INTRODUCTION

Silurian rocks are reported from the Istanbul-Zonguldak Terranes in NW Anatolia, in the Taurides-Anatolides, as well as in the SE Anatolian Autochthon. The NW Anatolian Istanbul-and Zonguldak terranes were separated from the main body of NW Gondwana as a part of the Avalonian-Central European Terrane Assemblage (Perigondwanan Terrane Assemblage e.g. Nance et al, 2012) and drifted towards N across the Rheic Ocean. By this the differences (e.g. Lakova and Göncüoğlu, 2005) in the paleogeographical setting has resulted in dissimilarities in litho- and biostratigraphy (Figure 1) between the Northern (Istanbul-Zonguldak) and Southern (Taurides-SE Anatolian Autochthon) areas (Göncüoğlu and Kozlu, 1997). In the former group there are also differences in the lithostratigraphy (e.g. Kozlu et al, 2002a).

In the Anatolides, the metamorphic edge of the Tauride-Anatolide platform, Middle and Upper Silurian low-grade metamorphic turbidites with black lydites and brownish limestone bands had been reported only from the Konya area, dated by conodonts (Göncüoğlu et al, 2000).

SILURIAN IN THE SE ANATOLIAN AUTOCHTHON AND THE TAURIDES

During the Silurian, the Tauride-Anatolide terrane was still attached to N Arabia and the sea-level rise following the Hirnantian glacial period resulted in a transgression of glacial valleys and peneplained lowlands in both areas. The earliest Silurian (Rhuddanian) black shales and lydites are observed in the SE Anatolian Autochthon in Çermik- Korudağ and Çat Yayla locations. The contact in these areas is tectonic. Subsurface data, however, obtained from only a limited number of deep boreholes (e.g. Gökiçi-1, Telhasan-1, Çiksor-2 etc.) shows that the deposition here commences on the Hirnantian glaciomarine sediments. Recent wells between Diyarbakır-Batman and Bismil also cut “hotshales”.

SILURIAN

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In the Taurides the primary relations between the Ordovician and the Silurian black shale-lydite unit is better preserved. The thickness of this lower level with black shales and lydites, also known as “hot shales” is highly variable.

Figure 1: Generalized columnar sections of the Silurian successions in the Perigondwanan Istanbul-Zonguldak and Balkan terranes (Sachanski et al, 2010).

The lowermost part of the Silurian succession is represented by black-dark gray, cleaved, pyrite rich shales with mica-rich lamination. The thickness of this level varies between 5-15 cm and 3-4 meters. It is followed by thin laminated lydites with black shale laminae or bands. This part is Llandovery in age and varies between 14-22 meters in Taurides and 18-38 meters in the SE Anatolian Autochthon. In the Western Taurides the thickness of this package is reduced to 3-4 meters and is laterally transitional to nodular limestones with black shale interlayers.

The depositional environment of this Llandovery series is open marine but temporally restricted where anoxic conditions prevailed. This is evidenced by the presence of a rich graptolite fauna together with widespread pyrite crystallization. The simplified model of Lünning et al (2000) attributing the enrichment of organic remains to upwellings in offshore shelf seems to be a reliable explanation. The anoxic conditions
must have seized with the maximum sea level towards the end of Wenlock, from whereon no black shales were observed. The deposition then changes from offshore shelf by shallowing upward sequences to shallow shelf conditions. The onset of the Wenlock nodular limestone–shale deposition on the Llandovery black shales in Eastern Taurides is an example for open marine carbonate and distal shelf depositional conditions. These conditions prevailed until middle Early Devonian with intermittent shallow shelf deposition. This time interval is characterized by storm dominated shelf conditions by deposition of tempestitic limestone-shales alternation in southern Central Taurides. In SE Anatolian Autochthon distal shelf deposition continued until Middle Devonian.

**Korudağ Section**

In Korudağ section in the SE Anatolian Autochthon to the W of Çermik the basal part of the Silurian is covered by the Atatürk Dam Lake even during the dry seasons (Figure 2).

![Figure 2: General view of the Korudağ section to the W of Çermik –Diyarbakır. The red arrow points to the section location](image)

Gökiçi-1 well in the close vicinity of the section penetrated the Lower Silurian and the underlying Hirnantian glaciomarine sediments. Along the section (Figure 3) the lowermost outcrops are the graptolite-rich black shales with lydites (Figure 4) shale-lyd. The measured thickness of the black shale-lydite succession is 32 meters. The lowermost black shales include graptolites of Rhuddanian age. The top of the black shale reaches up to the Upper Wenlock. The overlying turbiditic gray sandstone shale alternation is already Late Silurian in age and includes sedimentary features of
distal shelf environment. Upwards follows a shallowing up sequence of shale-sandstone-limestone with calcarenite and sandstone alternations.

Figure 3: Measured section of the Silurian succession in Çermik-Korudağ, SE Anatolian Autochthon.
A similar succession outcrops in the vicinity of Hazro is known as the Dadaş Formation (Erkmen and Bozdoğan, 1979, Steemans et al., 1996), where the shale-sandstone-limestone alternation is 150-200 meters thick (Bozkaya et al., 2011). This formation also includes the Lower Devonian.

The Silurian of the W and Central Taurides differs somehow from the excursion area. Typical sections from these areas are Kemer-Kesme Boğazı Section from the W Taurides and the Ovacık-Hırmanlı and Bozyazı-Tekmen sections from the Central Taurides.

**Kemer Kesme Boğazı Section**

This section is located to the W of Antalya-Kemer and forms a tectonic slice. As in other sections, Lower Silurian black shales are transgressive on the Hirnantian glaciomarine sediments (Figure 5). The thickness of the “hot shales” in this area is reduced to 6-14 meters. In contrast to other sections this lower unit includes thin-bedded (3-5 cm) dolomitic nodular limestone bands.

The upper part of the Kemer section is characterized by a succession of 24 meters thick quartz-arenites with dolomitic nodular limestone intercalations. No fossils were obtained yet from this part of the succession. Considering the stratigraphic position this unit is ascribed to Upper Silurian-Lower Devonian.
Figure 5: Cross-section of the lower “hot shale” part of the Silurian in W Taurides (Kemer–Antalya).

Figure 6: Lower Telychian “Orthoceras Limestone” lithofacies in the Kesme Boğazı section, Western Taurides.
The Silurian succession of W Taurides differs from others in the absence of the black shale-lydite level in the lower part and the reduced thickness of the open shelf type nodular “Orthoceras Limestones”. Moreover, in this section the rapid transition from open shelf to proximal shelf-saphka conditions is an important dissimilarity.

**Ovacık Karayarlar Section**

In the Ovacık-Hirmanlı section of the Southern Central Taurides at the Mediterranean coast, the Silurian successions are well-exposed. The “hot shales” in the lower part of the succession are about 18 meters thick. They are followed by 4 meters thick dark gray shales with bands and lenses of Orthoceras-bearing nodular limestones and 6 meters thick Orthoceras-bearing nodular limestones with dark gray shale interlayers. The depositional features rapidly change then to a storm-dominated shelf environment where dark gray shales with tempestitic carbonates (Figure 8) were formed.
The thickness of this upper level is about 150-200 meters (Figure 9). No fossils were obtained from this unit. Demirtaşlı (1984) included this level to his Hırmanlı Formation and assigned to it an Early Silurian age. Upwards the tempestides are transitional to shallow marine deposits and proximal shelf-coastal plain carbonates continue towards Lower Devonian without any considerable depositional break.
Bozyazi-Tekmen Section

This section again starts with black shales on the Hirnantian conglomeratic-sandy glaciomarine sediments with sandstone lenses (Sarmiento et al, 1999; Kozlu et al, 2002b). The basal part is 16 meters thick and comprises some lydite bands (Figure 10). The black shales are micaceous and rich in pyrite. The following level is an 11 meters thick black shale-lydite alternation with Aeronian graptolites. The overlying “second hot shale level” is 4-4.5 meters thick and is conformably overlain by gray fine-grained sandstone-shale alternation with lenses of nodular “Orthoceras Limestones”. Towards top, the succession continues with an alternation of gray shales and nodular limestones and grades into the Lower Devonian carbonate-quartz arenite succession. The gray shale-nodular limestone part of the succession has not yielded any fossils and preliminarily attributed to Upper Silurian. The depositional characteristics of the Silurian succession in this area are the same as the other Tauride sections.
Figure 10: Measured columnar section and fossil findings in the Silurian succession in Bozyazı-Tekmen, southern Central Taurides.

To summarize briefly, the correlation chart (Figure 11) of the Silurian successions in the SE Anatolian Autochthon (Korudağ), Eastern (Değirmentaş-Halevikdere) and the Central (Tekmen) shows that the depositional features of the Taurides do not differ very drastically, except the thickness change of the “hot shale” levels from E to W. Even though not sufficiently documented, the existence of deeper marine sediments towards N (e.g. ribbon cherts in the Konya area, Göncüoğlu et al, 2011) may indicate that the Anatolides have represented the slope of the Tauride-Anatolide Platform facing to N.
Another critical issue is the lack of biostratigraphic data in the upper part of the Silurian, which prevents a more reliable paleogeographic interpretation (see the Introduction chapter).

Figure 11: Correlation of the Silurian successions in E Taurides (Değirmentaş-Halevikdere), S Central Taurides (Tekmen) and the SE Anatolian Autochthon (Korudağ).

SILURIAN IN THE DEĞİRMENTAŞ-HALEVIK DERE
Değirmentaş-Halevikdere Section is one of the best preserved Paleozoic successions in the Geyikdağ Unit of the E Taurides (Figure 12).
Figure 12: Measured Columnar section of the Silurian rocks in Değirmentaş-Halevik Dere, E Taurides.
A detailed mapping of the Silurian units was performed by MTA (Demırtaşlı 1967; Özgül, 1973; Metin et al, 1986; Ayan, 1988) and TPAO (Aziz and Erakman, 1980; Kozlu, 1990). The initial approach was to include the glacial Hirnantian sediments (Halevikdere Formation in this volume) as basal conglomerates to the lower part of
the Silurian succession (Halit Yaylası Formation of Demirtaşlı, 1967) and differentiate
the black shales (Puşcutepe Shale) and the overlying shales and nodular
“Orthoceras Limestones” (Yukarıyayla Formation) as distinct lithostratigraphical
entities.

The most recent measured stratigraphic section (Figure 12) shows the
lithostratigraphic revision, where four informal sequences were established. From
bottom to top these are:

I- Black shale-lydite succession (22 m)
II- Limestone-black shale succession (30 m)
III- Shale-limestone succession (40 m)
IV- Black shale and siltstone succession (60 m).

Each of these successions is then subdivided into packages with distinct lithological
features and their fossil contents are shown on Figure 13.

The succession starts with a thick lydite bed on the 1 meter thick, brownish altered
mudstones of the glaciomarine sediments. The lydites are black and made up of
cryptocrystalline quartz and very fine disseminated graphite. The overlying black
shales with very thin-bedded lydites (Figure 14) already include graptolites of Par.
acuminatus Zone, indicative for the lowermost graptolite zone of Rhuddanian,
lowermost substage of Llandovery, Lowermost Silurian.

The following package is represented by a 5 meters thick level of intensively folded
black shale-lydite unit. The fold-axes are layer-parallel or overturned indicating to a
mega-slumping event during the late middle Aeronian. After an interval of 4m lydites
the next graptolite-rich black shale lydite package is observed. The graptolites found
in this package are indicative for the Sp. guerichi and Sp. turriculatus zones of lower
middle Telychian (Figure 13).

The second succession (Limestone-black shale succession) starts with the first
coarser grained detritic rocks (e.g. siltstones and mudstones) followed by the first
carbonate bands; calcarenitic in the lower part and nodular in the middle part and
with Cephalopods in the upper part. This first carbonate band may pinch out laterally
or replaced by calcarenites or sandstones.
Figure 13: Measured columnar section, field view and cross section of the Silurian succession in Değirmentaş–Halevik Dere, E Taurides.
The overlying black shales are about 8 meters thick and include Sheinwoodian (Early Wenlock) graptolites. The “second nodular limestone interval” is thicker and younger than Wenlock in age. This data is also supported by conodont data (Göncüoğlu et al, 2004). The third informal unit, the “Shale-limestone succession” at about 50 meters from the basis starts with a 16 meters thick argillaceous limestone rich in cephalopods. This limestone level includes deep-water ostracods and conodonts of Late Silurian age (Göncüoğlu et al, 2004). The following level is an alternation of black shale and locally argillaceous and nodular gray limestones. The last package of this succession is characterized by the crinoid-rich partly nodular limestones (Figure 15). This package is attributed to the Pridolian. The youngest informal member of the Silurian succession is represented by the “Black shale and siltstone succession”. It comprises black and dark gray siltstones. The first light gray limestone layers above this member include brachiopods and tentaculites and are probably Lochkovian in age. The Silurian-Devonian boundary is arbitrarily located into the 2.5 meters thick black shales just below these limestone bands.
The depositional features of the Silurian succession are the same as the other Tauride sections.

Figure 15: Crinoidal limestone in the upper part of the “Shale-limestone succession” in the Değirmentaş-Halevik Dere section.

**BIOSTRATIGRAPHIC CONSTRAINTS**

Except a very limited number of conodonts obtained from the nodular limestones the ages of the Silurian rocks are based on graptolites. Figure 16 shows the most critical (zonal) graptolites obtained from the Değirmentaş- Halevik Dere section.

**STOP DESCRIPTIONS**

**STOP 5: SILURIAN SEQUENCE**

The Silurian succession in Değirmentaş-Halevik Dere will be observed on the road cuttings on the dirt road in Halevik Dere. The complete section is about 150 meters thick and located in the middle of the roughly E-dipping homoclinal structure between the Hirnantian glaciomarine deposits of the Halevikdere formation and Lochkovian nodular limestones of the Yukarıyayla Formation. The panoramic view of the Silurian succession is given in figures 13 and 17. The details of the section are as follows.
Figure 16: 1 – 4: Parakidograptus acuminatus (Nicholson); specimen 2.1; level 2., 5: Cystograptus vesiculosus (Nicholson); specimen 4.2; level 4., 6 – 8: Akidograptus ascensus Davies; 6&7 – specimen 1.2; 8 – specimen 1.3; level 1., 9: Spirograptus guericichi Loydell, Štorch & Melchin with the age-diagnostic graptolite Torquigraptus planus (Barrande) in the lower left corner of the picture; specimen 10.1; level 10., 10: Spirograptus turriculatus Barrande; specimen 19.1; level 14., 11: Monograptus belophorus (Meneghini) = Monograptus flexilis Elles (Štorch, 1994); specimen 14b.6; level 14b. All graptolite figured herein are housed in the General Directorate of Mineral Research & Exploration (MTA), Ankara, Turkey.
I. Black shale-lidyte succession (22 m).

Highly siliceous rocks (lydites), more or less siliceous organic-rich black shales and interlayers of black shales.

**Package Ia (6 m).** Thick lydite bed (30 cm) in the lowermost part followed by siliceous black shales and lydite beds vary in thickness from 1 to 5 cm and generally in the lower part very thin layers of black shale. The package is abundant of Rhuddanian graptolites (Figure 16. 1 – 8 and Figure 19 A).

**Package Ib (5 m).** Strongly deformed black lydites and siliceous shale (Figure 18; slump deposits).

**Package Ic (4 m).** Lydites. The lydite beds vary in thickness from 1 to 10 cm (generally 5 cm).

**Package Id (7 m).** The upper part is dominated by more or less siliceous organic-rich black shales and very thin interlayers of black shales, which include abound in Telychian graptolites (Figure 16. 9 and Figure 19 C). The lower part is dominated by lydites. The lydite beds vary in thickness from 1 to 8 cm (generally less than 8 cm).

II. Limestone-black shale succession (about 30 m).

Black shale with two limestone intervals.

**Package IIa (6 m).** Black shale, locally silty and slightly siliceous shale with Telychian graptolites in the lowermost part.
Figure 18: The “slumped” black lydites and siliceous shale level (Package Ib) in the black shale-lydite succession.

**Package IIb (2.5 m).** “The first limestone interval”. Calcarenite in the lower part, nodular limestone and mudstone in the middle part and massive gray limestone with *Orthoceras* in the upper part.

**Package IIc (8 m).** Black shales with Wenlock graptolites, locally silty with slightly siliceous shale in the lower part.

**Package IIId (4.5 m).** “The second limestone interval”. Gray nodular, argillaceous limestone in the lower part and platy limestone with *Orthoceras* located in the upper part of the section. Thin layers of gray mudstone separate some of the platy beds. The limestone beds vary in thickness from 5 to 50 cm (generally less than 20 cm).

**Package IIe (8 m).** Black shale.

### III. Shale-limestone succession (about 40 m).

Alternation of argillaceous and nodular limestones with shales. Shales predominate in the middle part of the interval.

**Package IIIa (16 m).** Yellowish-brown in lowermost part gray, platy to massive, argillaceous limestone rich in *Orthoceras*. Thin layers of calcareous greenish-gray mudstone separate some of the platy beds. Gray to black shale in the lower part.
Figure 19: Field views of some important rock-units to be visited along the road – cuttings in Değirmentaş–Halevik Dere section. A: The basal contact of the Silurian succession. The geologists collect graptolites from the *Parakidograptus acuminatus* Zone – the lowest Silurian graptolite zone. Over their heads is the band with strongly deformed black lydites and siliceous shale (slump deposits) is visible. B: Typical view of the “Black shale-lydite succession” above the slumped deposits. The hammer head is the boundary of Package Ic and Package Id. C: The graptolites abound in the upper part of Package Id – *Spirograptus guerichi* Zone. D: “Limestone-black shale succession”, Package IIb – “The first limestone interval”. E: Overall view of the “Limestone-black shale succession”. F: Dark gray to
black shale interbedded with gray limestone – “Shale-limestone succession” (Package IIIb). G: Thinly interbedded pale gray limestone (nodular or platy) and grey and greenish-grey, calcareous mudstone – “Shale-limestone succession” (Package IIIc). The crinoidal limestone is on the left of the photo. H: Overall view of the Black shale and siltstone succession.

**Package IIIb (13 m).** Dark gray to black shale interbedded with gray limestone, weathers yellowish-brown, locally argillaceous and nodular. The limestone beds vary in thickness from 5 to 30 cm (generally less than 20 cm).

**Package IIIc (11 m).** Thinly interbedded pale gray limestone (nodular or platy) and grey and greenish-grey, calcareous mudstone. Individual limestones are typically 0.10-0.30 m thick. The middle part is dominated by mudstones, with relatively few limestone beds (Figure 19G). Crinoidal limestone in the lower part.

**IV. Black shale and siltstone succession (about 60 m).**
Black shales are the main constituent of this succession. Siltstones are mainly in the upper half of the interval (Figure 19H).

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