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SEDIMENTARY CHARACTERISTICS OF THE HÜDAİ FORMATION (EARLY CAMBRIAN) WITHIN THE AYDINCIK (İÇEL) AREA, S TURKEY

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Abstract: The study area is located in Aydıncık (İÇEL) area where Early Cambrian rocks are represented by the Hüdai Formation. The formation represents three different parts in the vertical sequence which has a thickness of approximately 830 metres. The basal part of the formation consists of a rhytmic alternation of horizontal laminated sandstone, ripple trough cross-laminated sandstone, mixed sandstone-shale, and rarely metashales. The middle part comprises dominantly metashales. The upper part is made up by an alternation of horizontal laminated sandstone, mixed sandstone-shale and rarely metashales. Vertical variations in the formation is caused by marine transgressious and regressious, and by fluctuations in sediment supply. Lower to middle parts of the formation characterize a fining-upward sequence, and middle to upper parts display a coarsening-upward sequence.

In the Hüdai Formation, four lithofacies are recognized based on lithology and sedimentary structures. These are (1) horizontal laminated sandstone (predominantly quartzarenite) indicating deposition from tidal currents during the high velocity phases of tidal cycles; (2) ripple cross-laminated sandstone (predominantly quartzwacke) deposited in lower part of intertidal (sand-flat) environment; (3) mixed sandstone-shale revealing deposition in mid-intertidal flat environment; and (4) shale (or metashale) deposited mainly in upper intertidal (mudflat) environment.

Key words: sedimentology, Early Cambrian, clastics, Hüdai Formation, facies, Turkey

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INTRODUCTION

The study area is located in Aydıncık (İÇEL) area which is known as a part of the Central Taurides (Fig. 1). Sedimentary rocks of the Hüdai Formation are typically exposed in a cliff near the shoreline (Fig. 2), and also in Çıra tepe (Fig.3). The formation consists mainly of alternating beds of slightly metamorphic sandstone (quartz arenite/ wacke) and shale (or slate) which are interpreted as beach deposits (Dean and Özgül, 1994; Gönсüoğlu, 1997).

In the Taurides, Hüdai Formation and its equivalent sedimentary rocks have not been extensively investigated from a sedimentological viewpoint. Dean and Özgül (1994) and Göncüoğlu (1997) have provided a brief information about stratigraphy of the Hüdai (Quartzite) Formation. This study aims to determine sedimentological characteristics of the formation.

STRATIGRAPHY

The Hüdai Formation and its equivalent sedimentary rocks represent the basal part of the thick sediment pile in the Tauride Belt which lies along the southern Turkey (Fig. 1A). These sedimentary rocks have been investigated under different names such as the Hacıishaklı Formation (Demirtaşlı, 1987), Hüdai Quartzite (Dean and Özgül, 1994), and the Feke Formation (Kozlu and Göncüoğlu, 1997). In the study area, the thickness of the Hüdai Formation is approximately 830 metres. The thickness has been measured from the coastline (fine-sand beach) to Çıra tepe (Fig. 3).

The Hüdai Formation is apparently conformable upon the Sipahili Formation (Infra-Cambrian from Koç, 1996 and Koç *et al.*, 1997) at the coastal area, and is conformably overlain by the Çaltepe Formation (Lower to middle Cambrian after Dean and Monod, 1970 and Özgül and Gedik, 1973) at Çıra tepe. The basal part of the formation consists of a rhythmic alternation of cream-beige colored, horizontal laminated sandstone (predominantly quartz-arenites), ripple cross-laminated sandstone (quartzwacke) and green colored mixed sandstone-shale and also shales (or slates; Fig. 2 and 4). The middle part is dominated by shales. The upper part is mainly made up by alternating massive, cream-beige colored, horizontal laminated sandstones (quartz-arenites) and dark green colored mixed sandstone-shale, and rarely shales with thickness of several metres. These sedimentary rocks

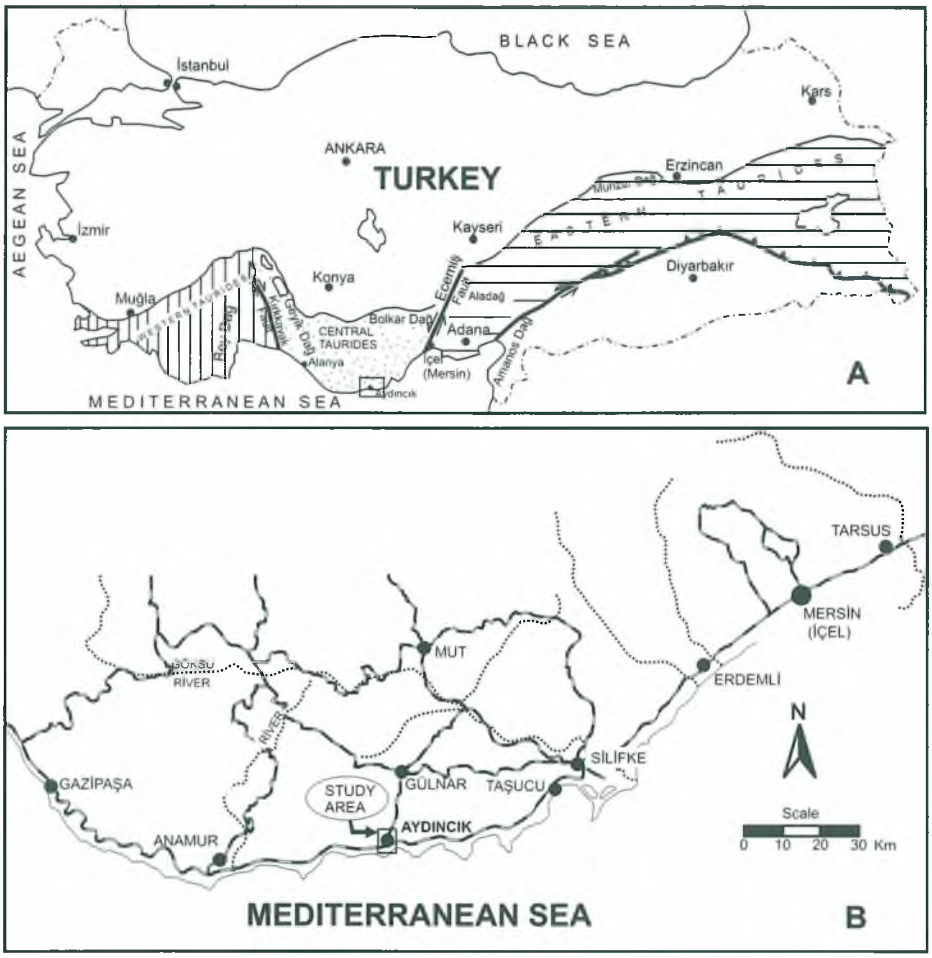

Fig. 1. **A.** A schematic map illustrating the Tauride Oregenic Belt and its subdivisions (From Özgül, 1983); **B.** Location map of the study area

dip roughly northwards and the angle of dip ranges from 38° to 72° (Fig. 2). The bedding surfaces and tectonic fractures often display a specularite enrichment.

Fig. 2. An excellent exposure of the Hüdai Formation at the coastal area showing a rhythmic bedding. The beds are facing to the north. The sequence comprises cream colored, horizontal laminated sandstone (h), ripple cross-laminated sandstone (cr) predominantly red in color, and green colored mixed sandstone-shale (m) and rarely shale

The Hüdai Formation is unfossiliferous, so that the age of the formation remains obscure. In literature, the age of formation is attributed to the Early Cambrian by comparison with overlying and underlying units (Demirtaşlı, 1987; Dean and Özgül, 1994; Göncüoğlu, 1997).

MATERIALS AND METHODS

A stratigraphic section has been measured from the present-day coastline to Çıra tepe (Fig. 3). During the fieldwork, fifty-two samples were collected. Thin-sections were prepared from the samples and examined under a petrographic microscope. Mineralogical and chemical compositions of the selected samples were characterized by X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses. Percentages of grains in thin-sections were estimated by using comparison charts.

SEDIMENTARY FACIES

In the Hüdai Formation, four lithofacies are recognized based on lithology and sedimentary structures. These are: (1) horizontal laminated sandstone, (2) ripple cross-

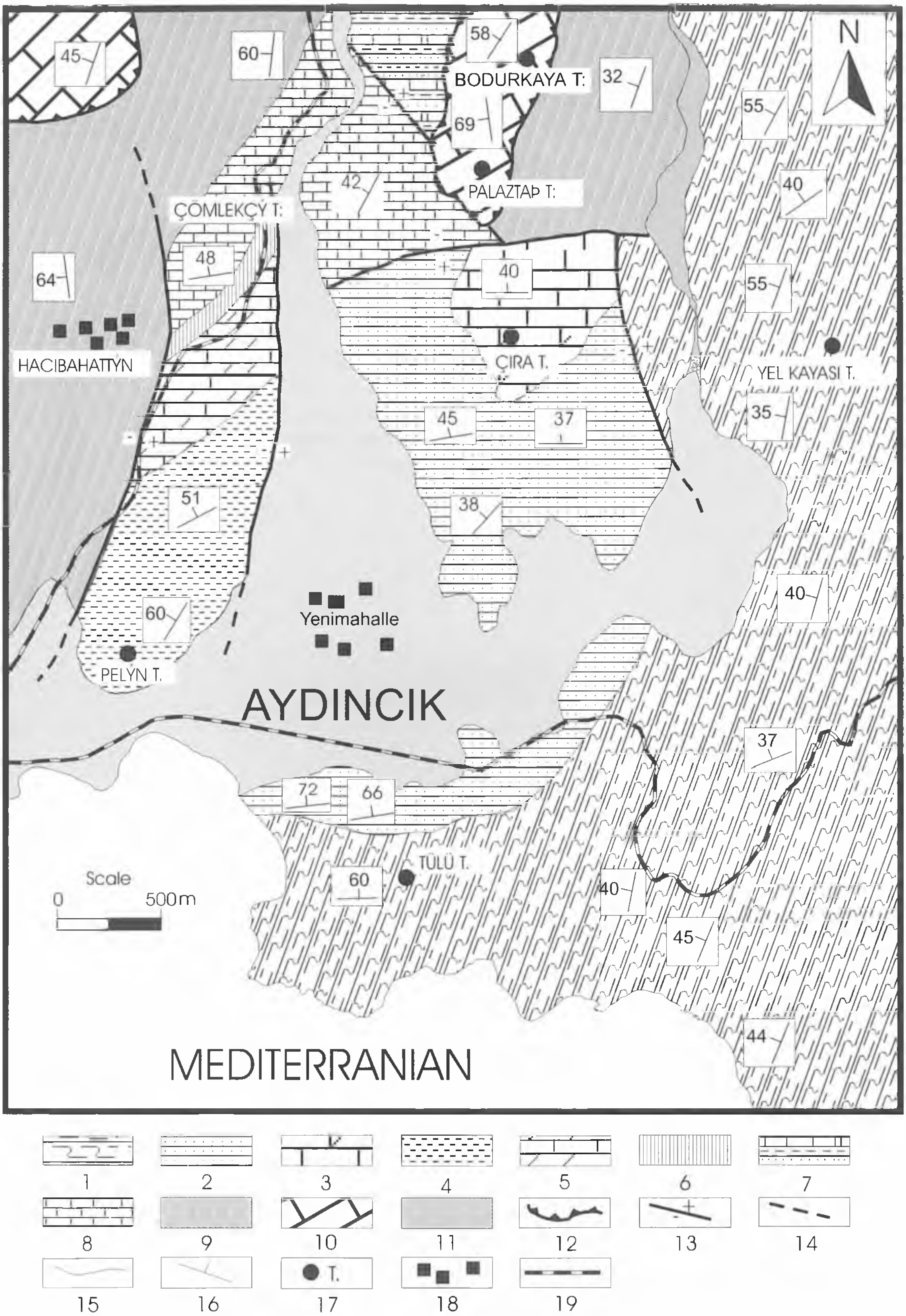

Fig. 3. Geological map of the study area (Modified from Koç, 1996). *1* – Sipahili Formation (Infra-Cambrian); *2* – Hüdai Formation (Early Cambrian); *3* – Çaltepe Formation (Early to Middle Cambrian); *4* – Seyditehir Formation (Late Cambrian to Ordovician); *5* – Büyükeceli Formation (Middle Ordovician); *6* – Akdere Formation (Late Devonian); *7* – Korucuk Formation (Early Carboniferous); *8* – Kırtıldağı Formation (Late Permian); *9* – Murtçukuru Formation (Late Triassic); *10* – Cehennemdere Formation (Jurassic to Early Cretaceous); *11* – alluvium; *12* – thrust fault; *13* – fault; *14* – probable fault; *15* – formation boundary; *16* – strike and dip of bedding; *17* – hill; *18* – district; *19* – main road

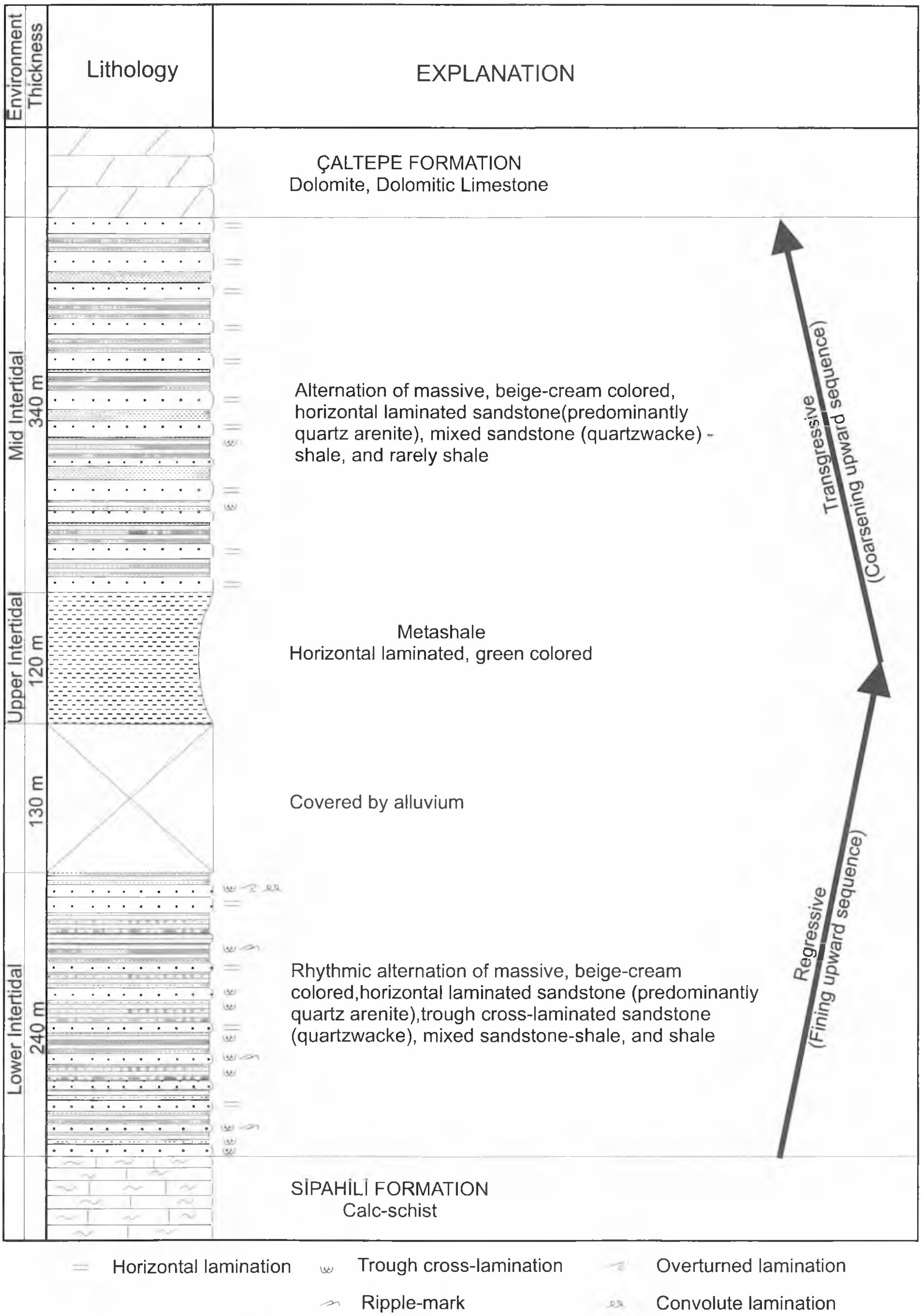

Fig. 4. A measured section of the Hüdai Formation showing variations in the vertical sequence

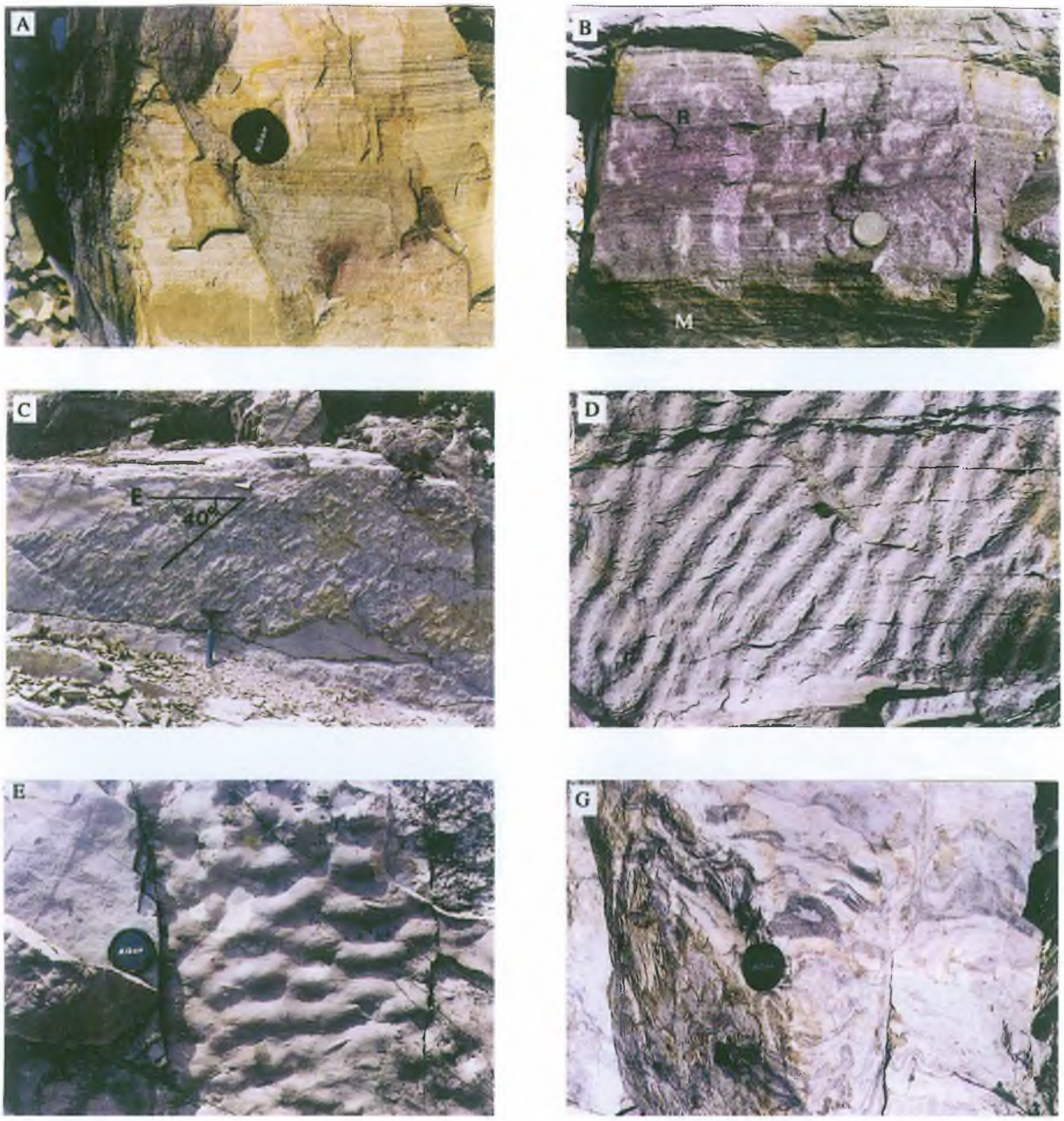

Fig. 5. Sedimentary structures in the Hüdai Formation. **A.** Horizontal laminated sandstone. Dark laminae indicate clay rich intervals. **B.** Typical ripple cross-laminated sandstone (R). Arrow indicates reactivation surface. M – Alternating laminae of sandstone shale in the mixed sandstone-shale. **C.** General view of ripple-marks on the bedding surface in the cross-laminated sandstone facies. The pitch of ripple-crest is measured as 40° E. **D.** Symmetrical, flat-topped ripples in the cross-laminated sandstone facies. **E.** Interference ripples in the cross-laminated sandstone facies. **F.** Large scaled overturned lamination (A) in the cross-laminated sandstone facies. Arrow indicates current flow direction. The right-hand part of the photograph (B) show wavy and lenticular bedding (w) in the mixed sandstone-shale facies. Dark areas indicate clay-rich intervals (w). **G.** Convolute lamination in the cross-laminated sandstone facies showing syn-depositional deformation

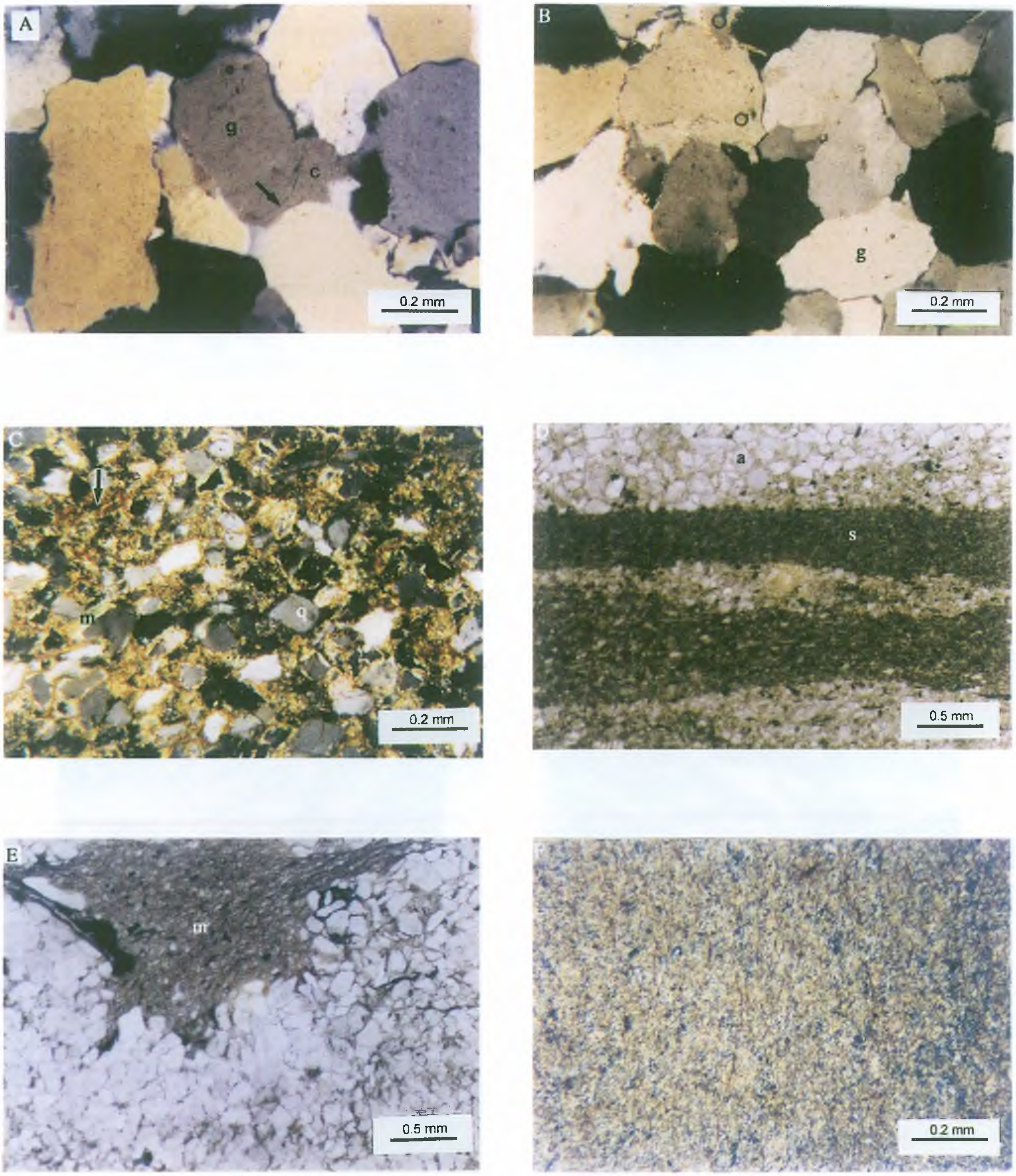

Fig. 6. Photomicrographs of the rock-types in the Hüdai Formation. **A.** Quartz arenite with abundant quartz overgrowth cement (c); g - quartz grain, arrow indicating original grain boundary. Cross-polarized light. **B.** Quartz arenite with a metamorphic appearance showing tightly interlocking quartz grains (g). Cross-polarized light. **C.** Typical appearance of quartzwacke. q – quartz grain, m – muscovite, arrow indicating clay-matrix. Cross-polarized light. **D.** Interlaminae of shale (s) and sandstone (a) in the mixed sandstone-shale facies. Plain polarized light. **E.** Mud-drape (m) in the mixed sandstone-shale facies. Plain polarized light. **F.** Microscopic view of the shale. Cross-polarized light.

Table 1

Chemical compositions of the selected samples characterizing different rock-types

Sample No	F1	F-9	F-11	F-16	AK-2	G-2	M-2	M-13	M-18	M-21	M-3	M-17	T-1
SiO_2	85.5	92.3	91.5	98.57	96.2	88.95	68.44	65.42	73.91	63.3	55.39	51.2	54.61
TiO_2	0.3	0.2	0.2	nd	0.1	nd	nd	0.07	0.58	0.1	1.47	1.2	0.66
Al_2O_3	7.3	3.4	3.6	0.59	1.2	7.14	13.28	13.83	7.93	14.0	18.68	20.5	19.68
Fe_2O_3	2.0	1.4	1.3	0.25	0.6	0.94	3.91	5.09	5.12	6.2	7.15	6.1	8.52
MnO	≤0.1	≤0.11	≤0.1	nd	0.1	nd	nd	nd	0.01	nd	nd	0.1	nd
MgO	0.3	0.1	0.2	nd	0.1	0.9	2.74	2.04	0.85	3.3	5.76	4.7	6.51
CaO	0.1	0.1	0.1	0.2	0.1	0.88	1.0	0.89	0.23	1.0	1.0	0.4	1.02
Na_2O	≤0.1	0.1	0.1	0.16	0.1	nd	nd	nd	1.13	nd	nd	0.1	nd
K_2O	3.6	2.2	1.9	0.31	0.4	3.37	8.89	10.1	10.82	9.4	9.11	11.0	7.52
P_2O_5	0.1	≤0.1	≤0.1	nd	0.1	0.11	0.26	0.18	0.21	0.3	0.22	0.1	0.2
Total	99.4	100.0	99.1	100.08	99	102.29	98.52	97.62	100.79	97.4	98.78	95.4	98.72
Rock type	Sa	Qa	Qa	Qa	Qa	Sa	Qw	Qw	Qw	Qw	Sh	Sh	Sh
Color	beige	cream	beige	cream	beige	pink	red	red	red	red	green	green	green

Oxide in wt %; Fe_2O_3 = total iron as ferric oxide; nd = not detected; Qa = quartz arenite, Sa = subarkose; Qw = quartzwacke; Sh = shale

laminated sandstone, (3) mixed sandstone-shale and (4) shale (or slate).

Horizontal laminated sandstone

Description

This facies is typified by massive, cream-beige colored, dominantly horizontal laminated, rarely structureless (because of metamorphic effect), moderately well-sorted, medium grained sandstone which consists predominantly of quartz-arenites. Some are subarkosic sandstones. In some intervals, clay interlaminae are present (Fig. 5A) Petrographic examination and XRD analysis reveal that the grains are mainly monocrystalline quartz with some microcline, plagioclase, mica, pyroxene, zircon, tourmaline and apatite. The mineralogical composition of the subarkoses consists of 5–25% feldspar, 75–95% quartz, and trace amount of the other minerals.The quartz arenites generally have elevated SiO_2 values greater than 90% wt, whereas subarkoses include SiO_2 content slightly less than 90% wt (Table 1). The grain-size ranges from 100 to 600 μm, mostly 150–350 μm. Diagenetic hematite with euhedral crystal-shape is occasionally present.

Under the microscope, these rocks appear often as a metamorphic quartzite because of abundant quartz overgrowth cement (Fig. 6A), and also metamorphic effect. In these cases, the quartz grains appear angular and tightly interlocking (Fig. 6B). The quartz overgrowth cement is generally in an optical continuity with the grain. In some cases, the original grain boundary is delineated by a dusty-line and/or a thin iron oxide-clay coating (Fig. 6A).

Interpretation

Horizontal lamination is restricted to moderately well-sorted, medium-grained sandstones and so is regarded as a structure of the upper flow regime. Elevated quartzose nature of the sandstones suggests an origin from tidal currents. Because the difference in current strength between tidal cycles seperate the muddy from the sandy fraction. Sand deposition takes place during the high velocity phases of a tidal cycle (Boggs, 1987).

Ripple cross-laminated sandstone

Description

This facies is composed of various colored (predominantly red, and also yellow, cream, and green colored), trough cross-laminated (Fig. 5B), fine grained (up to 200 μm in size), medium to poorly sorted quartzwackes (Fig. 6C), containing a clay matrix greater than 15% in volume.These rocks often show alternating light and dark laminae. The dark laminae are formed of relatively clay-rich intervals. The bed thickness varies generally from 15 cm to 50 cm, up to 1 metre.

Small-scale cross-bedding is the diagnostic feature of the this facies, and is closely associated with reactivation surfaces (Fig. 5B). On the bedding surface, various ripple-types are present, including symmetrical, asymmetrical, and interference patterns (Fig. 5C, D, and E). The wave ripples (symmetrical) are common, and their straight crestlines trend dominantly at N 40° W direction. Both wave and current ripples are generally 6 to 8 cm in lenght and approximately 1 cm in height. In some intervals, overturned and convolute laminations are occasionally present (Fig. 5 F and G).

Petrographic examination of thin-sections shows that the grains are mainly monocrystalline quartz with angular grain-shape. Their mineralogical composition is similar to quatrzarenites. Hematite is commonly found as late diagenetic mineral with euhedral crystal-shape. Chemical composition of the sandstones in this facies differs from quartzarenites with relatively high Al_2O_3 content ranging 7 to 14% wt (Table 1). Hematite content in the red sandstones ranges from 3.9 to 6.2% wt.

Interpretation

In overall, red color and depositional features such as small-scale trough cross-bedding, reactivation surfaces, and various ripple-types are characteristics of the tidal-flat environment (Boggs, 1987; Tucker, 1991; Klein, 1970). Wide sandy areas occupy the middle and lower parts of the intertidal flats (Larsonneur, 1975). Sedimentation on the tidal flats take place in response to both tidal processes and waves.

The red color of some beds in this facies is due to the presence of ferric oxide (Fe_2O_3; Einsele, 1992; Van Houten, 1973; Turner, 1980; Friedman *et al.*, 1992). The red color reflects the dominantly oxidizing nature of the depositional and early diagenetic environment (Tucker, 1991; Eren, 1999).

The ripple trough cross-laminated sandstone facies is interpreted as unidirectional traction-current deposits. Tidal cross-beds show commonly reactivation surfaces because the reversing tides can cause erosion of cross-beds that are rebuilt during the next advance tide (Boggs, 1987). Relatively weak tidal currents and waves interact on the sand-dominated intertidal flats to produce various ripple types. The interference ripples indicate changes in flow direction. Both overturned and convolute laminations indicate a soft sediment deformation, and probably were resulted by the shearing action of tidal currents on the liquedized sediments.

Mixed sandstone-shale

Description

This facies is generally characterized by alternating laminae of green colored sandstone and mudstone which are 1–10 mm in thickness (Fig. 5B and 6D). Sandy intervals consist of fine-grained, poorly sorted, and silty quartzwacke. Whereas muddy intervals are silty and/or micaceous clayey. Wavy and lenticular bedding is also characteristic sedimentary feature in this facies (Fig. 5F). Other depositional features are small-scale cross-bedding, microscopic-sized flaser bedding, and mud drapes (Fig. 6E).

Interpretation

The lithological and depositional features of this facies demonstrate deposition in a medium energy mid-intertidal zone (mixed flat; Legg, 1985; Boggs, 1987). Alternating sand and mud laminae are produced by alternating current and slack water conditions (Reineck, 1975; Klein, 1970; Reineck and Singh, 1980). Sandy laminae are deposited during periods of current activity and mud during slack water periods.

Shale (or metashale) facies

Description

This facies consists of green colored, horizontal laminated (or foliated), usually micaceous shale with variable silt and sand contents (Fig. 6F). In some intervals, sand lenses and laminae are present. The chemical composition of metashales is characterized with high SiO_2, Al_2O_3 and KO_2 contents, ranging in 51.2–55.4, 18.6–20.5, and 7.5–11.0 wt% respectively (Table 1). XRD analyses indicate that illite and kaolinite are main minerals. Chlorite is also present.

Interpretation

Depositional environment of formerly shale facies is interpreted to be upper part of intertidal environment (Knight and Dalrymple, 1975; Reineck and Singh, 1980) which is named as mud flat by Reineck (1975). The sediments of this facies reflect deposition in quite-water conditions from suspension with settling.

EVOLUTION OF VERTICAL SEQUENCE

Transgression and regression cause deposits of laterally adjacent tidal-flat environments to become superimposed, generating characteristic sequence of vertical facies (Fig. 4). The lower part of the Hüdai Formation appears as a fining-upward sequence that begins with dominantly the ripple cross-laminated sandstones of lower tidal environment (sand flat; Fig. 2) interbedded with the horizontal laminated sandstone facies, mixed sandstone-shale, and rarely shale, followed upward by the shale facies of the upper intertidal zone. The upper part of the formation appears as a coarsening-upward sequence consisting of thick shale at lower interval and alternating thick sandstone and mixed sandstone-shale facies, and also shale at the top. This indicates transition from upper intertidal to mixed intertidal environments. The thick alternations of laminated sandstone with mixed sandstone-shale and shale are related to alternation of strong tidal current and slack water phases and/or a fluctuation in sediment supply. The sandy layers were rapidly deposited during periods of strong current activity from suspension, and the shale facies during slack water periods.

CONCLUSIONS

The Hüdai Formation consists of slightly metamorphic sandstone, shale, and their alternations. Litho-types and sedimentary structures suggest deposition in an intertidal-flat environment under different energy conditions. In the vertical sequence, the formation displays fining-upward and coarsening-upward sequences.

In the formation, four lithofacies have been described.

These are (1) horizontal laminated sandstone deposited from tidal currents under the upper flow regime; (2) ripple cross-laminated sandstone deposited from relatively gently tidal currents; (3) mixed sandstone-shale deposited from alternating current and slack water; and (4) shale deposited in quite-water conditions from suspension.

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