in this transition zone commences with platform carbonates and passes rapidly upwards into dominantly clastic sediments. This local transition is based on sedimentologic evidence and faunal contents which have been identified by Ramsbottom (pers. comm., 1979). The top boundary with the overlying mudstones and siltstone of the Gokgol "member" is also gradational. The rocks vary in lithology from laminated calcareous fossiliferous shales to terrigenous mudstones and include some silty and sandy streaks. The predominantly muddy sediments of this member can be assigned to three main lithofacies designated; 1. Massive clayey lime wackestone and mudstone 2. Mudstone with goniatite beds and 3. Non-fossilifere us mudstones (which are described in the next chapter). In the Kokaksu section the thickness of this member is approximately 40 metres. Laterally outcrops of this member can be seen, from west to east; in the Kokaksu, Ulutamdere, and Gokgol sections of the Zonguldak area, and the Tarlaagzi section.

In this member goniatites, brachiopods and bivalves have been used for biostratigraphic correlation while plant fossils have been utilised only where marine fossils are generally absent. The base of this sequence is characterised by the incoming of some typically Upper Carboniferous brachiopod species, well defined;

Gigantoproductus elongatus,
Gigantoproductus expansus,
Gigantoproductus cf. tulensis,

and some goniatites, bivalves and trilobites,

Dimorphoceras sp,
Streblochordium sp,
Anthracoceras,
Cravenoceras sp,
Dielasma sp,
Stenoscisma ?
Aviculopecten sp,
Chonotes,
Myalina sp,
Posidonia cf. corrugata
Posidonomia Becheri BROM.
Productoides indet
Phillipsenella cf.

According to Ramsbottom (pers. comm., 1980), the various Gigantoproductus species are representative of the Basal Namurian, while Cravenoceras sp and Anthracoceras belong to the Namurian E zone and Posidonomia Becheri BROM is assigned to the P1 (= V3b) zone of northern England. However, according to Wagner (pers, comm., 1980), Posidonomia Becheri represent a much wider range in the north-west European faunal assemblages. The specimen of Phillipsenella cf , has been identified by Owens (1979). According to him this genus occurs in the S.W. province of England and South Wales, in Lower Limestone Shales (Courceyan age). This occurrence of Phillipsenella is the first record of Upper Carboniferous trilobites from Northern Turkey. However, faunal knowledge is still rather inadequate in some regions and is frequently insufficient for a biostratigraphic zonation. The distribution of conodonts is not known and there is little information on spores, especially from the basal part of this member. Nevertheless, considerable progress has been made in recent years on the knowledge of faunal and microfloral elements of the Visean-Namurian transition in northern Turkey. According to Dil and Konyalı (1978), the Visean limestones may be divided into three zones (V1 - 2 - 3), each with numerous fossils, which show that the Zonguldak basin belongs to the same biogeographic province as the Russian Platform. Especially in the Kokaksu section, the Culm facies (V3c) is very characteristic with a transition upwards into the Namurian succession.

According to marine fossils listed above this member may be assigned to the Basal Namurian, in terms of the north-west European successions.

2.4.3.2. GOKGÖL "MEMBER"

The second member of the Alacaağzı Formation is also limited in location to the more western outcrops of northern Turkey, The best exposures are found in the stream cuts of Üzülmez tributaries (Gökgöl section) where this member reaches its maximum thickness of about 70 metres. In the same stream at Zonguldak, the based boundary of this member is gradational with the Kokaksu "Member". The upper boundary of this member is always marked by a sharp contact with the parallel-laminated to microcross-laminated sandstones of the overlying Tarlaağzı "Member". The Gökgöl "Member" can be distinguished from adjacent members by its higher content of silt and sand units, the dark mudstones containing occasional thin, light-coloured, silty laminae. Plant fragments and carbonaceous debris are common and generally concentrated on the bedding planes. Moreover, the mudstone beds contain secondary siderite nodules. These silty mudstones are interbedded with micaceous carbonaceous sandstones which are usually parallel-laminated, dark grey to brown, and moderately sorted. Fine to medium grained sandstone forms a few erosively based beds up to 0.20 - 0.40 m in thickness. Thus, five main lithofacies can be designated in this member, namely: 1. Silty mudstone with siderite nodules 2. Fossilifereous silty mudstone (with bivalves) 3. Muddy siltstone 4. Massive fine grained sandstones 5. Parallel laminated micaceous, carbonaceous sandstones.

This member can be traced laterally from west to east from Kokaksu to Ulutamdere and Üzülmez dere (Gökgöl section) in the Zonguldak area and it can be identified in the exposure at Tarlaağzı in the Amasra area. Towards the top, these sediments are marked by the rapid replacement of marine deposits by near-shore, deltaic and subcontinental deposits, which contain early Namurian plant remains such as;

Diplotmema adiantoides, SCHLOTHEIMA
Sphenopteris adiantoides, SCHLOTHEIMA
Diplotmema edlatoides,
cf.Lyginopteris larischi(STUR) PATTEISKY

and some bivalves

Edmondia cf sulcata,
Palaeoneilo sp,
Solenomorpha,
Myalinids,
Phestia

Since the Gökgöl section in Zonguldak shows the most complete succession of the Namurian in northern Turkey, there has been a tendency to use this succession as the standard for correlation with Namurian rocks elsewhere. The fauna and flora found in this member again suggest an early Namurian age in terms of the north-west European succession.

2.4.3.3. TARLAAĞZI "MEMBER"

The third member of the Alacaağzı formation is best exposed in the extreme western and eastern outcrops of the Carbonifer ous in northern Turkey and displays a somewhat different facies character in the middle of the Gökgöl section at Zonguldak. This member is probably the most extensively developed subdivision of the Alacaağzı Formation in the westernmost section such as Alacaağzı, Kireçlikağzı, and in the coastal exposures to the east of Zonguldak. The best exposures occur in the Tarlaağzı shoreline (Amasra) where the member reaches a maximum thickness of about 250 metres. However, the full thickness of these rocks is not fully exposed in the Zonguldak area (Gökgöl section). As described earlier, where best developed the basal sandstones of the Tarlaağzı member abruptly succeed the topmost units of the Gökgöl member. The upper boundary of this member is represented by the overlying pebbly sandstones (fluvial channel-fill conglomerates) of the basal part of the overlying Asma "Member".

Lithologically, this member is dominated by fine to medium grained, well sorted sandstones which display good internal sedimentary structures, an aspect that assists in distinguishing this Tarlaağzi "Member" from the other members. Most sections of the member show a good coarsening-upwards sequence, passing from mudstones to silty mudstone with secondary siderite nodules, followed by fine grained, ripple-laminated sandstones and coquina bands and capped by coarser sandstones that sometimes display large-scale trough cross bedding and may be cut by small channels with a pebbly sandstone fill. This assemblage of sediments can be assigned to the following lithofacies groups: 1. Muddy siltstones 2. Massive, fine-grained sandstones 3. Ripple-laminated sandstones
4. Megarippled sandstones 5. Coarse-grained, cross-bedded sandstones
6. Micaceous, carbonaceous sandstones with drifted coal fragments
7. Pebbly sandstones with scour fills.

This member occurs on the far west side of the studied area, for example at Alacaağzı and Kireçlikağzı. It is thinner at Zonguldak and reaches its greatest thickness (140 metres) in the east at Tarlaağzı (Amasra area). Lithologically, this member is much siltier and muddier in the middle of the studied area at Zonguldak. In the Tarlaağzı "Member" at Amasra Gigantoproductus expansus occur in several bands in the succession, although this fossil can also be found in the lower levels of the Kokaksu members in the Zonguldak area. Moreover, the Tarlaağzı member contains some bivalves such as;

Rugosochonotes,

Leuftenia spp. lumulata,

which implicate a lower Namurian age for this member.

2.4.3.4. Asma "Member"

The areal extent of this uppermost member is identical with that of the entire formation. The best exposures are found in the Gokgol section near "Asma" coal shaft. The basal boundary is marked by the appearance of erosional channel-fill sandstones, displaying successive fining-upwards sequences, repeated several times. The upper boundary of this member displays a transitional boundary into the mudstones of the succeeding Kozlu Formation. The Asma "Member" displays a variable lithology which can be assigned to six main lithofacies;

1. Pebbly sandstones with scour fills
2. Coarse grained cross-bedded sandstones
3. Massive fine-grained sandstones
4. Medium grained trough cross-bedded sandstones
5. Organic rich mudstones, and
6. Seat-earths and coals.

The sandstones possess lenticular geometry and are variable in thickness from 10 cm to 3 metres. Large or medium scale trough cross-bedding and cross-lamination are the most common sedimentary structures in this member. Petrologically, the sandstones display some important differences from those of the Gokgol and Tarlaagzi members. Although their quartz content is comparable, there is an obvious decrease in the proportion of polycrystalline quartz grains. Lithic fragments are the third most important component after feldspar grains, but they are here mostly of volcanic nature. A few Ganisters have also been found in this "Member", especially in the Gokgol section.

Lateral variability is difficult to trace for this member, since it occurs at outcrops only in the Zonguldak area, however, it can be traced both to the west (Alacaagzi) and to the east (Amasra) on the basis of borehole data and samples. Finally, the Asma "Member", in general, does not display any marker horizon of "datum-line" character, so that it is not possible here to define with precision the time-interval for this member, although this may be obtained by more detailed researches on the flora and microflora. However, the Gökgöl section in Zonguldak has yielded some fossil flora;

Stigmaria ficoides

Lepidodendron sp. cf. L. rimosum

from Alacaağzı; Lepidedondron floited tiwigs.

The possible age-range for this member is from middle Namurian (B) to the Lower part of Upper Namurian (C).

2.4.3.5. GENERAL CONSIDERATION CONSERNING THE AGE AND CORRELATION OF THE ALACAAGZI FORMATION

Fauna and flora groups are of crucial importance for correlation with other parts of the world, particularly when attempting to delimit the classic ammonoid zones of Western Europe. With regard to the floral correlation, one thing must be borne in mind, as Wagner & Higgins(1979,p.17)has pointed out "The indirect nature of the correlation makes it quite likely that the migration factor plays a fairly important role, not only in modifying the stratigraphic ranges of individual species of related taxa in one area and another."

The main subdivision of the Carboniferous system in Western Europe is into two sub-systems: The Dinantian and the Silesian. The boundary between these major divisions lies at the base of the Namurian Series (Ramsbottom et al. 1978) (Fig. 4). In the U.S.S.R. the Lower-Middle Carboniferous boundary, which equates most closely to the Mississippian-Pennsylvanian boundary of North America, lies at the base of the Reticuloceras zones and thus falls within the Namurian of Western Europe. This one was assigned to

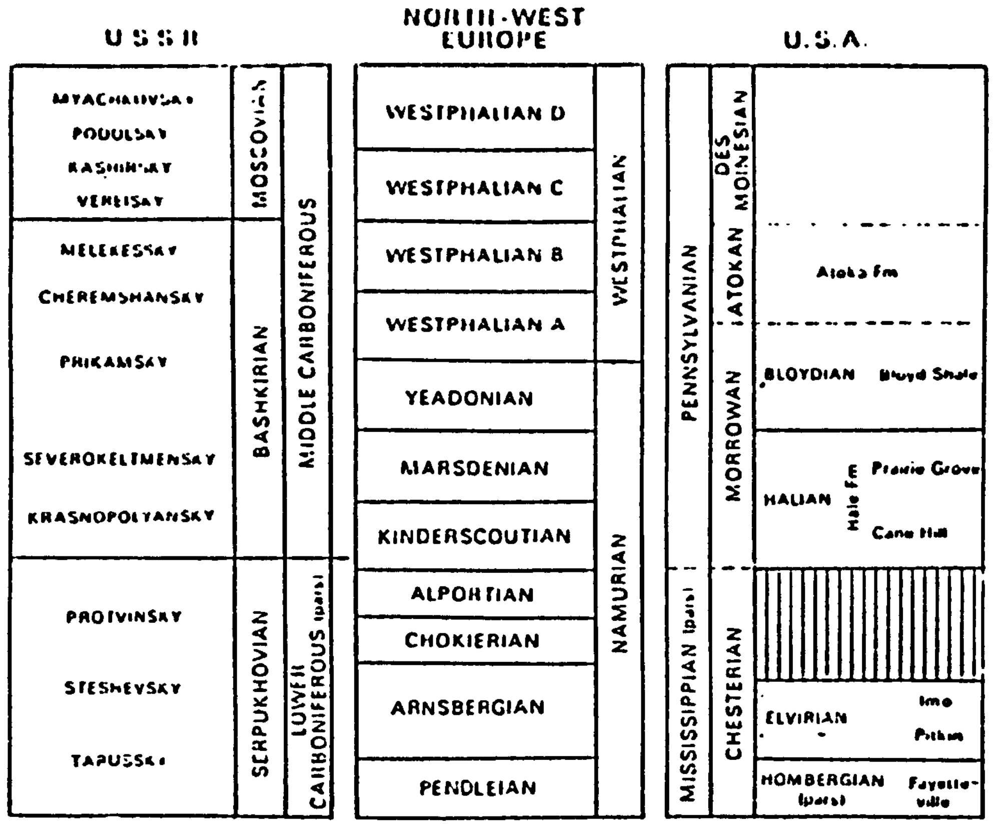


Fig-4- The main subdivision of the Carboniferous system and their correlation after Ramsbottom et al. 1978.

the Namurian B in Hearlen (1935) and is equivalent to the Kinderscoutian and Marsdenian stages of the current classification. According to Aisenverg et al. (1979b) in the Donetz Basin the Bashkirian beds consist of rhythmic alternations of mudstone, siltstone and sandstone, with subordinate coal seams and limestone. Apart from the limestone bands a similar rhythmic alternation can be seen in Northern Turkey, which is thus close to the Donetz Basin in some aspects but shows little relation to Upper Carboniferous deposits from other parts of the U.S.S.R., which probably have a close link with the Western European successions. The boundary between Namurian A and B in Western Europe is marked by significant changes in floral composition, since the Kulm flora disappears at this level, while the impoverished Namurian B flora already shows a Westphalian aspect. Aisenverg et al. (1979a,p.43) add "palaeontological studies have made it clear that an important faunal break exists in the middle of the Namurian in the U.S.S.R.". According to Hevlena (1977), in the coalfields of Upper Silesia and Lower Silesia of Poland and Czechoslovakia, the floral break (Florensprung) of Gothan occurs near the Namurian A - B boundary and is associated with an erosional disconformity. Einor et al. (1979) have suggested that in many areas of the U.S.S.R. the stratigraphic break below the Bashkirian separates an earlier marine, mainly carbonate, succession from a clastic sequence of mixed marine and lagoonal facies (Fig. 5). They state (1979, p.74) that "Since the movements at the end of Serpukhovian times took place on various different continents, they should be regarded as a world-wide event".

In the Zonguldak area the most distinct lithological and faunal change occurs at the end of the Visean rather than within the Namurian. There is no evidence of a widespread break in sedimentation to be observed in the marginal parts of the Northern Turkey basins. The top of the Visean sediments is marked by the rapid replacement of marine deposits by near-shore, deltaic and subcontinental deposits, including coaly beds with early

Fig.5.–Correlation of the main Carboniferous sections at the Lower–Middle Carboniferous boundary.(Composed by O.L.Einor).

Lower Carboniferous				Middle Carboniferous							Series	
Viséan	Serpukhovian			Bashkirian						Moscovian	Stages	
											Variants of Boundary $C_1 - C_2$	
C_{1B}^{2} B_2	C_{1C}^{3}		C_{1D}^{4}	B_3		C_{2F}^{1}	C_{2G}^{2}	C_{2H}^{3} C_{2I}^{4}		C_{2K}^{5}	Suites	Donetz Basin
C_{1g}^{v}	$C_{1g_2}^{v}$ $C_{1a_1}^{n}$	$C_{1a_2}^{n}$	C_{1b}^{n}	$C_{1e_1}^{n}$	$C_{1e_2}^{n}$	C_{2a}^{b}	C_{2b}^{b} C_{2c}^{b}	C_{2d}^{b}	C_{2e}^{b}	C_{2a}^{m}	Zones	
Oksky	Steshevsky, Tarussky	Protvinsky	Nadprotvinsky Beds	Krasnopolyansky	Severokeltmensky	Prikamsky	Tscheremshansky: Lower	Tscheremshansky: Upper	Meleklessky	Vereisky	Russian Platform (horizons, superhorizons)	
Ladeininsky	Nizhnegubakhinsky	Verkhnegubakhinsky	Bogdanovsky	Siuransky (Yakhyinsky)	Akavassky	Askynbashsky	Tashastinsky		Asatausky		Urals (horizons)	
				Lower Substage			Upper Substage				Tien-Shan (substages, zones, horizons)	
				Reticuloceras	*Branneroceras*		*Gastrioceras*					
Mashatsky	Keltemashatsky	Koikebiltausky		Seslavinsky	$C_2^{b_1}$		$C_2^{b_2}$			Koltchinsky		
Viséan	Namurian						Westphalian				Series	West European Stages and Zones
			A	B	C		A		B	C	Heerlen (1935) Units	
Dinantian	Silesian										Subsystem (1958)	
P_2	E_1 E_2	H_1	H_2	R_1 R_2	G_1		G_2	'Anthracoceras'			Goniatite Zones	
Dinantian	Chokier			Andenne				Chatelet			Belgian Units	
	Pendleian, Arnsbergian	Chokerian	Alportian	Kinderscoutian, Marsdenian	Yeadonian		Westphalian A		Westphalian B	Westphalian C	VII Int. Carb. Cong. 1971	
Mississippian				Pennsylvanian							System	North America
	Chesterian			Morrowan			Atokan (Bendian)				Series	
				Lipinella	*Millerella*		*Profusulinella*			*Eofusulina*	Zone	
Hypergoniatites-Ferganoceras	*Uralopronorites-Cravenoceras*	*Fayettevillea-Delepinoceras*	*Homoceras-Hudsonoceras*	*Reticuloceras-Bashkirtoceras*	*Bilinguites-Cancelloceras*		*Gastrioceras*, *Branneroceras*	*Diaboloceras*, *Axinolobus*	*Diaboloceras*, *Winslowoceras*	*Paralegoceras*, *Eowellerites*	Goniatite Genozones (after V.E. Ruzhentcev)	

Namurian plant remains such as Diplotmema adiantoides. Also the megaspore studies of Dijkstra (1952) do not support the idea of a major break in Namurian times in the Zonguldak area. He showed that the megaspores indicate a very sharp boundary between the Alacaağzi Formation and the Kozlu Formation.

In recent years some detailed researches have been undertaken in Namurian microflora from Northern Turkey. Artüz (1959) studied the "Ali Molla" coal seam in the Zonguldak area, and identified some microflora which is of Middle Namurian age. However, the composition of this microflora does not correspond with the microflora of assumed Middle Namurian rocks throughout the entire area (Ağralı 1963; Akyol 1974; Nakoman 1977). Ağralı (1969, 1970) recognized nine biozones in the Namurian of the Amasra area and suggested that only the Namurian A is represented in the Amasra area. Akyol (1974) and Nakoman (1977) have disputed on polynological ground whether the "Ali Molla" coal seams belong to Middle Namurian but suggest they are possibly Upper Namurian or Westphalian A in age (Fig. 6). Nakoman (1977) recognized eight biozones in the Namurian rocks of Üzülmez Colliery at Zonguldak and showed that the spore content are almost the same in both area (Zonguldak and Amasra).

Nakoman also recorded the presence of Rotaspora (Sch) Agr., Procoronaspora Butt & Will., Tripartites Sch., Remisporites Butt & Will., spores that represent Namurian age all over the world.

It is possible to use marine bands as datum planes in Western Europe and some other parts of the world, but their absence or discontinuous nature in the basins of Northern Turkey does not permit the precise levels of correlation possible in other areas, except for the lowest part of the stratigraphic succession. The present study indicates that the Alacaağzı Formation probably belongs to the Namurian A - B stages, and possibly extending into the Lower Namurian C. A possible correlation of the members of the Alacaağzı Formation is indicated in Fig. (7).

	Coal Seam	A.	Z.
NAMURIAN	ALİ MOLLA ?	?	?
		n.9	n.8
		n.8	n.7
		n.7	n.6
	ULUBAY ÜSTÜ	n.6	n.5
	ULUBAY	n.5	n.4
	ÖZTÜTEN	n.4	n.3
	ÖZTÜTEN A.PİÇİ	n.3	n.2
	ÖZTÜTEN B.PİÇİ	n.2	
	ÖZTÜTEN C.PİÇİ	n.1	n.1

A: AMASRA after Ağralı (1969)
Z: ZONGULDAK after Nakoman (1977)
n: Palynological zone

Fig 6– The correlation of the Namurian biozones for Amasra and Zonguldak area, after Ağralı & Nakoman.

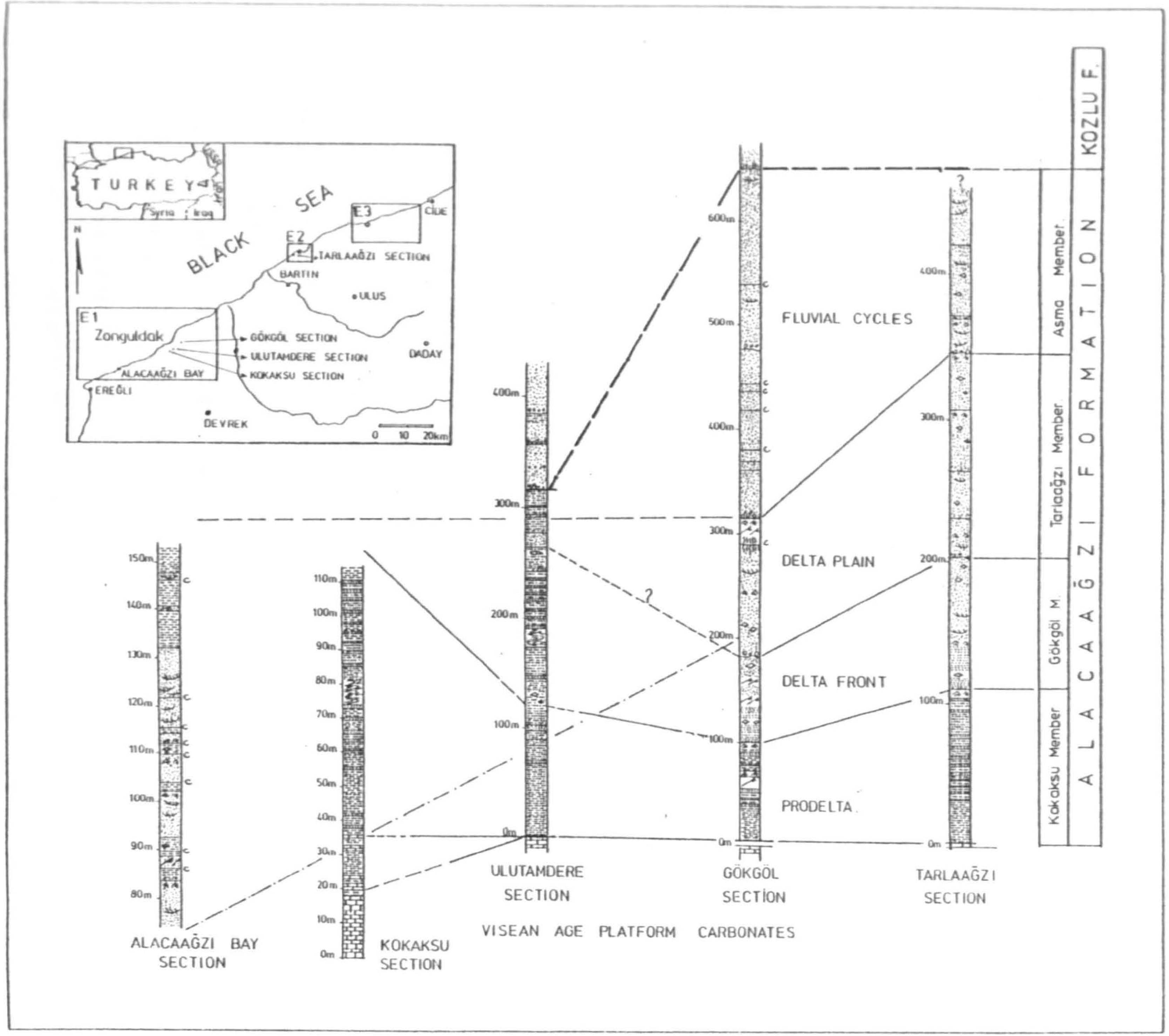


Fig 7. A possible correlation of the members of the Alacaagzi Formation.

c - Coal Seams.

2.4.4. KOZLU FORMATION

The type section is at Kozlu in the Zonguldak area, and particularly in the Istanbul-Zonguldak road cutting, although the basal contact of this formation with the Alacaağzı Formation is not readily identified here. According to BayKal (1971) the sequence commences with the Kürt Şerif Conglomerate. In this study the mudstones below the Kürt Şerif Conglomerate, formerly considered to form the upper part of the Alacaağzı Formation in the Zonguldak area are assigned to the Kılıç "Member" in accordance with the views of Zeiller and Ralli (1895, 1896), although these authors placed these muddy beds in a separate unit lying between the Alacaağzı Formation and Kozlu Formation. The second member of the Kozlu Formation comprises a succession of fining-upward cycles, each grading from pebbly sandstone into fine-grained sandstone and varying in thickness from 20 - 60 metres. These beds are here termed the Dilaver "Member" (Fig.16,17,18,19,20).

The Upper boundary of this formation is marked by thick conglomeratic layers just above the Agop coal seam. The Kozlu Formation is well-developed throughout the sandy area and the thickness in the type area is more than 700 metres. The lithology of the Kozlu Formation can be characterised as consisting almost entirely of continental clastics and prolific coal seams. Indeed, it contains more coal than any of the other formations. The lithology of the Kozlu Formation can be summarized under the following lithofacies:

1. Micaceous carbonaceous sandstones
2. Medium grained sandstones
3. Coarse grained sandstones
4. Pebbly sandstones with scour fills
5. Massive or horizontally bedded framework conglomerates
6. Organic rich mudstones
7. Seat-earths and coals.

Laterally this formation can be traced from Zonguldak towards Amasra in the east and southeast to the Azdavay area. Although there are no Kozlu Formation outcrops in Alacaağzı, Kireçlikağzı and Pelitovası areas, the formation can be detected from boreholes. The Kozlu Formation contains an abundant megaflora and spores. The biostratigraphic data will be given in more detail for each member (see below). According to this floral content the Kozlu Formation falls approximately into the Yeadonian-Westphalian A sequence.

2.4.4.1. KILIÇ "MEMBER"

This lower member has a limited lateral extent, occurring only within the main Zonguldak basin, where its thickest development (30 metres) is attained in the upper part of the Upper part of the Gökgöl section. Apart from this type section, Kılıç equivalents can be detected in the Upper part of the Ulutamdere section, in the eastern part of Ihsaniyedere at Zonguldak.

The basal boundary is placed within the mudstone sequence immediately above the topmost sandstones of the Alacaağzı Formation (Asma member). The absence of a sharp lithological break is attributed to the fact that the fining-upwards cycles that constitute the Asma member of the Alacaağzı Formation gradually pass upwards into the Kılıç "Member". On the other hand the upper boundary of the Kılıç with the overlying hard pebbly sandstones of the Dilaver "Member" is abrupt. This is the most poorly exposed member of the Kozlu Formation. The typical Kılıç "Member" lithology is dark grey mudstone and siltstone, and further details are presented in Chapter 3. The Buyuk Kılıç, Topuz, Sülman, Civelek and Ömerağa are important coal seams occurring in this member. Plant fossils are abundant and are indicated overleaf, with the principal localities;

LOCALITY: 37; South of 520 Coal Colliery.

PLANTS: Neuralethopteris larischi (SUSTA) LAVEINE
Neurodontopteris cf. beraliana (ZALESSKY) comb. nov.
Sphenophyllum amplum KIDSTON
Annularia jongmansi WALTON
Mariopteris beneckei HUTH

LOCALITY: GELIK I; From road cutting, before Gelik Colliery.

PLANTS: Lyginopteris baeumleri (ANDRAE) GOTHAN
Neuralethopteris schlehani (STUR) CREMER

LOCALITY: Acık Yarma 8; West of Guntepe Colliery

PLANTS: Paripteris gigantea (STERNBERG) GOTHAN
Lepidostrobophyllum sp.
Neuralethopteris schlehani (STUR) CREMER
Karinopteris acuta (BRONGNIART) BOERSMA
Lyginopteris baeumleri (ANDRAE)

According to the floral evidence the lower part of the Kiliç "Member" is best assigned to the Namurian C (Yeadonian), while the upper part of this member is of Lower Westphalian A age and is thus compatible with the Kozlu Formation, as noted by Arni (1939).

2.4.4.2. DILAVER "MEMBER"

This upper member of the Kozlu Formation is exposed throughout the entire Carboniferous region of Northern Turkey, extending for about 200 km from west to east. The type section is at Dilaver, in the Zonguldak area, (Asma-Dilaver road cutting) and the maximum thickness of the Dilaver "Member" is about 700 metres.

The base of the Dilaver "Member" is taken at the base of the first conglomerate (Kürt Şerif), while the upper boundary of the Dilaver "Member" is generally marked by the abrupt appearance of a further series of thick conglomerates (12 - 30 metres) . Lithologically the Dilaver member consists of mudstones, sandstones, and conglomerates showing great lateral variability and arranged in a succession of fining-upward sequences, generally dominated by thick sandstones. These rocks can be assigned to several lithofacies, namely:

1. Muddy siltstone
2. Medium-grained cross-bedded sandstones
3. Coarse grained cross-bedded sandstones
4. Pebbly sandstones with scour fills
5. Massive or horizontally bedded framework conglomerates
6. Massive, matrix-supported conglomerates
7. Organic-rich mudstones
8. Seat-earths and coals

The Dilaver "Member" outcrops extensively overlie in the Zonguldak area, but its soft nature leads to much obscuring of exposures through heavy alteration, and it is therefore difficult to correlate exactly from one outcrop to another. In the Amasra area there are few exposures of the Dilaver "Member" the outcrops being strongly disturbed by local faulting and heavy alteration. However, towards the far east of the Amasra area near Özkem village, road cuttings through part of the Dilaver "Member" are found. The Dilaver "Member" is very important with the presence of a number of coal seams rendering this "Member" very important economically, as discussed in the next section.

The range of facies present in the Dilaver "Member" of the Zonguldak area has yielded a variety of floral assemblages but only a restricted fauna, such as fish scales.

<u>Rhadinichthys sp</u>,

This member contains abundant plant fossils, as shown below with their localities also indicated on the (Enclosure1).

LOCALITY: II; Upper Levels of locality Gelik I.

PLANTS: <u>Neuralethopteris schlehani</u> (STUR) CREMER
<u>Sphenopteris limai</u> ZEILLER
<u>Asterophyllites palaeceous</u> STUR
<u>"Seeds"</u>

LOCALITY: Açık Yarma 6; West of Güntepe Colliery.

PLANTS: <u>Sphenopteris limai</u> ZEILLER

LOCALITY: Açık Yarma 7; 150 metres further north from Locality 6

PLANTS: <u>Sphenophyllum amplum</u> KIDSTON
<u>Karinopteris acuta</u> (BRONGNIART) BOERSMA
<u>Sphenopteris limai</u> ZEILLER
<u>Neuralethopteris schlehani</u> (STUR) CREMER
<u>Sphenopteris (Renaultia?) cf. typica</u> (STUR)
<u>Lepidostrobus sp</u>.

RANGE: Westphalian A (Lower?)

LOCALITY: Açık Yarma 8; 300 metres further north from Locality 7.

PLANTS: <u>Paripteris gigantea</u> (STERNBERG) GOTHAN
<u>Lepidostrobophyllum sp</u>.
<u>Neuralethopteris schlehani</u> (STUR) CREMER
<u>Karinopteris acuta</u> (BRONGNIART) BOERSMA
<u>Lyginopteris baeumleri</u> (ANDRAE)

RANGE: Yeadonian-Westphalian A

LOCALITY: Açık Yarma 10A; approximately 500 metres further north of Locality 8.

PLANTS: <u>Mariopteris mosana</u> WILLIERE
<u>Asterophyllites cf. palaeaceus</u> STUR

RANGE: Namurian-Westphalian A

LOCALITY: Açık Yarma 10B; higher level of locality 10A.

PLANTS: <u>Neuralethopteris schlehani</u> (STUR) CREMER
<u>Sphenopteris cf. pseudocristata</u> STERZEL
<u>"Seeds"</u>

RANGE: Namurian-Westphalian A

LOCALITY: 33 South of Kırat Tepe
PLANTS: <u>Neuralethopteris schlehani</u> (STUR) CREMER
<u>cf. Karinopteris acuta</u> (BROGNIART) BOERSMA
RANGE: Namurian Westphalian A

According to Wagner (pers. comm. 1981) the Sphenopteris Limai ZEILLER recorded from localities, Açık Yarma 6 and 7 has been found only in the Zonguldak region and is not known in European locations. This plant was placed in Westphalian A - Westphalian B by Zeiller, but since this species has not been found at stratigraphic levels higher than that of locality 7, which otherwise contains species confined to the Lower Westphalian A or Yeadonian, it is likely that the range of Sphenopteris Limai does not extend into the Westphalian B as proposed by Zeiller, in the Zonguldak area.

LOCALITY: 40; East of Yeşildağ Tepe

PLANTS: Cf. Paripteris sp
Karinopteris acuta (BRONGNIART) BOERSMA
Lyginopteris hoeninghausi (BRONGNIART) KIDSTON
Sphenophyllum cf. cuneifolium STERNBERG

RANGE: Westphalian A

According to the fossil evidence this member may be approximately assigned a Westphalian A age. However, the upper part of the member laterally passes into a lithological sequnce closely resembling the Karadon Formation, which has been assigned a Westphalian B age.

2.4.4.3. GENERAL CONSIDERATION CONSERNING THE AGE, CORRELATION AND ECONOMIC ASPECTS OF KOZLU FORMATION

(i) Correlation of the different areas according to spore content:

Major time-stratigraphic intervals are delineated by the most abundant spore taxa and by the occurrence of certain genera and species that have relatively short stratigraphic ranges. Several authors, such as Artüz (1957, 1963); Yahşiman (1956, 1959, 1960, 1961); Ergönül (1959, 1960, 1961); Okay and Artüz (1964); Ağralı (1964, 1969, 1970); Ağralı and Konyalı (1969); Akyol (1968, 1974) and Nakoman (1976, 1977), have indicated that the Kozlu Formation contains the thickest and most widespread coals in the Carboniferous of Northern Turkey, and that Lycospora and Densosporites are the most abundant spore groups. However, Calamospora, Cyclograinsporites, Crassispora and Punctatisporites are also present. Ağralı (1969, 1970) attempted to correlate the Zonguldak and Amasra areas. He recognized six palynological zones and thirteen sub-zones of the Westphalian A sequence in the Amasra area. His A1 zone is equal to Nakoman's (1977) A2 zone in the Zonguldak area which yields approximately the same spore content as in the "Çay" coal seam. However, the A1 zone of the Zonguldak area, which basically contains Kılıç "Member" coal seams does not appear to be represented in the Amasra area (Akyol, 1974). Also Nakoman (1977) suggested that his zone 5 at Zonguldak is not represented in the Amasra area (see Fig. 8).

(ii) Correlation of the Different Areas According to Fossil Flora and Coal Seams;

The Kozlu Formation also has a rich megaflora, consisting of about fifty nominal species, nearly all of which are from the Zonguldak, Pelitova of Kurucaşile area and Azdavay areas, and several of these have been considered new species or genera by previous workers. More than thirty floras have been collected by the present author, in the Zonguldak, Pelitova and Azdavay regions, during the field seasons of 1979 and 1980. However, in the Amasra region the Kozlu Formation is known almost entirely from mining galleries and boreholes and the fossil evidence indicates that, after formation of the Alacaağzı sequence, deposition continued with only minor interruptions through the Westphalian (Baykal, 1971). There is much confusion about the correlation of the various Kozlu Formation seams. The same name has been given to different seams, and the same seam has been assigned different names for different areas. As a result, information derived from the literature is hard to evaluate, and the use of coal seams

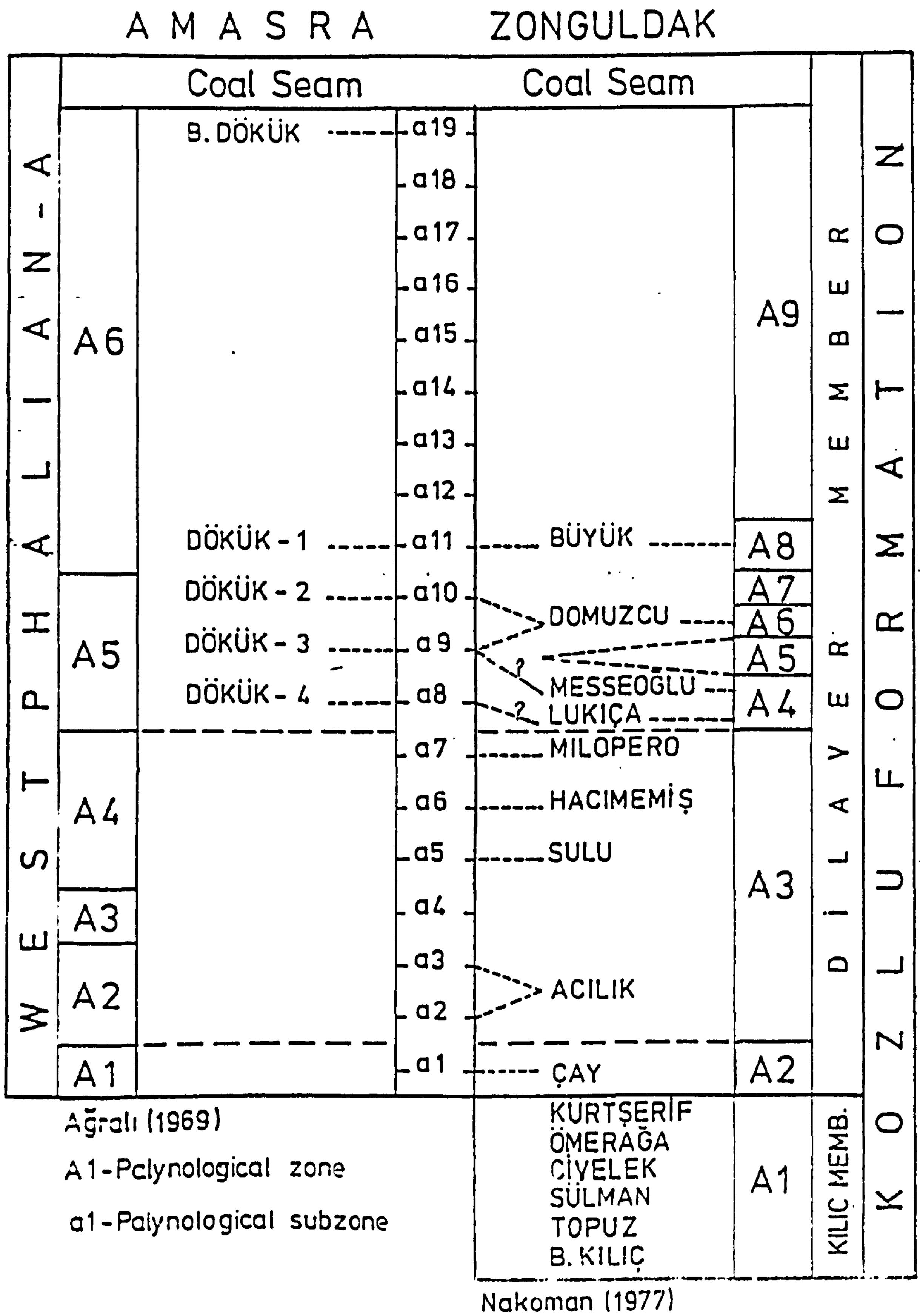


Fig 8- Palynological correlation of Westphalian- A, for Amasra and Zonguldak area, modified after Ağralı & Nakoman.

as stratigraphic marker horizons in Northern Turkey is not yet reliable. However, in the Zonguldak area the coal-bearing sequences have been fairly precisely correlated on the basis of spores in the coals and stratigraphical position in the sequence (Fig. 9).

The outcrops of coal-bearing rocks are rather scarce in the area; approximately thirty coal occurrences have been recorded many of which are prospects or small abandoned mines, and more than ten of these localities have been mined seriously. The Kozlu Formation in the Zonguldak area contains 17 workable seams ranging from 1 - 2.8 metres in thickness and totalling 28.9 metres of coal (Biron 1961). Boreholes indicate that in the Bartin area (Amasra) the Kozlu Formation reaches a thickness of 150 - 300 metres and contain thick mineable coal seams, especially "Dökük" coal seams. Both the Pelitova zone of the Kurucaşile area and the Azdavay area (Enc.3-4) display a strongly disturbed and imbricated structure. Thus, only the Nanepinar mine is still operating in the Pelitova, and the Maksut mine in the north of the Azdavay area, while others, such as the İlyas Geçididere mine in Pelitova, the Söğütözü mine in the north of Azdavay were abandoned several years ago because of mining problems. However, according to fossil plants and palynological studies, Namurian and Westphalian A Formations do not appear to be present in these areas.

(ii) General Correlation with Western Europe.

On the basis of fossil plant evidence the lower boundary of the Kozlu Formation appears to lie below the boundary between the Namurian C (Yeodonian) and Westphalian A in Western Europe. It should be pointed out that the Westphalian of north-western Europe has been distinguished rather arbitrarily from the Upper Namurian, since in most areas marine bands occur throughout the Upper Namurian and the lower Westphalian. However, Upper

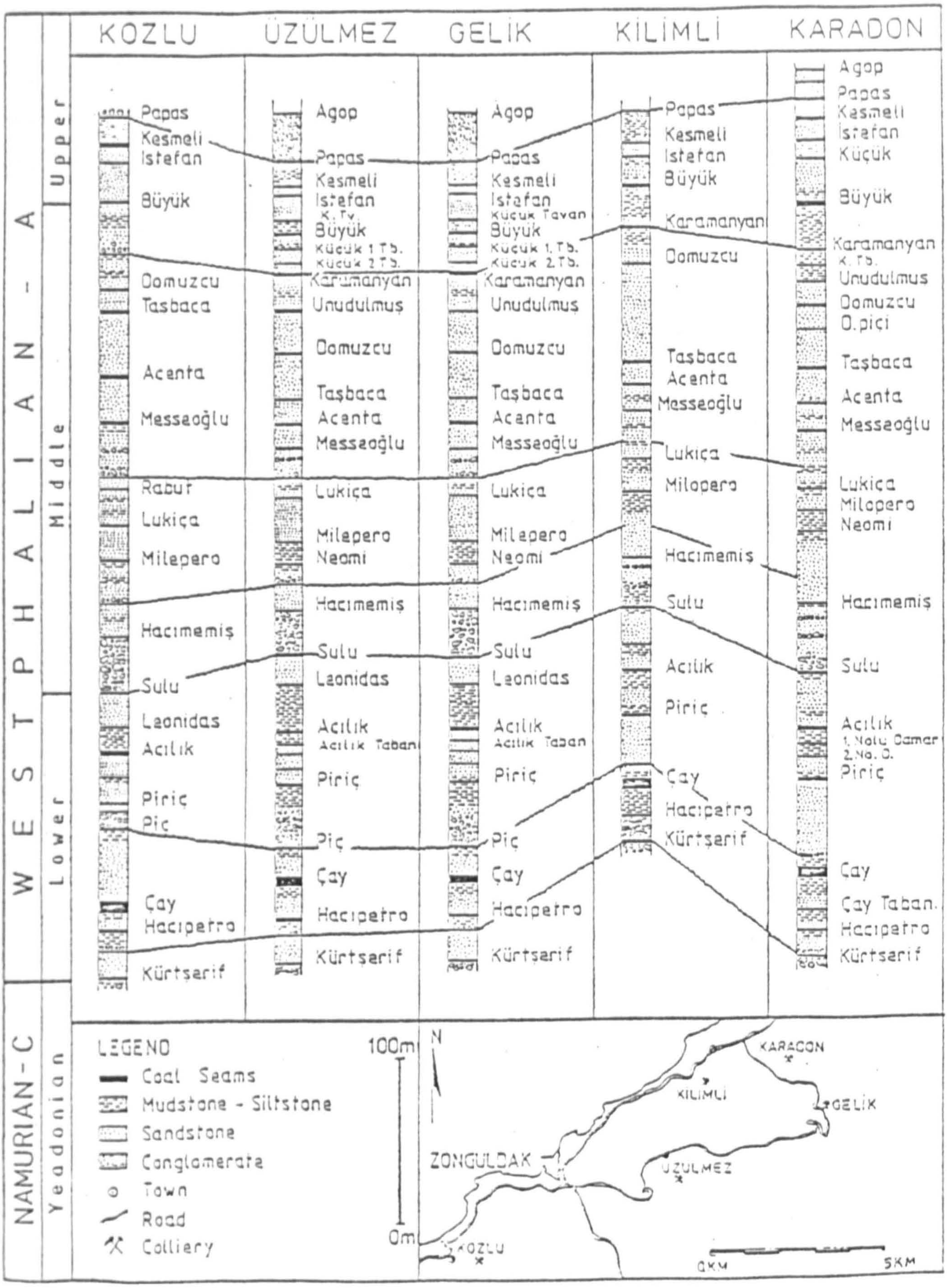


Fig- 9. The correlation of coal seams in the Kozlu Formation from Zonguldak area.

Namurian megafloras are virtually indistinguishable from those of the lowermost Westphalian and there is apparently no major faunal or floral break either (Wagner & Higgins 1979). Thus it is difficult to establish the Namurian/Westphalian boundary all over the studied area in Northern Turkey. Only the Westphalian A/B boundary is marked by a fairly sharp change in floral and spore assemblages.

2.4.5. KARADON FORMATION

The most typical development of the Karadon Formation is in the Kozlu-Zonguldak road cutting and various parts of the Zonguldak area (Enclosure 1). However, rocks assigned to the Karadon Formation are also developed in the Amasra, Pelitova and Azdavay areas.

The lower boundary of the formation is taken at the abrupt lithological break below the conglomerates marking the base of the Karadon Formation. (See Fig.a). However, despite this rapid change in facies the presence of transitional layers with composite floras proves that deposition has been continuous. The upper boundary of the Karadon Formation with Kızıllı Formation is transitional. However, it is possible that this chronostratigraphic boundary is marked by the "Tavan" coal seams of the Karadon Formation in the Amasra area (Tokay, 1961, Agralı, 1970).

The gross geometry of the Formation can be described as a wedge that thickens eastwards from the Zonguldak area towards Amasra, where it attains some 500 metres (according to borehole evidence). Coal-bearing beds are mostly found in the lower part of the Karadon Formation. The coals are irregular in thickness, especially in the Kilimli and Ihsaniye coal mines of the Zonguldak area. On the east (Kilimli) side of the Zonguldak area there are more mineable coal seams than in the western (Ihsaniye) part of the area, and there are even more thick seams farther to the east in the Amasra region.

The Karadon Formation comprises a complex assemblage of non-marine conglomerates, sandstones, siltstones, mudstones , coals and some refractory clays (Schieferton). They can be designated under several lithofacies:

1. Massive or horizontally bedded framework conglomerates
2. Massive, matrix-supported conglomerates
3. Coarse-grained, cross-bedded sandstones.

4. Micaceous carbonaceous sandstones
5. Organic rich mudstones
6. Seat-earths and coals

The Karadon Formation, and especially the upper part of the sequences of organic-rich mudstones contain clays and shales that form actual and potential mineral resources. These fire-clays or "Schieferton" of the Karadon Formation have been tested for their fire-brick potential and have been extracted by Sümerbank at Filyos since 1945.

The vertical variations in the gravel/sand/ mud proportions, the grain size and sedimentary structures can be used to divide the formation into different facies associations, details of which are presented in Chapter IV. However, the inter-relation of these sequences through time and space is fairly complex and lacks lithological distinctness, so that they cannot be regarded as members. Precise mapping of those sequences is by no means impossible, but would require a great deal more time that would be devoted to it during the present study (Fig. 17, 18, 20, 23).

The flora of the Karadon Formation obtained in this study is shown below, as identified by Wagner (pers. comm. 1981).

ZONGULDAK AREA

LOCALITY:	26; South of Kilimli
PLANTS:	Annularia jongmansi WALTON Asterophyllites sp. Calamites sp. indet. Alloiopteris sp. indet.
RANGE:	Westphalian A - B
LOCALITY:	Acik Yarma 10C; approximately 100 metres further from Locality 10B.
PLANTS:	Eusphenopteris cf. obtusiloba (BRONGNIART) NOVIK
RANGE:	Westphalian A-B

LOCALITY: 15; 10 Temmuz Mevkii, just behind the Primary School Garden.

PLANTS:
Sphenophyllostachys
Sphenophyllum emerginatum BRONGNIART
Eusphenopteris obtusiloba (BRONGNIART) NOVIK
Alloiopteris sp.
Karinopteris (Sphenopteris) andraeana (V. ROEHL)
Lonchopteridium karvinensis (Purkynova) comb. nov.
Mariopteris muricata (SCHLOTHEIM) ZEILLER
Paripteris lunguaefolia BERTRAND
Palmatopteris sturi GOTHAN

RANGE: Westphalian B (Lower)

LOCALITY: 22; Büyük Kılıç Colliery, over the gate of galarie.

PLANTS: Eusphenopteris schumanii (STUR) VAN AMERON

RANGE: Westphalian A - B

LOCALITY: Odun Deposu; in the Zonguldak-Ankara road cutting.

PLANTS:
Asterophyllites grandis STERNBERG
Mariopteris sp. indet.
Annularia jongmansi WALTON
Alethopteris davreuxi BRONGNIART

RANGE: Westphalian A (Upper) - Westphalian B

BARTIN (AMASRA) AREA

LOCALITY: Sondaj 60; from 860 metres.

PLANTS: Paripteris linguaefolia BERTRAND

RANGE: Westphalian B - C

LOCALITY: Sondaj 78

PLANTS: Mariopteris muricata (SCHLOTHEIM) ZEILLER

RANGE: Westphalian A (Upper) - C (Lower)

AZDAVAY AREA

LOCALITY: Özkem 2; 500 metres south east of Özkem village.

PLANTS: Mariopteris muricata (SCHIOTHEIM) ZEILLER
Sphenopteris sp.
Eusphenopteris obtusiloba (BRONGNIART) NOVIK
Sphenopteris (Crossotheca) Schatzlarensis (STUR) KIDSTON
Sphenopteris artemisiaefolioides CREPIN
Cordaites sp.

RANGE: Westphalian B

All these fossil plant clearly indicate that the Karadon Formation belongs mainly to Westphalian B and may extend into Westphalian C. It is noteworthy that none of the plant assemblages range into Westphalian D and it therefore appears that the Karadon Formation does not include rocks of Westphalian D age.

2.4.5.1. GENERAL COSIDERATION CONSERNING THE AGE AND CORRELATION OF KARODON FORMATION

Traditionally, the base of the Karadon Formation in the Zonguldak area has been regarded as part of a regional unconformity. Ralli and Zeiller (1895, 1896) proposed the existence of a hiatus between the Kozlu and Karadon Formations. However, Egemen (1959) has concluded that the fossil plants indicate the presence of "transition beds" between these Formations. Arni (1939) offered a phytopalaeontologic solution for this boundary stating that Lonchopteris is characteristic of the upper part of the Kozlu Formation but an assemblage including Lonchopteridium, Lonchopteris Chaudescise BERTR., indicates the lower part of the Karadon Formation, which he termed the "Ihsaniye Beds". Jongmans (1939) pointed out that the lower Karadon of the Azdavay area contains plants indicating equivalence to the middle and upper parts of the Kozlu Formation at Zonguldak which implies diachronous downward migration of the lithological boundary towards the east. Grancy (1939) subdivided the Karadon Formation of the Azdavay area according to fossil plant content into three units: The Lower Karadon; (assigned to the Upper Westphalian A and Lower Westphalian B); the Middle Karadon (Middle Westphalian B - Westphalian C); and the Upper Karadon (Westphalian C-Stephanian). Tokay (1961) recognized similar divisions in the Amasra area. He adds that the Westphalian B can be distinguished from the Westphalian A by the phytopalaeontological evidence. The upper limit is considered to be a refractory clay horizon which generally forms the base of the Westphalian C and is known as the "Schlehan" unit. However, Ağralı (1970) assigns this unit to the Middle Westphalian C. According to Tokay (1961) beds allocated to the Westphalian D stage consist of sandstone and conglomerates which overlie the "Tavan" coal seam (Westphalian C). According to Yahşiman (1961b), it is very difficult to distinguish Westphalian A and Westphalian B in Northern Turkey by means of spore content. The reason is that Setosisporites praetextus exists in both Westphalian A and B, thus definite identification of Westphalian B depends on finding Pollenites, because this spore does not exist in the Namurian or Westphalian A. Ağralı (1970) recognized five palynological zones (twelve subzones) in the Westphalian B of Amasra, according to distribution of Densosporites and Lycospora spore groups. He also erected four palynological zones and twenty one subzones in the Westphalian C of the Amasra region (Fig.10). He suggested that after deposition of the "Kalın" coal seam, there is some discontinuity in the sedimentation.

Up to the present day it has not proved possible to subdivide the Westphalian B and C successions of Northern Turkey in a satisfactory manner.

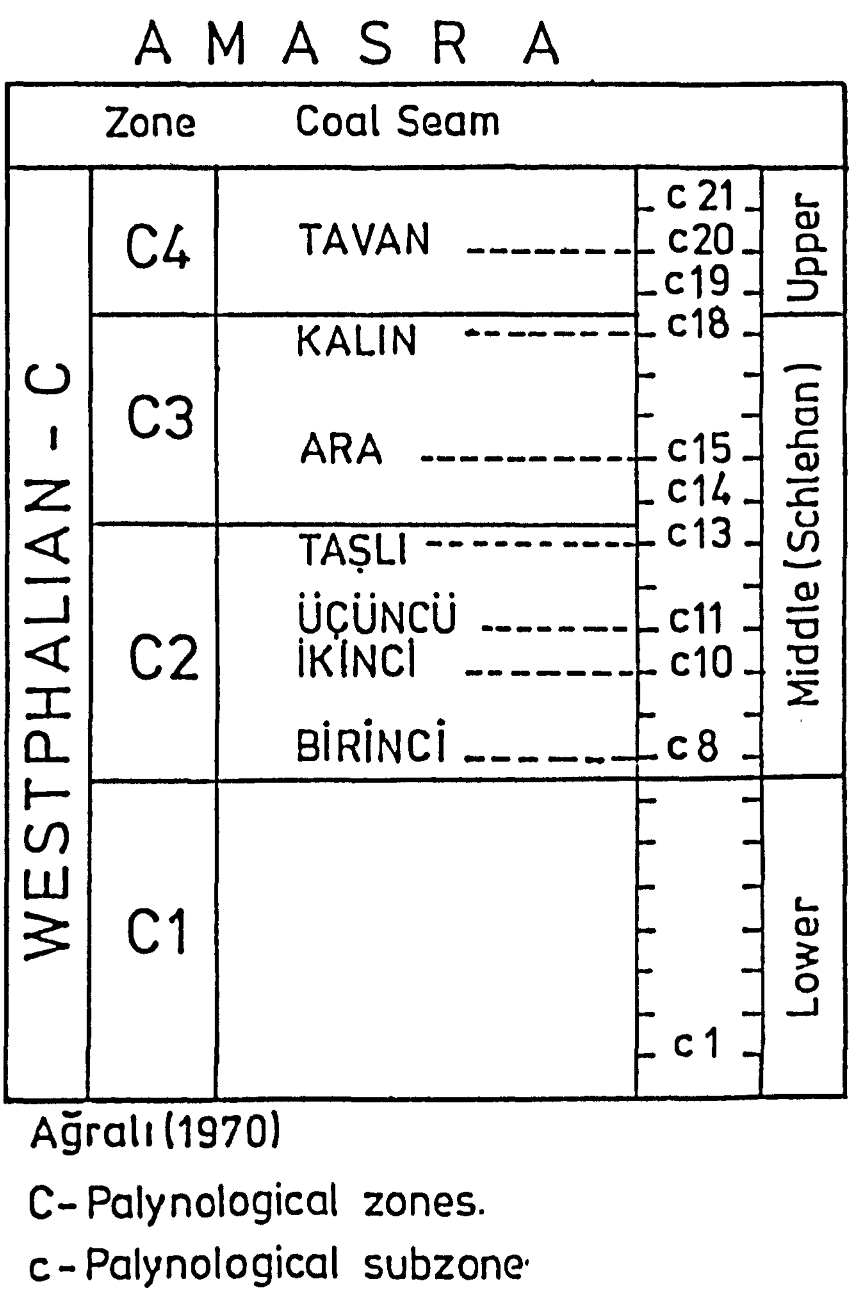


Fig 10– Palynological zones of Amasra area after Ağralı, 1970.

Wagner (1975) has suggested that the Westphalian B/C boundary in Western Europe can only be determined accurately in the belt of Paralic coal measures. On palaeontological criteria this boundary cannot be placed exactly. Therefore it may be correct to include the Karadon Formation entirely within the Westphalian Band C. The base of Karadon Formation is marked by the disappearance of the Lyginopteris flora, while the presence of the Westphalian C is marked by the abundance of Neuropteris and by Paripteris Linguaefolia. According to Tokay (1961) and Agrali (1970) the top of Westphalian C is marked by Tavan coal seam, in the Amasra area. The upper part of the Karadon Formation sequence is not known in the Zonguldak area, but is developed in the Amasra and Pelitova regions because of the unconformably overlying limestones of the Cretaceous, which transgress rather abruptly on the different horizons of this formation in the Zonguldak area.

The correlation potential of non-marine bivalves is rather good in the Westphalian of NW Europe. However, in Northern Turkey there are no significant occurrences of bivalves in the Karadon Formation.

Finally, the Karadon Formation can be correlated with the lower Pennsylvanian rocks of the United States, (Artuz, unpublished data, 1980), and may include the entire Moscovian of the U.S.S.R., together with the upper part of the Bashkirian (Fig. 5) according to the correlation chart presented by Einor et al., (1979), In the U.S.S.R. the position of the

Bashkirian/Moscovian boundary is still controversial in so far as correlation with Western European units is concerned. However, Steponow et al., (1962) placed this boundary at a position corresponding to the Westphalian B/C boundary in Western Europe.

2.4.6. KIZILLI FORMATION

Rocks assigned to the Kızıllı Formation typically occur only to the east of the Zonguldak area, for example in the Pelitova area of Kurucaşile, and in the Azdavay area, especially near Kızıllı village. However, the original extent of the Kizıllı Formation in the Zonguldak area is unknown. In the Pelitova and Azdavay areas, the base of the Kızıllı Formation is represented by pebbly sandstones and pink sandstones which overlie the "Tavan" coal seam of the Karadon Formation. These pebbly beds are followed by the Kurudere coal seam group consisting of three closely-spaced seams. The Kızıllı Formation is covered unconformably by Cretaceous flysch in the Azdavay area, although in the Pelitova area the Kızıllı Formation is followed by Permian red beds, in slightly faulted contact.

The Kızıllı Formation frequently displays two major facies associations: a "coarse member" consisting of sandstone and intraformational conglomerate and a "fine member" dominated by siltstone and mudstones. However, commonly there is no sharp distinction between successive coarse and fine members. In the Pelitova area, coal seams near the base are followed by greenish argillaceous sandstones, while the upper part includes poorly consolidated green and wine-red mudstones and sandstones, which are slightly carbonate-cemented. The maximum thickness of this succession is approximately 100 metres, and is attained in the type-area of Kızıllı in the Azdavay area (Fig.21,22,24,25).

The Kızıllı Formation contains a limited flora, as follows:

LOCALITY: Pelitova; Nanepınar

PLANTS: Alethopteris grandini (BRONGNIART) GOEPPERT
Sphenopteris limai ZEILLER

RANGE: Westphalian C - D

LOCALITY: Cide, IGD.5; Ilyas geçidi dere

PLANTS: Eusphenopteris neuropteroides (BOULAY) NOVIK
Sphenophyllum emarginatum forma truncatum SCHIMPER

RANGE: Westphalian D

LOCALITY: Cide, IGD.7; Ilyas geçidi dere

PLANTS: ? Lobatopteris cf. vestita (LESQUEREUX) WAGNER
Neuropteris attenuata LINDLEY & HUTTON
Lobatopteris cf. calva WAGNER

RANGE: Westphalian D

LOCALITY: Cide, IGD.8; Ilyas geçidi dere

PLANTS: Neuropteris cf. scheuchzeri HOFFMANN

RANGE: Westphalian D

AZDAVAY AREA

LOCALITY: Azdavay - Yahyabeş village

PLANTS: Neuropteris attenuata LINDLEY & HUTTON

RANGE: Westphalian C - D

LOCALITY: Azdavay - KI - 4 (Kızıllı village)

PLANTS: Neuropteris ovata HOFFMANN var. ovata

These fossil flora indicate that the Kızıllı Formation may be assigned to the upper part of the Westphalian C, but is mostly of Westphalian D age.

2.4.6.1. GENERAL CONSIDERATION CONSERNING THE AGE AND CORRELATION OF THE KIZILLI FORMATION

Ağralı (1970) recognized two palynologic zones in the (concealed) Westphalian D sequence of the Amasra area. He showed that the rocks of the lower Westphalian D zone (termed the Kurudere Series by Ağralı) contain assemblages rich in the Lycospora spore group. However, the rocks of the Upper Westphalian D zone (named the Bakacak Series by Ağralı) contain abundant Densosporites spores. This author suggested that the lower, middle and upper Kurudere coal seams can be found at different levels in different boreholes.

The upper part of the Kızıllı Formation contains red beds. Actually red beds (possibly at much higher stratigraphic levels) had been recognized to the east of the studied area in Bayburt by Ketin (1951). Later, Ağar (1977) suggested a volcano-sedimentary origin for these red beds. Recently these strata have been re-examined by Wagner and Demirtaşli. According to Dr. R.H. Wagner (pers. comm., 1980), Stephanian rocks are represented in this area and alternate with volcanic tuffs. This discovery is important because further to the west in the Amasra area, the term Stephanian has been applied to such red beds which up to the present have not yielded definite Stephanian megaflora. For example, Tokay (1961) and Ergönül (1961) argued for the existence of Stephanian rocks in the Amasra area. Their conclusion was based on the following criteria:

a) The appearance of certain spore species of Pollenites and Bentzisporites known from elsewhere to occur at the base of the Stephanian;

b) The local presence of a small amount of limestone in the sequence of rocks assigned to the Stephanian, as opposed to the Westphalian D strata which lack limestones. The conclusions of Tokay and Ergönül (1961) were based on borehole materials but the surface exposures have not yielded any direct evidence of Stephanian in the studied area. However, the fossil plants collected in the present study demonstrate that the beds here included within the Kızıllı Formation are entirely of Westphalian D age.

The Westphalian D stage is presently defined on the presence of the plant fossil Neuropteris ovata, as in the north-west European type section, the Lorraine Coalfield (Laveine, 1977). This plant fossil is also common in the Kızıllı Formation of the Azdavay area of Northern Turkey.

2.4.6.2. GENERAL CORRELATION OF THE LATE WESTPHALIAN

In the U.S.S.R., according to the palaeobotanical data provided by Fissunenko (1974), the Lower Moscovian substage can be correlated with the Westphalian C of Western Europe. The Upper Moscovian substage is also correlated with the Westphalian D of Northern Turkey. The best section for these late Carboniferous deposits occurs in the European part of the U.S.S.R. and they have been assigned to the Kasimovian and Gzhelian substages. Bouroz et al.(1978,p.24)has suggested that "the Gzhelian land plants of the Euramerican realm are generally those of the higher Stephanian and the assemblages are not too different from those of the Kasimovian".

Northwest Europe during Moscovian or Upper Westphalian times suffered a sharp decrease in marine sedimentation and correlation is therefore mainly on the basis of floras, aided by non-marine bivalves. The continental environment seems to have advanced at this time all over the world.

2.5. TECTONIC CONSIDERATIONS

As shown in the geological map (Enclosure 1), the main Zonguldak area displays anticlinal and synclinal structures of general east-west trend. Dips on the northern limbs are generally lower than those on the south, indicating a distinct asymmetry to the structure. Moreover, the southern limb of the main syncline is complicated by a number of minor folds and associated faults of general east-west direction. These structures will be detailed below.

2.5.1. BASIN MARGIN AND MARGINAL FAULTS

Starting from the south of the basin in the Zonguldak area the visean limestones are almost continuously exposed, resting on older formations as mentioned earlier in this chapter. All along the southern half of the basin the limestones dip at high angles to the northwest, reaching 70°- 80° in the Üzülmez Dere (Dere = stream), Kokaksu dere, Ulutamdere in the Zonguldak area. It was probably this steep dip that persuaded previous workers to state that the southern boundary was faulted. However, the field evidence presented earlier concerning the Alacaazı Formation proves that boundary represents a lithological transition but has been subsequently affected by marginal faulting around much of the basin, although the northern margin of the basin has not been observed, being concealed now below the waters of the Black Sea. This lower part of the basin filling sequence is exposed only in the Zonguldak and Amasra areas; further east in Azdavay there is no trace at outcrop of a Visean - Namurian contact, although some boreholes in Azdavay area have penetrated Visean limestones at depths exceeding 300 metres. Generally speaking, the structure in the Zonguldak area is broadly an elongate dome shape, The west flank of this dome, dipping into the

Black Sea, forms the under sea reserves of Kozlu area. This flank dips at approximately 40 degrees, as seen in the Birons galari profile (Fig. 2).

In the Zonguldak area the principal anticline and synclines have been named by Ralli (1933), the Kozlu anticline, Üzülmez syncline, Eliksu anticline and Alacaağzı syncline. According to Tokay (1961) two anticlines and two synclines occur in the Amasra region, namely the İnkum anticline, Gavarpınar syncline, Dıştaşlık anticline and the Tarlaağzı trough.

In the present account only very brief notes will be given on the major faults which cuts the area, according to their importance. The Midi Fault dips 40°- 50° W, displacing in the Çaydamar mine the uppermost seams of Alacaağzı Formation, or lowermost Kozlu Formation. The Karadon Fault forms the western termination of the mining area, but is not accurately known. The other major fracture is the Kuzey Fault, found in the north of the Zonguldak basin. Smaller in throw, but still important, is the Milopero fault which has a displacement of 40 metres and forms the northeast boundary of the undersea workings. The Incirharman Fault, which is quite prominent in all the mine-workings and has a westward horizontal throw of 10 metres, is also important for mining. Tokay (1961) has suggested that the general tectonic movements took place during the later part of Westphalian D times, producing cross-folding superimposed on the intensive fold and thrust structures in the eastern part of the basin, and gave isopachous map of Amasra area.

In the Azdavay area Cretaceous flysch contains displaced and mixed slide masses of Westphalian A,B,C and Namurian rocks. Underneath this group, at depths to which only a few boreholes penetrated, there is an almost outhoctonous relatively less disturbed sequence of Carboniferous formations, consisting of probable Westphalian D and older formations, as well as limestones which have behaved more rigidly than the overlying groups.

CHAPTER 3

DEFINITION AND DESCRIPTION OF LITHOFACIES

3.1. INTRODUCTION

Nowadays, most clastic sedimentologists use the term lithofacies only in the descriptive sense, such as "cross-bedded sandstone". In other words, the usage of the term is restricted to the description of rocks or group of rocks differing from the others by virtue of their primary lithologic characteristics. These facies-defining lithologic parameters include; composition, colour, grain size, sedimentary structures, organic remains, geometry and boundary relations. The clastic lithofacies analysis offered here is based almost entirely upon field observations, and is therefore by no means complete or fully objective.

3.2. LITHOFACIES DESCRIPTION AND INTERPRETATION

3.2.1. LITHOFACIES 1: ARGILLACEOUS LIME WACKESTONES AND PACKSTONES WITH CHERT BEDS

Description: This lithofacies consists of argillaceous lime muds with shelly wackestones and packstones. The rocks are dark to light grey in colour on fresh surfaces. Patches of iron staining may be related to bioturbation indicated by "swirling" fabrics in thin section. Fine skeletal material is present, either scattered or in discrete horizons. This lithofacies is mainly found underlying the Alacaağzı formation and also occurs in the transitional zone overlying the Visean limestone. This lithofacies is best seen in the Kokaksu stream, 1.5 km south of Zonguldak, and is also well exposed at Ulutamdere stream and Gökgöl sections (Figs.11,12,13)In the south the oldest part of the section is unconformably overlain by the Upper Cretaceous age Velibey Sandstone. In the south the lower part of the section consists of well bedded, grey to cream coloured argillaceous lime muds with some fine dolomite. According to Dil and Konyalı (1978), who first measured the section, faunas contained in these beds indicate that the Zonguldak coal field is part of the same biogeographic Province as the Russian platform. Higher in the section, broken bivalves, echinoderm debris and sparse foraminifera are present, scattered in laminated lime mudstones. Towards the top, argillaceous lime wackestones containing fragments of recrystallized molluscs, foraminiferas, crinoid debris and algal clasts are sparsely distributed in the matrix of argillaceous lime mud.

The highest beds consist of a 0.5 - 1 m bed of coarse skeletal grainstones with occasional corals interbedded with lime mudstones and chert beds which contain a sparse fauna of broken brachiopods, bivalves, echinoderms and corals.

Interpretation: The faunal content of these limestones is indicative of a shallow marine environment (Pattison pers. comm. 1980). The combination of grain, and mud-supported textures indicates variable conditions, which are more likely to be encountered in such a shallow sea (Heckel 1972, Wilson 1975). The fragmental nature of bioclasts, and the grainstone aspect, due to the abundance of echinoid plates with syntaxial overgrowths, suggests that these rocks are high energy marine products. However, lime and argillaceous muds dominate the sequence, suggesting prevailing low energy conditions (Folk 1959 and 1962, Dunham 1962). Therefore, bioclastic material was probably introduced into a low-energy environment by storm-indicated currents, or exceptionally powerful tidal currents. The unbroken nature of many bioclasts suggests that some may have been very locally derived.

According to one current concept, the silica is contemporaneous with sedimentation, according to the other view, the silica is a post-depositional replacement of the host rock, generally a limestone. In the first case the silica may be carried to the sea by river waters and the chert must be biochemically deposited. To avoid this difficulty, the second concept appears much more logical. The silicification of limestones, in which the calcium carbonate is replaced by silica, generally in the form of chert, is very common in ancient bedded chert sequences of Pettijohn (1975). For example, the shallow-water limestone-associated cherts, called "cratonic cherts" by Pettijohn (1975), are thought to be silicification products.

In summary, this lithofacies is interpreted as representing deposition in a shallow, relatively sheltered lagoon or embayment.

3.2.2. LITHOFACIES 2; MASSIVE CLAYEY LIME WACKESTONE AND MUDSTONE

Description: This lithofacies varies from argillaceous lime wackestone to calcareous fossiliferous mudstone. Fresh surfaces are dark blue and grey in colour, although some variation occurs, according to the proportion of terrigeneous clay.

This lithofacies is best seen in the Kokaksu dere, Ulutamdere, and Gökgöl sections, Zonguldak, where it makes up part of the Kokaksu Member. The mudstones contain numerous large brachiopods, many in life position, and also bryozoan and echinodermal fragments. Despite the breakage there is little indication of wear and the fragments are randomly oriented, with faunal elements (listed below) that again suggest a shallow shelf environment.

The following fossils have been found in the Kokaksu stream section at Zonguldak, in the upper part of lithofacies 2, and identified by Pattison (1980);

Gigantoproductus elongatus
Gigantoproductus expansus
Gigantoproductus cf.
Gigantoproductus cf. tulensis
Productus indet

Interpretation: The presence of both lime mud and terrigeneous mud indicates a quiet environment where fine material accumulated from suspension (Folk, 1959; Heckel 1972). Such low energy environments may occur either in deep water or in very shallow sheltered environments (Heckel 1972). The nature and distribution of the fauna suggests that deposition was in a shallow marine shelf environment. Moreover, the mud-supported texture of this lithofacies throughout suggests the regional occurrence of low energy conditions, which may be envisaged within a shelf environment at or below wave-base.

3.2.3. LITHOFACIES 3: MUDSTONES WITH GONIATITE BEDS

Description: This lithofacies comprises dark grey to black mudstone, often highly fissile and breaking with a conchoidal fracture. Goniatites occur infrequently in such lithological units and this lithofacies is gradational to lithofacies 4 (Nonfossilifereous silty mudstone with siderite nodules).

Lithofacies 3 occurs typically in the Kokaksu Member of the Alacaagzı Formation and good exposures include the Kokaksu stream section (Zonguldak) and Tarlaagzi section of the Amasra area (Fig.), together with the roadside exposures of "Ilıksu", west of Zonguldak.

Within the mudstones the laminae are parallel and most are 1 - 3 mm thick, sometimes forming shales. The colour depends on the state of weathering. Rusty brown limonite coating occurs on many bedding planes.

The fauna consists mainly of goniatites and pectinoid bivalves. Most goniatites are flat lying. No systematic examination of faunal composition has been carried out in the present study. The principal localities from which goniatites have been obtained, going from west to east, are listed below:

Road side exposures of "Iliksu" on the Istanbul-Zonguldak road-locality contains:

Cravenoceras sp
Chonetes sp

"Kokaksu" stream section, located 1.5 km south of Zonguldak contains:

Dimorphoceras sp,
Streblochondria sp,
Dielesma cf,
Aveculopectan sp,
Stenoscisma
Cravenoceras sp,
Anthracoceras sp,
Posidonia cf. corrugata
Posidonomia Becheri BROM

Nautiloid indet.
Myalina sp.
Phillipsenella sp.

Further east, the Tarlaağzı coastal section near Amasra, contains:

Anthracoceras
Cravenoceras sp.
Posidonia cf. corrugata
Caneyella sp.

Interpretation: According to Heckel (1972), the dark colour of mudstone is caused by high concentrations of finely divided iron sulphide and unoxidised organic matter. He suggested that the type of environment in which such deposits were formed was generally inhospitable to benthonic and nectobenthonic life.

The existence of plant fragments and abundant carbonaceous material indicates the influence of a terrestrial influx on this marine environment. The presence of the bivalves in the goniatite band suggests that here, at least, conditions were not euxinic. However, it can be argued that the fauna lived in the upper oxygenated water and only descended to the floor on death, in which case, the bottom conditions may have been euxinic. It is generally accepted that goniatite faunal bands represent periods of high salinity in an open marine shelf environment (Stevenson and Gaunt, 1971). The absence of any features indicative of current activity, and the fine grained nature of the sediment suggest that the sediments of this lithofacies were deposited from suspension in quiet marine waters.

3.2.4. LITHOFACIES 4: NON FOSSILIFEROUS SILTY MUDSTONES WITH SIDERITE NODULES

Description: This lithofacies develops transitionally from the homogeneous mudstones and grades into siltstones, by an increase in the proportion of silt. Where the percentage of siltstone becomes significant, lithofacies 3 becomes indistinguishable from lithofacies 4. Depending on the silt proportion the appearance of this facies may vary from mudstones with rare and faint silt streaks to current rippled and wavy silt and mud interlaminations. Scattered plant fragments and carbonaceous debris are common.

This lithofacies is typically displayed in the Alacaağzı Formation, especially in the Tarlaağzı coast section of the Amasra region. Other examples occur in the Kokaksu dere, Ulutamdere and Üzülmez dere (here termed the Gökgöl section) stream sections and the Alacaağzı coast section of the Zonguldak area(Fig,11,12,13,14,15).

Siderite is present in this facies throughout the entire studied area. In sequences associated with marine bands in the Tarlaağzı section of the Amasra area siderite layers alternate with grey silty mudstones (Plates 1-2). These layers grade into segmented dish-shaped nodular masses as the enclosing sequence coarsens and becomes less marine. The siderite nodules may be up to 2 metres in diameter and 1 metre in thickness.

Interpretation: The fine grain-size and structureless nature of this lithofacies favour deposition from suspension. The absence of marine fossils and presence of fibrous plant fragments and coal debris all suggest fresh water influence and incursion of an advancing terrigeneous supply. In other words, the environmental significance of this lithofacies may be rather wide.

According to Berner (p. 210, 1980), siderite is rare in modern marine environments. He contends that siderite is not stable in the marine environment and therefore is rare in modern marine sediments. Thus, their occurrence in ancient shales may serve as useful palaeosalinity indicators. He described siderite as a relatively common constituent of ancient non-marine sediments, where it is normally found in association with coal beds and freshwater clay. Mulici et al. (1979) described siderite nodules in the Middle Pennsylvainia coal-bearing sequences of Tennessee. They observed two types of siderite occurrence:

Plate 1. Non-fossilifereous poorly laminated silty mudstones, with siderite nodules (lithofacies 4) from the Alacaağzı Formation.
<u>Locality:</u> Tarlaağzı shoreline, Amasra area. (Height of exposure is 15 m).

Plate 2. Siderite beds displaying faint internal lamination in mudstones of lithofacies; from the Alacaağzı Formation.
<u>Locality:</u> Ulutamdere (stream cut) of the Zonguldak area.

"(1) The conformable disk-shaped masses in the marine intervals, and

(2) the irregularly shaped masses in the fresh water-swamp and upper deltalplain environments."

These authors asserted that both nonmarine and marine siderite deposits are lithified quickly, whether they precipitated chemically as a primary sediment or formed diagenetically.

In the light of above experience in the Alacaağzı Formation, siderite occurs as conformable disk-shaped masses alternating with grey silty mudstone which is considered to be marine in origin. However, these layers grade into segmented disk-shaped nodules as the sequence coarsens upwards, which may be interpreted as thin siderite layers developed within the lower delta-plain environment.

Finally, the presence of ripple-laminated silty layers in lithofacies 4 may indicate current reworking of already deposited sediment by low energy currents (Simons et al., 1965; Allen 1970).

3.2.5. LITHOFACIES 5: FOSSILIFEROUS SILTY MUDSTONES

Description: This lithofacies consists of dark green to grey mudstone with an increased amount of silt. The mudstones appear darker and iron-oid towards the top of lithofacies 5 sequences. It differs from lithofacies 4 through its faunal content. Additionally there are some layers rich in comminuted plant debris. Also small horizontal burrows are encountered on bedding planes of the more silty units while coarse silt and fine sand also occur as streaks or lamination when abundant at certain levels. This lithofacies occurs within the coarsening upward sequence that involves the middle and upper portions of the Alacaağzı Formation. In the Gökgöl section in Zonguldak the following fossils were found and identified by Pattison (1980);

Solenomorpha
Palaeoneilo sp.
Edmondia cf. sulcata
Myalinids
Phestra ?

and Karadon Formation (Plate 3).

Interpretation: The general fine grain-size of this facies suggests predominent deposition from suspension. However, undulatory laminated silt indicates current reworking of deposited sediment by low energy currents (Simons et al., 1965; Allen 1963b, 1970). The silt content and plant debris also indicate a terrigenous supply. Although the fossil content shows marine influence it is less fully marine than the goniatite-rich faunas of lithofacies 3 (Ramsbottom, 1977), and suggests a partially enclosed lagoonal environment.

This lithofacies shows close similarities with Elliott's (1974b) interdistributary bay mudstones which generally develop in shallow water bodies which may be fresh, brackish or marine. According to him, flood-generated processes dominate interdistributary bay sedimentation and combine to produce an association of sedimentary sequences, each of which represent infilling of the shallow bay. (See next Chapter, pp 108).

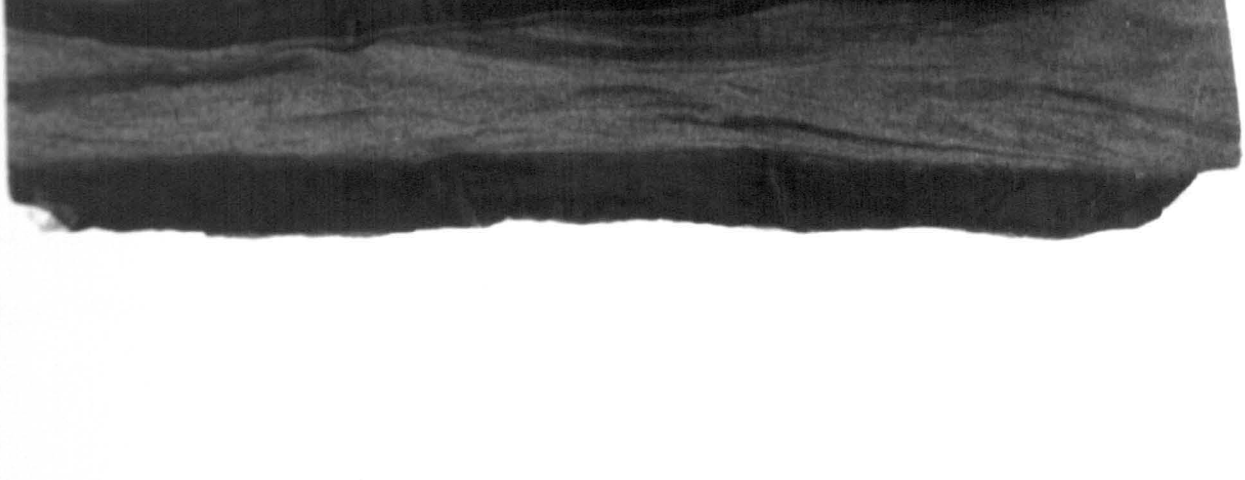
The dark, iron-rich mudstones at the top of the Alacaağzı Formation suggest deposition in a quiet sheltered environment which may be some sort of interdistributory bay or sheltered lagoon, free from any high energy accumulation of detrital sediments.

3.2.6. LITHOFACIES 6; MUDDY SILTSTONES

Description: This is essentially a siltstone facies with prominent mud partings. The lithofacies commonly comprises 1.5 cm thick siltstone beds, wholly or partly wavy laminated, separated by mudstone laminae. Within the dark siltstones there are occasional thin, light coloured, fine-grained sandstones. This lithofacies is gradational into lithofacies 5

Plate 3. Fossilifereous silty mudstones, containing abundant **flora**, with some more blocky units of silty mudstone, from the Karadon Formation (Lithofacies 5).
<u>Locality</u>: Roadcut, 500 metres east of Özkem village, in the Azdavay area.

Plate 4. Muddy siltstones (Lithofacies 6), with flaser and wave-ripple lamination, probably representing a lacustrine environment, from the Kılıç 'Member' of the Kozlu Formation.
<u>Locality</u>: Gelik collieries road cutting, Zonguldak.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and 7. Comminuted plant fragments are generally concentrated on bedding planes and their orientation appears to be random. These plant fragments are associated with abundant tiny mica flakes , which occur in the horizontally laminated part of the muddy siltstones.

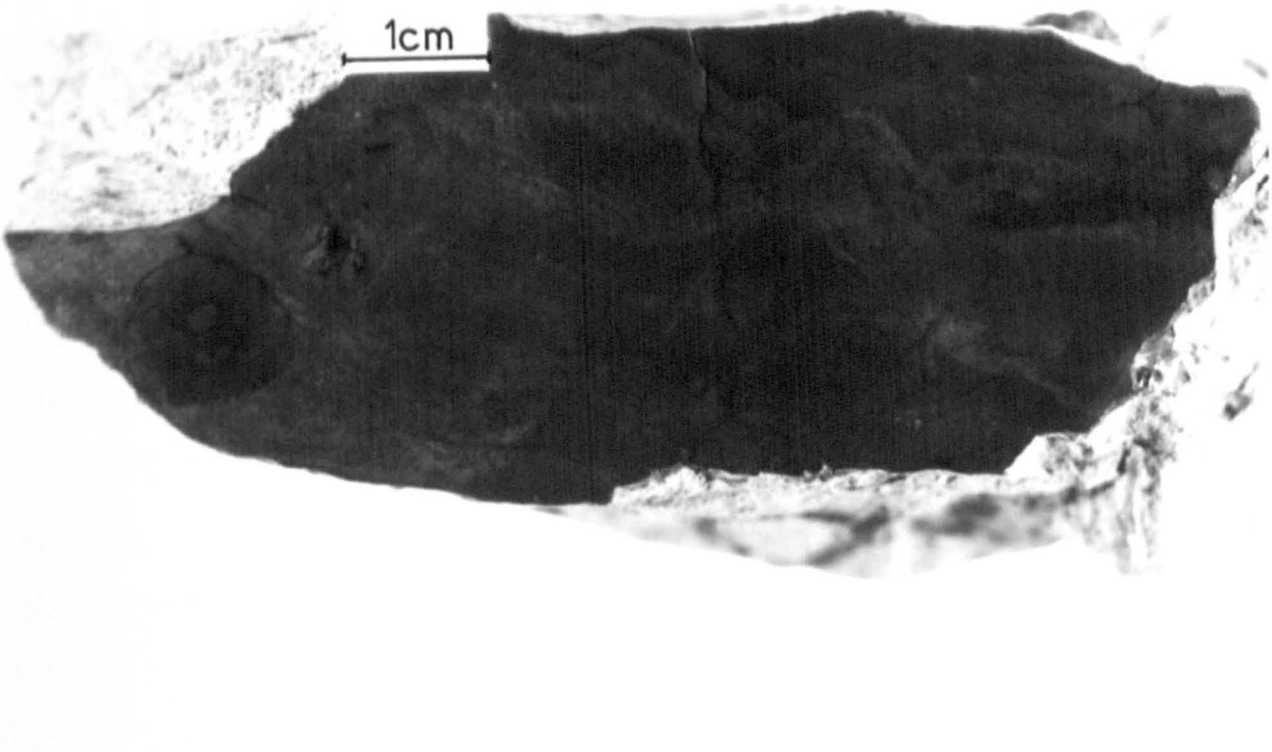
This lithofacies occurs in several outcrops, but is typical of the Kokaksu Member of the Alacaağzı Formation and the Kılıç Member of the Kozlu Formation (Figs. 11,16), Karadon and Kızıllı Formations(Plates 4-5). Interpretation: This lithofacies is associated with both marine and nonmarine sequences. The occurrence and nature of the wavy lamination suggests the presence of low amplitude ripple forms in the silt. Overall, the lithofacies again appears to have been deposited from suspension, although with some fluctuation in the strength of currents (Collinson, et al., 1977). The random orientation of plant fragments indicates that current activity was minimal and deposition was possibly at, or below wave-base. Levell (1980) suggests that a shallow marine occurrence of a comparable muddy siltstone is possible. However, Allen, P.A. (1981a)has described similar lithofacies in the Devonian lake margin environments of S.E. Shetland.

3.2.7. LITHOFACIES 7; ORGANIC RICH MUDSTONES AND CLAYSTONES

Description: This lithofacies may be black, grey, green, cream or red in colour. The lithofacies is poorly laminated and contains a very restricted fauna. Large plant fragments are abundant and widespread. Sometimes lithofacies 7 contains Stigmaria rootlets, thus grading into a seat-earth. Ironstone nodules and good specimens of "Neuropteris" and several other plants also occur. Fossil plants frequently occur on top of the coals (known as a "roof-shale flora" in the literature).

Plate 5. Muddy siltstones with sandy streaks, displaying parallel to undulatory lamination (Lithofacies 6), from the Kızıllı Formation.
Locality: Kizilli section of Azdavay area.

Plate 6. Organic-rich mudstones and claystones (Lithofacies 7) mottled by rootlets, from the Kozlu Formation.
Locality: Dilaver section of the Zonguldak area.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Also at this horizon most of the well preserved leaf and stem specimens are found. Details of fossil plant occurrences are given in Chapter 4.

This lithofacies is especially common in the Kozlu Formation all over the studied area, and is typically developed in the Açık Yarma section, 2 km northwest of Kırat Tepe in the Zonguldak area (Enclosure I) Plate 6. This type of mudstone also has been found in the Kızıllı Formation of the Azdavay area (Yahyabeş Village). At this last locality this lithofacies contains the following bivalves, which were identified by Riley (1980);

Curvirumula sp.
Curvirumula trapeziforma
Carbonita (ostracods)

Organic-rich black mudstones sometimes contain fish fragments as in the Kozlu-Zonguldak road cutting exposure, 500 metres west of Zonguldak city boundary sign on the Istanbul road. This has been identified by Riley (pers. comm., 1980) as:

Rhadinichtuys sp.

This lithofacies sometimes contains fossil charcoal. Note also that the fire clay, known as "Schieferton" commonly alternates with this lithofacies and coal bands (Lithofacies 18) are also found.

Interpretation: Finely laminated, organic-rich black fissile shale units have previously been interpreted as organic-rich muds accumulating in the centre of a lake or else during a phase of little detrital input (Scott, 1978). Generally speaking, this lithofacies is deposited mainly from suspension, (Allen 1965a) The plants may have already been living on the floodplain itself or else may have been brought in together with the sediments. They are interpreted as floodplain deposits (i.e. overbank deposits) rather than as interdistributary bay sequences(Elliott, 1974b), because true marine fossils are absent, and because of their close lateral and vertical association with fluvial lithofacies. On the other hand, the argillaceous nature of the mudstones and the presence of bivalves and rare fish scales indicate that the area was constantly under water, such as would be consistent with lake deposition. Scott(1979) has suggested that such lake deposits were probably formed by swamp subsidence and the nature of the flora would suggest that they come from swampy lake margins. Alternatively, the muddy layers were deposited in shallow temporary lakes or ponds which originated by ephemeral rainfall in flood-plain areas. A similar situation can be deduced for the sequence in the Istanbul - Zonguldak road cutting (Plate 7). As shown in this section thick conglomerate commonly succeeds this lithofacies. Therefore it is suggested that during periods of exceptionally high flow, when the stream inundated the flood basin, it was sufficiently powerful to carve a shallow "flood" channel through the floodplain, and thus carry with it coarse sediments. The red coloured mudstones of the Kızıllı Formation are similar in all respects (except colour) to the lithofacies 7 units of the Kozlu Formation and are again interpreted as flood plain deposits formed in a rather more arid environment (Plate 8).

3.2.8. LITHOFACIES 8; PARALLEL LAMINATED MICACEOUS CARBONACEOUS SANDSTONES

Description: This lithofacies is usually represented by parallel-laminated, grey to brown, moderately to well sorted, fine sandstones with lamination marked by mica-rich layers carrying some carbonaceous material. Fine to medium grained sand forms sharp-based beds up to 0.20 - 0.40 m in thickness. The lemination produced by differences in grain size, is emphasized by mica content and often by abundant comminuted plant fragments. Occasionally, thin quartz-rich streaks and isolated ripples

Plate 7. Organic rich dark mudstones, which have yielded fish scales (Lithofacies 7), from the top of the Kozlu Formation; overlying conglomerates belonging to the Karadon Formation.
Locality: Kozlu-Zonguldak road cutting.

Plate 8. Red mudstones with thin silty partings (Lithofacies 7), from Kızıllı Formation.
Locality: Kızıllı section of the Azdavay area.

occur. This lithofacies is generally succeeded by ripple-laminated or trough cross-laminated sandstone. In a few cases parallel-laminated sandstones follow pebbly sandstones, or these facies may alternate with each other to form lenticular sand bodies, generally occurring near the base of the fineing upwards sequences.

This lithofacies typically occurs in the Kozlu Formation, especially in the Açık Yarma, Gelik sections and the Kozlu-Zonguldak road cutting (Plate 9, 10) of the Zonguldak area.

Interpretation: According to Harms et al. (1975) parallel-laminated and low-angle planar cross-stratified sediments are characteristic of the breaker zone and zone of swash and backwash, but similar structures may be formed in slightly deeper water close to river outfalls where the sea or lake shore gradually shoals.

P.A.Allen (1981a) has suggested that the presence of horizontally-stratified fine sandstones in the Devonian lacustrine sequences of S E Shetland, results from the wide distribution of river-derived sediment rather than concentration in deltas.

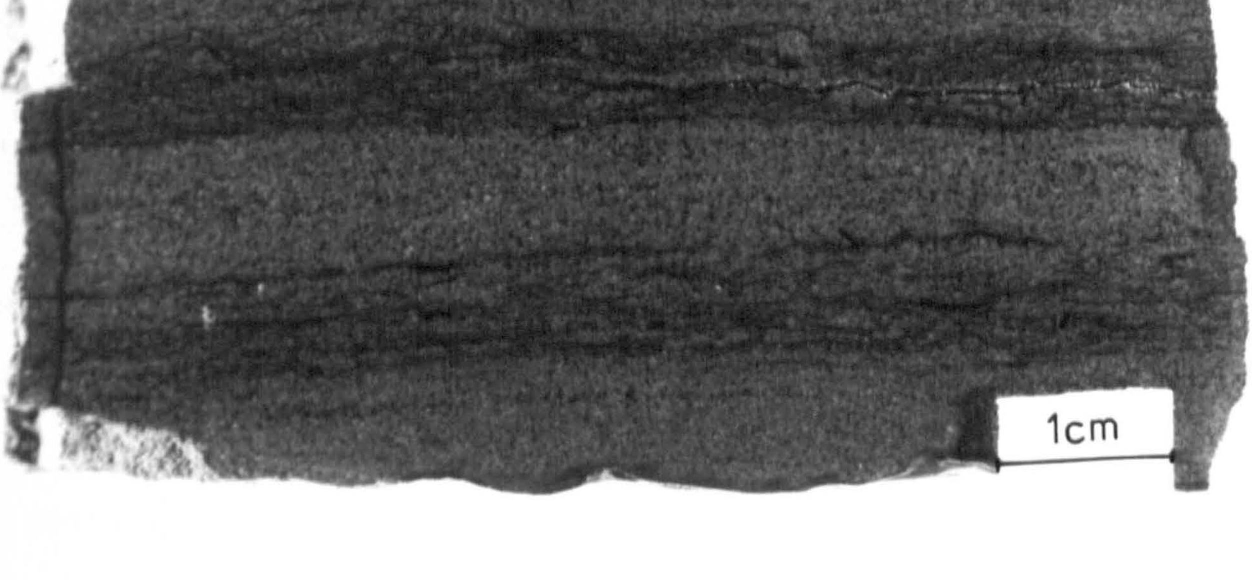
In the study area the grain size and abundance of easily transported material within this lithofacies suggests deposition in a relatively sheltered area mainly from suspension but with some minor traction to account for the isolated ripples. The parallel laminated nature of the sandstones, combined with parting lineation and good sorting or winnowing, indicates deposition from unidirectional currents in the lower part of the upper flow regime (Allen 1964, Simons et al., 1965).

3.2.9. LITHOFACIES 9: MASSIVE FINE GRAINED SANDSTONES

Description: This lithofacies is characterized by fine to medium grained, moderately sorted sandstones, and the presence of micaceous and disseminated carbonaceous material. The beds are 1 cm to 1 metre in thickness. The

Plate 9. Parallel-laminated micaceous, carbonaceous sandstones (Lithofacies 8), from the Kozlu Formation.
Locality: Kozlu-Zonguldak road cutting.

Plate 10. Close-up of parallel laminated sandstone which contains carbonaceous and micaceous material associated together with poorly ripple-laminated fine sandstones.
From same locality as Plate 9.


1cm

bases are sharp, erosive and usually flat, but may display scours and some loading. The beds are often lenticular. No internal structures can be discerned, apart from a rather irregular horizontal plane near the top of some units. P.C.L. has been observed on some upper surfaces.

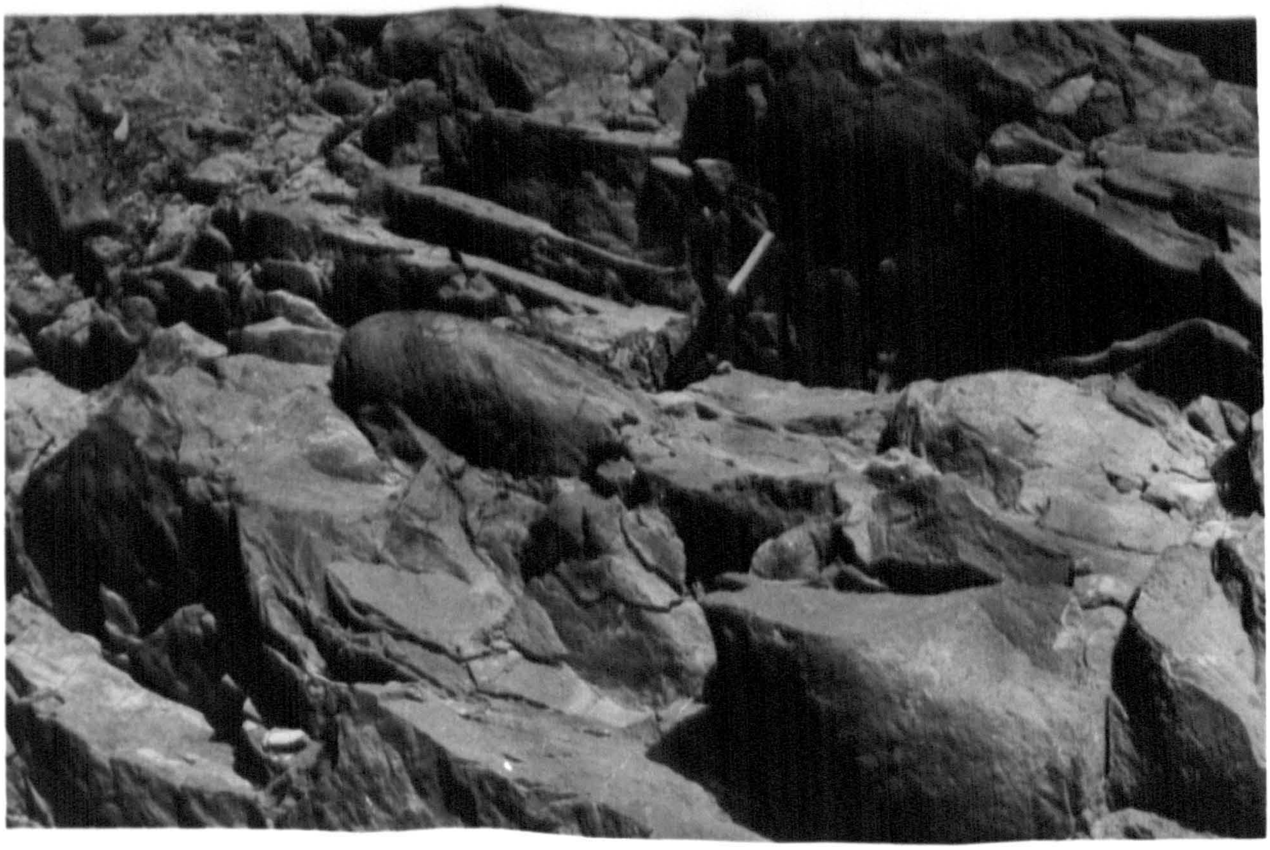
This lithofacies is typically developed in the Gökgöl and Tarlaağzı "Member" of the Alacaağzı Formation. For example, in the lower part of the Ulutarndere stream, above which is found a series of laterally continuous, medium-grained, parallel-laminated to massive sandstones. Individual beds are usually distinct, even where they are in mutual contact. Sometimes, amalgamation occurs and wood fragments are aligned parallel to the azimuths recorded from the primary current lineation. The amount of basal erosion is small and in most cases the scours are only 10 to 20 cm deep.

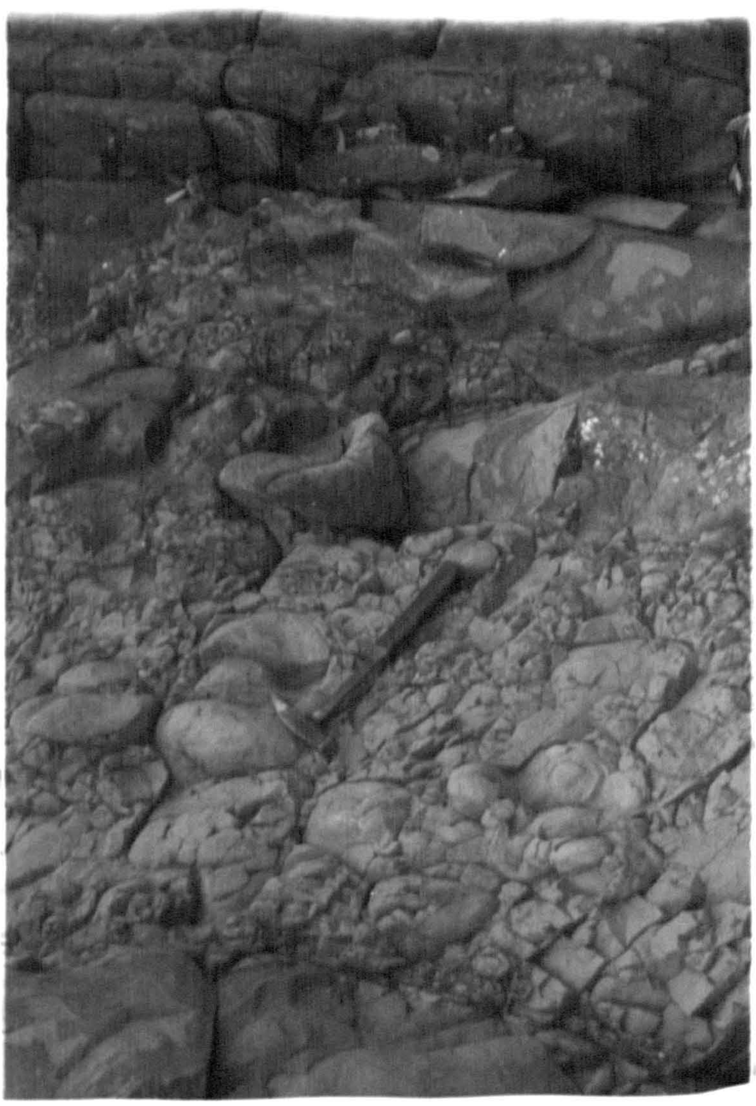
In the study area some Ball and Pillow structures have been found and associated with this lithofacies, such as in the Gökgöl section (Plate 11) of the Zonguldak area and in the Tarlaağzı section (Plate 12) of the Amasra area. These resemble the deformation structures described by Kelling and Williams (1966) from the Lower Limestone Shales (Tournaisean) of South West Wales. In each of these deformed units the upper surface is clearly erosional although the lower boundary may be less obviously scoured. Moreover, some units have internal surfaces of erosion with truncated folds. The pillows themselves may be structureless or show laminated structure. In the latter case, the laminae are generally curved or deformed (Reineck and Singh, 1980).

Interpretation: The general aspect of this facies is reminiscent of turbidite sequences: arenites with erosive bases and bed amalgamation. However, the common occurrence of predominantly structureless and

Plate 11. Massive, fine-grained sandstones (Lithofacies 9) which contain large Ball and Pillow structures, from the Alacaağzı Formation.
Locality: Gökgöl section of Zonguldak area, behind the building.

Plate 12. Possible deformation or Ball and Pillow structures, in fine-grained silty sandstones, from the Alacaağzı Formation.
Locality: Tarlaağzı shoreline of the Amasra area.





conspicuously lenticular beds marks a significant difference from the typical turbidite sequence. Jones (1977) has suggested for a similar facies that fairly rapid deposition occurred from some kind of erosive, turbulent, but laterally restricted current. Collinson, et al. (1977, p.66) suggest that the same idea " the characteristics of this facies suggest rapid dumping of sediment from powerful, initially erosive, currents". The presence of Ball and Pillow structures also supports this idea, the pillows clearly indicating that rapid deposition occurred. Moreover, the long axes of the pillows do not show a consistent orientation, as might be expected if they were related to a local slope, as suggested by Hubert et al., (1972).

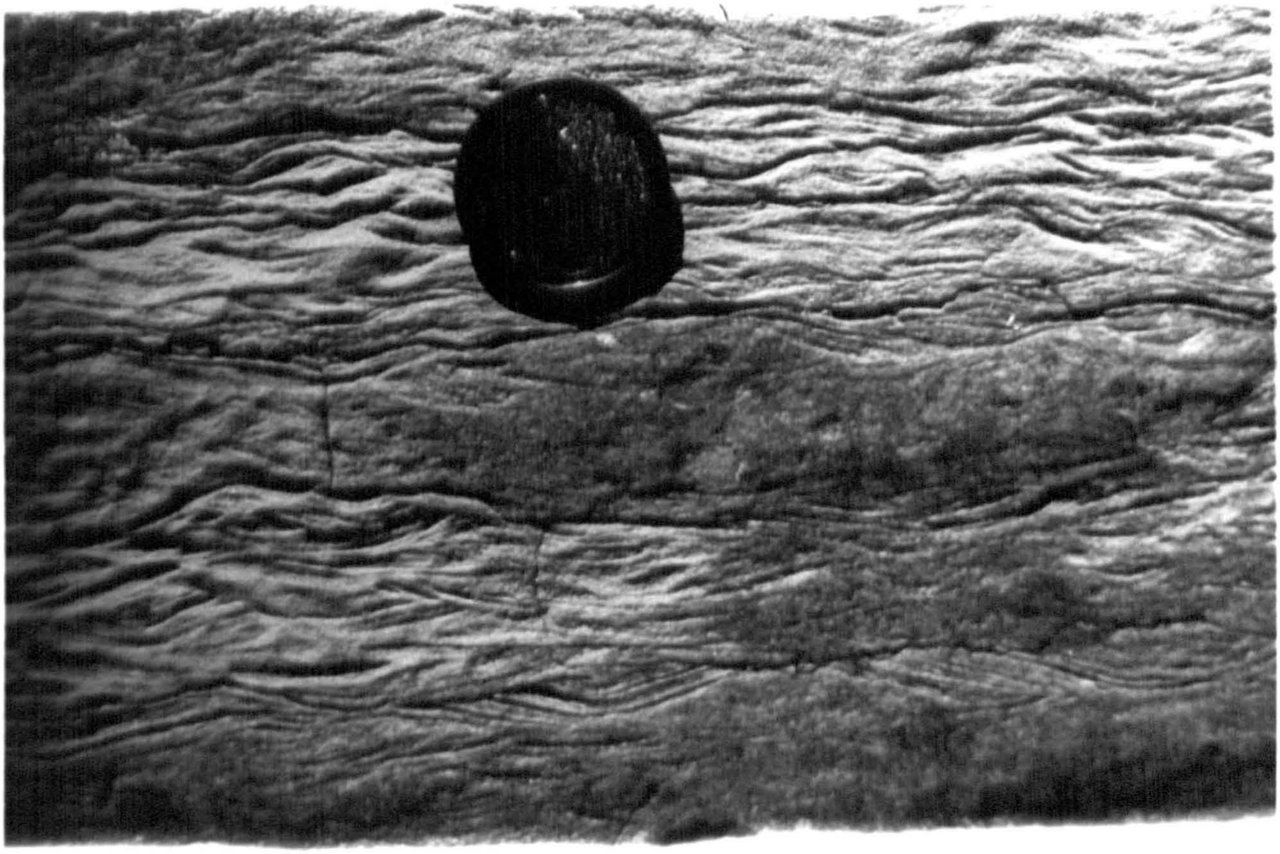
In summary it is possible that these beds were deposited by currents erosive and powerful in their early stages which subsequently dropped their load rapidly, causing localised loading and leading to vertical deformation.

3.2.10. LITHOFACIES 10; RIPPLE LAMINATED SANDSTONES

Description: The sediments of this lithofacies vary from clean, well sorted, fine to medium grained sandstones to poorly sorted "dirty" micaceous and carbonaceous sandstones, forming micro cross-laminated sets sometimes separated by minor units of silt or mud. Some of the current ripples show internal silty drapes and laminae within the beds, associated with convolute lamination (Plate 13). Commonly current ripples occur near the base of the sandstone body and clean wave ripples near the top. The bases of individual beds are sharp. This lithofacies is readily distinguished from all the others because the ripples are much smaller (individual cross-laminated sets are

Plate 13. Ripple-laminated sandstones (Lithofacies 10). Lower part shows current ripples, middle part contains convolute lamination, current lamination and gradually passes upwards into wave lamination, and micro. cross-laminated sets separated by minor units of silt or mud. From the Alacaağzı Formation.
Locality: Tarlaağzı shoreline of Amasra area. Scale is approximately one-half of that of Plate 14 (below).

Plate 14. Wave rippled fine-to-medium sandstones (Lithofacies 10), displaying straight-crusted forms and lamination picked out by fine carbonaceous debris. From the Alacaağzi Formation.
Locality: Kireçlik ağzı bay, 30 km west of the Zonguldak.



approximately 2 cm thick). On top of the wave ripples coquna beds commonly occur. In some cases interwoven and linsen types (cf. de Raaf et al., 1977) are found. Ripples may be straight-crested or linguoid in plan and lamination is picked out by fine carbonaceous debris.

The best examples of this lithofacies are in the Tarlaağzı "Member" of the Alacaağzı Formation, found in various exposures in the study area, but especially at Kireçlikağzı Bay, (Plate 14) and at Alacaağzı Bay (Plate 15), located approximately 40 km west of Zonguldak, where the ripple laminated sandstones are abundant. The Kılıç "Member" of the Kozlu Formation also displays this type of lithofacies, for example, in the Gelik section of the Zonguldak area and in Yahyabeşköy (Azdavay area).

Interpretation: Allen (1963a) interpreted the structure of asymmetrical ripple structure as due to the migration of small scale ripples under conditions of net sedimentation. The degree of stoss side erosion or "climb" of the ripple drift is controlled by the rate of sediment fall out from suspension (1968a, p.112). He adds that three dimensional asymmetric ripples have been described from a wide range of fluvial and marine environments (Allen 1968a, p.130).

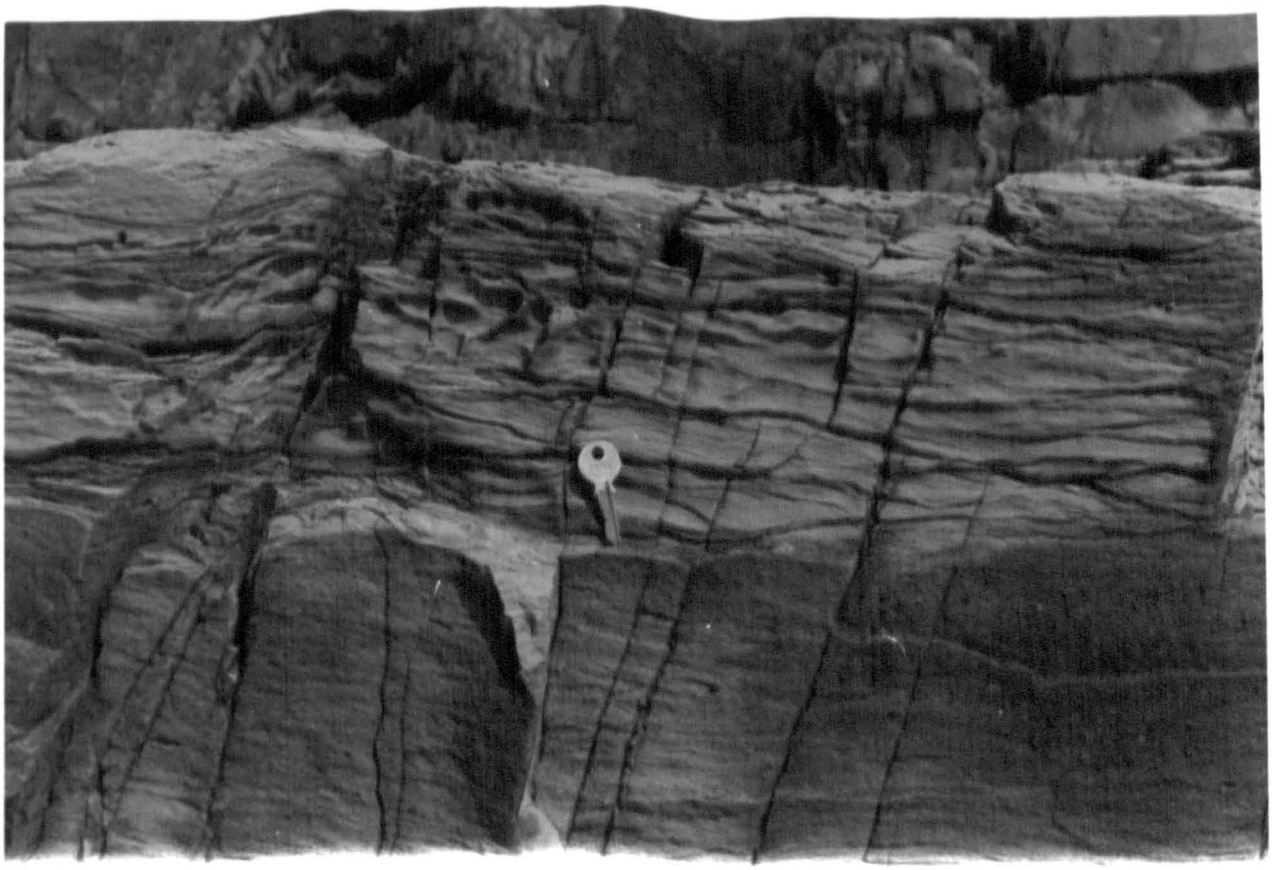
Harms and Fahnestock (1965) observed two types of ripple in the Rio Grande, one lunate and the other lungoid. Later, Harms (1969 showed that there is a whole range of forms between current dominated and wave dominated ripples.

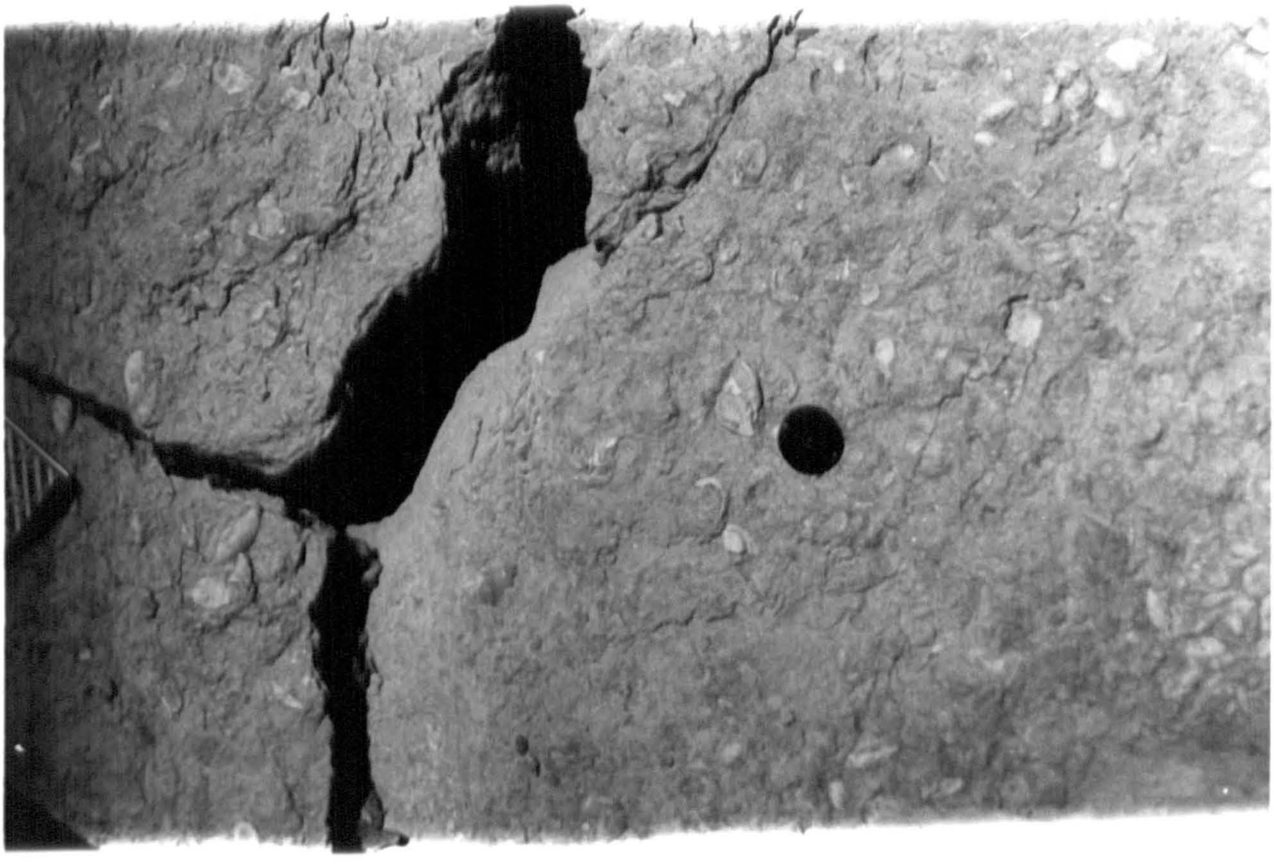
This lithofacies results from the activity of unidirectional and bidirectional (wave) currents in the lower part of the lower flow regime, the currents operating with rather fluctuating strength in some cases (Simons and Richardson, 1961).

De Raaf et al., (1977) have shown that in a shallow marine late Devonian/early Carboniferous succession of County Cork, Ireland,

Plate 15. Wave-rippled fine sandstones (Lithofacies 10), from the Alacaağzı Formation.
Locality: Alacaağzı bay, 40 km west of Zonguldak.

Plate 16. Coquina beds with coarse sandy matrix (Lithofacies 11), containing abundant whole or broken brachiopods, from the Alacaağzı Formation.
Locality: Tarlaağzı shoreline, Amasra area.





that interwoven and linsen types of cross lamination are the most common structures with the subordinate horizontal and undulatory lamination.

In the study area, linsen intervals were probably produced under conditions of low to moderate wave action. For the interwoven wave rippled sediments, it is reasonable to infer continuous wave activity. There is no evidence of emergence, such as desiccation cracks and the cessation of the wave activity is marked in most cases by a draping of dark grey mud over the symmetrical profile of the wave generated cosets. However, most of the time lithofacies successions are capped by coquina beds which may indicate storm activity on top of the ripple laminated sandstones.

3.2.11. LITHOFACIES 11; COQUINA BEDS WITH COARSE SANDY MATRIX

Description: Coquina units are most commonly associated with rippled sandstone units of lithofacies 10. The lower part of the coquina beds contains a sparse brachiopod fauna. The upper part contains brachiopod shell fragments and is dominated by obscure horizontal stratification. This lithofacies contains predominantly Gigantoproductus, (Plate 16), within a coarse sandy matrix. The beds vary from 10 - 50 cm in thickness, are very extensive and may be traced for several kilometres. The coquina beds commonly occur in the Tarlaağzı "Member" of the Alacaağzı Formation, and are typically developed at Tarlaağzı Bay, Amasra. In this area, the coquina beds display a dark brown, coarse sandy matrix and contain an abundance of whole or broken shells which are 1 - 5 cm in size, of equidimensional shape and randomly orientated on the bedding surfaces. In plan view a few in situ brachiopods are present.

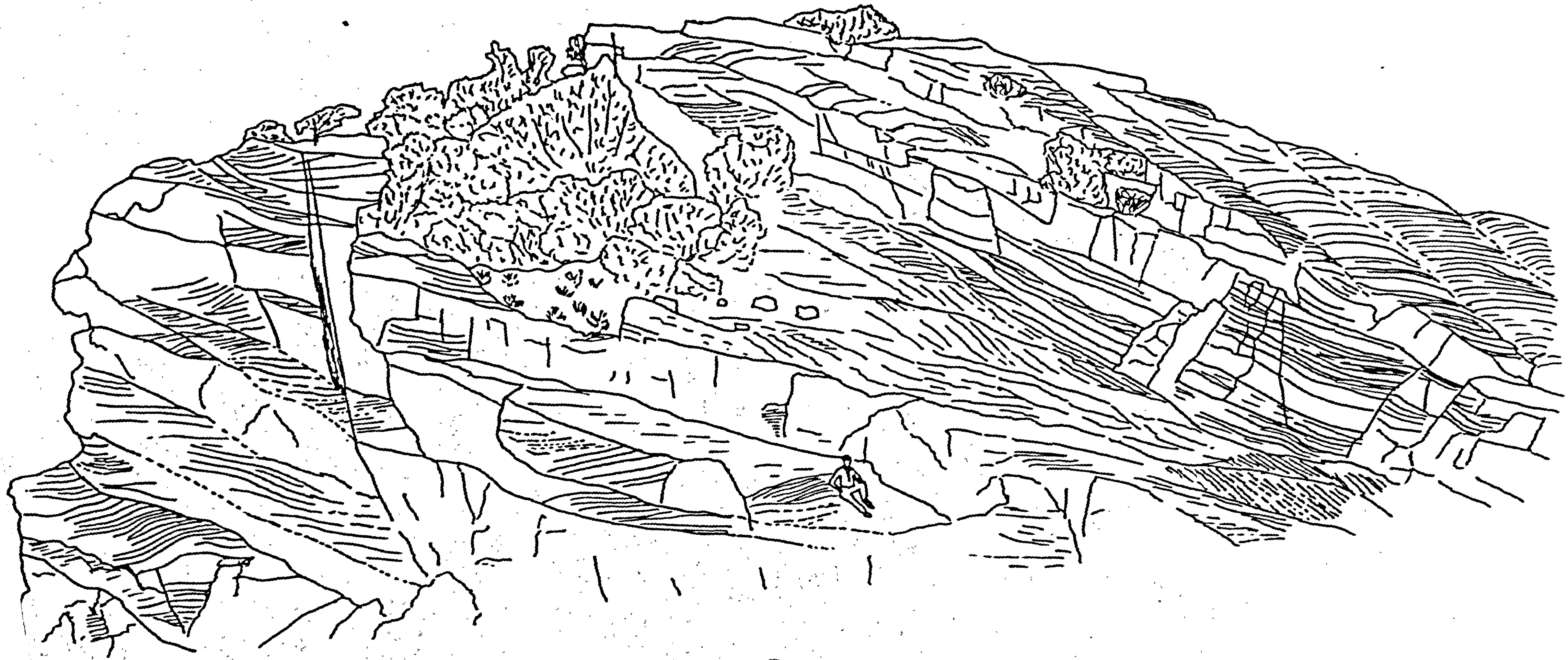
Interpretation: Powers and Kinsman (1953) proposed that pressure fluctuations attendant with storm-swell were capable of producing in situ sorting of shell beds. However, Curray (1960) suggested that some shell concentrations could be back-strandline deposits that became submerged and buried following a rise in sea-level. According to Morton and Winkler (1979), modern shell beaches are formed by landward and longshore transport. Shell beds associated with shelf deposits of the modern Missisippi delta have also been attributed to low sedimentation rates and reworking by Coleman and Gagliano (1965). Finally, Cant (1980) interpreted in situ brachiopod-bearing siltstone interbedded with hummocky cross stratification as a storm-dominated shallow marine sediments in the Silurian-Devonian of Nova Scotia.

In the study area the lateral persistence of this lithofacies suggests that it probably is representative of an ancient shoreline. Presumably, the shoreline was migrating with time across the basin. The fragmental, coarse and relatively well sorted nature of the shells indicates a high energy environment. The coquina beds may be accumulated in an inter deltaic setting as sand was transported laterally by longshore currents from a nearby delta.

3.2.12. LITHOFACIES 12: LARGE-SCALE RIPPLE BEDDED SANDSTONES

Description: Fine to medium grained, well-sorted sandstones forming beds 6 cm to 2 metres in thickness. The beds are often markedly lenticular, usually because the top of the bed is convex upwards with a well developed straight crest resembling large-scale wavy bedding. Internally this lenticular sandstone body shows shallow trough or very low angle planar cross-bedding (Plate 17). Most of the cross-bedding is of the trough type, with sets ranging from 6 cm to 2 metres and averaging 40 cm. Rare trough sets reach 2 metres, and low angle planar sets are about 2 metres. In a few places, there is gradual upward decrease of set scale, accompanied by upward fining of grain size. Lower bounding surfaces of cross-bedded units are horizontal to slightly irregular, but not noticeably scoured. There is no evidence of channeling within the facies. Body fossils are absent and trace fossils exceedingly rare. In the study area, large scale rippled sandstones were typically observed in the Tarlaağzı "Member" of the Alacaağzı Formation and the best localities are in the Alacaağzı Bay of Zonguldak (Plates 17-18), and Tarlaağzı Bay, Amasra. In the latter locality the large scale ripples occur in medium to coarse grained sandstones, sometimes displaying migrating ripples (Plate 19) with superimposed small ripples.

Allen (1968) showed that small scale ripples and large scale ripples comprise two distinct site-populations. Allen cites Bagnold (1956) concerning the probable genetic differences between these ripple types. Mc Cave (1971) noted a further distinction in a study of the Southern Bight of the North Sea between large-scale ripples which he calls "megaripples". The nomenclature has become further confused as a consequence of the divergent traditions of flume workers and field workers. The former refer to the larger ripples (megaripples of field



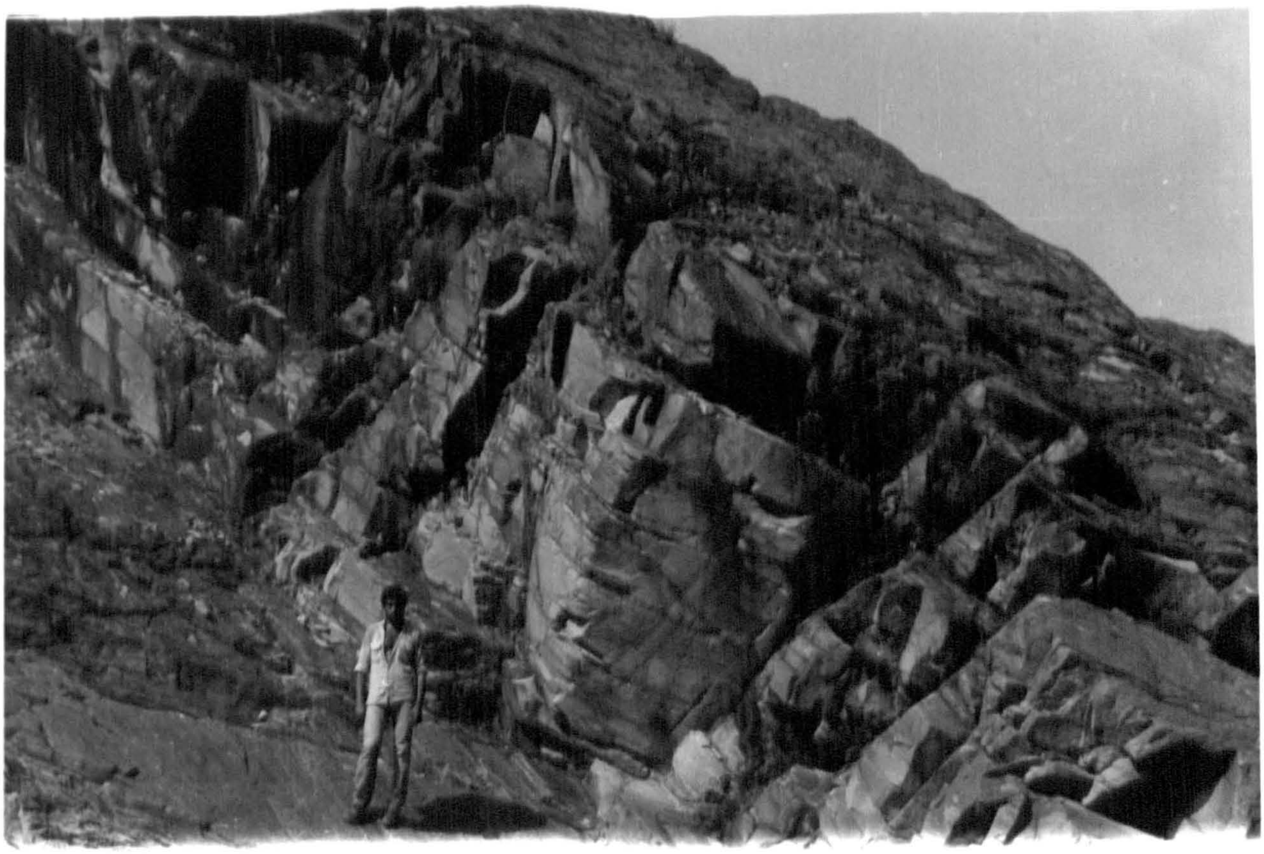
Sketch of Plate 17.

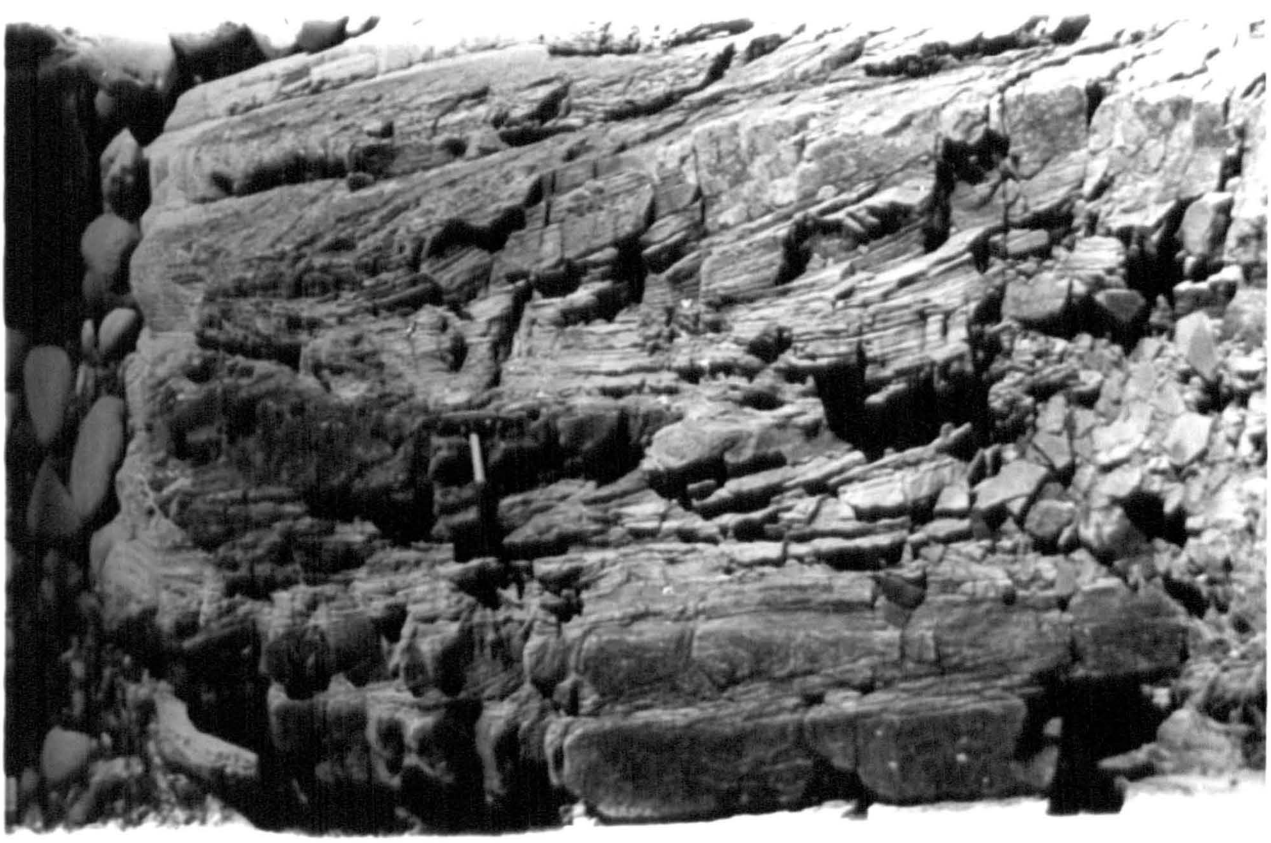
Plate 17. Large - scale ripple bedded sandstone (Lithofacies 12), The beds are often markedly lenticular, with well developed straight crests (seen best on the right of this photograph) resembling Large _ scale wavy bedding, from the Alacaağzı Formation.

Locality: Alacaağzı bay, 40km west of Zonguldak.

Plate 18. Close-up of Plate 17, showing internal structure of large-scale ripple-bedded sandstones. On the right hand side of the picture, straight-crested bed-forms are preserved.
From the Alacaağzı Formation.
Locality; Alacaağzı bay, 40 km west of Zonguldak.

Plate 19. Internal structure of large-scale rippled sandstones, displaying migrating ripples with superimposed small ripples, from the Alacaağzı Formation.
Locality: Tarlaağzı shoreline, Amasra area.





workers) as "dunes". Terminology for large bedforms is complex, and the terms sand wave, megaripple, dune and giant ripples are commonly used by investigators to describe the same feature. The criteria used by different investigators to identify bedforms include spacing, shape and height - to - spacing ratio. In the present study it was decided to adhere to Allen's original (1968) terminology, using "large-scale ripples".

Interpretation: In the study area large scale rippled sandstones appear to have been formed mainly by wind-generated currents, such as those observed by Swift et al., (1979) in the middle Atlantic Bight, North American Atlantic Shelf. The straight-crested nature of these large scale ripples are usually regarded as indicating low-energy sandwaves (Reineck and Singh 1980), while high-energy sandwaves form the largest landforms and occur in water depths of more than 4 - 5 metres, being formed in coarser-grained sediments. Allen (1978) has suggested that dune wave length is directly related to water depth, larger dunes developing at high-water stages, smaller dunes at low-water stages. It has also been suggested (Allen & Collinson 1974, Allen 1978) that sandwaves are large dunes, which are in better equilibrium with deeper and faster flows than smaller dunes.

In recent studies Dalrymple et al., (1978) have indicated that in addition to small ripples, two types of megaripples (small sand waves, and dunes), and giant ripples (large sand waves) are developed in the Bay of Fundy, Canada. The lithofacies described above may fall into their first type, which is characterized by straight to smoothly sinuous lee faces that lack irregularities and with a wavelength of 2 - 3 metres. Scour pits are not present in the troughs, consequently, lateral continuity is good and the height is very regular along an individual bedform.

This large-scale rippled sandstone lithofacies can be confused in the field with the hummocky cross-stratified sandstone lithofacies of other authors, such as Harms et al., (1975 p.87), and Hamblin and Walker (1979). Basically, hummocky cross-stratification shows horizontal and low angle lamination accompanied by basal channeling that can lead to amalgamation with underlying beds, and units are normally interbedded with bioturbated siltstones. However, the large-scale rippled sandstone lithofacies differs from hummocky cross-stratification (in the absence of channelling and of intercalated bioturbated siltstone). The only similarity is that the structure displays very low angle (2°- 15°) curved to undulatory laminae which may be broadly trough shaped. According to Harms et al., (1975) hummocky cross-stratification is produced in the lower shoreface of offshore facies by relatively large storm waves formed by rough seas, at flow velocities greater than those required to form wave ripples. However, the large scale rippled sandstone described here appear to have developed in an environment characterized by relatively lower energy processes rather than one dominated by periodic high energy flows. The only indication of strong wave energy is provided by the migrating ripple forms (Plate 19), which may represent traces of longshore bars, probably formed by marine reworking of sand close to a zone of high sediment supply, for example at a river outflow. According to Horikowa (1981, p.13), to establish a relationship between the longshore current and the longshore sediment-transport rate, it is necessary to know the horizontal and vertical longshore-current velocity distributions in the nearshore area. In this study, obviously this kind of relationship cannot be determined. Moreover, migrating ripples of this type can be produced by unidirectional tidal currents which was suggested by Anderton (1976) from Scottish Dalradian.

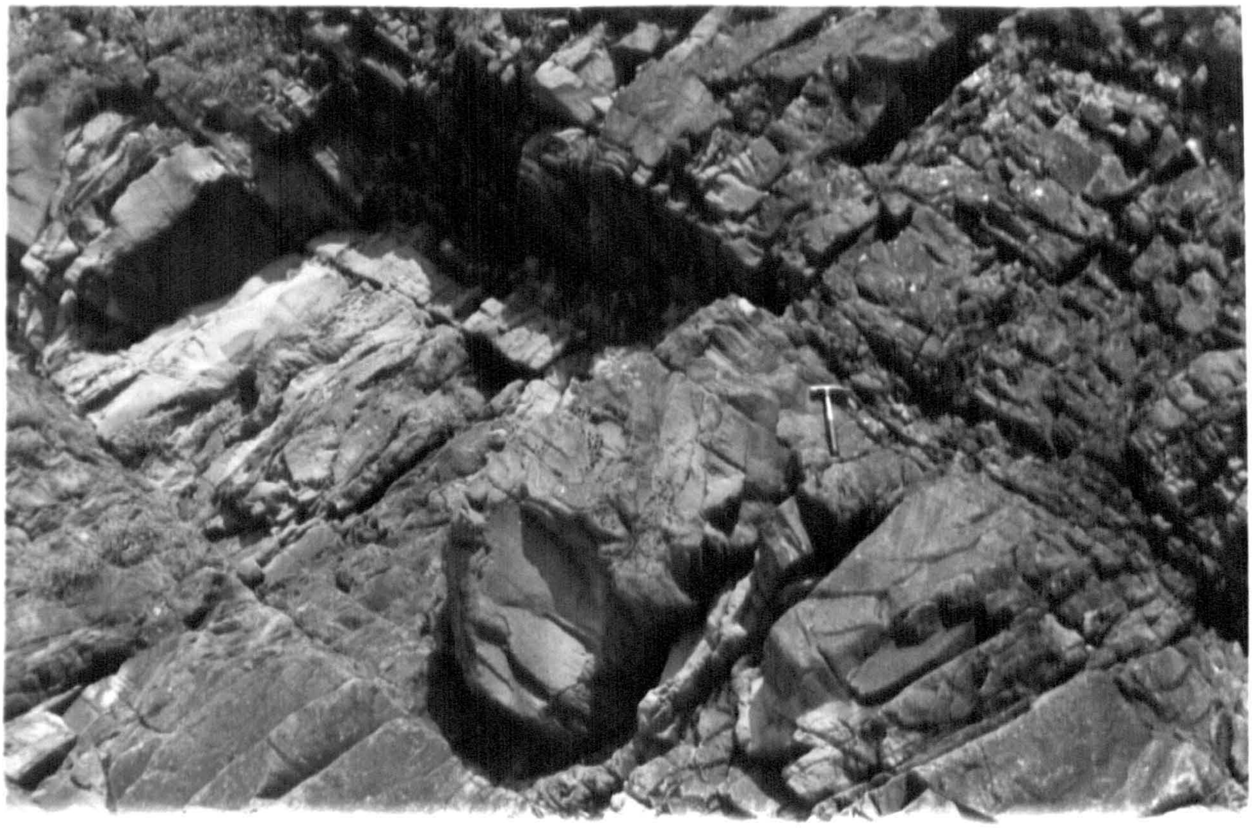
Since there is little indication of tidal activity elsewhere in the studied sequence, this possibly has been rejected. Also mud drapes are a common feature in tidal sands and have been explained by the migration of sand waves under influence of strongly asymmetrical tides, and that the mud drapes are formed at slack water, Allen (1981). Also, this feature has not been observed in the study area. Thus these migrating ripples are probably associated with longshore currents, or river outflow deposits.

3.2.13. LITHOFACIES 13: MEDIUM GRAINED TROUGH CROSS-BEDDED SANDSTONES

Description: This lithofacies includes medium grained sandstones with trough sets. Mudstones and siltstone clasts occur, together with small logs and tree impressions, which are found predominantly on the lower part of the foresets. Some of the trough sets are small-scale (14 - 20 cm in thickness) but most are large-scale (individual sets 1.0 - 1.5 m thick and 2 - 6 metres wide). The best examples of such large-scale trough cross bedding occur in the Kozlu-Zonguldak road cutting (between the abandoned Kasaptarla coal mine and the road, see Fig. 18). Good examples of small - and - large scale trough cross-bedded sandstone are found in the Tarlaağzı "Member" of the Alacaağzı Formation. In the Alacaağzı Bay outcrop the lower bounding surfaces of trough sets are usually erosive, and the sets generally pass upwards into undulatory laminated sandstones (Plates20,21)and sometimes contain drifted coal laminae (Plate 22). Seen from the front this type of cross-bedding resembles large-scale festoon bedding. Hamblin (1961) has suggested that cosets of small-scale trough cross-beds are indicative of a low level of mechanical energy. Simons et al., (1965) demonstrated

Plate 20. Medium grained, trough cross-bedded sandstones (Lithofacies 13). Large-scale shallow trough cross beds gradually pass upwards into large scale undulatory bedded sandstone, where the hammer rests, from the Alacaağzı Formation.
<u>Locality</u>: Alacaağzı bay, 40 km west of Zonguldak.

Plate 21. Polished section of small-scale trough cross lamination in lithofacies 13, associated with interdistributary bay environments; from the Alacaağzı Formation.
<u>Locality</u>: The Alacaağzı bay, 40 km west of the Zonguldak area.




1cm

Plate 22: Large - scale trough cross - bedded sandstone (Lithofacies 13) with drifted coal laminae (especially centre), from the Alacaagzi Formation.

Locality: Alacaağzi bay, 40 km west of Zonguldak.

that this places the flow in the upper part of the lower flow regime, while Harms and Fahnestock (1965) have attributed trough-shaped cross-bedding to the filling of a pre-existing erosion hollow or scour in the stream bed. On the other hand, Allen (1963) and Reineck (1960, 1963) considered that since sets are produced by lateral migration of ripple bedforms, the height of the set should be proportional to the depth of water. Allen (1968) and Harms et al., (1975) have described the sinuous crested bedforms responsible for trough cross-bedding as dune structures that have been separately discussed in lithofacies 12 (large-scale rippled sandstones). Basically, in this study trough-cross bedded sandstone is formed from migrating sinuous large ripples in the Fluvial environment as suggested by Allen (1963a and Reineck (1960, 1963), and ascribed to the upper part of the lower flow regime (Simons et al., 1965).

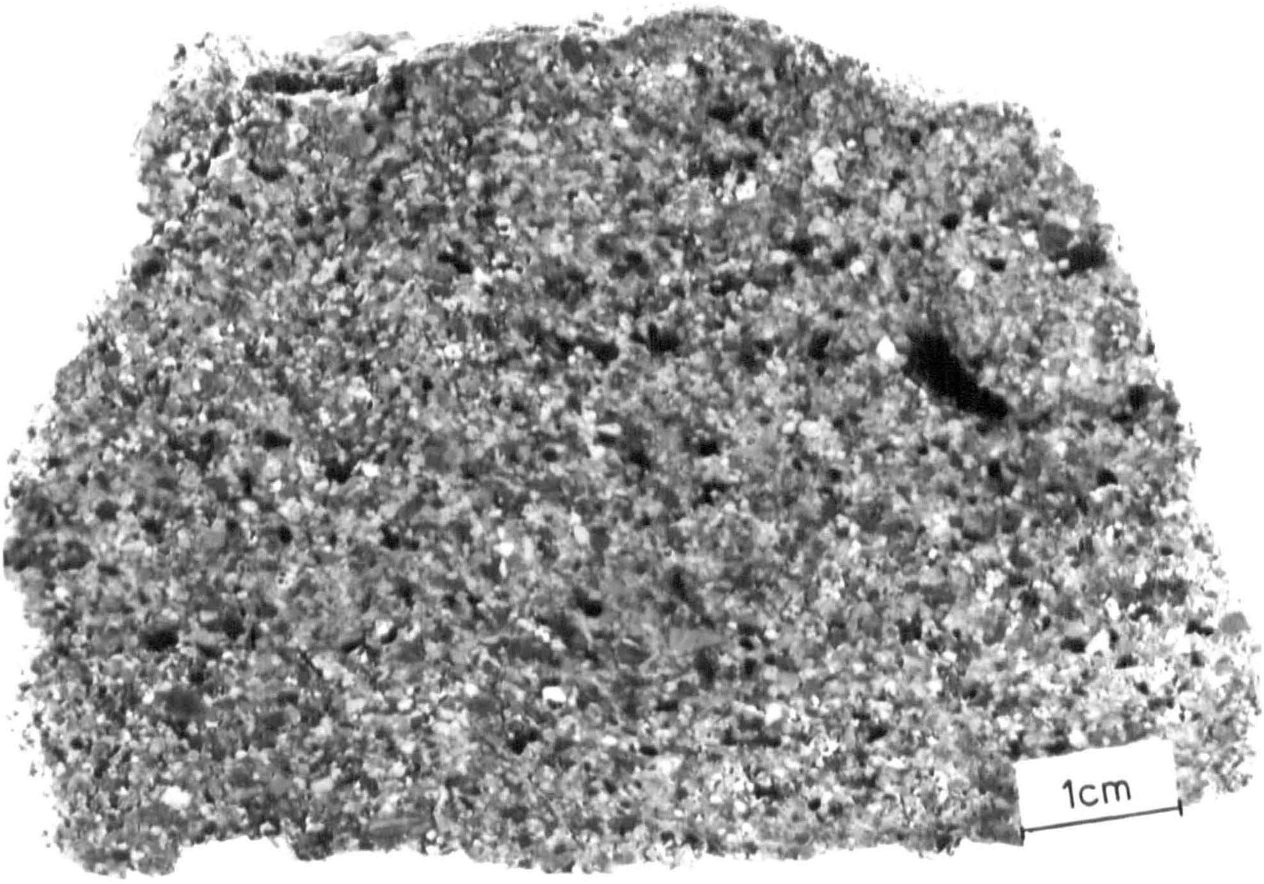
3.2.14. LITHOFACIES 14: PLANAR AND SIGMOIDAL CROSS BEDDED SANDSTONE

Description: The cosets of sigmoidal and planar cross-bedding generally occur in medium to coarse sandstones that are often poorly sorted and contain mudstone clasts and wood debris (Plate 23). This lithofacies has provided most of the useful palaeocurrent indicators in the present study. The cross-beds of this lithofacies are almost entirely of the sigmoidal type, although a few planar or low angle cross-beds have been observed.

Planar cross-bedded units occur in coarse to pebbly sandstones. Forest laminae are normally graded, but reverse grading also occurs. Laminae dip at between 15 - 25^{o} , and the lower bounding surfaces of most sets are erosive, while the foresets are typically tangential rather than strictly tabular. The individual cross-bedded units within the sets are usually from 10 cm to 2 metres thick. The foreset laminae are

Plate 23. Medium to coarse grained sandstone from planar cross-bedded sandstone (Lithofacies 14). Note relatively poor sorting and content of mudstone clasts, wood debris and black coal fragments; from Kozlu Formation.
<u>Locality</u>: Kozlu-Zonguldak road section, Zonguldak area.

Plate 24. Sigmoidal cross-bedded sand sheets (Lithofacies 14), showing stacked nature. On top of a few sigmoidal-cross bedded sandstone swale-fill mudstones are developed (see Plate 54). From the Kızıllı Formation (meandering channel-fill assoc.)
<u>Locality</u>: Ilyas Geçidi Dere section, Kurucaşile area.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generally 0.5 - 5 cm thick, but normally lack smaller-scale (intraset) cross-laminae. Commonly there is an overall fining upwards within the sets, from a pebbly or granular base.

Sigmoidal cross-beds are commonly produced by sheets of sand characterised by horizontal or gently inclined topsets terminating down stream in a steep avalanche face (Plate 24). These sigmoidal cross-beds can be compared with Blucks **cross-stratified sand sheets (Bluck 1979, Text Fig.2)** or may fall into Allen s (1963b) epsilon cross-stratification category. They commonly begin as sheets of ripples which, by overtaking each other, build up foresets that increase in thickness in the growth direction (Bluck, 1971, p.106). In the study area two types of sigmoidal cross-beds have been recognised:

(a) Sigmoidal cross-bedded sand sheets, characterised by a lower boundary displaying some ripples, pebbles and mud partings above an essentially erosive base, although the general appearance is of a stacked series of sand bodies (Plate 24). On top of a few sigmoidal-cross bedded sandstones swale-fill mudstones are developed.

(b) The second type of sigmoidal unit has an asymtotic lower boundary which may be marked by lag deposits. Layers and beds of this type of cross-bedding display foreset dips perpendicular to the general flow direction in that region. Some of the inclined layers maybb composed of thick mud or interlaminated mud and sand layers (Plates 25,26,56). In the literature such structures have been referred to as epsilon-cross bedding (Allen 1963), longitudinal cross-bedding Reineck & Singh (1980) or lateral accretion surfaces (Leeder, 1973).

The sigmoidal cross-bedded sandstones can be seen best seen in the exposures between Kasaptarlacoal mine and Kozlu-Zonguldak road (Plate 25), and in the Çelik and Açık Yarma sections of the Zonguldak area. Sheet-

Plate 25. Lateral accretion surfaces of meandering stream deposits, displaying asymmetric lower boundaries, commonly marked by lag deposits. Some of the inclined layers are composed of thick mud or interlaminated mud and sand layers; from the Kozlu Formation.
<u>Locality</u>: Kozlu-Zonguldak road cutting, Zonguldak area.

Plate 26. Close-up of lower left part of Plate 25, showing mudstone and carbonaceous material between the well-laminated inclined sandstone units. Note hammer at left for scale.

like sigmoidal cross-bedded sandstones are best displayed in the Yarandor Formation of the Ilyas geçidi dere section of Kurucaşile area (Plate 24). The second type of sigmoidal cross-bed is displayed in the Kozlu-Zonguldak road cutting (Plate 25,26). Unfortunately, this exposure has now been concealed by buildings.

Interpretation: The origin of planar cross-bedding appears to be primarily controlled by hydraulic conditions at the time of deposition. Simons and Richardson (1961) and Simons et al., (1965) have shown, from flume experiments, that for a given depth of water the bedform produced is dependent on the velocity. Jopling (1963, 1965) suggested that high-angle, angular-based cross-bedding is formed at a lower water velocity than low-angle asymptotically based cross-bedding for a similar depth. He believed the depth of water to be an important factor. Allen (1965) also showed that the lee-side profile of ripple bedforms is dependent on the water velocity and sediment characteristics. On the other hand, planar sets of cross-bedding have been recorded in several different environments and it is clear that the presence of planar sets is not enough to specify an environment.

The sigmoidal cross-bedded, sheet-like sandstones are distinguishable from dunes and megaripples not only by the absence of prominent stoss sides, but by their commonly isolated occurrence. According to Bluck (1979) cross-stratified sand sheets are sensitive to changes in water depth, velocity and sand supply. Several authors have reported similar large-scale, sigmoidal beds in ancient fluvial sandstone units (Jackson, 1978; McBryde and Casey, 1979; Casey 1980). These large-scale cross-beds are usually referred as "epsilon cross-stratification", a term originally proposed by Allen (1963b), and are generally interpreted as having originated by lateral accretion of point bars. Also, Leeder (1973) determined that sigmoidal bedding was formed by point bar accretion.

However, Casey (1980) interpreted the sigmoidal beds as lateral accretionary surfaces of coarse grained "side bars" which descended into the channels without slip faces.

In the study area the type (a) sigmoidal units are attributed to semi-continuous bar migration (thus accounting for the stacked nature of the sand bodies) whereas type (b) units are attributed to lateral accretion under conditions of alternating low-and-high-water stages. The nature and degree of preservation of both types of sigmoidal-cross bedding suggests that rapidly waning flood conditions inhibited the the formation of lower flow regime bedforms (Simons et al., 1965). Presumably from time to time the fluvial-channels migrated laterally, producing widespread, multistoried sheet sand bodies.

Thus, the net movement of lateral beds involved translation at an oblique angle to the fluvial axis. Bar translation has been cited as a critical factor in the preservation of well developed sigmoidal-cross bedding (Casey, 1980). Broad, shallow channeling and some smaller-scale cross-beds may have formed during falling discharge of the river. Generally the presence of a capping muddy or very fine grained layer (swales), marks the top of a genetically related sequence, which is indicative of a point-bar succession.

3.2.15. LITHOFACIES 15: PEBBLY SANDSTONES WITH SCOUR FILLS

Description: This lithofacies comprises massive beds of coarse and pebbly, poorly sorted sandstone which have a characteristic weathering pattern. The weathered surface is dark grey to dark brown but the rock is pink to light grey when fresh. The beds are very broadly lenticular in geometry and are laterally variable in thickness, up to several metres. These sandstones mostly have planar to irregular erosive bases and contain clasts derived from the underlying facies. Extrabasinal pebbles also occur at the base of the sandstone and mud flakes occur in many units. Moreover, the beds display faint to prominent internal erosional surfaces lined by linear material of silt or fine grade, and commonly contain wood fragments. Apart from occasional isolated trough cross-bedding (lens-shaped), and faint sigmoidal cross-bedding (low-angle), internal structures are absent.

The best examples of this lithofacies occur in the Kozlu Formation especially in the Gelik road section, Zonguldak (Plate 27). Here the lower part of the pebbly sandstones erosively cut into lacustrine deposits. In most exposures the ground mass of the pebbly sandstones is a medium-grained sandstone, with a little iron staining and also some kaolinite which occurs interstitially between the quartz grains and is probably derived from weathering of detrital feldspar grains. Units of this lithofacies are also well exposed in the Ilyas Geçididere of the Kurucaşile area (Plate 28).

Interpretation: The thickness of the units of this lithofacies is variable, difficult to determine, and is a function of scour depth during flood flow. Sediments in the lower part are generally massive or flat bedded (Plate 29, 30). In the downstream direction and in the outer bar edge, these massive sediments give way to foreset bedding. The upper part of this flood-fill facies is characterized by flat or low-angle topset stratification, which covers the underlying massive sediment and which grades upstream into the channel deposits of the preceding straight reach. A similar situation has been described by Bluck (1976).

Numerous examples of massive pebbly sandstone have been described from the fossil record. For example, Klein et al., (1972) described such deposits in the front of the Cretaceous Reconcove Delta, while Jones (1977) described a similar facies from the Roaches Grit sandstones

Plate 27. Low sinuosity stream deposits pf pebbly sandstones, with erosive base (Lithofacies 15), displaying low-angle planar cross bedding in a channel fill sandstone, overlying lacustrine deposits of the Kilic Member of the Kozlu Formation.
Locality: Gelik road cutting, Zonguldak area.

Plate 28.. Pebbly sandstones of low-sinuosity braided river type, with erosive base, cut into lacustrine deposits. This coarse unit represents a channel fill sequence; from Kizilli Formation.
Locality: Ilyas Geçidi Dere section, Kurucaşile area.

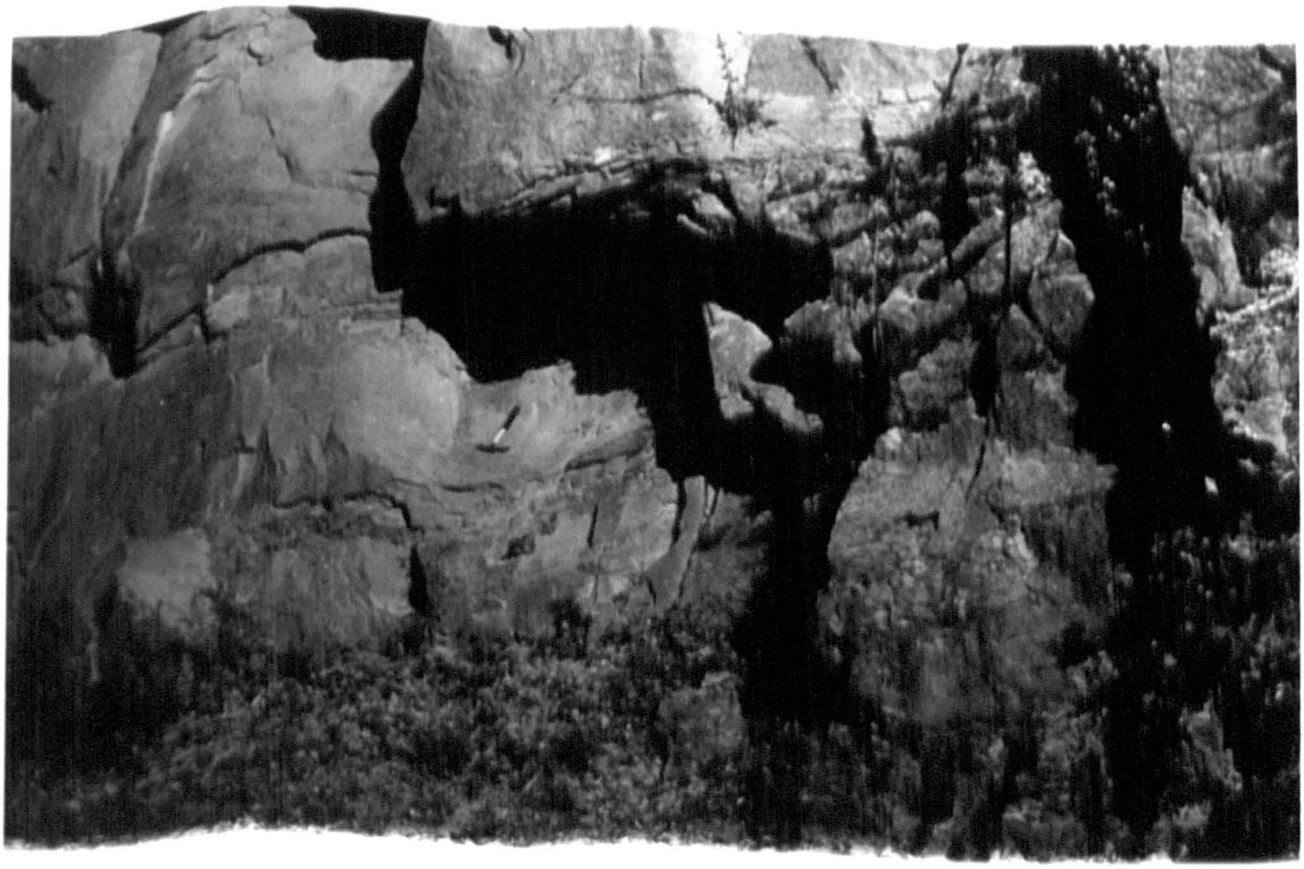
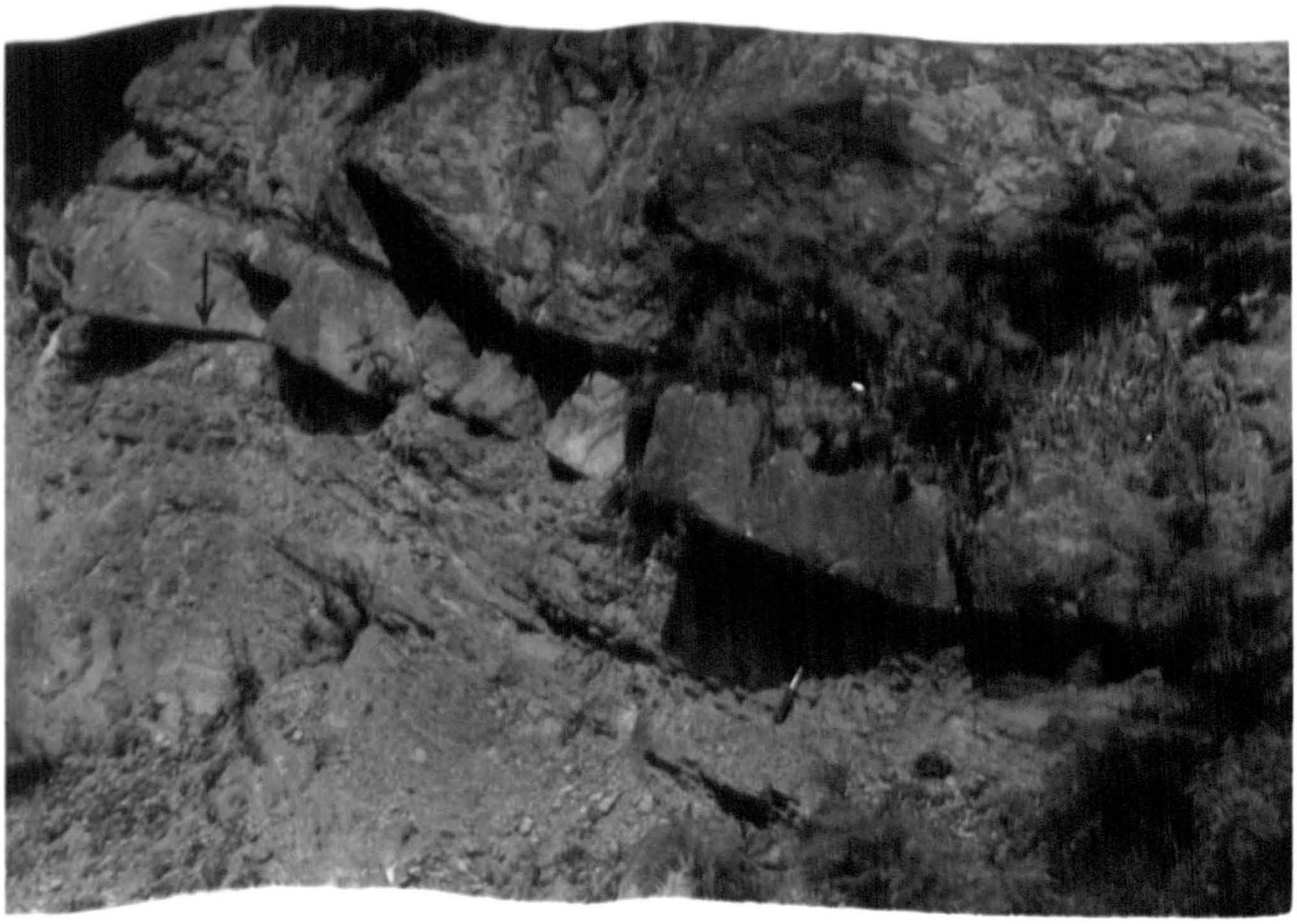


Plate 29. Sandy braided river channel-fill deposits containing wood and peat fragments. Note rather undulatory cross-cutting basal relation with underlying laminated siltstones of flood-basin type of Dilaver Member of the Kozlu Formation. Arrow indicates margin of large scale lens-shaped scour.
Locality: Dilaver section, Zonguldak area.

Plate 30. Close-up of the right central part of Plate 29. In the base of the channel plant fragments, small pebbles and wood debris can be detected.



of south-west Pennines in the Namurian succession of England. The erosive base, broadly lenticular geometry and the pebbly grain size suggests powerful currents and bed load (tractional) deposition, probably within channels. Isolated cross-bedding provides further evidence for tractional sediment transport, indicating a current in the upper part of the lower flow regime (Simons et al., 1965). The prominent erosional surface may result from the pulsating nature of currents, while the absence of any marked grain size difference may favour either pulsating currents of equal maximum strength, or uniform supply.

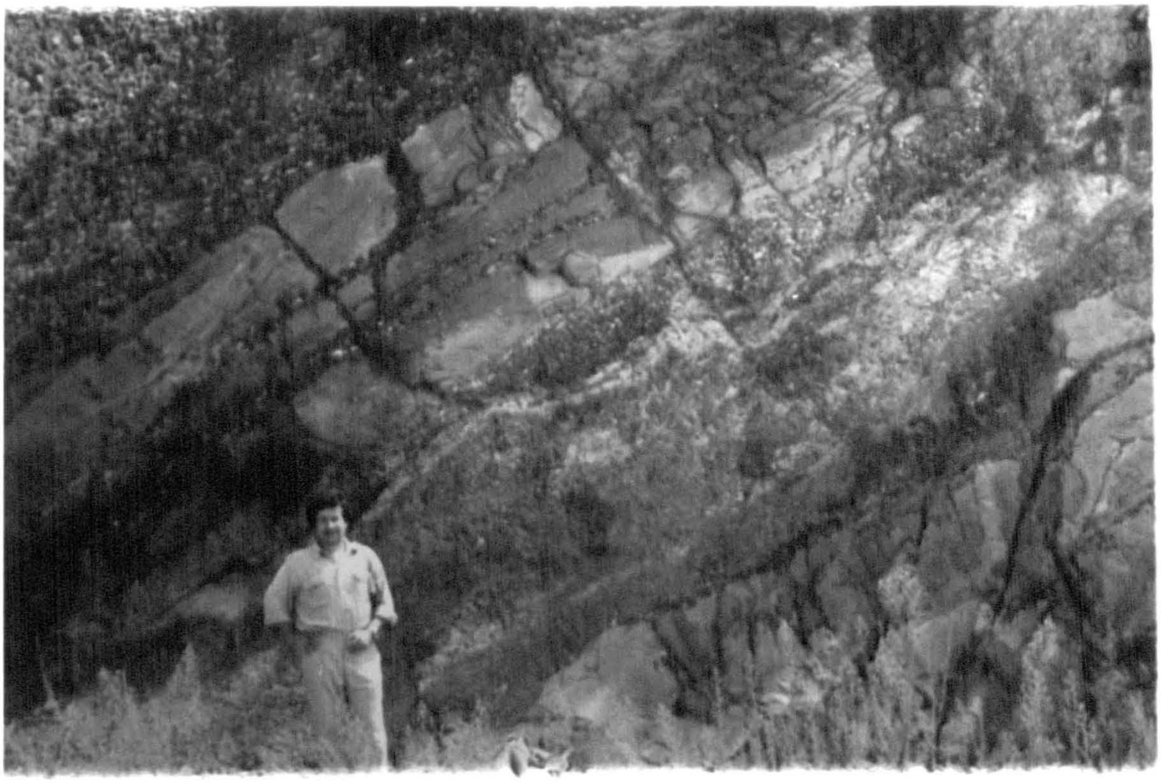
3.2.16. LITHOFACIES 16: MASSIVE OR HORIZONTALLY BEDDED FRAMEWORK CONGLOMERATES.

Description: This lithofacies includes a wide size range from pebbly sandstone to sandy conglomerates, with pebble sizes from 1 cm to 5 cm. The rudites include clast, or more rarely, matrix-supported fine conglomerates. Beds are apparently massive, with sedimentation units generally greater than 0.5 metres in thickness. The conglomerate beds are up to 5 metres thick and only rarely show sedimentary structures of tractional origin, but some units exhibit internal structures such as normal and reverse grading, together with mudstone partings, and some imbrication of the pebbles. Some horizontally stratified or cross-bedded sandstones are interbedded with the conglomerates but normally they do not display conspicuously erosive interfacies. The bottom surfaces of sandstone bodies within the conglomerate are either flat or broadly concave upward (Plates 31-32).

This lithofacies typically occurs in the Dihaver "Member" of the Kozlu Formation in the Zonguldak area (Figs 19-20). The conglomerates in this section contain sieve deposits, and traction-formed sedimentary structures,

Plate 31. Massive or horizontally bedded framework conglomerates (Lithofacies 16), including internally imbricated and horizontally stratified or cross bedded pebbly sandstone within the clast-supported conglomerates, which represent humid-fan or pebbly braided stream deposits; from the Karadon Formation.
Locality: Kozlu-Zonguldak road cutting, Zonguldak area.

Plate 32. Poorly stratified, mainly clast-supported conglomerates (Lithofacies 16). Pebbles are crudely aligned or poorly imbricated and display overall fining upward sequence, in these stream-flow dominated humid fan deposits; from the Karadon Formation.
Locality: Kozlu-Zonguldak road cutting, Zonguldak area.



including channeling and low angle cross-bedding. Furthermore, the conglomerates often grade into the overlying sand-silt lithofacies, and form repetitive fining upward cycles. This conglomeratic section is approximately 75 metres thick in each cycle.

Interpretation: The study of conglomerates has been undertaken recently in much more detail. For instance, Middleton and Hampton (1973) have discussed the processes of deposition of thick conglomerates while Walker (1975) has attempted to construct very general models of conglomerate deposition with particular reference to flysch sequences. Winn and Dott (1977) described clast-supported fabrics, bimodal alignment of clast axes to the inferred palaeocurrents, and inclined stratification of some conglomerates and suggested that in submarine channels local traction currents may have deposited or reworked the gravels.

Wasson (1977) described alluvial flow in the lower Derwent Valley in south eastern Tasmania, which were built by debris flows and stream flows. Kelling and Holroyd (1978) described modern and ancient deep-sea conglomerates in terms of channelized (1) and nonchannelized (2) deposits which are either organized (A) or disorganized (B). Heward (1978b) has noted that Carboniferous alluvial fan sequences from Spain contain many features in common with resedimented conglomerates of the turbidite association.

The intercalated sandstone beds with flat bases are interpreted as fluvial accretionary bar deposits, and the concave-upward beds are believed to be scour - or channel -fill deposits. Generally speaking, the geometry of this lithofacies and the repetitive fining-upward cycles suggest an origin as point-bar deposits, possibly in a meandering river. Finally, the normal grading and framework-supported nature of some conglomerates are characteristic of sediment deposited under waning flow by accretion of successively smaller clasts rolled as bedload, such as noted by Allen P.A. (1981c) in the stream-flow dominated Devonian alluvial fan deposits in the Shetland Islands.

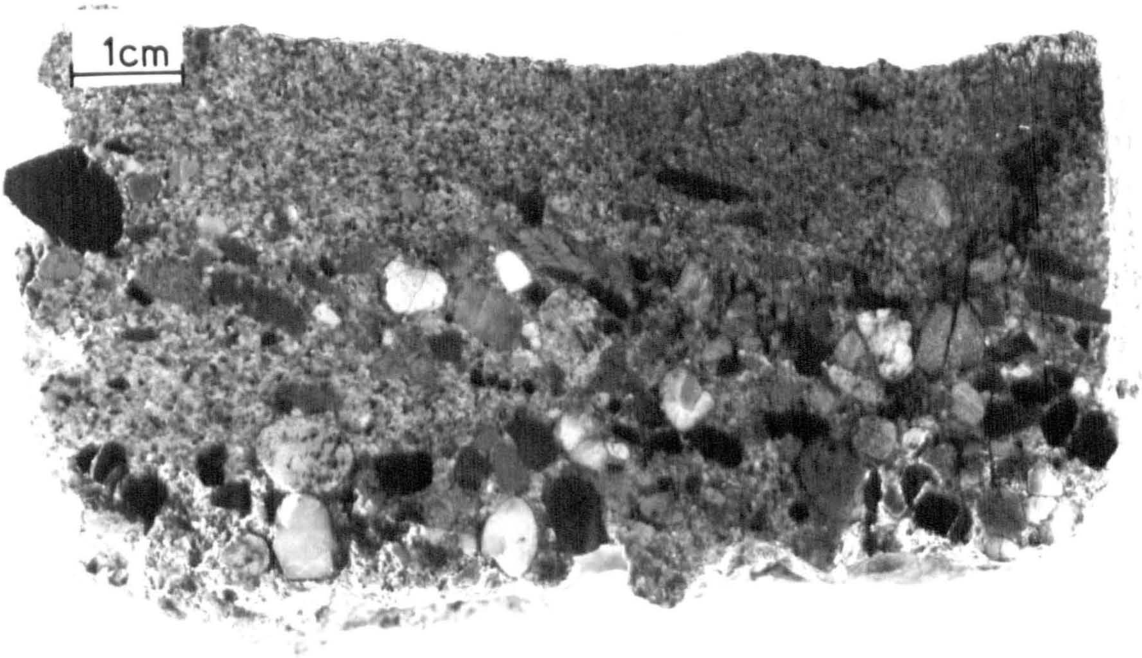
3.2.17. LITHOFACIES 17; MASSIVE MATRIX-SUPPORTED CONGLOMERATES

Description: Units of this lithofacies are mainly unstratified, polymodal conglomerates with an abundant sandy or silty matrix and occasional clast-supported rudites in units ranging from 1 - 20 metres in thickness. The polygenetic pebbles or cobbles occur in a coarse sandy matrix and their size ranges from 1 cm up to 25 cm. The average clast size is normally in excess of 0.5 - 10 cm. Unstratified conglomerate beds are laterally extensive and also contain occasional sandstone bases, which may represent either separate depositional events or pulses of supply within a single prolonged event. The predominant facies is horizontally bedded conglomerate, while trough cross-bedded and plane-bedded fine conglomerate to pebbly sandstone is less abundant (Plate 33).
In the matrix supported conglomerate clast orientation is poorly defined. The coarse units of this lithofacies have parallel bounding surfaces, but a few display channel bases, often irregular. The units comprise multiple intersecting sets of shallow troughs, commonly about 10 cm thick. In many cases they are interbedded with and show lateral transition to horizontally bedded pebbly sandstone, which is too coarse to detect current lineation. However, it was proved possible to make a few measurements. Generally a thin horizon of coarse pebbly sandstone occurs at the base of individual units and then conglomerates develop towards the top (cf. inverse graded conglomerates of P.A. Allen, 1981c).

This lithofacies is typically developed in the Karadon Formation of the Zonguldak area, especially at the Açık Yarma locality (Plate 34). Volcanic rock fragments are common in the Karadon Formation conglomerates, and in most areas quartzite is second in abundance, followed by vein

Plate 33. Massive partly matrix-supported conglomerates (Lithofacies 17). Polygenetic pebbles display imbrication in a coarse sandy matrix. Pebbles are mainly quartz, chert and volcanics, together with coal fragments; from the Kozlu Formation.
Locality: Gelik road section, Zonguldak area.

Plate 34. Matrix-supported conglomerates forming bands in a sequence of lenticular, cross-bedded pebbly sandstones (channel-fill sequence of pebbly braided stream), from the Karadon Formation.
Locality: Açık Yarma section, Zonguldak area.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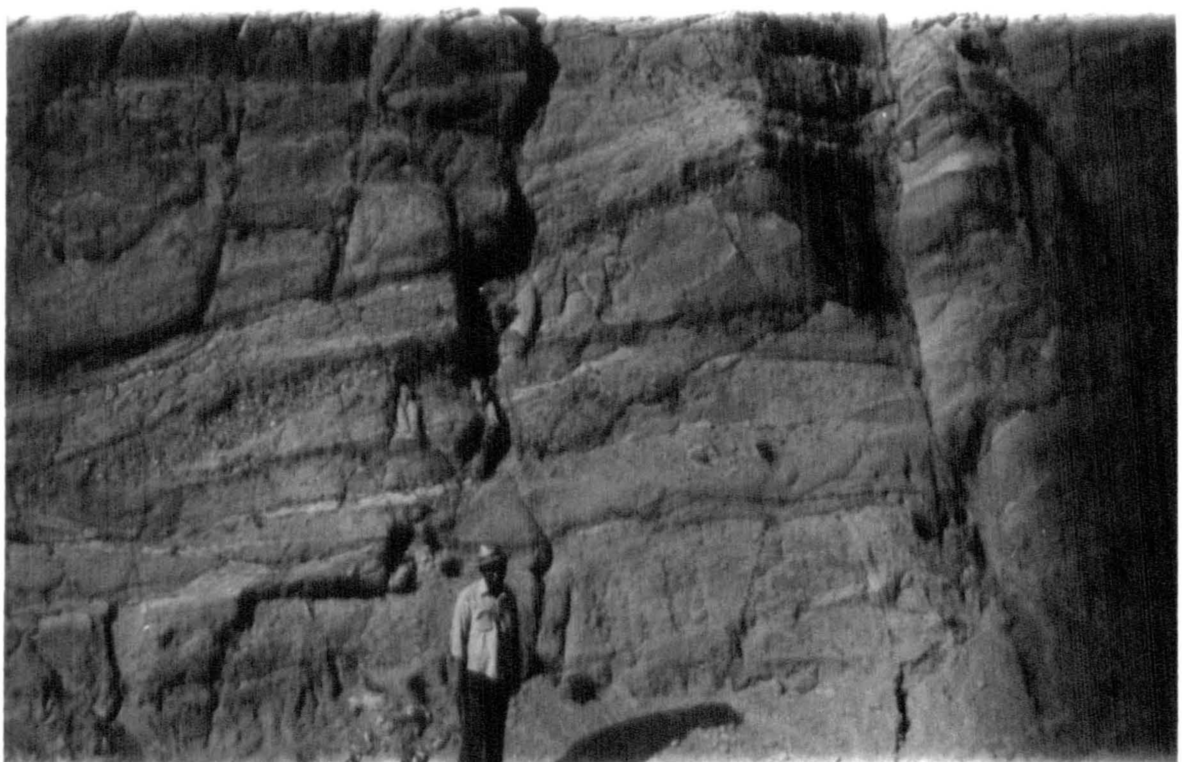


quartz. Lesser quantities of chert and miscellaneous fine-grained siliceous rocks, metamorphic rocks and clasts derived from underlying rocks are also present.

Interpretation: With regard to formation of conglomeratic deposits of this type in a terrestrial environment, Heward (1978b) showed that unstratified conglomerates may be interpreted as debris flow deposits, reworked debris flow deposits, or the deposits of powerful streams. Their sharp non-erosive bases, their occurrence is well-defined, relatively thick units, the absence of stratification, the lack of sorting, the presence of inverse and normal grading, and the nature of the fabric are all in accord with transportation and deposition by a debris flow mechanism. P.A. Allen (1981c) has deduced that the essentially unstratified nature of the conglomerates indicates that bedload rolling of clasts in equilibrium with ambient flow conditions was limited. The significance of the occasional clast-supported conglomerates is open to discussion. For instance Walker, (1975), and Walker and Mutti , (1973) have stated that framework-supported conglomerates associated with turbidites may be interpreted as resulting from deposition from a deposition from a dispersion above the bed or from debris flows, with no bedload rolling. Rodine and Johnson (1976) have shown that debris containing very high percentages of poorly sorted granular materials can flow on very gentle slopes.

The upward transition within single beds from matrix to framework support can be interpreted by consideration of mass flow mechanisms. Also, P.A. Allen (1981a) has suggested that the high matrix contents of these conglomerates, combined with low quantities of fine-grained (clay grade) sediment, imply deposition from a high concentration dispersion rather than viscous flow.

The polymodal nature of the Karadon Formation conglomerates suggests that grain size selection processes during transport were not important. The thickness of these conglomerate beds implies the operation of mass-flow or streams of considerable magnitude. The lack of stratification and fabric implies a transport process in which the clasts were restricted in movement relative to each other. In the Karadon Formation it appears that the very coarse sands of the matrix and the large clasts were transported together by the same stream flow.

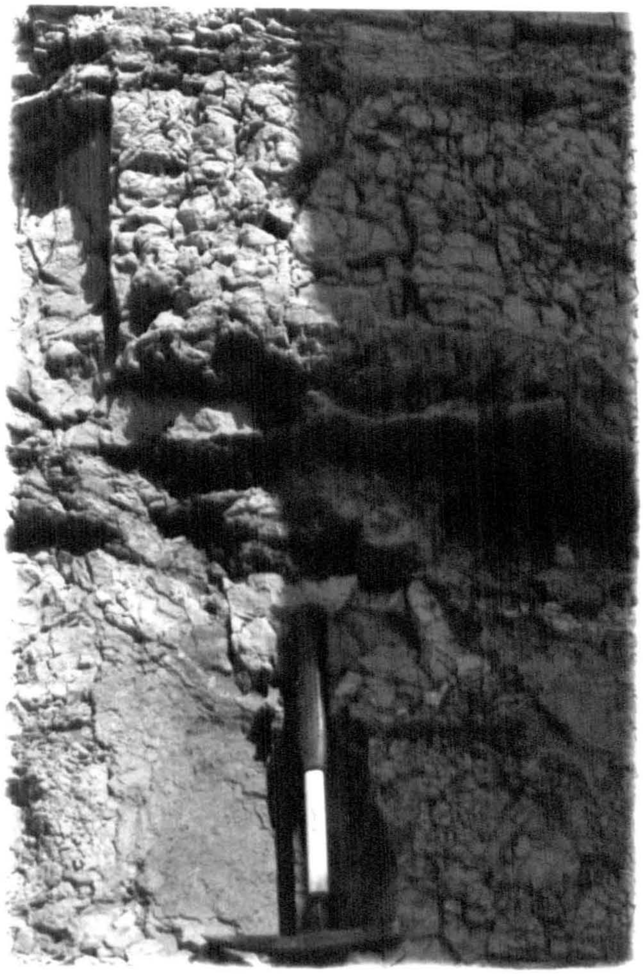
3.2.18. LITHOFACIES 18; SEAT-EARTH AND COAL

Description: These lithofacies have little volumetric (but great economic) importance and are poorly exposed. Seat-Earths are recognised by the presence of rootlets in their growth position (Plate 35). The sediments in which they occur vary from muddy siltstone to organic-rich mudstone. The silty parts are often iron-rich and bed thicknesses usually range from 30 to 1.80 cm. Most of the seat-earth units are poorly laminated grey mudstones, sometimes containing sphaerosideritic nodules, tree trunks, very thin coaly partings and abundant stigmarian rootlets (Plate 36). Often there is rapid alternation of seat-earths with coals. The coal is often gradational into organic-rich mudstone in which a few large plant fragments lie parallel to the bedding.

The best examples of seat-earths are in the Alacaağzı Formation of Alacaağzı Bay and Üzülmez dere, Zonguldak. They are recognized by the presence of small dark rootlets penetrating a muddy siltstone (Plates 35,36). The thickness of the best exposed seat-earth cannot be accurately determined here although it appears to be at least 1.5 metres in thickness. Similar seat-earth exposures have been found in the Kozlu Formation of the Açık Yarma section, Zonguldak and rare examples are also known from the Karadon Formation.

Plate 35. Seat-earth, within overbank deposits of low-sinuosity sandstones. Note the presence of rootlets in their growth position. From Kozlu Formation.
Locality: Bağlık Mevkii , Zonguldak area.

Plate 36. Seat-earth units, from sequence attributed to the inner-interdistributary bay environment, with tiny coaly partings and abundant stigmarian rootlets; from the Alacaağzı Formation.
Locality: Alacaağzı bay, 40 km west of Zonguldak.



Most of the coal seams immediately follow seat-earth deposits. The development of coals in the Kozlu Formation is quite variable in different parts of the Zonguldak coalfield. Sometimes there is reversal of the normal order in the Kozlu Formation, and in the Karadon Formation thin muddy siltstones with comminuted plant fragments commonly overlie the seat-earth, which is a simple root bed without coal. The coal seams generally range in thickness from 10 cm to 8 metres and average mineable coal seams are 1.5 metres in thickness. The thickest coal seam is found in the Kozlu Colliery, Zonguldak, and is termed the "Çay damar". This coal seam is recorded as reaching 8 metres in thickness.

Interpretation: The presence of rootlets indicates that plants were growing in situ and that the associated coal is probably therefore autochthonous(Plate57). However, in the Alacaağzı and Karadon Formations some of the thinner coal seams appear to be allochthonous, or "drifted" coals. Pebbly or coarse sandstone or conglomerate beds are normally arranged in pockets or sequences (1.5 - 10 metres thick), separated by coals which lack underlying rootlet beds and do not form part of an upward sequence (Plate 58).

The thick in situ coals can only be produced under conditions allowing constant and uniform subsidence of a swamp area. According to Heward (1978b,p.480) the development of thick coal seams in the Matellana coalfields, northern Spain, reflect a critical interaction of subsidence and rate of plant accumulation (drifted or in situ), in the absence of clastic sediment supply. Horne, et al., (1978) showed that in the Appalachian region rapid subsidence during sedimentation results generally in abrupt variations in coal-seam geometry, whereas slower subsidence rates follow greater lateral continuity. Scott (1979) has pointed out that the roof-shale flora is critical to ecological interpretation of the coals and particularly the comparison between coal forming floras as shown by the palynology and the roof-shale vegetation as shown by the macrofloras. It has not been possible to undertake this kind of comparison in the present study.

Clearly the environment of deposition of this lithofacies must have been in very shallow water, such as might be found in swamps, lagoons, delta-top interdistributary areas, coastal plains or in fluvial overbank situations (cf. Collinson, 1969).

CHAPTER 4

FACIES ASSOCIATIONS

4.1. INTRODUCTION

The eighteen individual lithofacies already described in Chapter 3 have been grouped into two broad facies complexes, based on the following environmental categories:

A - Coastal Complex

B - Alluvial Complex

The recognition of lithofacies associations necessitates comparison with recent sedimentary environments and processes, but it should be borne in mind that ancient sequences are the products of successive environments developed over a long period of time and are therefore generally more extensive, both vertically and laterally, than modern equivalents. In the case of the examples from northern Turkey, by no means all of the depositional assemblages which characterise modern environments have been recognised but there are obviously some similarities to modern environments. In this study, one of the main problems is in defining the contacts between each environmental association, especially in poorly exposed and tectonically deformed areas.

Most previous workers have suggested that the Upper Carboniferous rocks of the Northern Turkey were deposited in continental conditions (Ralli 1933, Jongmans 1939, among others). In a pioneer study Ralli (1896) showed the similarity of the Alacaagzi Formation to the Kulm facies of Western Europe and suggested a limnic origin for the coal-bearing strata. Arni (1939) was the first to indicate that the Karadon Formation conglomerates might be fluvial in origin in the Zonguldak area. Ziljstra (1952) postulated high fluvial energies to account for the coarse nature of sedimentation during Westphalian A times and for the different thickness of coal layers. Jongmans (1955) suggested that there are no indications of marine conditions in the younger levels of the Carboniferous, above the lower part of the Namurian and that the area was almost limnic. Egemen (1956) also stated that the Upper Carboniferous scenery and atmosphere changed from paralic to paralo-limnic and to more limnic or inland conditions of life.

4.2. THE COASTAL COMPLEX

4.2.1. INTRODUCTION

In this study it is shown that the depositional environment of the Alacaagzi Formation was essentially deltaic, and two types of deltaic sequence are recognised. The first sequence is exposed in the Western part of the studied area (in Zonguldak) and represents a fluvial-dominated delta type, comparable to the Mississippi delta. The second sequence is developed to the east, at Tarlaagzı (Amasra area) and represents a wave-dominated delta-type, similar to the Ebra Delta. Probably they both accumulated in a humid climate, where vegetation was abundant and biological and chemical processes were of prime importance.

In this study, the Pro Delta Association and Delta Front Association represent marine and quasi-marine environments on the frontal part of the delta while the Delta Plain Association represents the terrestrial realm. The terms Pro Delta Association and Delta Front Association are used to describe the deposits of the appropriate environments as described by Coleman and Gagliano (1965, p.143). These workers divided the Delta Front environment into four sub-environments, namely distal bar, distributary mouth bar, distributary channel and subaqueous levee. In this study, some of these subenvironments will be mentioned as appropriate. Diagrams illustrating the vertical distribution of lithofacies with the appropriate facies association interpretation are provided at the end of the Thesis (Figs.11-15), or within this chapter.

4.2.2. PRODELTA ASSOCIATION - A

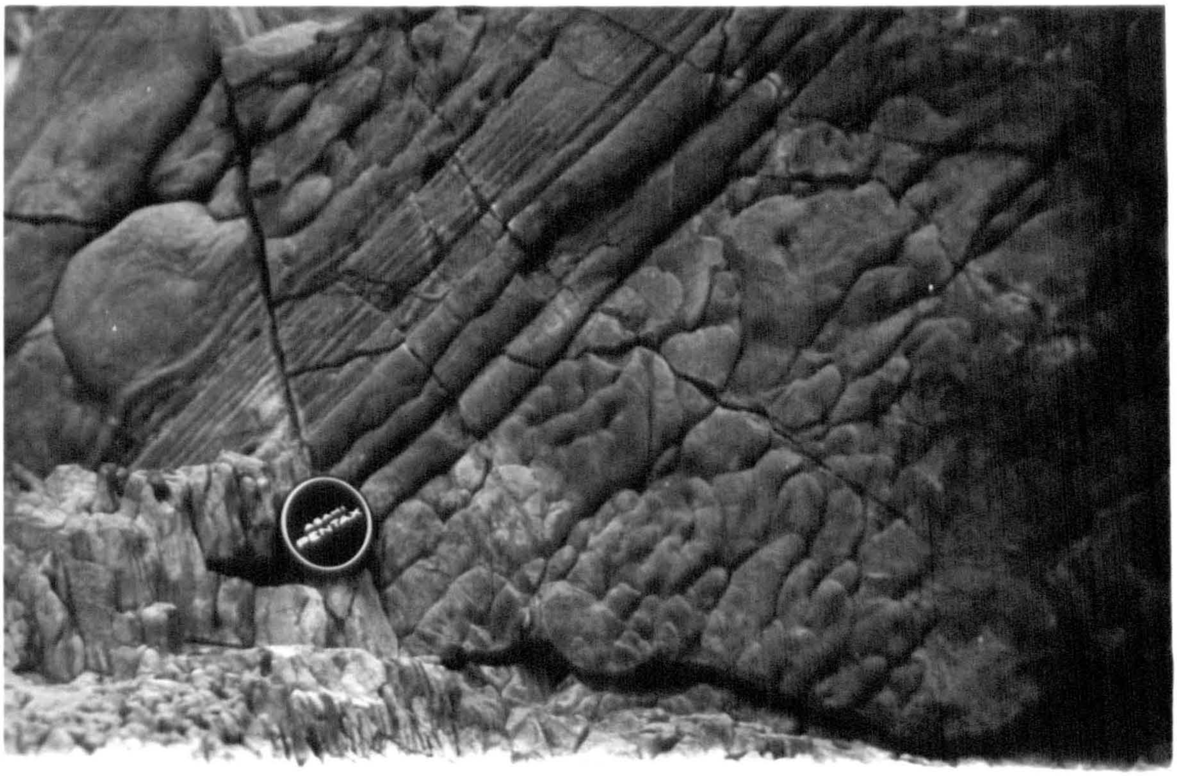
Description: The Prodelta association is predominantly made up of lithofacies 3 and 4, Goniatite-bearing mudstones and non-fossiliferous silty mudstones with siderite nodules. The thickness of the Prodelta Association is 40 - 70 metres and laterally continuous from the west (Zonguldak) to the east (Amasra). The bulk of the Prodelta Association is made up of mudstone. The main development of the Prodelta Association occurs in the basal part of the Alacaağzı Formation (Kokaksu Member). The lithofacies of the Prodelta Association are best developed in the Kokaksu dere, Üzülmez dere, Ulutandere stream sections of the Zonguldak area and the Iliksu road cutting of the Istanbul - Zonguldak highway. The mudstones are usually homogeneous and laminated. Carbonate-cemented concretions up to 20 cm in diameter have been found in the laminated part of this facies. In these Prodelta Association mudstones, scattered fine silt and bivalves may occur. No trace fossils have been found, but concentrations of small, flat lying plant fragments also occur. The distribution of the faunal beds of lithofacies (3) has already been discussed in Chapter 3. Preservation is mainly as impressions in mudstone but uncrushed preservation of goniatite shells is common. Somewhat higher in the sequence sharp-based, thin siltstones and fine sandstones are also common. These fine-grained sandstone beds display sole marks and sedimentary structures (Plate 37), characteristic of "thin bedded" or "distal" turbidites (Walker, 1978). A few sandstone beds display Bouma sequences and flute casts, but more commonly are dominated by either horizontal lamination or ripple-lamination (isolated ripples)(Plate 38).

Plate 37. Flute-casts and possible tree trunk-grooves on base of thin, poorly graded sandstones within Prodelta Association. Current flow direction towards south-west. From the Kokaksu "Member" of the Alacaağzı Formation.

Locality: Tarlaağzı bay, Amasra area.

Plate 38. Fine grained sandstones with elongate flutes on base, from the Prodelta Association, Kokaksu "Member" of the Alacaağzı Formation.

Locality: Tarlaağzı bay, Amasra area.




1cm

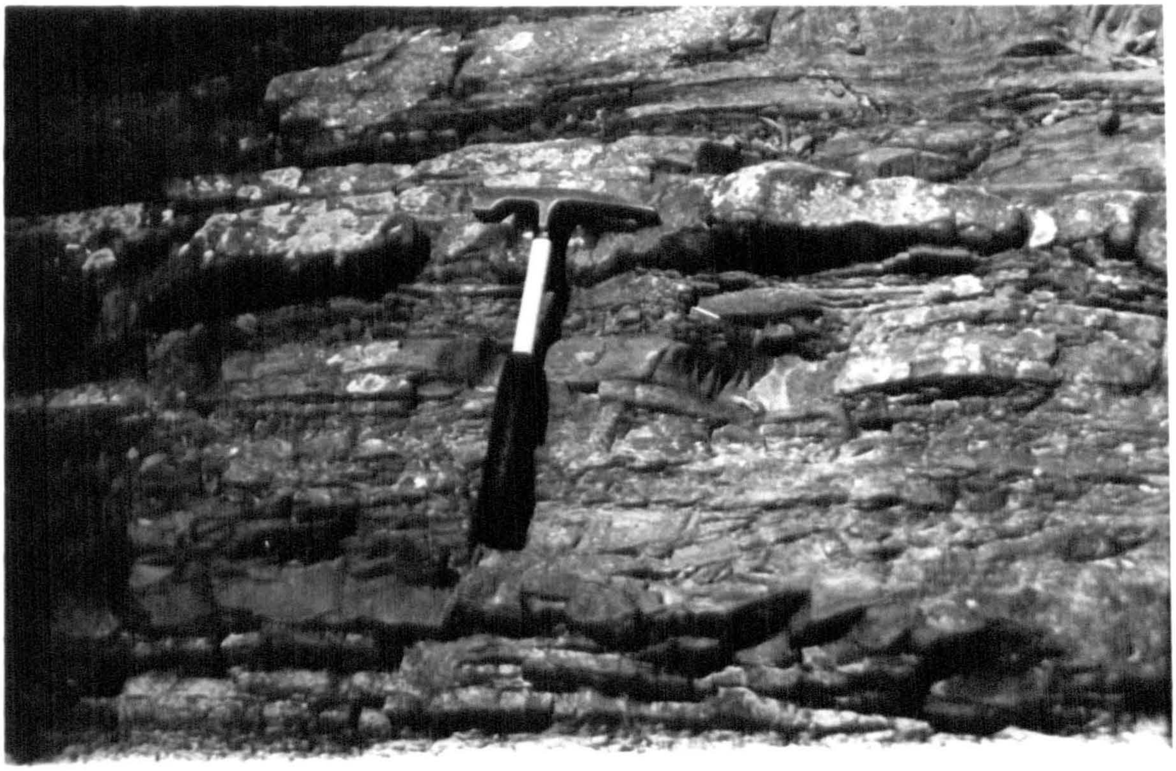
This coarser sediment is parallel-bedded, with very thin laminae, usually less than 1 mm thick. Flat or curved erosion surfaces, with a relief of up to about 10 metres, occur in the coarser beds. Plant stems are concentrated above many of the erosive bases. There is a gradual upward passage into the Delta Front Association. Laterally the Prodelta sequences became thinner towards the eastern part of the region. This facies association has yielded no reliable palaeocurrent data, apart from some flute cast orientations. Towards the top of the Prodelta units, fine grained sandstone beds sometimes display scour and fill structures (Plate 39) associated with bed-amalgamation and a dominance of horizontal stratification, plant fragments and muddy partings. These features are similar to those of proximal turbidites, (Walker, 1965, 1978 and Collinson, 1968).

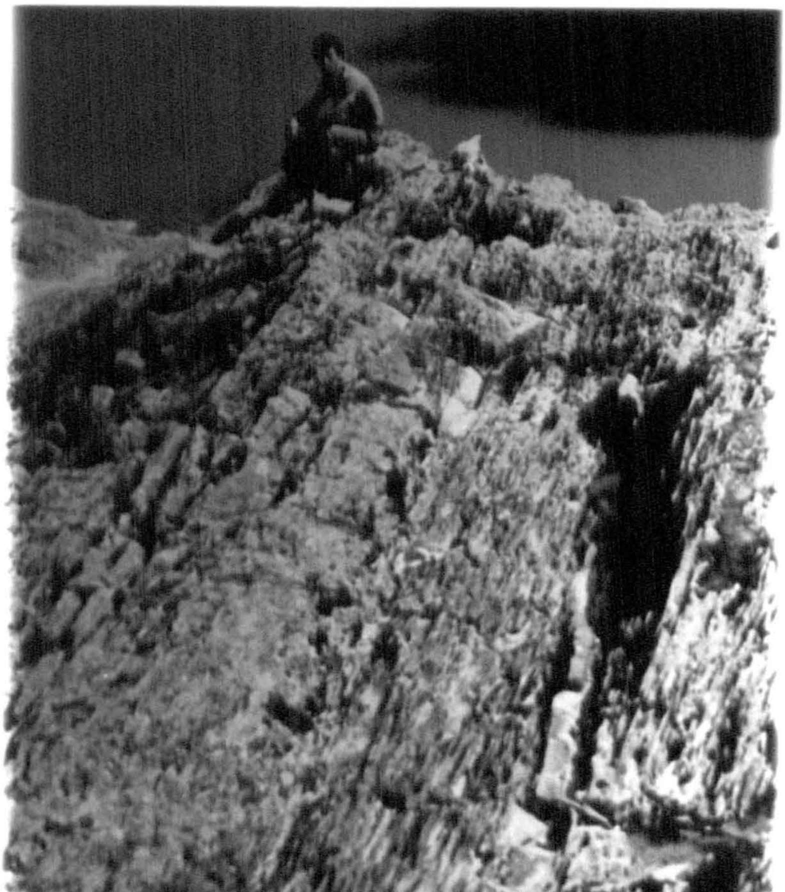
Interpretation: The Kokaksu Member of the Alacaağzı Formation of the Zonguldak and Amasra areas is interpreted as the basinal equivalent of the coarse fluvial-deltaic complexes. The thin sandstone beds are best explained by a prodelta turbidite model (Kepferle, 1978; Walker, 1978), since they occur in distinct packages that correlate laterally with deltaic deposits. According to Walker (1978) prodelta turbidites differ from submarine fan turbidites in that they are fed by deltas rather than submarine canyons or upper fan channels. They accumulate on relatively smooth slopes and usually consist of classic turbidites without the coarser resedimented facies and channelling associated with submarine fans.

The intervening sediments were probably deposited very slowly in quiet waters in which the deltaic influence operated. There is not much evidence for extensive faunal colonisation of the bottom. Generally, goniatite faunal bands represent high salinity, marine or near marine conditions,

Plate 39. Fine grained sandstone with load casts at the base and ripples on top, structures associated with bed-amalgamation and a dominance of horizontal stratification, plant fragments and muddy partings, resembling the proximal turbidites of the Prodelta Association. From the Alacaağzı Formation.
Locality: Üzülmez dere stream cut of Gökgöl section, Zonguldak area.

Plate 40. Distal Delta Front sub-association. Thin horizontally stratified or rippled sandstones are intercalated with poorly laminated siltstones containing abundant plant fragments from the Alacaağzı Formation.
Locality: Ulutandere section, Zonguldak area.





(Calver, 1968). In the parallel laminated sandstones, some erosion surfaces demonstrate occasional powerful channellised current activity. However, the interbedded siltstone units in the Kokaksu Member were presumably deposited under quiet water conditions.

Discussion: The prodelta environment has been subdivided by some authors (Fisk et. al., 1954; Coleman and Gagliano, 1965), into the proximal and distal. In this study this kind of division can be made. The lower part of the sequence probably represents the distal part of the prodelta while the upper part of the sequence is characterised by the proximal turbidite-like nature of the sandstone beds. Similar sandstones with a turbiditic character have been reported from a variety of ancient delta-front and shallow marine environments, such as examples from the Pennines described by Collinson (1969), McCabe (1975), and Jones (1977).

4.2.3. DELTA FRONT ASSICIATION - B

The Delta Front Association is represented by relatively large scale coarsening upwards sequences. They record an upwards passage from prodelta facies into shoreline facies, which are usually sandstone-dominated (Collinson,et al 1978).

In the study area, the Delta Front Association is best developed in the Gökgöl "Member" of the Alacaağzı Formation, gradationally overlying the prodeltaic Kokaksu "Member". These sequences basically occur in two areas (Zonguldak and Amasra) and will be described and correlated in the following order:

a) Distal Delta Front Sub-Association.

b) Proximal Delta Front Sub-Association.

4.2.3.1. DISTAL DELTA FRONT SUB-ASSOCIATION: B1

Description: This subfacies association is characterised by thin, horizontally stratified or rippled sandstone beds interclated with rippled siltstone with abundant plant debris (Plate 40). The base of this sub-association is taken at the first appearance in the sequence of small scale-ripple-laminated sandstones. These usually appear immediately above the highest beds of the Prodelta Association. Thus there is gradual upwards passage between the two sub-associations. The upper boundary of the Distal Delta Front with the Proximal Delta Front is not very distinctive. However, the Proximal Delta Front or Distributary Mouth Bar sands were deposited with a sharp contact on top of the thin-bedded sands. The Distal Delta Front sub-association comprises the following lithofacies: 4, 5, 6, 8, 10, namely non-fossiliferous silty mudstones with siderite nodules, fossiliferous silty mudstones, muddy siltstones and parallel laminated mucaceous carbonaceous sandstones and ripple laminated sandstones. The mudstone is usually micaceous, calcareous and fossils are rare. Some units yield a few goniatites, while others yield a bivalve fauna and siderite lenses are obviously present.

Interpretation: The thick dark grey muddy sequence indicates deposition from suspension at the base of the delta front and beyond (Kelling & George 1971). In several examples of these facies, thin erosive-based coarse siltstones and fine sandstone beds occur within the mudstones and siltstones (de Raaf, et al., 1965; McBride et al., 1975). The small scale cross-lamination may be produced by the migration of ripples (Allen, 1968). This indicates a lower flow regime (Simons et al., 1961) and the formation of cosets under conditions of net sedimentation. The dropping of the massive sandstone over the ripples suggests deposition from suspension despite the coarse grain size. The presence of micaceous carbonaceous sandstone which has discrete well-sorted laminations, suggests that deposition took place in the lower part of the upper flow regime, (Simons and Richardson, 1965). The occasional thin sandstone beds and lenses intercalated with the mudstone were deposited either by ebb currents generated by storm surges (Brenchley et al., 1980; Hamblin and Walker 1979), or from suspension clouds carried by storm waves (Reineck and Singh, 1972).

4.2.3.2. PROXIMAL DELTA FRONT SUB-ASSOCIATION - B2

Description: This assemblage consists mainly of lithofacies 4, 5, 6, 8, 9, 10, 13. The proximal delta front sheet sandstones or distributary mouth bar sands were deposited on top of thin bedded distal sand and silt facies. Distributary channels were scoured into underlying mouth bar sands and silts in the same manner as in the Chatsworth Grit Sandstones, Kerey (1978). The thickness is about 70 metres, and laterally continuous toward the east.

The upper part of this sub-association is gradational into fine-grained sandstones, siltstones and interdistributory bay lutites which belong to the Delta Plain Association. (Plate 41).

(i) Delta front sheet or mouth bar sandstones: B2a, characterised by sandstones with horizontal bedding and low-angle cross-stratification. These fine to very fine sandstones are moderately sorted with relatively large amounts of wood chips, plant fragments and mica flakes. The delta-front sheet sandstones grade upwards into coarser sediments. In some cases these coarse beds have planar but erosive bases and grade upwards from parallel lamination into current ripple lamination, as in the Gökgöl section of the Zonguldak area (Fig. 13). Most of the time they show sharp-based flat laminated sandstone and the upper part of each sandstone bed displays trough cross-bedding of variable direction, as seen in

TOP

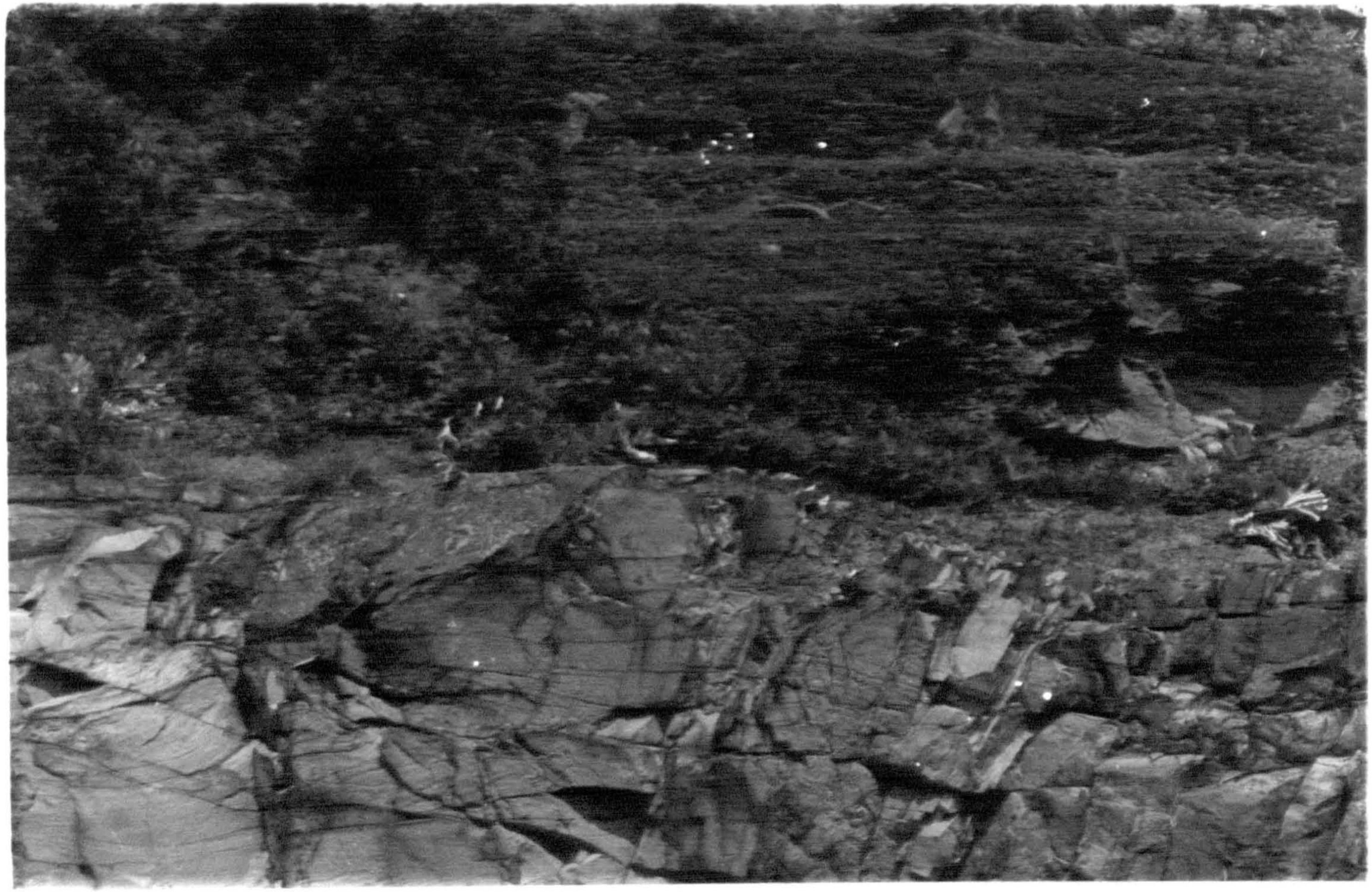


Plate 41. Proximal delta - front sheet - like sandstone sub - association (B2) abruptly overlain by interdistributary bay sequence of muddy siltstones (C1a). Note penecontemporaneous deformation features in sandstones at lower left of photograph. From the Alacaagzı Formation.

Locality: Alacaağzı bay, 40 km west of Zonguldak.

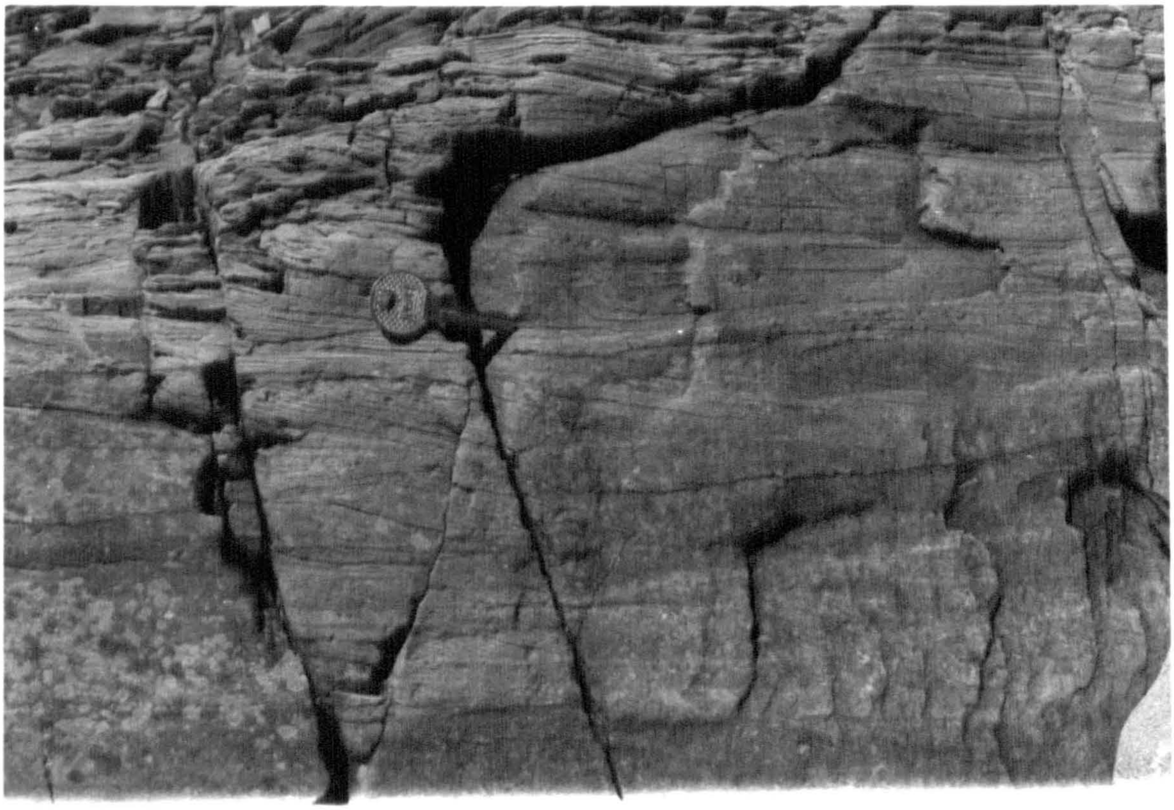
Kireçlikağzı and Alacaağzı bay of Zonguldak and Tarlaağzı bay of Amasra, which indicates a considerable amount of wave reworking (Plates 42-43).

(ii) Distributary channel fill sandstones:B2b,some of these erosive-based major sandstone bodies have been assigned to the distributary channel facies but it is considered that both subaqueous and sub-aerial levees are also represented. The distributary channel fill sandstone is recognised by its broad, low-angle trough cross stratification (Fisher et al., 1969; Reineck & Singh 1980). These sandstones form thick beds (1 - 2.5 metres) which are laterally impersistent. Many erosive-based units show clay-clast basal lag deposits and some wood fragments. Moderate to low angle (15° - 20°) trough cross stratification is the dominant internal structure. Some beds exhibit graded, fining upwards sequences, up to 20 cm thick with parallel lamination passing up into undulatory and ripple lamination. Siderite nodules (in the Tarlaağzı section), and ball and pillow structures (Gökgöl section) are found (Plates 11-12).

Interpretation: The proximal delta front assemblage has been described and interpreted by various workers in recent environments. The Delta front sheet sandstones or mouth bar sandstones do not seem to have formed bar fingers, as in the present day Missisippi (Gould, 1970). Instead it appears that the mouth bar covered a large shallow area, as the river mouth constantly changed position. In the modern examples, fluviatile channel deposits overlie the distributary mouth bar sands with a strongly erosive surface, as in the Missisippi Delta. Both current and wave ripples are abundant and wood fragments are present in the Missisippi mouth bars (Coleman and Gagliano 1965). In the Alacaağzı Formation, especially the Tarlaağzı Member, medium-grained ripple laminated sandstones were deposited in shallow water, as

Plate 42. Delta front sheet or mouth-bar sandstones (B2a). Mostly sharp-based, even bedded, sandstones, the the upper most part displaying trough cross-bedding of variable direction, which indicates considerable wave reworking. From the Alacaağzı Formation. Locality:Kireçlikağzı bay, 30 km west of Zonguldak.

Plate 43. Delta-front or mouth-bar sandstones displaying wave ripples on an upper bedding surface, From the Alacaağzı Formation. Locality: Tarlaağzı Shoreline, Amasra area.



proved by the wave ripples. A similar situation is described by Jones (1977) and suggests that current velocities were similar to those in present day density underflows. In all modern examples, such as the Rhone Delta, the density currents have cut channels on the Delta Slope (Oomkens 1967). This feature is absent in the Alacaağzı Formation, probably because the currents spread out widely and as argued above, there is no evidence for the existence of a significant delta slope, apart from some flute casts that have been observed in the Gökgöl section of the Zonguldak area and Tarlaağzı section of Amasra area here.

The internal scours, clay clasts, and channel lag deposits suggest deposition under conditions of rapid flow, and with frequent shifting of major channels. The overlying parallel laminated sandstones may represent channel-fill sediments after channel abandonment or could be an interdistributary bay sequence. However, the Delta slope shows no evidence of syn- sedimentary faulting or slump structures.

4.2.4. DELTA PLAIN ASSOCIATION - C

The fluvial-dominated examples of this facies association are characterised by small-scale coarsening upwards sequences, and include natural levee, crevasse splay, marsh and restricted bay deposits, and fluvial distributary channel sandstones (Ferm and Cavaroc, 1968; Collinson 1969; Elliott, 1974a, 1975; McBridge et al., 1975; Horne and Ferm 1976; among others). These authors suggest that fine laminated or bioturbated mudstones and siltstones are deposited from suspension across the entire interdistributary area during river flooding. Plant debris is often abundant, together with a brackish or freshwater fauna. Rooted horizons frequently develop towards the top of the sequence and peat-vegetation may accumulate. In the study area the Delta Plain

Association is arbitrarily divided into 4 sub-divisions:

a - Inter Distributary Complex Sub-Association

b - Overbank Sub-Association

c - Delta Abandonment Sub-Association

d - Strand Plain Sub-Association

4.2.4.1. INTER DISTRIBUTARY COMPLEX SUB-ASSOCIATION - C1

Distributary Complex Sub-Associations generally include two kinds of sequence: Interdistributary bay and interdistributary channel sequences. The distributary complex occupies the middle and upper parts of the Alacaagzi Formation in the study area.

(i) Interdistributary bay sequence - C1a

Description: The interdistributary bay sequences are generally represented by ripple laminated sandstones (lithofacies 10) and micaceous siltstones and sandstones (lithofacies 8), rich in plant fragments and with rare bioturbation. The association is best represented in the Alacaağzı Formation at the Tarlaağzı section of the Amasra area, which at the base of this sequence of silty interbeds are parallel laminated and become coarser and more ripple laminated upwards. The transition from poorly bedded mudstones into the interbedded silty zone with siderite nodules is not well defined. However, the junction with the overlying sandstone is abrupt and this sandstone is capped by coquina beds in the Formation of the Gökgöl section, Zonguldak area (Fig.13), a series of rippled sandstones is interbedded with parallel laminated fine sandstones and silty mudstones with plant fragments. Also in the Gökgöl section, siltstones with abundant plant fragments show interdistributary bay or lagoonal character. Sometimes these sequences pass laterally into distributary channel fill pebbly sandstones or contain coarse sandstone lenses.

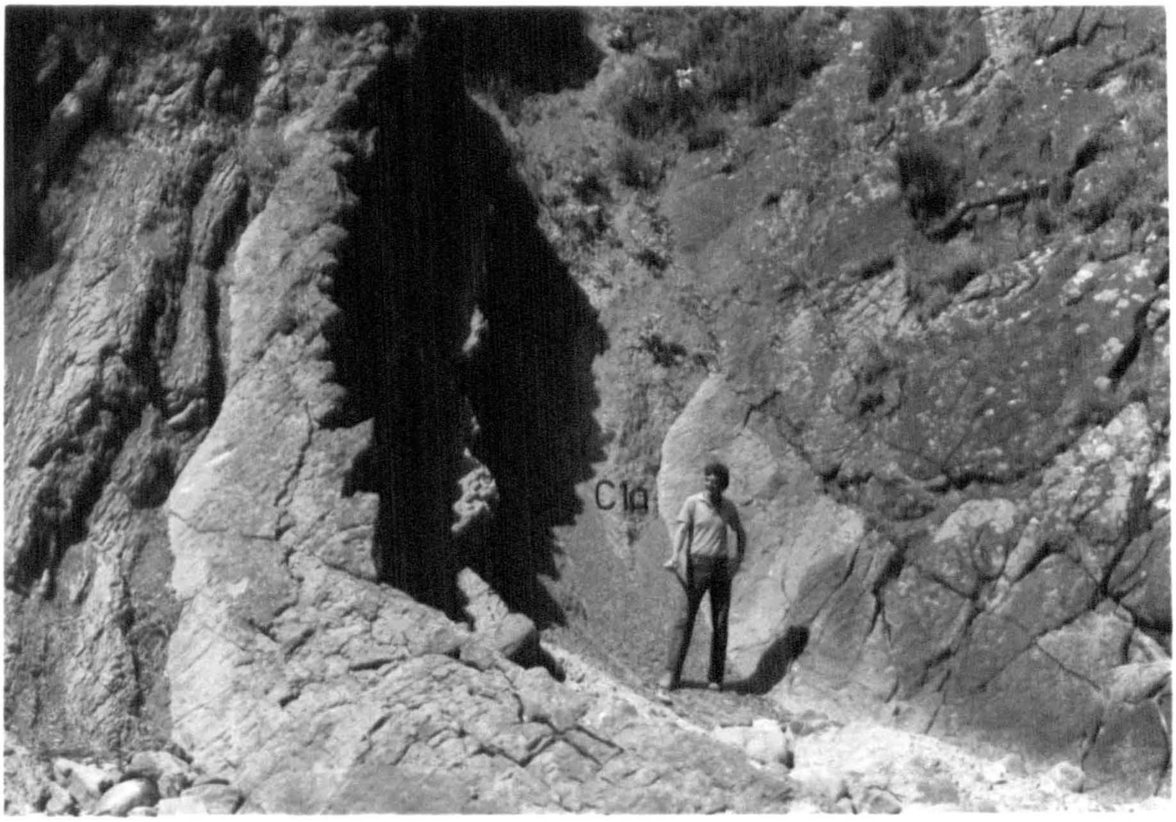
Interpretation: In the study area, dark iron-rich mudstones transitional to siltstones suggests deposition of these sediments in a quiet, sheltered environment which may be some type of interdistributary bay or sheltered lagoon, free from high energy accumulation of coarser detrital sediments. Interdistributary bays are generally shallow-water bodies which may contain fresh, brackish or marine waters. Flood-generated processes dominate interdistributary bay sedimentation. Oomkens (1970) claimed that for shallow bays of this type to be filled by gradational coarsening upwards sequences, the receiving waters must be at least brackish in order to provide a density contrast with the incoming river water. Elliott (1974) showed that rippled and cross-laminated interbeds can be formed by the overbank flooding of a distributary channel, and also suggested that some coarsening upward sequences can develop from the encroachment of levees into the bay environmant. The occurrence of some bivalves in the Gökgöl section may indicate brackish to freshwater conditions. However, in the Tarlaağzı section each interdistributory mudstone sequence is overlain by wave-rippled sandstones capped by a brachiopod coquina, suggesting extensive wave activity and probable higher salinities (Plates 44-45).

(ii) Inter Distributory Channel Sequences - C1b

Description: In the Alacaagzi Formation, distributary fluvial channel deposits are identified from the nature of the abundant cross-bedding (commonly trough), the scale of the bedding units varying from large scale near the base to thin, rippled bedded and cross-laminated units near the top. The low variance of palaeocurrent data suggests that the rivers were of low sinuosity. Detrital wood, drifted coal and clay chips are abundant throughout but are most common at the base of the channel-fill and in the basal portions of individual scour units

Plate 44. Interdistributary bay sequences (C1a). Each thin interdistributary mudstone sequence is overlain by a more resistant wave-rippled sandstone.
From the Alacaağzı Formation.
Locality: Tarlaağzı Shoreline, Amasra area.

Plate 45. Close-up picture of upper surface of sandstone at right of plate 44. Note straight-crested wave ripples. Small brachiopods commonly occur in the troughs of these ripples, but are not seen in this photograph.

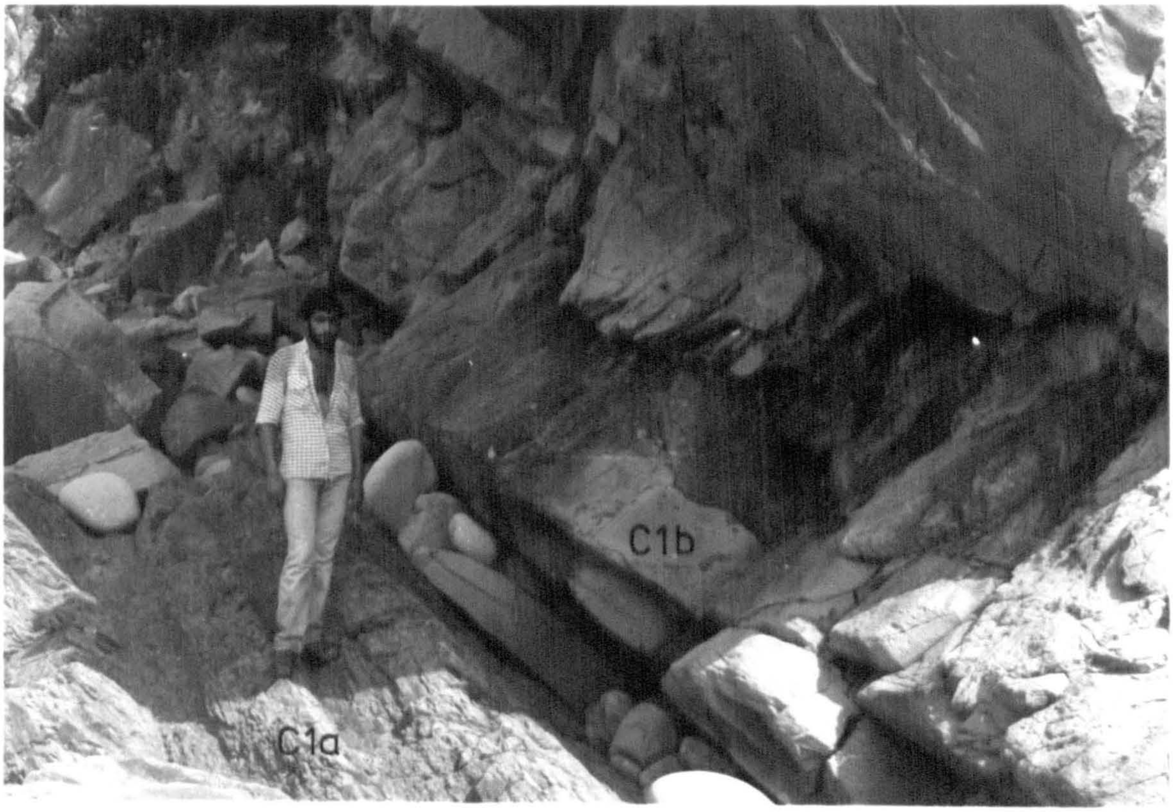

C1a

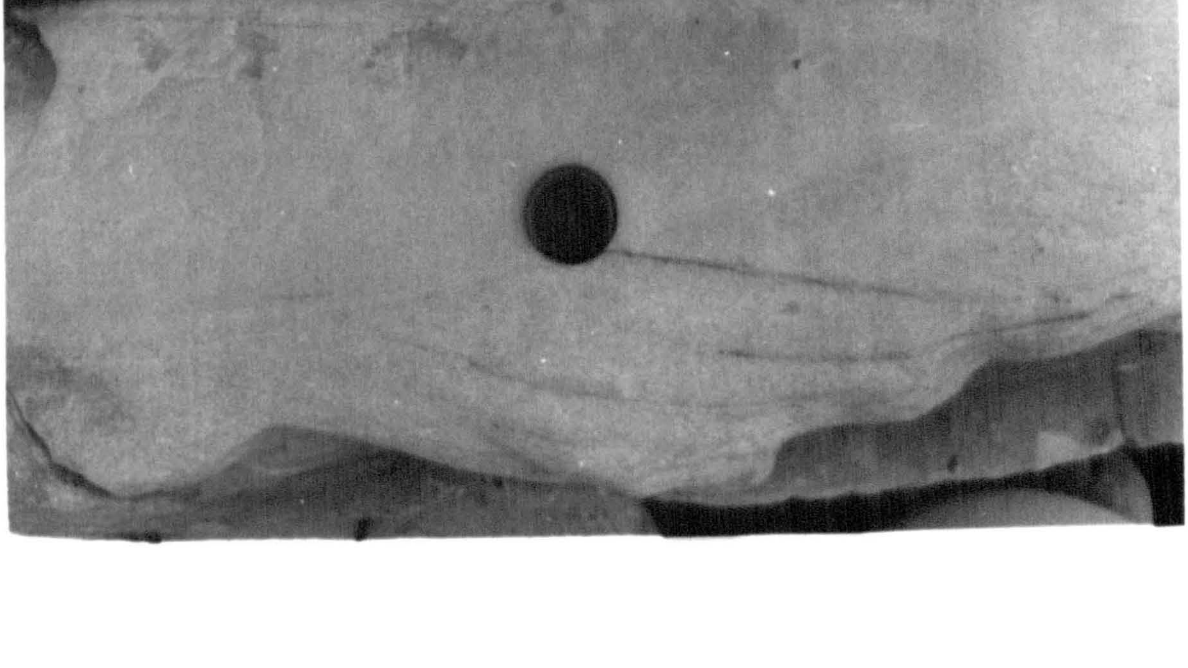
(Plates 46-47). Internal erosion surfaces are frequent. Distributary fluvial channels are represented by massive pebbly sandstones. The actual basal content of these distributary channel deposits is exposed at a few localities, such as the Ulutamdere and Üzülmezdere stream cuts in Zonguldak area, and Tarlaağzı bay of the Amasra area. In these areas the massive pebbly sandstones of the distributary channels gradually passes upwards into massive, fine grained sandstones, micaceous sandstones and ripple laminated sandstones of the delta plain association. This is similar to the "fining-upwards" cycle of Allen (1965b).

Interpretation: The Delta Plain Association is dominated by the Distributary Fluvial Channel deposits. Some criteria discussed below indicate that the distributary channels in the Alacaağzı Formation were of meandering or low-sinuosity braided variety. Some of these possibilities which suggest low-sinuosity or mere braiding are as follows: Aggradation of channels and avulsion are due to high rates of sediment dumping. This suggests a rapidly prograding distributive net where branching of low-sinuosity distributaries carried water and sediment to the delta front. Bluck (1976, p.452) showed that Scottish streams of low sinuosity build a sequence of alternating coarse and fine sediments as they migrate laterally. The coarse sediments are built by bars which are now seen forming in the present active channel zone. Some of the modern examples of braided rivers such as the Kosi River (Gole and Chitale 1966) are characterised by wide channels, rapid and continuous shifting of the locus of sedimnt deposition and the position of the channels. Coleman(1969) suggested that, in the Brahmaputra River, the braid-channels originate through a combination of tectonic activity and catastrophic floods, which are both common in the present day regime. Williams and Rust (1969) showed that

Plate 46. Interdistributary channel-fill deposits (C1b) cut into inter-distributary bay sequence (C1a). The channel sandstone displays large-scale trough cross beds together with drifted carbonaceous material. From the Alacaağzı Formation.
<u>Locality</u>: Alacaağzı bay, 40 km west of Zonguldak.

Plate 47. Close-up of Plate 46, showing detail of channel-fill sandstone with trough cross-bedding, clay and coal chips.


C1b
C1a



facies relations in the Donjek River of Canada are mostly gradational within channels, commonly forming fining upwards sequences. According to Brown et al(1973) two settings for distributary channels are possible. The channel may be cut into delta-plain facies. In this case avulsion shifts the channel across an interdistributary bay to a new site of progradation. When the channel is part of a significantly prograding lobe, it will build over and cut into its own channel-mouth bar and delta front.

The first case is very rare in the study area. In one example, at the Tarlaağzı section, distributary channels are cut directly into interdistributary bay sediments. However, a second type is more common, for example, in the Gökgöl section of the Zonguldak area, and is characterised by extensive delta prograding, with initial development of mouth bar sands followed by formation of a distributary channel, cut into its own channel-mouth bar sands.

4.2.4.2 OVERBANK SUB-ASSOCIATION - C2

(i) Natural Levee Sequence - C2a

Description: Natural levee sequencesare characterised by ripple-cross lamination, climbing ripples, root marks, and a well sorted "suspension type" (Visher 1969) grain size distribution. Kolb and Van Lopik (1966) and others have noted that the height, width and stability of the natural levees flanking distributaries decreases downstream. According to Scott and Fisher (1969), natural levee deposits are formed as the result of overbank flow during the flood stage. Levees are thickest and the sediment is coarsest adjacent to the channels, these sediments grading laterally into interdistributary muds and organics forming the marshes.

Such a levee-unit is well developed in the Formation of the Alacaağzı (Plate 48) and Kireçlikağzı sections of the Zonguldak area. In these

Plate 48. Possible natural levee deposits (C2a), with ripple cross-lamination and soft sediment deformation. From the Alacaağzi Formation.
Locality: Kireçlikağzı bay, 30 km west of Zonguldak.

Plate 49. Possible crevasse splay deposits. Mostly thin, parallel to lenticular-bedded sandstones, overlain by a thin zone of soft sediment deformation (SD) and interdistributary channel fill sandstones (S). From the Alacaağzı Formation.
Locality: Tarlaağzı shoreline, Amasra area.


C2a


S
SD

sections upward coarsening in grain size is seen, in relation to the underlying and laterally equivalent interdistributary bay deposits, which show a decrease in grain size and thickness, and increase in mud partings, carbonaceous debris, and sediment transport away from the distributary channels. The basal surface of the coarse sediments may display scour and fill structures while the smaller units show flaser bedding, or fine sand and silt ripples, interlaminated with silty, carbonaceous mudstones.

Interpretation: Levees normally occur adjacent to the distributary channel on the deltaic plain, or in the bay areas (Scruton, 1960; Fisher et al., 1969; Elliott, 1974; Coleman 1976). The undulatory, unchannellised bases of these Carboniferous sandstones, with abundant clay clasts, may represent sheet erosion, as suggested by Elliott (1974). Levees generally develop through accumulation of flood deposits, and the predominance of parallel lamination with isolated climbing ripples is consistent with this interpretation (McKee et al., 1967). The larger clasts within these laminated units indicate high flow energy, the grains travelling by traction in laminar flow (Simons et al., 1965). The coarsening upwards nature of this sequence is considered to reflect progradation of levees and major cravasse splay lobes into the interdistributary areas.

(ii) Crevasse Splay Sequence - C2b

Description: The crevasse splay sequence consists of siltstones with sandstone interbeds. Examples are restricted to the Gökgöl and Tarlaağzı "Members" of the Alacaağzı Formation; they overlie members of the proximal delta front sub-association (mouth bar sandstone and distributary channel fill sandstone) (Plates 39&49).

The siltstones range from muddy to coarse-grained. Plant debris and siderite nodules occur throughout the siltstone units. Rootlets may occur in siltstones which immediately overlie sandstone interbeds, as in the Gökgöl section. Individual sandstone beds are less than 30 cm thick; they have a lenticular shape, sharp erosive bases with load casts and scour marks with some clay drapes . The top surfaces of beds may be sharply defined or they may pass gradationally upwards into the overlying siltstones. Wave and current ripple forms have been observed upon the top surface of some beds.

Modern crevasse splay deposits are characterised by their lens-shaped geometry, by the occurrence of small scale cross-bedding, the fine-grained sandy nature and the variability of palaeocurrent directions (Coleman 1969; Arndorfer 1973). Minor crevasse splays occur as discrete coarse beds in the bay muds and silts, and may also occur in levee sequences. Collinson (1969, p.206) recorded flute and groove casts on the erosive bases, and grading, parallel lamination and current ripple lamination internally. In the Alacaağzı Formation the crevasse channels exhibit unidirectional trough cross-bedding and current ripple lamination. These channels are characterised by their lenticularity, scoured bases, upward fining grain size, and soft-sediment deformation, with load casts as mentioned above.

Interpretation: The grey homogeneous siltstones are considered to represent deposition of fine-grained sediment from suspension in the interdistributary bays and lagoons during periods of low river stage. The different types of sandstone interbed are comparable to sheet deposits from overbank floods and the distal part of crevasse splay lobes (Allen, 1965c, Reading1970, Elliott 1974b). Each bed represents a single flood episode with deposition taking place during waning flow; this results in a graded transition upwards into the overlying siltstones. Occasionally, sedimentation may have taken place in sufficiently shallow water to cause emergence and enable plant colonisation. Periods of emergence were followed by deposition of relatively coarse grained, thick bedded (0.40 m) sandstones. The stacked nature of these sandstones and their association with minor channel fill sandstones of proximal delta front sub-association suggest a crevasse splay origin (Elliott 1974b, 1975). Also some clear well sorted sandstones with ripple laminated tops suggest active processes of sediment reworking during their accumulation. However, these do not have the gradational bases and the low-angle accretion surfaces described by Elliott (1975) for typical crevasse-splay sandstones.

4.2.4.3. DELTA ABANDONMENT SUB-ASSOCIATION - C 3

Description: Typically sediments assigned to this sub-association include micro cross-laminated sandstones, carbonaceous siltstones and mudstones. Silt laminae are micro-graded and interlaminated with black fissile mudstones. In the upper portion of the sequence leaf imprints are preserved in light-coloured mudstone and iron coatings on bedding planes are common. The delta abandonment sub-association typically occurs in the Alacaağzı Formation of the Gökgöl section (Fig. 13) and Alacaağzı bay section of Zonguldak. The sequence (delta abandonment part) commences with wave-rippled sandstones overlain by mudstone which grades upwards into dark grey, fossilifereous, calcareous siltstones. Capping the siltstones is a coarse grained sandstone unit. This sandstone unit fines upwards and grades into carbonaceous, root-mottled siltstones which, in turn, grades into a coal layer. In this sub-association the majority of coals are considered to be of autochthonous origin. This conclusion is based upon the presence of this rootlet zone which is immediately below the coal, thus constituting a true seat-earth. Many small siderite nodules are associated with the rootlets (Plates 50-51).

Interpretation: Plant fragments are commonly concentrated on top of the abandoned delta plain distributary channels, and thus match the manner in which the seat-earths and coals usually rest directly upon the distributary channel fill sandstone. The occasional beds of mudstone or siltstone (sometimes ripple laminated) found below the seat-earth and coal may possibly represent lagoonal areas on the delta plain, formed as a result of differential subsidence. Following abandonment the whole of the delta plain subsided, gradually forming a laterally extensive peat-bearing marsh; as subsidence continued this peat was flooded and covered by fluvial sandstones.

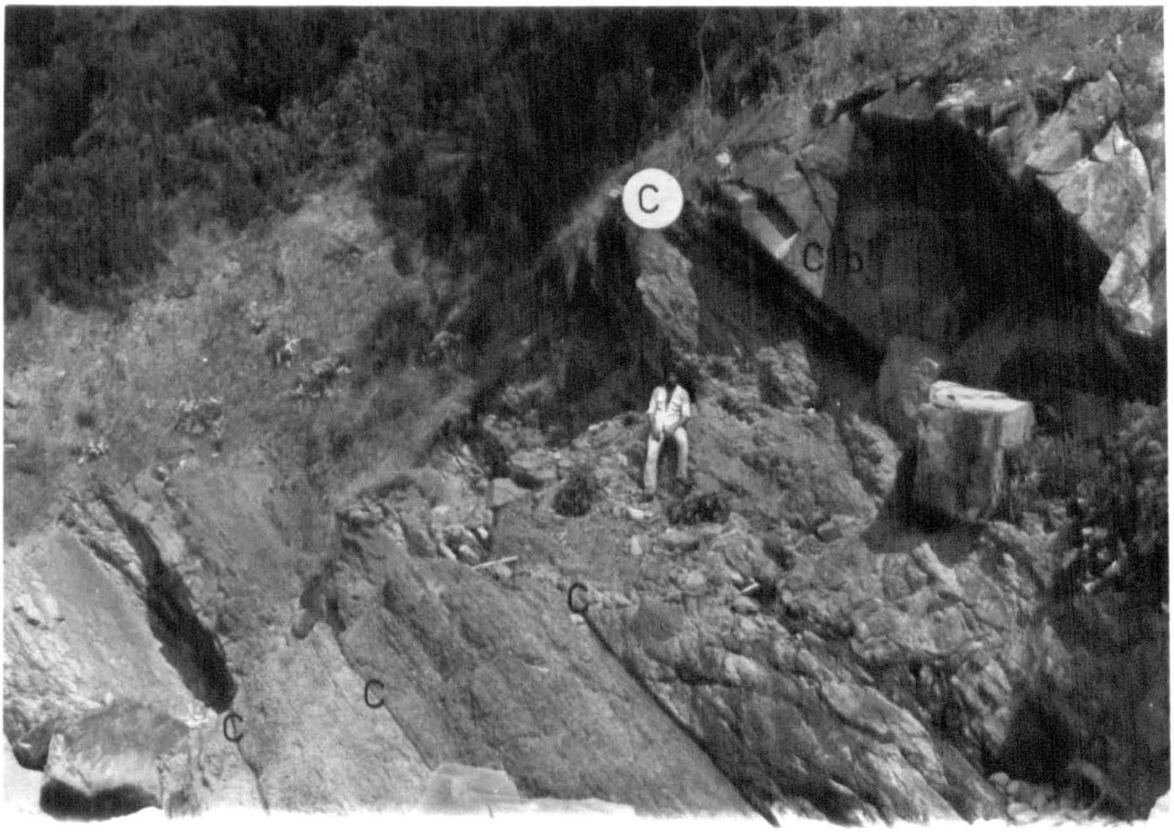
The formation of coals during delta abandonment, at the onset of transgression, has been described by Fisk (1960), Coleman and Gagliano (1964) and Elliott (1974a).

According to Elliott (1974b) this type of abandonment facies comprise a laterally persistent coal in the proximal area of the lobe and a thin, fossiliferous horizon in the distal area, which reflect relatively slow rates of sedimentation.

In the fluvial-dominated delta system of the Gökgöl section of the Zonguldak area, abandonment facies marker horizons are extremely thin, compared with the progradational facies. However, in the wave-dominated delta system of the Tarlaağzı sequence of the Amasra area, basinal processes appear to have played an important role. A relatively thick sheet of marine sandstones, siltstones or mudstones gradually extends across the entire area of the former delta. In some cases coal is not formed on top of the sandstone probably because the immediately overlying coquina beds shows that storm events have influenced the area

Plate 50. Fine-grained sequences dominated by laminated, micrograded siltstone passing up into seat-earth and coal (C) with mudstone and rootlets. At least four such sequences are evident in this exposure, the topmost being overlain abruptly by interdistributary channel-fill sandstones (C1b). These fine grained cycles represent Delta Abandonment Sub-Association (C3). From the Alacaağzı Formation.
Locality: Alacaağzı Bay, 40 km west of Zonguldak.

Plate 51. Possible Delta-abandonment sediments (C3) with seat-earth and thin coal layer developed on top of micro-trough cross bedded sandstone and overlain by sharp-based, sheet sandstone. From the Alacaağzı Formation.
Locality: Alacaağzı bay, 40 km west of Zonguldak.


C
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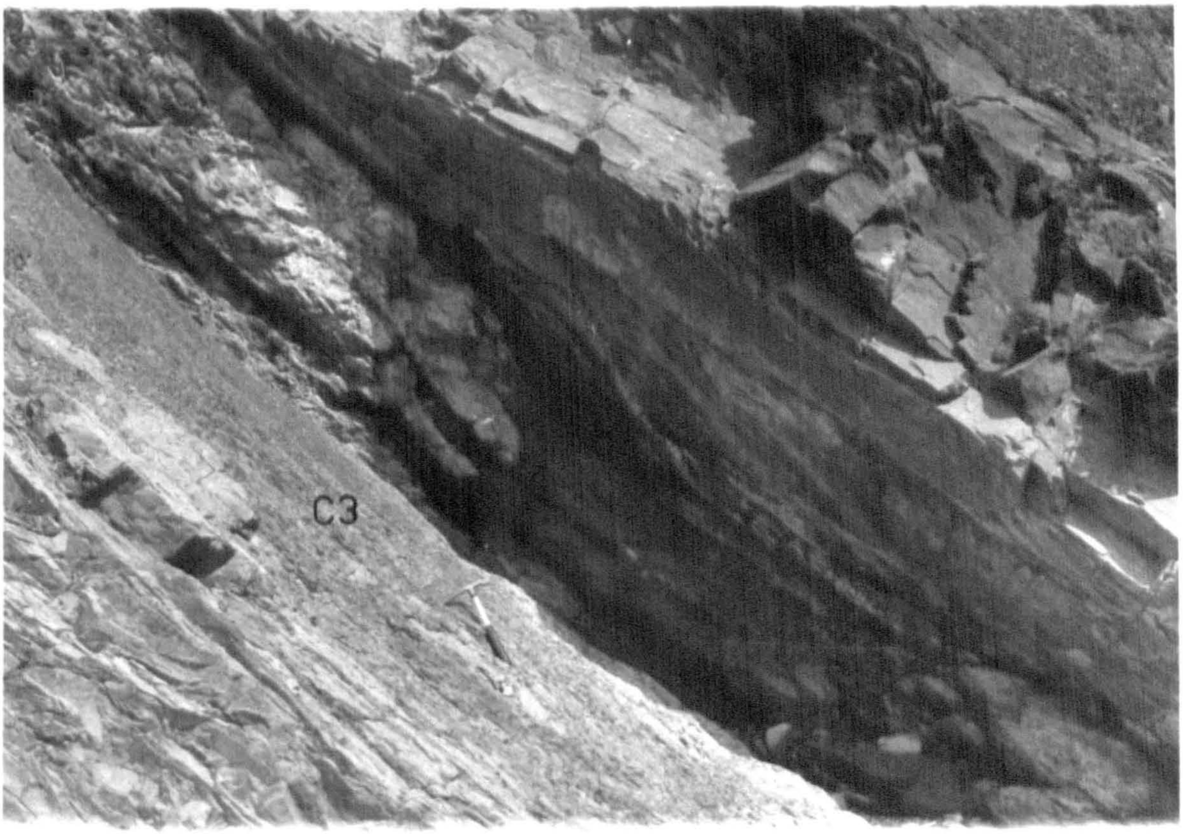

C3

as discussed in the next section.

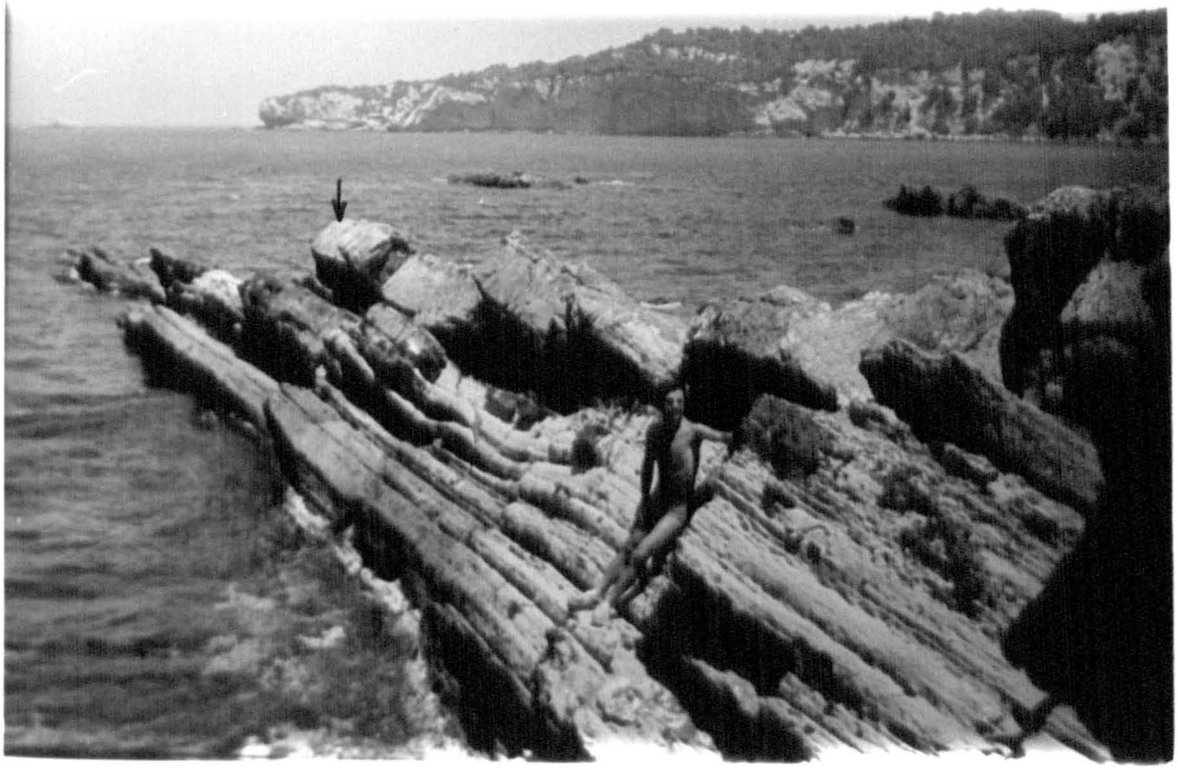
4.2.4.4. STRAND PLAIN SUB-ASSOCIATION - C4

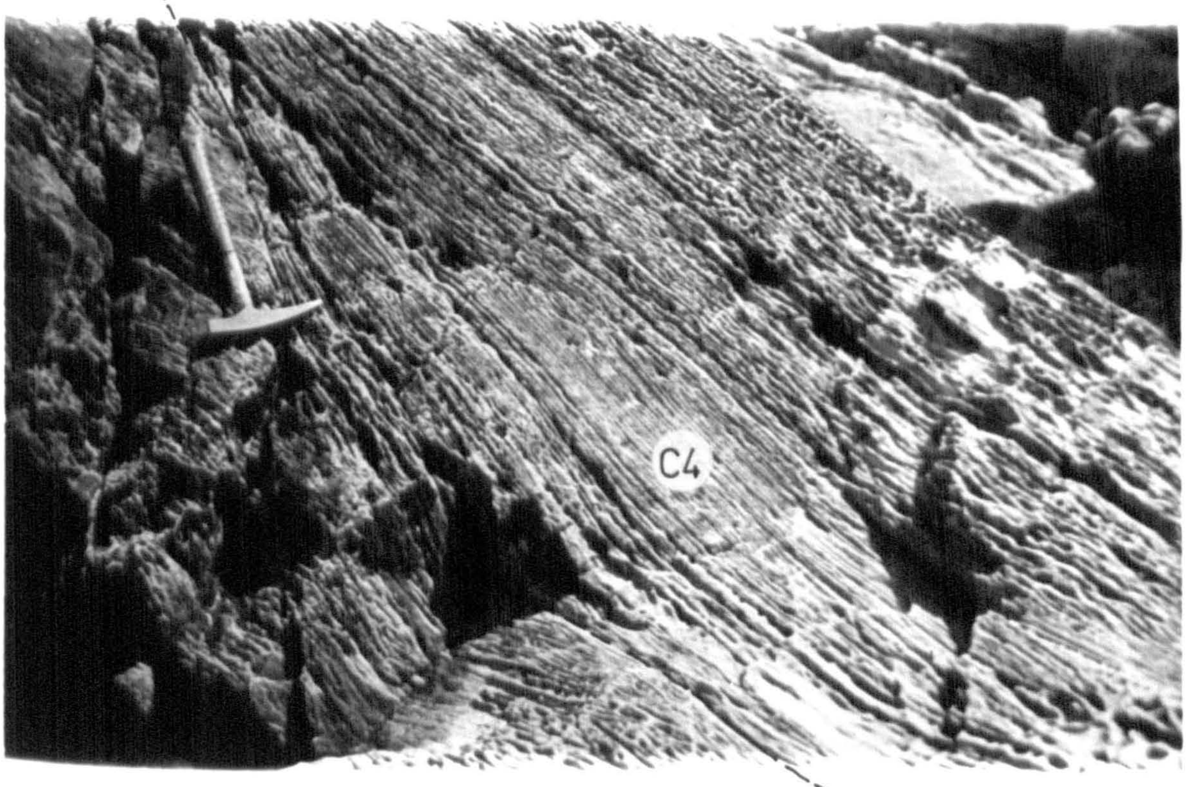
Description: This comprises units almost entirely composed of whole or broken brachiopods, within an extremely coarse sandy matrix. The beds from 10 - 50 cm in thickness and are very extensively exposed in the Tarlaağzi section of the Amasra area. Here the units may display medium-scale trough cross bedding. The strand plain sub-association is broadly coarsening upwards (Fig. 15). The lower part of the sequence is sometimes burrowed and contains a sparse brachiopod fauna. The upper (shore-face) part contains abundant brachiopod shell fragments and is dominated by low-angle cross-bedding and horizontal bedding with minor small-scale cross-bedding (Plate 52).

Interpretation: The fragmental, coarse and relatively well sorted nature of the coquinas favours a high energy environment which probably resulted in winnowing of fine sediment and the concentration of larger shell fragments during major storm episodes, while the lateral persistence of the facies units suggests that it probably represents an ancient shoreline. Presumably the shoreline was migrating across the basin. However, the truncated and reworked nature of the coquinas found at the base of the lenticular sand units indicates that the shoreline was under the influence of channellized currents, probably of fluviatile origin (Güven, 1977). In the Tarlaağzı example the strandplain sub-association may have accumulated in an interdeltaic setting, since sand was transported laterally by longshore currents from a nearby delta (Plate 53).

Plate 52. Wave-rippled thin sandstones overlain by 60 cm thich brachiopod-bearing coquina bed (arrowed) of strand plain sub-association (C4). From the Alacaağzı Formation.
Locality: Tarlaağzı shoreline, Amasra area.

Plate 53. Possible rip-channel structure of strand plain sub-Association (C4), cut through wave-rippled sandstones and caused by possible long shore currents, from the Alacaağzı Formation.
Locality: Tarlaağzı shoreline, Amasra area.




C4

4.3. THE ALLUVIAL COMPLEX

4.3.1. INTRODUCTION

This facies association comprises the deposits of broad floodplains and flood basins. Two distinct types are generally recognised, corresponding to meandering and braided channel patterns. The floodplains of several rivers or of several tributaries within a large river system typically combine to produce broad alluvial plains. In this study, three assemblages have been recognized, two determined by fluvial channel morphology and the third relating to the nature of the interfluvial environment:

(a) Meandering Stream Association

(b) Braided Stream Association

(c) Lacustrine Association

4.3.2. MEANDERING STREAM ASSOCIATION - D

The characteristic features of meandering rivers include: the meandering shape of the channel, point bar deposits and fining upward sequences (Note, however, that Bluck, 1980 showed that fining upward sequences were also present in braided stream deposits in the Old Red Sandstone of Scotland). The original model for meandering rivers was described by Bernard and Major (1963), based on studies of the Brazos River of southeast Texas. They determined that lateral migration of the point bar produced a typical fining-upward sequence. Cross-bedding sets should become smaller upwards towards the top of the point bar. In small channels, where point bars are steeper, successive increments of lateral accretion may be recorded as epsilon cross-bedding (Allen, 1963b, 1965c; Moody-Stuart 1966; Puidefabriges 1973; Elliott 1976). It is in the high sinuosity meandering rivers that preservation of flood plain deposits is most likely. In addition, the preservation of overbank fines depends on external factors such as tectonic and climatic changes, as demonstrated by Allen (1974). Where the rate of subsidence is low, a meandering river may be able to erode away most of its overbank sediment. However, not all meandering rivers produce fining upward channel-fill sequences. For example, McGowen and Garner (1970) suggested that, in meandering rivers carrying coarse sand and gravel the normal, fining upward sequence may be truncated or succeeded by one or more thick tabular sets of cross-beds deposited by lobes of sediment (chute bars) built out on the downstream part of the point bar by flood waters passing through a chute cut through the convex bank of the meander. A small pebbly, meandering river studied by Bluck (1971) showed quite different features; pebbly rifles were well developed, pebbles formed the upstream faces of point bars and sand accumulated mainly on the downstream ends. Moreover, Jackson (1975 , 1976b) has shown that sequences formed in tightly curved meanders do not show consistently fining-upwards successions. He termed this restricted type of meandering rivers, streams of "intermediate sinuosity".

This review suggests that the classical meandering river model of Allen and Bernard and Major cannot be applied to many meandering rivers. The following section seeks to relate the various ideas outlined above to the north Turkish sequences, and especially those in the Kozlu Formation. For this purpose the terminology of Walker and Cant (1979) has been adopted in part.

4.3.2.1. THE MAIN CHANNEL SUB-ASSOCIATION - D1

Description: Meandering within the fluvial channel is maintained by erosion on the outer banks of meander loops, and deposition on the inner parts of the loops. The main depositional sub-environment is the point bar, which builds laterally and downstream across the flood plain (Walker and Cant, 1979). The channel floor commonly has a coarse "lag" deposit of material that the river can transport only at peak flood times. Walker and Cant proposed that the preserved deposits of the active channel will pass upward from trough cross-bedded coarse sands to small scale, trough cross-laminated fine sands.

Channel lag deposits found in the Formation of the Kozlu, Dilaver section of Zonguldak; within sequences attributed to meandering channels, are ascribed to lateral erosion of bank material. Such deposits include flakes and blocks of overbank mudstones and plant debris (sometimes large) (Plates 29-30). Also finer grained sediments were accumulated within channels, along with subordinate coarse material. Normally, however, pebbly coarse sandstones rest directly above the basal erosional surface of channel floor and are composed of low-angle planar and trough cross bedding. Beds are either laterally continuous or lens shaped and in both cases they have sharp tops. The overlying sheet-like sandstone units contain sigmoidally-bedded units with numerous carbonaceous siltstone drapes. The sandstone sheets are similar in grain size and internal stratification to the sandstones of the sigmoidally-bedded units. In colour, the sandstones grade from greyish-olive and olive grey to brown and yellow as size decreases. Angular, pebbly-sized fragments of sandstone and siltstone of intraformational origin are common throughout the Dilaver "Member" of the Kozlu Formation. It is often possible to distinguish relatively minor erosion surfaces within these major sandstones (Plate 54).

<u>Interpretation</u>: The characteristics of this facies strongly suggest deposition in stream channels migrating across alluvial plains (Bridge et al., 1980). The major erosion surfaces and basal breccias should be therefore overlain by the deposits of channel bars that have migrated laterally. However, Stewart (1981) has showed that basal erosion surfaces do not always bear lag deposits, and overlying sediments may be coarser or finer than those which are cut by the erosion surface. Mudclasts among the constituents of the conglomerates probably originated from bank erosion and the destruction of mud layers deposited during low stages (Bluck, 1971). In the modern single-channel streams with sinuousthalwags these deposits are characterised by large scale trough cross-stratification, produced by sinuous-crested dunes migrating over point-or-side-bars.

The upward decrease in grain size and systematic variation in internal structure within these minor bedsets probably records conditions of falling stage after a flood. Dessication of exposed "low-flow" deposits provides a ready source of intraformational sandstone and siltstone fragments that can be incorporated into overlying flood deposits.

The deposits described above also have some similarities with the facies of some braided rivers (e.g. Coleman 1969; Collinson 1970; Cant and Walker 1978). The observed unidirectional palaeocurrents within major sandstone bedsets (see Chapter6) support a river channel bar environment in the single channel streams. Lateral bar migration is certainly common in braided streams, however frequent channel abandonment is not common. The multistorey character of the major sandstone bedsets is to be expected when lateral bar migration is combined with net aggradation (Bluck, 1971; Bridge ,1975; Bridge and Leeder,1979).

4.3.2.2. POINT BAR SUB-ASSOCIATION - D 2

Description: The terms "point bar" and "scroll bar" are a source of confusion in the literature. The scroll bar may be considered to be the end stage of the evolution in an individual point bar. In general, the scroll bar is formed of fine sand and silt derived from suspended loa. The term point bar will be used here(in the sense of Nanson, 1980) to indicate the largely unvegetated body of sediment formed within the active channel against the convex bank of a bend. Bluck (1971) showed that point bars consist initially of a platform of sediment well below the level of the convex bank, which has a flat or slightly cambered cross section.

In the Açık Yarma section of the Kozlu Formation in the Zonguldak area, there are some interesting features of the deposits interpreted as point bar sediments. A few centimetres above the sharp-based sandstones forming the base of the sequences there are pebbly sandstones (Fig. 17). This situation may result from destruction of the channel walls, resulting in transport of pebbles out towards the floodplain.

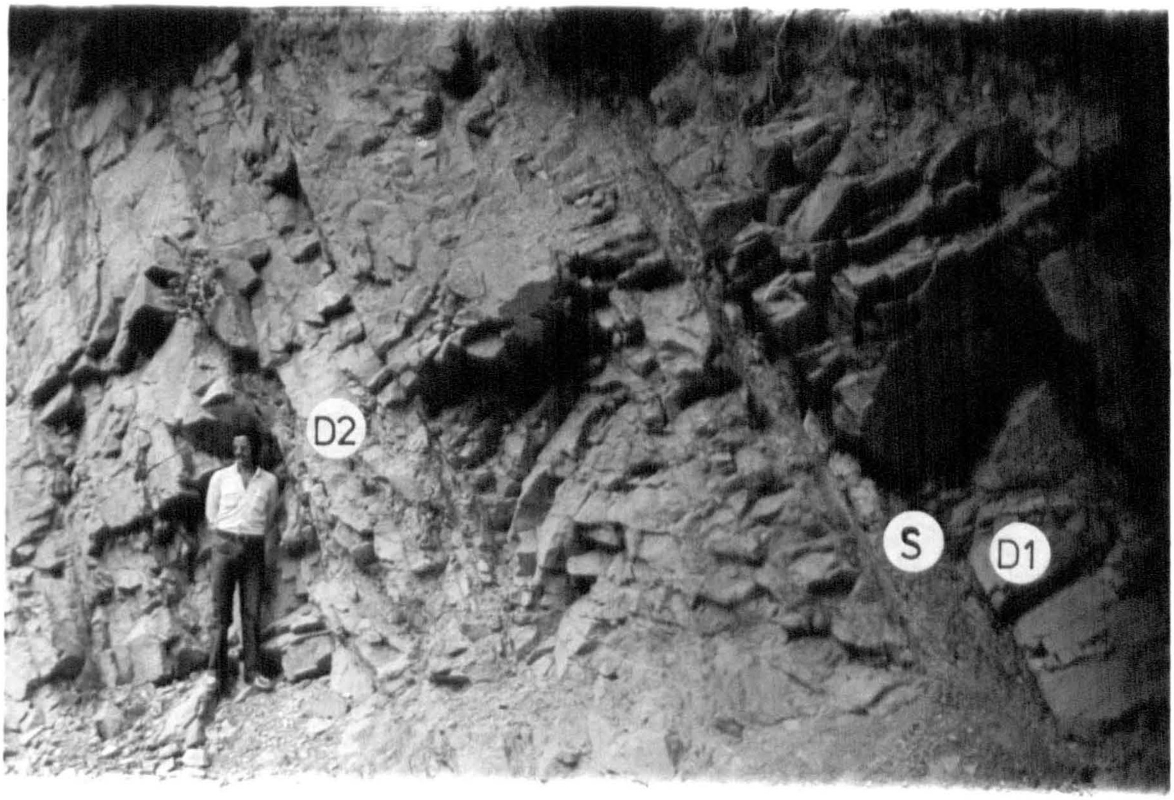
Some presumed point-bar deposits have been recognised in various parts of the Kozlu Formation, and are best displayed in the Dilaver, Gelik and Açık Yarma section of the Zonguldak area and the Ilyas geçidi dere of Kurucaşile area (Plates 24,54,55,56). Generally, these point bar sequences start with the deposition of sigmoidally (epsilon) cross-bedded coarse sediments, followed by progressively finer sediments,laid down on the aggrading surfaces. Flat bedding with parting lineation is common. Sometimes the flat bedded sets exhibit erosive bases. On the top of the point bar deposits silty and muddy layers are present, sometimes with micro cross-lamination. However, this fining upwards profile is not always well developed. The abruptly overlying fine grained sequence is

Plate 54. Meandering channel-fill sandstone (D1), at right, erosively succeeds sigmoidally cross-bedded sandstone (see Plate 24 for better view of these) of point bar deposits (D2) with intervening muddy swale-fill (S) deposits. This entire sequence may represent part of anastomosed stream environment. From the Kızıllı Formation.

Locality: Ilyas Geçidi Dere, Kurucaşile area.

Plate 55. Thick bedded, aharp-based sandstone of the point bar sub-association (D2) erosively succeeding muddy, possibly lacustrine, deposits (F2b). From the Kozlu Formation.

Locality: Dilaver road cutting, Zonguldak area.


D2
S
D1


D2
F2b

Plate 56. Epsilon - cross bedding medium sandstones (near base of sequence) passing up into trough cross-bedded sandstones showing upward dimination in scale of troughs. Entire sequence is interpreted as a point bar succession (D2) and overlies a vertical accretion sub - association with coal layers.

Locality: Acik Yarma, 400 meters north of Kırat Tepe, Zonguldak. Coal - adit entrance is approximately 1.20 meter high.

suggestive of "swale-fills". However, Jackson (1976a) demonstrates that coarse sediments can be deposited high in the vertical sequence at the upstream end of a point-bar, probably as a result of higher shear stress there.

Interpretation: The sigmoidally cross bedded units have been termed "epsilon cross-stratification" by Allen (1963), and interpreted as a meandering stream deposit, possibly representing lateral accretion of point bars. Jackson (1978) however, points out several short comings of "epsilon cross-stratification" as an indicator for point bar deposits of meandering streams. Epsilon cross stratification may be best regarded as indicating lateral bar deposition. Several authors have reported similar large-scale, sigmoidal beds in ancient fluvial sandstone units (Jackson, 1975; Bridge, et al.1980) . Collinson (1968, 1969) described large scale cross bedding from the Kinderscout Grit in Derbyshire, and considered the examples to be the deposits of "Gilbert Type" deltas. However, McCabe (1975) and Jones (1977) showed that these large sets (giant cross-bedding) lie within channels. Also, giant epsilon bedding recently has been observed in coarse-grained point bars of late Pliocene fan delta systems near Bologne by Ori and Lucchi (1981).

Flat bedding with parting lineation is characteristically developed in the lower part of the upper flow regime (Simons et al., 1965) while erosion at the base of flat bedded sets probably occurred during flood stages. Small scale cross-lamination on top of the point bar was probably produced by migrating ripple trains (Allen, 1963) formed under lower flow regimes (Simons et al., 1965). Consequently, a large proportion of floodplain alluvium will be formed in bends where a high proportion of fining upwards sediments is being accumulated. Moreover, it is necessary to consider the thick deposits of coarse, undifferentiated sediment which Jackson (1976a) found to be characteristic of the upstream end of most point bars. Secondary currents must be important, moving diagonally onto the bar and active at least during low flows (Bluck, 1971; Jackson, 1975), especially in the formation of the large downstream portion of most point bars, for here shear strength is low and slack-water zones sometimes exist.

4.3.2.3. CHANNEL ABANDONMENT SUB-ASSOCIATION - D3

Description: Meander loops can be abandoned gradually (chute cut-off) or suddenly (neck cut-off) (Allen, 1965a, p.118, 119, 156). During chute cut-off, the river gradually reoccupies an old swale, and simultaneously flow gradually decreases in the main channel (Walker and Cant, 1979).

Lewin (1978, p.32) showed that two types of erosional modification to the floodplain surface are common. Firstly, flow chutes may cut into unvegetated gravel point bars. A second erosional modification occurs where water seeping through the gravels is sufficient to entrain and transport them.

The abandonment sub-association in the north Turkish Carboniferous successions comprises complexly interbedded fine to very fine grained, moderately/poorly sorted sandstones and siltstones. Major bedding surfaces may be planar or display channel-shaped erosion surfaces, and the coarser units are gradually replaced upwards by fine sediments. Large scale cross-stratification is usually of the trough type and set thickness ranges from 5 to 40 cm, mostly being between 10 - 20 cm. Isolated sets of large-scale planar cross-stratification occur rarely. Small-scale trough cross-stratified sets range up to 3 cm in thickness, and trough widths range from 4 to 7 cm across. Drifted and in situ plant fragments are common. In general, bedsets become thinner and finer grained in the down-current direction. Palaeocurrents are unidirectional.

Interpretation: Each bedset of a given type is interpreted as the deposit of a single flood on a floodplain. Large and small scale cross-stratification and horizontal stratification were produced by bed load deposition of sand, moving as dunes, ripples or on a flat bed. The vertical sequence suggests a gradual upward change from a waning flood to suspended load deposition during the closing stage, as suggested by Casey (1980).

The sheet-like units of siltstone and sandstone have similarities to the floodbasin deposits of modern floodplains (Allen, 1963), while those filling channels may represent the last stage of channel abandonment, or even swale fills (Frazier and Osanik 1961; Boersma, 1967). The superposition of progressively finer and thinner bedsets in channel-fills can be explained by progressive abandonment of crevasse (or chute) channels. Lateral migration of crevasse channels by bank erosion and point bar deposition (e.g. Kruit 1955) may explain the common occurrence of asymmetrical channel fills with lateral accretion surfaces.

In the Kozlu Formation the cut-off process is associated with meandering streams. The abandoned channels are slowly filled by siltstones and mudstones with some organic material; also some suspended material is introduced during overbank flows. Most of the cut-off channels become lakes with abundant flora, sometimes including freshwater fauna as well.

4.3.2.4. VERTICAL ACCRETION SUB-ASSOCIATION - D4

Description: The vertical accretion sub-association is developed outside the main river channel, deposition in the flood basins, ox-bows and levees taking place by addition of sediment during flood stage, when the river overtops its banks (Walker and Cant 1979).

Such sediments are represented within the Kozlu Formation by laterally extensive sheets, although very broad channel fills also occur. The sediment is greyish-red coloured siltstone, with lenses or thin sheets of silty, very fine sandstone. Towards the top of the Kozlu section a flood basin origin is most likely. Sediment was introduced mainly in suspension, with some weak bed-load transport before final deposition.

Interpretation: The distinction between the deposits of vertical and lateral accretion is not represented by any significant change in grain size characteristics, therefore it is difficult to differentiate them. However, the lateral accretion units have erosional bases. Possibly individual accretion units are not simple layers, but consist of a complex of intertonguing beds separated by erosion surfaces.

Walker and Cant (1979) have suggested that lateral accretion took place within the main channel, although vertical accretion deposits may occur near the channel. Where the flood waters sweep along a stream, the vertical deposits tend to be silty, and are commonly cross laminated. Further away from the river, the flood waters may stagnate and only mud is deposited.

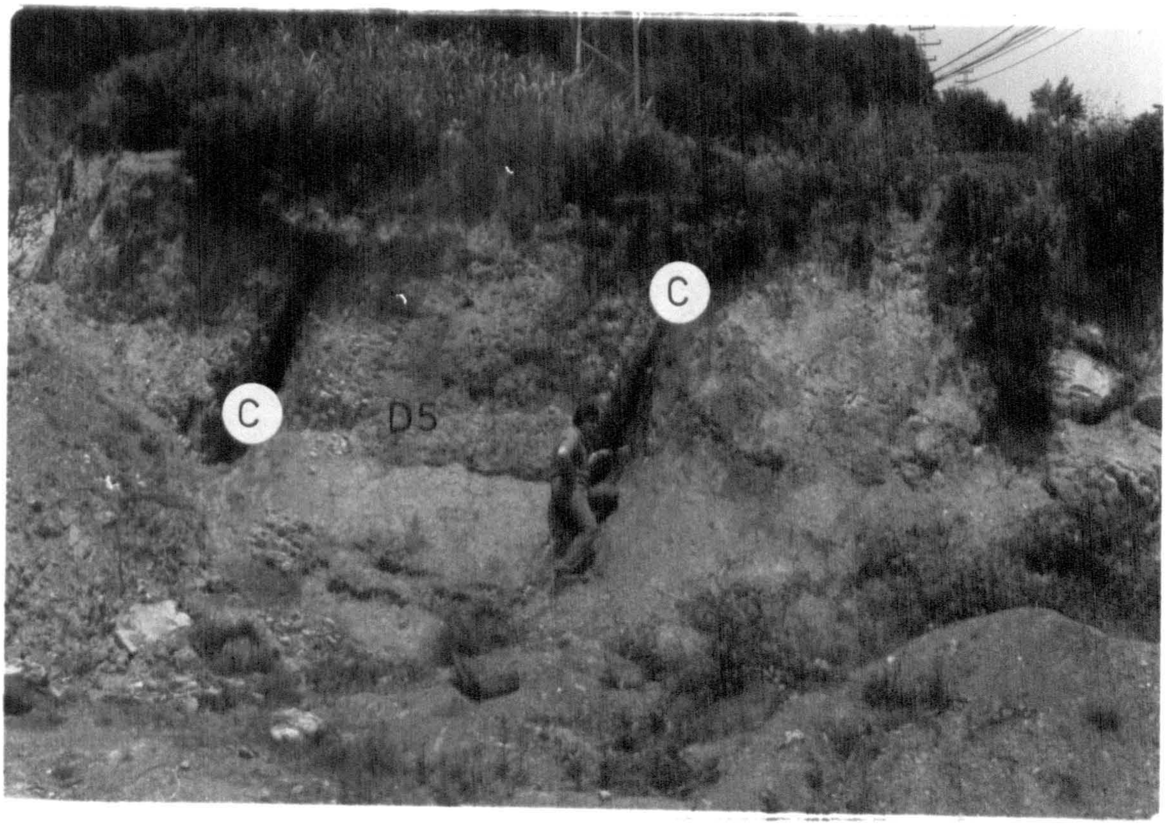
4.3.2.5. SWAMP SUB-ASSOCIATION - D5

Description: In the study area, non-laminated, soft muds appear to have been locally deposited within seasonally-flooded environments. Coals with seat-earths are common, which is suggestive of an autochthonous origin. The presence of thin vertical rootlets penetrating and homogenising the sediment immediately below the coal thus constructing a genuine seat-earth. Many small siderite nodules are associated with the rootlets. Stigmaria have been recorded in situ throughout the Kozlu Formation. The swamp sub-association is composed of mainly very fine-grained sediment and settles from overbank flows after the coarser sediments have been deposited on levees and crevasse splays. The size and shape of the swamp area depends on the history of the flood basin. Field evidence in the Kozlu sequences suggests that the swamp area was elongated and trended parallel to the channel. Also the nature of the abundant flora (see pp. 141) suggests that the swamp areas were low, wet and thickly vegetated (incorporation of abundant organic material in the area). Especially in the Karadon Formation there is thick deposition of clay sediments (Schieferton) which are associated with accumulation of organic matter, especially plant debris (which in some of the levees is exceptionally well preserved) and coal layers (Plates 57-58).

Interpretation: In the study area poorly laminated mudstones and rootlet beds are interpreted as deposited from suspension of fines within stagnant floodwaters. Scott (1978) has suggested that coal horizons with seat-earths containing abundant stigmarian rootlets indicate a "swamp" environment. The coals are thought to have formed in situ as evidenced by their seat-earths and their flora. Locally, the coarse-grained sandstones may represent point bars. However, the isolated thin coarser sandstone units probably represent crevasse splays from nearby rivers (Allen, 1965). Sediments of a flood basin contain the finest grades of all the alluvial sediments. There may be a slight upward fining in each flood basin sequence of silt-clayey sub-association (the evidence of more prolific vegetation and more prolonged subsidence).

Plate 57. Steeply-dipping sequence (younging to left) displaying cycles of parallel-laminated siltstones and soft mudstones capped by coals (C), in the swamp sub-association (D5) of the flood-basin environment. Note the absence of coarse sediment above successive coal layers. From the Asma "Member" of the Alacaağzı Formation.
Locality: Asma-Dilaver road cutting, Zonguldak area.

Plate 58. Possible drifted coal intercalated within muddy layers of flood basin environment, and erosively overlain by pebbly low sinuosity channel-fill sandstone (at left). From the Kozlu Formation.
Locality: Road cutting near 320 Colliery, Zonguldak area.


C
C
D5


E1b

4.3.3. BRAIDED STREAM ASSOCIATIONS - E

In competition with the meandering river system, the processes and products of low sinuosity multi-channel (braided) rivers are poorly understood. The best known studies are: the Donjek River (Williams &Rust 1969); Brahmaputra (Coleman, 1969); Platte (Smith, 1970); Tana (Collinson, 1970); some Scottish rivers (Bluck 1976); South Saskatchewan (Cant and Walker 1978).

Some general models for braided rivers in recent years have been reviewed by Miall (1977), who proposed four general models based on facies assemblages and vertical sequence. However, Collinson(1978) proposed two types of braided river sequence, based on their dominant lithology; namely pebbly braided rivers and sandy braided rivers.

There is little agreement concerning nomenclature of the geomorphological elements in these rivers. The term "bar" is used here to refer to "long, low, slipface-bounded features that occur on a scale larger than that of individual bedforms, such as ripples, sand waves, dunes and transverse "bars", (Cant & Walker, 1978).

Collinson (1978) distinguished three types of bars: side bars, descending gradually into the channel with no slip faces; mid-channel bars and islands (the equivalent of the "cross channel bar" of Cant and Walker, 1978); alternative bars, which are characterised by slip faces on their downstream side. Internally, these probably produce tabular cross bedding. The first and third types are roughly triangular in plan view and are attached with regular spacing on alternate sides of the channels. However, Casey (1980) used the term "lateral bar", which is a more general term, referring to any bank-attached bar. Thus "side bars", "alternate bars" and "point bars" may all be considered specific kinds of lateral bars.

Cant & Walker (1978) used "sand flats" for large transverse bars that emerge during waining flood stages to form the nucleus of larger, more complex sand bodies.

Collinson (1978) has recognized two major groups of large-scale, asymmetrical bedforms, namely sandwaves and dunes.

Sandwaves have high length to height ratios. They normally have rather sharp-based slip faces and their upper surfaces carry superimposed ripples. Internally, they give rise to tabular sets of cross-bedding which are often inter-bedded with units of cross-lamination. These forms have been called "linguoid bars" (Collinson, 1970) or "transverse bars" (Smith, 1970). These features can be regarded as bed forms and are not in the true sense "bars".

Dunes have low length to height ratios and form at depths and velocities above those of sandwaves, can normally be expected to produce trough cross-bedding on a variety of scales.

In the study area, braided stream sediments can be grouped into two categories:

(i) Sandy low-sinuosity stream sub-association;

(ii) Pebbly braided stream and humid fan sub-association.

4.3.3.1. SANDY, LOW-SINUOSITY STREAM SUB-ASSOCIATION - E1

In the study area the upper part of the Kozlu and Karadon Formations contain this kind of sub-association. Such deposits are gradational between pebbly braided river deposits and those which formed in gently meandering streams. Overbank and channel fill sequences constitute the major part of the deposits, together with natural levee, crevasse splay, and flood basin deposits. Sometimes differentiation is not well developed and one can recognize only channel fill and overbank deposits.

(i) Overbank Sequences:- E1a

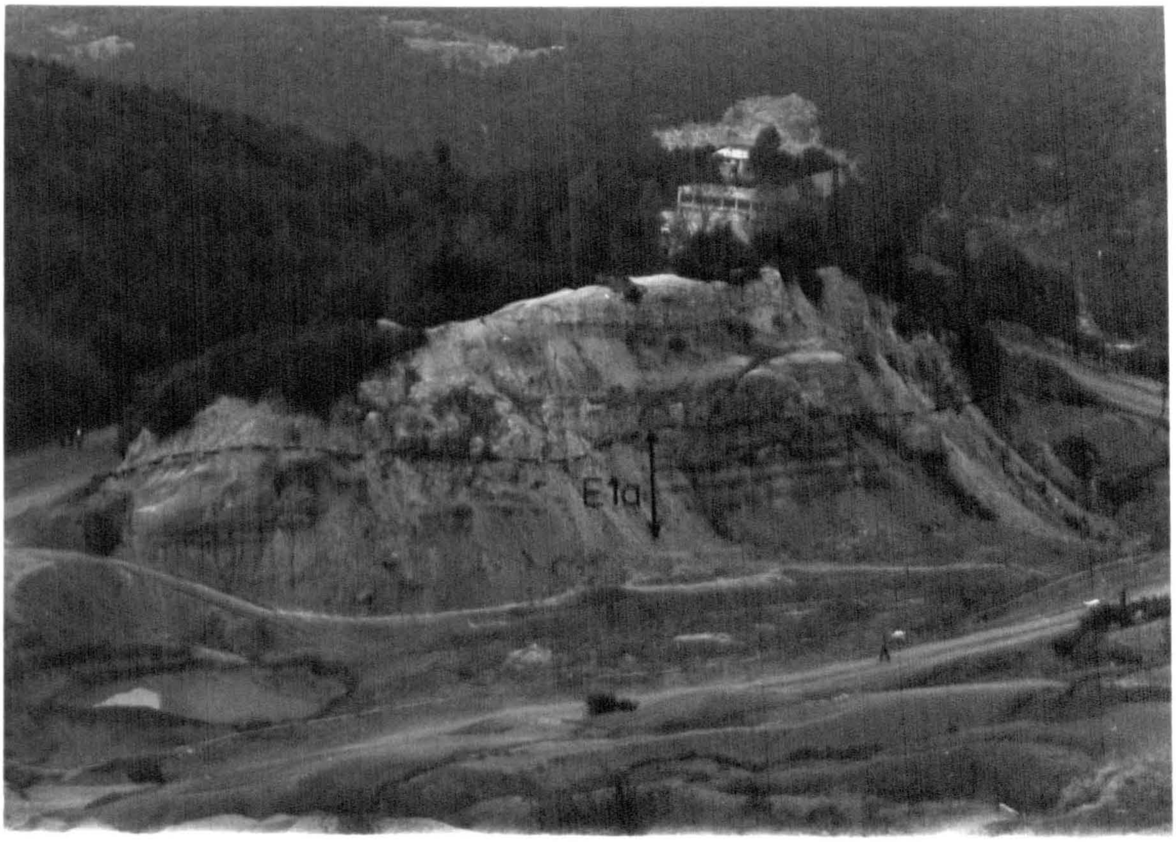
<u>Description</u>: These are mainly represented by siltstones and mudstones and are generally horizontally laminated. The systematic vertical variation is similar to Allen's (1965) "fining upwards" cycle, and changes upward from fine grained sandstones to siltstones and mudstones, clays (fine clays) and coal. The Schieferton with interbedded coal layers have crucial stratigraphic, economic and sedimentologic importance (Plate 59). Their colour is normally dark grey to cream, but white clays also occur within these deposits, and scattered charcoal has been also observed.

The upper levels of the Karadon Formation display this kind of deposit. For example, in the Kozlu-Zonguldak road cutting, near the "Zonguldak 10 km" road sign, yellowish silty sandstones intercalated with tiny coal layers also display indistinct sigmoidal cross-bedding (Plate 60). Again, the road cutting from Açik Yarma section towards Kilimli village (in the Zonguldak area), the upper part of this sequence includes some sigmoidal beds and thin horizontally bedded sheet-like sandstones (Plate 61). Such units, may range up to several metres in thickness. The sand is usually well sorted. In addition to these "sheet-like" overbank deposits there are also wedge-like crevasse splay deposits. According to Casey (1980), the major difference between these two types of flood-plain deposits is that "sheet splay" deposits are essentially a continuation of the main channel and sediment transport is in a downstream direction, whereas overbank crevasse-splay deposits are formed by lateral overspilling and sediment transport may be perpendicular to the axis of the fluvial system.

Most of these sequences are capped by coals. In the study area, the coal seams of Karadon Formation's are of this type, and are the product of *in situ* plant growth and decay, the seat-earth being the soil on which the earliest plants grew. Later, plants probably rooted themselves into the

Plate 59. Horizontally bedded siltstone, mudstones and clays (Schieferton) interbedded and capped by coal layers (E1a). This sequence represents part of the sandy low-sinuosity stream sub-association of the Karadon Formation.
Locality: Near Karadon Village, Zonguldak.

Plate 60. Overbank deposits (E1a) of sandy low-sinuosity stream sub-association, showing sandstones displaying possible medium scale sigmoidal cross-bedding. From the upper part of the Karadon Formation.
Locality: Kozlu-Zonguldak road cutting, near the "Zonguldak 10 km" road sign.


E1a

accumulating vegetation or peat. The occasional beds of mudstone or ripple laminated sandstone below the seat-earth and coal may represent lacustrine deposits (as seen in the Ilyas geçidi dere section of the Kurucaşile area and in the Yahyabeş and Özkem section of the Azdavay area).

Interpretation: The sheet-like sandstone units suggest that sand deposition occurred outside the main channels. Similar sheet-like overbank sandstone units have been called "sheet-splay deposits" by Galloway et al., (1979 p.32) in the Oakville Formation of Texas.

According to Casey (1980), during the waning stages of floods, organic-rich fine sediment was deposited from suspension, forming thin drapes on the bar surfaces and somewhat thicker drapes on the overbank sheet sands. The preservation of planar bedding, both on the bars and in the overbank areas, suggests that rapidly waning flood conditions inhibited the formation of lower flow regime bedforms. Broad shallow channeling and some smaller scale cross-beds may have formed during falling stages.

The development of in situ coal in the sandy braided flood plain implies that the environment must have had a high water table and may have been permanently submerged as an overbank back-swamp (Collinson, 1978).

However, in the Karadon Formation the plant fragments are commonly concentrated on the top of the abandoned fluviatile channels and thus seat-earths and coals usually rest directly upon the sandstones, which may indicate that coal developed mainly within the channel area, rather than outside it.

The alumina-rich Schieferton layer originated through leaching of Aluminium from soil in a semi-arid environment. They are attributed to precipitation from slightly reducing groundwaters in a permanently saturated soil, comparable to Wilson's (1965) development of siderite nodules (in Collinson 1978). Therefore the presence of Schieferton may result from a climatic change, from hot, humid climate to the semi-arid climate of the Karadon Formation (especially the upper part).

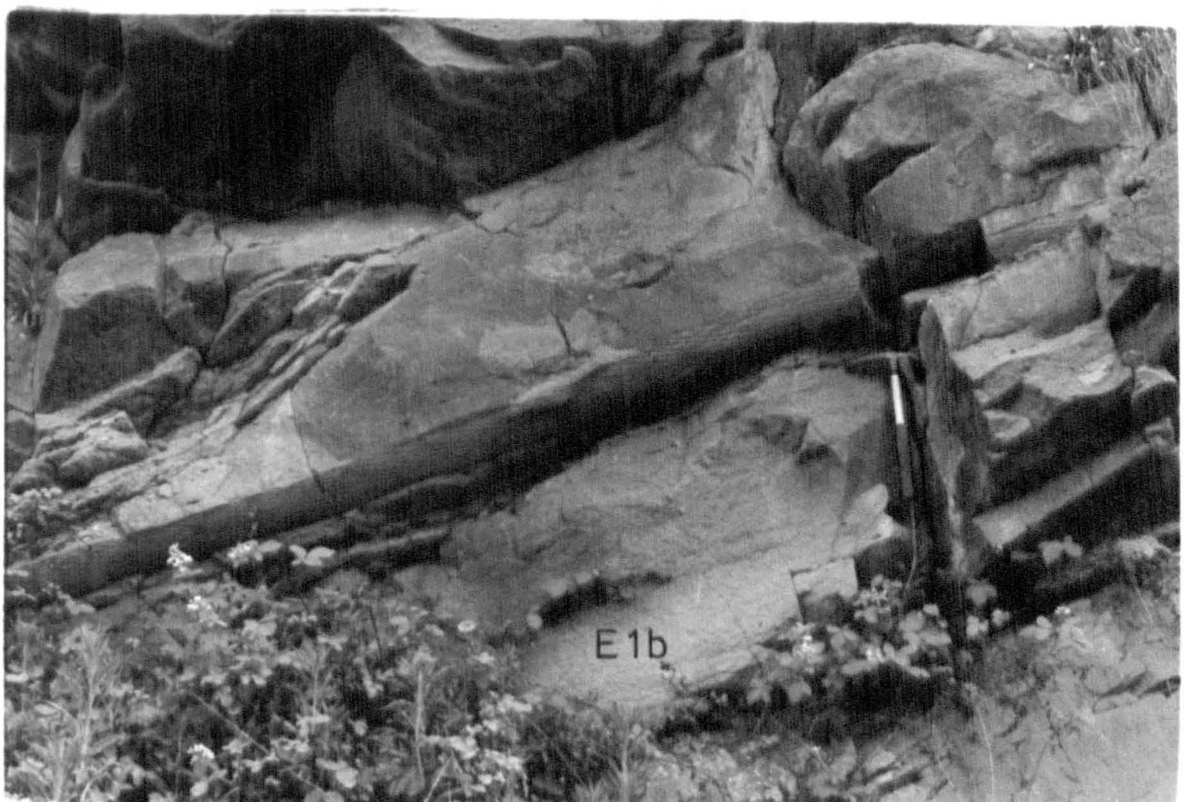
(ii) Channel Fill Sequences:- E1b

Description: In the study area, fluvial channel-fills are represented mainly by massive pebbly sandstones and by the trough cross-stratified and sigmoidal cross-stratified sandstone lithofacies of the Kozlu and Karadon Formations. Palaeocurrent data from low sinuosity rivers generally have relatively low variance. In the Kozlu Formation the palaeocurrents display little dispersion, suggestive of straight or low sinuosity channels of constant grade and sediment supply. Detrital wood and clay chips are abundant (Plate 62) throughout, but are concentrated at the base of the channel and in the basal portions of individual scoured units. The channels in the Karadon Formation tend to be very variable in depth and width, and do not conform to any simple pattern. The channel floor commonly has lag deposits, and above the lag, sand is transported through the system as bed-load. There is little evidence for the existence and nature of bedforms in the channel. However, some thick channel-fill sandstones show cosets of medium-scale cross-beds which may represent smaller bedforms in the shallower parts of the river. The wide lateral extent of the cross-bed cosets, irrespective of the underlying lithology, indicates shallow water-flows. Moreover, small-scale trough cross-beds are common. The best examples of this sequence occur in the Gelik section, Açık Yarma section and Dilaver section of the Zonguldak area, and in the Özkem, Kızıllı section of the Azdavay area, (Plates 28,29,30).

Plate 61. Sheet-like alternating thin sandstones and siltstones of the overbank deposits of the sandy, low-sinuosity stream sub-association (E1a) in the Kozlu Formation.
Locality: Dilaver road cutting of the Zonguldak area.

Plate 62. Channel-fill cross bedded sandstones of the sandy, low sinuosity stream sub-association (E1b) with "Lepidodendron" tree trunk, in the Dilaver "Member" of the Kozlu Formation.
Locality: Small quarry between the abandoned Kasaptarla coal mine and the Kozlu-Zonguldak road cutting, Zonguldak area.


E1a


E1b

Interpretation: The lack of large-scale tabular cross-bedding in the Karadon Formation indicates that major bedforms, such as sandwaves, dunes etc., were not very important in these channels. However, in the Kozlu Formation under conditions of low discharge, channel fills would be dominated by cosets of medium-scale, low angle cross-beds as seen in some outcrops, such as the Gelik section of Zonguldak area. Deposition within channels during waning flood stages may cause channel beds to aggrade, preserving flood stage sedimentary structures. The massive pebbly sandstones were probably rapidly deposited at high discharge.

Bluck (p.452, 1976) showed that Scottish streams of low sinuosity build a sequence of alternating coarse and fine sediments as they migrate laterally. A similar situation has been observed in the Karadon Formation and especially in the Açikyarma section, Zonguldak. However, several criteria indicate that rivers in the Kozlu and Karadon Formations were of low sinuosity. For example, the laterally continuous nature of the cosets is probably due to lateral migration of the braided river, forming sheet deposits. The undulatory bases and the wedge-shaped nature of some cosets may also suggest a braided nature. Moreover, the medium-scale cross-beds in both small and large channel associations are of low sinuosity origin.

According to the review by Collinson (1978), braided rivers are characterised by wide channels and by rapid and continuous shifting of the locus of sediment deposition and channel-position. An extreme example of the lateral shifting of a braided stream is the Kosi River (Gole and Chitale, 1966).

Smith (1970) suggests that high regional slopes, variable discharge and abundant sediment supply are the most important factors controlling braiding. These critical points are applicable to the Karadon Formation type of braided river. The geographical setting of the Karadon Formation indicates that high regional slopes may be a possible controlling factor. Coleman (1969) suggested that, in the Brahmaputra River, the migration of braided channels is due to a combination of tectonic activity and catastrophic floods, which are both common in the presentday regime. The lower reaches are usually meandering, but if they are heavily charged with sediment and at high discharge, they may develop a braided pattern, despite the prevalence of fine-grained material.

In conclusion, the upper part of the Kozlu Formation and the Karadon Formation display the characteristics of low to medium sinuosity river deposition rather than widespread meandering deposition.

4.3.3.2. PEBBLY BRAIDED STREAM AND HUMID FAN SUB-ASSOCIATION - F2

In this section Collinson's (1978) present day pebbly braided rivers and humid fans model has been taken as the basis for terminology, and applied to the Karadon Formation. Also, Schumm (1977), emphasised the importance of wet alluvial fans and discusses their characteristics both in the field (modern and ancient) and in laboratory experiments. The Kosi River fan is considered a good present day example of a humid alluvial fan, which Gole and Chitale (1966) described as an inland delta. Present day alluvial fans which occur as complexes along mountain fronts lose their topographic individuality downstream, merging into braid plains with the same mean flow direction. According to Rust (1978) braided rivers fall into two parts: proximal and distal.

Description: The distal part of the pebbly braided stream sub-association contains clast-supported conglomerates which indicate an active channel-fill lithofacies. Williams and Rust (1969) showed that the middle reaches of the Donjek river are also characterised by inactive tracts supporting abundant vegetation on levels or terraces slightly above the active tract.

The distal part of the Karadon Formation sequences are composed mainly of Bluck's (1967) facies B, C and D types of conglomerates. The facies B type of unit is erosively based and comprises a single cross-bedded set of rather sandy conglomerate. However, horizontally bedded, internally imbricated conglomerates, which may appear massive where bedding is thick and texture is uniform in the Karadon Formation, represents the proximal part of the pebbly braided stream sub-association. This sub-association presumably developed along the mountain margins. Deposits are coarse-grained and poorly sorted (Plates 31 , 32). Such units are almost exclusively bed load deposits. These alluvial fan like deposits grade into coarse-grained braided river deposits. Most abundant are channel deposits which show lenticular shapes. Thin units of finer-grained sediments were also observed, together with coarse pebbly conglomerates (Plates 31,32).

Interpretation: The generation and preservation of thick sequences of conglomerates in the Karadon Formation requires substantial relief and thus usually implies tectonic acivity, associated with faults or the basin-flanking uplifted source areas, during or immediately prior to deposition. According to Collinson (1978), this type of sediment body may be similar to present-day humid fans and pebbly braided rivers. McGoven and Groat (1971) showed that such successions are often very extensive and are dominated by stream deposits, compared with those in fault-bounded settings and highly intergradational, from thick conglomerates to cross-bedded pebbly sandstones with less pebbles and more scouring on the bases of beds.

In the Karadon Formation, the single erosively based,cross-bedded sets of sandy conglomerate suggest that the whole unit is the result of a single flow, interpreted as a sheet flood, which deposited the lag pebbles and the sandstone unit as the flood waned. However, broad lens-shaped, stacked conglomerate bodies are interpreted as the products of continuous or multiple stream flows.

4.3.4. LACUSTRINE ASSOCIATION - F

In the study area, the Kozlu Formation towards the top of the sequence consists mostly of lacustrine deposits. The criteria used to distinguish deposits of this Association in the studied rocks are:
a generally fine-grained sequence with moderate lateral persistence, the absence of marine fauna, no evidence of tidal currents, the presence of abundant suspended sediment and non-marine fauna such as Curvirumula, fish scales, rain prints and a general coarsening-upwards sequence. Collinson (1978) suggested that in lake deposits signs of emergence are common, reflecting the frequent, perhaps even annual oscillations in lake level. Individual shoreline facies, such as those associated with beaches, lagoons and barrier islands are never thick.

Two types of lake sub-associations have been recognized in the Upper Carboniferous successions of northern Turkey; namely

(1) Fining upwards sub-association, and

(2) Coarsening upwards sub-association.

4.3.4.1. FINING-UPWARD LACUSTRINE SUB-ASSOCIATION - F1

Description: Sequences of this type have been recognized in the Kozlu-Zonguldak road cuttings (Plate63,7). The sequence commences with sharp-based, fine-grained sandstones and gradually passes upwards to siltstones. The top of the section comprises finely laminated medium grey mudstones capped by black fissile shales, which contain fish scales According to Riley (pers comm., 1980) these fish may be of lake type.

The total thickness of this sub-association is approximatly 30 metres and it is overlain by thick conglomeratic beds.

Interpretation: The absence of any carbonates or marine fauna suggests that these lakes were small and may have developed as ponds in the alluvial plain environment. The erosive base to the succession displays the typical upward-fining pattern with siltstone and mudstone, suggesting the development of a shallow pond. The overlying conglomerates suggest renewal of active stream flow across the former lake environment (Plate 63,).

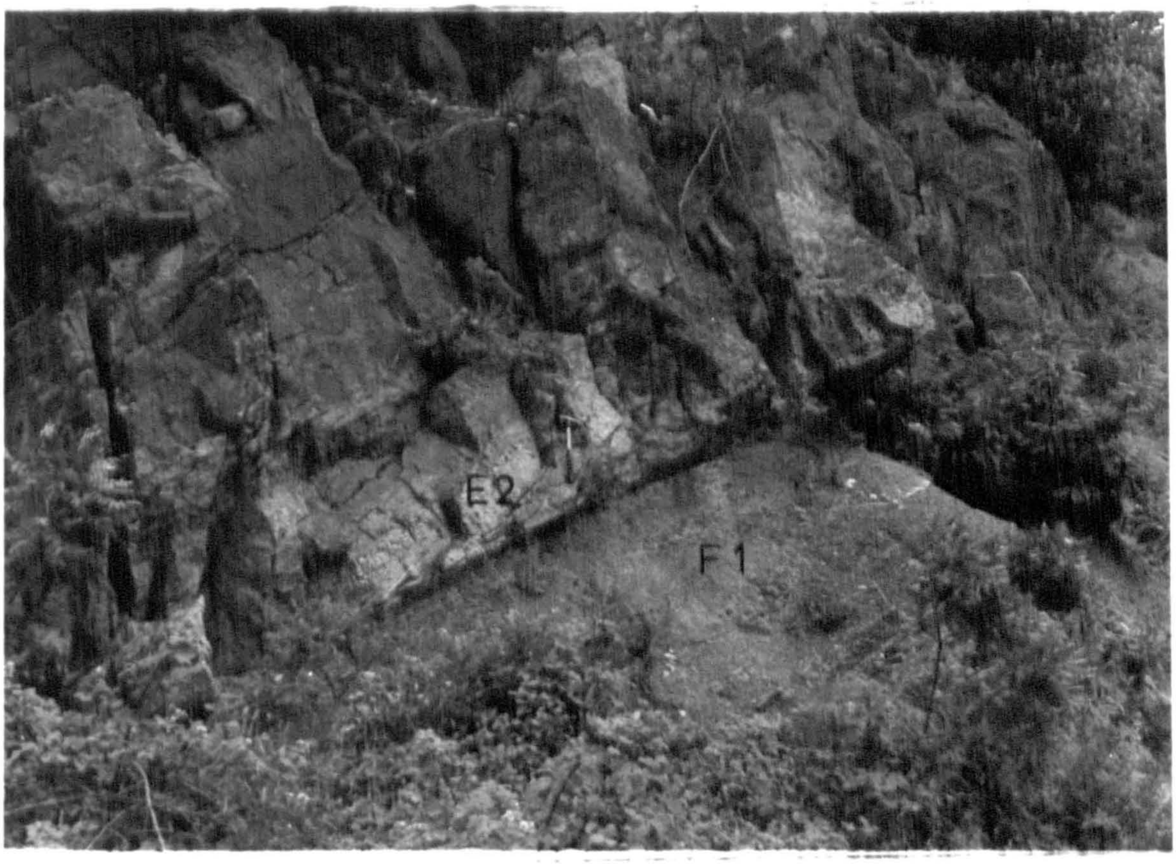
Discussion: The fining-upwards aspect of these lake deposits is somewhat controversial in view of the generally accepted concept of coarsening upwards sequences characterising lake deposits. In this section two possible solutions are offered for such a fining-upwards sequence in lake deposits:

(a) These lake deposits may have been of "playa" type (Collinson, 1978) where the lake was very shallow and local, where one flood brings sediment into the lake and deposits coarse material at the bottom, the waning energy resulting in deposition of finer sediments from suspension nearer the top of the sequence.

(b) Alternatively, a "normal" coarsening upward sequence was developed in the lake (see below) but the succeeding fluvial channeling, represented by the overlying conglomerates, erosively removed most of the upper coarser parts of these lake successions.

Plate 63. Fining-upward lacustrine sub-association (F1) at top of Kozlu Formation of the Karadon Formation. At the base are siltstones passing up into dark shales which contain fish scales. There are abruptly succeeded by pebbly braided channel-fill deposits which mark the base of the Karadon Formation and belong to the Humid Fan sub-association (E2).
Locality: Kozlu-Zonguldak road cutting, Zonguldak area.

Plate 64. Upper surface of wavy-bedded silty sandstone showing some irregular mud cracks infilled with carbonate and rain-drop impressions, within the Fluvio-Lacustrine Interaction and bay sequences (F2b); from the Kozlu Formation.
Locality: Açık Yarma, approximately 400 metres north of Kırat Tepe, Zonguldak area.


E2
F1

4.3.4.2. COARSENING-UPWARD LACUSTRINE SUB-ASSOCIATION - F2

These sequences consist of medium grey mudstones at the base, passing upwards to siltstones and silty sandstones. Two main types of sequence have been recognised:

(i) Lacustrine shelf sequences - F2a

Description: These sequences include grey, green and red siltstones and mudstones in units that may be finely laminated or massive. The upper portions of the sequences are mainly sandy siltstones with wavy and flaser structures. The colours may represent different oxidation states of iron. The cross-laminated lenses in the Kılıç "Member" of the Kozlu Formation of the Zonguldak area, especially in the Açık Yarma and Gelik sections, are composed of light grey, coarse siltstone to very fine sandstone, and dark grey mudstones to silty mudstones displaying "flaser" bedding (Reineck & Wunderlich, 1968). The flaser structures are similar to those described by de Raaf et al., (1977) and Allen P.A., (1981b). Linsen structure also occurs, i.e. sand intercalated in mud, usually taking the form of flat, connected lenses, although isolated lenses of sand are also found. Upward gradation from sandy siltstone to silty sandstone is accompanied by a change from wave-to current-produced structures, preserved mainly as microtrough cross-lamination.

Interpretation: Deposition of the lower part of this lacustrine shelf sequences was from suspension with negligible traction current activity below effective wave base. A similar situation is recorded from Permo-Triassic lacustrine deposits in the Eastern Karoo Basin, South Africa by Dijk et al., (1978). Despite the presence of graded lamination there is no evidence of density flows. The sedimentation rate was low, with a varying contribution of organic matter. In the upper part of the sequence the "flaser" structures are interpreted as being generated under conditions of modest and rather continuous wave activity by de Raaf et al., (1977) and Allen P.A. (1981b). The "linsen" structure has been interpreted by de Raaf et al., (1977) as being formed under conditions of moderate but rather continuous wave action on a partly sediment-starved substrate. However, Allen P.A. (1981b) has noted that linsen bedding comprises connected unidirectional lenses with a form-discordant internal structure, a feature commonly associated with current ripples, rather than with wave generation (Clifton, 1976).

(ii) Fluvio-Lacustrine Interaction and Bay Sequences - F2b

Description: These sequences include parallel bedded, fine-grained sandstones, medium to dark grey, with parallel lamination and thin (up to 10 cm) very low angle planar cross-sets and small scale cross-stratification.

In the Kozlu Formation of the Açık Yarma section, Zonguldak, wavy bedded silty sandstones show some irregular mud cracks (Plate 64). A sample of this material was discussed with Dr. Eagar (pers comm., 1981) who agreed the features were "dessication" cracks infilled with carbonates rather than trace fossils, a conclusion confirmed by Prof. Chaloner (1980) who suggested that the "negative surface" (i.e. upper) "shows dessication crack infills and rain-drop impressions". The upper part of this section displays plant rootlets and becomes more silty, the laminated to massive siltstones being overlain by interlaminated siltstones and mudstones. These features are common in interdistributary bay environments where overbank flooding has introduced fine sediment (Coleman and Gagliano, 1965; Horne & Ferm 1976). The interlaminated siltstones and mudstones contain plant fossils and thin coals are sometimes present on the top. In most cases the overlying sediments contain sideritic layers, especially in the Gelik section of the Zonguldak area. Above this section, siltstones and very fine-grained sandstones display wave ripples, and lenticular flaser bedding. Finally, all these beds are cut by erosively based, upward-fining channel-fill sandstone sequences which display pebbly bases.

Interpretation: These sequences are interpreted as resulting from progradation of a small delta system into temporary lakes (Scott, 1978; Hyne et al., 1979; Surdam &Stanley,1979; Dijk et al., 1978; Link and Osborne 1978).

The fauna and flora suggest a freshwater lake environment, uninfluenced by marine processes. The rivers deposited bed-load silt and sand as distributary mouth bar and delta front sediments, together with considerable quantities of suspended-load muds in the centre of the lake.
Such intermontane-type lakes are not necessarily saline, in nature, thus indicating the prevalence of an open-basin hydrologic regime, and deposition within a continuously subsiding basin. The concordantlybased silty sandstones are commonly succeeded by highly carbonaceous siltstones and and mudstones with plant fossils. This probably records the gradual change to marsh and bay conditions.

4.3.5. DISTRIBUTION OF PLANT FOSSILS IN THE ALLUVIAL COMPLEX

4.3.5.1. INTRODUCTION

According to many palaeobotanists, the terrestrial realm can be divided into areas of erosion and areas of deposition. Geologically speaking, areas of deposition are often referred to as "basins", even though it is not necessarily implied that these are well defined, down warped areas. For instance Pfefferkon (1980) suggested that "the term basin designates an area which is low enough to receive and keep sediments". There are two types of flora in the depositional basin: the first type are the floras growing in the depositional basin, termed the "basinal flora"; the second type, the "extrabasinal flora" consists of plants derived from the erosional environments, which are transported into the depositional environment and are ultimately preserved and fossilized. Also according to Pfefferkon (1980), there are two types of extrabasinal floras. The first type is the "Extrabasinal lowland flora", while the second type is the "Extrabasinal upland flora". The term "upland flora", introduced by Chaloner (1958), includes those floras growing in elevated mountainous terrains. As Chaloner has pointed out, the upland areas are characterised by net erosion and the preservation of fossil plant assemblages is thus very rare, compared to the lowland areas,

In the study area, most of the plants collected clearly belong to the basinal flora and there is no indication of extrabasinal flora (pers. comm., Wagner 1981). Moreover there is no trace of the Gondwana flora, and all the plants are of Euroamerican types (Plates 65-70).

4.3.5.2. LOCAL OCCURENCES

Zonguldak area: More than 30 different plant species have been found in this area and their localitys are shown in (Enclosure 1) and illustrated in (Plates 65,66). These occurrences will be briefly described

Plate 65; Fossil plants from the Zonguldak area.

(All magnifications x3).

a - Diplotemema adiantoides (Schlotheim) GOTHAN

Alacaagzı Formation: Gökgöl section of Uzulmez dere.

b - Neurodontopteris cf. beraliana (ZALESSKY) comb. nov.

Alacaagzı Formation: 37; south of 520 Colliery.

c - Karinopteris acuta (BRONGNIART) BOERSMA

Kozlu Formation: Açık Yarma 8, north of Kırat Tepe.

d - Paripteris gigantea (STERNBERG) GOTHAN

Kozlu Formation: Açık Yarma 8, north of Kırat Tepe.

e - Sphenophyllum amplum KIDSTON

Alacaağzı Formation: 37; south of 520 Colliery.

f - Sphenopteris (Renaultia?) cf. typica (STUR)

Kozlu Formation: Açık Yarma 7, west of Guntepe Colliery.

g - Lyginopteris baeumleri (ANDRAE) GOTHAN

Kozlu Formation: Gelik 1, road cutting near Gelik Colliery.

h - Neuralethopteris schlehani (STUR) CREMER

Kozlu Formation: Gelik 11, upper levels of locality Gelik 1.

i - Mariopteris beneckei HUTH

Alacaağzı Formation: 37; South of 520 Colliery.

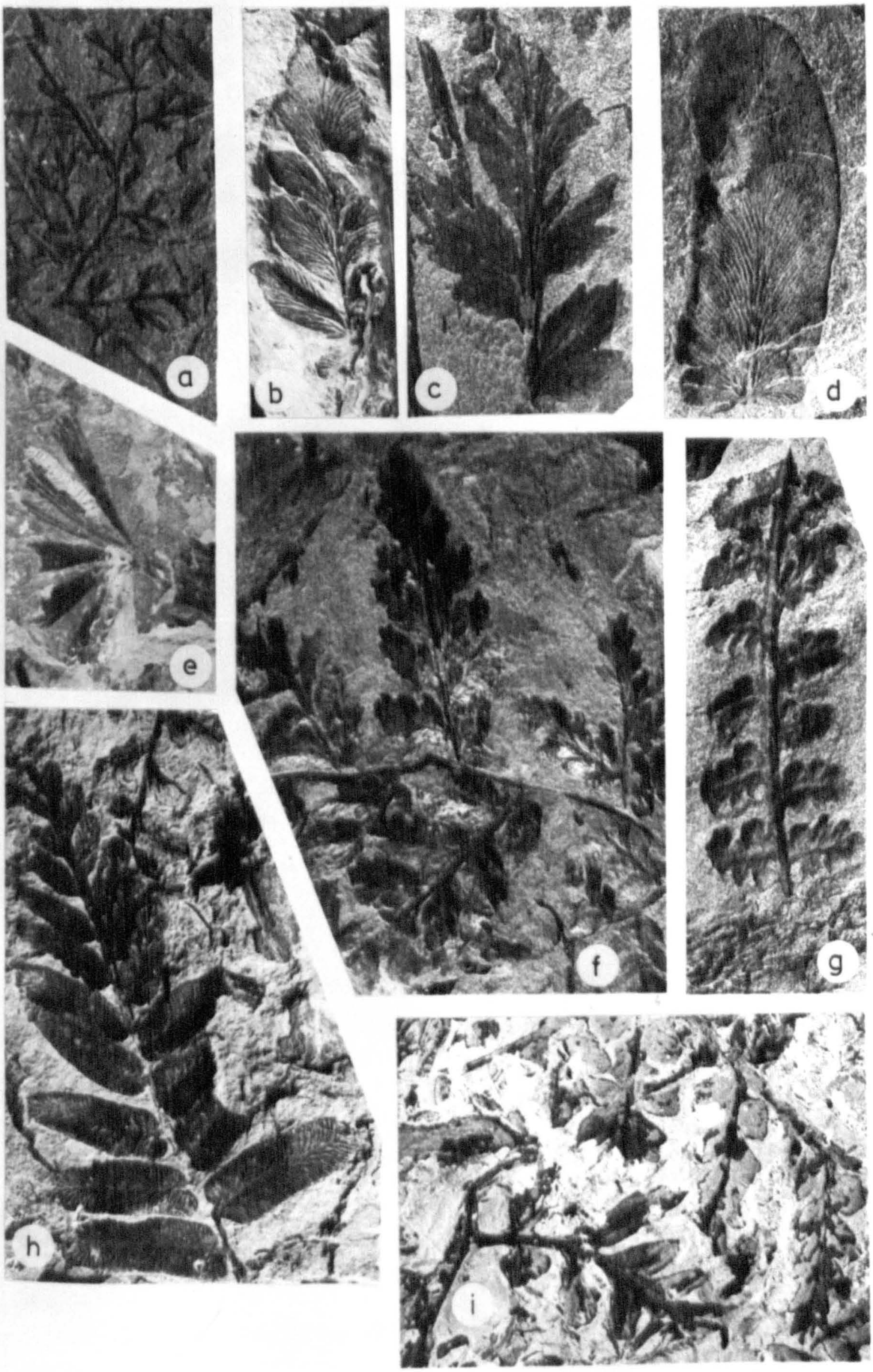

a
b
c
d
e
f
g
h
i

Plate 66; Fossil plants from the Zonguldak area.

(All magnifications x3)

a - Mariopteris moaana WILLIERE (big one)

Asterophyllites cf. palaeaceus STUR

Kozlu Formation: Açık Yarma 10A, north of Kırat Tepe.

b - Sphenopteris cf. pseudocristata STERZEL

Kozlu Formation: Açık Yarma 10B, north of Kırat Tepe.

c - Eusphenopteris schumannii van Ameron

Kozlu Formation: near Kılıç Colliery.

d - Neuralethopteris schlehani (STUR) CREMER

Kozlu Formation: Açık Yarma 10B, north of Kırat Tepe.

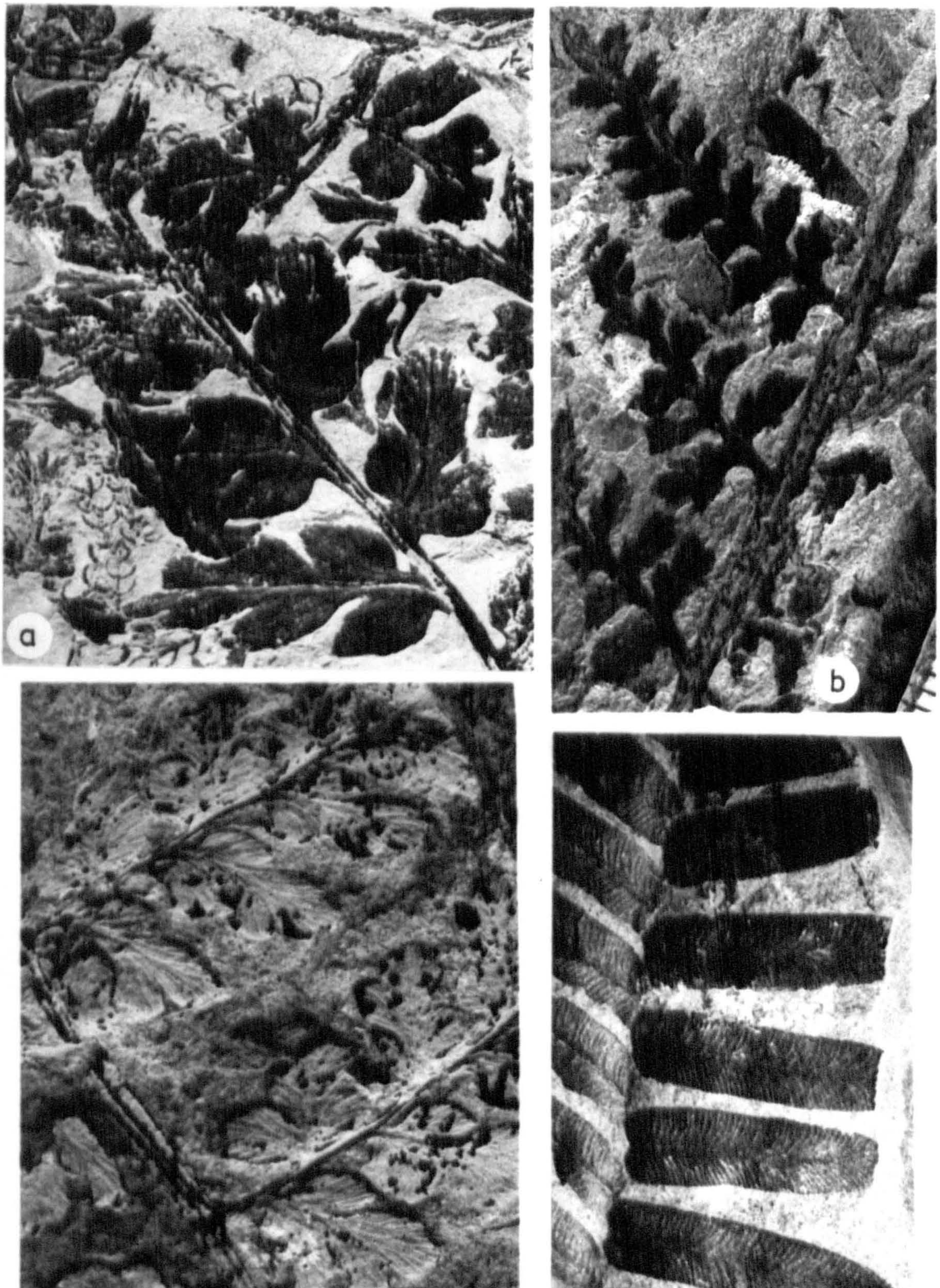

a
b
c
d

Plate 67; Fossil plants from the Zonguldak area.

(All magnifications x3)

a - Linopteris neuropteroides (VON GUTBIER) POTONIE

Karadon Formation; east of the Kasaptarla Colliery in the road cutting.

b - Sphenophyllum emarginatum BRONGNIART

Karadon Formation; 10 Temmuz Mevkii, just behind the Primary School garden.

c - Sphenophyllum cf. cuneifolium STERNBERG

Kozlu Formation; East of Yeşildağ Tepe.

d - Sphenopteris coriacea Marrat

Kozlu Formation: Kokaksu dere.

e - Alloiopteris sp.

Karadon Formation: 10 Temmuz Mevkii, just behind the Primary School garden.

f - Sphenopteris limai ZEILLER

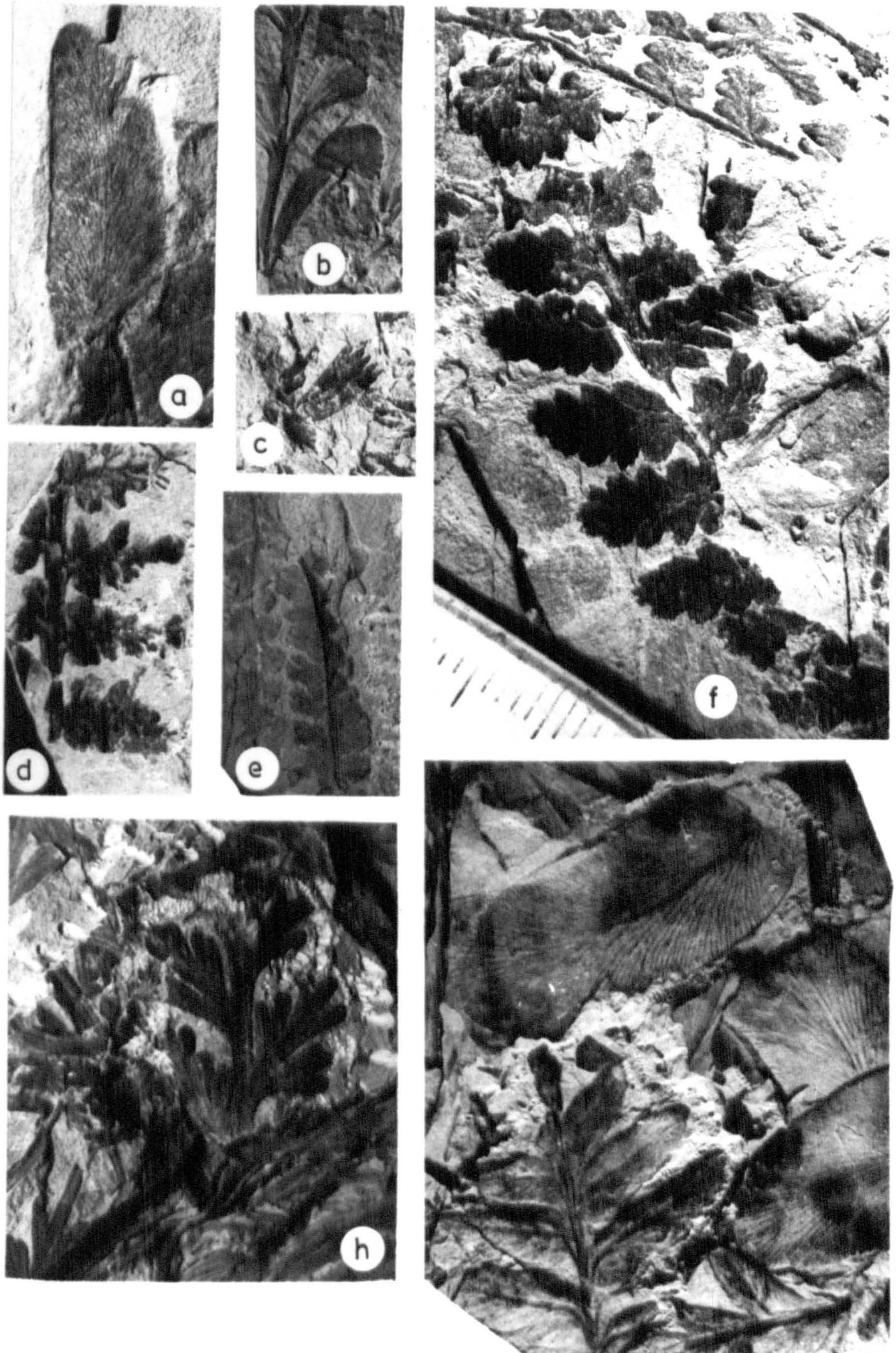
Kozlu Formation: North of Üzülmez.

h - Palmatopteris sturi GOTHAN

Karadon Formation: 10 Temmuz Mevkii; just behind the Primary School garden.

i - Paripteris linguaefolia BERTRAND

Karadon Formation: 10 Temmuz Mevkii; just behind the Primary School garden.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i

Plate 68; Fossil plants from the Zonguldak and Azdavay areas.

(All magnifications x3)

a - Karinopteris (Sphenopteris) andraeana (V. ROEHL) BOERSMA
Karadon Formation: 10 Temmuz Mevkii, just behind the Primary School garden.

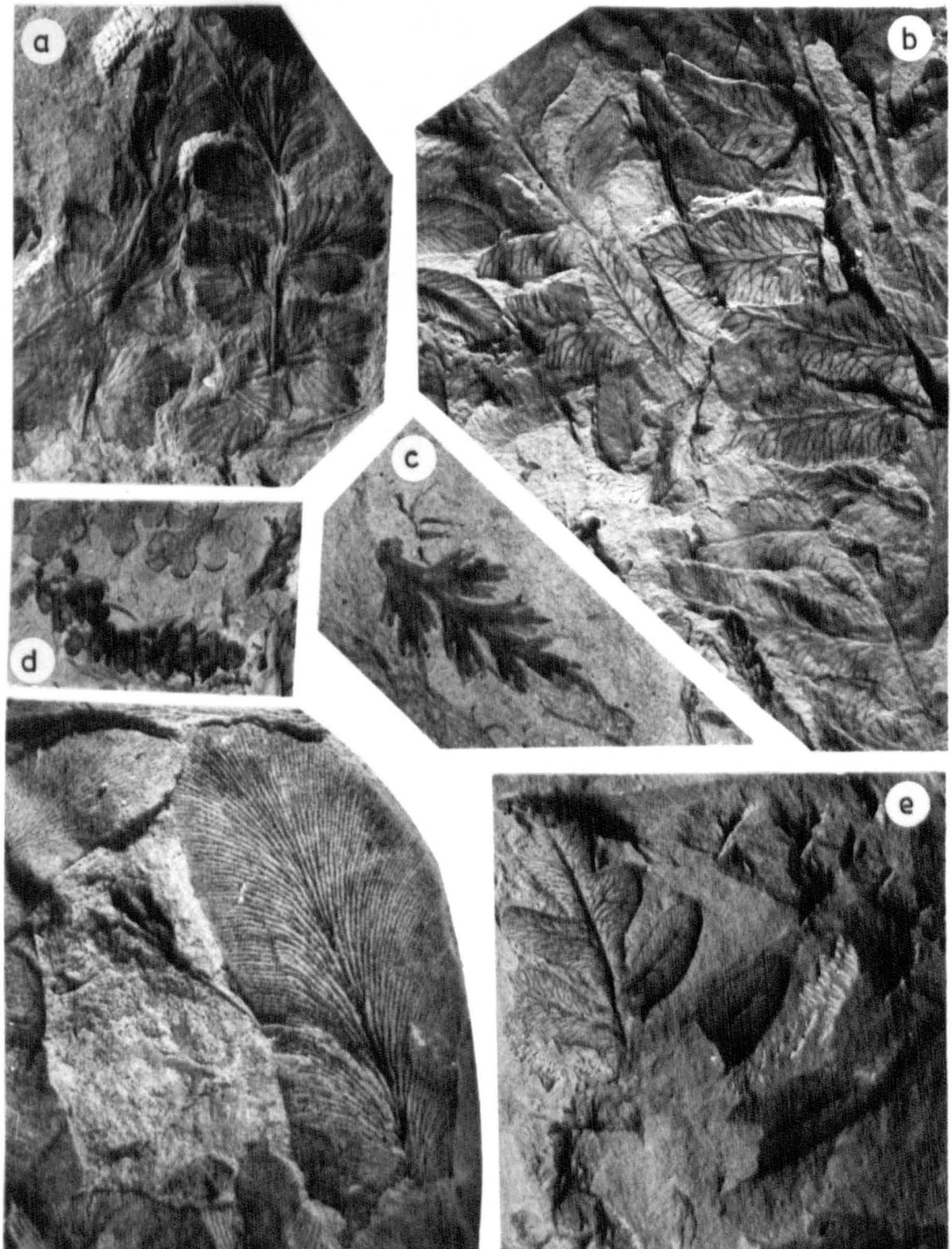
b - Lonchopteridium karvinensis (Purkynova) comb. nov.
Karadon Formation: 10 Temmuz Mevkii, just behind the Primary School garden.

c - Sphenopteris (crossotheca) schatzlarensis (STUR) KIDSTON
Karadon Formation: 500 metres south east of Özkem village, in the Azdavay area.

d - Sphenophyllostachys sp.
Karadon Formation: 10 Temmuz Mevkii, just behind the Primary School garden.

e - Same species as b, from same locality.

f - Paripteris linguaefolia BERTRAND
Karadon Formation: 10 Temmuz Mevkii, just behind the Primary School garden.


a
b
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e
f

Plate 69; Fossil plants from the Zonguldak, Kurucaşile and Azdavay areas.

(All magnifications x3)

a - Eusphenopteris obtusiloba (BRONGNIART) NOVIK

Karadon Formation: 10 Temmuz Mevkii, just behind the Primary School garden. (Zonguldak)

b - Eusphenopteris neuropteroides (BOULAY) NOVIK

Kizilli Formation: Ilyas geçidi dere, of Zonguldak area.

c - Eusphenopteris obtusiloba (BRONGNIART) NOVIK

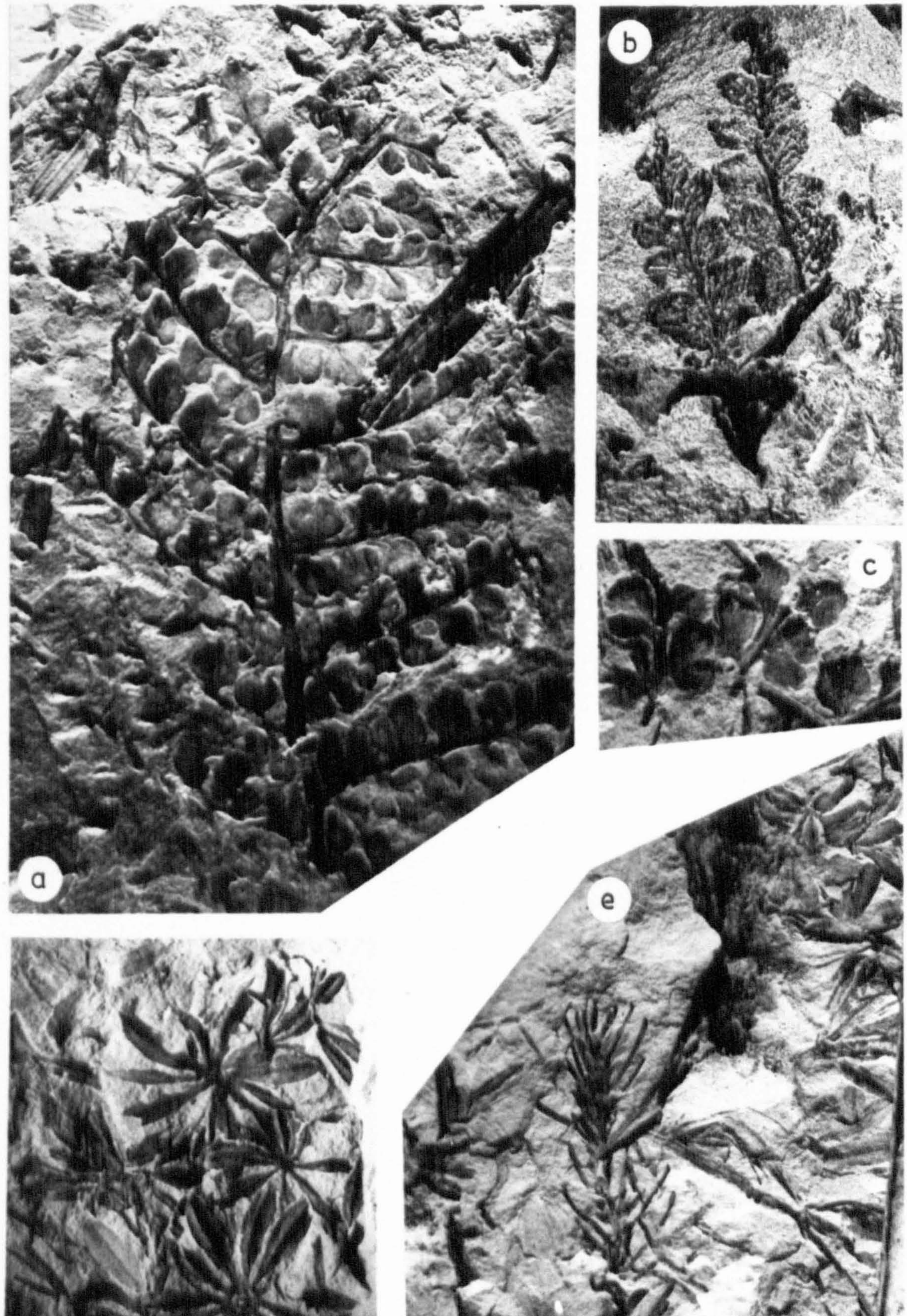
Karadon Formation: 500 metres south east of Özkem village in the Azdavay area.

d - Annularia jongmansi WALTON

Karadon Formation: 26; south of Kilimli in the Zonguldak area.

e - Asterophyllites sp

Karadon Formation: 26; south of Kilimli, in the Zonguldak area.



a
b
c
d
e

Plate 70; Fossil plants from the Azdavay area

(All magnification x3)

a; Neuropteris attenuota LINDLEY &HUTTON

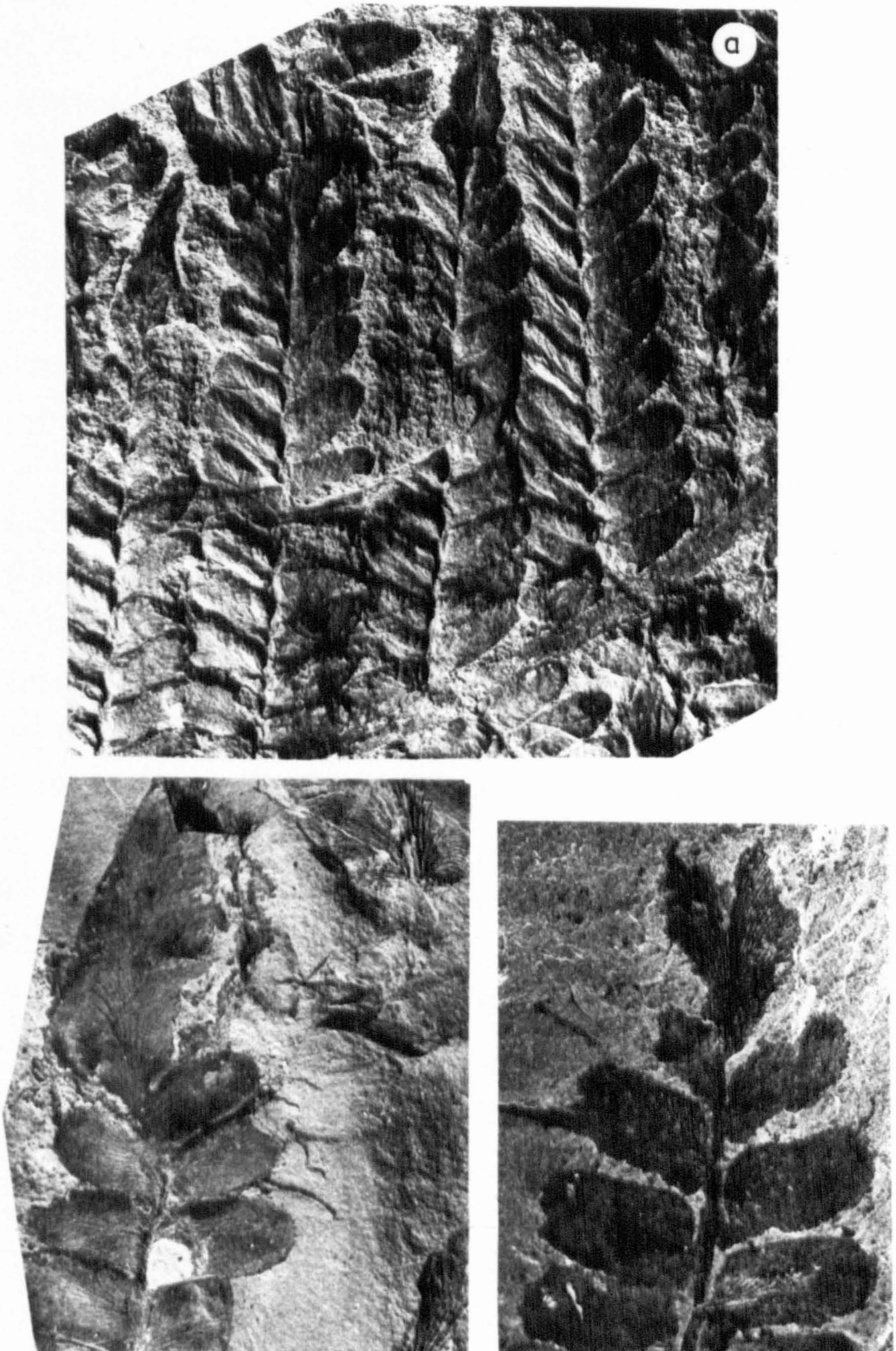
Kızıllı Formation: Near Yahyabeş village, north of Azdavay area.

b; Neuropteris ovata HOFFMANN var. ovata.

Kızıllı Formation: Near Kızıllı village, Azdavay area.

c; Neuropteris ovata HOFFMANN var. ovata.

Kızıllı Formation: Near Kızıllı village, the Azdavay area.


a
b
c

here in chronological order.

The Alacaağzı Formation is a fluvially dominated deltaic sequence mostly composed of coarsening upwards muddy siltstones with plant fragments that are comminuted and are not well preserved. Only a few of these have been identified, and these include Diplotmema Adiantoides and Lyginopteris Larischi, found in the interdistributary bay facies of the deltaic sequences. In the upper part of the delta top facies, fluvial cycles consisting of upward fining mudstones contain indeterminable carbonaceous material and many are capped by thin coals. In the carbonaceous seat-earths rootlets of Stigmaria, and Lepidedendron floited twigs have been found. This association resembles the abandonment facies of Elliott (1974a, 1975).

The Kozlu Formation contains abundant, laterally continuous thick coals and seat-earths. All the flora indicate Alluvial-plain environments, and basically they can be divided into two types: swamp flora and floodplain flora. Plants assigned to the swamp flora occur in a sequence of sediments interpreted as lacustrine and commonly succeed either a coal seam or previous lake/delta fill, since these small lakes may have formed by subsidence of a swamp area. The derivation of the sediments must be by rivers or floods from outside the lake area and the plants incorporated in the lake deposits may also have been brought in with the sediments or may represent a local flora, as suggested by Scott (1978). Another example of the swamp flora environment is found in the upper delta plain-fluvial coals which have been described from the Appalachian Region by Horne et al., (1978), and from the Durham coal field by(Haszeldine, and Anderton, 1980). Rapid subsidence during sedimentation seems to have played a major role in this environment, which appears to be well represented in the lower part of the Kozlu Formation.

Only a few identifiable plants have been found in the sandy delta fills and interdistributary bay deposits of these sequences, probably because the strength and turbulence of the currents tended to break up the plant material. Thus layers of comminuted plant debris are common. Moreover, the channel-fill sandstones include large wood fragments, mainly stems of Calamites and less commonly Stigmaria.

The second group, the floodplain floras, contain the richest plant assemblages. According to Allen (1965) poorly laminated shales containing a large and very variable flora and thin siltstone bands are best interpreted as floodplain/crevasse splay deposits. The Kozlu Formation floodplain mudstones contain the richest and most diverse flora in this formation, forming the so-called "roof shale flora". These overlie coal seams and contain abundant fern-like foliage such as Eusphenopteris,Neuropteris which are typical members of the flood plain flora.

In the Karadon Formation, coal seams are intimately associated with multi-storey conglomeratic channel-sandstone bodies which are interpreted as the deposits of braided rivers and contian lowland floras. However, they sometimes occur as separate groups of coal zones which may contain upland floras. In the present study, no upland floras have been found (Wagner, pers comm., 1981). Jongmans (1955), however, recorded several floras in northwestern Turkey, without attaching any interpretation to them. However, Leary and Pfefferkon (1977) in their study of an early Pennsylvanian flora from west-central Illinois recognised several species similar to Jongmans's species such as, Mesocalamites cistiiformis, Asterophyllites equisetiformis, Asterophyllites longifolius, Alethopteris lonchitica, Alloiopteris quercifolia, and Cordaites principalis, and interbedded them as upland floras.

Amasra Area; The Alacaağzı Formation in this area is composed mainly of wave-dominated deltaic sequences, capped by delta-plain deposits

including some seat-earths and thin coal seams. Apart from comminuted plant fragments, no other identifiable flora has been found.
Plant specimens collected from boreholes in the Bartın area and kindly made available by M.T.A. personnel, unfortunately do not provide any additional information concerning the sub-environments and floral distribution, although they have proved to be of stratigraphic value (see Chapter 2).

Kurucaşile Area: Floras collected from the Kızıllı Formation in this area are mainly of the basinal type and the flood plain floras are abundant. The carbonaceous mudstones include finely comminuted plant fragments as well as leaf and stem fragments, plant imprints, and some randomly orientated tree trunks. In some lake-fill sequences fossil floras have also been found.

Azdavay Area: It will be recalled that the situation of the Upper Carboniferous rocks in this area is rather different from that of the more northerly outcrops and they are greatly affected by post-Paloeozoic tectonism. However, most of the mainly Westphalian D fossils collected from these outcrops display basinal floras.

CONTAINS
PULLOUTS

-21	X-6	X-7	X-3	X-5	X-8	X-9	X-10	X-13	X-16	X-17	X-18	X-19	X-21	X-23	X-24	X-26	X-27	X-28	D-1	D-2	D-4	D-6	D-7	D-11	D-13	D-22	D-23	MP-1	A2-K	A2-6	A2-5	A2-1
7	29.4	29.9	20	20.5	31.4	29.8	35.6	27.5	33.9	23	26.4	14.1	26.6	24.5	27.8	24.9	30.8	29	28.9	30.7	23.1	27.3	23.9	25.3	28.5	36	34.9	30.3	18.6	24.6	30.7	27.7
3.9	3.9	3.8	5.7	3.3	3.1	3.3	4.2	3.7	2.3	8.1	3	4.1	4.5	3.6	5	6.3	7.2	4	7	7.4	7.4	7.2	5.9	5.8	4.5	11	8.7	10	8	3.4	2.5	6.4
0.5	11.7	13.8	17.5	18.6	12.1	18.3	8.2	8	6.8	4.5	5.4	6.1	3.2	6.4	8.5	18.3	19.9	10.6	11.1	9	8.4	10.1	13.7	18.6	16.1	23.1	19.6	12.4	17.4	12.3	5.6	6.1
0.2	7.5	6.7	9.4	10	8.7	10.9	5.4	14.2	10.3	7.7	7.3	5.3	8	7.5	8.2	5.6	6.8	5.9	7.3	10.6	7.4	7.5	8.4	5.4	9	1.6	5.3	8.4	3.8	6.1	6.5	7.1
2.1	0.3	0.6	0.6	0.3	1.2	3.6	1.1	1.2	1.9	0.4	0.9	0.6	2.2	0.9		0.7	0.9	0.6	0.6	1	1.3	2.2	2.8	0.6				1.8		0.6	0.6	1.3
1.5	4.5	6.2	4.2	2.8	1.8	1.3	3.1	3	2.9	3.6	7.9	7.9	2.9	7.3	3.8	1.7	2.2	2.5	1.3	2.2	3.2	5.3	1.5	2.2	1.1	0.6	4.7	1.8	1.3	0.3	0.6	1
6.3	4.5	6.2	6.6	3.6	1.8	1.8	6.8	8	1.3	17.2	4.8	15.5	3.5	11.8	10.4	1.7	1.2	1.5	10.5	3.2	2.6	2.5	3.7	2.6	1.9	1.1	1.2	4.9	3.5	1.5	1.2	11.9
6.6	11.1	6.2	6.4	3.6	7.1	6.1	12.1	8.7	8	9.5	3.1	14.4	7.4	10.3	6.9	2.3	3.4	3.7	2.5	4.2	11.2	5	5.3	10.2	7.3	2.7	1.6	3.1	1.9	0.9		4.2
5.4	1.8	2.9	0.9	2.2	8.1	2.8	3.7	2.5	1.6	6.3	3.6	3.2	3.8	3	3.1	2	4.3	3.7	2.8	1.6	4.8	3.8	0.9	3.5	1.1	1.6	0.3	1.8	1.6	0.6	0.9	8.1
5.6	11.1	11.1	10	21.4	9.6	12.5	8.7	7.4	17.7	5.4	14.8	7.9	13.1	11.2	9.8	25.2	14.3	23.6	17.1	15.7	17.7	12.9	16.4	15.7	13.3	12.6	12.8	16.7	26.4	17.8	14	9
5.7	6.9	7.9	3.3	4.7	9.3	2.3	3.1	9.6	7.4	10.9	7.9	8.2	14.4	9.1	6.6	6.3	2.5	8.1	0.9	2.6	7.4	2.8	4.6	1.6	13	5.6	4	3.1	4.8	3.7	8.4	12.2
	0.3	0.3	0.9		0.6			0.9			0.6	1.5	0.6		0.3			0.3			0.6			0.3					0.9			0.9
5.1	6.9	4.4	14.2	8.9	4.7	5.8	7.9	4.9	5.5	4.1	8.2	11.1	9.6	4.2	9.5	5	5.9	6.2	9.8	10.9	4.8	12.9	11.8	8	3.9	4	6.8	5.6	11.6	28	28.9	3.9
						1.5			0.3	0.9							0.3			0.6		0.3	0.9									
1.4 9.7	45 70.4	47.5 72	41.9 67.7	42.4 57.2	46.6 70.5	51.4 65.5	48 75.9	39.2 63.2	43 58.9	35.6 72.5	34.8 60.2	24.3 63.8	34.3 59.5	34.5 63.8	41.3 69.6	49.5 61.1	57.9 72.5	43.6 59.1	47 65.2	47.1 63.3	38.9 59.6	44.6 66.3	43.5 61.2	49.7 69.6	49.1 68.8	48.6 77.4	63.2 77.7	52.7 66.2	44 59.3	40.3 62.2	38.8 64.8	40.2 69.8
2.3 7.7	7.8 12.2	7.3 11.1	10 16.1	10.3 13.9	9.9 15	14.5 18.5	6.5 10.3	15.4 24.8	12.2 16.7	8.1 16.5	8.2 14.2	5.9 15.5	10.2 17.7	8.4 15.5	8.2 13.8	6.3 7.7	7.7 9.6	6.5 8.8	7.9 10.9	11.6 15.6	8.7 13.3	9.7 14.4	11.2 15.7	6.0 8.4	9 12.6	1.6 2.5	5.3 6.5	10.2 12.8	3.8 5.1	6.7 10.3	7.1 11.8	8.4 14.6
5.6 2.5	11.1 17.4	11.1 16.8	10 16.1	21.4 28.9	9.6 14.5	12.5 15.9	8.7 13.8	7.4 11.9	17.7 24.3	5.4 11	14.8 25.6	7.9 20.7	13.1 22.7	11.2 20.7	9.8 16.5	25.2 31.1	14.3 17.9	23.6 32	17.1 23.8	15.7 21.1	17.7 27.1	12.9 19.2	16.4 23.1	15.7 22	13.3 18.6	12.6 20.1	12.8 15.7	16.7 21	26.4 35.6	17.8 27.5	14 23.4	9 15.6
7 5.2	29.4 65.3	29.9 62.9	20 46.3	20.5 48.3	31.4 67.4	29.8 58	35.6 74.2	27.5 70.1	33.9 78.8	23 64.6	26.4 75.8	14.1 58	26.6 77.5	25.4 71	27.8 67.3	24.9 50.3	30.8 53.2	29 66.5	28.9 61.5	30.7 65.2	23.1 59.4	27.3 61.2	23.9 49.3	25.3 51.6	28.5 58	36 51.4	34.9 55.2	30.3 57.5	18.6 42.3	24.6 61	30.7 79.1	27.7 68.9
3.9 9.4	3.9 8.7	3.8 8	5.7 13.2	3.3 7.8	3.1 6.6	3.3 6.4	4.2 8.7	3.7 9.4	2.3 5.3	8.1 22.7	3 8.6	4.1 16.9	4.5 13.1	3.6 10.4	5 12.1	6.3 12.7	7.2 12.4	4 9.1	7 14.9	7.4 15.7	7.4 19	7.2 16.1	5.9 12.2	5.1 11.8	4.5 9.2	11 15.7	8.7 13.8	10 18.9	8 18.2	3.4 8.4	2.5 6.4	6.4 15.9
0.5 5.4	11.7 26	13.8 29	17.5 40.5	18.6 43.9	12.1 25.9	18.3 35.6	18.2 17.1	8 20.4	6.8 15.8	4.5 12.6	5.4 15.5	6.1 25.1	3.2 9.3	6.4 18.5	8.5 20.6	18.3 37	19.9 34.4	10.6 24.3	11.1 23.6	9 19.1	8.4 21.6	10.1 22.6	13.7 28.2	18.6 37.9	16.1 32.8	23.1 32.9	19.6 31	12.4 23.5	17.4 39.5	12.3 30.5	5.6 14.4	6.1 15.2
1.4 6.5	45 52.3	47.5 54.2	43.2 52.6	42.4 49.1	46.6 54.5	51.4 56.8	48 54	39.2 46.1	43 49.5	35.6 41.1	34.8 41.5	24.3 30.1	34.3 45.2	34.5 39.9	41.3 49.3	43.5 55.8	57.9 63.4	43.6 51.2	47 52.7	47.1 54.6	38.9 44.3	44.6 53.2	48.5 55.4	49 54.7	49.1 59.2	70.1 77.2	63.2 70.9	52.7 57.7	44 52.7	40.3 59.1	38.8 62	40.2 48
1.4 1.5	36.6 42.5	34 38.8	32.4 39.4	40.3 46.7	37.1 43.4	37.2 41.1	34.1 38.4	37.9 44.5	42.4 48.9	33.8 39	44.2 52.7	40.8 50.6	38 50.1	40.2 46.4	32.1 38.3	37.5 42.3	32.2 35.3	40 47	31.6 35.5	35.9 41.6	46.2 52.6	36.7 43.8	35.3 40.3	37.9 42.3	31.8 38.4	19.6 21.5	24.7 27.7	33.6 36.8	35.9 43	26.3 38.6	22.6 36.1	31.6 37.7
6.3 7	4.5 5.2	6.2 7.1	6.6 8	3.6 4.2	1.8 2.1	1.8 2	6.8 7.6	8 9.4	1.3 1.5	17.2 19.9	4.8 5.7	15.5 19.2	3.5 4.6	11.8 13.6	10.4 12.4	1.7 1.9	1.2 1.3	1.5 1.8	10.5 11.8	3.2 3.7	2.6 3	2.5 3	3.7 4.2	2.6 2.9	1.9 2.3	1.1 1.2	1.2 1.3	4.9 5.4	3.5 4.2	1.5 2.2	1.2 1.9	11.9 14.2
0.2	0.25	0.28	0.23	0.5	0.19	0.26	0.16	1.14	5.2	0.13	0.18	0.6	0.14	0.16		0.4	0.23	0.29	0.35	0.32	0.2	0.12	0.37	0.28	0.31	0.29	0.17	0.16	0.62	0.19	0.18	0.9

AZDAVAY AREA

MP = Kızıllı Formation

AZ = Azdavay (Özkem Section)

Karadon Formation

ZONGULDAK AREA

AY = Açık Yarma Section = Kılıç "Member" of the Kozlu Formation.

X = Kozlu and Karadon Formation.

D = Dilaver Section = Kozlu Formation.

GE = Gelik Section

G = Gökgöl Section

A = Alacaağzı Section

U = Ulutamdere Section

Alacaağzı Formation

TABLE 1.

SAMPLE NUMBER	GE.5 (1)	GE.5 (2)	GE.9	GE.11	GE.12	G.3	G.4	G.20	G.34C	G.37	G.38	G.41	G.46	G.49B	G.50	G.54	G.61A	G.62A
LITHOFACIES SYMBOL																		
STRAIGHT QUARTZ	24.5	17.7	21.6	22.5	26.6	25	33.8	26.1	25.9	21.7	24.9	29.3	26.9	14.1	20	22.8	43	27
UNDULATORY QUARTZ	7.1	6.4	13.7	7.8	5.1	8.7	3.8	4.3	6.6	6.6	5.3	2.3	6.9	6.9	5.1	5.5	5.3	11
POLYCRYSTALLINE QUARTZ	1.2	15.5	14.9	17.8	3.8	4.7	11.4	15.6	10	14.2	7.5	7.7	10	15.4	12	21.3	16.7	18.8
K. FELDSPAR	6.8	9.1	5.8	8.4	11.8	5.6	5.9	14.7	9	11.2	9	10.2	4.2	8.8	6.3	9.9	3	7.5
PLAGIOCLASE	0.3	1.2	1.2	0.6	0.3	1.9	2	4.3	2.2	2.4	0.6	2	1.8	1.6	0.6	2		1.9
OPAQUE MINERALS OR COAL	9	3.9	1.5	5.3	3.5	5.3	4.5	1.9	1.9	1.8	2.8	3.4	4.5	1.2	3.3	0.9	2.7	1.6
CLAY	6.2	11.6	2.4	10.3	8.6	2.2	1.7		1.5	2.1	8	1.7	3.3	7.2	7.2	1.7	1.7	4.1
BIOTITE	6.8	3	3.3	2.8	11.5	10.6	5.8	8.5	18,7	11.2	13	14.8	8.1	13.8	10.8	1.7	6.7	2.5
MUSCOVITE	5	3.9	0.9	3.1	2.6	5.9	4.5	3.8	4.7	3.6	6.8	4.8	3.9	4.7	5.4	1.2	6.3	1.2
ROCK FRAGMENTS	6.8	9.1	22.5	7.5	11.8	5.3	6.9	8	6.8	13	5	7.4	8.5	8.5	9.6	12.6	6.7	3.1
IRON OXIDE	9.6	9.1	4.6	7.5	8.9	6.9	10	3.3	7.5	8.1	8.4	10.8	12.7	8.2	5.7	9.3	1.3	3.1
HEAVY MIN.				0.3	0.3	0.6		1.4	0.6	0.6			0.9		2.1		0.7	0.3
CEMENT	15.8	9.1	7	5.9	4.8	17.2	8.9	8	4.4	3.3	6.8	4.6	8.1	8.2	12	10.2	6	11.9
CHLORITE	0.6		0.3				0.7				1.5	0.8		1.3		0.6		
QUARTZ	32.8 70.2	39.5 67.1	50.2 63	48.1 74.2	35.5 59.8	38.4 75	49 79	46 63	42.5 70.2	42.5 61.5	37.7 72.1	39.3 66.7	43.8 75	36.4 65.8	39.1 69.2	49.6 66.9	65 87	56.8 75.4
FELDSPAR	7.1 15.2	10.3 17.5	7.0 8.8	9.2 14.2	12.1 20.4	7.5 14.6	6.1 9.8	19.0 26.0	11.2 18.5	13.6 19.6	9.6 18.4	12.2 20.7	6.0 10.3	10.4 18.8	6.9 12.8	11.9 16.1	3 4	9.4 12.5
ROCK FRAGMENTS	6.8 14.6	9.1 15.4	22.5 28.2	7.5 11.6	11.8 19.8	5.3 10.4	6.9 11.1	8 10.9	6.8 11.2	13 18.8	5 9.5	7.4 12.6	8.5 14.6	8.5 15.4	9.6 17.9	12.6 17	6.7 9	9.1 12.1
Q (STRAIGHT)	24.5 74.7	17.7 44.7	21.6 43.0	22.5 46.8	26.6 74.9	25 65.1	33.8 69	26.1 56.7	25.9 60.9	21.7 51.1	24.9 66	29.3 74.6	26.9 61.4	14.1 38.7	20 53.9	22.8 46	43 68.2	27 47.5
Q (UNDULATORY)	7.1 21.6	6.4 16.2	13.7 27.3	7.8 16.2	5.1 14.4	8.7 22.6	3.8 7.7	4.3 9.3	6.6 15.5	6.6 15.5	5.3 14	2.3 5.8	6.9 15.7	6.9 18.9	5.1 13.7	5.5 11.1	5.3 8.4	11 19.4
Q (POLYCRYSTALLINE)	1.2 3.6	15.5 39.1	14.9 29.7	17.8 37	3.8 10.7	4.7 12.2	11.4 23.3	15.6 33.9	10 23.5	14.2 33.4	7.5 19.9	7.7 19.6	10 22.8	15.4 42.3	12 32.3	21.3 42.9	16.7 26.5	18.8 33.1
QUARTZ	32.8 44.5	39.5 48.6	50.2 57.2	48.1 55.7	35.5 41.3	38.4 50.5	43 60.6	46	42.5 48.4	42.5 48.1	37.7 44.7	39.3 46.6	43.8 55.4	36.4 44.3	57.1 45	49.6 62.9	65 75.1	56.8 66.8
LABILE	34.7 47.1	30.2 37.1	35.2 40.1	28 32.4	41.8 48.7	35.2 46.4	30.2 37.3	42.6	43.9 49.9	43.8 49.5	38.7 45.8	43.4 51.4	31.9 40.3	38.6 46.9	38.1 46.2	27.6 34.9	19.8 22.9	24.1 28.3
MATRIX	6.2 8.4	11.6 14.3	2.4 2.7	10.3 11.9	8.6 10	2.2 2.9	1.7 2.1		1.5 1.7	2.1 2.4	8 9.5	1.7 2	3.3 4.2	7.2 8.7	7.2 8.7	1.7 2.2	1.7 1.9	4.1 4.8
GRAIN SIZE	0.22	0.24	0.66	0.32	0.16	0.07	0.13	0.16	0.16	0.21	0.17	0.14	0.12	0.2	0.07	0.44	0.14	0.48

SAMPLE NUMBER	B1-B	A6	A2B	B1B	U-4	U-39	U-43	U-46B	U-47	AY-11	AY-12	AY-21
LITHOFACIES SYMBOL												
STRAIGHT QUARTZ	18.1	20.2	21.2	17.6	31.4	22.2	21	25.3	14.1	26.7	30.6	27
UNDULATORY QUARTZ	5.3	4.4	4.7	7.7	7.3	10.6	14	6.2	5.3	7.6	5.1	3.9
POLYCRYSTALLINE QUARTZ	3.4	2.5	5	2.5	4.3	23.1	16.3	9.1	8.4	15.1	15.1	10.5
K. FELDSPAR	6.5	5.6	7.5	6.8	10.9	2.8	12.7	6.2	10	7.9	11.4	10.2
PLAGIOCLASE		0.3	0.3	0.3	2.6		1.3	2.5	2.8	2.1	2.8	2.1
OPAQUE MINERALS OR COAL	4.7	7.8	6.9	6.8	3.6	2.2	1	5	5.6	1.8	0.8	1.5
CLAY	9.6	9.9	8.4	10.5	3	1.9	3	1.9	0.6	3	1.7	6.3
BIOTITE	8.1	11.5	9.7	7.4	8.9	1.2	4.6	12.2	3.1	5.5	2.8	6.6
MUSCOVITE	10.6	3.1	1.9	9.6	2.6	0.9	0.7	5	1.2	6.7	3.7	5.4
ROCK FRAGMENTS	13.7	10.6	9	12.5	8.9	15.6	18	14.7	19.4	10	16.6	15.6
IRON OXIDE	7.4	8.1	8.1	6.8	2.3	10.3	1.3	6.8	1.9	7.6	1.7	5.7
HEAVY MIN.	1.6	1.6	1.2	1.4	1.3	0.6			1.6			
CEMENT	10.9	14.3	15.9	9.9	12.6	8.4	5.7	4.4	25.9	6.1	6.6	5.1
CHLORITE							0.3	0.6			0.8	
QUARTZ	26.8 57	27.1 62.2	30.9 64.8	27.8 58.6	43 65.7	55.9 75.2	51.3 61.6	40.6 63.4	27.8 46.3	49.4 71.2	50.8 62.2	41.4 59.7
FELDSPAR	6.5 13.8	5.9 13.5	7.8 16.4	7.1 14.9	13.5 20.6	2.8 3.8	14.0 16.8	8.7 13.6	12.8 21.3	10.0 14.4	14.2 17.4	12.3 17.7
ROCK FRAGMENTS	13.7 29.1	10.6 24.3	9 18.8	12.5 26.4	8.9 13.6	15.6 21	18 21.6	14.7 23	19.4 32.3	10 14.4	16.6 20.3	15.6 22.5
Q (STRAIGHT)	18.1 67.5	20.2 74.5	21.2 68.6	17.6 63.3	31.4 73	22.2 39.7	21 40.9	25.3 62.3	14.1 50.7	26.7 54	30.6 60.2	27 65.2
Q (UNDULATORY)	5.3 19.8	4.4 16.2	4.7 15.2	7.7 27.7	7.3 16.9	10.6 19	14 27.3	6.2 15.3	5.3 19.1	7.6 15.4	5.1 10	3.9 9.4
Q (POLYCRYSTALLINE)	3.4 12.7	2.5 9.2	5 16.2	2.5 9	4.3 10	23.1 41.3	16.3 31.8	9.1 22.4	8.4 30.2	15.1 30.6	15.1 29.7	10.5 25.4
QUARTZ	26.8 37.7	27.1 34.9	30.9 40.7	27.8 33.4	43 50.7	55.9 68.9	51.3 55.8	40.6 46.1	27.8 38.5	49.4 57.2	50.8 56.1	41.4 46.5
LABILE	34.6 48.7	40.5 52.3	36.5 48.3	44.8 53.9	38.8 45.7	23.3 28.7	37.6 40.9	45.6 51.7	43.7 60.6	34 39.4	38.1 42.1	41.4 41.5
MATRIX	9.6 13.5	9.9 12.8	8.4 11.1	10.5 12.6	3 3.6	1.9 2.3	3 3.3	1.9 2.2	0.6 0.8	3 3.5	1.7 1.9	6.3 7
GRAIN SIZE	0.05	0.11	0.13	0.12	0.17	0.21	0.26	0.14	0.21	0.19	0.24	0.2

SAMPLE NUMBER	X-6	X-7	X-3	X-5	X-8	X-9	X-10	X-13	X-16	X-17	X-18	X-19
LITHOFACIES SYMBOL												
STRAIGHT QUARTZ	29.4	29.9	20	20.5	31.4	29.8	35.6	27.5	33.9	23	26.4	14.1
UNDULATORY QUARTZ	3.9	3.8	5.7	3.3	3.1	3.3	4.2	3.7	2.3	8.1	3	4.1
POLYCRYSTALLINE QUARTZ	11.7	13.8	17.5	18.6	12.1	18.3	8.2	8	6.8	4.5	5.4	6.1
K. FELDSPAR	7.5	6.7	9.4	10	8.7	10.9	5.4	14.2	10.3	7.7	7.3	5.3
PLAGIOCLASE	0.3	0.6	0.6	0.3	1.2	3.6	1.1	1.2	1.9	0.4	0.9	0.6
OPAQUE MINERALS OR COAL	4.5	6.2	4.2	2.8	1.8	1.3	3.1	3	2.9	3.6	7.9	7.9
CLAY	4.5	6.2	6.6	3.6	1.8	1.8	6.8	8	1.3	17.2	4.8	15.5
BIOTITE	11.1	6.2	6.4	3.6	7.1	6.1	12.1	8.7	8	9.5	3.1	14.4
MUSCOVITE	1.8	2.9	0.9	2.2	8.1	2.8	3.7	2.5	1.6	6.3	3.6	3.2
ROCK FRAGMENTS	11.1	11.1	10	21.4	9.6	12.5	8.7	7.4	17.7	5.4	14.8	7.9
IRON OXIDE	6.9	7.9	3.3	4.7	9.3	2.3	3.1	9.6	7.4	10.9	7.9	8.2
HEAVY MIN.	0.3	0.3	0.9		0.6			0.9			0.6	1.5
CEMENT	6.9	4.4	14.2	8.9	4.7	5.8	7.9	4.9	5.5	4.1	8.2	11.1
CHLORITE						1.5			0.3	0.9		
QUARTZ	45 70.4	47.5 72	41.9 67.7	42.4 57.2	46.6 70.5	51.4 65.5	48 75.9	39.2 63.2	43 58.9	35.6 72.5	34.8 60.2	24.3 63.8
FELDSPAR	7.8 12.2	7.3 11.1	10 16.1	10.3 13.9	9.9 15	14.5 18.5	6.5 10.3	15.4 24.8	12.2 16.7	8.1 16.5	8.2 14.2	5.9 15.5
ROCK FRAGMENTS	11.1 17.4	11.1 16.8	10 16.1	21.4 28.9	9.6 14.5	12.5 15.9	8.7 13.8	7.4 11.9	17.7 24.3	5.4 11	14.8 25.6	7.9 20.7
Q (STRAIGHT)	29.4 65.3	29.9 62.9	20 46.3	20.5 48.3	31.4 67.4	29.8 58	35.6 74.2	27.5 70.1	33.9 78.8	23 64.6	26.4 75.8	14.1 58
Q (UNDULATORY)	3.9 8.7	3.8 8	5.7 13.2	3.3 7.8	3.1 6.6	3.3 6.4	4.2 8.7	3.7 9.4	2.3 5.3	8.1 22.7	3 8.6	4.1 16.9
Q (POLYCRYSTALLINE)	11.7 26	13.8 29	17.5 40.5	18.6 43.9	12.1 25.9	18.3 35.6	18.2 17.1	8 20.4	6.8 15.8	4.5 12.6	5.4 15.5	6.1 25.1
QUARTZ	45 52.3	47.5 54.2	43.2 52.6	42.4 49.1	46.6 54.5	51.4 56.8	48 54	39.2 46.1	43 49.5	35.6 41.1	34.8 41.5	24.3 30.1
LABILE	36.6 42.5	34 38.8	32.4 39.4	40.3 46.7	37.1 43.4	37.2 41.1	34.1 38.4	37.9 44.5	42.4 48.9	33.8 39	44.2 52.7	40.8 50.6
MATRIX	4.5 5.2	6.2 7.1	6.6 8	3.6 4.2	1.8 2.1	1.8 2	6.8 7.6	8 9.4	1.3 1.5	17.2 19.9	4.8 5.7	15.5 19.2
GRAIN SIZE	0.25	0.28	0.23	0.5	0.19	0.26	0.16	1.14	5.2	0.13	0.18	0.6

SAMPLE NUMBER	X-21	X-23	X-24	X-26	X-27	X-28
LITHOFACIES SYMBOL						
STRAIGHT QUARTZ	26.6	24.5	27.8	24.9	30.8	29
UNDULATORY QUARTZ	4.5	3.6	5	6.3	7.2	4
POLYCRYSTALLINE QUARTZ	3.2	6.4	8.5	18.3	19.9	10.6
K. FELDSPAR	8	7.5	8.2	5.6	6.8	5.9
PLAGIOCLASE	2.2	0.9		0.7	0.9	0.6
OPAQUE MINERALS OR COAL	2.9	7.3	3.8	1.7	2.2	2.5
CLAY	3.5	11.8	10.4	1.7	1.2	1.5
BIOTITE	7.4	10.3	6.9	2.3	3.4	3.7
MUSCOVITE	3.8	3	3.1	2	4.3	3.7
ROCK FRAGMENTS	13.1	11.2	9.8	25.2	14.3	23.6
IRON OXIDE	14.4	9.1	6.6	6.3	2.5	8.1
HEAVY MIN.	0.6		0.3			0.3
CEMENT	9.6	4.2	9.5	5	5.9	6.2
CHLORITE					0.3	
QUARTZ	34.3 59.5	34.5 63.8	41.3 69.6	49.5 61.1	57.9 72.5	43.6 59.1
FELDSPAR	10.2 17.7	8.4 15.5	8.2 13.8	6.3 7.7	7.7 9.6	6.5 8.8
ROCK FRAGMENTS	13.1 22.7	11.2 20.7	9.8 16.5	25.2 31.1	14.3 17.9	23.6 32
Q (STRAIGHT)	26.6 77.5	25.4 71	27.8 67.3	24.9 50.3	30.8 53.2	29 66.5
Q (UNDULATORY)	4.5 13.1	3.6 10.4	5 12.1	6.3 12.7	7.2 12.4	4 9.1
Q (POLYCRYSTALLINE)	3.2 9.3	6.4 18.5	8.5 20.6	18.3 37	19.9 34.4	10.6 24.3
QUARTZ	34.3 45.2	34.5 39.9	41.3 49.3	43.5 55.8	57.9 63.4	43.6 51.2
LABILE	38 50.1	40.2 46.4	32.1 38.3	37.5 42.3	32.2 35.3	40 47
MATRIX	3.5 4.6	11.8 13.6	10.4 12.4	1.7 1.9	1.2 1.3	1.5 1.8
GRAIN SIZE	0.14	0.16		0.4	0.23	0.29

considered and he pointed out (Folk 1974, p.125), "the perfect classification of sandstone will never exist". He ignored the percentage of clay matrix in his classification.

The most convenient scheme for the present purpose is that proposed by Pettijohn (1954) and modified by Dott (1964) and will be used in this chapter. Basically the Pettijohn (1954) classification uses only framework grains of quartz, feldspar and rock fragments of sand size. As a secondary criterion, the classification distinguishes between the "clean" sands or arenites/sands with less than 15% matrix and the "dirty" sands or wackes (those with more than 15% matrix).

The first petrological description of the Upper Carboniferous rocks in Northern Turkey was that of Bayramgil (1951). He observed that the Upper Carboniferous rocks are partly composed of arkose and graywacke and partly of conglomerates in which sillimanite-bearing quartz grains, pebbles of metamorphic and igneous rocks, such as quartz-porphyry and, more rarely, dacite and andlesite are present. According to Bayramgil the Alacaağzı Formation formed of alternations of psammites and pelites. He considered the psammites to be micaceous arkoses, and rarely noted tourmaline needles in the quartz grains. It was stated that the arkoses may pass vertically upwards to graywackes. He also suggested that the source rocks were mainly granites or gneises with some volcanic debris probably derived from quartz-porphyry. Bayramgil (1951) pointed out the existence of andesitic pebbles in the uppermost part of the Karadon Formation, which he used to distinguish the Karadon Formation from the other formations.

5.2. DESCRIPTION OF ROCK CONSTITUENTS

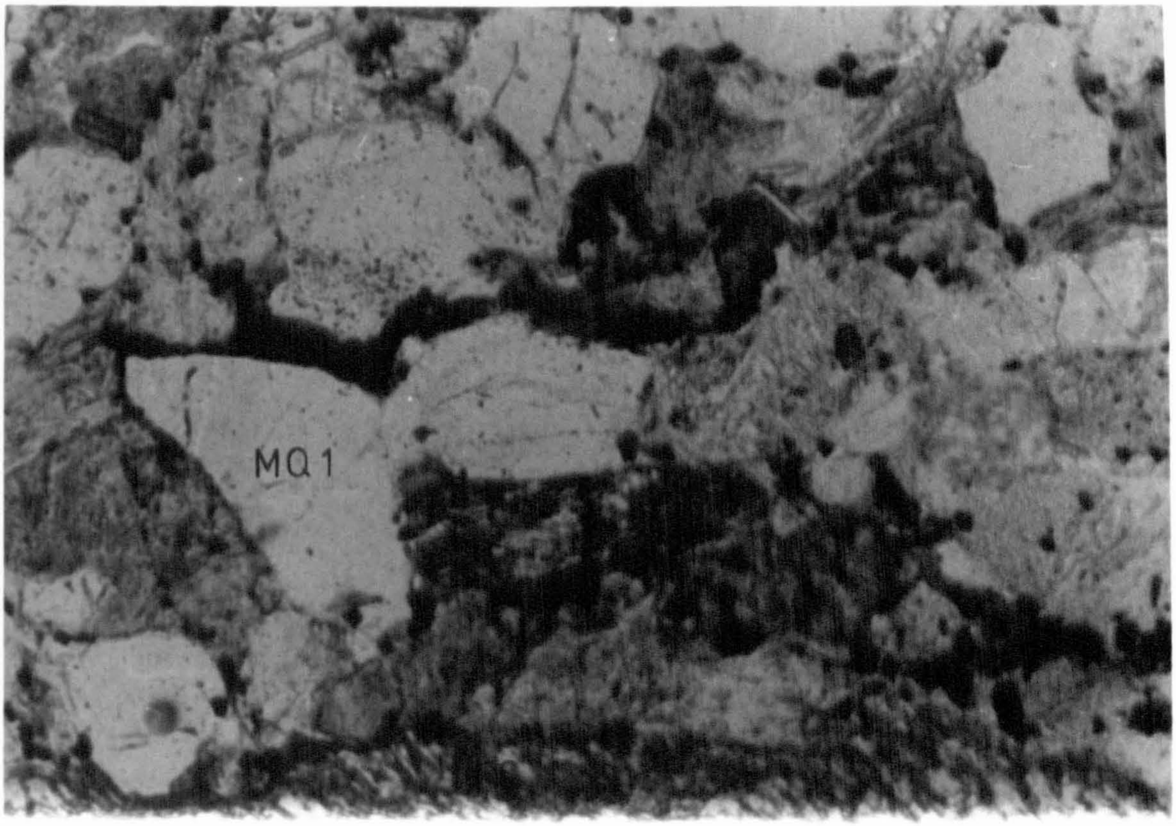
5.2.1. QUARTZ

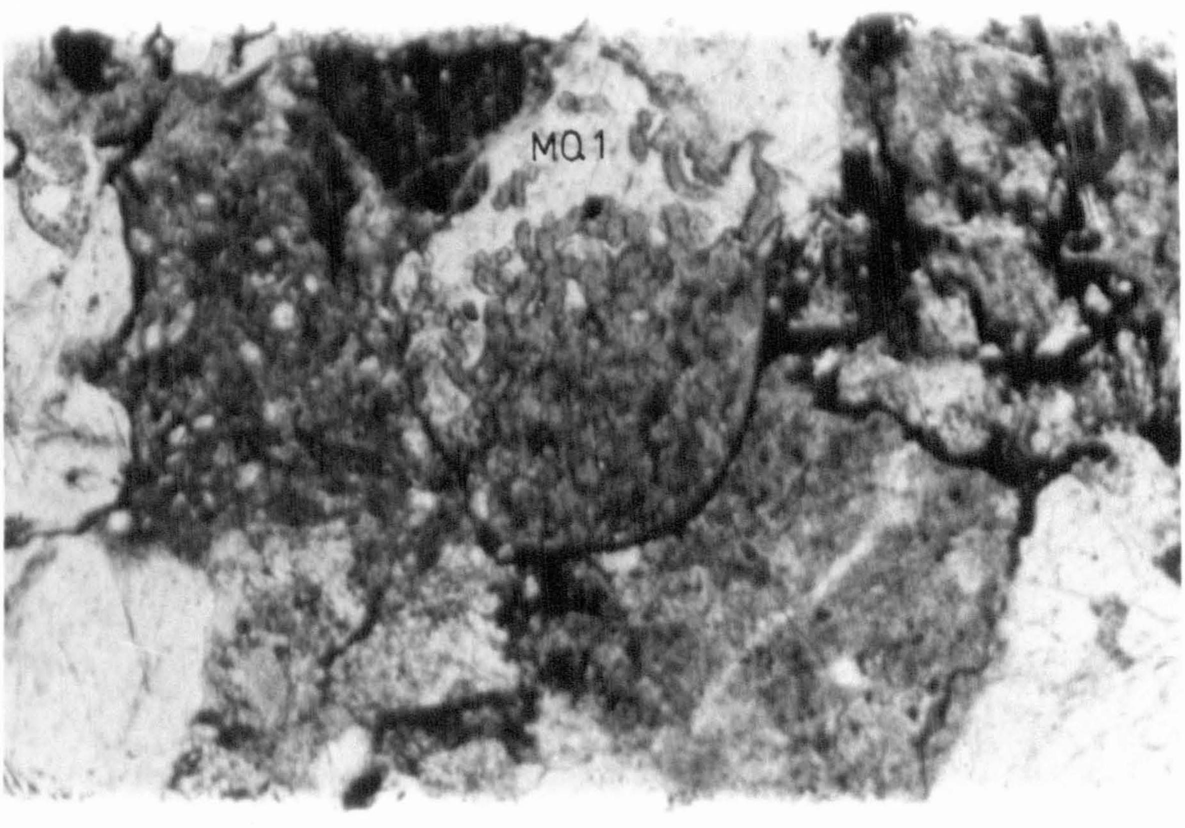
Many of the sandstones studied are dominated by mineral quartz grains and the siltstones also commonly contain abundant quartz grains. The mudstones may contain as much as 20% of quartz in silt-size particles. For the discrimination and description of the quartz types involved in this study, a modified version of the "Empirical Classification" of Folk (1968) has been used. The genetic significance of each type has been discussed according to Krynine (1940), Blatt and Christie (1963), Blatt (1967), Folk (1968) and Young (1976). The main criteria for such a classification are the extinction character and crystallinity.

(i) Monocrystalline, straight quartz, MQI: Within the area studied monocrystalline quartz grains have a slightly undulose extinction. The percentage of nonundulatory quartz among monocrystalline quartz grains in the fine and very fine sand grades is considerably greater than that in the coarser-grained sandstones. This contrast could be due to the destruction of the less stable, strained quartz, but large undulatory grains, when broken down into small fragments, may appear to give straight extinction. The crystals commonly contain variable amounts of microlite and a few fluid inclusions. In rare instances, the microlite inclusions can be identified as rutile, zircon crystallites or carbonaceous matter (Plate 71). Vermicular chlorite is also a common inclusion. Provenance: This type can be compared to Folk's (1968 p.74) empirical "A" type. It is also similar to the "non-undulose stable quartz" of Young (1976). Although the monocrystalline straight quartz was first assigned to plutonic rocks by Krynine (1940), later Blatt (1967) showed that it is an equivocal type. It may come from any relatively unstrained or recrystallised source rock of plutonic, vein or metequartzitic origin.

Plate 71 - Monocrystalline straight quartz (MQ1) with carbonaceous inclusions. Grains are subangular to angular. In the lower part of the photograph a psammite (PS) grain also occurs. From the Kozlu Formation. (x200, P.P.L.)
Sample GE5; Gelik section, Zonguldak area.

Plate 72 - Monocrystalline straight quartz (MQ1) with vermicular chlorite. From Asma "Member" of the Alacaağzı Formation. (x200, P.P.L.)
Sample; G62A, Gökgöl section, Zonguldak.


MQ1


MQ1

Some of the crystals counted as MQI have undoubtedly a volcanic origin as deduced from embayed idiomorphic or hypidiomorphic outlines and from the relative clarity of the crystals (Folk 1968, Blatt 1967, 1972). Moreover, the vermicular chlorite in the quartz grains is thought to be of hydrothermal origin (Blatt et al., 1972), (Plate 72).

(ii) Monocrystalline Undulose Quartz, MQ2: The grains again appear to be single individuals with xenomorphic outlines, displaying a distinct undulose extinction with variable intensity. Maximum undulosity of the extinction in some grains causes a semicomposite appearance (Folk, 1968) (Plate 73). Subdivision of this type, with respect to the range of extinction angle, is possible but has not been undertaken here due to invalidity of undulosity determinations when carried out on a normal microscope stage (Blatt and Christie, 1963; Blatt, 1967). Provenance: This type again can be compared to Folk's (1968) "A3" and "A4" types, and they are also similar to undulose and polygonized-unstable types of Young (1976). This is again one of the equivocal types that may have been derived from any relatively strained rocks of plutonic or more probably metamorphic origin (Blatt 1967, Folk 1968). According to Young (1976) this type of quartz crystal delineates the preliminary stages of deformation and thus they possibly reflect an origin in low grade metamorphic rocks.

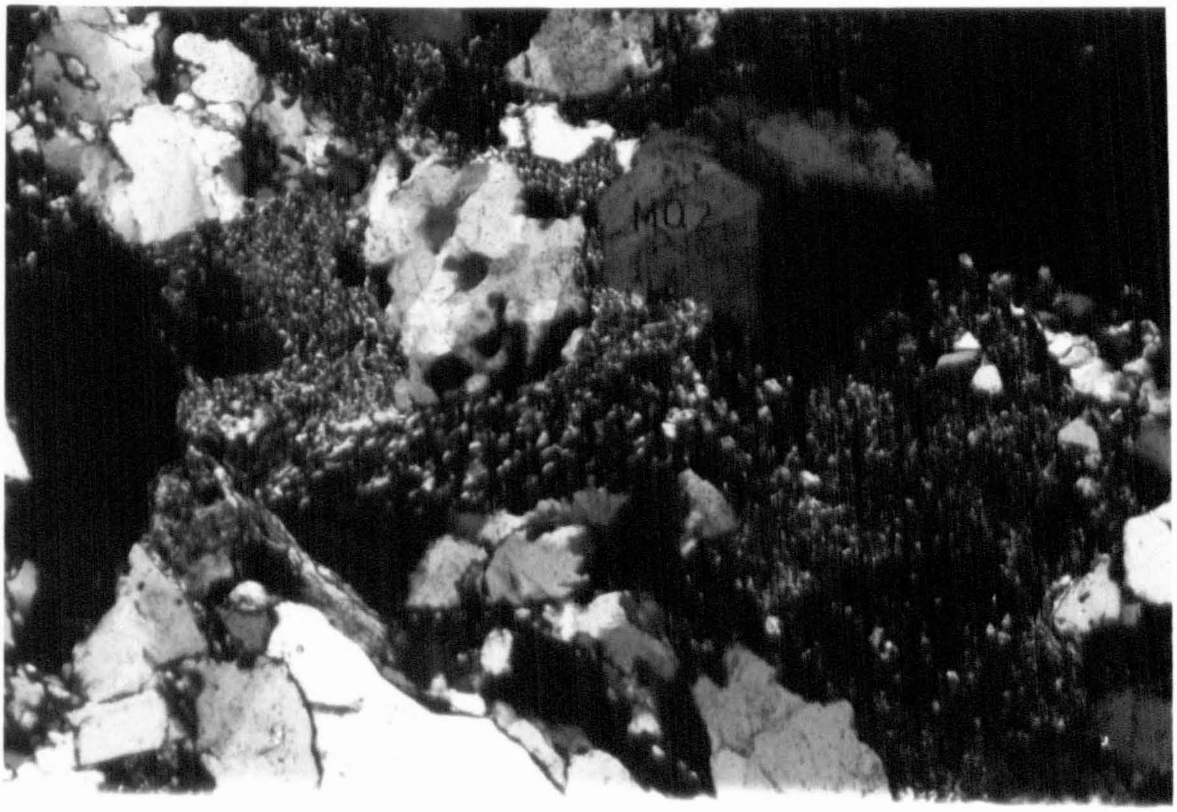
(iii) Polycrystalline Quartz, PQ: The grains are composite and made up of more than three subindividual crystals with widely different optical orientations. Straight or more commonly crenulated (sutured) contacts, and straight or almost straight extinction, are the other important characteristics of the subindividual components, but recrystallized areas within polycrystalline fragments are uncommon. More, the average size of the polycrystalline quartz grains is twice as coarse as the monocrystalline

Plate 73 - Monocrystalline undulose quartz grain (MQ2), displaying a distinct undulose extinction. From the Kozlu Formation. (x200, X.P.L.)

Sample GE9; Gelik section, Zonguldak area.

Plate 74 - Polycrystalline quartz grain (PQ). The grains are composite and common to abundant micaceous and chlorite inclusions are ubiquitous. From the Kozlu Formation. (x500, X.P.L.)

Sample GE5; Gelik section, Zonguldak area.


MQ2


PQ

quartz grains as suggested by Blatt (1967). Common to abundant micaceous and chloritic inclusions are ubiquitous in these composite grains (Plate 74).

Provenance: This type of quartz is similar to Krynine's (1940) "stretched" or "schistose metamorphic" type, or to Folk's (1968) empirical "A6" type composite quartz. It also resembles the "newly crystallized unstable type" of Young (1976). All the authors quoted above agree that this is a definite metamorphic type, derived probably from schists. However, Blatt (1967) suggested that massive plutonic rocks also can supply appreciable amounts of polycrystalline quartz to the sediments. According to Young (1976) elongated polycrystalline crystals represent mild deformation and low grade metamorphic rocks. The grains with all elongated subindividuals are similar to the "sheared quartz" of Folk (1968, p.77) and probably indicate an origin from gneiss, metaquartzite or sheared granites.

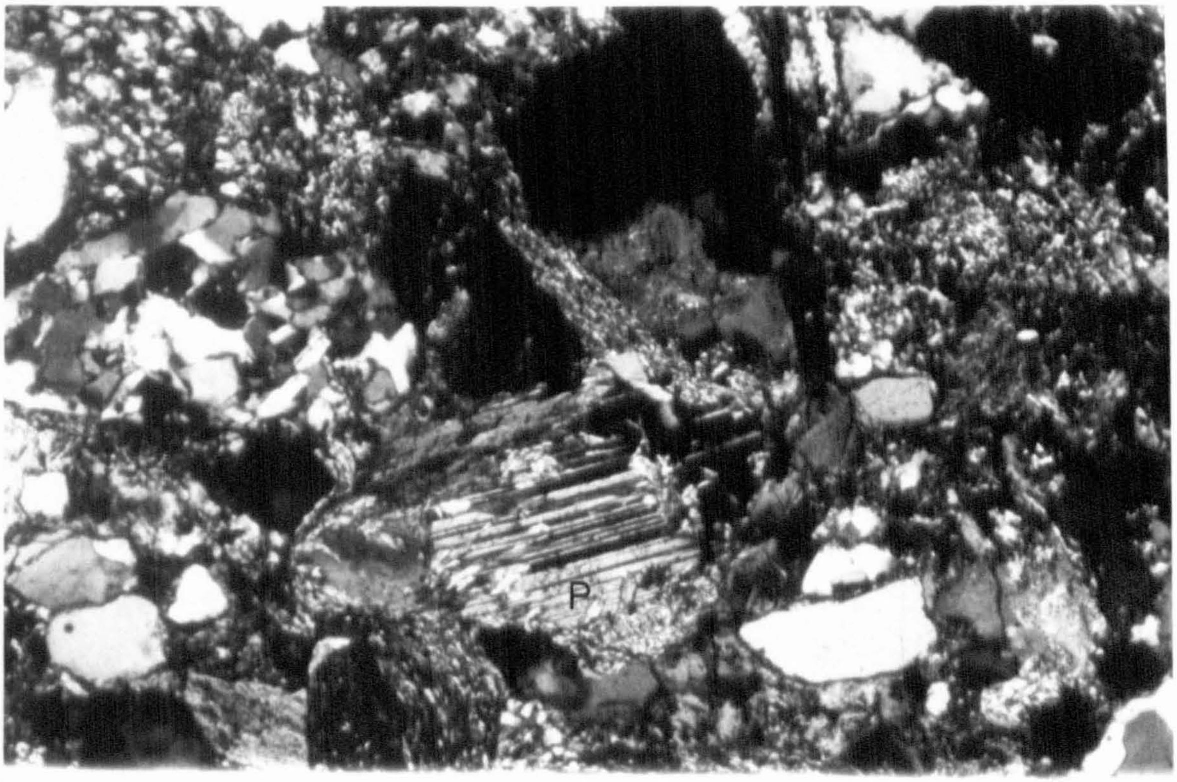
5.2.2. FELDSPAR

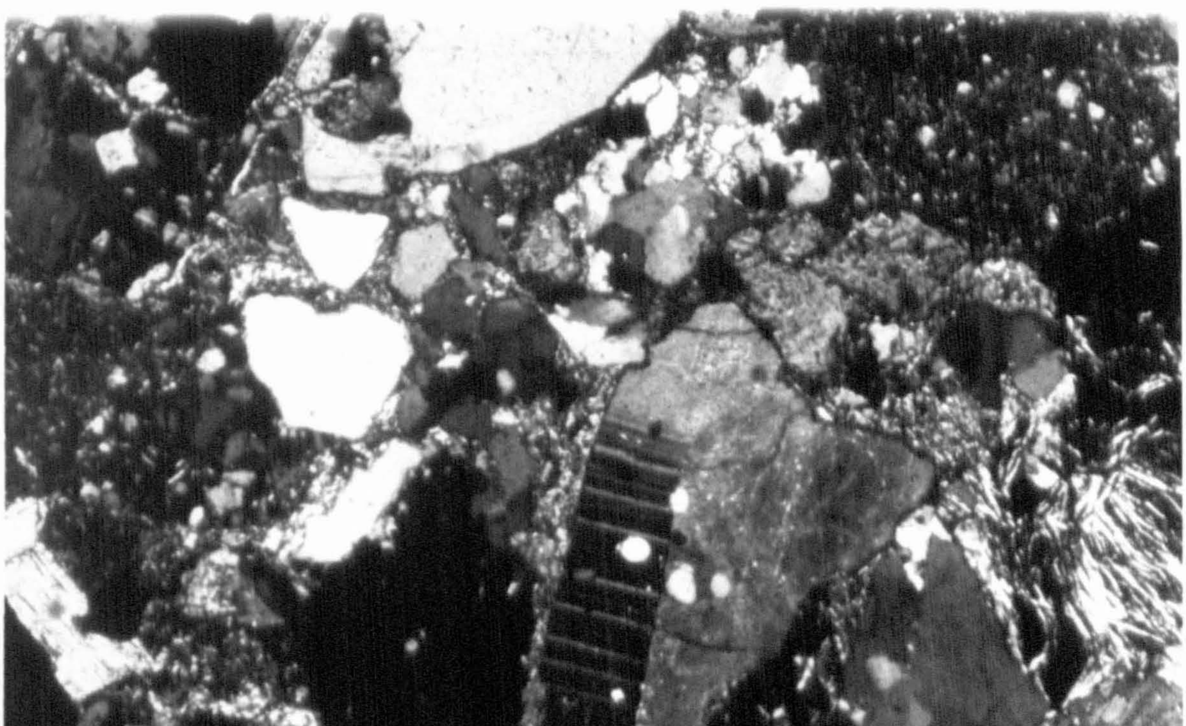
In the study area several types of feldspar have been recognized. They include orthoclase, microcline and a variety of plagioclose compositions. Orthoclase occasionally shows simple twinning of the Carlsbad and Baveno type. Perthitic orthoclase is common, but perthitic microcline is rare. K-Feldspar grains display fresh and slightly sericitized surfaces. Plagioclase grains occur in the form of idiomorphic or hypidiomorphic crystals, and most plagioclose exhibits albite twinning. Most of the feldspar has been altered to sericite (Plate 75).

Provence: Feldspar has been widely used for the study of provenance and dispersal in sandstones (e.g.Ermanovic,1967; Allen 1965; Friend and Moody-Stuart, 1972). Much of this work has concentrated on plagioclase, which promises to be useful in provenance studies

Plate 75 - Plagioclase (P) replacement by sericite. The clay minerals are growing along cleavages or twin planes. This is believed to be formed by the in situ alteration of plagioclase. Flakes of mica are randomly orientated in the Asma "Member" of the Alacaağzı Formation. (x200, X.P.L.) Sample G37; Gökgöl section, Zonguldak area.

Plate 76 - Plagioclase and Alkali Feldspar with quartz inclusion, suggesting a granitiod source for this grain. Asma "Member" of the Alacaağzı Formation. (x200, X.P.L.) Sample G54; Gökgöl section, Zonguldak area.


P



The relative rarity of the feldspar may be due to prolonged abrasion and a high rate of weathering, or it may simply mean that little feldspar was aveilable in the source area. Schists, phyllites and slates or older sediments provide little or no feldspar (Folk, 1968, p.83). However, the undeformed nature of the Alkali Feldspar suggests a granitoid source area (Pers comm, R.A.Roach, 1981), (Plate 76). Moreover the presence of some zoned plagioclose grains suggests a volcanic origin as well (pers comm., Öngen 1979).

5.23. ROCK FRAGMENTS

Rock fragments are usually polymineralic. It is difficult to assess whether some smaller fragments were originally discrete grains of separate minerals. However, most attention has been paid to the identification of rock fragments. Like quartz and feldspar, rock fragments have been used for studies of provenance in sediments. Currently they offer the most direct evidence of the nature of source rocks and due to the varying degrees of stability of many rock fragments they are potentially useful as dispersal indicators (Cameron and Blatt, 1971). The rock fragments are presented here in four categories with respect to their source.

(i) Metamorphic Rock Fragments: These are the most common rock fragments for the entire area. Most of the polycrystalline quartz grains described above represent small clasts of metamorphic rocks although they have been counted as quartz resistates for ease of classification. The quartzite rock fragments are also common; these are grey coloured, fine to coarse grained and may contain a few mica flakes. Some of the quartzite grains are mylonitized, as a result of extreme deformation and these grains consist of alternative subparallel bands and lenticles of finely granular quartz and sometimes feldspar. Both schistose and phyllitic rock fragments are present and were combined in point counting. Micaschist, chlorite schist and actinolite schist fragments are also present (Plate 77).

(ii) Volcanic Rock Fragments: The fine aphanitic nature and pre-, or post-depositional alteration render precise determination difficult. All through the Upper Carboniferous succession in northwestern Turkey volcanic grains are observed, and acid volcanoes are especially abundant. Devitrified glass fragments and glassy shards are also common, together with a few basalt grains. Some of the volcanic rock fragments were subsequently fractured, strained and veined with quartz. It is particularly difficult to distinguish the devitrification products of glass-rich volcanics and sedimentary cherts. According to Potter (1978, p.425) also some argillaceous low-rank metamorphic grains can be confused with the grains mentioned above, especially in those grains too small to be effectively recognised by elongate fabrics (Plates 78, 79, 80).

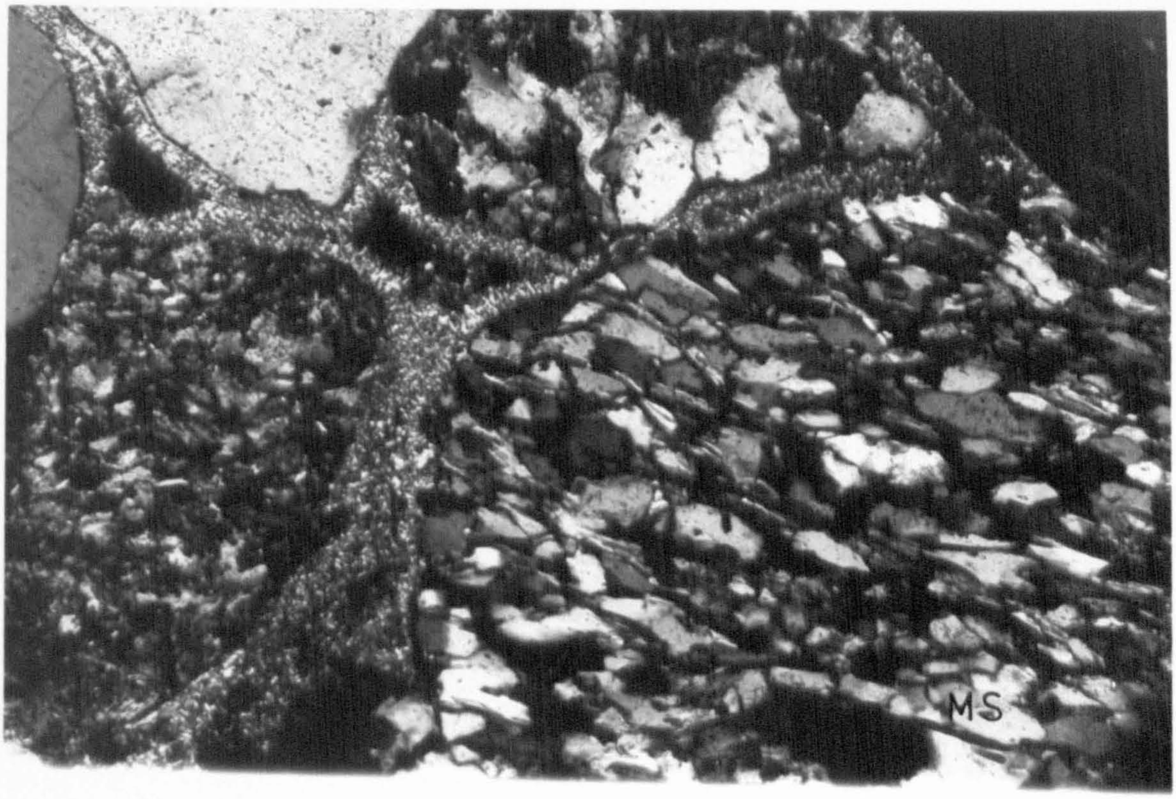
(iii) Sedimentary Rock Fragments: Three main types of sedimentary rock fragments have been recognised; pelitic rock fragments, chert and sandstone (Plates 81 - 82) fragments. Dark, fine grained, nonfoliated detrital particles are designated as pelitic rock fragments. Some of these grains are clearly composed of silt-size quartz and clay minerals and sericite or muscovite is present. These grains probably are shale fragments or may have been derived from slates. The chert grains generally display a mosaic texture and sometimes contain finely dispersed iron. Several chert grains are veined with polycrystalline quartz. The aggregate nature of the grains is revealed by the typical pinpoint birefringence under cross-nicols. There is little textured evidence with which to distinguish between a source from chert nodules or from bedded chert but some indications of fossils may suggest a bedded chert origin (Plates 83 - 84). Sandstone fragments are more

Plate 77 - Possible micaschist (MS) rock fragments with surrounding silicaeous (opaline) cement. From the Kozlu Formation. (x500, X.P.L.)

Sample D.1; Dilaver section; Zonguldak area.

Plate 78 - Altered mafic volcanic rock fragments (VR), possibly of spilitic origin. From the Kızıllı Formation. (x200, X.P.L.)

Sample 1GD.2; Ilyas Geçidi Dere, Kurucaşile area.


MS

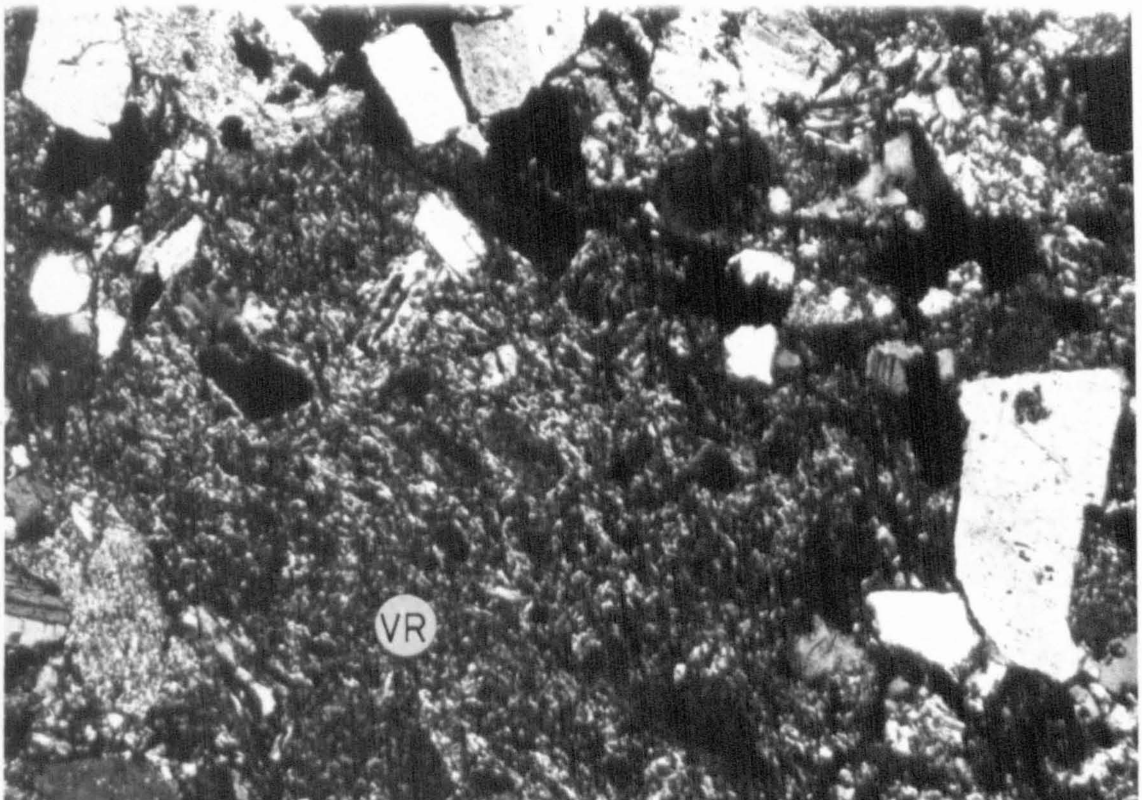
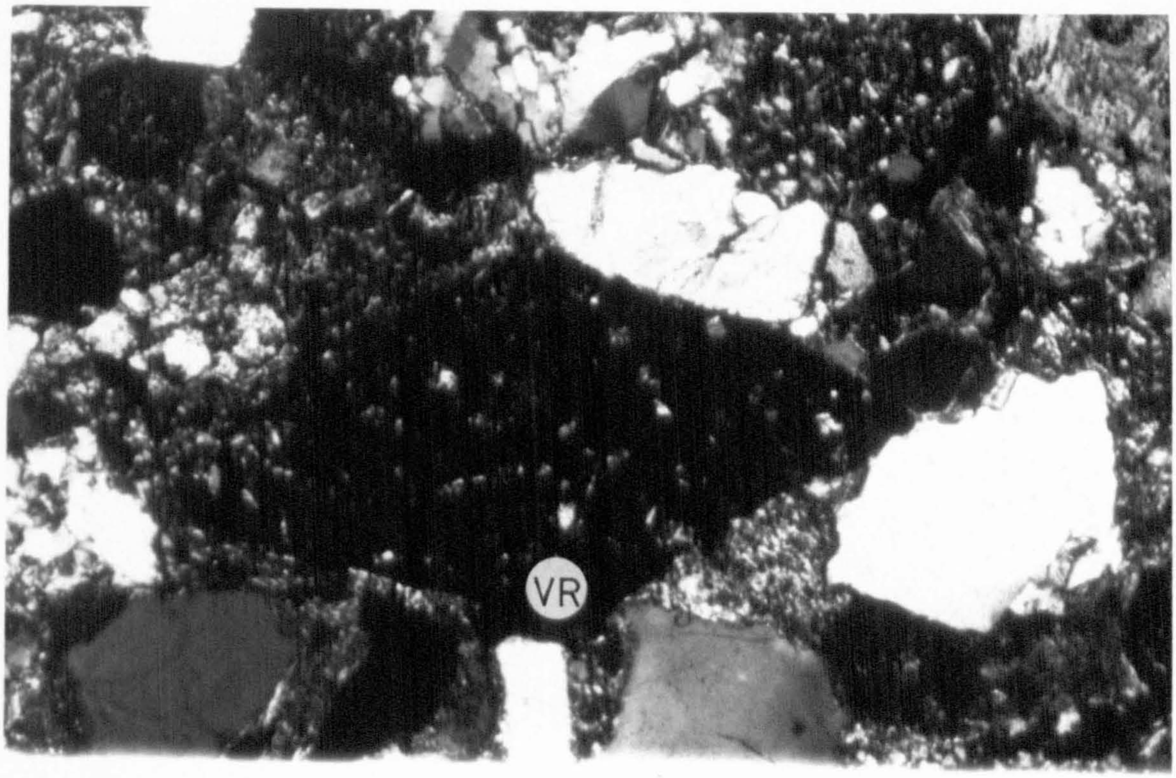

VR

Plate 79 - Altered volcanic rock fragments (VR), possibly devitrified glassy shards. From the Asma "Member" of the Alacaağzı Formation (x200, X.P.L.)

Sample G37; Gökgöl section, Zonguldak area.

Plate 80 - Volcanic rock fragments (VR), possibly basalt grains with small stellate plagioclase laths. From the Alacaağzı Formation. (x200, X.P.L.)

Sample G62 A; Gökgöl section, Zonguldak area.


VR

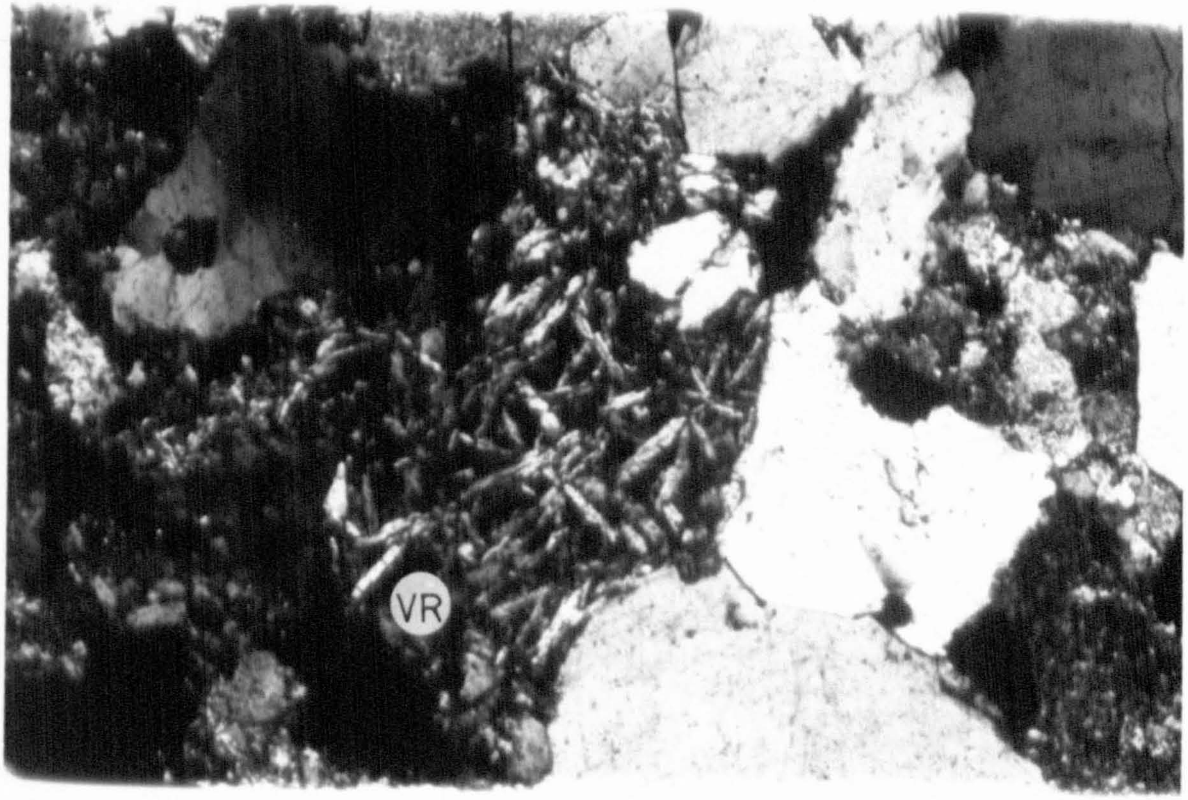
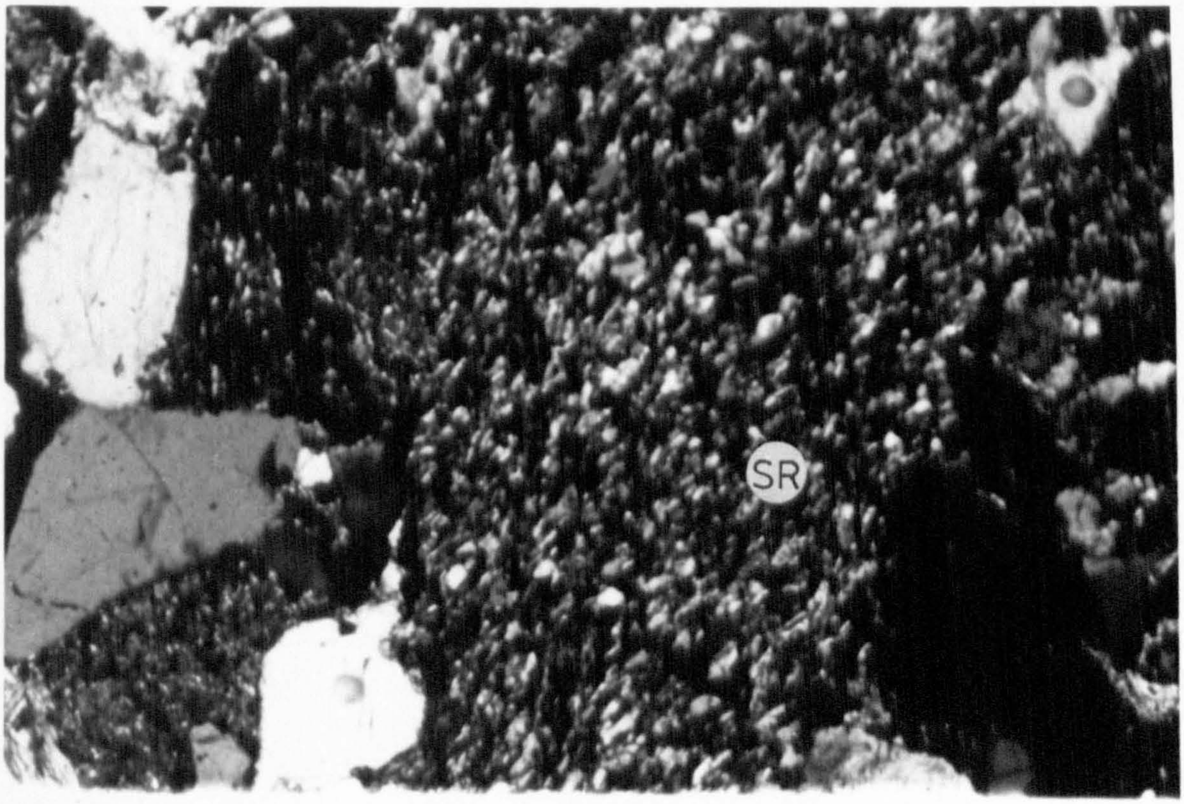

VR

Plate 81 - Sedimentary rock fragments (SR), possibly semi-psammite.
From the Kozlu Formation. (x200, X.P.L.)
Sample GE5; Gelik section, Zonguldak area.

Plate 82 - Chert (C) and recrystallised sandstone (S) grains embedded in a clay matrix. From the Kızıllı Formation. (x200, X.P.L.)
Sample K1 B; Kızıllı section, Azdavay area.


SR

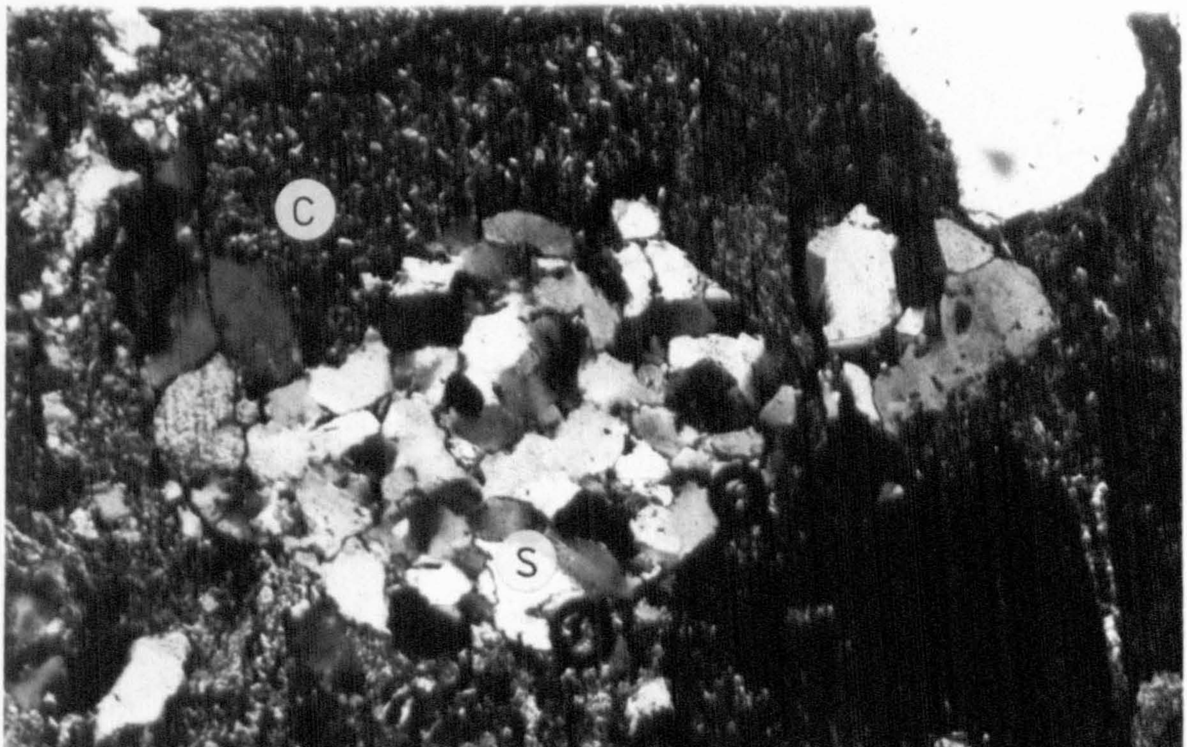
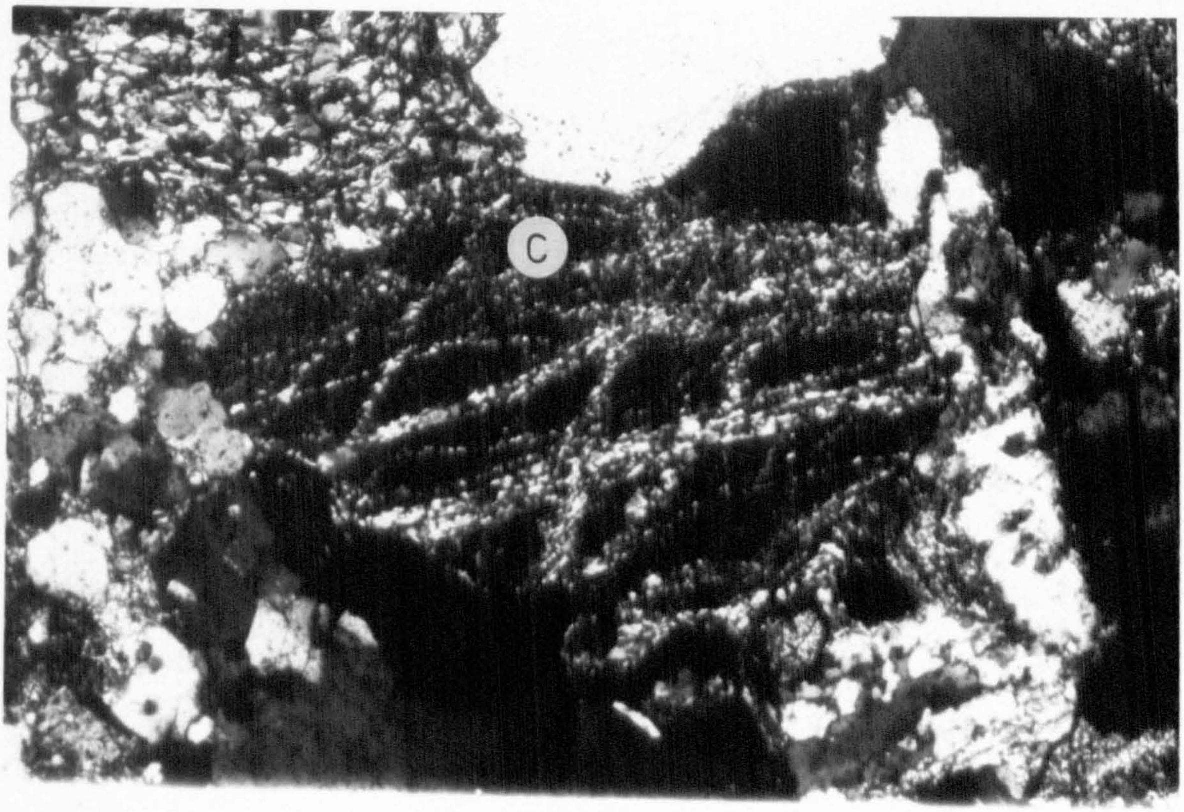

C
S

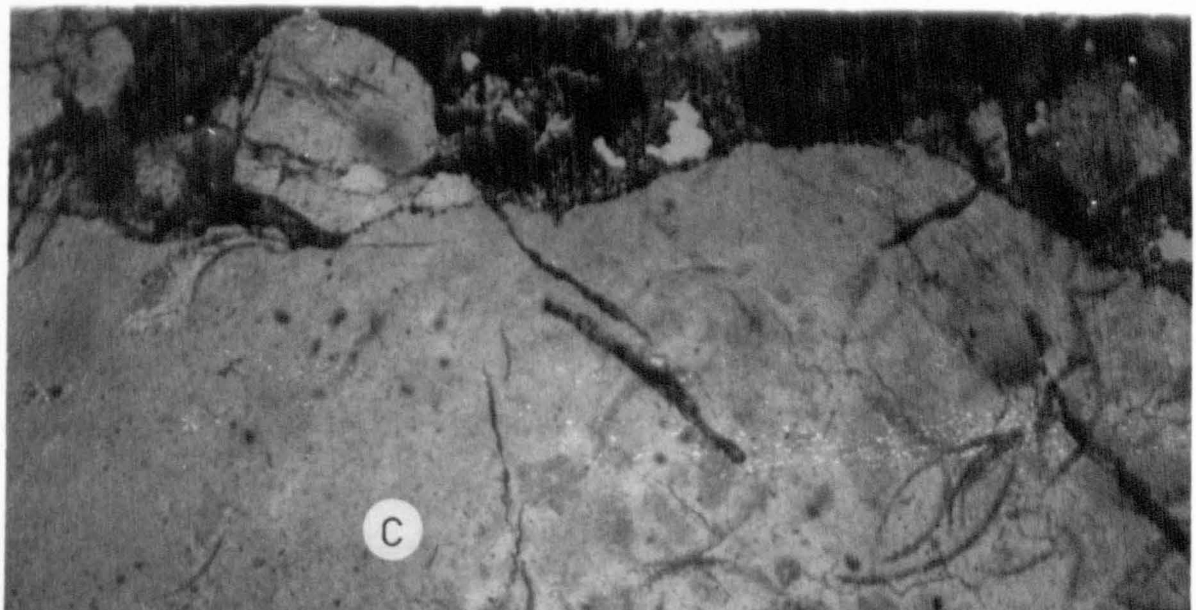
Plate 83 - Chert grain (C) displaying mosaic texture and veined by polycrystalline quartz. From the Alacaağzı Formation. (x200, X.P.L.)

Sample G62 A; Gökgöl section, Zonguldak area.

Plate 84 - Grain probably of partly silicified fine-grained limestone, displaying fossil shells, clearly indicating the sedimentary origin. From the Karadon Formation. (x200, P.P.L.)

Sample Ö5; Özkem section, Azdavay area.


C


C

common towards the upper part of the succession and at the topmost level (in the Kızıllı Formation) a few Carbonate fragments also appear (Plate 85).

Igneous Rock Fragments: Apart from the straight-extinction quartz grains described above, that represent small clasts of igneous rocks (Basu et al., 1975), some undeformed alkali feldspar and granophyric feldspar grains (quartz and feldspar, together) may suggest an igneous rock origin (granitoid source). Some grains have a pseudo-clastic texture, consisting of angular to subhedral quartz, orthoclase, and sodic plagioclase set in a finely banded cryptocrystalline groundmass. This texture is typical of quartz-feldspar porphyrys.

5.2.4.MICAS

(i) Biotite: In general, biotite is the most common type of mica, and is a very durable mineral, extremely difficult to round and almost impossible to fracture, because it is so elastic (Plate 86). Large mica flows can be observed in hand specimens, and they are very well oriented parallel to the bedding in most cases. In some samples the biotite appears to have lost some titanium and have acquired a slight green tinge (Öngen pers. comm., 1979). However, Folk (1974) has suggested that biotite may become bleached to a pale golden colour through loss of iron (not titanium) in weathering, or through hydrothermal attack may turn from brown to green (green biotite) representing an intermediate stage in the passage of biotite to chlorite, probably under reducing conditions.

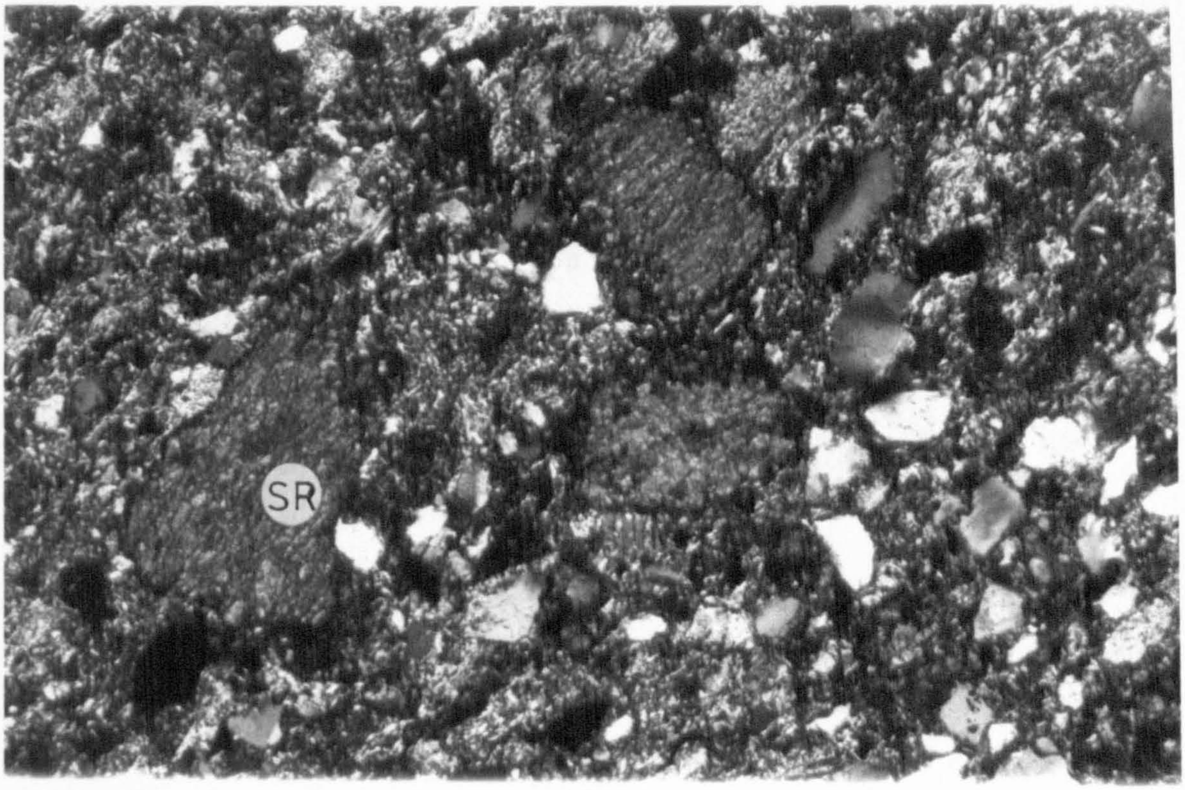
(ii) Muscovite: Muscovite is one of the minerals most resistant to weathering and general alteration and,as secicite, is itself a stable alteration product of other minerals. According to Phillip and Griffen (1981, p.273), muscovite is more characteristic of metamorphic rocks than of igneous environments, where the alumina content seldom exceeds that required by

Plate 85 - Secondary siderite patches (SR) within immature sandstone with scattered quartz grains. From the Kızıllı Formation. (x200, X.P.L.)

Sample IGD6 B; Ilyas Geçidi Dere section, Kurucaşile area.

Plate 86 - Possible micaschist clasts, accompanied by mica flakes (M). From Kozlu Formation. (x500, X.P.L.)

Sample X.10; Kozlu-Zonguldak road cutting, Zonguldak area.


SR

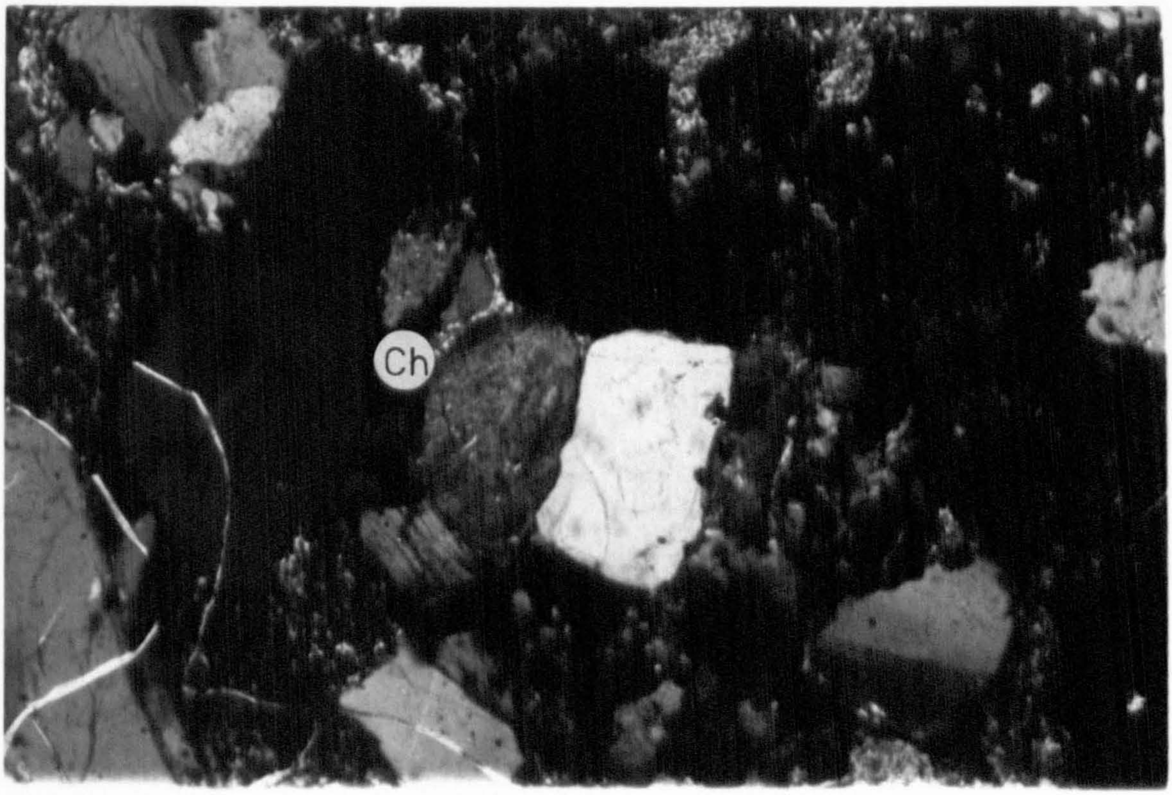

M

feldspar. They add that primary muscovite is a "plutonic" mineral favoured by high pressure, especially directed pressure, and is not found in volcanic rocks. Metamorphic rocks of nearly all kinds and grades contain muscovite, and it is typical of schists and gneisses, but at higher grades the muscovite tends to dissociate in favour of microcline and sillimanite. In the studied rocks, muscovite occurs abundantly as sericite (Plate 86) interlayered with clay minerals. Inclusion of accessory minerals (such as zircon, opaque) in some muscovite grains may help to identify their primary origin rather than a secondary origin (alteration products).

(iii) Chlorite: Ferrous iron is usually present to supply the green colour (Plate 87). This mineral occurs as detrital grains with well-defined outlines (flakey) or as irregular, structureless patches. The latter are vermicular in shape (Plate 72) and could not have withstood transport and thus presumably result from diagenetic alteration of clayey material. Therefore this secondary chlorite has been counted as matrix. Other varieties of chlorite group minerals (penninite and serpentine groups, pers comm., Öngen (1979) exist in the Upper Carboniferous rocks of Northern Turkey, although they have not been discriminated here due to insufficiency of microscopic criteria. Primary chlorite occurs in low-grade metamorphic rocks (especially the green schist facies) and in hydrothermal environments (Phillips and Griffen, 1981). There is little doubt that the chlorites of the Upper Carboniferous sandstones of northwestern Turkey have a twofold origin. The flakey chlorites probably were derived from low-grade metamorphic rocks of schist or greenschist facies while the prismatic chlorites may represent the alteration products of ferromagnesian minerals and might have been derived

Plate 87 - Bent chlorite flake (CH), showing well defined outline, probably derived from low-grade metamorphic rocks. From the Kozlu Formation. (x200, X.P.L.) Sample GE5; Gelik section, Zonguldak area.

Plate 88 - Clay/siliceous coatings around detrital grains, possibly altered K-Feldspar (F). From the Asma "Member" of the Alacaağzı Formation. (x500, X.P.L.) Sample G54; Gökgöl section, Zonguldak area.


Ch


F

from ultramafic rocks, such as serpentinites.

5.2.5. ACCESSORY MINERALS

Heavy Minerals: The accessory or heavy minerals are not major constituents of the studied rocks. Zircon is the most abundant anisotrophic heavy mineral and shows pink to purple colours in thin sections. Some zircons are rounded and may indicate derivation from metamorphic (high grade metamorphism) or sedimentary sources. A few euhedral zircon grains occur.

Opaque Minerals: These are commonly black, angular or conchoidally fractured grains, or sometimes patchy grains are abundant. A few coal fragments also may have been counted in this class. No attempt was made to differentiate opaque minerals and carbonaceous material in this study, because of the relative rarity and identification difficulty in the microscope.

Secondary Iron Minerals: This category includes brown, red, orange and yellow iron minerals which may be hematite, siderite, geothite or limonite, unless these minerals are clearly pseudomorphous after another mineral, e.g. biotite. Siderite forms as a replacement, as a directly precipitated ooze, or as concretions from iron minerals. According to Phillips and Griffen (1981, p.53) sedimentary siderite represents the precipitation of soluble ferrous bicarbonates in oxygen-poor environments. Siderite alters to iron oxides and hydroxides, usually geothite or limonite. Hematite is steel grey to black, with a metallic lustre in reflected light, and a tendency to a marginal red hue. Most occurrences are red and translucent. However, their earthy-amorphous appearance indicates that they are secondary in origin (Plate 71).

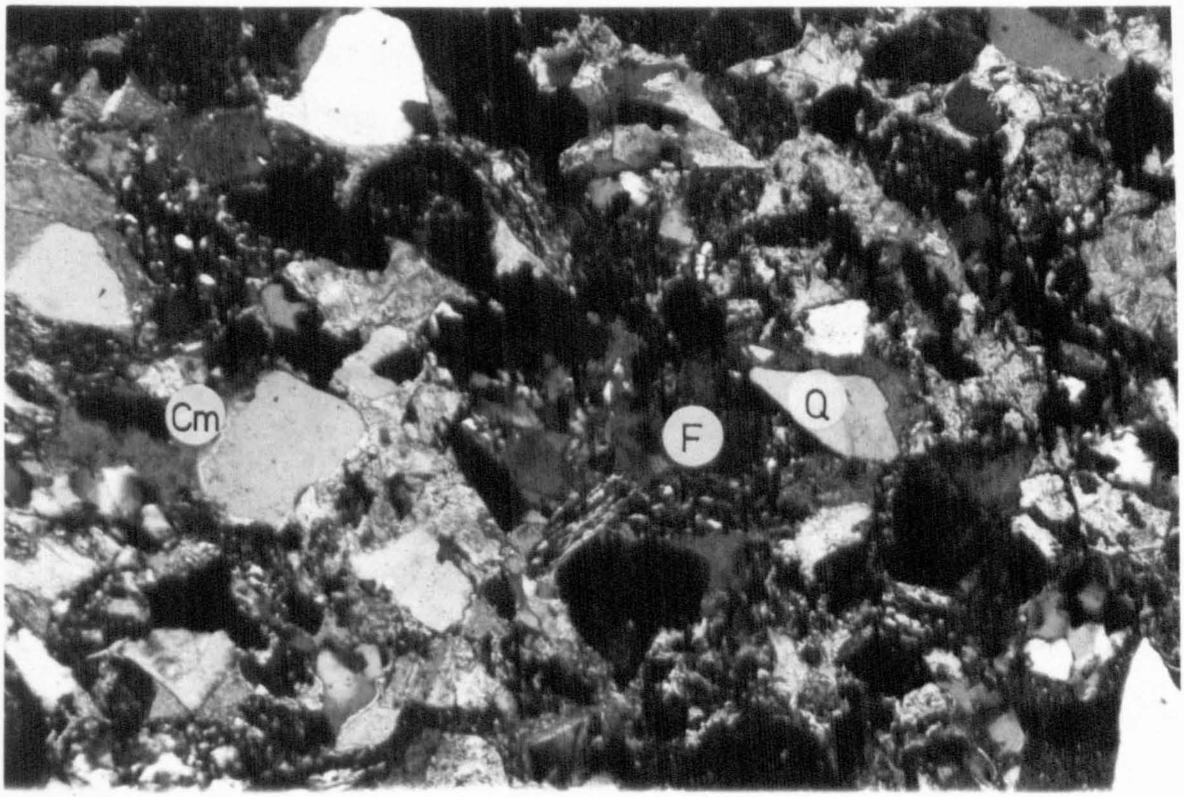
Clay minerals: Clays are sheet structure silicates closely allied to the micas, and nearly all clays are crystalline and display similar optical properties. Thus they are difficult to distinguish microscopically, Folk (1974). In the studied thin sections clay occurs most commonly as a coating on detrital grains (Plate 88). Kaolinite is the most common type of clay mineral in all the sandstones examined. Although it is difficult to recognise in thin sections, and is somewhat variable in character, most of the kaolinite recognised here is a fibrous, colourless material with weak birefringence . Kaolinite aggregates frequently occur in intimate association with decomposing muscovite, suggesting a genetic connection, but kaolinite has also been observed to form from the alteration of feldspar. Many of the clay mineral aggregates in the studied sandstone consist of both kaolinite and sericite.

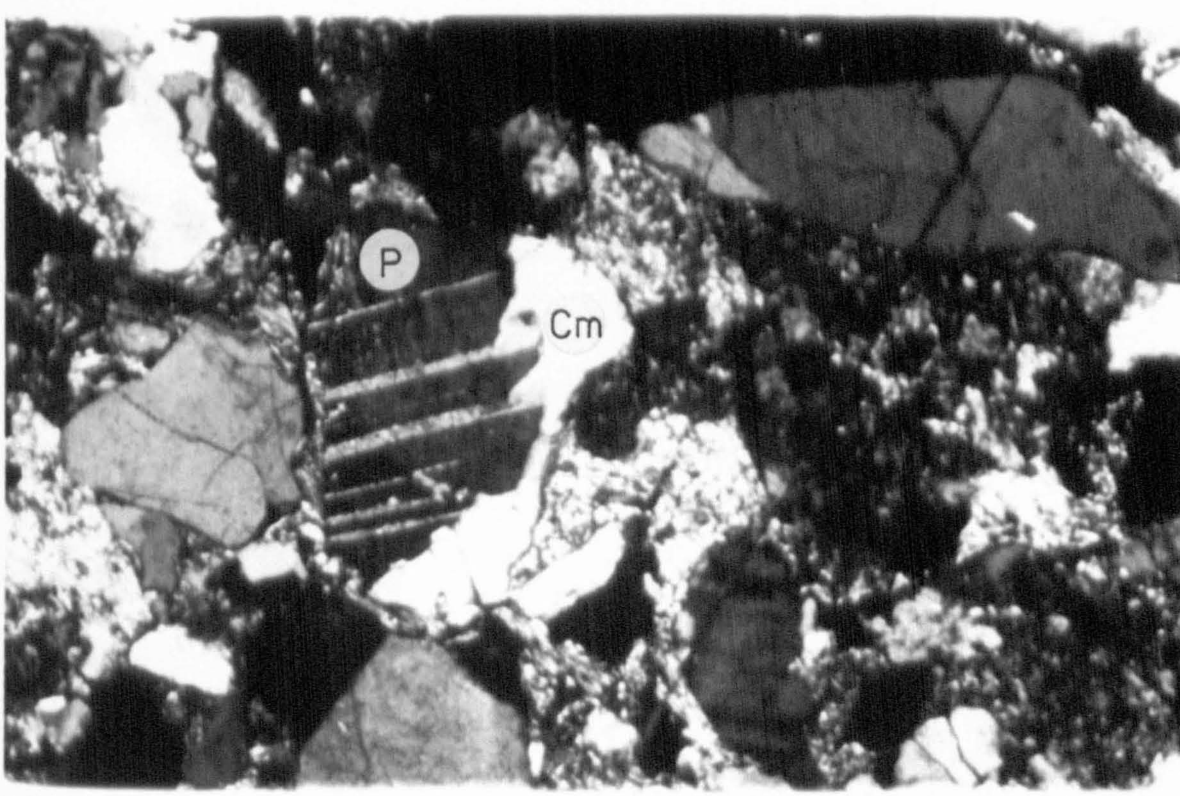
5.2. 6. ASPECTS OF CEMENTATION, DIAGENESIS AND ALTERATION

The term "cement" is used after Dickinson (1970) and includes, in order of abundance, carbonate, silica, feldspar and clay minerals. Only carbonate and silica comprise more than 10% in some thin sections(Plate 89). Carbonate cement is more common in the lower part of the succession (Alacaağzı Formatıon) and also in the topmost levels (Kızıllı Formation). Quartz and feldspar often show corroded margins when in contact with calcite cement, and in some cases feldspar has been replaced by calcite(Plate90) Generally, the entire interstitial space has been replaced by calcite cement. Especially in the Kızıllı Formation sandstones the carbonate occurs as plates which are slightly larger than the mean grain-size of the sandstone, thus enclosing several detrital grains and providing clear evidence for post-depositional growth of the crystals.

Plate 89 - Carbonate cement (CM) around Quartz (Q) and feldspar (F) grains showing corroded margins when in contact with calcite cement. From the Alacaağzı Formation. (x200, X.P.L.) Sample TA5; Tarlaağzı section, Amasra area.

Plate 90 - Plagioclase (P) grain partially replaced by calcite cement (CM). From the Kozlu Formation. (x200, X.P.L.) Sample GE11; Gelik Section, Zonguldak area.


Cm
F
Q


P
Cm

However, in the lower part of the Alacaağzı Formation this kind of calcite overgrowth has not been recorded. Cementing iron oxides occur in many thin sections and especially in the Kozlu and Karadon Formation samples. Siderite is the dominant iron mineral but hematite also occurs. Most commonly iron oxides occur as grain-coating granular veneers which may coalesce to fill small residual interstices, and also form larger irregular patches and stringers. The actual amount of cement depends on the grain size and packing . Siliceous cement occurs as optically continuous overgrowths in some thin sections but this is not (Plate 91) quantitatively important. Especially in the upper part of the Kızıllı Formation, some quartz-rich sandstones contain quartz overgrowths which appear to have developed at a time when abundant free pore-space was available and they clearly pre-date the formation of platy carbonate cement. It seems that pressure solution plays an important role in generating authigenic silica. Heald (1956, 1959) showed that the dissolution of quartz and the effects of pressure solution can be influenced by the clay content. The experimental investigation of Renton et al., (1969) also indicated that the effects of pressure solution increase markedly with decreasing grain size. Chalcedonic silica is a less common cementing constituent, and occurs interstitially, filling small, sub-ovoid pores either partially or completely. It is most frequently encountered in sandstones of the Kozlu Formation.

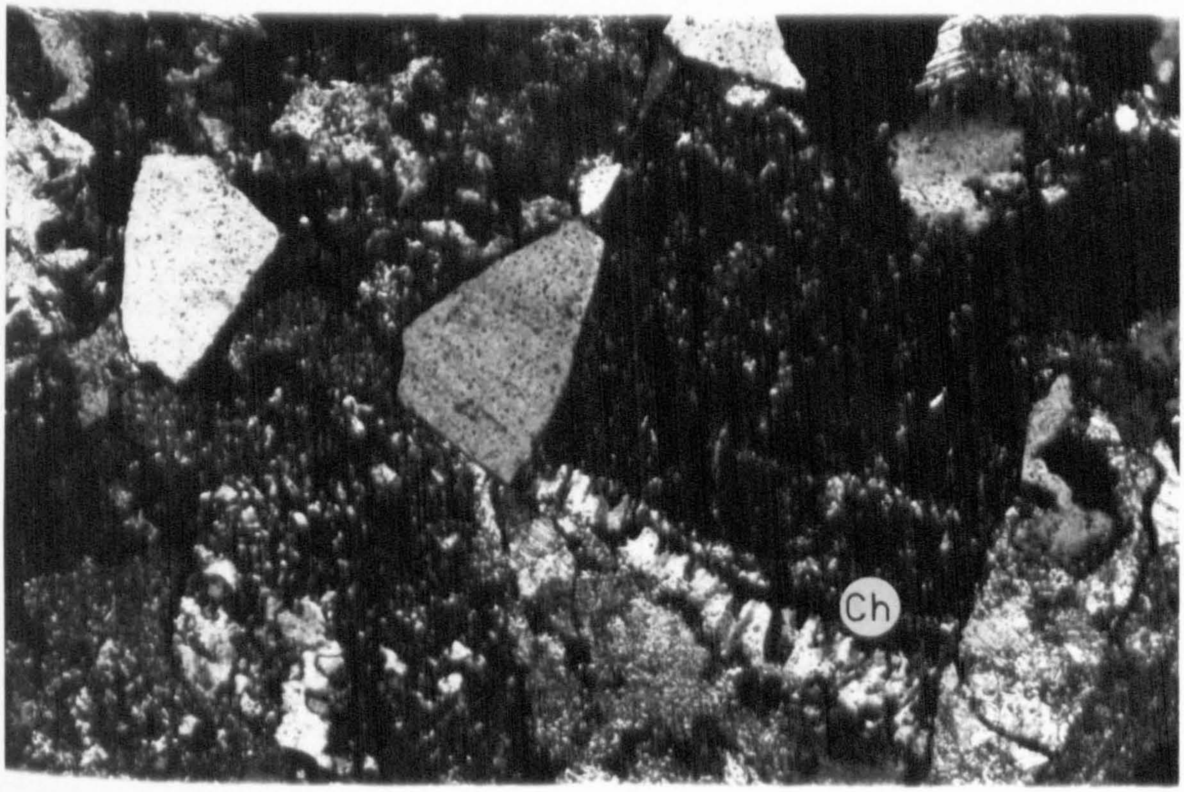
In most of the sandstone examined K-Feldspar appears particularly susceptible to alteration. Marginal corrosion of the grains by clay minerals and iron oxides is common. It is possible that some of the alteration of these feldspar grains took place during weathering or transport rather than through diagenetic alteration, as suggested by Greensmith (1957) from the Upper Carboniferous sandstones of Derbyshire.

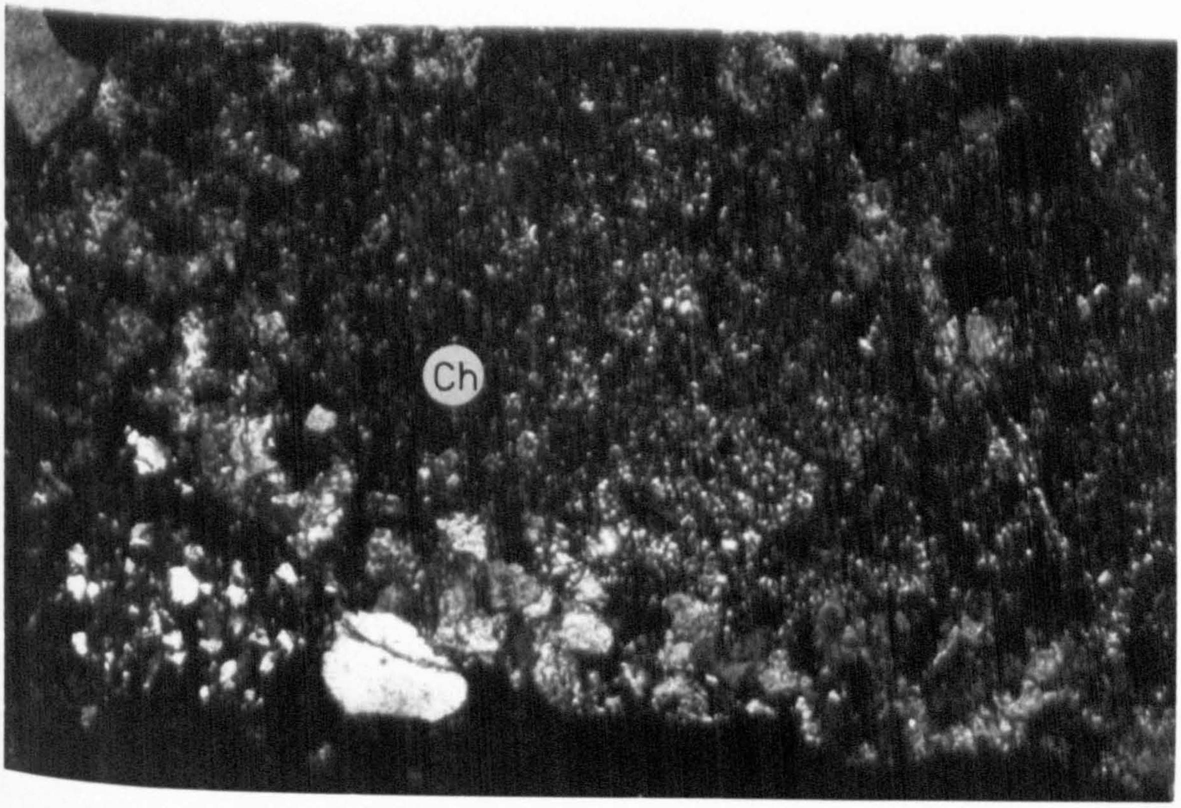
Plate 91 - Siliceous cement, occuring as optically continuous overgrowths on the edge of a chert (CH) grain. From the Kızıllı Formation. (x200, X.P.L.)

Sample AZ8; Kızıllı section, Azdavay area.

Plate 92 - The corroded margin of chert (Ch) in contact with mesocrystalline calcite cement. (x125, X.P.L.)

Sample AZ8; Kızıllı section, Azdavay area. Kızıllı Formation.


Ch


Ch

However, in the Alacaağzı, Kozlu and Karadon Formations the small amount of feldspar present may exert a marked influence on diagenetic changes (Plate 88). Microscopic identification of clay minerals has proved to be difficult due to their extremely fine grained-size. Nevertheless, some feldspar grains appear to have been completely pseudomorphed by clay mineral aggregates or sericite flakes. Moreover, some clay minerals commonly occur in the cracks of fractured feldspar.

Alteration of muscovite is common, and sometimes it is almost entirely replaced by sericite and illitic flakes.

It can be concluded that the high initial porosity and permeability of the Kozlu and Karadon sandstones promoted formation of clay minerals, mainly through diagenetic alteration of detrital feldspar grains by circulating ground water. Permeability was the basic control of the degree of diagenesis. Moreover, it is possible to distinguish two phases of diagenesis in these rocks:

Early Diagenesis - This term refers to changes occurring during burial to a few hundred metres, where elevated temperatures are not encountered and where uplift above sea level (or lake level) does not occur, so that the pore spaces of the sediment are continually filled with water (Berner, 1980).

In the studied area some destruction of lamination by burrowing the formation of siderite concretions, the infiltration of clay and iron oxide precipitation are regarded as early diagenetic effects.

Siderite nodules are abundant in the lower part of the Alacaağzı Formation. According to Berner (1980, p.210), in the marine environment the authigenic iron minerals most commonly formed during the early diagenesis of organic-rich, anoxic sediments in pyrite (FeS_2). However, in the interstitional waters of anoxic, organic-rich, non-marine sediments one commonly encounters high concentrations of dissolved iron that results in the formation , during early diagnosis, of reduced authigenic iron minerals such as siderite.

The more or less simultaneous infiltration of clay and iron oxide precipitation are both important in the early diagenetic history of the studied areaWalker, Waugh&Crone(1978) found such an association to be typical of mechanically infiltrated clays, deposited from waters containing clay particles in suspension sinking into dry and very permeable sediments.

This early diagenetic phase may or may not be accompanied by growth of authigenic quartz and feldspar.

Late Diagenesis - In the studied sections, replacement of detrital feldspar by colourless clay minerals may be assigned to this episode. Some clay minerals appear to be related to marginal corrosion of quartz and feldspar (Plate 88). This phase of the clay mineral formation is believed to have occurred late in the diagenetic history of the sediment. The other indicator of late diagenetic events is the growth of secondary quartz in the Kızıllı Formation. This mineral fills pore-spaces left after growth of colourless clay. Possibly the K+ activity was too high for silica precipitation and instead quartz dissolution took place because of increases in PH, as is suggested by Dypvik and Vollset (1979) from the Jurassic sandstones of the North Sea. The other evidence for late diaganesis in the Kızıllı Formation is corroded margins of quartz (especially chert) and a few feldspar grains by Calcite cement which provides post depositional evidence for this formation (Plate 92).

5.3. SANDSTONE COMPOSITION OF THE ALACAAGZI AND KOZLU FORMATIONS

The triangular diagram for the Alacaagzı Formation sandstone has been plotted with the following poles: Q pole - quartz, F pole - feldspar, R pole - all rock fragments (including cherts). Plots for different sections are shown in Fig. 26. According to this scheme the Alacaağzı Formation sandstone falls into the categories of subarkose to sublitharenite of Pettijohn (1954). In terms of the areal distribution of these different categories, the Gokgol section sandstones (Uzulmezdere stream-cut of Zonguldak area) mainly fall into the subarkose category while the Gelik and Açık Yarma sections (Zonguldak area) sandstones fall roughly between the subarkose and sublitharenite categories. However, the Ulutamdere section samples fall mainly within the sublitharenite field. These differences are mainly due to grain size, sedimentary environment and transportation factors. Grain size is also important in determining the sandstone composition. For instance a bivariate scatter plot (Fig.32a) demonstrates that coarse grained sandstone samples of the Alacaağzı and Kılıç "Member" of the Kozlu Formation sandstone tend to have higher quartz content than fine-grained sandstone samples, as has been observed by Flores (1978) in Pennsylvanian rocks of northeastern Kentucky. Also the very fine grained sandstones contain more feldspar than the other coarser-grained sands. This is consistent with the work of Fuchtbauer (1960) who also condluded that detrital feldspar/quartz ratios are strongly dependent on grain size. The depositional environments of the Gökgöl, Tarlaağzı and Asma "Members" of the Alacaağzi Formation also have exercised a significant control on quartz/feldspar ratios. For example, most of the Asma "Member" of the Alacaağzı Formation falls into the subarkose category, because these sediments were deposited under fluvial conditions. On the other

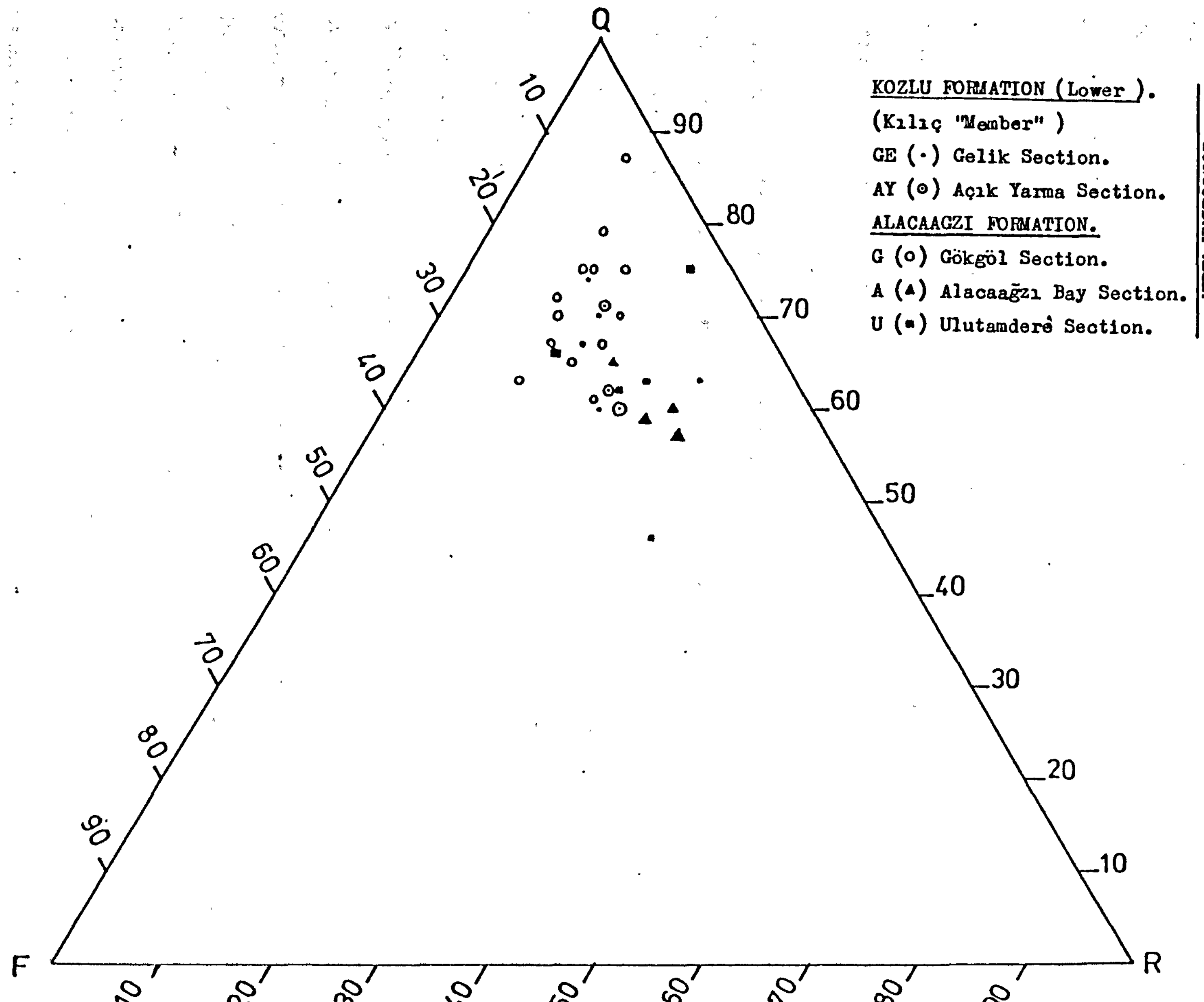


Fig 26. QFR diagrams for sandstones in the Alacaağzı and the Kılıç "Member" of the Kozlu Formation.

hand, if the sedimentary environments have been influenced by marine activity, the sandstones, such as those in the Tarlaağzı member, for instance, fall into the lithic arenite and sublitharenite fields (Fig.26). Furthermore, the labile grains are concentrated in the finer fractions and are relatively depleted in the coarser grades, a relation that results from the mechanical breakage of grains during grain-to-grain collisions during transportation (Odam et al., 1976). Some samples are very close to "wacke" class, because the matrix component is about 15% or above (Fig. 28). The Q L M triangles for the Alacaağzı Formation sandstones have been plotted with the following poles; Q pole - quartz, L pole - labile, M pole - matrix. Feldspars, micas, opaque minerals, heavy minerals and unstable rock fragments are counted as labile components, and only clay minerals are counted as matrix. The mineralogy or composition of the cement is not included in this classification (cement-free basis). The high percentage of matrix (Fig.28) is probably due to the diagenesis of feldspar. According to Pettijohn, Potter and Siever (1972, p.166) "matrix may not result from primary deposition and it may be introduced by infiltration shortly after deposition or it may be of diagenetic origin". Matrix is possibly produced by the transformation of argillaceous and volcanic rock fragments after deposition in the Alacaağzı Formation. Also it may well be that feldspar altered diagenetically to clay after transportation.

Q L M diagrams (Fig.28) reveal that the Alacaağzı Formation sandstones are generally quartoze and contain high amounts of labiles and relatively smaller amounts of matrix. In contrast, the Tarlaağzı "Member" of the Alacaağzı Formation contains comparatively more labile material, whereas the Asma "Member" contains relatively more quartz and less labile material.

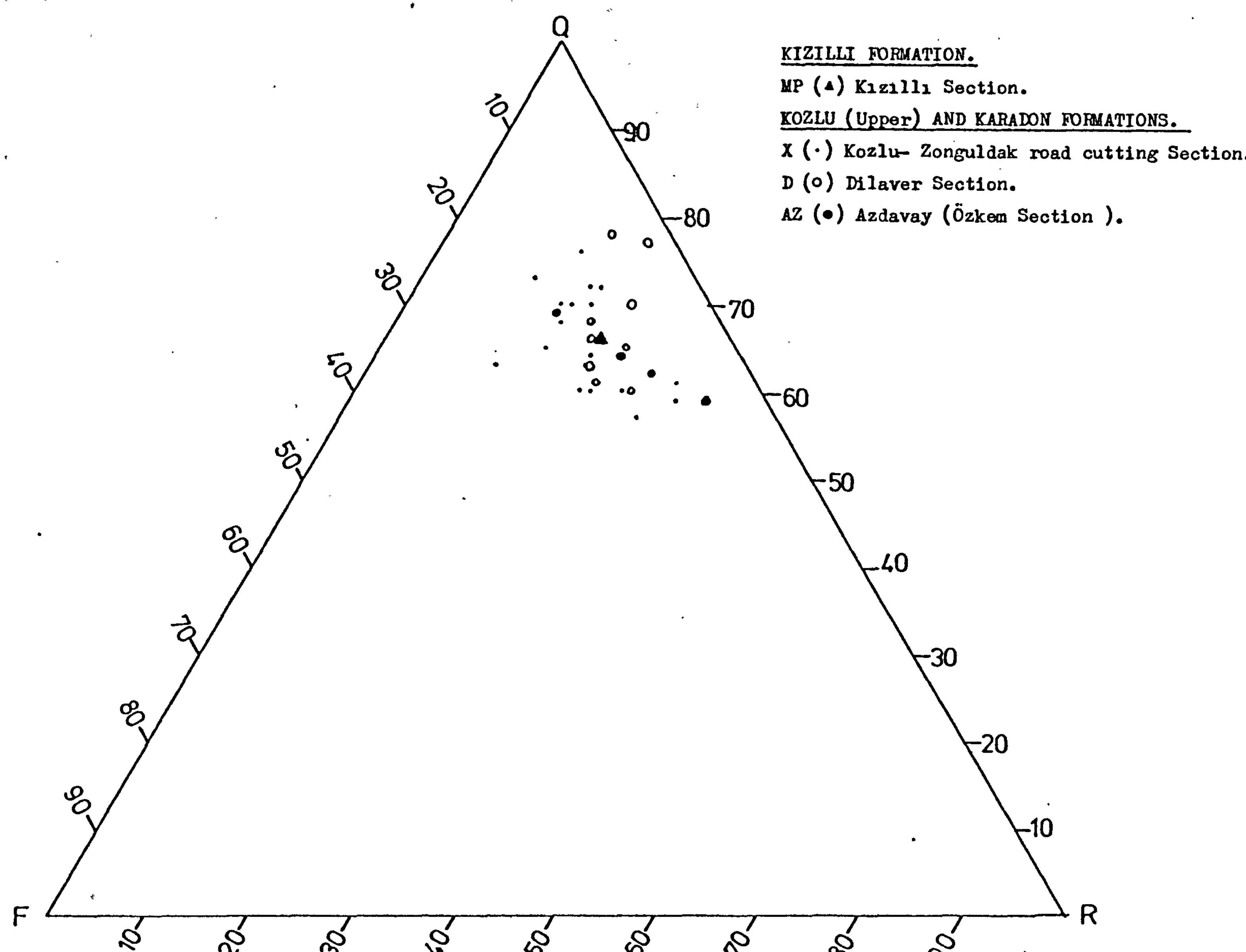


Fig 27. QFR diagrams for sandstones of the Kozlu and Karadon Formations, together with one representative sample of the Kızıllı Formation.

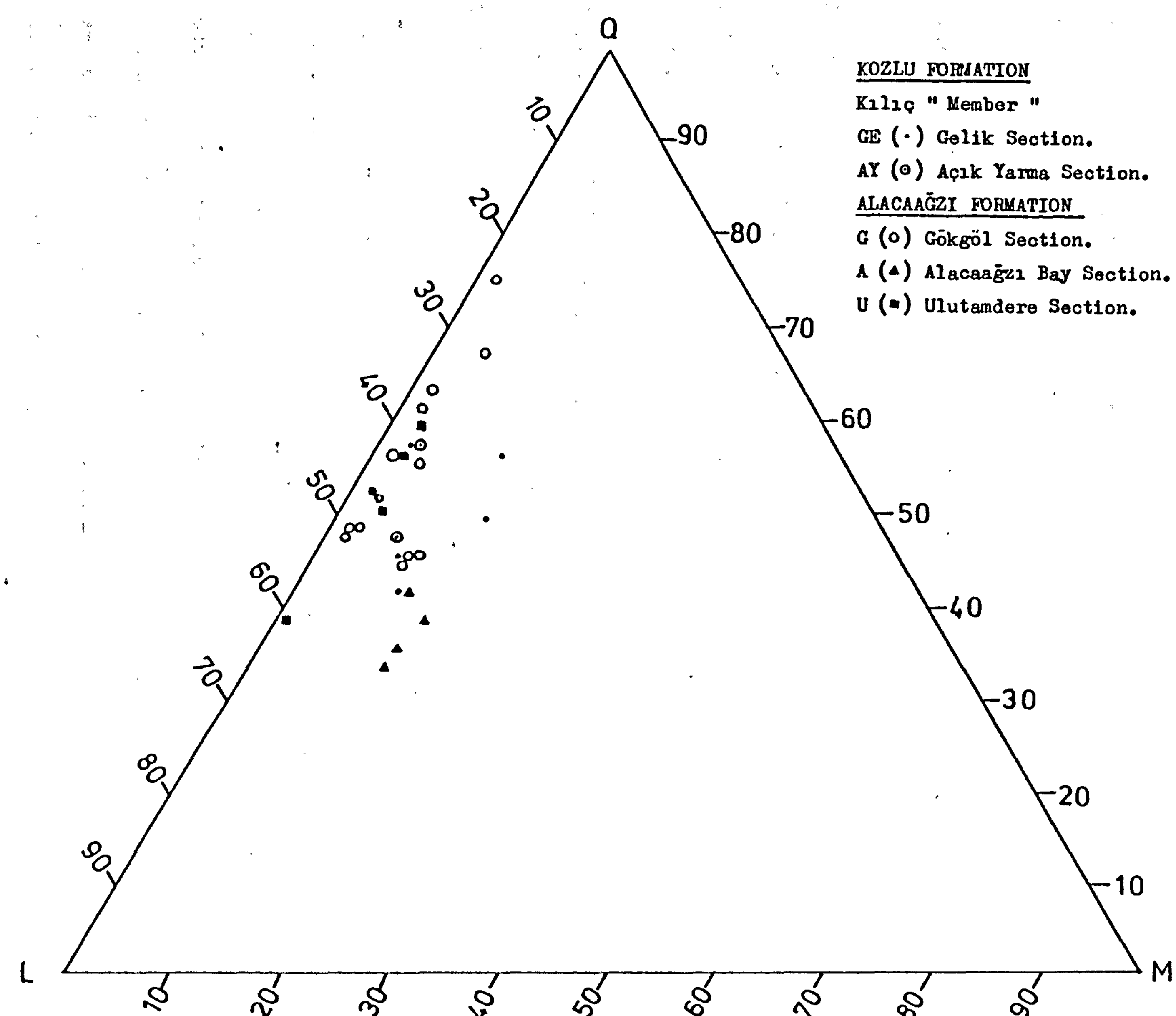


Fig 28. QLM diagrams for sandstones in the Alacaağzı Formation and the Kılıç "Member" of the Kozlu Formation.

Qst-u-p diagrams (Fig. 30) show that the Asma "Member" of the Alacaagzı Formation and Kılıç "Member" of the Kozlu Formation contain less undulatory quartz material than the Gökgöl "Member" of the Alacaagzı Formation. Also polycrystalline quartz is more abundant in the Tarlaağzı "Member" of the Alacaağzı Formation. The proportions of straight extinction quartz grains are not significantly different in those groups of sandstones. The relative abundance of polycrystalline quartz in the coarse grained sandstones of the Asma "Member" is possibly due to the following factors;

i) the individual grains of the finer sandstones may be derived from the breakdown of aggregates of polycrystalline grains or

ii) the difficulty in identifying polycrystalline quartz grains in the fine-grained sandstones.

5.3.1. PROVENANCE - GENERAL CONSIDERATIONS

The Qst-u-p diagrams also may be used to understand the provenance. According to Basu et al., (1975, p.873) the plotting of the relative percentage of four variables (1 - undulose, 2 - nonundulose, 3 - polycrystalline quartz and 4 - numbers of crystal units per polycrystalline grain) on a single diamond-shaped diagram enables one to discriminate sands of plutonic and low-rank or high-rank metamorphic parentage, both for recent and ancient sands. However, in this study, the crystal density of polycrystalline quartz has not been differentiated. According to this diagram, (Fig.30), the quartz grains in the Alacaağzı Formation were derived mainly from a highly heterogeneous metamorphic source area. Similarly Mack et al., (1981) have suggested that the relative abundance of metamorphic rock fragments and unstable polycrystalline quartz indicates that the

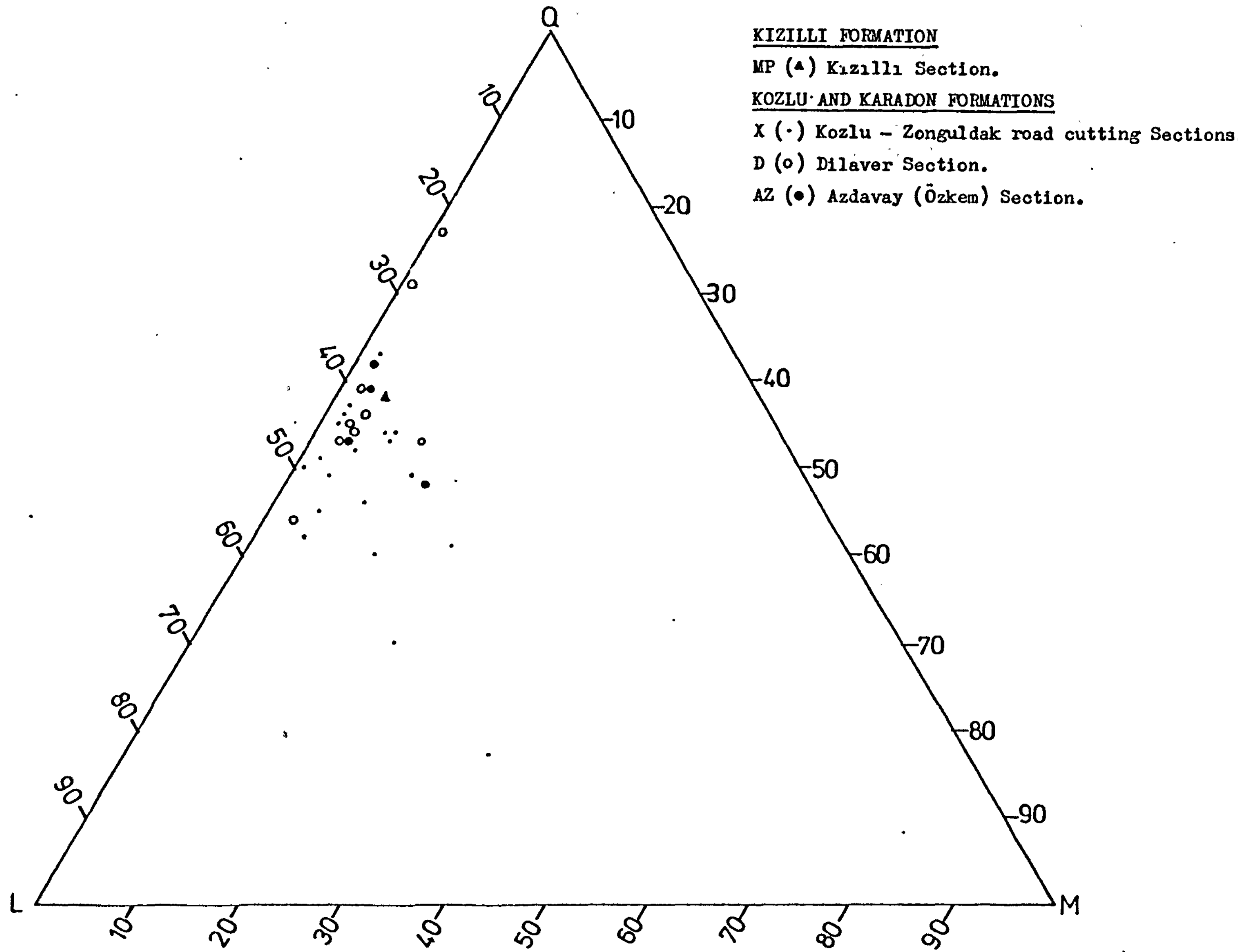


Fig 29. QLM diagrams for sandstone in the Kozlu and Karadon Formations, together with reprasentative sample of the Kızıllı Formation.

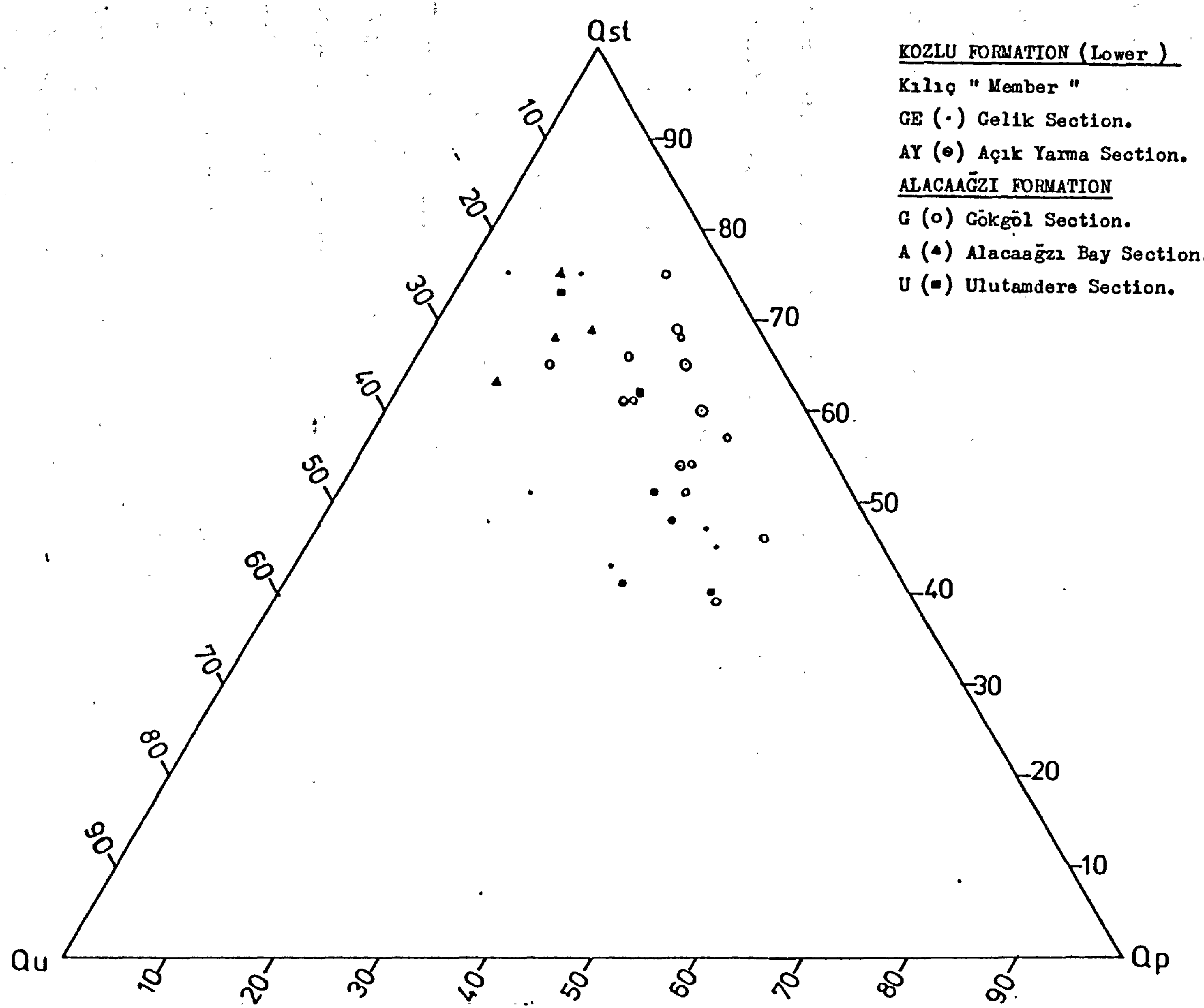


Fig 30. Q_{st-u-p} diagrams for sandstone in the Alacaağzı Formation and the Kılıç "Member" of the Kozlu Formation.

Hartselle and Parkwood sandstones (Mississippian) of Alabama were derived primarily from low rank metamorphic source rocks.

The Alacaağzı Formation sandstones are mainly poorly sorted, immature, and their lower parts contain significantly more calcite cement than the upper parts, probably because of the environmental differences. Similarly, Flores (1978) pointed out that delta-plain sandstones commonly have more cement than alluvial plain sandstones in the Pennsylvanian of northeastern Kentucky. The high cement content and common occurrence of calcite cement in the delta-plain sandstones are diagenetic changes that resulted directly from their proximity to open marine conditions. Partial removal of the matrix by winnowing probably created pore space in which interstitial cement precipitated during diagenesis of the sediments.

In the Alacaağzı Formation sandstones, quartz grains are mainly lineated, angular to subangular in shape, and show strain-induced features which might indicate the existence of major shear zones in the source area. Also some quartz grains contain secondary vermicular chlorite. In most of the thin sections Perthitic K - Feldspar had been recognized and is mainly replaced by calcite. Plagioclases are mainly oligoclase and show some inclusions. The most abundant rock fragments are chert, micaschist, chlorite schist, actinolite schists, siderite, lithic fragments (basalt), volcanic grains (which may suggest a minor amount of volcanism), and towards the top of the formation, old sedimentary rock fragments such as Illate, siltstone and mudstone. This secondary sediment contribution was provided by sedimentary source rocks into the Asma "Member". Micas often appear to have been deformed by compaction. Sometimes biotite laths may contain rutile needles, possibly due to overgrowth, and sometimes their colour has been changed to green due to loss of titanium. Euhedral zircon is the only heavy mineral observed, and may possibly indicate an igneous source.

Briefly, the source area was composed of low to high-grade metamorphic rocks, incorporating some igneous rocks, and the whole complex was periodically characterised by volcanic activity. The sedimentary rock fragments also suggest a subordinate sedimentary source. However, although compositional maturity of the sandstones varies within the Formation, the grain types and relative proportions of the non-quartz fraction are essentially consistent, suggesting that all of the sandstones were derived from the same source area.

5.4. THE KOZLU AND KARADON FORMATION SANDSTONE COMPOSITION

Sandstone of the Kozlu and Karadon Formations range from very fine grained to coarse grained and are generally dirty, immature, and moderately sorted. Also percentage of quartz against grain size (Fig.32b) illustrates that more or less gentle line than the Alacaağzı Formation example.

According to the Q F R diagram (Fig. 27) the Kozlu and Karadon Formation sandstones mainly fall into the sublitharenite class. However, a few rock samples of the Kozlu Formation fall into the subarkose and lithic arenite categories. Therefore the Kozlu Formation rocks show a wide compositional range. For example, fine grained sandstones of the Kılıç Member in the Kozlu Formation mainly belong to the sublitharenite category. Quartz grains show mostly straight extinction, and are subangular to angular, but they also may show a zonal inclusion system. In the sandstones quartz grains are generally lineated and secondary porosity can be seen. In the lower part of the Kozlu Formation potassium feldspars and a few plagioclases are recognizable, the percentage of plagioclase increasing towards the top of the sections. Muscovite and biotite are rare. The rock fragments include muscovite schist, actinolite schists, mylonite, abundant siderite, chert and some sedimentary rock fragments (especially siltstone and sandstone) are represented. Also abundant volcanic grains (porphyritic), together with some basalt grains, were observed.

Q L M diagrams indicate that the Kozlu Formation sandstones contain 40 - 60 percent of quartz, 40 - 50 percent of labiles and a high matrix content. Generally speaking, these rocks contain less quartz and substantially higher labiles than the Alacaağzı Formation rock samples (Fig29). Similarly, the Karadon Formation contains more quartz, less matrix and 40 - 70 percent labiles. The Qst-u-p diagrams (Fig. 31) show that the Dilaver Member of the Kozlu Formation contains less undulatory quartz grains than the Karadon Formation sandstones, but more straight-extinction quartz grains. The distribution of polycrystalline quartz grains is more or less the same.

5.4.1. PROVENANCE

The Qst-u-p diagrams may also be used to understand the provenance by using the diagrams of Basu et al., (1975). However, these diagrams do not give a clear indication of the source area. For instance volcanic quartz grains cannot be included within this scheme, and the passage from low rank to high rank metamorphic source-rocks is not realistic, but only gives some general idea of the nature of the source rocks. According to the interpretation of Basu et al., the Kozlu Formation sandstones were probably derived from a low-rank metamorphic area, while the Karadon Formation sandstones were derived from both low-and-high-rank metamorphic areas.

Detailed analysis of this section shows that the lower part of the

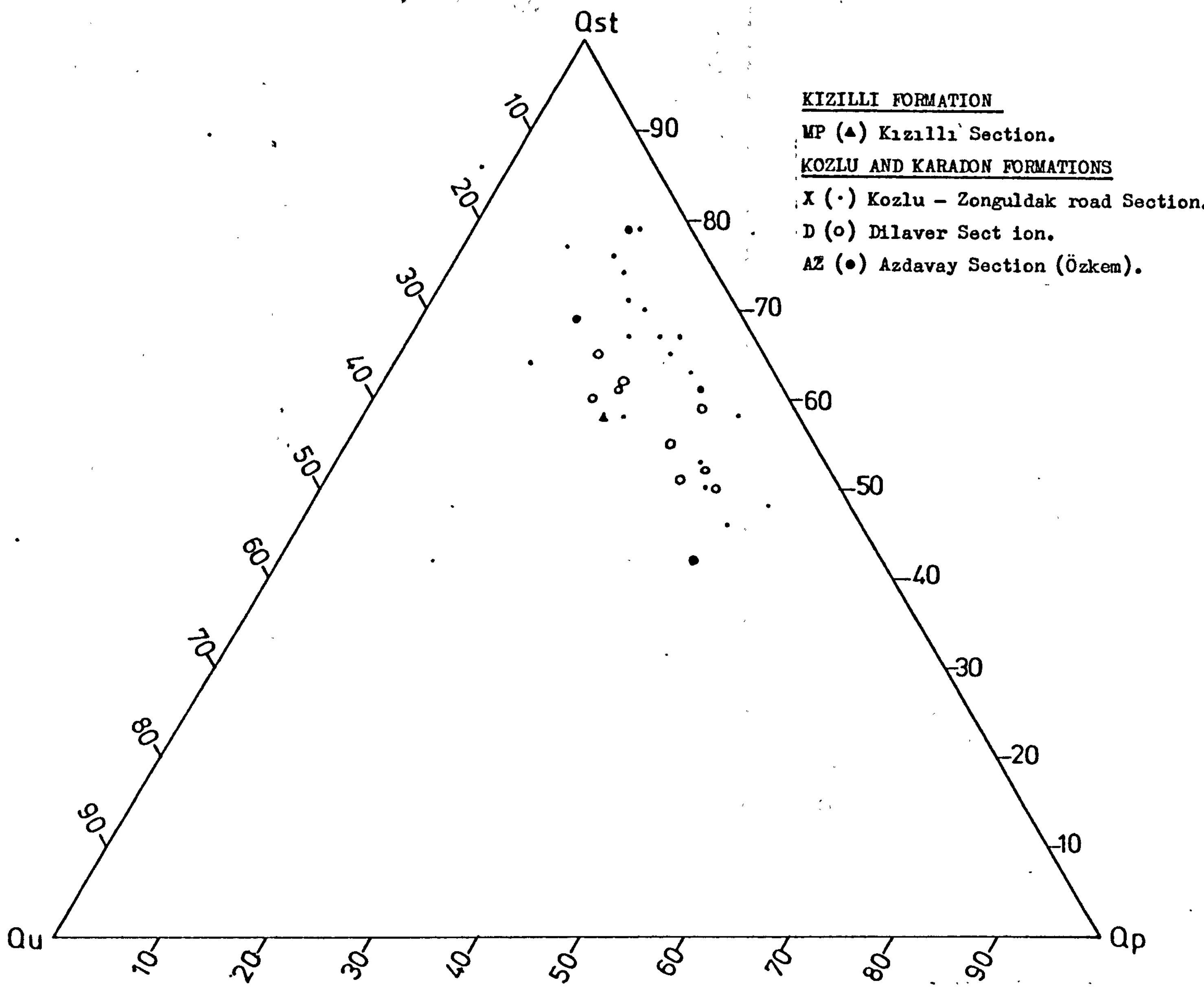


Fig 31. Q_{st-u-p} diagrams for sandstones in the Kozlu and Karadon Formations, together with one represantative sample of the Kızıllı Formation.

A

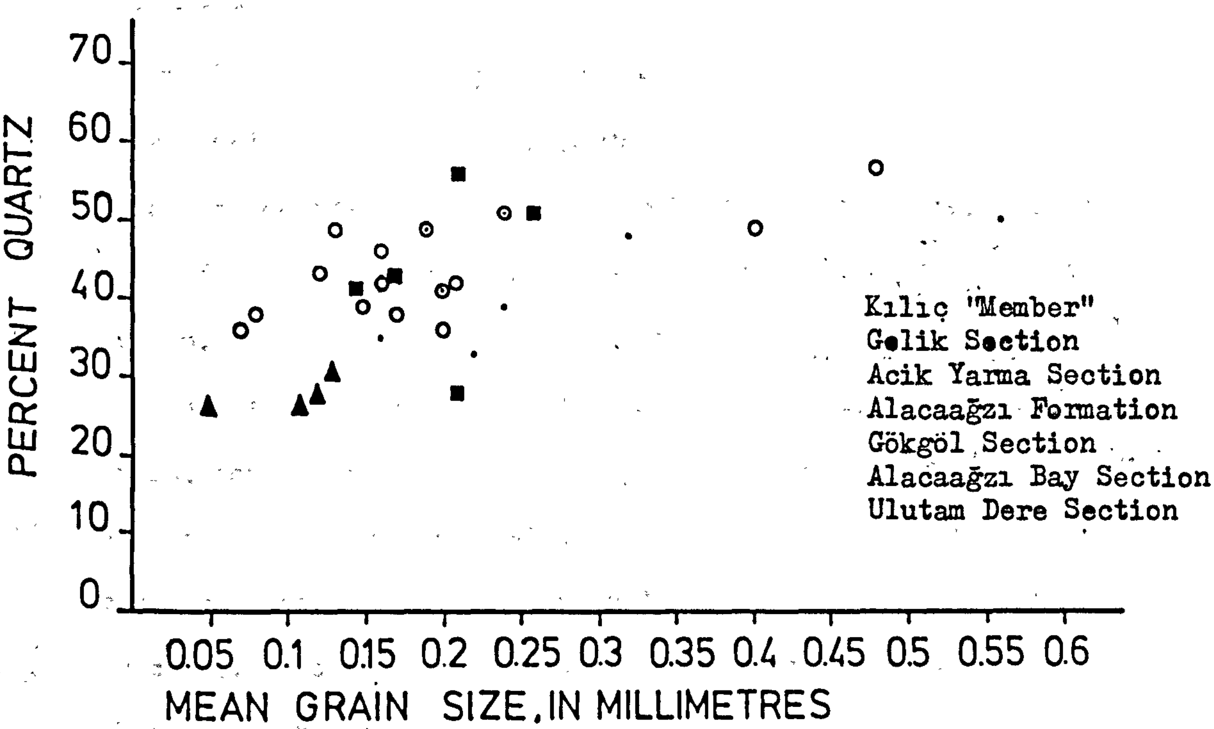


Fig 32 a- Mean grain size distribution of sandstones and siltstones from the Alacaağzı Formation and the Kılıç "Member" of the Kozlu Formation.

B

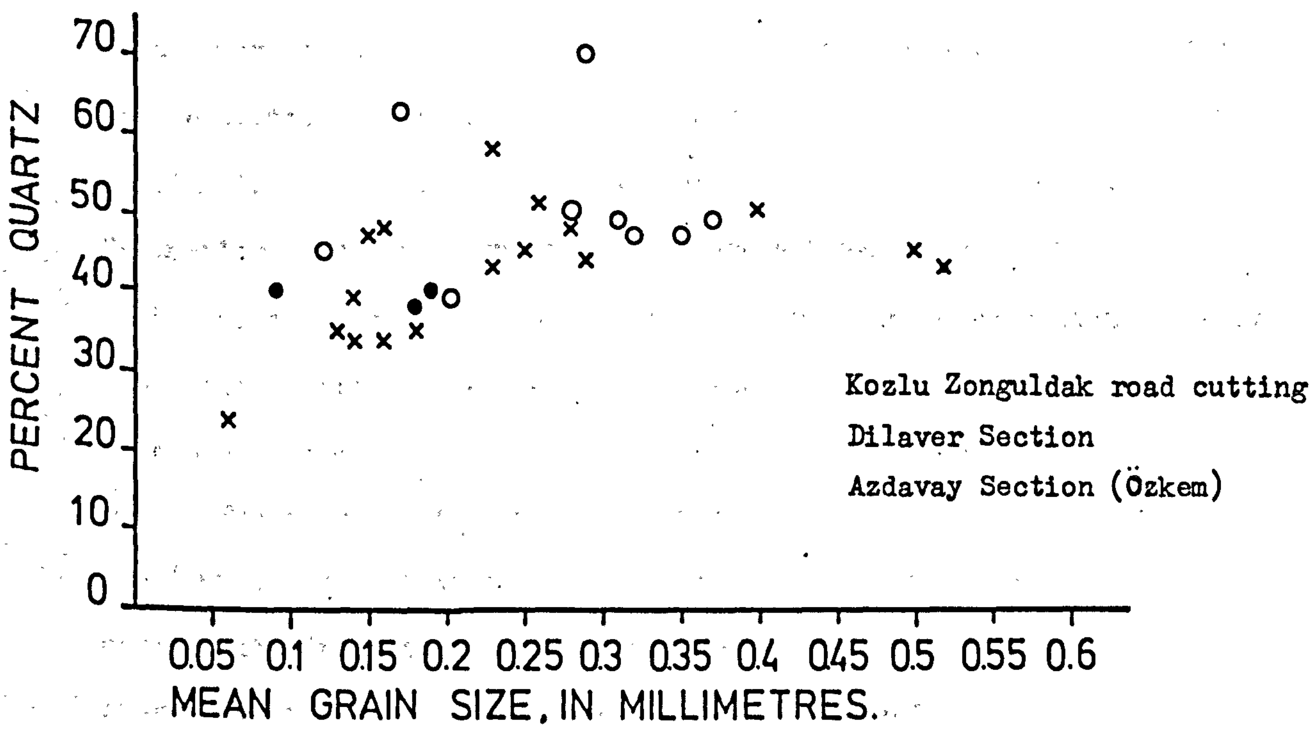


Fig 32 b-Relationship of mean grain-size to quartz content of sandstones and siltstones from the Kozlu and Karadon Formations.

Kozlu Formation sandstones has mainly a calcite cement, whereas the upper part of the Kozlu Formation contains more chert and clay matrix. In the lower Kozlu the plagioclases are mainly Na rich (albite), undeformed alkali feldspars (orthoclase - microcline) and granophyric feldspar (quartz and feldspar together), sometimes replaced by calcite. Some of the rounded and fractured quartz grains may indicate a volcanic origin. In some quartz grains, parallel inclusions and some liquid inclusions were observed, which may indicate a metamorphic origin (pers. comm., Öngen, 1979). Polycrystalline quartz and radial chalcedony have sometimes been changed to chert. The lithiclasts include micaceous sandstone, psammite, actinolite schist, micaschist, quartzite, mylonite, acid volcanic grains, devitrified glass fragments, glassy shards (Roach pers. comm., 1981), siderite patches, chert and coal fragments. Euhedral zircons are also observed. Randomly oriented micas and chlorites have again been deformed under compaction (Plate 87).

Sandstone composition of the upper part of the Kozlu Formation shows little variation. Most of the feldspar grains are altered and coated by haematite. Plagioclase grains are rare, although some are seen in combination with quartz grains and are often replaced by serisite. Sedimentary micaschist and fragments are abundant. Some of these sandstone samples belong to the Karadon Formation which contains mostly clay matrix, orthoclase (Perthitic texture). plagioclase and vermicular chlorite. Some rutile inclusions are observed in the mica grains as well. The micaschist clasts contain granular strained quartz with small muscovite plates which define the schistosity. Apart from these metaclasts, fragments of siltstone, sandstone, chert, diobase, volcanic glass and possible serpentine grains were observed.

Briefly the wide variety of rock fragments indicates that the Kozlu and Karadon Formation sandstones were derived from a source area which included medium-rank metamorphic rocks, granitic material, acid volcanic rocks, and an unmetamorphosed sedimentary sequence. An interesting point is that the lower part of the Kozlu Formation contains abundant myolinite fragments. This possibly indicates that some part of the source area indluded a shear zone, probably a thrust zone (pers. comm., R.G. Park, 1981). Park (1964) showed a similar situation in the Torridonian rocks, similarly Williams (1969) suggested that the provenance of mylonite pebbles in Torridonian rocks suggested their localized derivation from mylonite zones within the Lewisian complex in northwest Scotland.

5.5. THE KIZILLI FORMATION SANDSTONE COMPOSITION

According to the QFR diagrams the Kızıllı Formation sandstones fall into the subarkose and lithic arenite categories (Fig.27). The QLM diagrams show a moderately high content of labiles and quartz (Fig. 29). The Kızıllı Formation rocks are more uniform in character than the other formations and show a close grouping on the compositional plots. Q_{St-u-p} diagrams revealed that the Kızıllı Formation contains a mixed series of quartz grains; some samples contain a high amount of straight-extinction quartz. Therefore it is difficult to apply the diagrams of Basu et al., (1975) to the Kızıllı Formation sandstones.

The Kızıllı Formation sandstones mainly contain clay matrix but in the upper part of the section calcite cement is predominant. Generally speaking the Kızıllı Formation sandstones are immature, poorly sorted, with angular to subangular grains which become more rounded and sorted towards the top of the section.

Quartz grains are mostly scattered within an abundant cement and sometimes a faint micro-lamination and imbrication are observed. Orthoclase, secondary feldspar overgrowths and a few plagioclase grains (often replaced by calcite)can be seen. Micas are only rarely present. Most of the quartz grains are coated by iron, and often the sandstones are organic-rich. Rock fragments of chert, siltstone, mudstone, siderite patches and especially abundant micritic limestone grains, micaschist and some volcanic material (volcanic glass and few basalt grains) were observed. The upper part of the Kızıllı Formation sandstones generally show bi-modal grain size distributions, with well-rounded and lineated quartz grains, which sometimes show overgrowths. Volcanic and sedimentary rock fragments can also be seen in most samples.

5.5.1. PROVENANCE

The maturity of the sandstones in the upper part of the Kızıllı Formation sandstone is a function of their sedimentary environment. The well-rounded nature of the quartz grains reflects a high degree of reworking in the alluvialplain environments. However, the quartz-rich sandstones are possibly the result of numerous cycles of transport and erosion, each cycle contributing a progressive increase in roundness and a loss of unstable minerals. However, the lower part of the Kizilli Formation is dominantly composed of lithic arenites, the composition of which is similar to that seen in some modern river sands. Also the rarity of coarse micas may well indicate an alluvial plain environment. Similar comparisons have been made by Flores (1978) in the Pennsylvanian of northwestern Kentucky. He also suggested that the high cement content and common occurrence of calcite cement in the delta-plain sandstones are diagenetic changes that resulted directly from their proximity to open marine conditions.

In summary, the variety of rock fragments in the Kızıllı Formation (see pp. 166) most of them are indicators that they derived from a metamorphic source area. However, the abundance of limestone clasts towards the top of the Formation probably results from reworking of older carbonate platform sediments, together with a small amount of volcanic activity, in the intermontane area. The maturity and well rounded nature of the grains in the red sandstones of the Kızıllı Formation suggests a high degree of reworking in the intermontane alluvial plain environments (possibly with associated wind action).

CHAPTER 6

PALAEOCURRENT ANALYSIS

6.1. INTRODUCTION

Palaeocurrent measurements have been derived from a variety of sedimentary structures with the aim of studying regional variations in palaeoslope and relating this to the lithologic variations and environmental associations observed in the studied area. Palaeocurrent analyses were made to determine the overall direction of sediment transport and the sediment dispersal patterns that were obtained during the deposition of Upper Carboniferous rocks northwestern Turkey. The implications of these general transport directions with regard to environments of deposition, palaeoslope and location of the source area will also be discussed briefly. Most measurements were taken from cross-bedding and orientated plant debris (particularly large stem fragments). Primary current lineation and ripple cross lamination were used to a lesser extent. However, a detailed discussion of the entire dispersal (palaeocurrent) system of the basin is not provided here, since limitations of time made it impossible to carry out the systematic mapping of all the sedimentary structures (yielding vectorial data) which would be necessary for such a comprehensive study. Instead, vectors were obtained from a number of localities regarded as critical in interpretation of the basin.

6.2. VECTOR ANALYSIS

Most published palaeocurrent studies have been based on cross-bedding. Most cross-bedding is produced by the migration of sand waves and dunes (Potter and Pettijohn, 1963).

Allen (1968) suggested that two main sources of variation occur:

(i) variation of cross-bedding within individual channels,

and

(ii) variable orientation of different channels.

Most of the fluvial channels are orientated almost parallel to each other and also parallel to the regional slope. Deltas are certainly a separate case because of their tendency to radiate. The subject is complicated, because of the different types and scales of structure which may be measured (Allen 1966, 1967, Miall 1974), and which give different palaeocurrent patterns. For instance Selley (1968) has suggested that an epsilon cross-bedding type of large scale cross-bedding presumed to be the most typical of point bar deposits in high sinuosity streams (Moody-Stuart, 1966) is built up in a direction perpendicular to the primary current direction, owing to the outward migration of the point bar on the concave side of a river meander.

Smith (1972) measured the foresetdip directions of lobate sandwaves in the River Platte and found there was a considerable dispersion, and argued that ancient sequences with tabular cross-bedding formed by similar bedforms should also have a wide dispersion because of this in-channel variability. Therefore the nature of river hydrography may have an important effect on palaeocurrent range and variability.

Jones (1977, p.31) suggested that the present methods of palaeocurrent analysis, usually involving measurement of cross-bedding orientation and the calculation of variance and vector magnitude, do not provide a very reliable means of distinguishing between meandering and non-meandering rivers in ancient sequences. Other techniques, such as concentrating on trough cross-bedding, or considering only higher rank structures such as channel walls may prove to be more reliable.

6.3. METHODS OF STUDY

Measurements of angles of inclination, maximum dips, azimuths or directions of maximum dip of foresets and maximum thickness of the cross-bedded layer are relatively straightforward. The accuracy with which these properties can be measured contrasts sharply with the difficulty of precisely defining cross-bedding. If true bedding originally has not been deposited horizontally, this dihedral angle may be slightly larger than the angle of inclination following Potter and Pettijohn (1977, p.99). The bearing of the maximum dip direction is the amount of the foreset bed.

Many geologists prefer to measure up to 200 measurements of a single outcrop. Unfortunately, in the present study only a few measurements could be obtained for each outcrop. However, every major outcrop was visited, and palaeocurrent measurements were made if conditions were considered suitable.

The palaeocurrent data is presented as a regional map (Fig. 33) of Zonguldak area. On both the maps and cross sections, the palaeocurrent data has been plotted on circular rose diagrams. Readings have been grouped in forty degree intervals and all the readings presented and corrected to "Grid north". No measurements were taken for the orientation of the erosive bases of co-sets, which thus means that all the readings taken are attributable only the the depositional aspects of the palaeoflow. As many measurements as possible were made in exposed cross-beds. The vector mean azimuth of these readings was then calculated for each outcrop. The variability of the palaeocurrent pattern usually can be assessed by preliminary sampling of a few outcrops. More measurements are required (for a given level of accuracy) to estimate a variance then a mean.

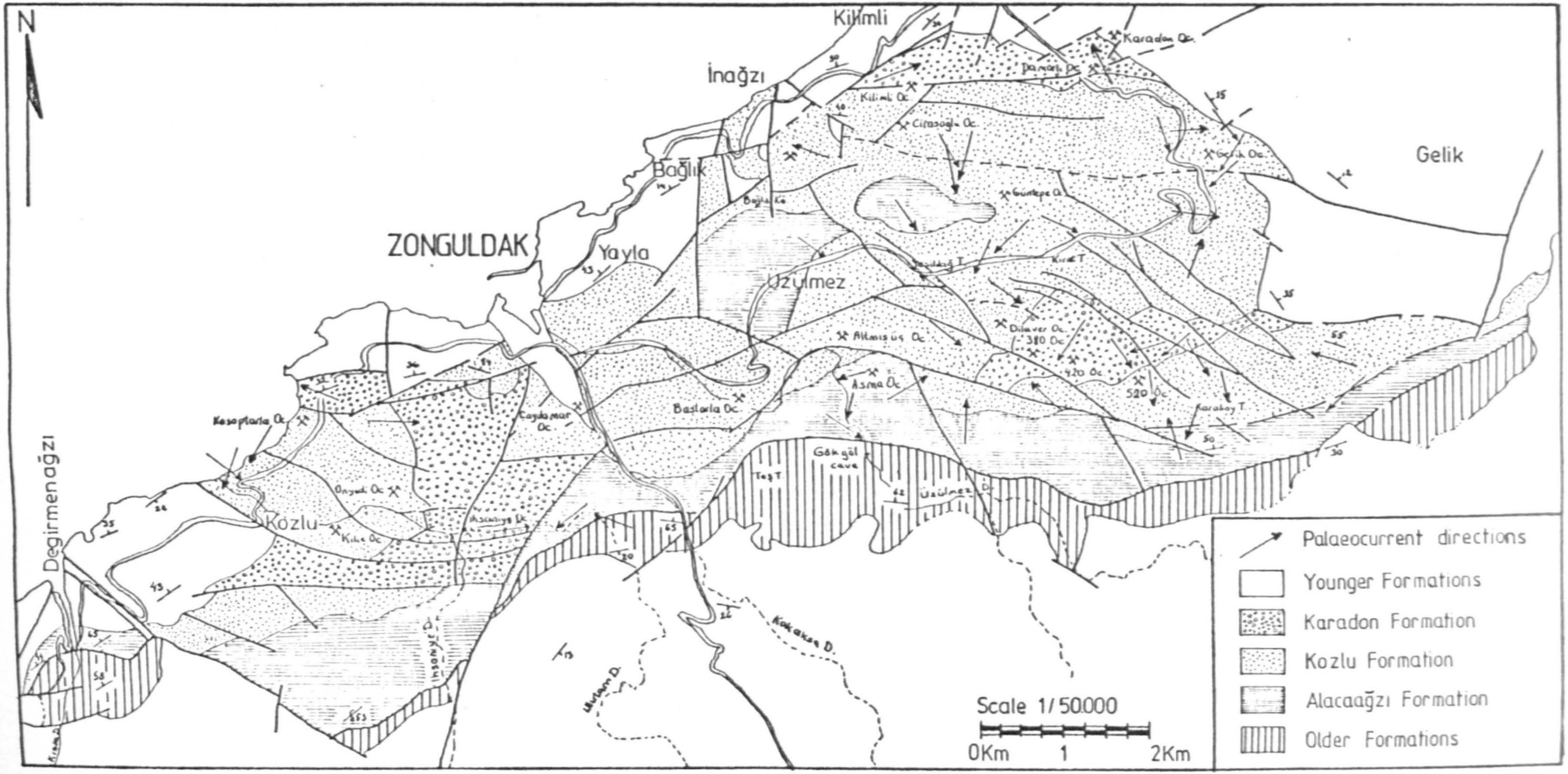


Fig 33. Palaeocurrent directions from the Upper Carboniferous rocks of the Zonguldak area.

Arrows indicate mean palaeocurrent direction at each outcrop represented by head of arrow.

In regions of tilted or folded strata, directional sedimentary structures no longer retain their original orientation. It is necessary, therefore, to correct their present attitude for tectonic deformation and to "restore" them to their original position before any palaeocurrent analysis can be made (Potter and Pettijohn, 1977 p. 371). The graphic solution may be accomplished by the conventional methods of descriptive geometry or by the use of stereographic projection. These observed data are grouped into appropriate class intervals from which a "current rose" is constructed. The current rose conventionally indicates the direction toward which the current moved. In the present study a class interval of 40 degrees has been chosen in view of the relatively small size of the vector populations measured. The midpoint of the modal class can serve as a point estimate (a specific direction rather than an interval estimate) of average current direction. "The midpoint of modal class is primarily useful for making regional and subregional complications, for it is usually inconvenient a regional map, even if enough data were collected at each outcrop, to construct such a current rose (Potter and Pettijohn, 1977)".

6.4. ANALYSIS OF RESULTS

The measurements taken from different formations have been treated separately. In the case of ripple lamination and cross bedding, measurements were taken in the vertical planes and the azimuths of maximum dip directions of the forests have been measured. For solitary cross-bedding, measurements were taken from each set encountered. For the grouped type, if the coset was composed of uniformly directed sets, one average measurement per coset was recorded. If the sets indicated different directions, the reading given by each set was recorded.

In the Alacaağzı Formation flow vectors of both the flutes and the cross-bedding show the same preferred direction, transport being towards the south-east in the Zonguldak area, although in the Amasra area other factors were also effective such as north easterly long shore currents and northwesterly wave directions. A summary of these relationships is depicted on the palaeogeographic map of northwestern Turkey (Fig.36). Probably the strand line also migrated towards the southeast with time, together with delta progradation. Insofar as this association has been interpreted as the product of prodeltaic delta front and delta top environments, highly variable or at least divergent vectors could be expected (Klein, 1967). Nevertheless, the significantly unimodal overall current direction implies that the palaeoslope that controlled flow systems in the upper delta plain and fluvial environments was still effective and persistent in time for the lower delta platform currents. Consequently, it is tentatively suggested that the "fluvially influenced offshore downslope" palaeocurrent model of Selley(1968) prevailed during the deposition of this deltaic sequence of the Alacaağzı Formation. Especially in the western part of the Zonguldak area, unidirectional palaeocurrents suggest a south-westward progradation, possibly across the regional palaeoslope, and a wide spread of ripple trends such as is commonly found in fluvially dominated sediments, could indicate a meandering style delta-top feature. Further support for a general southeast facing palaeoslope is obtained from flute-casts orientation which is 165° in the Zonguldak area.

However, in the eastern part of the area (Amasra) where the Alacaağzı Formation sediments were exposed to the influence of marine processes, the dominant vectors are more frequently aligned parallel with palaeostrike (NW - SE) and have more subordinate ebb and flood vectors.

Features of this type are interpreted as the products of longshore drift. Their dominant north-easterly orientations therefore are attributed to longshore currents which are believed to be responsible for the oblique and sub-parallel oriented cross-bedding, with respect to the shoreline. Moreover the apparent oblique orientation of ripples is attributed to a combination of longshore and wave induced currents (Fig. 34).

Additional evidence for a south-easterly facing slope in the Amasra area is provided by the flow-vectors derived from flutes on the base of prodelta turbidites measured in the Tarlaağzı Bay coastal exposures that yield a mean vector value of 145°. This presumably reflects erosive activity by density currents moving down the prodelta slope.

All the palaeocurrent directions detailed above consistently suggest that a dominantly SW - NE trending shoreline was a characteristic controlling feature of the Alacaağzı Formation. While fluvial discharge appears to have been uniformly directed towards the south-east, the western parts of the area are less effected by longshore drift, compared with the Amasra area, where longshore currents were operating with a dominant northeasterly trend which may be related to the prevailing wind direction.

In the Kozlu Formation the overall direction of fluvial transport appear to have been towards the SE but a high degree of palaeocurrent variance was also observed, especially in the Zonguldak area (Fig. 34). Although the precise reason for this high variance could be established only after a much more exhaustive analysis than has been possible in this study, the sum of the observations is consistent with the vector pattern to be anticipated from a meandering stream system characterised

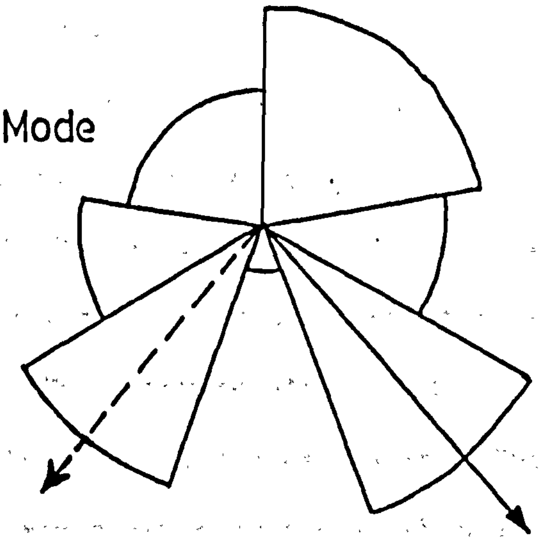
ALACAAĞZI FORMATION

ZONGULDAK AND AMASRA AREA

N=38

Modal value

Secondary Mode



KOZLU FORMATION

ZONGULDAK AREA

N=65

Modal value.

Secondary Mode.

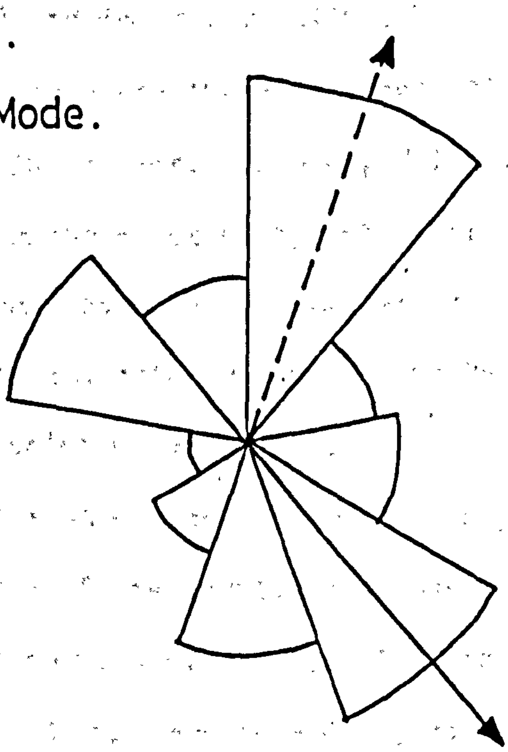


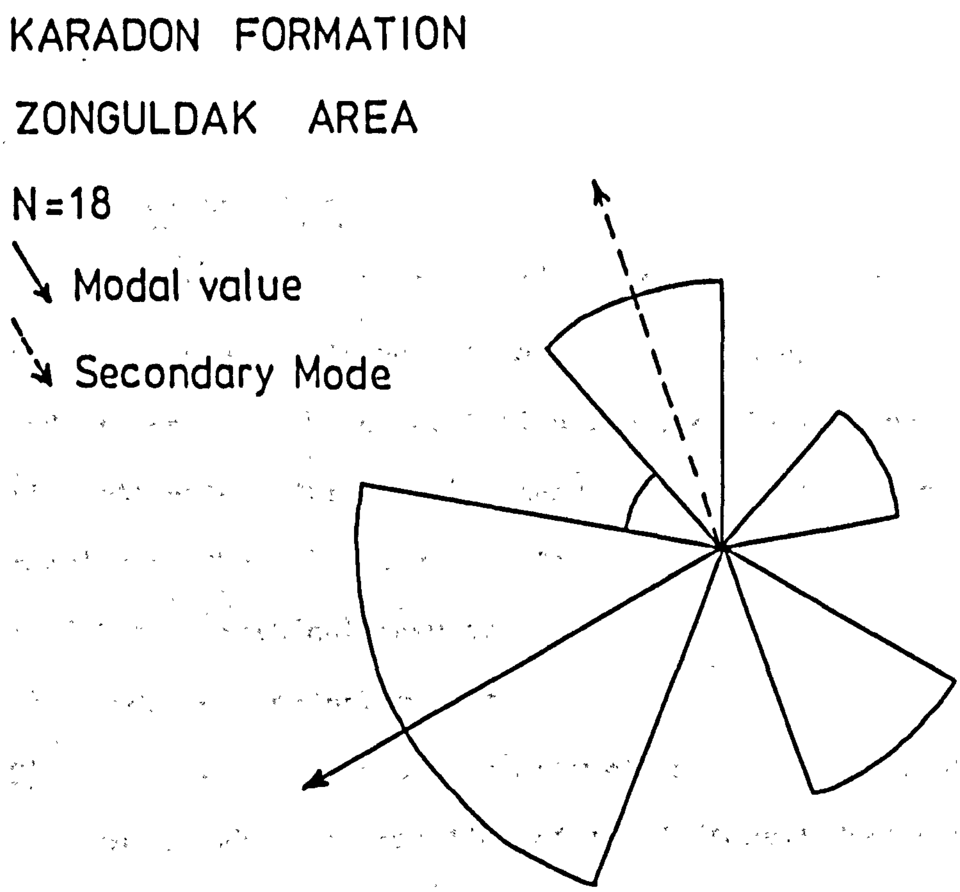
Fig 34. Vector transport directions for the Alacaağzı and Kozlu formations.

by relatively low falling stages. Moreover, the anomalous series of northwesterly current directions in the southern part of the Zonguldak basin (especially in the Kılıç "Member") are derived mainly from ripple-laminated sandstones within the lacustrine Facies Associations, and presumably reflect the directions of wind and wave-generated sediment transport within the Kılıç lakes and lagoons. Nevertheless , even excluding these lacustrine deposits, there remains a high variance for fluvial sequences. The interpretation of the palaeocurrent variance is rather complicated. For instance, Allen (1965) suggested that ancient meandering river sequence should show a palaeocurrent pattern with a high variance. Coleman (1969) showed that cross-bedding orientation in the mainly braided Brahmaputra River has a low variance, but Smith (1972, 1974) established the high values of variance of cross-bedding in some braided rivers and thus demonstrated that not all braided river regimes have a low variance. Cant and Walker (1976) suggested that straight and braided rivers with lobate sand waves may show a higher variance where there is substantial lateral movement during low and falling stages. However, Teisseyre (1978) observed that in mountain meandering streams, sand is transported as bed-load and forms channel sand bars in the Quarternary and the Lower Carboniferous fluvial deposits of Intrasudetic Basin. The resultant current roses and grand vector means pointing upchannel.

In the Karadon Formation, palaeocurrent analysis does not provide a very reliable means of distinguishing between meandering and non-meandering types of sequences. In the study area palaeocurrent measurements rely on trough cross-bedding, or tree trunks orientation. Vector means indicate current directions towards the west-southwest suggesting sediment derivation from a northern or north-easterly source.

However, there are some palaeocurrent directions towards the north-west and the south-east (Fig.35), and this variability presumably is a consequence of the highly meandering nature of the Karadon stream system, which nevertheless appears to have shifted significantly in orientation by comparison with the underlying Kozlu Formation. Additional evidence for slight change in the palaeocurrent orientation in the Zonguldak area is provided by tectonic activity. Conglomeratic nature of the Karadon Formation suggest tectonic uplift begun in the Westphalian B time in the Zonguldak area.

In the Kızıllı Formation the palaeocurrent analysis shows somewhat anomolous directions, especially in the Kızıllı Section of the Azdavay area. In this locality current transport is towards the NW, which suggests that during Westphalian D times a more southerly source area may have become more important, a conclusion that is also confirmed by the appearance of limestone rock fragments in the sandstones. However, it is noteworthy that in the İlyas Geçidi Dere section of the Kurucaşile area southeasterly current directions prevail, suggesting that this area remained within the general basinal framework established for the Amasra and Zonguldak sequences. In interpreting the evidence from the Azdavay area it is necessary to bear in mind the severe tectonic effects that have subsequently been superimposed on Carboniferous rocks, with as yet unknown consequences of rotation, deformation etc..



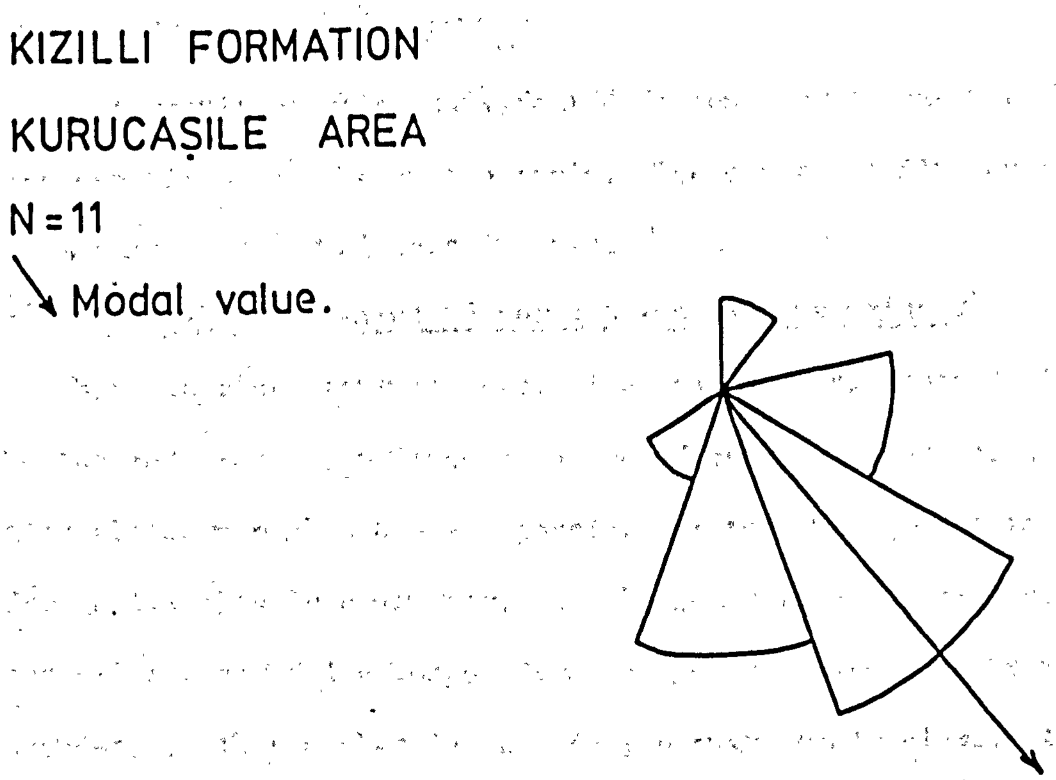


Fig 35. Vector transport directions for the Karadon and Kızıllı Formations.

CHAPTER 7: CONCLUSIONS

7.1. INTRODUCTION

The combined stratigraphical and sedimentological analysis described in the present study permits a general synthesis of the palaeoenvironmental and palaeogeographical evolution recorded in the Upper Carboniferous rocks of northwestern Turkey. The results of the study are summarised in this chapter in the following manner:

A) Stratigraphical results

B) Sedimentological results

C) Palaeoenvironmental reconstruction on the basis of the vertical and lateral distribution of the different facies associations

D) Synthesis of compositional data relating to patterns of sediment provenance, to determine the principal controls on sedimentation.

E) The overall depositional history and regional significance of the palaeoenvironmental and palaeogeographic results.

7.2. STRATIGRAPHICAL RESULTS

As a result of this study, four different Formations have been defined and described for the entire basin. These are briefly described below in ascending order of relative age.

A) Alacaağzı Formation (Uppermost Visean - Namurian C):

This comprises four members. The lowermost of these is the Kokaksu Member and provides a transition from Visean to Namurian, commencing with platform carbonates and passing upwards into goniatite-bearing, dominantly clastic sediments. The boundary with the overlying mudstones and siltstones of the Gökgöl "Member" is gradational while the upper boundary of this member is marked by a sharp contrast with the overlying Tarlaağzı "Member". The fauna and flora found in the Gökgöl "Member" again suggest an early Namurian age. The Tarlaağzı "Member" includes good coarsening upwards sequences and palaeontological data indicate a lower Namurian age. However the basal boundary of the succeeding Asma "Member" is marked by the appearance of erosional channel-fill sandstones, forming a series of fining-upwards sequences. The possible age-range for this member is from middle Namurian (B) to the lower part of the Upper Namurian (C).

No evidence for a widespread break in sedimentation has been observed at the base of the Alacaagzı Formation. The top of the Visean sediments is marked by the rapid replacement of marine deposits, by nearshore, deltaic and epicontinental deposits, including coaly beds with early Namurian plant remains such as Diplotmema adiantoides.

B) Kozlu Formation (Namurian C - Westphalian A):

The basal contact of this formation with the Alacaagzi Formation is not readily identified here. The mudstones below the Kürt Şerif Conglomerate (formerly considered to form the upper part of the Alacaağzı Formation in the Zonguldak area) are here assigned to the Kılıç "Member" of the Kozlu Formation. According to the floral evidence (see Chapter 2) the lower part of the Kılıç "Member" is best assigned to the Namurian C (Yeadonian), while the upper part of this member is of lower Westphalian A age. The second member of the Kozlu Formation comprises a succession of seven major fining upwards cycles with important coal seams. These beds are here assigned to the Dilaver "Member". The upper boundary of this formation is marked by thick conglomeratic layers capping the Agop Cod seam. According to the fossil evidence this member may be approximately assigned a Westphalian A age.

C) Karadon Formation (Westphalian B - C):

The lower boundary of this formation is taken at the abrupt lithological change represented by the conglomerates. The presence of transitional layers with composite floras proves that deposition was continuous. The upper boundary of the Karadon Formation is transitional. However, it is convenient to locate this lithostratigraphic boundary at the "Tavan" coal seams in the Amasra area. The Karadon Formation comprises a complex assemblage of non-marine conglomerates, sandstones, siltstones, mudstones, coals and refractory clays. The fossil plants clearly indicate that the Karadon Formation belongs mainly to the Westphalian B and may extend into the Westphalian C stage.

D) Kızıllı Formation (Westphalian D):

Rocks assigned to this formation occur only in areas east of Zonguldak, such as Kurucaşile and Azdavay. The Kızıllı Formation is covered unconformably by Permian and Mesozoic rocks. The Formation consists of alternating "coarse members", with sandstone and intraformational conglomerates, and "fine members", dominated by siltstones and mudstones. The fossil flora indicates that the Kızıllı Formation may be assigned to the upper part of the Westphalian C, but is mostly of Westphalian D age, as defined by the presence of the plant fossil Neuropteris ovata.

The Namurian successions of northwestern Turkey show close similarity with western European successions, apart from the paucity of marine bands (which only occur in the lower part) and poorly developed cyclicity. The Turkish successions are also broadly similar to the Namurian (early Bashkirian) of the Donetz Basin of the U.S.S.R.. However, there is no evidence of the Bashkirian-Moscovian (Namurian A/B) break in sedimentation to be observed in the Turkish examples. The Westphalian A, B, and C stages in northern Turkey display close stratigraphical and sedimentological similarities with coeval successions in northern Europe, such as the presence of abundant coal seams, sedimentological successions and floral evidence. On the basis of mega and micro-flora the Westphalian B - C can be correlated with the lower Pennsylvanian rocks of the U.S.A., (Artüz, unpublished data 1980), and may include the entire Moscovian of the U.S.S.R., together with the upper part of the Bashkirian. However, the correlation potential of non-marine bivalves is not as good as in NW Europe. The Westphalian D sequence of northern Turkey also can be correlated with the Upper Moscovian substage of the U.S.S.R..

7.3. SEDIMENTOLOGICAL RESULTS

Eighteen individual lithofacies have been recognized and interpreted according to their composition, colour, grain size, sedimentary structures, organic remains and boundary relations (see Chapter 3). These lithofacies have been assigned to two broad facies complexes (coastal and alluvial) and these two complexes have been divided into six Associations, namely: prodelta, delta front, delta plain, meandering stream, braided stream and lacustrine. These associations have been further subdivided into sub-associations and sequences (see Chapter 4). The stratigraphic distribution and environmental significance of these associations is discussed in a later section (7.4.), Here I will mention only a few more general aspects of the arrangement and compositional character of the sediments.

(i) The Alacaağzı Formation furnishes unusually complete examples of the delta-plain association with interdistributary bay, distributary channel, natural levee, crevasse splay (channel and lobe), delta abandonment and especially strand-plain deposits all well developed.

A noteworthy feature of the delta-plain sandstones is that they contain significantly more calcite cement than alluvial-plain sandstones, probably because of diagenetic changes that resulted directly from their proximity to open marine conditions.

(ii) The development of the lacustrine deposits shows considerable variations. The criteria used to distinguish deposits of the lacustrine association in the sequences include: the generally fine-grained nature of the sequence with appreciable thickness and moderate lateral persistence, the absence of marine fauna, the presence of abundant suspended sediment and of non-marine faunas. Although most of the sequences here attributed to lacustrine environments display the heterogenous or coarsening upwards arrangement generally accepted as typical for these deposits, some associations of this type display a fining-upwards aspect. This unusual arrangement is attributed to small ponds in the alluvial plain environment (Collinson's playa type, 1978).

(iii) As Van Houten (1977) has stated "in recent years the increased understanding of the behaviour of modern streams has provided a great deal of data to analyse deposits of some ancient ones". In the light of previous studies such as those of Padgett and Ehrlich (1976), Cotter (1971), Leeder (1973), Puigdefabregous (1973) and Nami (1976), it is possible to ascribe the fluvial sheet sandstones of the type seen, for example, in the Kozlu and Kızıllı Formations, either to lateral accretion on point-bars within a meander belt (as in the models of Allen, 1965) or to constant shifting of anastomosing channels in a low-sinuosity or braided river system (Smith and Putnam, 1980). It is difficult to distinguish between these two models of origin on the basis of existing vertical profile models (Allen, 1970; Cant and Walker, 1976, etc). However careful assessment of the internal arrangement of the sands-bodies and of the nature and relationships of the intervening fine-grained deposits enables the Kozlu sandstones of this type to be assigned to a point-bar accretion model whereas the Kızıllı sand-bodies appear to represent superposed fills of anastomosing stream-channels. Moreover, it is possible to determine some very appropriate palaeo-hydraulic data from aspects of these sandstones, using particularly the dimensions of the epsilon cross-beds. Thus the average height of the epsilon cross-stratification corresponds roughly to bankfull channel depth (h) and the average horizontal extent of a single accretion surface represents the point-bar width to bankfull channel width (w) used by previous workers (Moody-Stuart, 1966; Cotter 1971 and Elliott 1976). It is possible to calculate that the average width of the Kozlu channel illustrated in (Plate 56) was about 18 metres and the minimum bankfull depth was about 2.5 metres. In a similar fashion the thickness and distribution of the epsilon cross beds indicates that stream depth was greatest in the Kızıllı Formation (3 metres), while in the Kılıç "Member" the average river depth was at least 1.5 metres, rising to 2 metres in the Dilaver "Member".

(iv) The development of coals and seat earths in the different facies associations is also of interest. For example, in the Alacaağzı Formation most of the coals occur in interdistributary areas, and are related to delta lobe abandonment, capping crudely fining-upwards sequences. However, coals are also developed in the lake margin environments where they form the topmost units of small-scale coarseing upwards successions of small delta fills.

Most of the important thick coal seams and seat earths characterize the floodplain associations of the Kozlu Formation and are associated with laterally variable complex sandstone bodies. Between the thick coal seams there are thick mudstones with abundant horizons of stigmarian rootlets and ironstone nodules. This type of thick coal and seat-earth is interpreted as a swamp deposit. In many respects the Kozlu coal-sequences closely resemble the Westphalian C Pennart Measures of South Wales (Owen et al., 1966; Kelling, 1968, 1974).

However, in the Karadon Formation the development of in situ coal in the sandy braided flood plain implies that the environment must have had a high water table and may have been semi-permanently submerged as an overbank back-swamp (Collinson, 1978). The sedimentary model for Karadon coals resembles that for the tectonically controlled late Carboniferous basins of Cantabria, Spain (Heward, 1978), except that the Karadon Formation is dominated by stream-flow rather than debris-flow types of alluvial fan association and includes in situ coals rather than the allochthonous seams typical of the Cantabrian sequences.

In the Kızıllı Formation this impersistent coal occurs in the interfluve regions of an anastomosed stream network, now represented by a succession consisting of several units of large-scale, sigmoidally cross bedded sandstones that may represent side-filling of channels or lateral accretion, interbedded with thick siltstones and mudstones.

(v) Although subtle variations in clast content may be attributed to provenance factors (see section 7.5), the petrographic character, and particularly the mineralogical and textural maturity of the sandstones in these Upper Carboniferous successions appears to be closely controlled by environmental factors (see Chapter 5). The diagenetic history of the sandstones (including the nature and abundance of the cementing materials also appears to vary according to the nature of the original site of deposition.

7.4. PALAEOENVIRONMENTAL RECONSTRUCTION

7.4.1. ALACAAĞZI FORMATION

In the study area the Alacaağzı Formation marks a change from deposition of platform carbonates to a clastic shelf succession and a gradual upward increase in fluvial influence. The dominance of fluvial sandstones in the upper delta-plain suggests that these deltas were fluvial-dominated. The sheet-like geometry and wave ripples of the delta-front sandstones, however, indicate that there was significant reworking of channel mouth sands by wave action. In the Alacaağzı Formation, flow vectors derived both from the flutes and the ripples show the same direction, transport being towards the south east in both the Zonguldak and Amasra areas. The gradual southwards progradation of a river-dominated delta-system, is attested by crudely alternating coarsening and fining upwards sequences, reflecting periods of delta construction and shoreline progradation. However, in the Amasra area other factors were also effective such as northeasterly long-shore currents and northwesterly wave directions. A summary of these relationships is depicted on the palaeogeographic map of northwestern Turkey (Fig. 36). Probably the strand line also migrated towards the south east with time, accompanying the delta progradation. Generally speaking, the progradational episodes are indicated by the proximal delta-front sub-association, which generally succeeds the distributary complex sub-association. Delta progradation took place into a shallow massive basin. Marine processes were limited and sedimentation was mostly controlled by processes at the river mouth. Presumably subsidence rates were relatively high during accumulation of the Alacaağzı Formation, resulting in formation of thick sequences of delta-plain deposits(Fig.37).

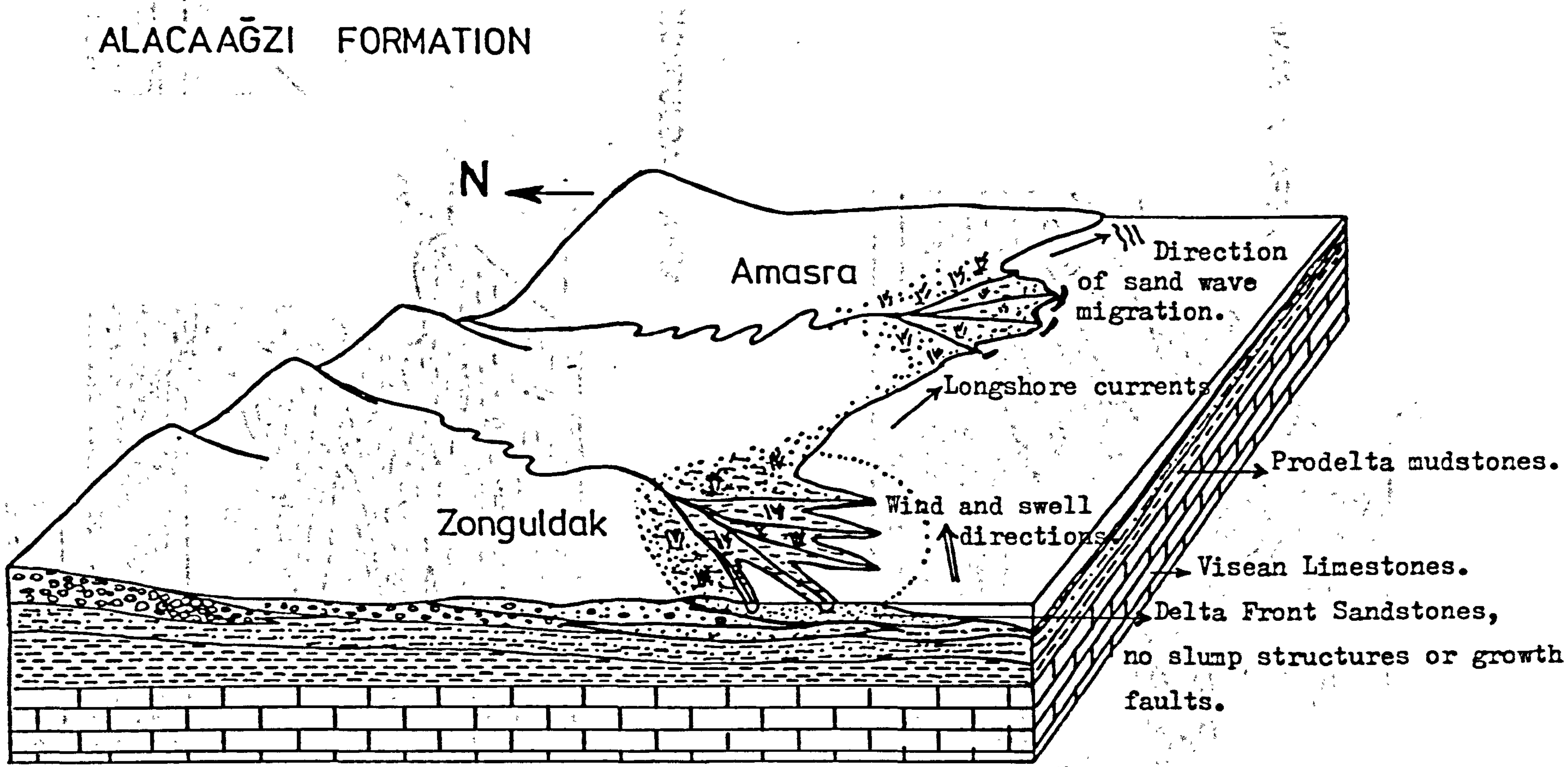


Fig 36. Highly schematised block diagram illustrating the general palaeogeographical relationships inferred for the Alacaağzı Formation deposits.

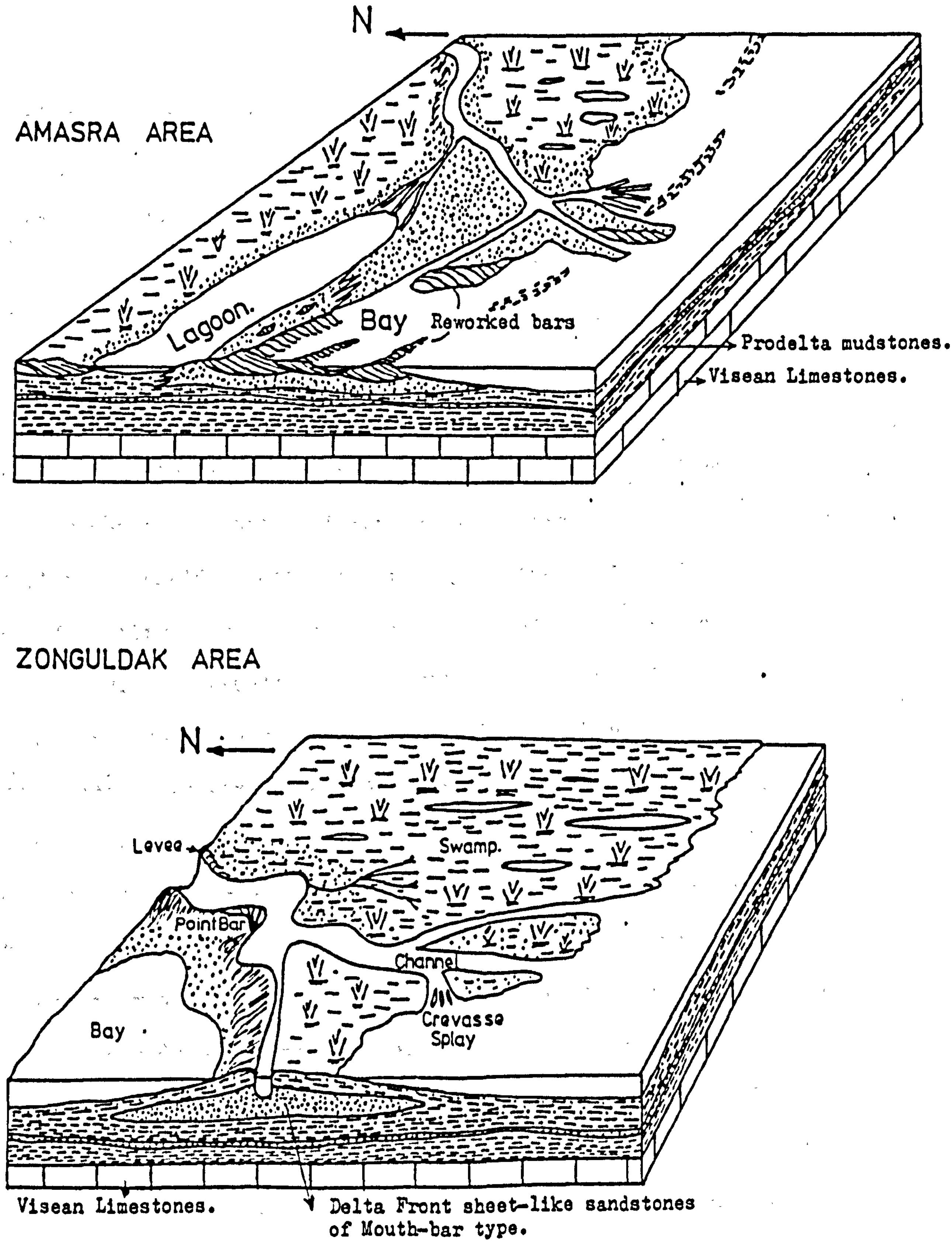


Fig 37. Detailed block diagrams illustrating the differing palaeoenvironmental interpretations of the deltaic sequences of the Alacaağzı Formation in the Amasra and Zonguldak areas.

7.4.2. KOZLU FORMATION

During formation of the basal Kılıç "Member" of the Kozlu Formation, active rivers constantly rejuvenating and cutting into contemporary lacustrine deposits, spread fluvial sequences laterally and vertically across much of the Zonguldak and Amasra area. Constant channel switching and abandonment, the lateral migration of channels across the flood-plains, coupled with a gradual isostatic adjustment of the floor in response to the weight of the accumulating sediment all probably promoted the repetitive sequences of fluvial deposits. In the Kozlu Formation the overall direction of fluvial transport appears to have been towards the SE but a high degree of palaeocurrent variance was observed, especially in the Zonguldak area (Fig. 34). Moreover, the anomolous series of northwesterly current directions in the southern part of the Zonguldak basin, especially in the Kılıç "Member" are derived mainly from ripple-laminated sandstones within the lacustrine facies associations, and presumably reflect the directions of wind and wave-generated sediment transport within the Kılıç lakes and lagoons. Nevertheless, even excluding these lacustrine deposits, there remains a high variance for the fluvial sequences, which is discussed in Chapter 6. Also in the Kozlu Formation rapid basin subsidence maintained slopes in the meandering thalweg range as aggradation took place. Many of the meandering sandstone units exhibit vertically alternating sandy braided stream deposits and lateral bar deposits, indicating that slopes in the Zonguldak area were very near to threshold value. A slight increase in gradient due to aggradation, therefore, induced a shift from a meandering thalweg pattern to a braided pattern. Conversely, an increase in subsidence rate caused a change in the opposite sense, as recorded by Casey (1980). Most of the small lakes appear to have formed on top of the same fining upwards cycles within the flood basin association. The swamp deposits are related to this sort of environments.

In summary, many of the Kozlu Formation sediments are alluvial, incorporating the products of meandering or low-sinuosity and occasional braided rivers, either as point bars or as overbank fines. Over large areas of these flood-plains, swamps developed following subsidence, and peat deposits were formed, while with additional local subsidence, small lakes were formed.

7.4.3. KARADON FORMATION

During Karadon Formation times the north Turkish area was traversed by coarse braided streams (with Alluvial fan-like conglomerates) and low-sinuosity rivers. Systematic lateral migration of the braided stream channels and the upper reaches of the low-sinuosity channels over broad, low-gradient fans (humid fans) resulted in the deposition of laterally persistent sheet like sandstones. As Miall (1977) has pointed out, the distinction between alluvial fan and braided stream deposits is somewhat arbitrary since sediment dispersal on alluvial fans, particularly on the distal parts, generally takes place by means of ephemeral braided streams.

In the Karadon Formation asymmetrically filled scours, formed as sediment moved downstream or laterally into small, abandoned braid channels or cross-bar channels. Large-scale sigmoidal cross-bedding may represent lateral accretion on bank-attached bars. The lens-shaped geometry of the pebbly sandstone units may indicate that the rivers shifted position by major avulsions rather than steady lateral migration. Friend et al., (1979), have suggested that this may be typical of streams with extremely "flashy" discharge. The bi-modal grain-size of sandy conglomerates could result from matrix infiltration after the pebbles were deposited or from the simultaneous deposition of sand and pebbles. The very coarse sandstone lenses interbedded with these conglomerates were deposited either in small interbar channels during periods of lower discharge or as small wedges marginal to longitudinal bars similar to the sand wedges described by Rust (1972).

In the Karadon Formation, palaeocurrent analysis does not provide a very reliable means of distinguishing between deposits of meandering and non-meandering types of river. Vector means indicate current directions towards the west-southwest, suggesting fluvial transport from a northern or north-easterly source. However, there are some palaeocurrent directions towards the north west and south east (Fig. 35), and this variability presumably is a consequence of the highly meandering part of the Karadon stream system, which nevertheless appears to have shifted significantly in orientation by comparison with the underlying Kozlu Formation. Additional evidence for a slight change in the palaeocurrent orientation in the Karadon Formation suggests that tectonic uplift began in Westphalian B times at least in the Zonguldak area.

7.4.4. KIZILLI FORMATION

Rocks assigned to the Kızıllı Formation typically occur only to the east of the Zonguldak area. For example, in the Kurucaşile and Azdavay area. However, the original extent of the Kızıllı Formation is unknown, therefore environmental reconstruction can only be limited. The Kızıllı Formation displays two major facies associations: "coarse member" association and a "fine member" association. The lower part of the Kızıllı Formation is characterised by deposits formed in more meandering types of sequences with epsilon cross bedding. Such sequences show close similarity with the present day anastomosed fluvial sequences. Possibly the system consists of rapidly aggrading channels and adjacent wetlands, caused by a rising local base-level downriver or by basin subsidence. In the Kızıllı Formation the palaeocurrent analysis shows somewhat anomalous directions, especially in the Kızıllı section of the Azdavay area where fluvial transport is towards the northwest. This suggests that during Westphalian D times a more southerly source area may have become more important, a conclusion that is reinforced by the appearance of limestone rock fragments in the sandstones. However, it is noteworthy that in the Kurucaşile area, south easterly fluvial current directions prevail, suggesting that this area still lay within the general basinal framework and southerly flowing drainage system established for the Amasra and Zonguldak sequences. In interpreting the evidence from the Azdavay area it is necessary to bear in mind the severe tectonic effects that have subsequently been superimposed on the Carboniferous rocks with as yet unknown consequences of horizontal translation rotation and deformation etc.

Finally, the distribution of the Kızıllı fluvial pattern suggests a unique fluvial style, probably controlled by rapid subsidence probably along the margin of an uplifted foreland, coupled with high sediment loads from nearby mountain building. These conditions suggest that Kızıllı deposition took place in an intermontane basin.

7.5. PROVENANCE AND CONTROLS OF SEDIMENTATION

The composition of the Alacaağzı Formation sandstones is mainly controlled by their sedimentary environments (see Chapter 5) and diagenetic history. However, a detailed study of the clast types (see pp. 161) permits some general assessment of the nature of the source area. The sediments of the Alacaağzı Formation were derived from a source area composed of low - to - medium-grade metamorphic rocks, incorporating some igneous rocks and the whole complex was periodically characterised by volcanic activity. A few sedimentary clasts also suggest the presence of a discontinuous sedimentary cover. Throughout the entire area in which the Alacaağzı Formation is exposed, the relative proportions of the non-quartz clast-types are essentially constant, suggesting that the sands were derived from a similar source area, indicated by the fluvial palaeocurrents to have lain to the north.

The wide variety of clasts present in the Kozlu sands (see pp.164) indicates that these sediments were derived from a source area which included exposures of medium-rank metamorphic rocks, granite material, acidic volcanic rocks and unmetamorphosed sedimentary sequences. An interesting point is that sandstones from the lower part of the Dilaver "Member" of the Kozlu Formation contain abundant myolinitic fragments. This may indicate that some part of the source area contained a shear belt, probably a thrust zone (Pers comm., Park, 1981).

The Karadon Formation sandstones are petrographically very similar to those of the Kozlu Formation, while the Karadon conglomerates yield pebbles mainly of quartzite, chert, volcanic rocks, feldspar, and subordinate amounts of sedimentary rocks such as sandstone and siltstone. Sandstone is the upper part of the Karadon Formation contains unusually high proportions of secondary clay (see Chapter 5). From this evidence it appears that the Karadon sediments were derived mainly from sedimentary sequences with subordinate outcrops of low to medium-rank metamorphic, and acid volcanic rocks.

The variety of rock fragments in the Kızıllı Formation (see pp. 166), indicate predominant derivation from a metamorphic source area. However, the abundance of limestone clasts towards the top of the formation probably results from reworking of older carbonate platform sediments, together with a small amount of volcanic activity, in the uplifted borders of the late Carboniferous intermontane areas of deposition.

In the Namurian and Westphalian A sequences while the compositional maturity of the sandstones varies according to the environmental association, the relative proportions of quartz grain types and of the non-quartz clasts remain essentially constant, suggesting that all the sands were derived from a similar source area, only the abundance of myolinite fragments in the Westphalian A sandstones marking any change. However, during the Westphalian B and C stages changes in the gross character of the sediments (appearance of conglomerates) in the suite of rock-fragments and the slightly different palaeocurrent data (towards SE), all indicate tectonic uplift of the source area, accompanied by slight changes in its nature (more sedimentary rocks exposed). This general pattern remained the same until the end of the Westphalian C stage for the entire basin. However, during early Westphalian D times the somewhat anomolous palaeocurrent directions of the Azdavay area (flow towards the NW) suggest that a southerly source area may have become more important, a conclusion confirmed by the appearance of limestone rock fragments in the sandstones. However, it appears that the Kurucaşile area remained within the general basinal framework and southwards-flowing drainage system previously established for the Amasra and Zonguldak sequences.

7.6. PALAEOGEOGRAPHICAL EVOLUTION AND REGIONAL SIGNIFICANCE

7.6.1. PALAEOGEOGRAPHICAL EVOLUTION

During the Visean times the Carboniferous sea appears to have transgressed towards the north and occupied the northern part of Turkey (Brinkmann , 1971), producing platform carbonates. Eventually the entire region formed part of an extensive shallow epicontinental sea. A few areas may have remained emergent and provided local sources for small amounts of clastic sediment that are represented in occasional clastic intercalations in the Visean limestone succession. During the late Visean and early Namurian there was increased tectonic activity throughout the Black Sea land mass,(Brinkmann's Pontian Massif, 1972) leading to renewed clastic input and formation of a repressive sequence. The Black Sea land mass was uplifted, and coarse sediment was shed southwards into the shallow sea, rapidly forming a series of coarsening upwards deltaic sequences. Rapid subsidence coupled with recurrent shifting delta lobes produced a vertical stacking of delta complexes and caused lateral facies changes. The western section (Zonguldak) was formed by the gradual southwards progradation of a river-dominated delta while the Amasra succession (to the coast) was formed by progradation of a wave dominated delta, with associated shoreline environments displaying more evidence of longshore transport, however the compositional uniformity of the sands contained in both deltaic sequences indicates that they were supplied by the same fluvial input and thus probably form parts of one major delta system, which was thus at least 100 km wide. Towards the end of Namurian tires (Namurian C or Yeadonian) the nature of the Asma "Member" of the Alacaağzı Formation indicates that fluvial cycles became well established in the delta plain environment. Marine processes were limited and sedimentation was mainly controlled by reworking in the vicinity of the river mouth. Progradation was terminated by delta abandonment, in some cases producing thin beds of fossiliferous siltstones, mudstones and rootlet beds with or without coals. Possible correlation of the members of the Alacaağzı Formation according to their facies associations is provided in Fig (7).

Abandonment was followed by a new fluvial input, which brought pebbly material and coarse sands southwards into the area. Faunal evidence suggests that by the end of the Alacaağzı deposition the deltas may have discharged into a brackish, rather than a fully marine basin, Later still in the Namurian, the Kılıç "Member" of the Kozlu Formation records establishment of a delta plain environment displaying well developed lacustrine environments. Westphalian A times were marked by widespread accumulation of coals, well represented in the Dilaver "Member" of the Kozlu Formation, and formed on the floodplains of rapidly migrating high-sinuosity streams. The meandering streams responsible for depositing these fining upwards Kozlu sequences (which are correlated throughout the Zonguldak area Fig. 38) flowed southwards across areas that previously formed parts of a delta-plain and rapid basin subsidence probably controlled the general topographic slopes in the area.

During Westphalian B and C times (Karadon Formation) the appearance of sandy low-sinuosity and braided rivers was followed by coarse pebbly braided streams and finally again by low-sinuosity streams. Systematic lateral migration of the braided stream channels over broad, low-gradient fans (humid fans) resulted in the deposition of laterally persistent sheet sandstones. The distribution of Karadon facies associations, for different parts of the study area is indicated in (Fig. 38). The generation and preservation of thick sequences of conglomerates and coarse sandstone in the Karadon Formation requires substantial hinterland relief, attributed to activity on basin-border faults. This process of episodic uplift caused a slight change in the braided stream pattern which induced streams to flow in a southwesterly direction. This episode of tectonic activity culminated in the late Westphalian B with the deposition of several extremely coarse and laterally persistent conglomerates. Sandy low-sinuosity and braided stream complexes, with conspicuous fine-grained sequences and thin coal beds were developed in the Westphalian C time interval, suggesting a temporary pause in the tectonic activity. A similar situation has been recorded in the coal-bearing Upper Cretaceous strata of Central Alberta, Canada, by, Jerzykiewicz and Mc Lean (1978).

During early Westphalian D times (Kızıllı Formation), the northwestern Turkish basin was characterised by a complex of meandering streams with wide floodplains on which vegetation flourished. These meander-belt deposits pass upstream into sedimpnts formed in low-sinuosity river channels, and ultimately are succeeded by possible anastomosed stream sequences. The general features pf the Kızıllı Formation sequences resemble those of Schafer's (1981) freshwater molasse basin in the Permocarboniferous of Saar-Nahe. Schafer has suggested that the prime sedimentary control involved increasing aridity of the climate. As a result, sedimentation in the Saar-Nahe region became more alluvial in character, combined with tectonic activity and intrusives. Similarly, the maturity and well rounded nature of the grains in the red sandstones of the Kızıllı Formation suggests a high degree of reworking in the intermontane alluvial plain environments (possibly with associated wind action), which may also indicate a climatic change from a semi-arid to an arid environment. Possible evidence for an earlier climatic change may be provided by the occurrence within the upper part of the Karadon Formation of thick units of refractory clay ("Schieferton"), attributed to prolonged leaching of palaeosols, (may also reflect a climatic change). This suggests a change from a hot, humid climate to a semi-arid climate during Westphalian C times.

7.6.2. REGIONAL SIGNIFICANCE

Some tenative palaeogeographic maps have been presented in the previous sections for a small area of northern Turkey (Fig.36). Because of the lack of detailed and accurate geological information from other parts of Turkey, it is not possible here to provide a broad palaeoenvironmental picture which would display the precise position of northwestern Turkish Upper Carboniferous successions within a regional setting. However, since Turkey is related to the Alpine-Himalayan mobile belt, there have been several attempts to explain the geological features of this country in terms of plate tectonics (Ketin , 1966; Brinkmann, 1971; Şengör et al., 1980;Şengör and Yilmaz 1981, among others). All these attempts have involved considerations of gross stratigraphic and structural data but none of these analyses have been based on detailed sedimentological studies. Moreover, most of these studies have been concerned with the Alpine orogenic belt and the Tethys Ocean, and there has been little treatment of Variscan (Hercynian) tectogenesis.

Brinkmann (1972, 1976) has outlined the effects of the Hercynian tectogenesis that occurred during the Carboniferous and Permian in the Black Sea area. Brinkmann's map (see Fig. 3), indicates that during the late Palaeozoic the area north of the North Anatolian fault was characterised by continental deposition, while equivalent sediments south of this line are of marine eugeosynclinal facies, passing southwards into a shelf sequence.

Demirtaşlı (1981) has summarized the Palaeozoic stratigraphy and Variscan events in the Taurus belt of southern Turkey. Mostof the Upper Carboniferous succession is missing and lower-upper Permian rests disconformably on Visean shelf carbonates and clastics in the eastern part of the Taurus. However, shelf sequences of Moscovian and Kasimovian age with a rich marine microfauna, are known in the Central Taurus. In western Turkey, similar rocks of Bashkirian to Moscovian age may be correlated with the Karlık Formation of the Kasımlar area (Dumont and Kerey, 1975), which is a regressive sequence of red sandstones and conglomerates. It is clear from Demirtaşli's study that in the Carboniferous the southern part of Turkey belonged to a region that was stratigraphically and palaeontologically distinct from northern Turkey and is plausibly linked with the Gondwana successions.

Şengör et al., (1980) have suggested that the evidence from the eastern Pontides indicates the existence of a Permian-Jurassic ocean, bordered by a south dipping subduction zone. Regional considerations suggest that the suture forms part of an orogenic belt resulting from the closure of the Permo-Triassic Palaeo-Tethys and the oceanic assemblage in viewed as part of a previously formed Cimmerian continent. Presumably this Cimmerian continent (Şengör 1979) was equivalent to the "Pontian Massif" of Brinkmann (1972) and the Black Sea land mass (as used in this study).

Recenly Şengör and Yilmaz (1981) have suggested that during the Permian the entire present area of Turkey constituted a part of the northern margin of Gondwanaland. However, the floral and faunal evidence presented in this study, together with the stratigraphical and sedimentological findings, have demonstrated that at least in Upper Carboniferous times northern Turkey was not part of Gondwanaland and is more plausibly regarded as part of the Laurasian Carboniferous assemblage (e.g. Smith et al., 1981). Similarly, Bergougnond and Fourquin (1980) have suggested that the North Anatolian belt (Pontids) belonged to the Eurasiatic continent facing the Tethyan Ocean during the mesozoic.

In recent years much work has been done regarding Variscan plate tectonics and it has become clear that the sedimentary and structural features of this orogen are not readily accounted for by conventional plate-tectonic models involving rectilinear continental collisions. For example, Lefort and Van Voo (1981) have suggested a kinematic model for the oblique collision and complete suturing between Gondwanaland and Laurasia in the Carboniferous, based on the general distribution of major strike-slip faults in Western Europe, northern Africa, and eastern North America. Scotese et al., (1979) and Rau and Tongiorgi (1981) also have suggested continental collision between Africa and North Europe as the prime cause of Variscan orogeny. They consider South Europe to be part of Gondwanaland and prefer to exclude the hypothesis of an infra-Palaeozoic oceanic proto-Tethys in southwestern Europe, in accordance with Flugel's (1975) suggestion for Turkey and with the lower Palaeozoic maps of Scotese et al., (1979). Moreover, the Proto-Mediterraneas or Proto-Tethys and Mid-European Ocean co-exist in the models of some authors, such as Dewey and Burke (1973) and Flugel (1975).

Finally, as indicated above the deposition of the late Carboniferous successions within the northwest Turkish basin probably was fault controlled. While the fault-motions responsible for the supply of sediment were essentially vertical, this does not exclude the possibility that the major controlling fractures were of strike-slip character, for example as in some modern basins of this type such as the San Andreas fault zone, and many others (see Reading 1980).

The final question is what happened to the Black Sea land mass which supplied the great volumes of detritus to the late Carboniferous of Northwestern Turkey? There appear to be two main possibilities. The landmass may have been subducted southwards beneath the Turkish Plate during the Mesozoic or it may have been removed laterally (to the east?) by major, strike-slip faulting, leaving this part of the northwestern Turkish Upper Carboniferous as a remnant of the former Cimmerian microcontinent. Although there is no incontrovertible evidence for a strike-slip fault system in the studied area, the proximity of this basin to the North Anatolian Transform Fault, which appears to have come into existence in the Mesozoic (Dewey et al., 1973), supports the second of these hypothesis. Moreover, the uplift and deformation which followed Late Carboniferous sedimentation, would render the identification of any lateral displacement of the basin margins. Heward and Reading (1980) have used the present separation of alluvial fan and associated sequences from their source areas as evidence for lateral displacemmnt of early Stephanian basin-fill successions in Cantabria, northern Spain.
Since the sedimentological evaluation of the northwestern Turkish basin shows close similarity with the northwestern European Upper Carboniferous successions, it may indicate a similar geotectonic history, involving significant strike-slip faulting.

In summary, the stratigraphical, sedimentological and faunal data presented in this study indicate that the various small, structurally separated outcrops of Upper Carboniferous rocks in northwestern Turkey were originally deposited within a single, large basin of deposition, formed on the southern margin of the Laurasian plate (perhaps as part of the

Cimmerian microcontinent). The late Carboniferous sediments record the gradual fragmentation of this basin by uplift and faulting, probably reflecting the initial stages of a late Hercynian phase of large-scale wrench-faulting caused by the post-Carboniferous oblique collision of the Eurasian and Gondwanan plates (Lefort VanVoo 1981). Subsequent Alpine deformation has further disrupted and displaced the Carboniferous sequences, as is manifest in the eastern part of the study area (Azdavay; see Plate 93).

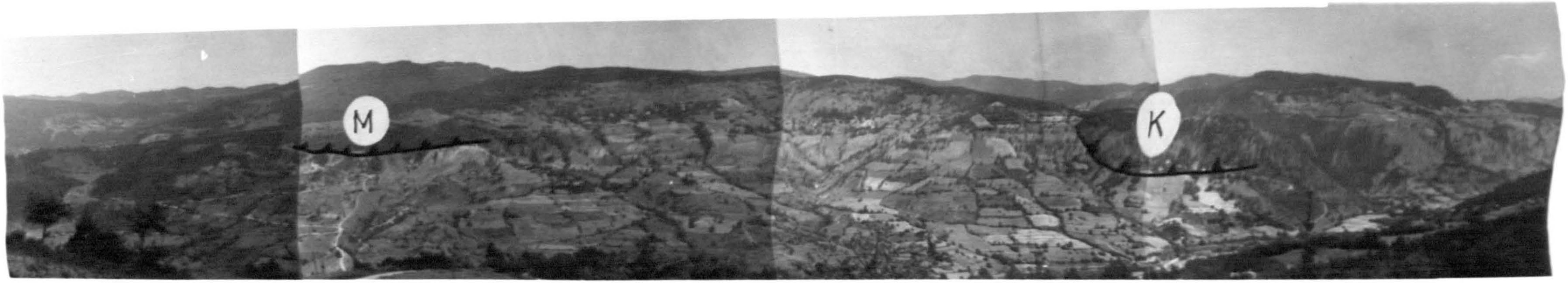


Plate 93: Panorama from SE to NW, of an area of Azdavay. Lower ground (beneath indicated thrusts) is occupied by Lower Cretaceous flysch, over which Upper Carboniferous and Permian rocks have been thrusted to form the thgh ground.

M = Maksut mine, K = Kozluviran village, ↓ = Bakırçay stream.

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İLYAS GEÇİDİ DERE SECTION (1)-Kurucaşile

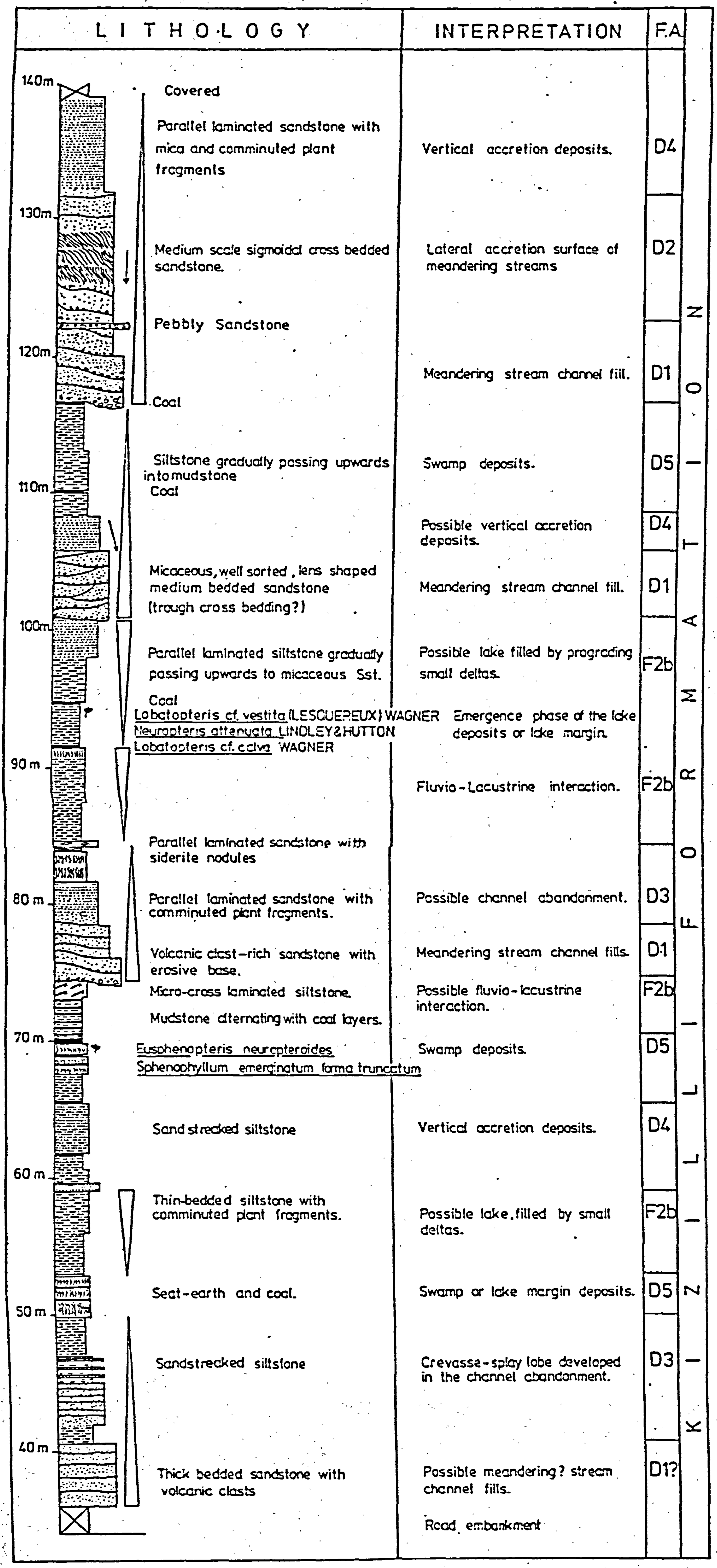


Fig 21.

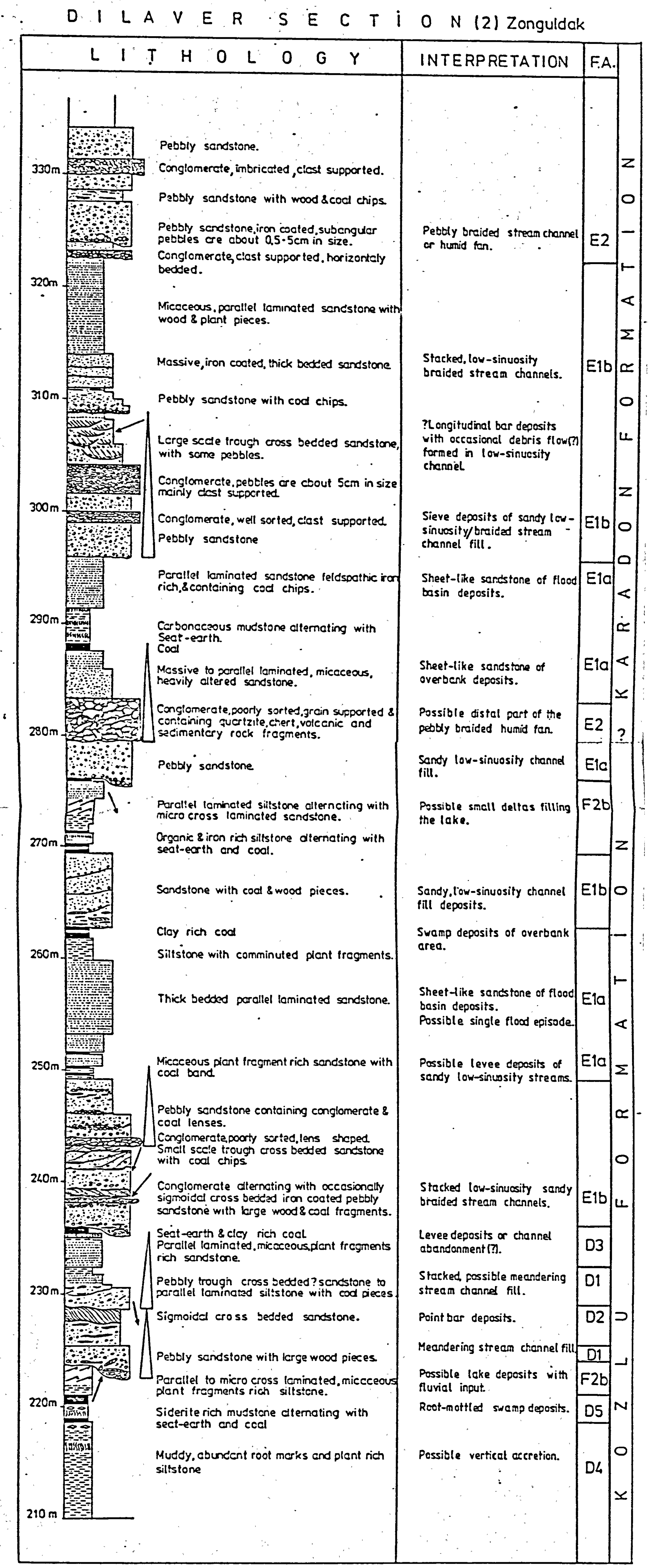

D I L A V E R S E C T İ O N (2) Zonguldak
L I T H O L O G Y
INTERPRETATION
F.A.
330m
320m
310m
300m
290m
280m
270m
260m
250m
240m
230m
220m
210 m
Pebbly sandstone.
Conglomerate, imbricated, clast supported.
Pebbly sandstone with wood & coal chips.
Pebbly sandstone, iron coated, subangular pebbles are about 0.5-5cm in size.
Conglomerate, clast supported, horizontaly bedded.
Micaceous, parallel laminated sandstone with wood & plant pieces.
Massive, iron coated, thick bedded sandstone.
Pebbly sandstone with coal chips.
Large scale trough cross bedded sandstone, with some pebbles.
Conglomerate, pebbles are about 5cm in size mainly clast supported.
Conglomerate, well sorted, clast supported.
Pebbly sandstone
Parallel laminated sandstone feldspathic iron rich, & containing coal chips.
Carbonaceous mudstone alternating with Seat-earth.
Coal
Massive to parallel laminated, micaceous, heavily altered sandstone.
Conglomerate, poorly sorted, grain supported & containing quartzite, chert, volcanic and sedimentary rock fragments.
Pebbly sandstone.
Parallel laminated siltstone alternating with micro cross laminated sandstone.
Organic & iron rich siltstone alternating with seat-earth and coal.
Sandstone with coal & wood pieces.
Clay rich coal
Siltstone with comminuted plant fragments.
Thick bedded parallel laminated sandstone.
Micaceous plant fragment rich sandstone with coal band.
Pebbly sandstone containing conglomerate & coal lenses.
Conglomerate, poorly sorted, lens shaped.
Small scale trough cross bedded sandstone with coal chips.
Conglomerate alternating with occasionally sigmoidal cross bedded iron coated pebbly sandstone with large wood & coal fragments.
Seat-earth & clay rich coal.
Parallel laminated, micaceous, plant fragments rich sandstone.
Pebbly trough cross bedded? sandstone to parallel laminated siltstone with coal pieces.
Sigmoidal cross bedded sandstone.
Pebbly sandstone with large wood pieces.
Parallel to micro cross laminated, micaceous plant fragments rich siltstone.
Siderite rich mudstone alternating with seat-earth and coal
Muddy, abundant root marks and plant rich siltstone
Pebbly braided stream channel or humid fan.
Stacked, low-sinuosity braided stream channels.
?Longitudinal bar deposits with occasional debris flow(?) formed in low-sinuosity channel.
Sieve deposits of sandy low-sinuosity/braided stream channel fill.
Sheet-like sandstone of flood basin deposits.
Sheet-like sandstone of overbank deposits.
Possible distal part of the pebbly braided humid fan.
Sandy low-sinuosity channel fill.
Possible small deltas filling the lake.
Sandy, low-sinuosity channel fill deposits.
Swamp deposits of overbank area.
Sheet-like sandstone of flood basin deposits.
Possible single flood episode.
Possible levee deposits of sandy low-sinuosity streams.
Stacked low-sinuosity sandy braided stream channels.
Levee deposits or channel abandonment (?).
Stacked, possible meandering stream channel fill.
Point bar deposits.
Meandering stream channel fill
Possible lake deposits with fluvial input.
Root-mottled swamp deposits.
Possible vertical accretion.
E2
E1b
E1b
E1a
E1a
E2
E1a
F2b
E1b
E1a
E1a
E1b
D3
D1
D2
D1
F2b
D5
D4
KARADON FORMATION
?
KOZLU FORMATION

Fig 20.

AÇIK YARMA SECTION (ZONGULDAK.)

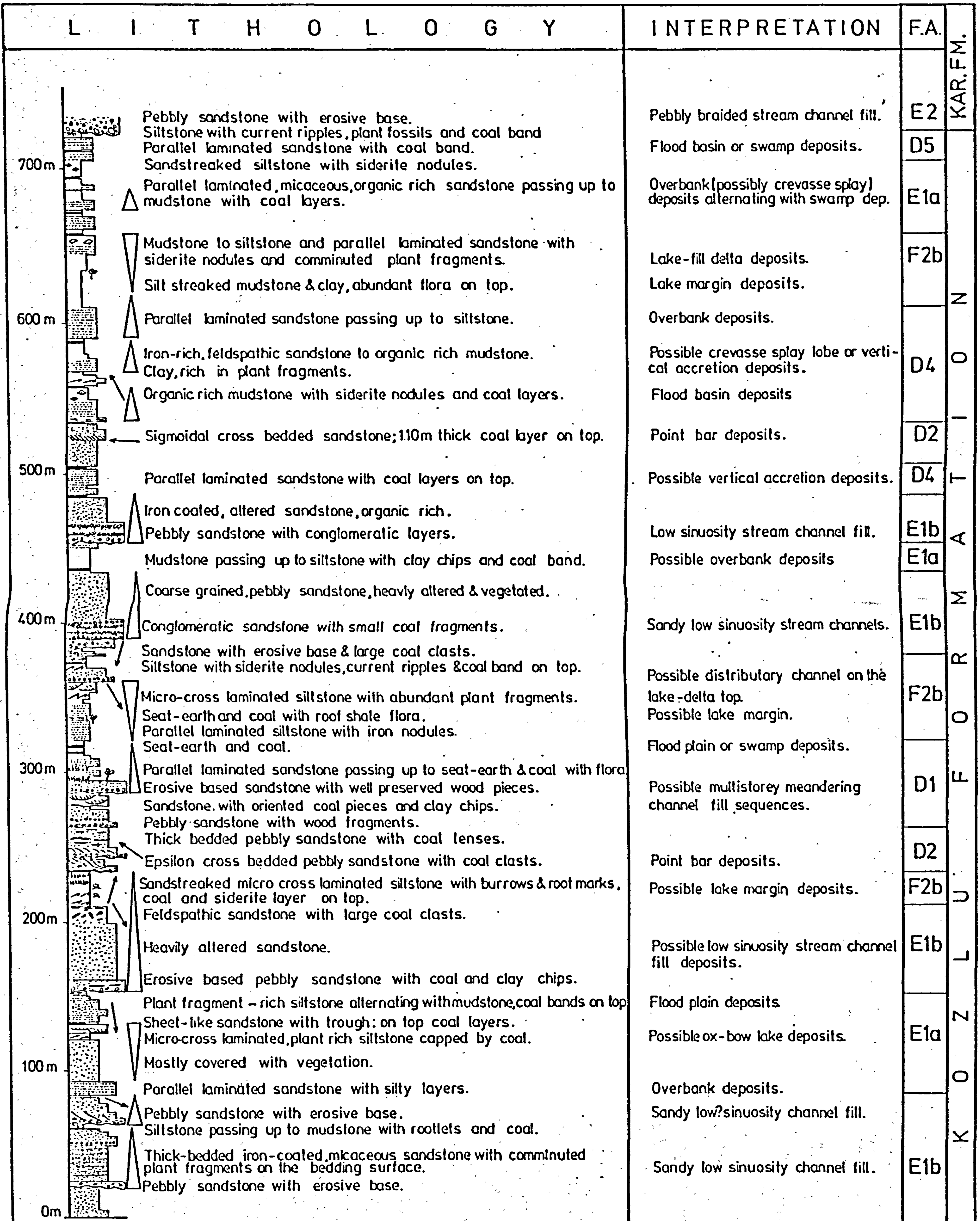


Fig. 17

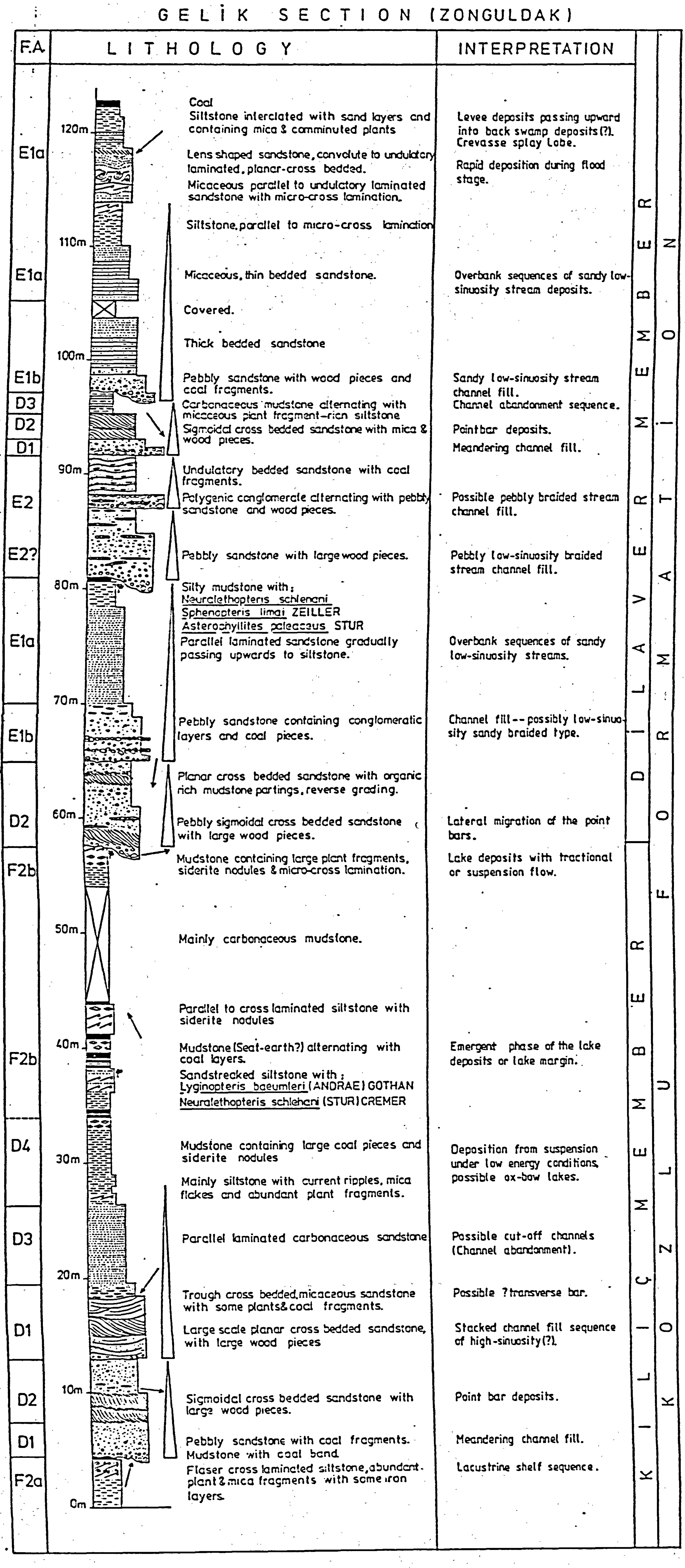
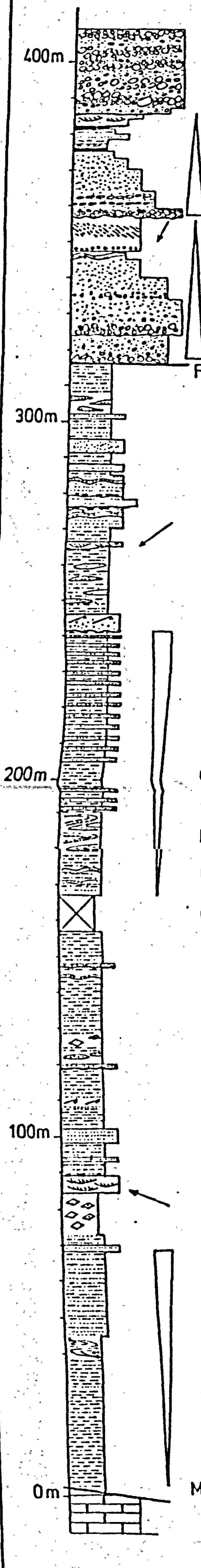

GELİK SECTION (ZONGULDAK)
F.A.
LITHOLOGY
INTERPRETATION
E1a
E1a
E1b
D3
D2
D1
E2
E2?
E1a
E1b
D2
F2b
F2b
D4
D3
D1
D2
D1
F2a
120m
110m
100m
90m
80m
70m
60m
50m
40m
30m
20m
10m
0m
Coal
Siltstone intercalated with sand layers and containing mica & comminuted plants
Lens shaped sandstone, convolute to undulatory laminated, planar-cross bedded.
Micaceous parallel to undulatory laminated sandstone with micro-cross lamination.
Siltstone, parallel to micro-cross lamination
Micaceous, thin bedded sandstone.
Covered.
Thick bedded sandstone
Pebbly sandstone with wood pieces and coal fragments.
Carbonaceous mudstone alternating with micaceous plant fragment-rich siltstone
Sigmoidal cross bedded sandstone with mica & wood pieces.
Undulatory bedded sandstone with coal fragments.
Polygenic conglomerate alternating with pebbly sandstone and wood pieces.
Pebbly sandstone with large wood pieces.
Silty mudstone with:
Neuralethopteris schlehani
Sphenopteris limai ZEILLER
Asterophyllites paleaceus STUR
Parallel laminated sandstone gradually passing upwards to siltstone.
Pebbly sandstone containing conglomeratic layers and coal pieces.
Planar cross bedded sandstone with organic rich mudstone partings, reverse grading.
Pebbly sigmoidal cross bedded sandstone with large wood pieces.
Mudstone containing large plant fragments, siderite nodules & micro-cross lamination.
Mainly carbonaceous mudstone.
Parallel to cross laminated siltstone with siderite nodules
Mudstone (Seat-earth?) alternating with coal layers.
Sandstrecked siltstone with:
Lyginopteris baeumleri (ANDRAE) GOTHAN
Neuralethopteris schlehani (STUR) CREMER
Mudstone containing large coal pieces and siderite nodules
Mainly siltstone with current ripples, mica flakes and abundant plant fragments.
Parallel laminated carbonaceous sandstone
Trough cross bedded, micaceous sandstone with some plants & coal fragments.
Large scale planar cross bedded sandstone, with large wood pieces
Sigmoidal cross bedded sandstone with large wood pieces.
Pebbly sandstone with coal fragments.
Mudstone with coal band.
Flaser cross laminated siltstone, abundant plant & mica fragments with some iron layers.
Levee deposits passing upward into back swamp deposits (?). Crevasse splay Lobe.
Rapid deposition during flood stage.
Overbank sequences of sandy low-sinuosity stream deposits.
Sandy low-sinuosity stream channel fill.
Channel abandonment sequence.
Pointbar deposits.
Meandering channel fill.
Possible pebbly braided stream channel fill.
Pebbly low-sinuosity braided stream channel fill.
Overbank sequences of sandy low-sinuosity streams.
Channel fill -- possibly low-sinuosity sandy braided type.
Lateral migration of the point bars.
Lake deposits with tractional or suspension flow.
Emergent phase of the lake deposits or lake margin.
Deposition from suspension under low energy conditions, possible ox-bow lakes.
Possible cut-off channels (Channel abandonment).
Possible ?transverse bar.
Stacked channel fill sequence of high-sinuosity (?).
Point bar deposits.
Meandering channel fill.
Lacustrine shelf sequence.
DİLAVER MEMBER
KILIÇ MEMBER
KOZLU FORMATION
ZONGULDAK FORMATION

Fig 16.

ULUTAMDERE SECTION (Zonguldak)



LITHOLOGY	INTERPRETATION	F.A.	Formation
Matrix-supported pebbles are poorly sorted, lineated & occasionally imbricated.	Pebbly braided stream deposits.	E2	KOZLU FORMATION
Small scale trough with abundant plant & wood fragments. Clay rich carbonaceous mudstone alternating with siltstone, sandstone (with current ripples) and coal layers.	Overbank sequences.	E1a	KOZLU FORMATION
Thick bedded conglomerate to sandstone, pebbles are mostly lineated.	Sandy, low-sinuosity stream deposits.	E1b	KOZLU FORMATION
Planar cross bedded pebbly sandstone.			KOZLU FORMATION
Conglomerate, clast-supported with loading & coal pieces. Pebbles are mostly quartzite, chert & volcanics, matrix-supported	Stacked, sandy low-sinuosity stream channel fill sequences.	E1b	KOZLU FORMATION
Fault			
Large scale sand lenses containing comminuted plants. Massive, micaceous sandstone lenses alternating with siltstone	Crevasse splay sequences.	C2b	ALACAAĞZI FORMATION
Parallel to undulatory laminated, micaceous with large plant fragments and some loading (erosive base?).	Interdistributary channel sequences.	C1b	ALACAAĞZI FORMATION
Siltstone alternating with iron rich sand lenses (siderite?)	Crevasse splay deposits.	C2b	ALACAAĞZI FORMATION
Massive to microcross laminated with some loading.	Interdistributary channel fill.	C1b	ALACAAĞZI FORMATION
Parallel laminated micaceous sandstone alternating with siltstone.	Possible natural levee deposits.	C2a	ALACAAĞZI FORMATION
Organic rich siltstone with mica flakes. Parallel laminated, micaceous, organic rich.			ALACAAĞZI FORMATION
Folded sand streaked siltstone.	Possible slump deposits.	C2b	ALACAAĞZI FORMATION
Undulatory laminated siltstone containing abundant plant & mica fragments.	Crevasse splay sequence.	C2b	ALACAAĞZI FORMATION
Covered with vegetation.			ALACAAĞZI FORMATION
Undulatory laminated sandstone band with plant pieces.	Interdistributary bay or lagoon.	C1a	ALACAAĞZI FORMATION
Organic-rich, micaceous siltstone with siderite nodules.		C1a	ALACAAĞZI FORMATION
Micaceous sandstone layer with mud drapes (erosive base)	Crevasse channels.	C2b	ALACAAĞZI FORMATION
Flaser bedded siltstone.	Interdistributary bay or lagoon.	C1a	ALACAAĞZI FORMATION
Parallel laminated, micaceous, lens-shaped sandstone with wood pieces alternating with plant fragment-rich siltstone.	Distributary channels and levee deposits.	C2a	ALACAAĞZI FORMATION
Trough cross bedded, micaceous sandstone.		C1b	ALACAAĞZI FORMATION
Mudstone containing abundant plant fragments & siderite nodules.	Interdistributary bay deposits.	C1a	ALACAAĞZI FORMATION
Massive sandstone with mica & plant fragments and erosive base			ALACAAĞZI FORMATION
Siltstone alternating with mudstone containing abundant comminuted plant fragments.	Distal delta front deposits.	B1	ALACAAĞZI FORMATION
Folded silt streaked mudstone.	Possible slump deposits.	A	ALACAAĞZI FORMATION
Mudstone alternating with siltstone and isolated sand layers.	Prodelta and possible distal turbidites.	A	ALACAAĞZI FORMATION
Midi Fault			

Fig 12.

GOKGÖL SECTION

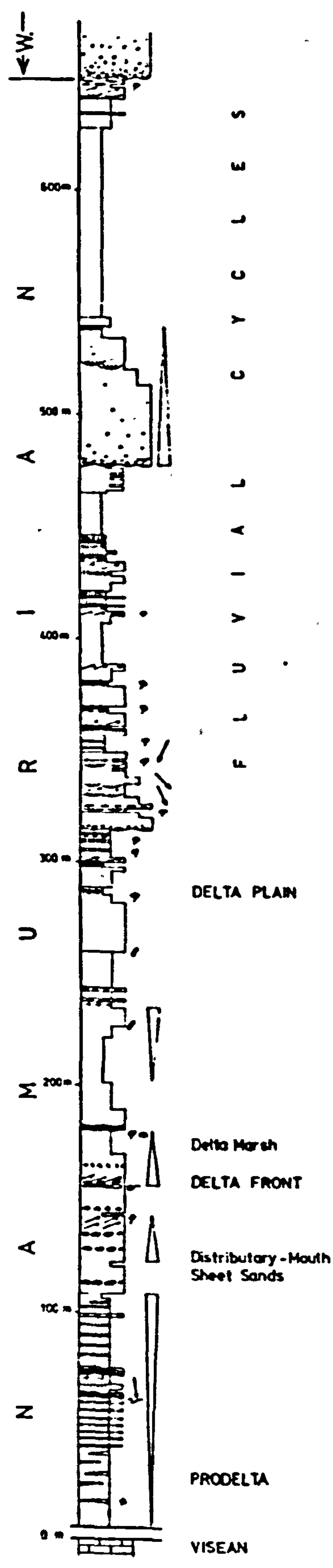
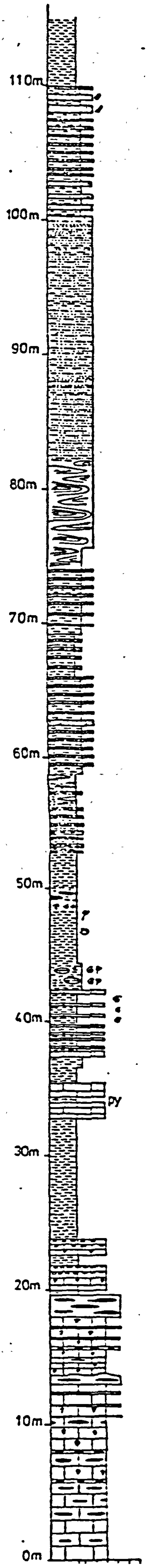


Fig 13.

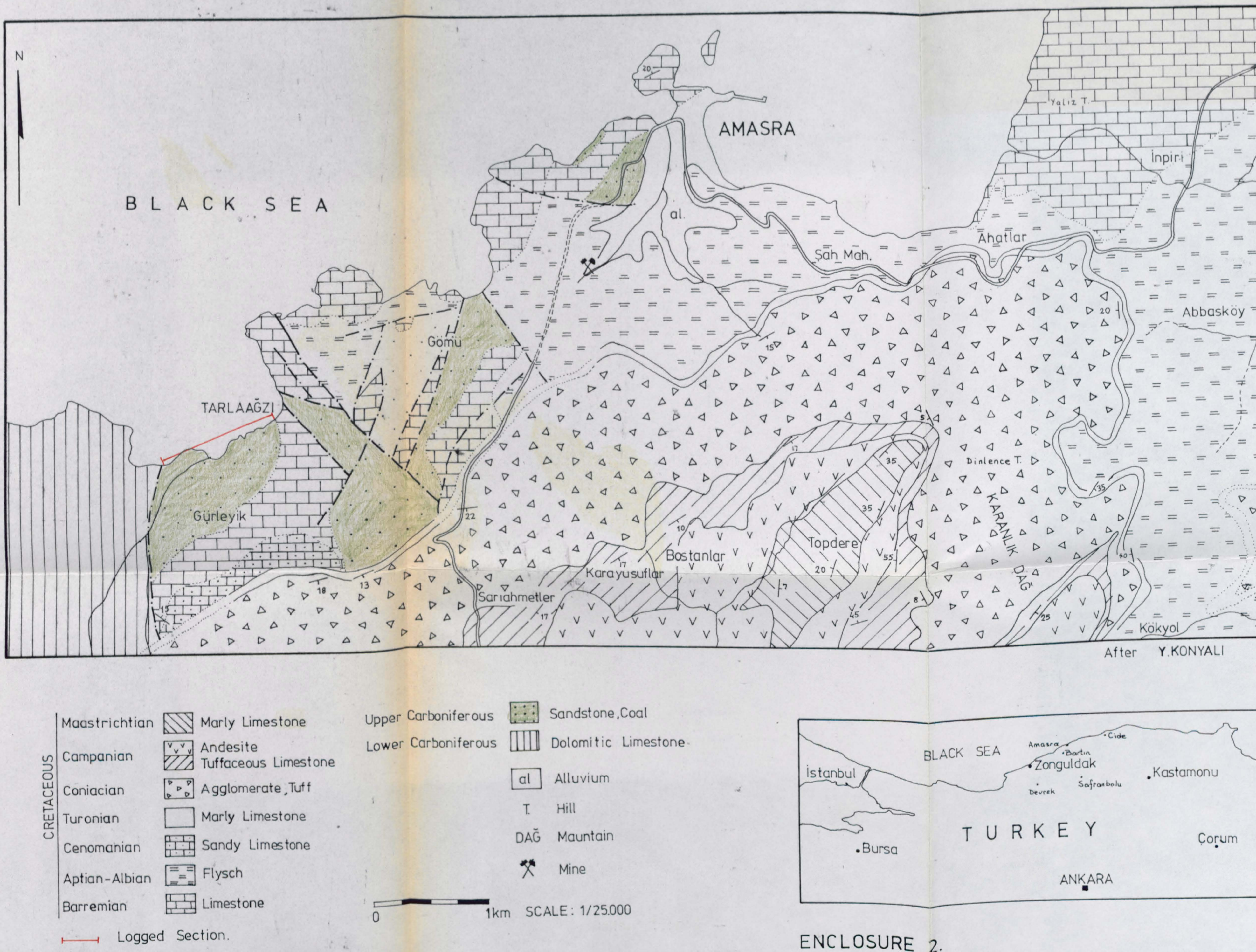
KOKAKSU STREAM SECTION (Zonguldak.)



LITHOLOGY	INTERPRETATION	F.A.
Mudstone with mica and comminuted plant fragments	Interdistributary bay or lagoon.	C1a
Parallel laminated sandstone alternating with comminuted plant-rich siltstone.	Possible natural levee sequence.	C2a
Micaceous sandstone layers.	Marginal delta front.	
Thin bedded sandstone alternating with mica and plant fragment-rich siltstone	Possible proximal delta front.	B2
Folded, comminuted plant fragment-rich sandstone and siltstone	Possible slumped-slope deposits(?).	
	Distal delta front.	B1
Mudstone alternating with siltstone and sandstone	Turbidite-like prodelta; possibly delta progradation starting from here (Regressive sequence).	A
Micaceous lens-shaped sandstone alternating with plant fragment-rich siltstone	Crevasse splay deposits.	C2b
Mudstone containing lens-shaped sandstone	Low-lying interdistributary area. (Crevasse channels or splays).	C2b
Mudstone with abundant comminuted plant fragments and chert lenses.	Interdistributary bay or lagoon.	C1a
Mudstone ; Wave ripple marks, Comminuted plant&mica fragments, Abundant Bivalves	Prodelta and shallow muddy shelf.	A
Mudstone with limestone nodules, comminuted plant fragments, goniatites and bivalves	Possible muddy strand plain.	?
Mudstone alternating with limestone containing plant fragments, goniatites and bivalves	Possibly end of the transgressive sequence.	
Sandy limestone	Prograding sandy mud flat.	
Limestone with corals and brachiopods, Nodular micritic limestone with lens-shaped mudstone and abundant brachiopods; <u>Gigantoproductus cf. tulensis</u>	Storm-dominated(?) beach ridge.	
Mudstone	Prograding mud flat.	
Brecciated limestone with corals		
Nodular micritic limestone with corals and brachiopods : <u>Gigantoproductus elongatus</u>, <u>Gigantoproductus expansus</u>	Beach ridge.	
Chert	Storm-dominated shelf.	
Coral-rich limestone alternating with chert		
Coral-rich limestone with brachiopod fragments.	Shallow marine shelf.	
VISEAN Limestone ; thick-bedded, coral-rich, with chert layers.		

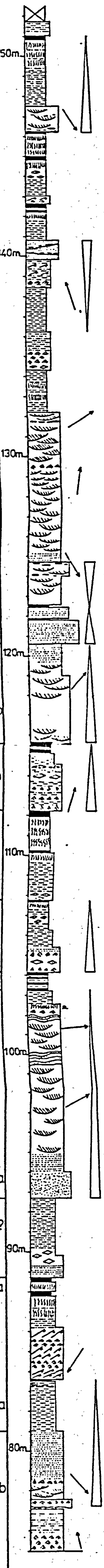
Fig 11.

GEOLOGICAL MAP OF AMASRA AREA



ENCLOSURE 2.

ALACAAĞZI SECTION (Zonguldak)



F.A.	Depth	LITHOLOGY	INTERPRETATION
		Covered with vegetation & Alacaağzı bay recent sediments.	
C1a	150m	Siltstrecked mudstone with comminuted plant fragments & root marks	Interdistributary bay deposits.
C1b		Micaceous, trough cross bedded sandstone, coal pieces.	Possible interdistributary channel fill.
C1a		Seat-earth and coal.	Interdistributary bay (swamp) deposits.
		Mudstone with siderite nodules & root marks.	
C2b		Micro cross laminated sandstone	Crevasse channel.
C1a		Mudstone, seat-earth and coal.	Interdistributary bay deposits.
C2b	140m	Lens shaped sandstone with coal pieces.	Crevasse channel deposits.
C2c		Sand strecked siltstone with wave ripples and current ripples.	Wave working of fluvially transported detritus in the natural levee sequence
		Carbonaceous mudstone.	Interdistributary bay deposits.
C1a		Siltstone with siderite nodules & wave ripples.	Wave reworking of outer bay deposits.
		Mudstone with comminuted plant fragments & seat-earth.	Swamp or marsh deposits of interdistributary bay sequence.
C1b		Large scale trough cross bedded sandstone with mud drapes mica flakes & burrows.	Possible migration of subaqueous dunes associated with interdistributary channel.
	130m	Medium scale trough cross bedded sandstone with coal & mica flakes occasionally alternating with wave ripples	Dunes partially eroded and washed out in moderate-high energy condition associated with interdistributary channels.
C2a		Medium scale trough cross bedded sandstone with coal chips.	Natural levee deposits.
C2b		Volcanic & organic clast-rich, parallel laminated sandstone alternating with coal layers.	Possible crevasse splay deposits.
C1b	120m	Micaceous sandstone with trough to parallel lamination	
		Large scale trough cross bedded sandstone with mica, plant & volcanic fragments.	Possible migration of subaqueous dunes by longshore currents.
C2b		Mudstone alternating with coal layers.	Interdistributary bay deposits.
		Micaceous, carbonaceous sandstone with mud drapes & wave ripples.	Wave-reworked sands; abundant penecontemporaneous erosion of mud (crevasse channel).
C1a		Mudstone with root marks & coal band.	Swamp deposits (low energy suspension).
	110m	Parallel laminated siltstone with siderite lenses, comminuted plant fragments & seat-earth	Back-barrier swamp deposits.
C2b		Mudstone, with siderite nodules, seat-earth and coal.	Swamp deposits.
			Possible abandonment of crevasse channels.
		Sandstone, with wave ripples & muddy siderite lenses.	Wave-formed lamination associated with high energy condition.
C1a		Clay rich mudstone alternating with coal	Swamp or marsh deposits.
		Carbonaceous siltstone with root marks.	
		Undulatory & large scale trough cross bedded sandstone with wave ripples & burrows on the top.	Sand dunes; storm and fair weather increments may be recognized.
	100m	Micaceous trough cross bedded sandstone.	Possible migration of dunes by longshore currents.
B2a		Massive to parallel laminated sandstone.	Wave- or current-formed lamination associated with high energy condition in the proximal delta front environment.
C3?		Parallel laminated sandstone to siltstone with lens shaped siderite.	Possible delta lobe abandonment.
C1a	90m	Seat-earth and coal	Swamp or marsh in the interdistributary bay area.
		Sandstone containing small scale planar cross bedding and wave ripples.	Possible washover cycle of barrier sands(?) with fluvial input.
C1a		Seat-earth and coal	Interdistributary or lagoonal deposits.
	80m	Parallel laminated sandstone gradually passing upwards to siltstone.	
C1b		Trough cross bedded sandstone with wave ripples on the top. Erosive based sandstone. Sandstone alternating with siltstone. Sandstone with wave ripples	Distributary channel fill deposits or channels cuts by storm surge ebb currents, and filled by fine sandstone, reflecting low energy condition.

Fig. 14.

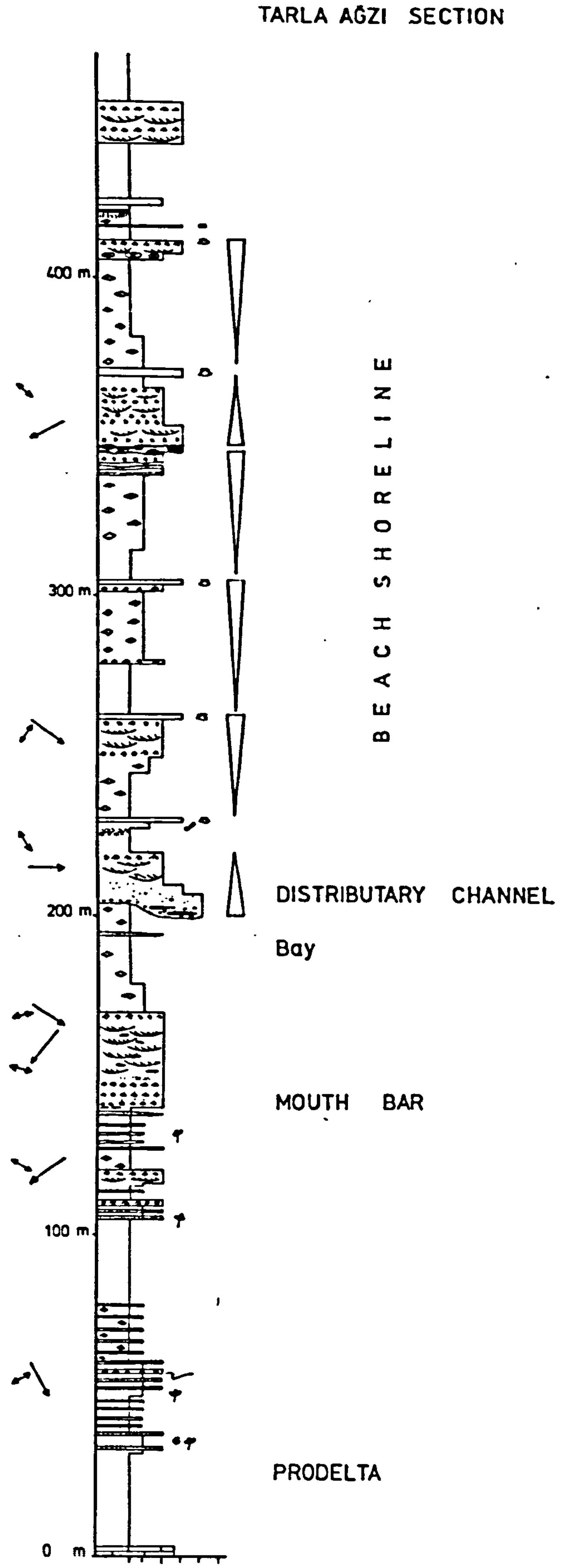

TARLA AĞZI SECTION
400 m
300 m
200 m
100 m
0 m
BEACH SHORELINE
DISTRIBUTARY CHANNEL
Bay
MOUTH BAR
PRODELTA

Fig 15.

İLYAS GEÇİDİ DERE SECTION (2) - KURUCAŞİLE

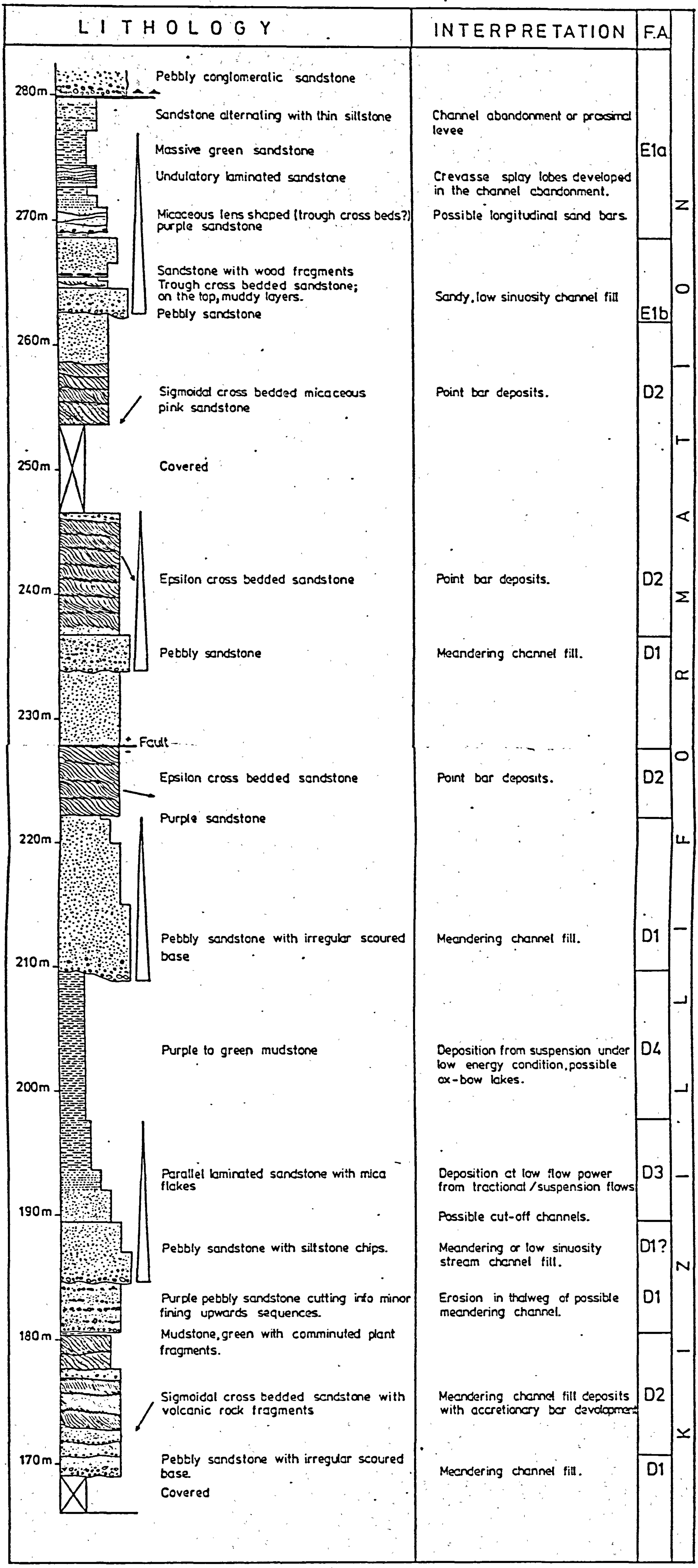
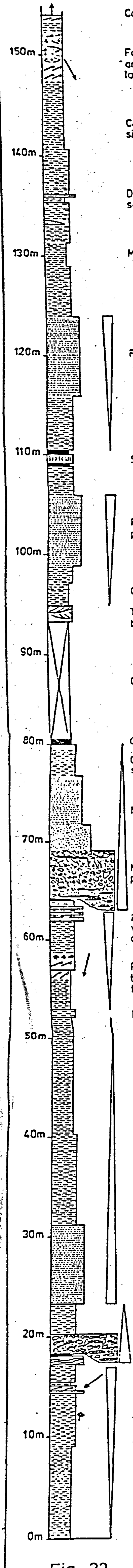


Fig 22.

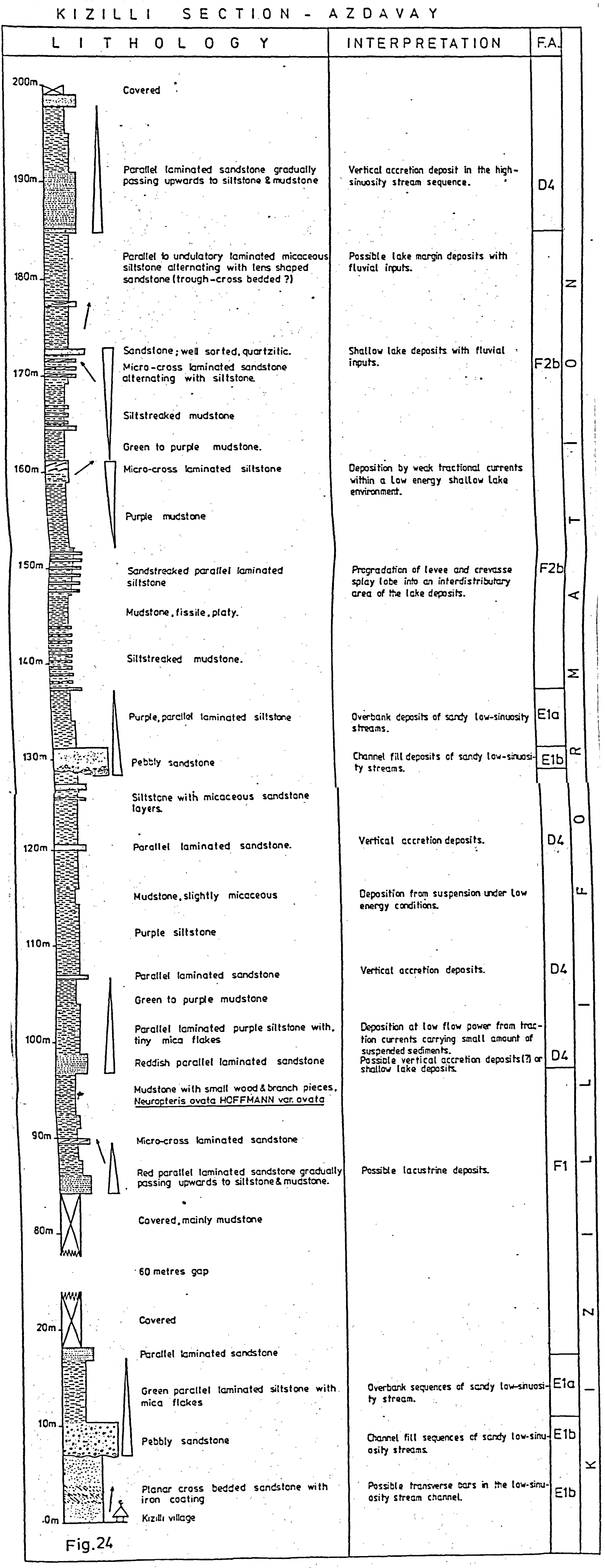
OZKEM SECTION (AZDAVAY)



LITHOLOGY	INTERPRETATION	F.A.
Covered, mainly folded mudstone.		
Folded mudstone alternating with siltstone and containing coal fragments & micro cross lamination	Possible lake margin deposits	F2b
Carbonaceous mudstone with lens shaped silty layers.	Crevasse splay lobes developed in the overbank of low sinuosity streams.	E1a
Dark grey siltstone containing lens shaped sandstone.	Crevasse splay deposits.	
Mudstone	Overbank deposits of low sinuosity stream sequences.	E1a
Feldspathic sandstone mostly altered.	Possible lake filled by prograding small deltas.	F2b
Seat-earth and coal	Emergence phase of the lake deposits.	
Parallel-laminated sandstone gradually passing upwards to siltstone.	Fluvio-Lacustrine interaction and bay sequences.	F2b
Green undulatory laminated mudstone.		
Trough cross-bedded siltstone with some branch pieces	Possible crevasse splay lobes in the lacustrine bay.	
Covered		
Coal	Overbank back swamp.	E1a
Carbonaceous, micaceous siltstone with some leaf pieces.		
Massive to parallel laminated sandstone.	Overbank sequences of sandy low sinuosity streams.	E1a
Matrix-supported conglomerates with chert pebbles, drifted coal pieces, & wood pieces.	Possible small fan delta sequences.	E2
Parallel-laminated sandstreaked siltstone with abundant plant pieces, mud drapes, silt clasts & loading.	Progradation of levee and crevasse splay lobe into an interdistributary bay of the lake deposits.	F2b
Parallel to micro cross laminated mudstone to siltstone containing comminuted plant fragments & wave ripples	Lacustrine wave reworking in the river generated sequences.	F2b
Parallel laminated siltstone		
Green parallel laminated mudstone with comminuted plant & branch fragments.	Possible lake margin deposits.	
Grey parallel laminated siltstone	Overbank deposits of low sinuosity stream sequences.	E1a
Feldspathic, iron stained sandstone.	Possible channel fill ?	
Siltstone, folded, micaceous with drifted coal fragments.		E1b
Conglomerate with oriented chert pebbles, wood fragments.	Possible fan delta prograding into the lake	E2
Micaceous, undulatory laminated sandstone.		
Siltstone with current ripples, comminuted plant fragments and sandstone layers. Mariopteris muricata Eusphenopteris obtusiloba Sphenopteris (Crossotheca) schatzlarensis Sphenopteris artemisiaefolioides Cordaites sp.	Fluvio-Lacustrine interaction and bay sequences.	F2b
Mudstone, folded, carbonate cemented	Possible lacustrine shelf sequences.	F2a
Road cutting (NE of Ozkem village)		

KARADON FORMATION

Fig. 23


KIZILLI SECTION - AZDAVAY
LITHOLOGY
INTERPRETATION
F.A.
200m
Covered
Parallel laminated sandstone gradually passing upwards to siltstone & mudstone
Vertical accretion deposit in the high-sinuosity stream sequence.
D4
190m
Parallel to undulatory laminated micaceous siltstone alternating with lens shaped sandstone (trough-cross bedded ?)
Possible lake margin deposits with fluvial inputs.
180m
Sandstone; well sorted, quartzitic.
Micro-cross laminated sandstone alternating with siltstone.
Shallow lake deposits with fluvial inputs.
F2b
170m
Siltstreaked mudstone
Green to purple mudstone.
Micro-cross laminated siltstone
Deposition by weak tractional currents within a low energy shallow lake environment.
160m
Purple mudstone
150m
Sandstreaked parallel laminated siltstone
Progradation of levee and crevasse splay lobe into an interdistributary area of the lake deposits.
F2b
Mudstone, fissile, platy.
140m
Siltstreaked mudstone.
Purple, parallel laminated siltstone
Overbank deposits of sandy low-sinuosity streams.
E1a
130m
Pebbly sandstone
Channel fill deposits of sandy low-sinuosity streams.
E1b
Siltstone with micaceous sandstone layers.
Parallel laminated sandstone.
Vertical accretion deposits.
D4
120m
Mudstone, slightly micaceous
Deposition from suspension under low energy conditions.
Purple siltstone
110m
Parallel laminated sandstone
Vertical accretion deposits.
D4
Green to purple mudstone
Parallel laminated purple siltstone with tiny mica flakes
Deposition at low flow power from traction currents carrying small amount of suspended sediments.
100m
Reddish parallel laminated sandstone
Possible vertical accretion deposits(?) or shallow lake deposits.
D4
Mudstone with small wood & branch pieces, Neuropteris ovata HOFFMANN var. ovata
90m
Micro-cross laminated sandstone
Red parallel laminated sandstone gradually passing upwards to siltstone & mudstone.
Possible lacustrine deposits.
F1
Covered, mainly mudstone
80m
60 metres gap
Covered
20m
Parallel laminated sandstone
Green parallel laminated siltstone with mica flakes
Overbank sequences of sandy low-sinuosity stream.
E1a
10m
Pebbly sandstone
Channel fill sequences of sandy low-sinuosity streams.
E1b
Planar cross bedded sandstone with iron coating
Possible transverse bars in the low-sinuosity stream channel.
E1b
Kızıllı village
0m
KIZILLI FORMATION
Fig.24

YAHYABEŞ SECTION (Azdavay)

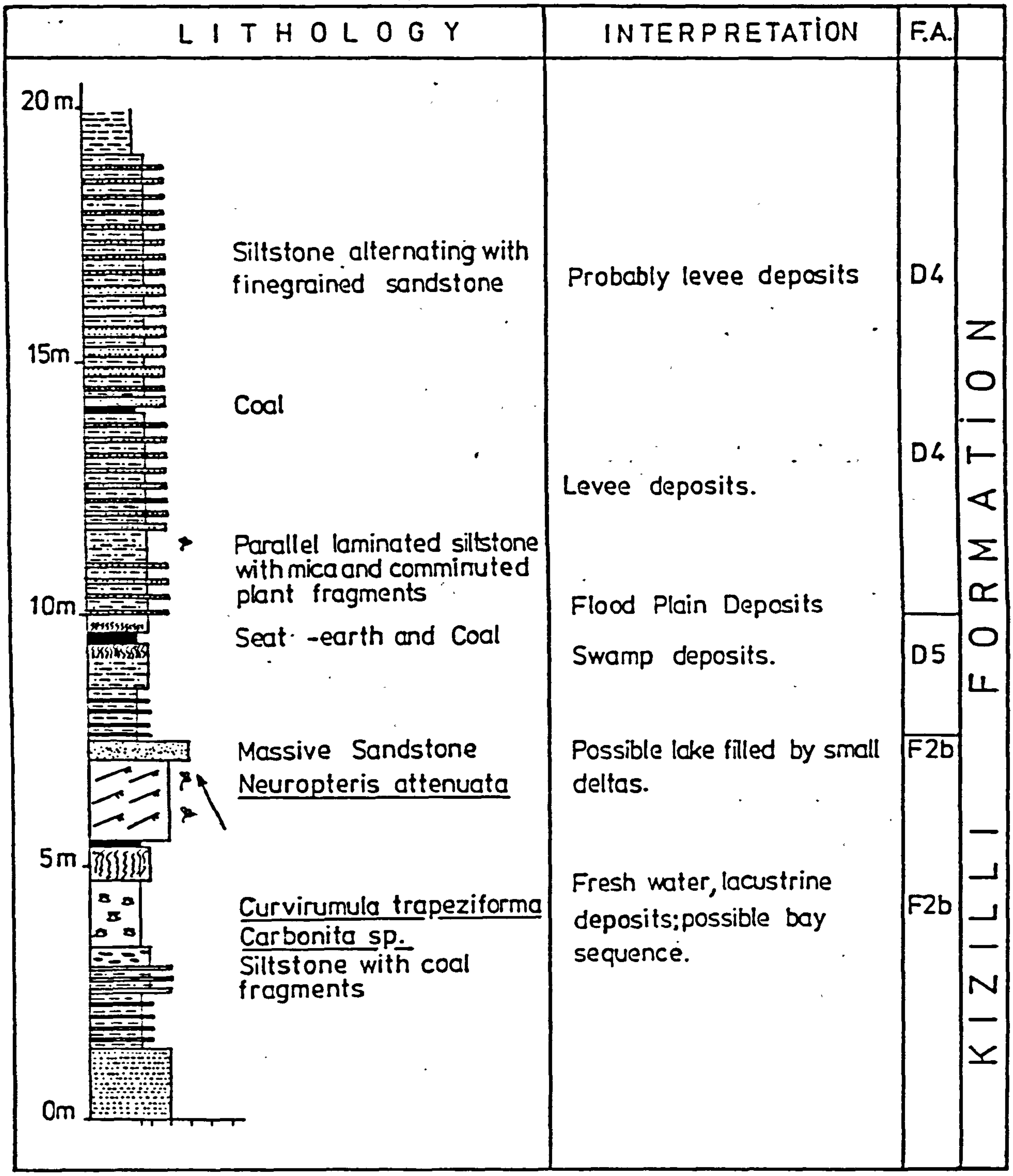
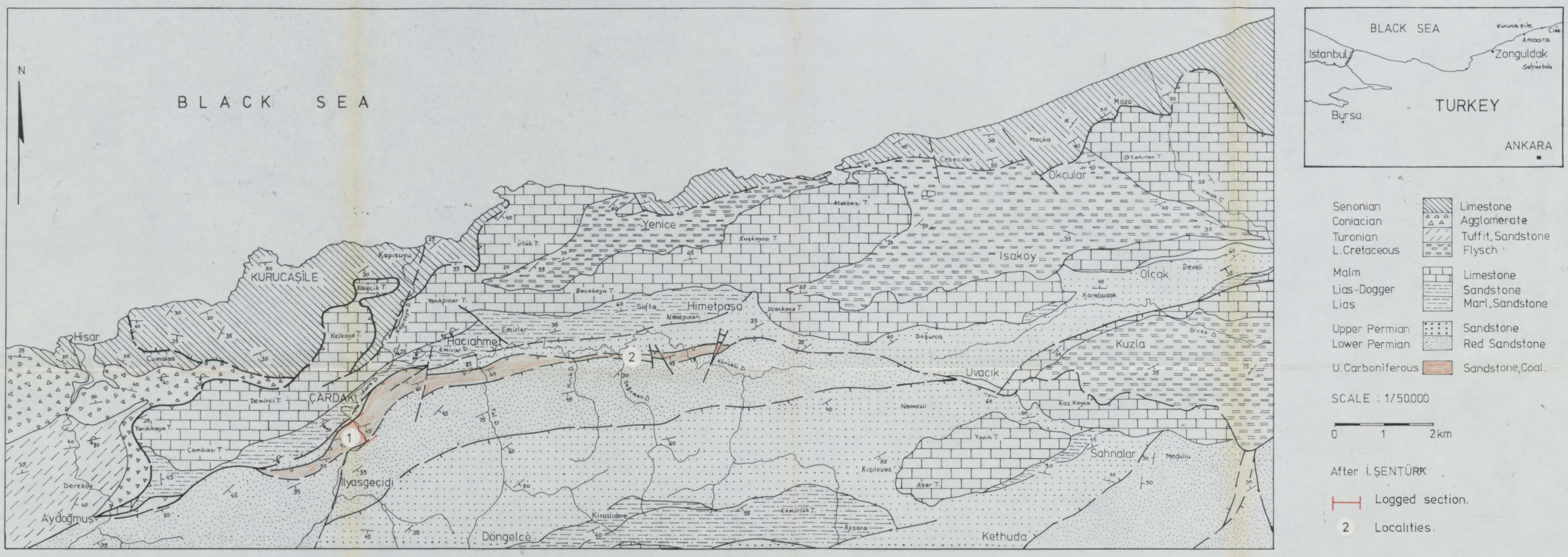
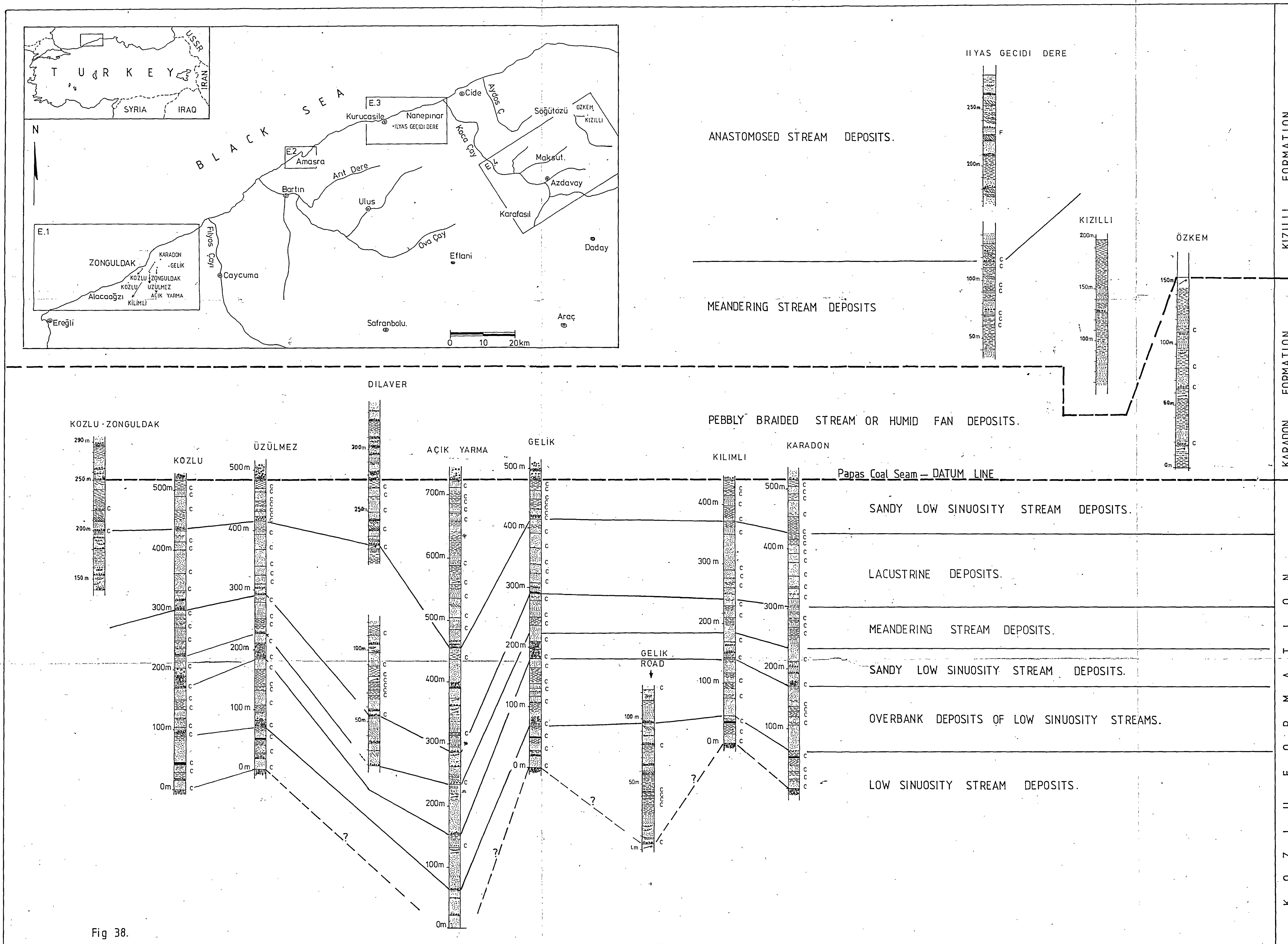


Fig 25.

GEOLOGICAL MAP OF KURUCAŞİLE AREA



ENCLOSURE 3.



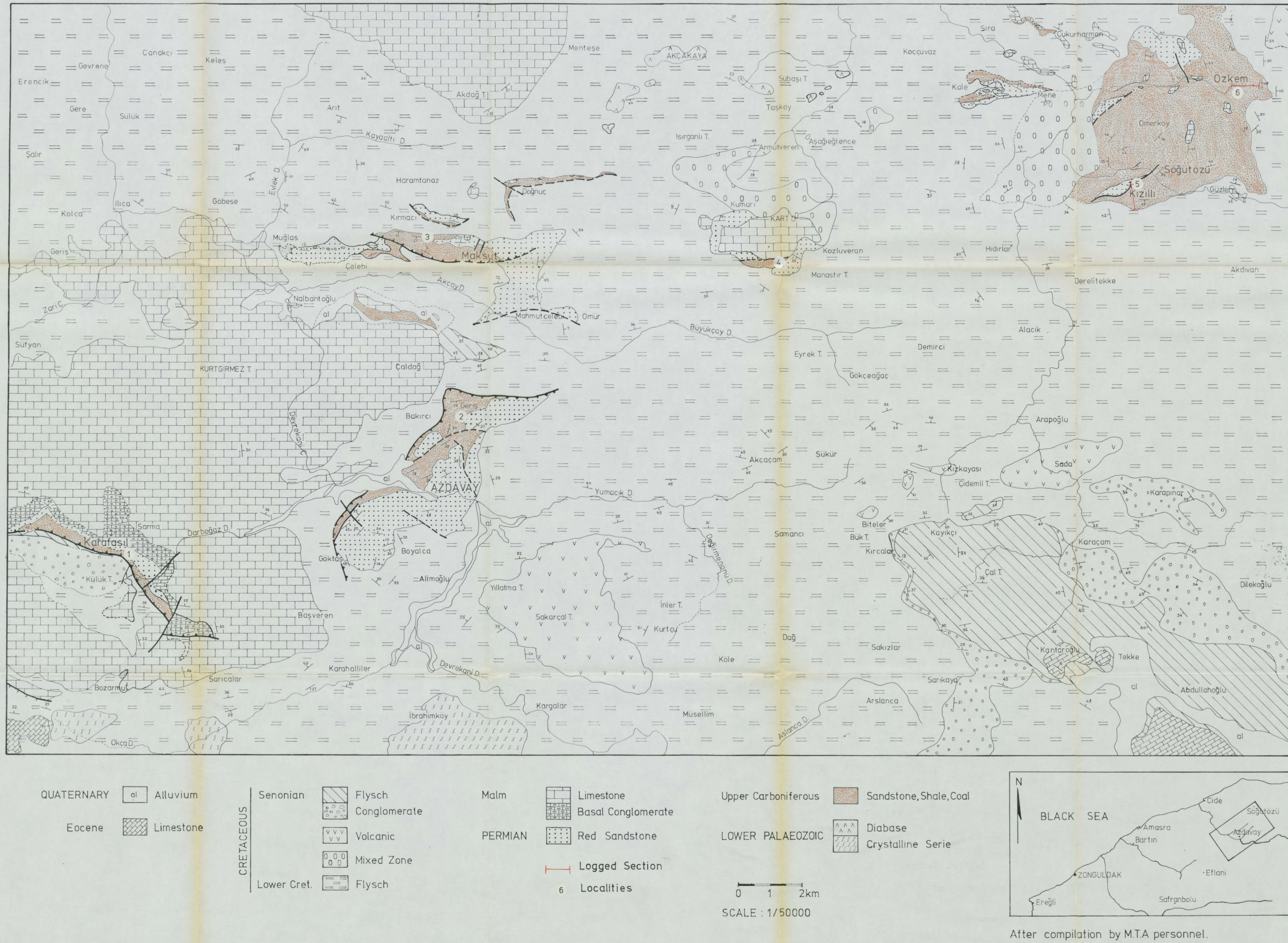
TURKEY
USSR
IRAN
SYRIA
IRAQ
N
BLACK SEA
E.1
E.2
E.3
Cide
Aydos Ç.
Söğütözü
ÖZKEM
KIZILLI
Kurucaşile
Nanepınar
ILYAS GEÇIDI DERE
Amasra
Koca Çay
Makşut.
Azdavay
Arıt Dere
Bartın
Ulus
Karafasıl
Ova Çay
Eflani
Daday
Filyos Çayı
Caycuma
ZONGULDAK
KARADON
GELİK
KOZLU
ZONGULDAK
KOZLU
ÜZÜLMEZ
AÇIK YARMA
KILIMLI
Alacaağzı
Ereğli
Safranbolu.
Araç
0 10 20km
ILYAS GECIDI DERE
KIZILLI
ÖZKEM
ANASTOMOSED STREAM DEPOSITS.
MEANDERING STREAM DEPOSITS
PEBBLY BRAIDED STREAM OR HUMID FAN DEPOSITS.
KIZILLI FORMATION
KARADON FORMATION
KOZLU FORMATION
DILAVER
KOZLU-ZONGULDAK
KOZLU
ÜZÜLMEZ
AÇIK YARMA
GELİK
KILIMLI
KARADON
GELIK ROAD
Papas Coal Seam — DATUM LINE
SANDY LOW SINUOSITY STREAM DEPOSITS.
LACUSTRINE DEPOSITS.
MEANDERING STREAM DEPOSITS.
SANDY LOW SINUOSITY STREAM DEPOSITS.
OVERBANK DEPOSITS OF LOW SINUOSITY STREAMS.
LOW SINUOSITY STREAM DEPOSITS.

Fig 38.

GEOLOGICAL MAP OF ZONGULDAK AREA IN TURKEY

After compilation by M.T.A personnel.

GEOLOGICAL MAP OF AZDAVAY AREA



ENCLOSURE 4.