SCHWEIZ. MINERAL. PETROGR. MITT. 82, XX1–XX19, 2002

Preliminary - For Proofreading

Mineralogic and organic responses to stratigraphic irregularities: an example from the Lower Paleozoic very low-grade metamorphic units of the Eastern Taurus Autochthon, Turkey

by *Ömer Bozkaya*[1], *Hüseyin Yalçın*[1] and *M. Cemal Göncüoğlu*[2]

Abstract

The paleogeographic and diagenetic-metamorphic evolution of Lower Paleozoic (meta-) sedimentary rocks in the Eastern Taurus Autochthon were studied by means of petrographic and XRD methods. Parameters such as illite crystallinity index, b_0 and % $2M_1$ proportion of K-white micas are characterized by an increase in grade from diagenesis at the top to epizone at the bottom. Organic data show a good correlation with phyllosilicate crystal chemical parameters. Three main zones and five sub-zones with distinct breaks at boundaries were distinguished throughout the Lower Paleozoic series. These boundaries seem to correspond to stratigraphic gaps, unconformities and/or irregularities that may have important implications regarding as yet unknown deformation events. The data indicate that the Eastern Taurus Autochthonous Unit was initially not only affected by typical sedimentary burial, but also preserved vestiges of an earlier regional thermal and/or deformational history. Alpine tectonic movements and related deformations caused but limited textural changes, thus did not completely erase some fingerprints of the Paleozoic mineralogic and organic transformations. The metamorphic evolution and relationships between the mineralogic, textural and organic properties and stratigraphic/metamorphic discontinuities in the Lower Paleozoic succession are controlled by diagenetic-metamorphic reactions and detrital input related to orogenic activity in the hinterland.

Keywords: clay mineralogy, very low-grade metamorphism, stratigraphic irregularities, Paleozoic, Taurus.

1. Introduction

Mineralogic (illite crystallinity = IC, $d_{(001)}$, basal intensity ratios, polytypes of K-micas and chlorite and b_0 of white micas) and organic matter maturation (organic matter reflection = OMR, conodont alteration index = CAI) studies of diagenetic to very low-grade metamorphic argillaceous sedimentary rocks have been used to reconstruct the thermal histories and the structural evolution of sedimentary basins and orogenic belts (i.e. FREY et al., 1980; HESSE and DALTON, 1991; WARR et al., 1991; YANG and HESSE, 1991). High-grade diagenetic to low-grade metasedimentary rocks mainly originate either from depositional burial and subsidence in sedimentary basins, from tectonic burial and heating in orogenic belts, or from hydrothermal alteration within contact metamorphic aureoles (HESSE and DALTON, 1991). Different tectonometamorphic settings at diagenetic to low-grade metamorphic conditions may be separated from one another by differences in their P-T-t paths (ENGLAND and THOMPSON, 1984; ROBINSON, 1987; BEVINS and ROBINSON, 1988; ROBINSON and BEVINS, 1989).

The Tauride-Anatolide Platform or the Tauride-Anatolide Composite Terrain (TACT, GÖNCÜOGLU et al., 1997) represents an Alpine continental microplate (Fig. 1). Surrounded by the northern and southern branches of the Neotethys, the TACT experienced crustal thickening related to the Latest Cretaceous Alpine closure of the Neotethyan ocean branches and subsequent collision with the surrounding continental microplates (e.g. SENGÖR and YILMAZ, 1981). The commonly accepted scenario for the evolution of the TACT

[1] Department of Geological Engineering, Cumhuriyet University, 58140 Sivas, Turkey. <bozkaya@cumhuriyet.edu.tr>
[2] Department of Geological Engineering, Middle East Technical University, 06531 Ankara, Turkey.

is that nappes or tectonostratigraphic units at the northern margin of the platform were sliced and emplaced towards the south onto a relatively autochthonous central part (Geyikdagı Unit of ÖZGÜL, 1976). These nappes can be followed in Turkey from the Aegean coast in the west to the Iranian border in the east.

In contrast to the allochthonous units of the Taurides, the relatively autochthonous Geyikdagı Unit contains better-preserved successions, in which Precambrian and Lower Paleozoic metasedimentary-sedimentary sequences can be studied in detail. Since the 1990s the overall assumption was that the Infracambrian to Permian deposition in this unit was continuous (e.g. DEMIRTASLI et al., 1983). More detailed biostratigraphic studies (DEAN and MONOD, 1990; GÖNCÜOGLU and KOZUR, 1998; GÖNCÜOGLU and KOZLU, 2000) have since identified important stratigraphic discontinuities within the Precambrian to Devonian successions of this unit. These findings may have critical implications on the Lower Paleozoic evolution of the Gondwanan margin. Preliminary petrographic studies in different parts of the Taurides, on the other hand, indicated that these stratigraphic irregularities are also reflected in the mineralogical composition of the lithostratigraphic units (e.g. BOZKAYA and YALÇIN, 1995, 1998). The aim of this study is to establish the thermal evolution by means of mineralogic and organic parameters, to explain the paleogeographic and diagenetic-metamorphic history, and finally find its response within the stratigraphic variations of the Lower Paleozoic rocks of the Geyikdagı Unit as a representative unit of the TACT. The mineralogic properties of the Upper Devonian to younger units including abundantly mixed-layer clays are beyond the scope of the present study due to the uselessness of the phyllosilicate parameters such as IC and b_0 (e.g. BOZKAYA and YALÇIN, 1998).

2. Geological Setting and Stratigraphy

Tectono-stratigraphic units of the TACT and their paleogeographic setting relative to the Geyikdagı Unit can be distinguished and differentiated by their stratigraphic and structural characteristics, as well as depositional and metamorphic features (ÖZGÜL, 1976). These units are called the “allochthonous units”. Palinspastically restored from north to south, they consist of: Bozkır, Bolkardagı, and Aladag units (Fig. 2a). The Bozkır Unit, the uppermost tectonic unit of the allochthonous nappe pile, mainly consists of Mesozoic slope to passive margin deposits. Within the Aladag Unit, the lowermost successions are Devonian in age, hence no information regarding the Early Paleozoic can be obtained. Detailed work on the

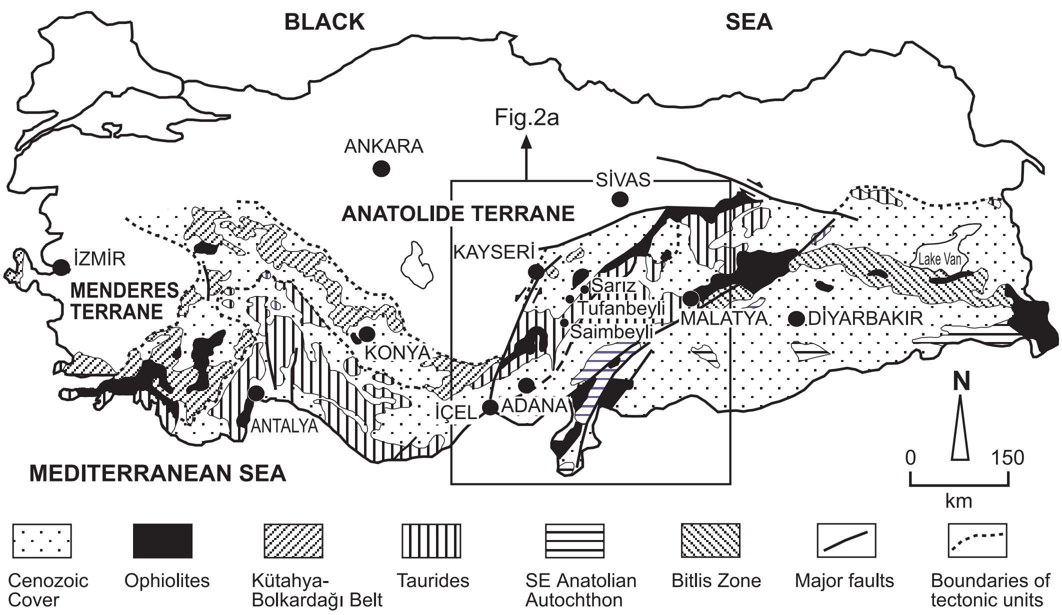

Fig. 1 Tectonic map of southern Anatolia (simplified from GÖNCÜOGLU, 1997).

Preliminary - For Proofreading

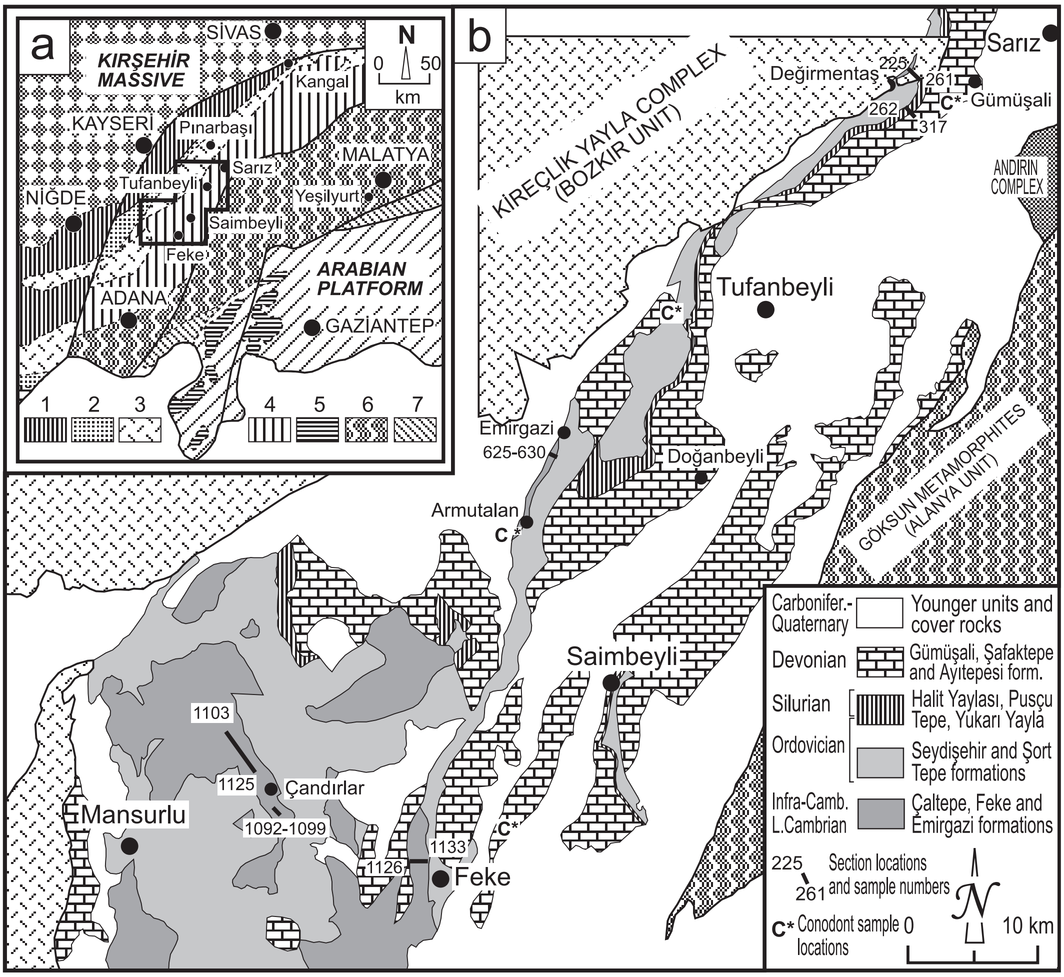

Fig. 2 (a) Tectono-stratigraphic overview of the Eastern Taurides, as proposed by ÖZGÜL (1976). 1 – Bolkardagı Unit, 2 – Aladag Unit, 3 – Bozkır Unit, 4 – Geyikdagı Unit, 5 – Antalya Unit, 6 – Alanya Unit, 7 – Misis Unit. (b) Geologic map of the Eastern Taurus Autochthonous Unit between Sarız and Feke (simplified from METIN et al., 1987), with sampling localities.

stratigraphy of the Bolkardagı Unit (also known as the Kütahya-Bolkardag Belt; GÖNCÜOGLU et al., 1997) indicated that a siliciclastic turbidite unit of mid-Late Silurian (middle part of Late Silurian) age is gradually followed by Early–Middle Devonian platform-type carbonates (GÖNCÜOGLU and KOZUR, 1998; GÖNCÜOGLU and KOZLU, 2000).

The study area is located between Kayseri and Adana in the western part of the Eastern Taurides (Fig. 2). The Eastern Taurus Autochthonous Unit (METIN et al., 1987) or the eastern part of the Geyikdagı Unit (ÖZGÜL, 1976), shows a relatively well-exposed section in the Sarız-Tufanbeyli-Saimbeyli area (Fig. 2b). In this area the Geyikdagı Unit is overthrusted by Kireçlikyayla melange (ERKAN et al., 1978), Andırın melange (METIN et al., 1987) and Göksun metamorphics (DEMIRTASLI et al., 1983).

The Lower Paleozoic parts of the autochthonous units, which were investigated in this study, consist of Emirgazi, Feke, Çaltepe, Seydisehir, Sort Tepe, Halit Yaylası, Pusçu Tepe, Yukarı Yayla and Ayıtepesi formations from bottom to top. The names of the formations were taken from previous studies (DEMIRTASLI, 1967; ÖZGÜL et al., 1973; DEAN and MONOD, 1990; KOZLU, 1990).

The Emirgazi formation is mainly made up of phyllitic slates and/or phyllites, alternating with metasiltstone, metasandstone and rarely recrystallized limestone (Fig. 3). The Feke formation is composed of purplish red colored metasandstones with yellow-green colored slate laminations. It overlies the Emirgazi formation with a sharp contact that is interpreted as a parallel unconformity (KOZLU and GÖNCÜOGLU, 1997). The overlying Çaltepe formation is characterized, from bottom to top, by white-gray dolomite, dark gray recrystallized limestone and green-pink nodular metalimestone of Upper Cambrian age (GÖNCÜOGLU and KOZUR, 1998). A transitional boundary exists to the overlying Seydisehir formation, which contains slate-metasiltstone alternations, intercalated with bands of recrystallized nodular limestone at the lower part, and shales alternating with siltstones at the middle to upper part. The lower part of this formation yields conodonts of Tremadocian age (GÖNCÜOGLU and KOZUR, 1999). Rocks of this member are more bright and cleaved than the overlying Arenigian parts and they show a distinct mineral orientation. After a stratigraphic gap including the Middle Ordovician and probably the lower part of the Upper Ordovician, the shales of the Ashgillian Sort Tepe formation unconformably overly the Seydisehir formation. Recent Darriwilian conodont findings from the Geyikdagı Unit in the southern Taurides (SARMIENTO et al., 1999) indicate that the Middle Ordovician rocks have been eroded in the studied area during the Ashgillian transgression.

The Late Ashgillian Halit Yaylası formation paraconformably overlies the Sort Tepe formation, and is made up of glacial conglomerates (GHIENNE et al., 2001) and sandstones including silty shale alternations. The Lower Silurian Pusçu Tepe formation includes shale and black shale-siltstone alternations. The Yukarı Yayla formation includes shales with limestone interlayers and was deposited during mid-Silurian. After a stratigraphic gap, that may cover the Upper to uppermost Silurian, the Lower Devonian Ayıtepesi formation unconformably covers the older units. It is followed by the Middle Devonian Safaktepe formation, represented by dolomitic limestone and limestone with sandstone-shale alternations that also include layers with conglomerate and sandstone with volcanic detritus in its upper part in some local areas (BOZKAYA and YALÇIN, 1995). It is unconformably overlain by Gümüsali (Upper Devonian) and Ziyarettepe (Lower Carboniferous) formations respectively. The Yıgıltepe formation unconformably overlying the Devonian rocks, is of Permian age and contains sandstone-limestone-dolomitic limestone with shale laminations.

3. Material and Analytical Methods

A total of 290 rock samples were collected along the measured sections (Fig. 2) across the Lower Paleozoic formations and were analyzed by X-ray diffraction (XRD) techniques and optical methods (optical microscopy, VR and CAI). Minerals and their textural properties were also determined by optical microscopy. XRD whole-rock analyses were conducted on a Rigaku X-ray diffractometer (type DMAX IIIC) with the following settings: CuKα, 35 kV, 15 mA, slits (divergence=1°, scatter=1°, receiving=0.15 mm, receiving-monochromator=0.30 mm) and scan speed 2°2θ/min. The scan speed was 1°2θ/min for oriented clay minerals and illite crystallinity measurements as recommended by KISCH (1991). Sample preparation and clay fraction separation processes were performed in the Geological Engineering Department of Cumhuriyet University (CU). Total rock and clay fraction (<2 µm) of fine grained metasedimentary rocks were described and the semi-quantitative percents of their mineral phases were calculated by the use of multi-component mixtures as external standards sensu BRINDLEY (1980). Clay fractions separated by the sedimentation method were analyzed at normal (air dried), glycolated (remained in a desiccator at 60 °C for 16 hours) and heated (heating at 490 °C for 4 hours) conditions. Quartz was used as an internal standard for the measurements of d-spacing of clay minerals.

The width of the 10-Å illite peak at half-height (illite crystallinity = IC) was measured as Δ°2θ values based on the Kübler index (KÜBLER, 1968, 1984). For the calibration of the IC measurements, the crystallinity index standards (CIS) supplied by WARR and RICE (1994) were used. A linear regression equation of $IC_{CIS}=1.1565xIC_{CU}-0.0669$ with $R^2=0.9894$ was obtained. All IC values are indicated and plotted as recalculated values. Since the 10-Å illite peak for paragonite-muscovite (intermediate sodium potassium mica = PM) and paragonite is widened asymmetrically towards high angles (FREY, 1987; FREY et al., 1988), IC values could not be measured in samples containing these minerals. IC values were not measured in diagenetic carbonate-rich samples due to possible negative effects of acid-treated calcareous samples (KRUMM, 1984; KÜBLER, 1984). Moreover, samples with less than approximately 50% illite in their clay fraction were excluded from IC determinations due to insufficient counting statistics.

The b_0 parameter, an empirical indicator of pressure (SASSI and SCOLARI, 1974; GUIDOTTI and SASSI, 1986; RAMIREZ and SASSI, 2001), was meas-

Preliminary - For Proofreading

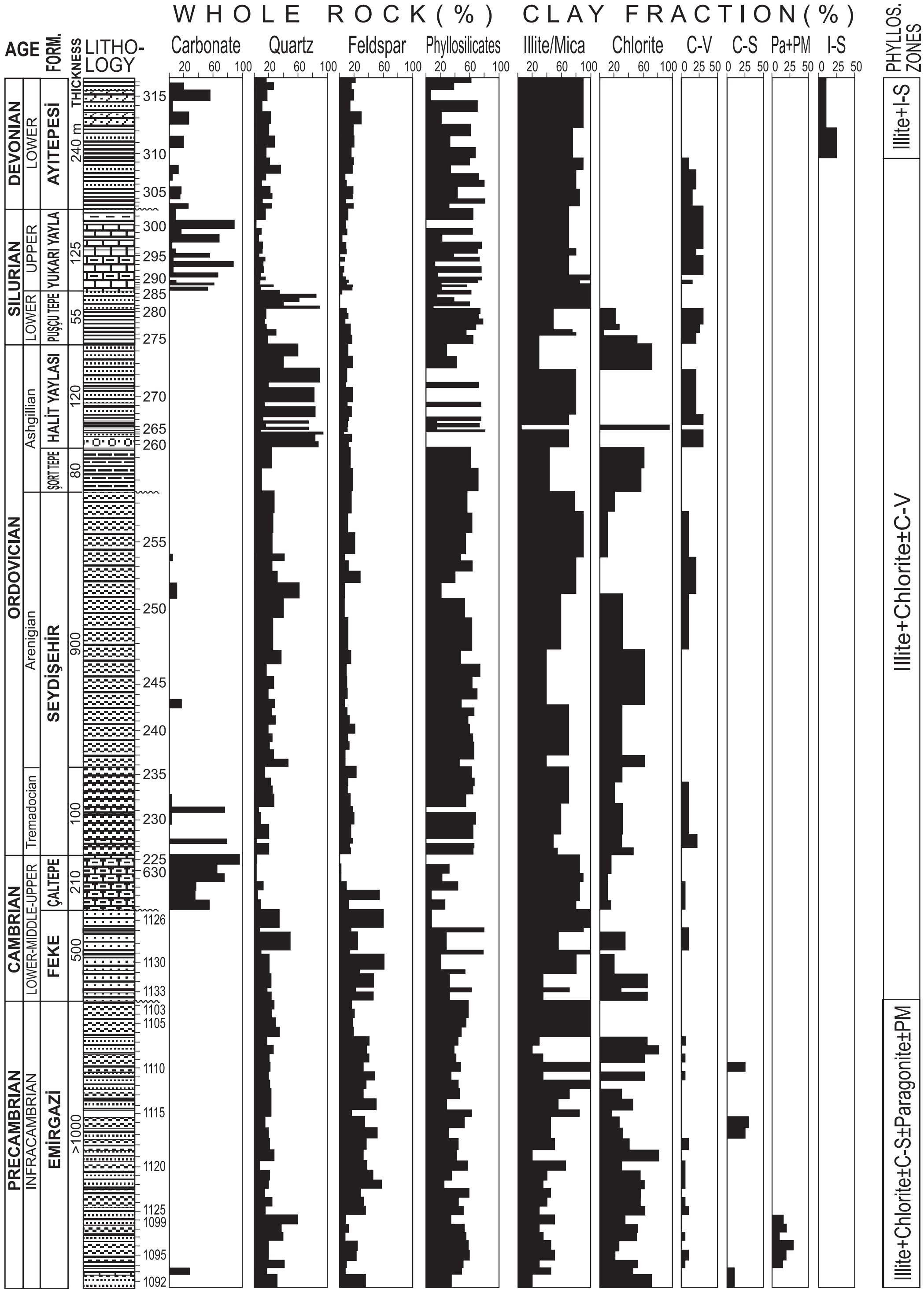

Fig. 3 (a) and (b). Vertical distribution of mineralogic and organic data in the Lower Paleozoic part of the Eastern Taurus Autochthonous Unit.

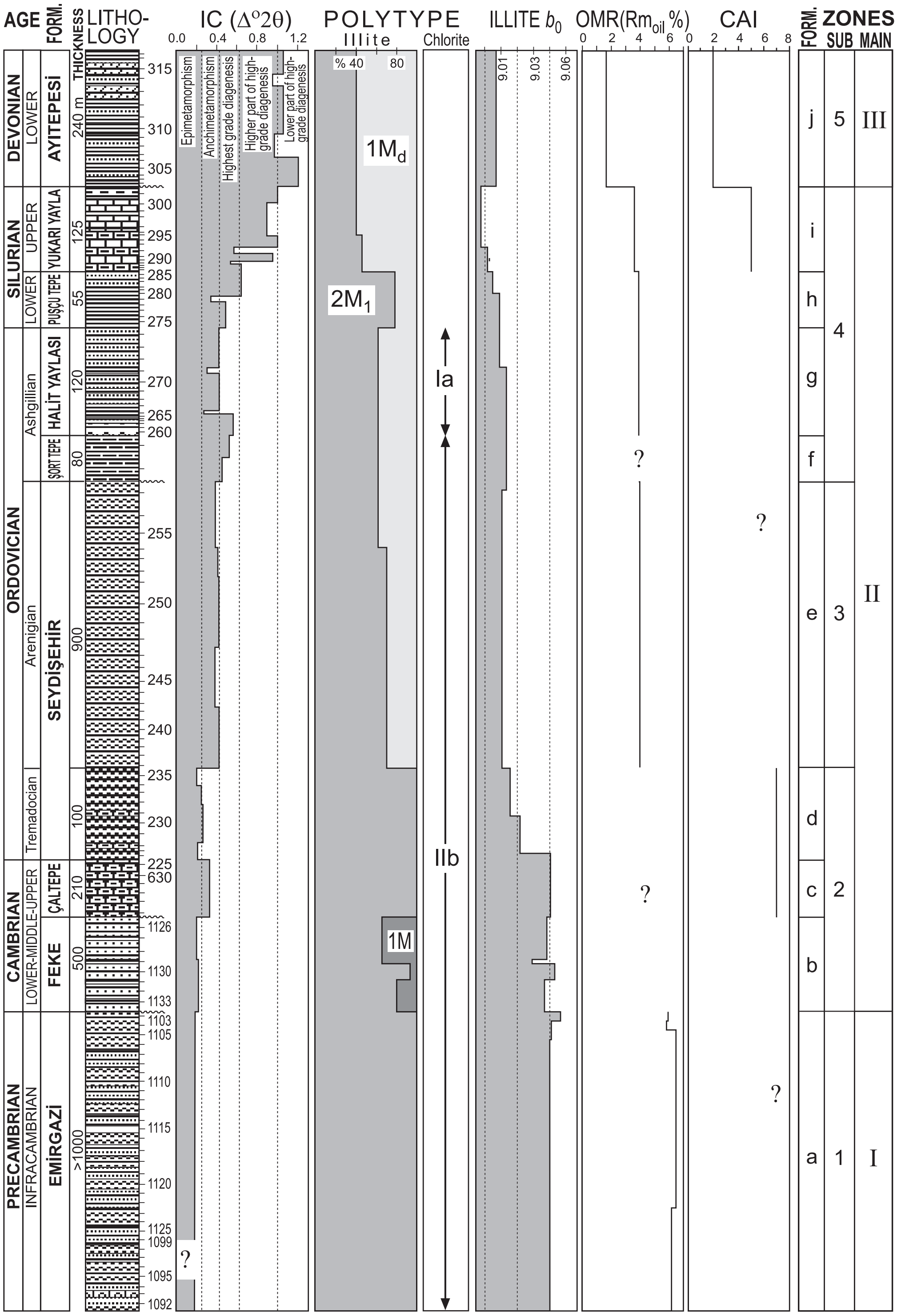

Fig. 3b

Preliminary - For Proofreading

ured on $d_{(060)}$ reflections using the (211) peak of quartz ($2\theta = 59.97°$, d = 1.541 Å) as a reference.

Illite and chlorite polytypes were determined with the diagnostic peaks between 2θ = 16–36° and 31–52° on non-oriented powder samples, respectively (BAILEY, 1988). To determine $2M_1$ and/or 1M % contents of $2M_1 + 1M_d$ and/or $2M_1$ + 1M + $1M_d$ polytype-bearing illite/muscovites, the ratios of $I_{(2.80)}/I_{(2.58)}$ Å and $I_{(3.07\ Å)}/I_{(2.58)}$ Å suggested by GRATHOFF and MOORE (1996) were used. The structural formulas of chlorites were calculated by using the XRD methods (BRINDLEY, 1961; BROWN and BRINDLEY, 1980; CHAGNON and DESJARDINS, 1991). In addition, for geothermometry purposes sensu CATHELINEAU (1988), chlorites in two samples were analyzed by Cameca Electron Microprobe (EMP) at the Université Blaise Pascal of Clermont-Ferrand (France) using mineral standards supplied by the BRGM (Orléans). The measurement device settings were 15 kV accelerating potential, 10 nA beam current and 10 s count time.

Vitrinite reflectance was measured in the Devonian to Cretaceous formations. In the Precambrian to Silurian formations the evolution of vitrinite plant precursors was not developed. In these units, solid homogeneous bituminite was used as proposed by CIULAVU et al. (2001). Bituminite has many optical similarities to vitrinite and due to a significant 1:1-correlation (bituminite versus vitrinite reflectance) in the range of values between 2.0 to 6.0 Rm_{oil}%, bituminite can be used in the same way like vitrinite reflectance (FERREIRO MÄHLMANN, 2001). The term organic matter reflectance (CIULAVU et al., 2001) used in our study refers to both, to the combined use of vitrinite and bituminite reflectance (FERREIRO MÄHLMANN, 1995).

The samples selected for organic matter reflectance (OMR) measurements were first treated with 10% HCl and then their total organic carbon (TOC) contents were measured at CU using a Leco SC 444 sulphur and carbon analysis instrument. Organic matter from samples with high TOC values was separated and polished sections were prepared. OMR values were determined with a Leitz-Wetzlar MPV II type microscope, 50x objective, mercury lamp (CS 100 W-2), double B12 filter and one B38 heating-absorbing filter, K510 barrier filter and point counter at Hacettepe University, Ankara. For OMR measurements, saphire (0.551% R) and glass (1.23% R) standards were used for calibration of the microscope. The measurements of mean random reflectance (Rm_{oil}%) were performed under oil and the rank of coalification is based on the North American ASTM-classification (TEICHMÜLLER, 1987). CAI data were compiled from GÖNCÜOGLU and KOZUR (1998, 1999).

4. Petrography

4.1. COMPOSITION AND TEXTURE

Lower Paleozoic metasedimentary rocks mainly include quartz, sericite, chlorite, plagioclase, calcite, dolomite, and rarely muscovite, biotite, zircon, tourmaline, goethite, pyrite and specular hematite minerals. Fine-grained biotite and zoned plagioclase, and alkali feldspar and specular hematite are typical minerals for the Emirgazi and Feke formations, respectively. In addition, perthitic orthoclase and granitic and metamorphic rock fragments are found in clastic rocks observed in the lowermost interval of the Late Ordovician Halit Yaylası formation.

(Meta-) clastic rocks show a clear metamorphic trend from Ordovician to Precambrian (Fig. 4a–h). Phyllitic slates, phyllites and metasiltstones are the dominant lithologies for the Emirgazi formation in which the primary clastic texture is commonly obliterated and a typical crenulation cleavage is superimposed on a slaty cleavage (Figs. 4a–b). Partly better preserved clastic texture and weakly developed cleavages are characteristic features for the slates of the Feke formation (Fig. 4c).

Samples from the Tremadocian and Arenigian part of the Seydisehir formation and also the Seydisehir and Sort Tepe formations were distinguished from each other by means of their characteristic microfabrics such as bedding-parallel with ?? weakly crenulation and cleavage (Figs. 4d–f), and weakly bedding and missing orientation (Figs. 4g– ?? h). On the basis of the field appearance, Tremadocian slates can be distinguished from Arenigian pencilled mudstones and/or siltstones. The Silurian and younger units of the Paleozoic formations entirely comprise diagenetic textured silisiclastic and carbonate rocks.

4.2. CHLORITE-MICA STACKS

Chlorite-mica stacks (=CMS) are found in slates and metasiltstones from the Seydisehir formation (Figs. 4e–h). The CMS are cut by cleavage planes (S_1) perpendicular to their long axes, and thus they show shortened shapes. Long axes of the CMS are generally parallel to the bedding (S_0), but at high angle to the poorly developed cleavage planes (S_1).

In the Tremadocian facies, deformed ellipsoidal and lozenge shapes of CMS and their stubby

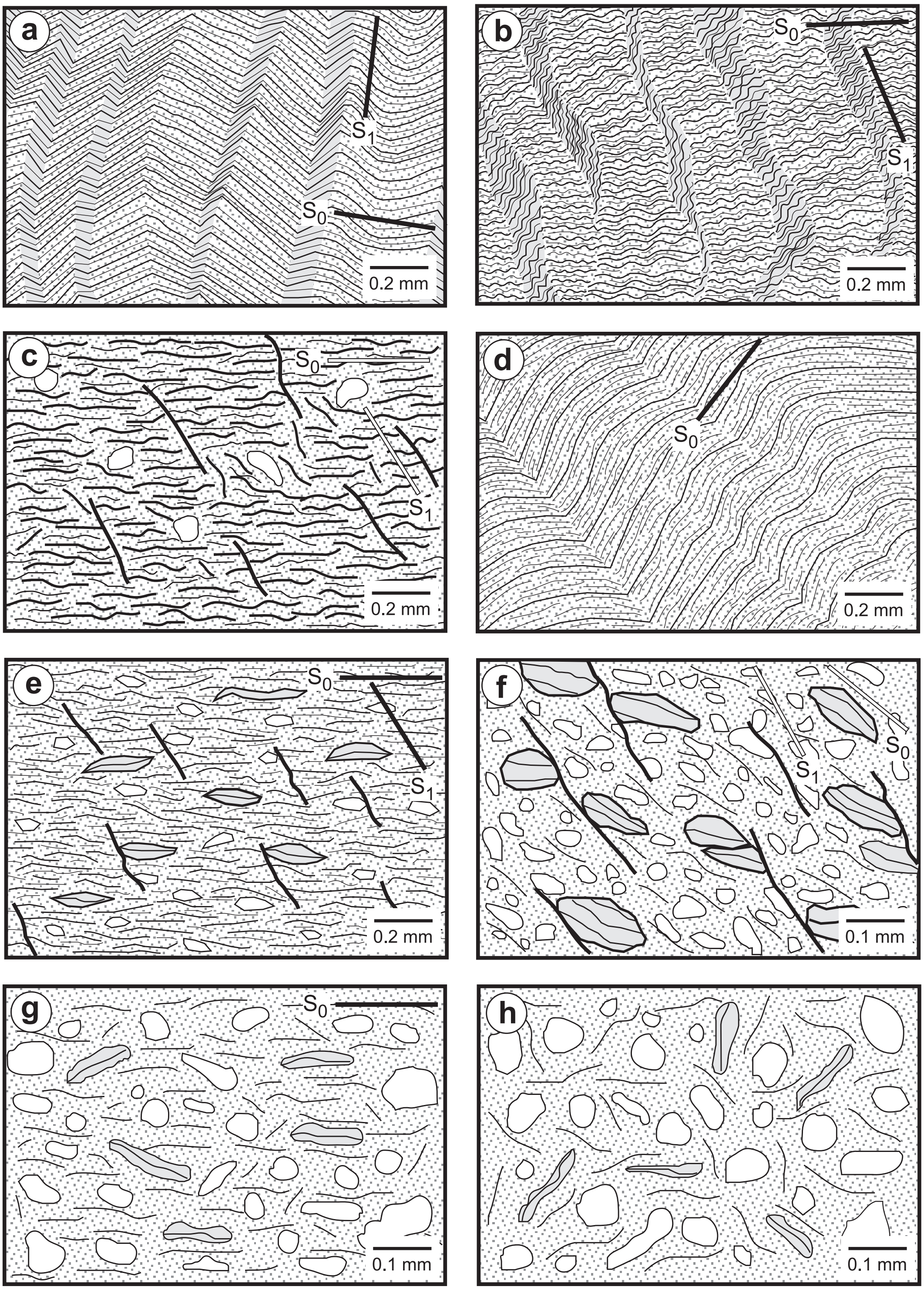

Fig. 4

Preliminary - For Proofreading

forms due to cutting by the cleavage (Fig. 4e) indicate that the CMS existed in the rock prior to the formation of the slaty cleavages. Therefore, it is believed that these CMS developed from clastic micas. The fact that the {001} planes of the phyllosilicates in most CMS are nearly parallel to the bedding, together with the observation of chloritized biotite relics and Fe-rich chlorites in some CMS of the Arenigian part, may indicate that they were formed by the alteration of detrital biotites.

The CMS anomalously increase in the Tremadocian part compared with the Arenigian part. In addition, biotites of the CMS were completely chloritized in the Tremadocian facies, but they were partly transformed into chlorites in the Arenigian facies. These observations indicate another petrographic criterion for distinguishing these facies, besides the above mentioned microfabric differences.

5. X-ray Mineralogy

5.1. BULK AND PHYLLOSILICATE MINERAL ASSEMBLAGES

Lower Paleozoic formations mostly contain, in the order of abundance, phyllosilicates, quartz, alkali feldspar, plagioclase and little amounts of calcite and dolomite. The amounts of quartz are enhanced in the Halit Yaylası formation, of feldspar in the Emirgazi and Feke formations, and of carbonates in the Çaltepe and Yukarı Yayla formations (Fig. 3a). Metacarbonates and carbonate rocks are composed of calcite, dolomite and detrital clasts such as quartz, plagioclase and phyllosilicates.

With respect to their relative amounts, phyllosilicates show a wide variety in mineral contents of illite, chlorite, mixed-layered chlorite-vermiculite (C-V), chlorite-smectite (C-S), illite-smectite (I-S), PM and paragonite. The different mixed-layer mineral phases were identified using the methods by Moore and Reynolds (1997). Among the phyllosilicate minerals, illite/muscovite is found in all units. Chlorite is mostly detected in the Cambrian–Ordovician, while C-V occurs in the Silurian–Devonian and the Cambrian-earliest Ordovician. C-S, PM and paragonite are only detected in the Emirgazi formation (Fig. 5), while I-S is only observed in the Ayıtepesi formation. The vertical distribution of the phyllosilicate minerals from Devonian to Cambrian shows a progressive evolution with stratigraphic depth. Three zones are distinguished on the basis of clay mineral associations (Fig. 3a): illite + chlorite ± C-S ± PM ± paragonite (Emirgazi formation = main zone I), illite + chlorite + C-V (Feke, Seydisehir, Sort Tepe, Halit Yaylası, Pusçu Tepe and Yukarı Yayla formations = main zone II), illite + I-S (Ayıtepesi formation = main zone III).

Increasing amounts of chlorite and illite, while decreasing C-V and I-S towards depth, indicate that C-V and I-S reflect an intermediate stage in transformation of vermiculite to chlorite and smectite to illite during burial diagenesis (Hoffman and Hower, 1979; Chang et al., 1986; Bozkaya and Yalçin, 1998). Among the other interlayering clay minerals, C-S appears locally in the Emirgazi formation including volcanogenic material and therefore a similar alteration process from biotite to C-S is assumed as described by Inoue et al. (1984) and Inoue and Utada (1991). On the other hand, PM and paragonite appear only in the Emirgazi formation.

5.2. ILLITE CRYSTALLINITY

Data on IC of the Lower Paleozoic units are presented in Figs. 3b and 6 showing values from high grade diagenesis to epizone. There is a clear trend of the I(002)/I(001) ratio towards higher values with decreasing metamorphic grade (Fig. 6).

The Emirgazi and Feke formations entirely show epimetamorphic IC values ($\Delta°2\theta$ = 0.19–0.22). The Çaltepe formation and Tremadocian parts of the Seydisehir formation are formed of high grade anchizonal and epizonal degrees ($\Delta°2\theta$ = 0.19–0.36). The Arenigian parts of the Seydisehir formation contain low-grade anchimetamorphic crystallinity degrees ($\Delta°2\theta$ = 0.38–0.42), whereas the IC of the Ashgillian Sort Tepe formation points to highest grade diagenetic conditions.

←*Fig. 4* Typical textural features of diagenetic and very low-grade metamorphic rocks from the Eastern Taurus Autochthon. (a) Crenulation folds and weak cleavage in phyllitic slates (TFK-1095) of the Emirgazi formation, (b) Distinct crenulation type of the slaty cleavage in phyllites (TFK-1105) of the Emirgazi formation, (c) Weak cleavage planes in slates (TFK-1129) of the Feke formation, (d) Weak crenulation folds in slates (TTB-227a) in the Tremadocian parts of the Seydisehir formation, (e) Weak cleavage planes in the slates with chlorite-mica stacks (TTB-226) in the Tremadocian parts of the Seydisehir formation, (f) Weak cleavage planes in the metasiltstones including abundantly chlorite-mica stacks (TTB-237) in the Arenigian parts of the Seydisehir formation, (g) Oriented grains parallel to S_0 in the metasandstones (TTB-241) in the Arenigian parts of the Seydisehir formation, (h) Unoriented detrital constituents in the metasandstone (TTB-250) in the Arenigian parts of the Seydisehir formation.

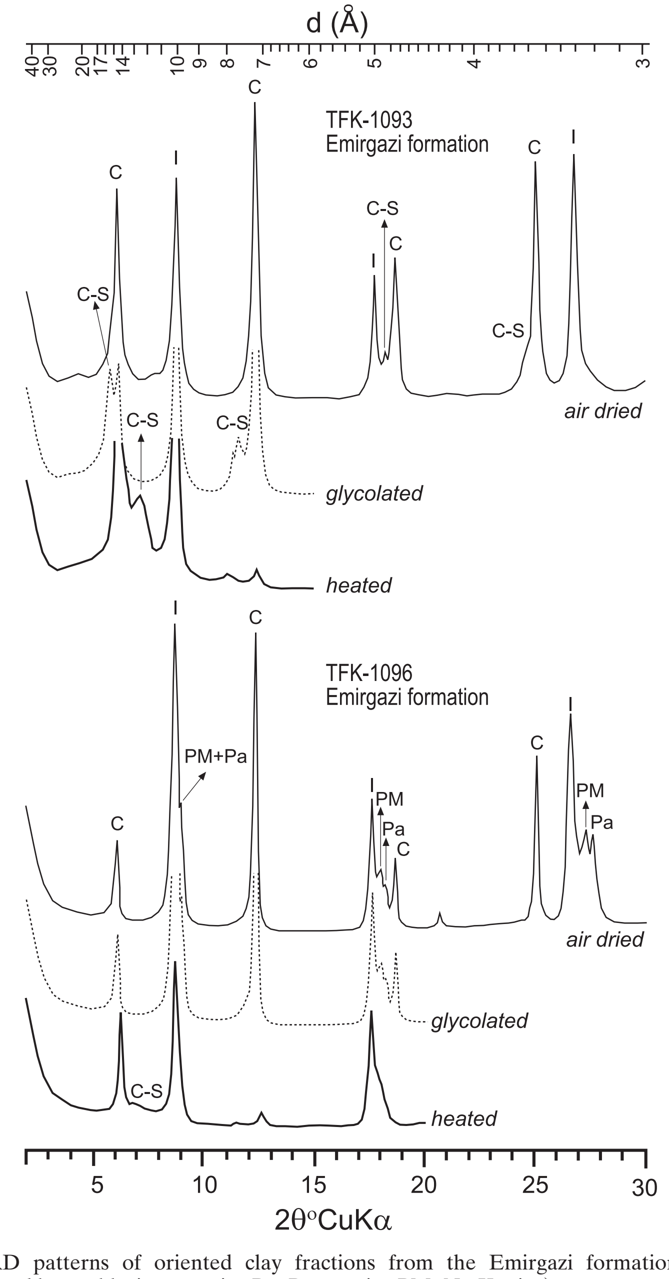

Fig. 5 Typical XRD patterns of oriented clay fractions from the Emirgazi formation (I=Illite/muscovite, C=Chlorite, C-S=Mixed layer chlorite-smectite, Pa=Paragonite, PM=Na-K mica).

The Halit Yaylası, Pusçu Tepe and Yukarı Yayla formations have highest grade diagenetic IC values ($\Delta°2\theta = 0.27–0.63$), while the Ayıtepesi formation yielded high- to low-grade diagenetic crystallinities ($\Delta°2\theta = 0.53–1.21$). The relatively high IC values in the Halit Yaylası formation is controlled by the abundance of detrital micas as determined by optical microscopy. On the basis of the IC values, three main zones and three subzones with sudden transition boundaries are determined. The diagenetic-metamorphic grades corresponding to these zones are summarized in Table 1.

Preliminary - For Proofreading

Table 1 Zoneography of diagenetic-metamorphic grade of the main zones and subzones in the Lower Paleozoic section of the Eastern Taurus Autochthonous Unit.

Zone		Diagenetic-Metamorphic Grade	IC (°Δ2θ)
III	5	Lower part of high-grade diagenesis	IC ≥1.0
II	4	Higher part of high-grade diagenesis	1.00 > IC ≥ 0.62
		Highest-grade diagenesis	0.62 > IC ≥ 0.42
	3	Lower part of anchimetamorphism	0.42 > IC ≥ 0.33
	2	Higher part of anchimetamorphism	0.33 > IC ≥ 0.25
I	1	Epimetamorphism	IC < 0.25

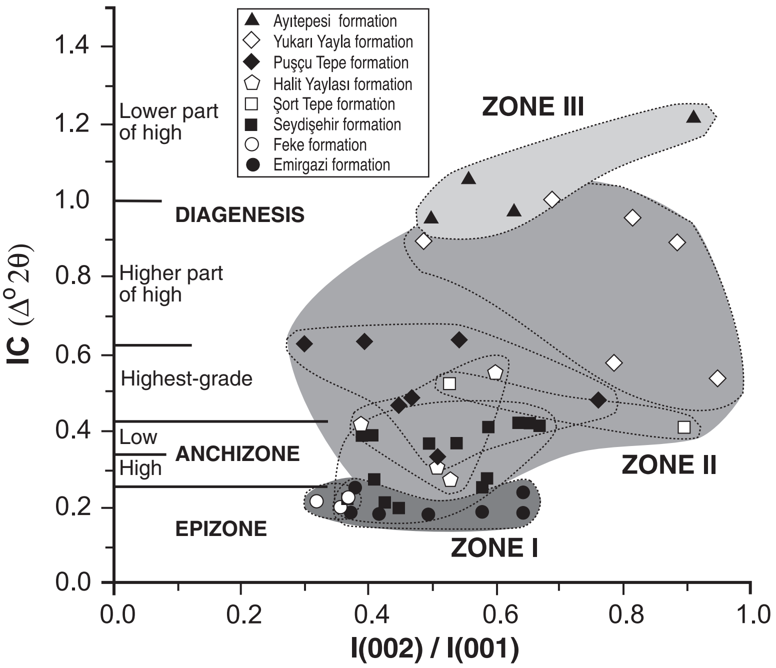

Fig. 6 IC versus I(002)/I(001) diagram of the Lower Paleozoic units in the Eastern Taurus Autochthonous Unit.

5.3. b_0 VALUES OF K-WHITE MICAS

The $d_{(060)}$ or b_0 values of illites or their octahedral Mg+Fe contents (determined on the basis of the regression equation suggested by HUNZIKER et al., 1986) increase from upper to lower parts in the Lower Paleozoic section (Fig. 3). They show a moderately positive correlation with IC. This correlation indicates a direct relationship between diagenetic-metamorphic grade and illite composition. Moreover, $d_{(060)}$ or b_0 values are grouped as main zones I, II and III, similar to the phyllosilicate paragenesis and IC data (Fig. 3b). The $d_{(060)}$ values of illites are 1.5037–1.5087 Å (average 1.5064 Å), 1.5009–1.5022 Å (average 1.5016 Å) and 1.4991–1.5011 Å (average 1.5002 Å) in zones I, II and III, respectively. High $d_{(060)}$ values of the Feke formation are related to the presence of 1M celadonitic mica.

According to these evaluations, the average Mg+Fe contents of illites are 0.33, 0.39 and 0.63 in the three main zones, respectively, and increase with metamorphic grade. With respect to these data, the illites show a progressive evolution towards a more phengitic composition (BOZKAYA and YALÇIN, 1999), from the upper to the lower parts of the succession. On the other hand, a rise in Mg+Fe content of illites together with metamorphic grade caused lower I(002)/I(001) ratios (Fig. 6), as previously determined by ESQUEVIN (1969).

Table 2 Microprobe analyses of major elements and structural formulas of chlorites (Numbers are mean values and numbers of measurements are given in brackets. All Fe is given as FeO).

Sample No	TTB-226(6)	TTB-259(5)
SiO_2	24.91	25.52
TiO_2	0.07	0.01
Al_2O_3	22.04	22.38
FeO	26.18	26.52
MnO	0.30	0.43
MgO	12.70	11.11
CaO	0.23	0.13
Na_2O	0.02	0.07
K_2O	0.05	0.06
H_2O	11.19	12.05
Σ	97.69	98.28
Tetrahedral		
Si	2.68	2.75
Al	1.32	1.25
T.C.	–1.32	–1.25
Octahedral		
Al	1.47	1.59
Ti	0.01	0.00
Fe^{2+}	2.35	2.39
Mn^{2+}	0.03	0.04
Mg	2.03	1.78
O.C.	1.26	1.20
T.O.C.	5.89	5.80
Interlayer		
Ca	0.03	0.02
Na	0.00	0.01
K	0.01	0.01
I.L.C.	0.06	0.05
T.L.C.	–0.06	–0.05

T.C. = Tetrahedral Charge, O.C. = Octahedral Charge, T.O.C. = Total Octahedral Cation,
ILC = Interlayer Charge, T.L.C. = Total Layer Charge.

5.4. STRUCTURAL FORMULAS OF CHLORITE

The tetrahedral Al and octahedral Fe^{+2} contents of chlorite were calculated from XRD basal reflections based on the equations of BRINDLEY (1961), BROWN and BRINDLEY (1980) and CHAGNON and DESJARDINS (1991). Average structural formulas on the basis of 14 oxygen were determined to be $(Si_{3.0}\ Al_{1.0})\ (Mg_{3.4}\ Al_{1.0}\ Fe^{+2}_{1.6})\ O_{10}\ (OH)_4$ for neoformed chlorite and $(Si_{3.0}\ Al_{1.0})\ (Mg_{3.4}\ Al_{1.0}\ Fe^{+2}_{1.6})\ O_{10}\ (OH)_4$ for CMS origin in the main zone I. Some neoformed chlorite in the sandstones in the Halit Yaylası formation (subzone 4g) contains excess Fe^{+2} (> 5).

5.5. CHLORITE THERMOMETRY

EMP analyses of authigenic or neoformed chlorites in the samples with no C-V and/or C-S interstratifications as detected by XRD, from the Seydisehir and Sort Tepe formations, were calculated on the basis of 14 oxygen and their structural formulas are given in Table 2. The empirical equation of CATHELINEAU (1988), using the Fe/(Fe+Mg) corrections of XIE et al. (1997), were applied for the determination of chlorite thermometry data. The samples with no C-V and/or C-S interstratifications as detected by XRD were selected for chlorite thermometry considering the criticism of various authors (SCHMIDT et al. 1997; MERRIMAN and PEACOR, 1999; FERREIRO MÄHLMANN, 2001). Chlorite (n = 6) in sample TTB-226 from the Tremadocian part of the Seydisehir formation (low epizone-high anchizone; subzone 2d) give a mean temperature of 265 ± 25 °C. Data for chlorite (n = 5) in sample TTB-259 from Sort Tepe formation (low-anchizone-high grade diagenesis; subzone 4f) correspond to a temperature of 229 ± 15 °C.

5.6. SMECTITE CONTENTS AND CRYSTALLITE SIZE OF K-WHITE MICA

Contents of swelling smectitic layers in illite/muscovite were determined using the XRD methods of SRODON (1984) and EBERL and VELDE (1989). Smectite contents of illite increase from Cambrian to Devonian. Proportions of smectite layers of illite/muscovite are 0–2, 3–4 and 4% in Cambrian-Ordovician, Silurian and Devonian formations, respectively.

The crystallite size of white K-mica decreases from metamorphic to diagenetic units from 20–50 nm for Cambrian–Ordovician, to 15–17 nm for Silurian, to 10 nm for Devonian rocks also using the XRD method proposed by EBERL and VELDE (1989).

5.7. POLYTYPES

Different illite/muscovite polytypes were found in the Lower Paleozoic units showing combinations of $2M_1$, $2M_1 + 1M_d$ and $2M_1 + 1M$. 1M polytypes are restricted to the Feke formation (Fig. 7). $2M_1$-contents of illite increase from Devonian to Ordovician formations (Fig. 3). There is a positive correlation between % $2M_1$ and IC data. On the other hand, two sudden transitions were found between Tremadocian–Arenigian parts of the Seydisehir formation, Pusçu Tepe and the Yukarı Yayla formations as well as at the boundaries of the IC main zones I-III. Chlorites are only Ia polytypes in the Halit Yaylası formation, whereas IIb polytypes occur in the older formations (Fig. 7).

Preliminary - For Proofreading

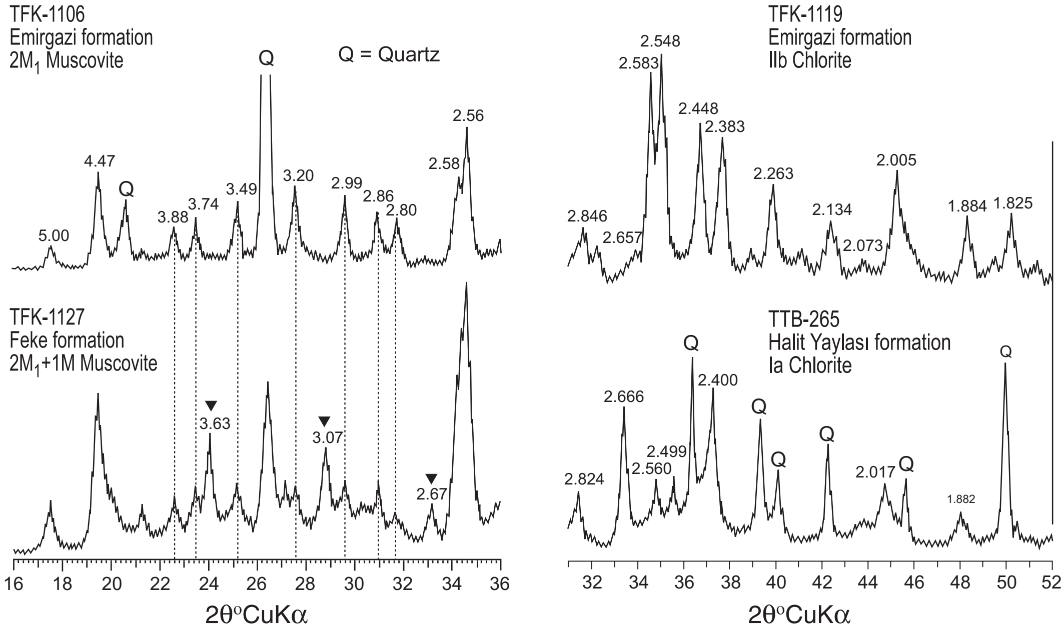

Fig. 7 Unoriented XRD patterns of illite and chlorite polytypes (dashed lines for $2M_1$, triangles for 1M reflections).

6. Organic Petrography

6.1. ORGANIC MATTER REFLECTIVITY

The Silurian (Pusçu Tepe), Carboniferous (Ziyarettepe) and Permian (Yıgıltepe) units contain a higher amount (1.44–14.46%) of TOC with respect to the other Paleozoic units. OMR values of the Lower Paleozoic samples increase from Devonian to Ordovician formations (Table 3, Figs. 3b and 8). The rank of coalification of the Emirgazi formation is of the meta-anthracite stage, for the Seydisehir to Yukarı Yayla formations it is of the anthracite stage, and for the Ayıtepesi formation of the low volatile bituminous stage. From the overlying formations, the Devonian Gümüsali formation is coalified in the high volatile bituminous stage, whereas the Carboniferous Ziyarettepe and the Permian Yıgıltepe formations show a rank of the sub-bituminous to high volatile bituminous coalification stage. OMR values show a positive correlation with IC data (Fig. 3b), there are, however, two drastic drops between the Emirgazi and Seydisehir formations, and between the Yukarı Yayla and Ayıtepesi formations.

6.2. CONODONT ALTERATION INDEX

Conodonts of the Çaltepe and Seydisehir formations have CAI values around 7. The next conodont-bearing unit is the Yukarı Yayla formation with a CAI value of 5 (GÖNCÜOGLU and KOZUR, 1998). Further up, Devonian formations have a distinctly lower CAI (2–3) with respect to the underlying formations (GÖNCÜOGLU and KOZUR, 1999).

7. Regional Geological Comments

The presence of volcanic rocks together with the high amount of zoned plagioclase and C-S in the clastic rocks of the Emirgazi formation indicate a period of extensive magmatic activity during the Precambrian. This aspect was previously recognized in the Western Taurides (e.g. GÜRSU and GÖNCÜOGLU, 2001a), but overlooked in the Eastern Taurides. Moreover, the association of paragonite, PM and C-S is a mineralogic response of the Emirgazi formation having been deposited in an extentional-transtentional basin characterized by relatively high heat flow and associated with active volcanism, as stated by KOZLU and GÖNCÜOGLU (1997). Felsic volcanic rocks in the Western Taurides have geochemical fingerprints of A-type felsic extrusives, formed during a post-collisional extensional event (GÜRSU and GÖNCÜOGLU, 2001a), not only in the Taurides but also in different parts of the NW Gondwanan pericratonic margin (e.g. GÖNCÜOGLU, 1997; SALEH, 2001) during the late pan-African orogen-

Table 3 VR data from the Lower Paleozoic section of the Eastern Taurus Autochthonous Unit.

Zone		Formation	Sample No	Mean Rm%	n	S.D.
III	5j	Ayıtepesi	TTB-314	1.64	4	0.13
II	4i	Yukarı Yayla	TTB-287	3.61	50	0.47
	4h	Pusçu Tepe	TTB-281a	3.79	52	0.50
	3e	Seydisehir	TTB-238	4.16	6	0.98
I	1a	Emirgazi	TFK-1103	5.94	28	0.68
			TFK-1104	5.87	11	0.70
			TFK-1105	6.47	31	0.67
			TFK-1123	6.07	9	0.83

n = measurement number, S.D. = standard deviation.

ic event. In the Western Taurides, GÜRSU and GÖNCÜOGLU (2001b) also showed that the pre-Lower Cambrian slates were affected by distinct deformation and very low-grade metamorphism, prior to deposition of Lower to Middle Cambrian Feke-type clastic rocks. Textures (Figs. 4a–b) and mineral assemblages in the Emirgazi Formation indicate a post-sedimentary very low-grade metamorphic event predating the deposition of the Feke formation, which has not been recognized previously.

The isolated appearance of 1M polytype celadonitic mica in the Feke formation may be related to an enrichment of magmatic (probably volcanic) detritus (MERRIMAN and ROBERTS, 1985; LOPEZ-MUNGUIRA et al., 1998). These studies also suggest that, prior to the deposition of the Feke formation, a period of rapid uplift occurred in the source region, by which the relatively deep-seated rhyolitic/quartzporphyritic rocks of the Emirgazi formation were eroded. This interpretation supports the idea that the lower boundary of the Feke formation represents an erosional unconformity overlying a pan-African basement (GÖNCÜOGLU, 1997; GÖNCÜOGLU and KOZLU, 2000).

Anomalously different phengite contents or b_0 cell parameters and high $2M_1$ % ratios of white K-micas in the Çaltepe formation with respect to the underlying Feke formation (relatively low b_0 values but the presence of 1M celadonitic mica) and the Tremadocian parts of the Seydisehir formation may be interpreted as mineralogic evidence for an important difference in the source regions. This may indicate regional paleotopographic irregularities or a change in the sediment transport direction during the Late Cambrian, as proposed by GÖNCÜOGLU (1997).

Sudden changes in IC, polytype variations and different b_0 values between the Tremadocian and Arenigian parts of the Seydisehir formation (Fig. 3b: subzone 2d–3e) can be interpreted in different ways. They may correspond to an important event, not yet identified by lithostratigraphic or biostratigraphic means in the Taurides. The anomalous increase of CMS in the Tremadocian part of the Seydisehir formation, on the other hand, may be interpreted by accommodation of volcanogenic biotite detritus into the depositional environment. However, there are no known biotite-rich pre-Lower Ordovician volcanic rocks in the Taurides. The only possible source for this kind of detritus are the Late Cambrian-Early Tremadocian island-arc volcanic rocks in the basement of the Istanbul Terrane in the north (GÖNCÜOGLU et al., 1997). This volcanism is assumed to result from southward subduction of the Iapetus oceanic plate beneath the northern Gondwana margin that gave way to the opening of a back-arc basin, in which the Seydisehir formation was deposited (GÖNCÜOGLU, 1997).

More critical are the obvious differences in mineral contents (Fig. 3b) between the Arenigian parts of the Seydisehir formation (subzone 3e) and the Ashgillian Sort Tepe formation (subzone 4f). An important stratigraphic hiatus encompassing the whole Middle Ordovician and lower Late Ordovician is recorded by paleontological data (DEAN and MONOD, 1990). We assume that the mineralogical variations at this boundary together with the regional anomalies such as stratigraphic hiati, unconformities and irregular distribution of the Ordovician units in the different parts of the Taurides reflect an important and yet unknown tectonic event in the Taurides that may record the Sardian movements in the peri-Gondwana shelf (KOZUR and GÖNCÜOGLU, 1998). Recently, VON RAUMER et al. (2002) suggested that this event is recorded in many other places in southern Europe and may be ascribed to the amalgamation of some continental terranes with Gondwana prior to the opening of an Early Paleozoic Tethys (Paleo-Tethys *sensu* STAMPFLI, 1996).

The latest Ordovician period, represented by the Halit Yaylası formation (subzone 4g) is characterized by the deposition of fluvio-glacial and glacio-marine deposits with high amounts of exot-

Preliminary - For Proofreading

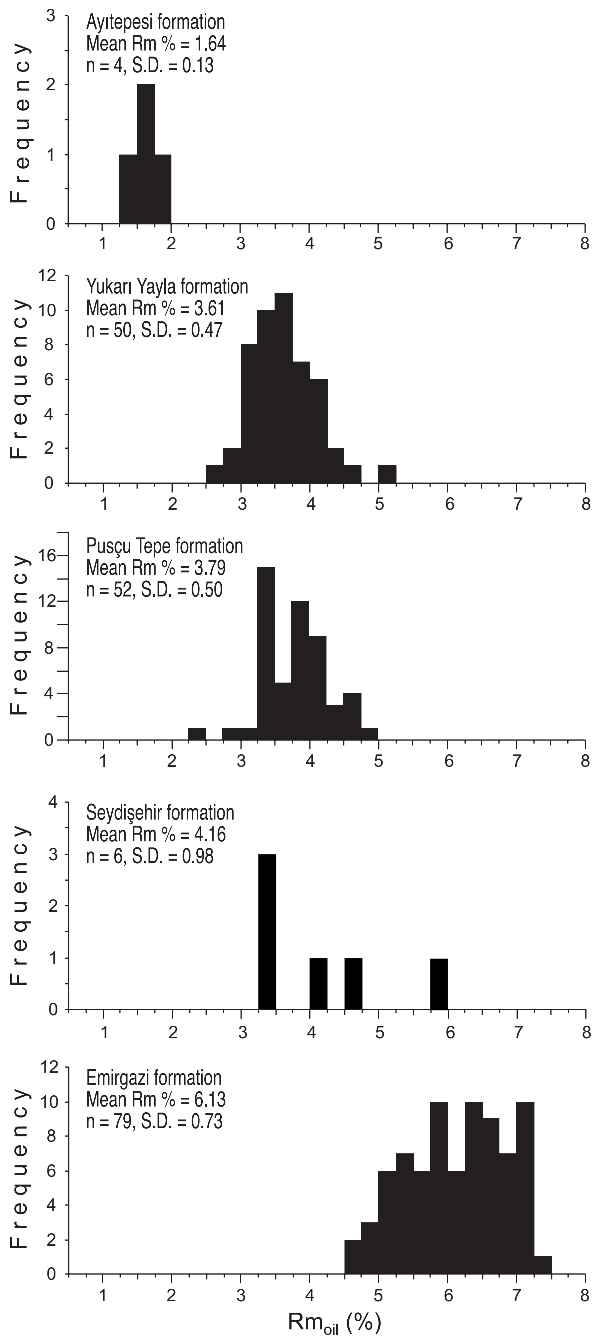

Fig. 8 Frequencies of VR (Rm$_{oil}$%) measurements in the Lower Paleozoic formations of the Eastern Taurus Autochthonous Unit.

ic pebbles, such as two-mica gneisses, granites-rhyolites and quartzites (GHIENNE et al., 2001). The relatively low IC values compared to the data at the top and the bottom of the formation are caused by detrital micas. Also the enrichment in detrital quartz grains is indicative for an external source that may very probably be the "Panafrican" basement of the Northern Africa/Arabian Peninsula. It is important to note that in previous studies (e.g. DEAN and MONOD, 1990; KOZUR and GÖNCÜOGLU, 1998) the Halit Yaylası formation was assigned to an Early Silurian age and the glacial coarse clastics in this formation were considered to be the basal conglomerates indicating an Early Silurian unconformity (e.g. DEMIRTASLI, 1967).

The Early Silurian in the Taurides is characterized by a regional transgression that was ascribed to rapid sea-level changes following the latest Ordovician glacial event (GÖNCÜOGLU and KOZUR, 1998) at the Perigondwana margin. This event is represented by the deposition of black shales with a very high content in organic matter in the Pusçu Tepe formation that has TOC values of up to 14.5%. Such very unusual TOC values are typical for the "hot shales" in N Gondwana (LÜNNIG et al., 2000) and may be used for a paleoclimatologic and paleogeographic correlation.

The Yukarı Yayla formation shows typical features of the higher parts of the high-grade diagenesis with low b_0, but high CAI and OMR. The Ayıtepesi formation has the lowest IC with lower parts of high-grade diagenetic degree and OMR values of the Lower Paleozoic formations. The sudden change in the CAI value of the Yukarı Yayla formation (CAI=5), compared with that of the overlying Devonian rocks (CAI=2–3) and the stratigraphic gap during the latest Silurian is indicative for a distinct event that has been ascribed to a Caledonian-time thermal alteration by KOZUR and GÖNCÜOGLU (1998). This event is also recorded in the peri-Gondwanan terranes in Eastern Europe and ascribed to the high heat-flow, related to the rifting along the northern Gondwana margin and the opening of the Paleo-Tethys (e.g. VON RAUMER et al., 2002).

8. Conclusions

Due to an increase in the grade of diagenesis/metamorphism, the degree of textural, mineralogic, chemical and organic parameters are increased depending on the stratigraphic age towards lower parts of the Lower Paleozoic succession. Based on mineralogic and organic data we have differentiated three main zones and five subzones in the Lower Paleozoic units and correlated the mineralogic data with the established stratigraphic gaps and/or unconformities ascribed to different geologic events during the Lower Paleozoic.

The CMS are generally parallel to the (S_0), but at high angle to the (S_1) in the autochthonous units. However, allochthonous rocks of the Taurides have varying angles among these (YALÇIN and BOZKAYA, 1997; BOZKAYA and YALÇIN, 1997, 2000). These differences are due to significant deformational propagation of stacks during allochthonous transportation, emplacement and thrusting to the south, as pointed out by the above-mentioned authors. This is an important criterion for differentiating between allochthonous and autochthonous units in the Taurides. Microfabric variations and also the abundances of the CMS and chloritization degree of biotites in the CMS is petrographic evidence for distinguishing the Tremadocian and Arenigian facies of the Seydisehir formation.

The percentage of $2M_1$, illite/mica polytypes and b_0 increases with decreasing IC values. There are good correlations among IC, % $2M_1$ and b_0 of illites/micas. These data indicate that the diagenetic-metamorphic characteristics of the Eastern Taurus Autochthonous unit were mainly caused by sedimentary burial at the initial site of deposition. The increasing b_0 values of the illites may also indicate increasing pressures towards the lower part (SASSI et al., 1976; GUIDOTTI and SASSI, 1986), except for the Feke, Çaltepe and Halit Yaylası formations because of the dominance of their detrital nature.

The IC pattern in the Lower Paleozoic formations shows a general trend with distinct irregularities. Furthermore, the marked changes (Figs. 3b and 6) in white K-mica chemistry, polytype composition, illite/muscovite b_0-parameter, organic matter VR and CAI between Emirgazi-Feke (subzone 1–2), Tremadocian–Arenigian part of Seydisehir (subzone 2–3), Seydisehir-Sort Tepe (subzone 3–4), and Yukarı YaylaAyıtepesi (4–5) formations correspond to more or less well established geologic events. Mineralogic/compositional difference of phyllosilicates between subzones 1 and 2, 3 and 4 as well as 4 and 5 are interpreted as metamorphic hiati or discontinuities reflecting stratigraphic unconformities. These hiati may be explained by regional correlations of tectono-metamorphic events known from other parts of the Taurides (KOZLU and GÖNCÜOGLU, 2000) as well as from some Gondwanan-peri-Gondwanan terranes, which display a similar succession during the Early Paleozoic. The data is yet inadequate to explain the metamorphic jump between the subzones 2 and 3. It may be related to a distinct change in the type of the detritus and hence in the source area or alternatively a thermal event prior to the deposition of Arenigian facies, which has not yet been identified by other geologic studies.

According to the CAI, there are considerable changes between the Seydisehir and Yukarı Yay-

Preliminary - For Proofreading

la, and between the Yukarı Yayla and Ayıtepesi formation. A more precise discrimination based on CAI in the former case is not possible as there is no CAI data from the Upper Ordovician sediments. In the second case, however, the CAI data is in line with the mineralogic and stratigraphic data. Considering the middle part of the Upper Silurian being deposited in the Kütahya-Bolkardag Belt in the central Taurides, this change indicates a distinct geological event during the latest Silurian.

In the study area the transition from the diagenetic to the anchimetamorphic zone is positioned within the uppermost part of the Ordovician Sort Tepe formation (Fig. 6), whereas in the allochthonous units of northern origin in the Taurides, the transition is between the Devonian and/or Carboniferous and underlying units (BOZKAYA and YALÇIN, 1997; YALÇIN and BOZKAYA, 1997; YALÇIN et al., 1999; BOZKAYA and YALÇIN, 2000). These differences imply that sedimentary burial was not exceeded by higher grades of diagenesis/metamorphism during and after the tectonic transport, which is the case for the northerly derived allochthonous nappes in the Taurides (e.g. YALÇIN and BOZKAYA, 1997; BOZKAYA and YALÇIN, 2000).

In conclusion, this preliminary study has clearly shown the presence of mineralogic changes within the Lower Paleozoic succession of the Eastern Taurus Autochthonous unit that correspond to stratigraphic irregularities. These may help to identify preserved fingerprints of regional geological events during the Early Paleozoic. The later tectonic movements and related deformations during the Cretaceous–Tertiary Alpine orogenesis only changed some limited textural features, but caused no extensive overprint. The parameters to determine metamorphic grade, in other words the differences in the mineralogic, petrographic and coal petrologic data, corresponding with stratigraphic/metamorphic discontinuities in the Lower Paleozoic section are controled by different tectono-thermal histories. A specific tectono-metamorphic history affects each section between two limiting unconformities, but each section is also influenced by detrital inputs containing fingerprints related to orogenic events in the hinterland. Finally, the earlier orogenic inheritances and sediment supplies should be taken into consideration in addition to the classic diagenetic/metamorphic processes for the construction of the very low-grade metamorphic patterns. The authors are aware of the fact that more detailed multi-disciplinary studies are required for a more comprehensive picture to decipher the very complex succession of events in the Taurides.

Acknowledgements

This study partly comprises the results of a project founded by the Research Foundation of Cumhuriyet University and is a contribution to IGCP Project No 421. The authors would like to express their thanks to Fatma Yalçın and Dr. Ümit Sengül, of the Mineralogy-Petrography and Geochemistry Laboratories of the Engineering Faculty of Cumhuriyet University, for their help in the laboratory studies, and to Zeynel Basıbüyük for his contribution in the field and laboratory work. They acknowledge Dr. A. Ihsan Karayigit (Hacettepe University, Ankara) for the measurement of organic matter reflectances and Dr. Hüseyin Kozlu (Turkish Petroleum Corporation, Ankara) for his valuable contributions on the stratigraphy of the Eastern Taurides. Additionally, we thank the reviewers, Dr. Meinert Rahn, Swiss Federal Nuclear Safety Inspectorate (Switzerland), Dr. Rafael Ferreiro Mählmann, University of Basel (Switzerland) for their helpful suggestions and critical comments. We also appreciate the constructive comments by Dr. Susanne Th. Schmidt, Université de Genève (Switzerland). ?Rahn Adress?

REFERENCES

BAILEY, S.W. (1988): X-ray diffraction identification of the polytypes of mica, serpentine, and chlorite. Clay Clay Min. 36, 193–213.

BEVINS, R.E. and ROBINSON, D. (1988): Low-grade metamorphism of the Welsh Basin Lower Paleozoic succession: an example of diastathermal metamorphism? J. Geol. Soc. London 145, 363–366.

BOZKAYA, Ö. and YALÇIN, H. (1995): Lithology and mineralogy of Eastern Tauride autochthonous and cover rock units (Sarız-Tufanbeyli-Saimbeyli region). Bull. Fac. Eng. Cumhuriyet Univ. Serie-A Earth Sci. 12, 1–37 (in Turkish, English abstract).

BOZKAYA, Ö. and YALÇIN, H. (1997): Mineralogic-petrographic characteristics of Devonian-Triassic diagenetic-very low-grade meta-sedimentary rocks from Aygörmez nappe (Pınarbası-Kayseri). Geosound, Spec. Symp. 20th Anniversary Geol. Eng. Edu. Çukurova Univ., 30 April–2 May, Adana. 30, 807–832 (in Turkish, English abstract).

BOZKAYA, Ö. and YALÇIN, H. (1998): Diagenesis and very low-grade metamorphism related to sedimentary burial of Paleozoic rocks in the Eastern Taurus Autochthon. Bull. Turkish Assoc. Petrol. Geol. 10, 35–54 (in Turkish, English abstract).

BOZKAYA, Ö. and YALÇIN, H. (1999): Relationships between degree of diagenesis-metamorphism and chemistry of phyllosilicates from Eastern Taurus Autochthon. Proc. 9th Turkish National Clay Symp. Istanbul Univ. 21–30. (in Turkish, English abstract).

BOZKAYA, Ö. and YALÇIN, H. (2000): Very low-grade metamorphism of Late Paleozoic–Early Mesozoic sedimentary rocks related to sedimentary burial and thrusting in the Central Taurus Belt, Konya, Turkey. Int. Geol. Rev. 42, 353–367.

BRINDLEY, G.W. (1961): Chlorite minerals. In: BROWN, G. (ed.): The X-ray Identification and Crystal Structures of Clay Minerals, Min. Soc. London, 242–296.

BRINDLEY, G.W. (1980): Quantitative X-ray mineral analysis of clays. In: BRINDLEY, G.W. and BROWN, G. (eds): Crystal Structures of Clay Minerals and Their X-ray Identification. Min. Soc. London, 411–438.

BROWN, G. and BRINDLEY, G.W. (1980): X-ray diffraction procedures for clay mineral identification. In: BRINDLEY, G.W. and BROWN, G. (eds): Crystal Structures of Clay Minerals and Their X-ray Identification. Min. Soc. London, 305–360.

Cathelineau, M. (1988): Cation site occupancy in chlorites and illites as a function of temperature. Clay Min. 23, 471–485.

Chagnon, A. and Desjardins, M. (1991): Détermination de la composition de la chlorite par diffraction et microanalyse aux rayons X. Can. Mineral. 29, 245–254.

Chang, H.K., Mackenzie, F.T. and Schoonmaker, J. (1986): Comparisons between the diagenesis of dioctahedral and trioctahedral smectite, Brazilian offshore basins. Clay Clay Min. 34, 407–423.

Ciulavu, M., Ferreiro Mählmann, R., Seghedi, A. and Frey, M. (2001): Very low grade metamorphism in the Danubian window, South Carpathians (Romania). EUG 11, Diagenesis and Low-Grade Metamorphism, J. of Conference Abstracts 6/1, p. 231.

Dean, W.T. and Monod, O. (1990): Revised stratigraphy and relationships of Lower Palaeozoic rocks, eastern Taurus Mountains, south central Turkey. Geol. Mag. 127, 333–347.

Demirtasli, E. (1967): Lithostratigraphic units and oil potential of the area between Pinarbasi-Sariz-Magara. M.T.A. Report No. 4389, Ankara (In Turkish).

Demirtasli, E., Metin, S. and Ayhan, A. (1983): Stratigraphy of the Eastern Taurus Autochthon. Int. Symp. Geol. Taurus Belt for Excursion I. Field Guide Book. 7–16.

Eberl, D.D. and Velde, B. (1989): Beyond the Kübler index. Clay Min. 24, 571–577.

England, P.C. and Thompson, A.B. (1984): Pressure-temperature-time paths of regional metamorphism; 1. Heat transfer during the evolution of regions of thickened continental crust. J. Petrol. 25, 894–928.

Erkan, E., Özer, S., Sümengen, M. and Terlemez, I. (1978): Sarız-Sarkısla-Gemerek-Tomarza arasının temel jeolojisi. M.T.A. Report No. 6546, Ankara.

Esquevin, J. (1969): Influence de la composition chimique des illites sur leur cristallinité. Bull. Centre Rech. Pau-SNPA 3, 147–153.

Ferreiro Mählmann, R. (1995): Das Diagenese-Metamorphose-Muster von Vitrinitreflexion und Illit-“Kristallinität” in Mittelbünden und im Oberhalbstein. Teil 1: Bezüge zur Stockwerktektonik. Schweiz. mineral. petrogr. Mitt. 75/1, 85–122.

Ferreiro Mählmann, R. (2001): Correlation of very low-grade data to calibrate a thermal maturity model in a nappe tectonic setting, a case study from the Alps. Tectonophysics, 334, 1–33.

Frey, M (1987): Very low-grade metamorphism of clastic sedimentary rocks. In: Frey, M (ed.): Low Temperature Metamorphism. Glasgow, Blackie and Son, 9–58.

Frey, M., Saunder. J. and Schwander, H. (1988): The mineralogy and metamorphic geology of low-grade metasediments, Northern Range, Trinidad. J. Geol. Soc. London 145, 563–575.

Frey, M., Teichmüller, M., Teichmüller, R., Mullis, J., Künzi, B., Breitschmid, A., Gruner, U. and Schwizer, B. (1980): Very low-grade metamorphism in external parts of the Central Alps: illite crystallinity, coal rank and fluid inclusion data. Eclogae geol. Helv. 73, 173–203.

Ghienne, J.F., Kozlu, H., Dean, W.T., Günay, Y. and Monod, O. (2001): Discovery of the northernmost Gondwanan evidence of an Upper Ordovician glacier: southern Turkey. Terra Abstracts. 11, p.103.

Göncüoglu, M.C. (1997): Distribution of Lower Paleozoic rocks in the Alpine terranes of Turkey: Paleogeographic constraints. In: Early Paleozoic Evolution in NW Gondwana. Turkish Assoc. Petrol. Geol. Spec. Publ. 3, 13–23.

Göncüoglu, M.C. and Kozlu, H. (2000): Early Palaeozoic evolution of the NW Gondwanaland: data from southern Turkey and surrounding regions. Gondwana Res. 3, 315–323.

Göncüoglu, M.C. and Kozur, H.W. (1998): Facial development and thermal alteration of Silurian rocks in Turkey. In: Gutiérrez-Marco, J.C. and Rábano, I. (eds), Proc. 6th Int. Graptolite Conf. (GWG-IPA) and 1998 Field Meeting, IUGS Subcommission on Silurian Stratigraphy. Temas Geológico-Mineros ITGE, 23, 87–90.

Göncüoglu, M.C., Dirik, K. and Kozlu, H. (1997): General characteristics of pre-Alpine and Alpine Terranes in Turkey: Explanatory notes to the terrane map of Turkey. Annales Geol. Pays Hellenique 37, 515–536.

Göncüoglu, Y. and Kozur, H.W. (1999): Palaeozoic stratigraphy and event succession in Eastern Toros, Turkey. In: North Gondwanan mid-Palaeozoic bioevent/biogeography patterns in relation to crustal dynamics. Abstracta Book Peshawar Meeting IGCP 421, September 8–26, 11–13.

Grathoff, G.H. and Moore, D.M. (1996): Illite polytype quantification using Wildfire© calculated X-ray diffraction patterns. Clay Clay Min. 44, 835–842.

Guidotti, C.V. and Sassi, F.P. (1986): Classification and correlation of metamorphic facies series by means of muscovite b_0 data from low-grade metapelites. N. Jb. Miner. Abh. 153, 363–380.

Gürsu, S. and Göncüoglu, M.C. (2001a): Characteristic features of the Late Precambrian felsic magmatism in Western Anatolia: implications for the Pan-African evolution in NW Perigondwana. Gondwana Res. 4, 169–170.

Gürsu, S. and Göncüoglu, M.C. (2001b): Geology of the late Pre-Cambrian rocks in Sandıklı area: implications for the Pan-african evolution in NW Gondwana. 4th Int. Symp. on the Eastern Mediterranean Geology. 21–25 May 2001, Isparta, Abstracts, 12–13.

Hesse, R. and Dalton, E. (1991): Diagenetic and low-grade metamorphic terranes of Gaspé Peninsula related to the geological structure of the Taconian and Acadian orogenic belts, Quebec Appalachians. J. Metamorphic Geol. 9, 775–790.

Hoffman, J. and Hower, J. (1979): Clay mineral assemblages as low grade metamorphic geothermometers: Application to the thrust faulted disturbed belt of ???
Montana, USA. In: Scholle, P.A. and Schluger, Schlager
P.R. (eds): Aspects of Diagenesis. Soc. Econ. Paleontol. Mineral. Spec. Publ. 26, 55–79.

Hunziker, J.C., Frey, M., Clauer, N., Dallmeyer, R.D., Fredrichsen, H., Flehmig, W., Hochstrasser, K., Roggwiler, P. and Schwander, H. (1986): The evolution of illite to muscovite: mineralogical and isotopic data from the Glarus Alps, Switzerland. Contrib. Mineral. Petrol. 92, 157–180.

Inoue, A. and Utada, M. (1991): Smectite-to-chlorite transformation in thermally metamorphosed volcanoclastic rocks in the Kamikita area, Northern Honshu, Japan. Am. Mineral. 76, 628–640.

Inoue, A, Utada, M., Nagata, H. and Watanabe, T. (1984): Conversion of triochahedral smectite to interstratified chlorite-smectite in Pliocene acidic pyroclastic sediments of the Ohyu District, Akita Prefecture, Japan. Clay Sci. 6, 103–116.

Kisch, H.J. (1991): Development of slaty cleavage and degree of vey-low-grade metamorphism: a review. J. Metamorphic Geol. 9, 735–750.

Preliminary - For Proofreading

KOZLU, H. (1990): Geology and hydrocarbon possibilities of the Tufanbeyli-Sariz-Gürün area. Turkish Petrol. Corp. Report, 1–138 (In Turkish, unpubl.).
KOZLU, H. and GÖNCÜOGLU, M.C. (1997): Stratigraphy of the Infracambrian rock-units in the Eastern Taurides and their correlation with similar units in Southern Turkey. In: GÖNCÜOGLU, M.C. and DERMAN, A.S. (eds): Lower Palaeozoic Evolution in northwest Gondwana, Turkish Assoc. Petrol. Geol. Spec. Publ. 3, 50–61.
KOZLU, H. and GÖNCÜOGLU, M.C. (2000): Correlation of the Cambrian to Devonian rock-units in the Central and eastern Tauride-Anatolide Platform, Turkey: a review. 8th Int. Meeting of IGCP 421 in 1st Congresso Iberico de Paleontologia, Evora, 12–14 Oct. 2000, Abstracts, 249–250.
KOZUR, H. and GÖNCÜOGLU, M.C. (1998): Main features of the pre-Variscan development in Turkey. Acta Universitatis Carolinae-Geologica 42, 459–464.
KRUMM, H. (1984): Anchimetamorphose im Anis und Ladin (Trias) der Nördlichen Kalkalpen zwischen Arlberg und Kaisergebirge – ihre Verbreitung und deren baugeschichtliche Bedeutung. Geol. Rundsch. 73, 223–257.
KÜBLER, B. (1968): Evaluation quantitative du métamorphisme par la cristallinité de l'illite. Bull. Centre Rech. Pau-SNPA. 2, 385–397.
KÜBLER, B. (1984): Les indicateurs des transformations physiques et chimiques dans la diagenèse, température et calorimétrie. In: LAGACHE, M. (ed.): Thérmométrie et Barométrie Géologiques, Soc. Franç. Minér. Crist., Paris, 489–596.
LOPEZ-MUNGUIRA, A., NIETO, F. and MORATA, D. (1998): Metamorphic evolution from diagenesis to epizone in Cambrian formations from NW Zafra (Ossa-Morena Zone, SW Spain). N. Jb. Mineral. Abh. 174, 131–157.
LÜNNIG, S., CRAIG, J., LOYDELL, D.K., STORCH, P. and FITCHES, B. (2000): Lower Silurian "hot shales" in North Africa and Arabia: regional distribution and depositional model. Earth-Sci. Rev. 49, 121–200.
MERRIMAN, R.J. and PEACOR, D.R. (1999): Very low-grade metapelites: mineralogy, microfabrics and measuring reaction progress. In: FREY, M. and ROBINSON, D. (eds): Low-Grade Metamorphism, Blackwell Sci. Publ. Oxford, 10–60.
MERRIMAN, R.J. and ROBERTS, B. (1985): A survey of white mica crystallinity and polytypes in pelitic rocks of Snowdonia and Llyn, North Wales. Mineral. Mag. 49, 305–319.
METIN, S., AYHAN, A. and PAPAK, I. (1987): Geology of the western part of the Eastern Taurus (SSE Turkey). Mineral Res. Explor. Bull. 107, 1–12 (In Turkish).
MOORE, D.M. and REYNOLDS, R.C.Jr. (1997): X-ray Diffraction and the Identification and Analysis of Clay Minerals. Oxford Univ. Press, 378 pp.
ÖZGÜL, N. (1976): Some geological aspects of the Taurus orogenic belt (Turkey): Bull. Geol. Soc. Turkey 19, 65–78 (in Turkish).
ÖZGÜL, N., METIN, S., GÖGER, I., BINGÖL, I. and BAYDAR, O. (1973): Cambrian–Tertiary rocks of the Tufanbeyli area. Bull. Geol. Soc. Turkey 16, 82–101 (In Turkish).
RAMIREZ, E. and SASSI, R. (2001): The baric character of the Patagonian basement as deduced from the muscovite $d_{060,331}$ spacing: a first contribution from Eastern Andean Metamorphic Complex (Andes, Chile). Eur. J. Mineral. 13, 1119–1126.
ROBINSON, D. (1987): Transition from diagenesis to metamorphism in extensional and collision settings. Geology 15, 866–869.
ROBINSON, D. and BEVINS, R.E. (1989): Diastathermal (extensional) metamorphism at very low grades and possible high grade analogues. Earth Planet. Sci. Lett. 92, 81–88.
SALEH, G.H. (2001): Evolution of Pan-African A- and I-type granites from the southeastern Egypt: inferences from geology, geochemistry and mineralization. Int. Geol. Rev. 43, 548–564.
SARMIENTO, G.N., GÜL, M.A., KOZLU, H. and GÖNCÜOGLU, M.C. (1999): Darriwilian conodonts from the Taurus Mountains, southern Turkey. Acta Univ. Carolinae-Geol. 43, 37–40.
SASSI, F. P. and SCOLARI, A. (1974): The b_o value of the potassic white micas as a barometric indicator in low-grade metamorphism of pelitic schists. Contrib. Miner. Petrol. 45, 143–152.
SASSI, F.P., KRAUTNER, H.G. and ZIRPOLI, G. (1976): Recognition of the pressure character in greenschist facies metamorphism. Schweiz. Mineral. Petrogr. Mitt. 56, 427–434.
SCHMIDT, D., SCHMIDT, S.Th., MULLIS, J., FERREIRO MÄHLMANN, R. and FREY, M. (1997): Very low-grade metamorphism of the Taveyanne formation of western Switzerland. Contrib. Mineral. Petrol. 129, 385–403.
SRODON, J. (1984): X-ray powder diffraction identification of illitic materials. Clay Clay Min. 32, 337–349.
SENGÖR, A.M.C. and YILMAZ, Y. (1981): Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75, 181–241.
STAMPFLI, G.M. (1996): The intra-Alpine terrane: a palaeotethyan remnant in the Alpine Variscides. Eclogae geol. Helv. 89, 12–42.
TEICHMÜLLER, M. (1987): Organic material and very low-grade metamorphism: In: FREY, M. (ed.): Low Temperature Metamorphism. Blackie and Son, Glasgow, 114–161.
VON RAUMER, J.V., STAMPFLI, G.M., BOREL, G. and BUSSY, F. (2002): Organization of pre-Variscan basement areas at the north-Gondwanan margin. Int. J. Earth Sci. 91, 35–52.
WARR, L.N. and RICE, A.H.N. (1994): Interlaboratory standardization and calibration of clay mineral crystallinity and crystallite size data. J. Metamorphic Geol. 12, 141–152.
WARR, L.N., PRIMMER, T.J. and ROBINSON, D. (1991): Variscan very low-grade metamorphism in southwest England: a diastathermal and thrust-related origin. J. Metamorphic Geol. 9, 751–764.
XIE, X., BYERLY, G.R. and FERRELL, R.E.Jr. (1997): IIb trioctahedral chlorite from the Barberton greenstone belt: crystal structure and rock composition constraints with implications to geothermometry. Contrib. Mineral. Petrol. 126, 275–291.
YALÇIN, H. and BOZKAYA, Ö. (1997): Burial and thrust-related very low-grade metamorphism in the upper Paleozoic meta-sedimentary rocks at the Kangal-Alacahan area, Sivas, Turkey. Geol. Bull. Turkey 40, 1–16.
YALÇIN, H., BOZKAYA, Ö. and BASIBÜYÜK, Z. (1999): Phyllosilicate mineralogy of very low-grade Malatya metamorphites of Upper Paleozoic age. Proc. 52nd Geol. Cong. Turkey, 10–12 May, Ankara, 271–278 (in Turkish, English abstract).
YANG, C. and HESSE, R. (1991): Clay minerals as indicators of diagenetic and anchimetamorphic grade in an overthrust belt, external domain of southern Canadian Appalachians. Clay Min. 26, 211–231.

Manuscript received November 28, 2001; revision accepted June 18, 2002.