THE LOWER TRIASSIC SORKH SHALE FORMATION OF THE TABAS BLOCK, EAST CENTRAL IRAN: SUCCESSION OF A FAILED-RIFT BASIN AT THE PALEOTETHYS MARGIN

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ABSTRACT: The Lower Triassic Sorkh Shale Formation is a dominantly red colored marginal marine succession deposited in the north-south trending Tabas Basin of east central Iran. It is correlated with the unconformity-bounded lower limestone member of the Elika Formation of the Alborz Mountains of northern Iran. The Sorkh Shale is bounded by the pre-Triassic and post-Lower Triassic interregional unconformities and consists mainly of carbonates, sandstones, and evaporites with shale being a minor constituent. Detailed facies analysis of the Sorkh Shale Formation resulted in recognition of several genetically linked peritidal facies that are grouped into restricted subtidal, carbonate tidal flat, siliciclastic tidal flat, coastal plain and continental evaporite facies associations. These were deposited in a low energy, storm-dominated inner-ramp setting with a very gentle slope that fringed the Tabas Block of east central Iran and passed northward (present-day coordinates) into deeper water facies of the Paleotethys passive margin of northern Cimmerian Continent. Numerous carbonate storm beds containing well-rounded intraclasts, ooids and bioclasts of mixed fauna are present in the Sorkh Shale Formation of the northern Tabas Basin. The constituents of the storm beds are absent in the fair weather peritidal facies of the Sorkh Shale Formation, but are present throughout the lower limestone member of the Elika Formation.

The Tabas Block, a part of the Cimmerian continent in east central Iran, is a rift basin that developed during Early Ordovician-Silurian Paleotethys rifting. Facies and sequence stratigraphic analyses of the Sorkh Shale Formation has revealed additional evidence supporting the Tabas Block as a failed rift basin related to the Paleotethys passive margin. Absence of constituents of the storm beds in the fair weather peritidal facies of the Sorkh Shale Formation, presence of the constituents of the storm beds in the fair weather facies of the Elika Formation (the Sorkh Shale equivalent in the Alborz Paleotethys margin) and southward paleocurrent directions of carbonate storm beds suggest that the low topographic gradient of the ramp in the Tabas failed rift basin was facing the Paleotethys Ocean, where the storms were generated. In addition, northward paleocurrent directions of the fair weather facies and northward increase in carbonate content of the Sorkh Shale sequence further indicate that the Tabas Basin was tectonically a part of the Paleotethys passive margin. It is apparent that relative sea level, basin geometry and tectonic movements along the bounding faults played significant roles during deposition of the Sorkh Shale Formation by controlling accommodation space and facies variations along the Tabas failed rift basin.

INTRODUCTION

The Paleozoic to Upper Triassic succession of east central Iran was formed mainly in the north-south trending Tabas Block (Fig. 1), which is bounded by the Nayband Fault in the east and the Kalmard-Kuhbanan Fault in the west. The Tabas Block is a part of the Cimmerian continent (Fig. 2) and covers an area of approximately 50,000 square kilometers. The Lower Triassic Sorkh Shale Formation (sorkh is Persian for red) crops out along the bounding faults of the Tabas Block (Fig. 1) and is easily distinguishable by its characteristic red color in the field. Although the Sorkh Shale Formation is defined as a shale facies in the Tabas Basin (Stocklin and Setudehnia 1971), detailed facies analysis (see below) indicates that this name is misleading as the shale content is less than 10% (limestone, dolomite and sandstone constitute the bulk of the formation) and its shale-like appearance is due to diagenetic alteration. Previous work on the Sorkh Shale Formation is of a general stratigraphic nature (see reviews by Shahrabi 2000 and Seyed-Emami 2003). It was first named and described by Gansser (1955). Stocklin et al. (1965) introduced the type locality of the Sorkh Shale Formation in Godar Sorkh, east of the village of Chiruk (southeast of Tabas), along the Nayband Fault (Fig. 1). Based on fauna and stratigraphic position, an Early Triassic age (Scythian) has been assigned to the Sorkh Shale Formation and its equivalent lower Elika Formation (e.g., Gansser 1955; Stocklin and Setudehnia 1971; Bronnimann et al. 1973; Seyed-Emami 2003).

The Tabas Block (Fig. 1), which is characterized by its conspicuous north-south trending mountains along its margins, has remained problematic in relation to the generally east-west Paleotethys margin of the northern Cimmerian continent. Lasemi (2001), based on regional facies and sequence stratigraphic analyses of the Paleozoic deposits of Iran considered the Tabas Block as a failed rift basin related to the Paleotethys margin during Devonian to Late Triassic time which was separated, along with the rest of the Cimmerian Plate, from northern Gondwana during the Permian. Recent detailed facies and sequence stratigraphic analyses of the Lower-Middle Triassic successions of the Cimmerian Plates of Iran (e. g., Tahmasebi 1998; Jahani 2000; Lasemi and Jahani 2001; Ghomashi 2007) have resulted in a better understanding of the stratigraphy and sedimentary basin evolution of the Cimmerian Plates of Iran prior to the late Triassic closure (Sengor and Natalin 1996) of the Paleotethys Ocean.

The purpose of this paper is to document facies variations

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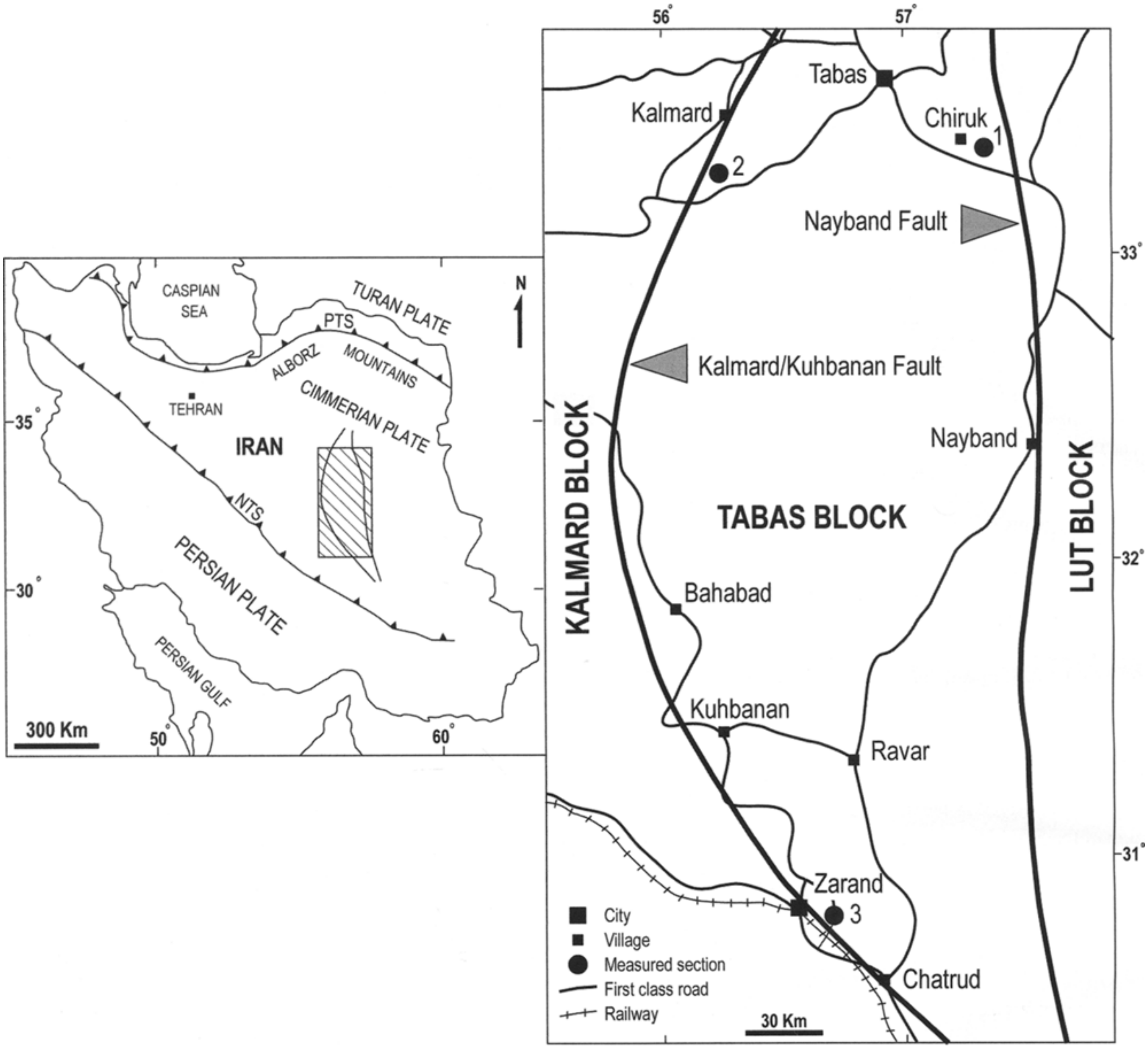

Figure 1. Location map of the study area of the Tabas Block (between the Kalmard-Kuhbanan Fault in the west and the Nayband Fault in the east) in east central Iran. The area between the Paleotethys suture (PTS) and Neotethys suture (NTS) on the index map comprises the Cimmerian plates of central and northern Iran. 1: Godar Sorkh section, 2: Godar Gachal section, 3: Islamabad section.

of the platform deposits of the Lower Triassic Sorkh Shale Formation that developed during the final stages of the Tabas Basin's evolution in relation to the Paleotethys passive margin. Although the nature of the Lower Triassic deposits and their style of sedimentation in the Tabas Basin are somewhat different from those of the Lower Triassic deposits of the Alborz Mountains at the northern passive margin of the Cimmerian Plate, the results of this study confirm that the Tabas failed rift basin was an integral part of the Paleotethys passive margin of northern Iran (Lasemi 2001).

METHODS OF STUDY

To determine facies types and their lateral and vertical variations in the Tabas Block, three outcrop sections were studied along the Nayband and Kuhbanan/Kalmard Faults. These sections (Fig. 1) include Godar Sorkh (locality 1, east of Chiruk and near the type-locality), Godar Gachal (locality 2, south of Kalmard) and Islamabad (locality 3, east of Zarand about 300 kilometers south of the Godar Gachal section). A total of 320 thin sections and polished surfaces of representative lithofacies were studied to provide petrographic details (composition, texture, fabrics and structures) to enhance the field descriptions. Grains

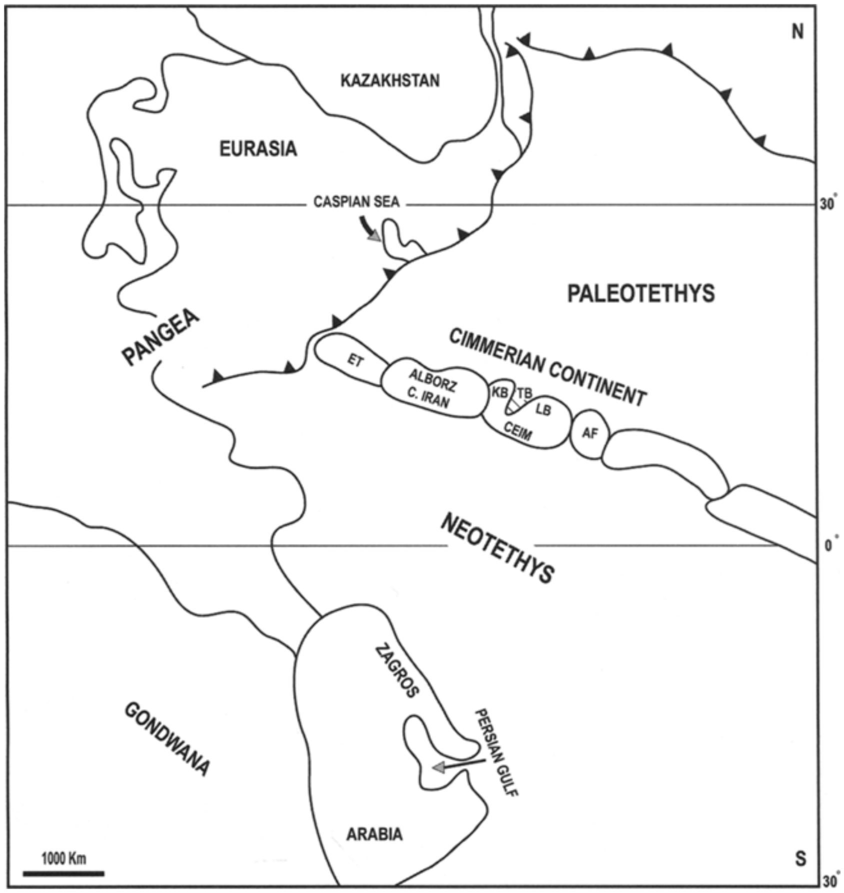

Figure 2. Early Triassic paleogeographic map showing the approximate position of the Tabas Block in the Cimmerian Continent (based on Sengor et al. 1988; Golonka and Ford 2000; Golonka 2002). AF, Afghanistan; ET, eastern Turkey; CEIM, Central East Iranian Microcontinent; KB, Kalmard Block; LB, Lut Block; TB, Tabas Block.

and matrix percentages were estimated using visual percentage charts in Flügel (1982). Siliciclastic rocks were classified based on the Pettijohn et al. (1987) and Folk (1974) systems. The textural scheme of Dunham (1962) was used to classify carbonate rocks, but here the upper size limit for matrix was considered to be 60 microns. Dunham (1962) assigned an upper size limit of 20 microns for carbonate mud and considered larger silt size particles that generally settle from suspension as carbonate grains. Facies types and their depositional settings are determined based on compositional, textural, fabric and structural (field and petrographic) criteria and comparison with modern and ancient environments (e. g., Purser 1973; Wilson 1975; Tucker and Wright 1990; Flügel 2004).

GEOLOGICAL SETTING

The Tabas Block is an elongate north-south trending basin between the Nayband and Kalmard-Kuhbanan Faults in east central Iran (Fig. 1). Central Iran, along with the Alborz Mountains of northern Iran, is located between the Neotethys and Paleotethys sutures of Iran (Fig. 1) and are a part of the Cimmerian Continent (Fig. 2) of Sengor (1984), which was separated from the Gondwana super-continent during the Permian (e. g., Dercourt et al. 1993; Stampfli and Pillevuit 1993; Scotese and Langford 1995; Sengor and Natalin 1996; Lasemi 2001). Located between the Lut Block in the east and the Kalmard Block in the west (Figs. 1 and 2), the Tabas Basin belongs to the Central East Iranian Micro-continent (CEIM) of Takin (1972) which is interpreted to have been rotated 135 degrees counterclockwise with respect to Eurasia since Late Triassic (e.g., Davoudzadeh et al. 1981; Soffel and Forster 1984; Alavi et al. 1997). Based on plate tectononic reconstructions (Sengor et al. 1988; Golonka and Ford 2000; Golonka 2002), the Cimmerian Plate of Iran, including the Tabas Block, were located approximately 15 degrees north of the equator, in the Paleotethys margin, during the Early Triassic (Fig. 2).

The Tabas Basin is subdivided into three sub-basins namely the Tabas in the north, the Nayband in the south and the Ravar-Mazino in the west, delineated by east-west and north-south trending faults (Aghanabati 2004). As noted by Stocklin (1968), the Tabas block is marked by its north-south trending ridges along its bounding Nayband (Shotori Mountains) and Kalmard-Kuhbanan (Kalmard Mountains) fault systems. The bounding faults of the Tabas Block have been persistent facies dividers and periodically reactivated since Late Precambrian time (Stocklin 1968; Nabavi 1976; Berberian and King 1981). The Tabas Basin was the site of continuous rapid subsidence during Paleozoic and Mesozoic times. Over 10 kilometers of Paleozoic through the Mesozoic succession of the Tabas Block pinches out to near zero to the east (Lut Block) and west (Kalmard Block) (Stocklin 1968; Bratash 1975; Aghanabati 1977, 2004). Lasemi (2001) considered the Tabas Block to be a failed rift basin throughout Devonian to Late Triassic times which formed during the Paleotethys rifting as a result of the Early Ordovician-Silurian continental extension along its bounding Nayband and Kalmard-Kuhbanan Fault systems.

REGIONAL STRATIGRAPHY

The Lower Triassic Sorkh Shale Formation of the Tabas Basin (over 150 meters thick) consists chiefly of thin- to medium-bedded red to pink or gray carbonates and sandstones. It shows considerable facies variation along the bounding faults of the Tabas Basin (Fig. 6). In Godar Sorkh (a distal section in the Tabas sub-basin closer to the northern Paleotethys margin), the formation consists chiefly of carbonate rocks (mainly limestone) with a few shale intervals (less than 10 meters) in its lower part. In the Godar Gachal section (in the Ravar-Mazino sub-basin close to the Kalmard Fault), the Sorkh Shale consists of 30 meters of limestone and dolomite and 11 meters of siliciclastics (shale and sandstone) in the lower part. In the Islamabad section, south of the Tabas Block (a proximal section in relation to the northern Paleotethys margin in the Nayband sub-basin), the formation is composed of over 50 meters of evaporites (mainly gypsum) at its base and inter-bedded limestone/dolomite (56 meters) and quartz sandstone (53 meters) throughout the rest of the section. The Sorkh Shale Formation of the northern part of the Tabas Basin (Godar Gachal and Godar Sorkh sections) is interbedded with numerous carbonate storm beds (Fig. 6).

The Sorkh Shale Formation unconformably overlies the Upper Permian Jamal Formation (Figs. 3 and 4A-B), which is over 470 meters thick and consists mainly of gray, thick-bedded to massive limestone and dolomite containing tidal flat, subtidal lagoon, barrier island and open marine facies related to the shallow marine environment of a ramp platform (Taheri 2002). It correlates with the Ruteh and Nesen Formations of the Alborz Mountains (Fig. 3). The Sorkh Shale is unconformably overlain by the Middle to Upper Triassic Shotori Formation (Fig. 3), which is up to 800 meters thick and consists of light brown to brownish gray thin- to thick-bedded dolomite and limestone that correlates with the middle and upper carbonate members of the Elika Formation (Fig. 3) of the Alborz Mountains (Seyed-Emami 2003). It is composed dominantly of lagoonal, intertidal and supratidal facies related to an arid homoclinal ramp setting (Ghomashi 2007).

The Sorkh Shale Formation is equivalent to the lower limestone member of the Elika Formation (Figs. 3 and 5) of the Alborz Mountains (Glaus 1964; Stocklin and Setudehnia 1971; Bronnimann et al. 1973; Seyed-Emami 2003). The lower Elika limestone is over 190 meters thick and consists of thin- to medium-bedded gray to yellowish gray or pink limestone. It consists dominantly of open marine (bioturbated bioclast lime mudstone-wackestone), barrier (bioclast/ooid/bioclast ooid grainstone) and lagoonal (bioturbated lime mudstone-wackestone and peloid bioclast wackestone-packstone) facies (Fig. 5) that are interbedded with storm deposits of various thicknesses (Tahmasebi 1998; Jahani 2000; Lasemi and Jahani 2001). Ooids, intraclasts, bivalves (*Claraia* and *Pseudomonotis*), gastropods, serpulids (*Spirobis*), crinoids and ostracodes are the main carbonate components of the lower limestone member of the Elika Formation (Seyed-Emami 2003; Tahmasebi 1998; Jahani 2000). These components are present in the storm layers of the Sorkh Shale Formation (Figs 5 and 6).

FACIES AND DEPOSITIONAL SETTING

Detailed field and petrographic facies analysis of the Sorkh Shale Formation in three stratigraphic sections along the main bounding faults of the Tabas Basin resulted in recognition of several genetically linked facies that are grouped into 5 facies associations including (A) restricted subtidal, (B) carbonate tidal flat, (C) siliciclastic tidal flat, (D) coastal plain, and (E) continental evaporite that are interbedded with numerous carbonate storm beds (S) in the northern distal area of the basin. Carbonate and siliciclastic tidal flat facies that form repeated asymmetric shallowing-upward cycles are the predominant facies of the Sorkh Shale Formation.

Restricted Subtidal Facies

The subtidal facies constitutes a minor part of the Sorkh Shale Formation. It is up to 10 meters thick and consists of the following facies: A1 (alternating thin bedded heavily

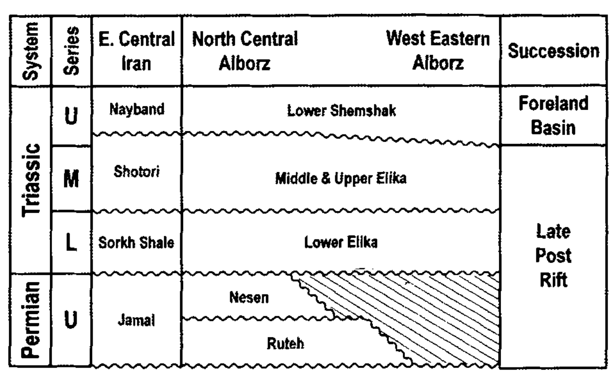

Figure 3. Stratigraphic nomenclature of the Triassic succession of east central Iran (Tabas Block) and the Alborz Mountains (northern Iran).

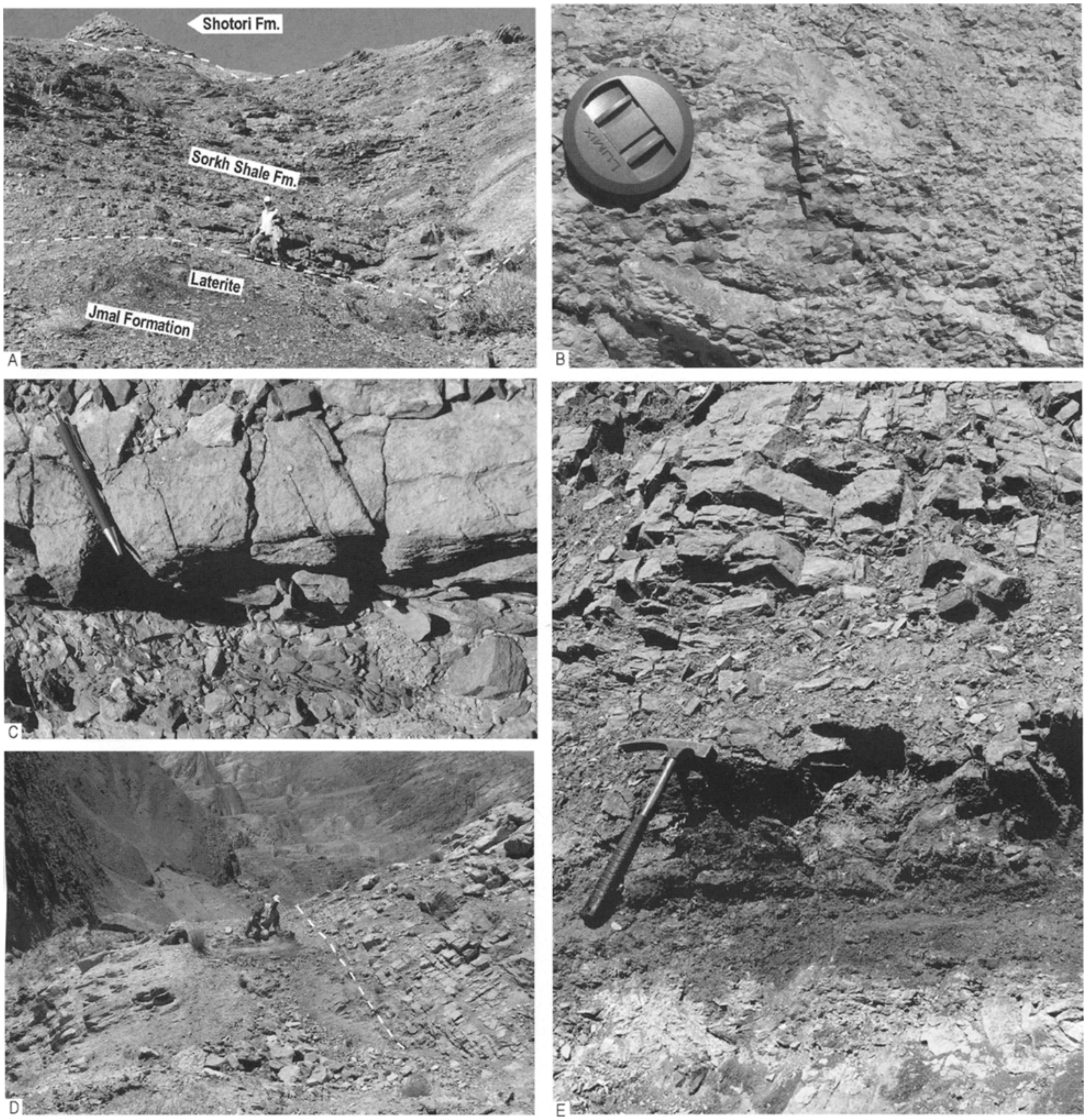

Figure 4. (A) Panorama (view to the southwest) of the Sorkh Shale succession (41 meters) in the Godar Gachal section; the formation overlies the Permian Jamal Formation with a distinct pisolitic laterite horizon (see B) and unconformably underlies, with a distinct paleosol, the Middle Triassic Shotori Formation (see C). (B) Close up view of A showing the well developed pisoids (lens cap diameter is 5.5 cm). (C) Close up view of the red paleosol on the upper contact of the Sorkh Shale Formation and the overlying basal transgressive pebbly dolomite of the Shotori Formation (Godar Gachal section). (D) View to the northwest (Islamabad section) showing the unconformable boundary between the Sorkh Shale Formation (left) and the lower part of the Shotori Formation (right). (E) Close up view of the uncovered red paleosol at the Sorkh Shale and Shotori contacts of photograph D.

bioturbated ostracode lime mudstone and thin bedded greenish gray shale, Fig. 7A-C), A2 (very thin bedded thinly laminated red shale, Fig. 7A) and A3 (ostracode/gastropod wackestone/packstone, Fig. 7D). Facies A1 grades to facies A2 which in turn grades to the tidal flat facies in a vertical succession (Figs. 6 and 7A).

The gray color, abundant burrows (Fig. 7B-C) and high concentration of carbonate/terrigenous mud in facies A1 indicates a very low-energy environment. Facies A2 is interpreted to have been deposited in a lagoonal setting during fluvial advance. Deposition in a lagoonal setting is supported by the vertical association of facies A2 with

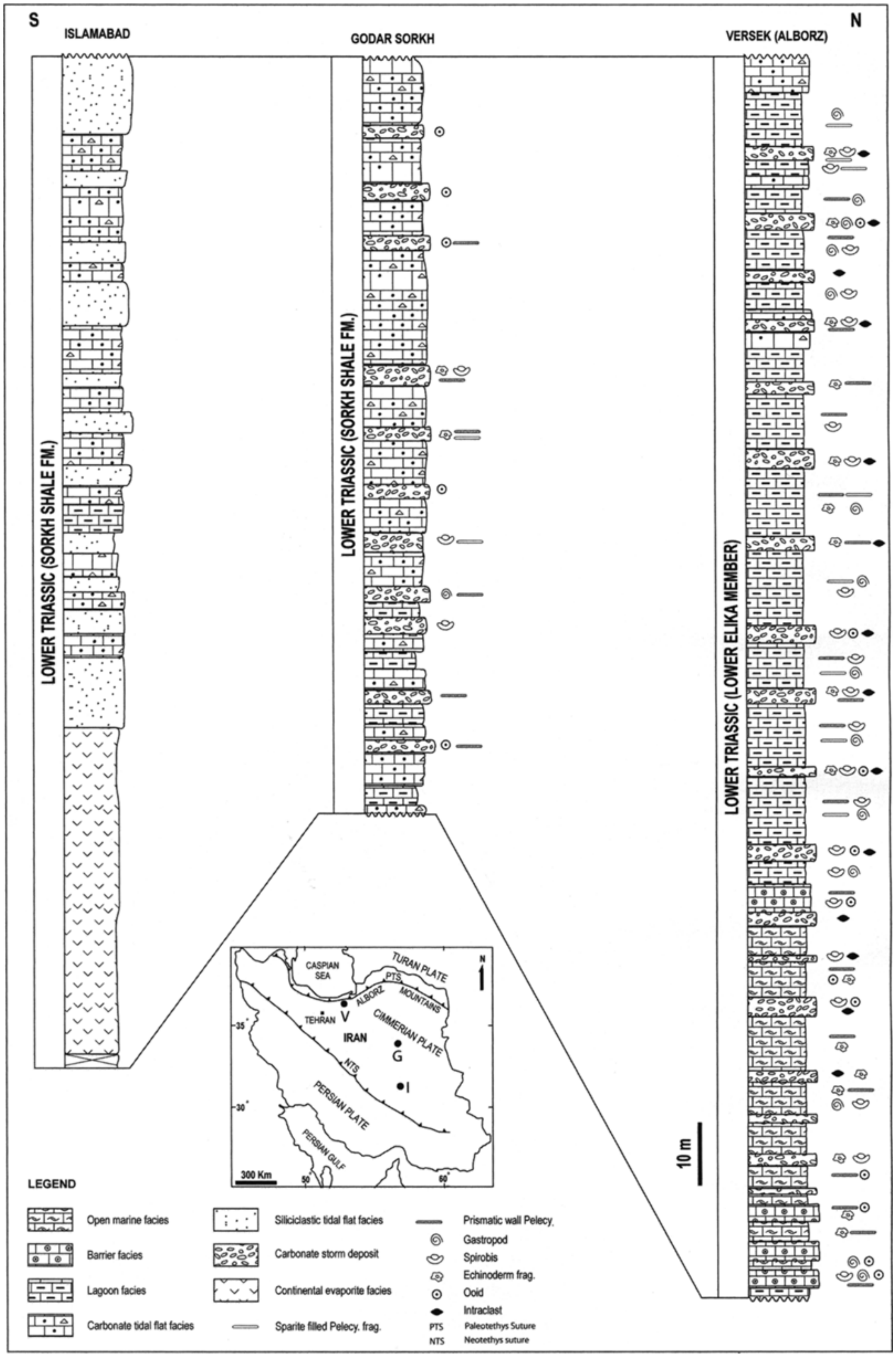

Figure 5. North to south cross section showing facies variations of the Lower Triassic deposits from the Veresk section (V) of the Alborz Mountains (Paleotethys passive margin) to the Godar Sorrkh (G) and Islamabad (I) sections of the Tabas failed rift basin. The mixed carbonate-siliciclastic peritidal facies of the proximal Islamabad section changes to a mainly carbonate tidal flat facies in the distally located Godar Sorkh section that in turn changes to the mainly open marine, barrier and lagoonal facies of the lower Elika member in the Alborz Paleotethys margin. Note the abundant carbonate storm beds in both the Sorkh Shale Formation and the lower limestone member of the Elika Formation. Note also that the components of the lower member of the Elika Formation are present in the storm beds of the Sorkh Shale Formation.

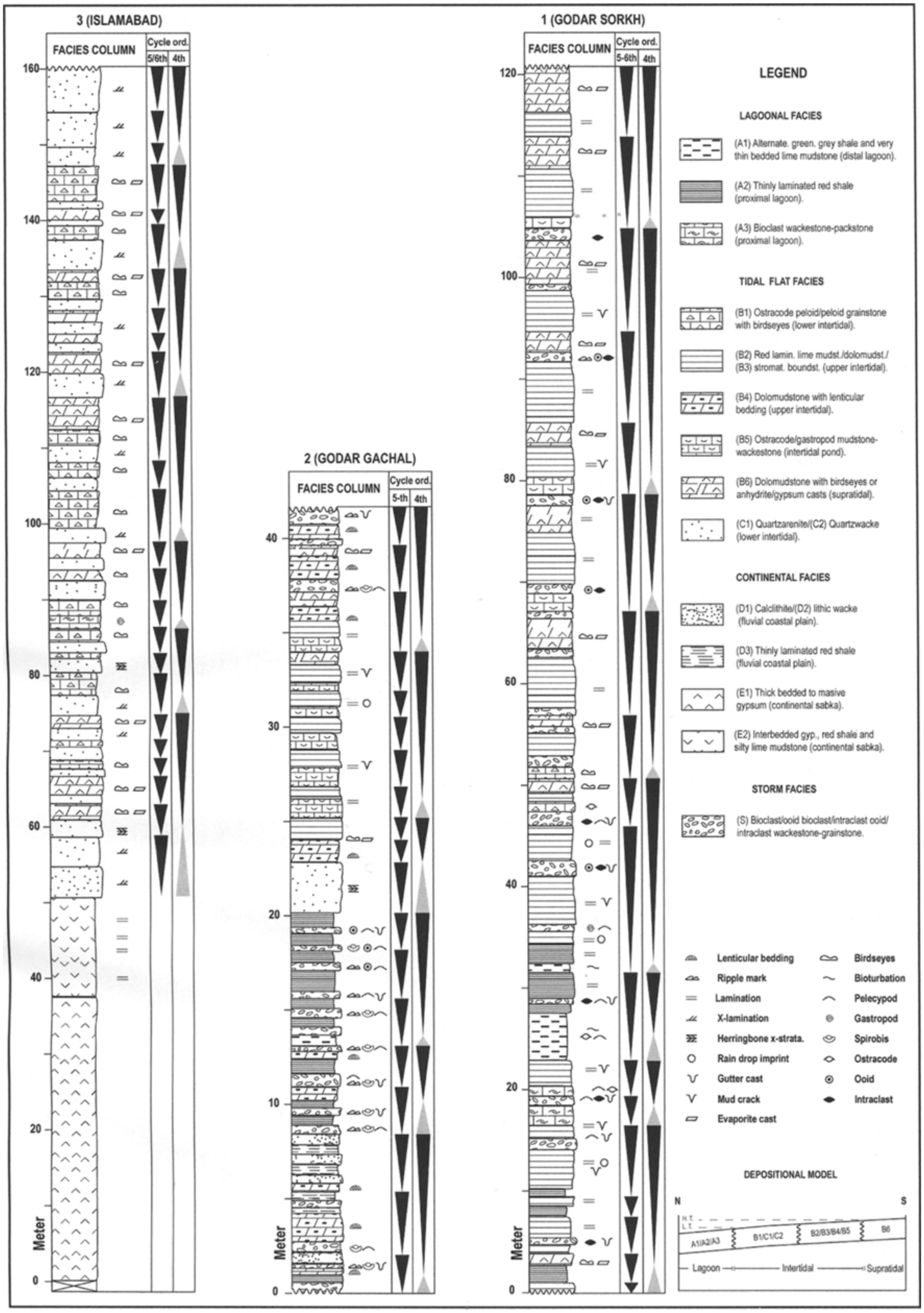

Figure 6. Facies columns, cyclostratigraphy and depositional model of the Sorkh Shale Formation in the southern proximal Islamabad section and the northern distally located Godar Gachal and Godar Sorkh sections of the Tabas Basin (for the location of the sections see Fig. 1). Note that the Sorkh Shale sequence consists of numerous high frequency (4th-6th order) shallowing upward peritidal cycles. Note also the increase in carbonate facies northward in the type locality of Godar Sorkh, the distal section closer to the Paleotethys margin.

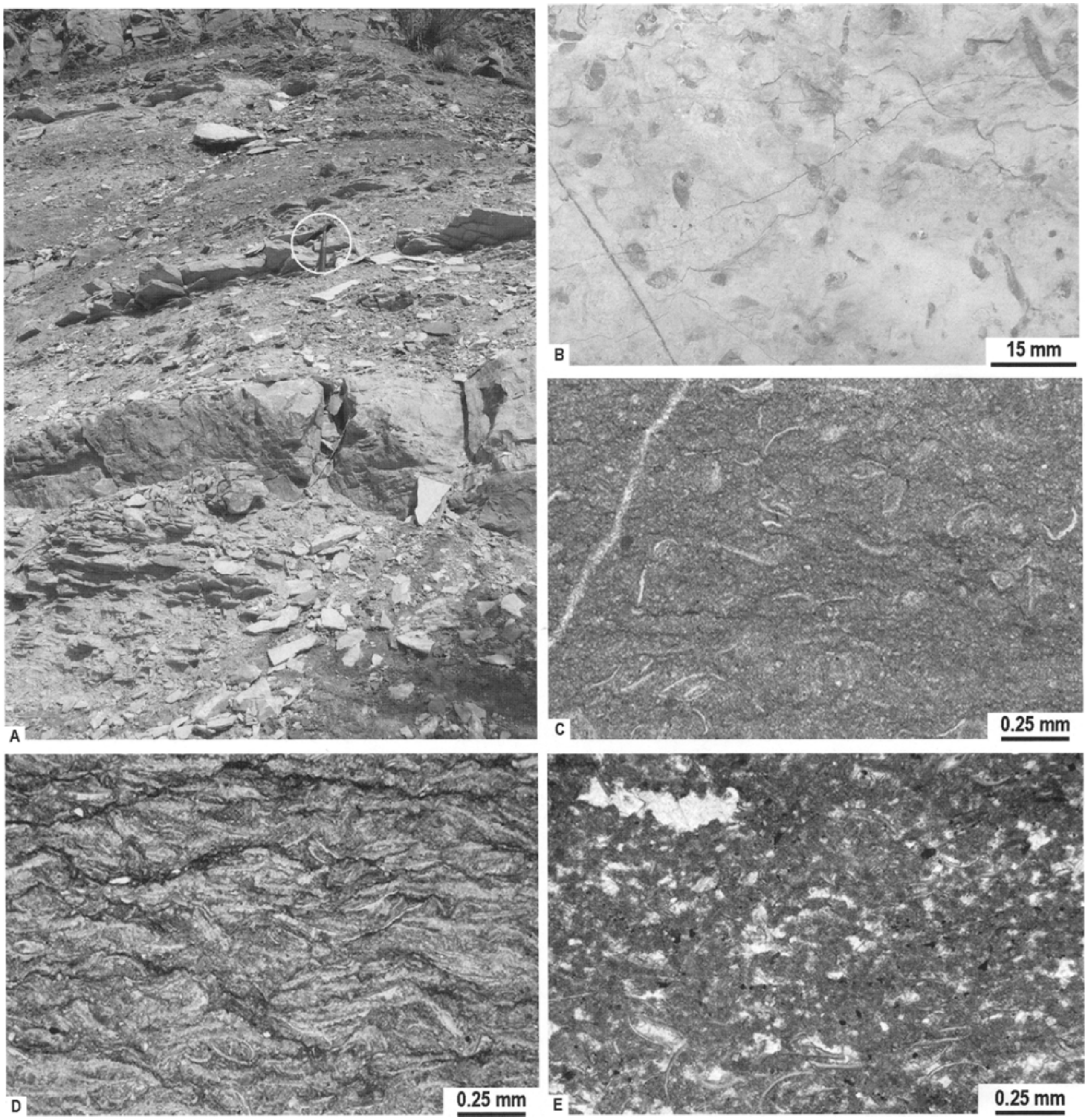

Figure 7. (A) Field photograph of the lagoonal to intertidal facies of the lower part of the Sorkh Shale Formation (hammer in the circle for scale) in the Godar Sorkh section. The resistive and thicker layers in the middle are carbonate storm beds. The lower part of the photograph displays a shallowing upward peritidal cycle changing upwards to alternating greenish gray shale and very thin bedded lime mudstone lagoonal facies. (B-D) Photomicrographs of lagoonal facies. (B) Bioturbated lime mudstone. (C) Ostracode wackestone. (D) Ostracode packstone. (E) Peloid grainstone with ostracode shells of the intertidal setting (irregular sparite filled voids are birdseyes).

the distal lagoonal facies (A1) and the overlying tidal flat facies (see Fig. 7A). The wackestone-packstone texture of facies A3 indicates deposition in the proximal part of a subtidal lagoon. The presence of abundant bioclasts of low-diversity restricted marine bioclasts of gastropods/ostracodes and the lack of normal marine fauna suggests a very restricted environment for facies A3. The possible analog for the restricted subtidal carbonate facies of the Sorkh Shale Formation is the restricted subtidal lagoon of the Persian Gulf (Shinn 1983a 1986; Flügel 2004).

Carbonate Tidal Flat Facies

Pure carbonate tidal flat facies constitutes the main part of the Sorkh Shale Formation in the northern distal sections, but mixed carbonate-clastic tidal flat facies are present in the lower part of Godar Gachal section and throughout the formation in the more proximal Islamabad section, south of the Tabas Basin (Fig. 6). In a shoreward direction, the carbonate tidal flat facies are: (B1) ostracode peloid/ peloid grainstone with birdseyes (Fig. 7E); (B2) red-pink laminated lime mudstone/dolomudstone (Fig. 8A-B); (B3) stromatolite boundstone (Fig. 8C); (B4) dolomudstone with lenticular beds of quartz sand (Fig. 9B); (B5) light gray very thin- to thin-bedded ostracode/gastropod mudstone-wackestone (Fig. 8B); and (B6) dolomudstone with birdseyes or laminated dolomudstone with evaporite casts (Fig. 8D-E). Facies B5 shows limited lateral extent and occurs only within the intertidal facies B2. Rain drop imprints (Fig. 8F), desiccation cracks (Fig. 9A), and laterally discontinuous laminae are recognized throughout this facies.

The grainstone to packstone texture and common birdseyes in facies B1, and its vertical association with lagoonal and upper intertidal/supratidal facies indicates deposition in a lower intertidal sub-environment (e.g., Dunham 1970; Shinn 1983a; Lasemi 1995). Facies B3, B4, and B5 are interpreted to have been deposited in an upper intertidal setting. Deposition in this zone is supported by the abundant mud content, laminations, lenticular bedding and vertical association with lower intertidal and supratidal facies. The gray color; limited lateral extent and occurrence within intertidal facies B2 supports an intertidal pond depositional setting for facies B5. Dolomudstone with birdseyes and discontinuous laminae with gypsum/anhydrite casts, mud cracks and rain drop imprints in facies B6 signify deposition in a supratidal environment (e.g., Shinn 1983a, 1983b). The characteristics of the Sorkh Shale carbonate tidal flat facies indicate deposition on an arid tidal flat similar to that of the modern carbonate tidal flats of the present day Persian Gulf (Purser 1973; Shinn 1983a, 1986; Flügel 2004).

Clastic Tidal Flat Facies

Pure clastic (quartz sandstone) tidal flat facies are interbedded with carbonate tidal flat facies in the more proximal Islamabad section, south of the Tabas Basin (Fig. 6). The quartz sandstone tidal flat facies comprise gray to white quartzarenite (C1) and quartzwacke (C2). The sandstones are laterally extensive and show high textural and compositional maturity. Very fine- to medium-grained, sorted and well-rounded, spherical and bimodal quartz grains (Fig. 9C-D), mainly with polished (frosted) surfaces, appear to be the only components of the sandstone facies. Locally, the quartz sandstone facies is diagenetically altered to red, shale like material (Fig. 10D) or to pink-red colored sandstone (Fig. 10C). Flat bedding with internal laminations (Fig. 9F), herringbone cross-laminations/cross bedding (Fig. 9E-F), flaser bedding and current ripples (Fig. 9E) are recognized in the quartz sandstone facies. The sandstones are thin- to medium-bedded and arranged into sharp-based fining-upward (upper part missing) cycles (Figs. 9F and 10A). In the Islamabad section (Fig. 6), the sandstone beds are overlain and underlain, with a sharp contact, by shallowing upward carbonate tidal flat cycles forming pure siliciclastic-pure carbonate double cycles (Fig. 10 B-C).

The high compositional and textural maturity, cross bedding, flaser bedding and lamination of the quartzarenite facies indicate high-energy conditions and constant reworking during deposition.. Vertical grading of facies C1 to poorly sorted quartzwacke (facies C2), herringbone cross-lamination/cross-bedding, flaser bedding, laminations and vertical association of the clastic facies with carbonate tidal flat facies suggest deposition in shallow intertidal environment. The frosting and bimod size distribution of the quartz grains suggests proximity to a desert environment (e.g., Klein 1977). The sand grains are interpreted as eolian dune sands, which were transported over the carbonate tidal flat (at the time of emergence) and subsequently reworked in the intertidal environment during the next platform flooding. The characteristics of the clastic tidal flat facies of the Sorkh Shale Formation are similar to the sand flats of the Holocene tidal flat facies of northwest Australia (Semeniuk 1981).

Continental Facies

Continental siliciclastic facies (D) and evaporite facies (E) are recognized in the lower part of the Sorkh Shale Formation in the Godar Gachal and Islamabad sections, respectively (Fig. 6). Continental siliciclastics beds in the lower part of the Godar Gachal section are about 3.5 meters thick and include (D1) calclithite, (D2) lithic wacke, and (D3) red shale. The sandstone facies (calclithite and lithic wacke) is of limited lateral extent and consists of quartz grains and 25% or more of carbonate and mudstone rock fragments that form 3 erosive-based, fining-upward cycles that are capped with red shale (Fig. 6). The low compositional maturity, limited lateral extent, erosive base and fining upward cycles suggest a fluvial coastal plain depositional setting for facies D.

The evaporite facies (E) is recognized in the lower part of the Sorkh Shale Formation in the Islamabad section (Fig. 6). According to Aghanabati (2004), gypsum beds also are present at the base of the Sorkh Shale Formation in the Lakarkooh area, about 60 kilometers north of the Islamabad section. In the Islamabad section (in the south of the Tabas Basin), the evaporite facies (over 50 meters thick) constitutes the base of the formation and underlies, with a sharp erosional contact, transgressive coarse siliciclastics laid down in the lower intertidal setting (Fig. 6). The

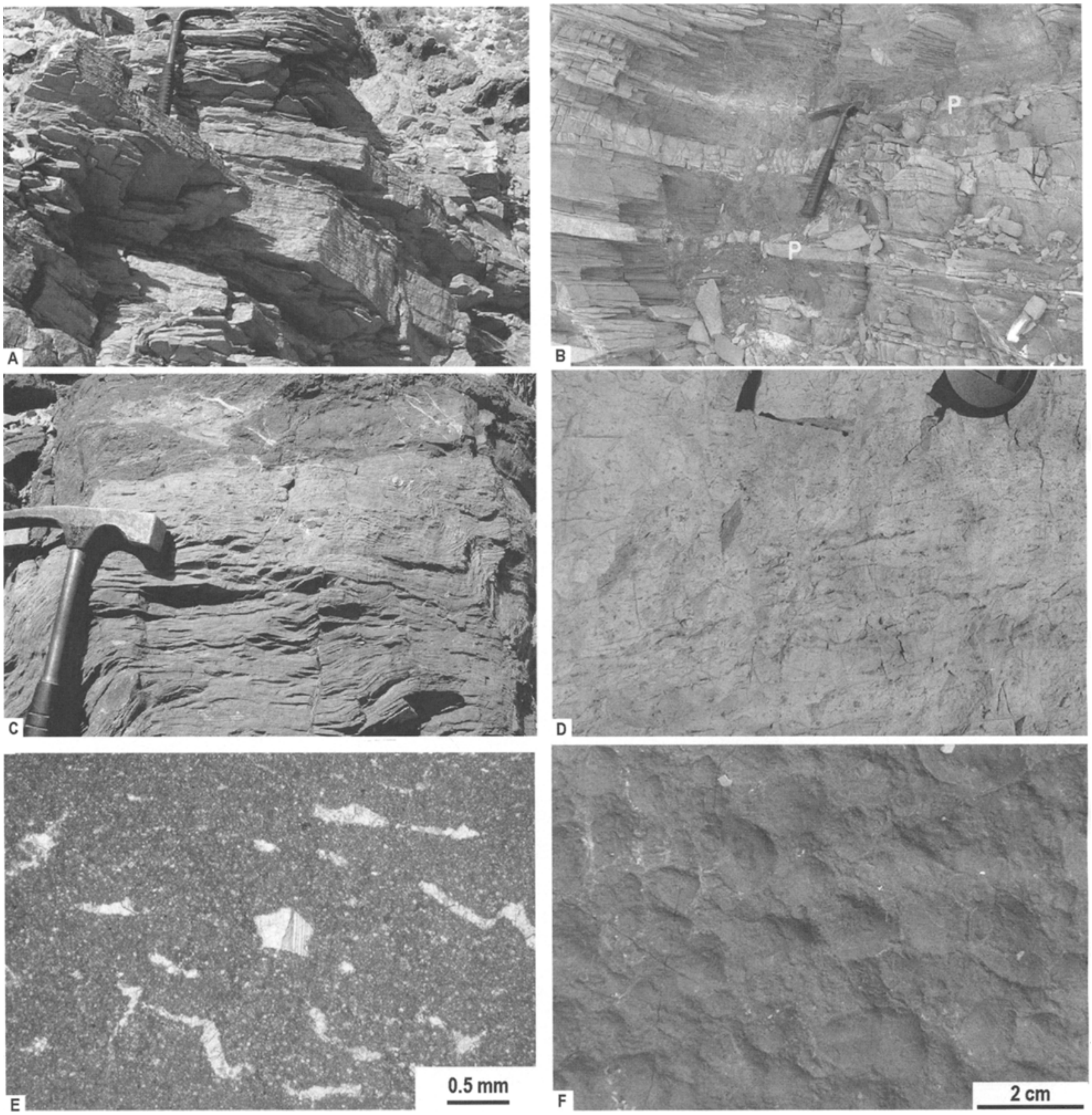

Figure 8. (A-C) Field photographs of intertidal facies. (A) Red laminated lime mudstone/dolomudstone facies. (B) Same as A with a few thin beds of gray ostracode/gastropod lime wackestone of limited lateral extent marked by letter P (intertidal pond facies). (C) Field photograph of wavy stromatolite facies that is sharply overlain by a storm facies. (D) Field photograph and (E) Photomicrograph of lime mudstone/dolomudstone with birdseyes (supratidal facies). (F) Rain drop imprint.

evaporates are white, gray and red to pink in color and consist (Fig. 6) of (E1) thick-bedded to massive gypsum and (E2) alternating bedded gypsum, thin bedded red shale and gray silty lime mudstone (Fig.10E). The absence of marine fauna, massive to bedded nature, the red shale intervals and its occurrence at the base of a pronounced transgressive surface (Fig. 6) suggest that the evaporite facies was deposited in a continental sabka environment. Deposition of facies E2 is interpreted to have occurred at the marginal area of a continental sabka; the silty lime mudstone facies records deposition during intervals of lower evaporation. It is likely that rapid subsidence of the Nayband sub-basin located along an east-west trending fault (Aghanabati 2004) south of the Tabas Block, resulted in the formation of a silled evaporite basin and deposition of evaporites during post-Permian sea-level lowstand.

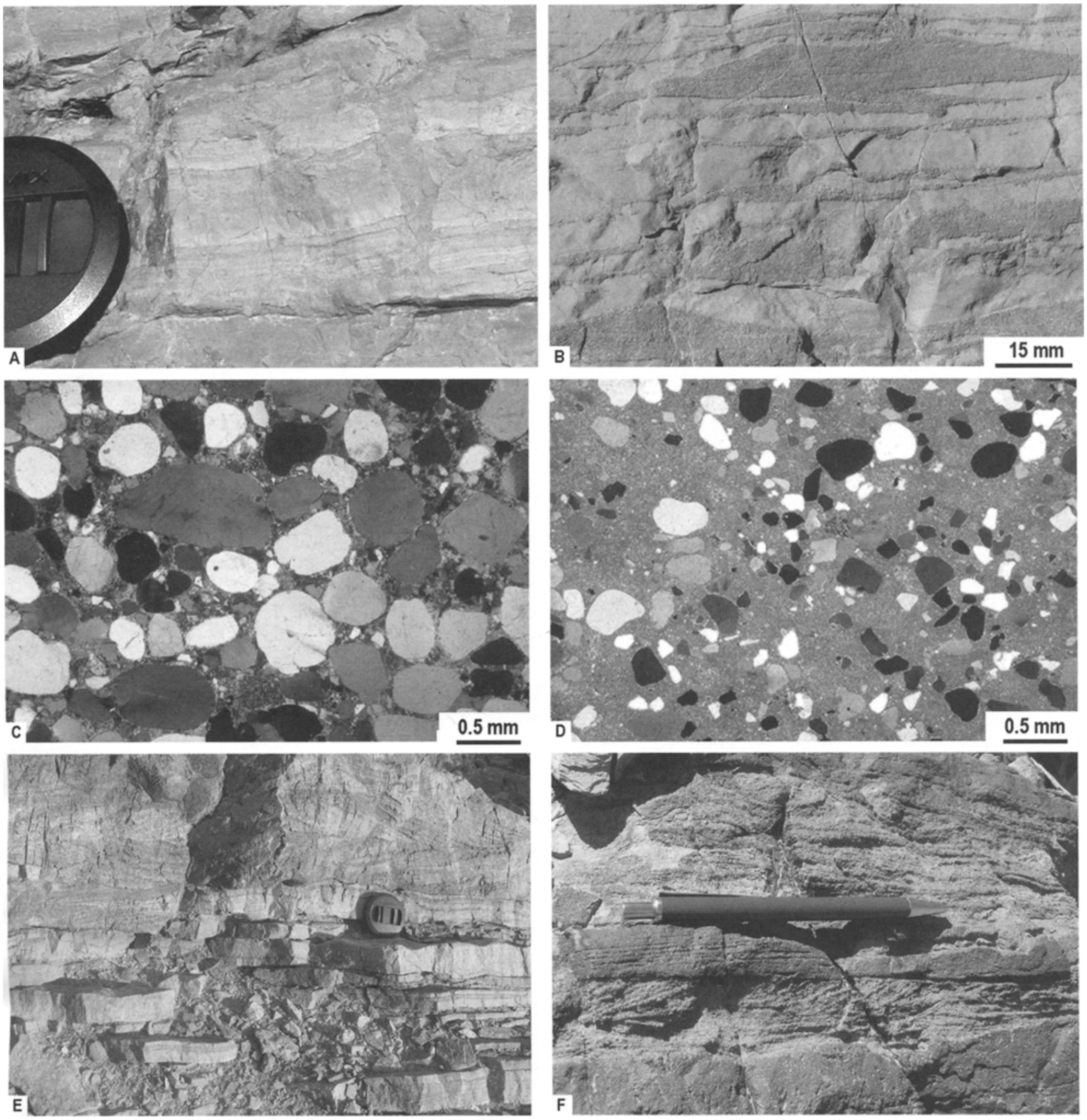

Figure 9. (A) Field photograph of a mud crack in the thinly laminated tidal flat facies near the base of the Sorkh Shale sequence in the Godar Sorkh section showing a small scale shallowing-upward cycle (diameter of the lens cap is 5.5 cm). (B) Field photograph of dolomudstone with lenticular bedding. (C and D) Photomicrographs of clastic intertidal facies. (C) Super maturely rounded bimodal quartzarenite (lower intertidal facies). (D) Quartzwacke (upper intertidal facies). (E) Field photograph of a coarsening upward cycle (lens cap diameter is 5.5 cm) composed of thin bedded and rippled quartzarenite (layer below lens cap), quartzwacke and siltstone (lagoonal) (behind lens cap) grading upwards to herringbone cross bedded quartzarenite (lower intertidal). (F) Field photograph of a couple of fining-upward tidal flat cycles composed of flat-bedded, laminated and herringbone cross-laminated quartzarenite (pen is 5.5 cm long).

Storm Facies

Numerous carbonate storm beds are present throughout the Sorkh Shale Formation in the Godar Sorkh and Godar Gachal sections, north of the Tabas Basin (Figs. 5 and 6). They are laterally extensive and consist of bioclast mudstone-grainstone and an ooid bioclast/intraclast and ooid/intraclast grainstone facies (Figs. 6, 7A and 11A-F). The storm beds comprise ooids, well-rounded intraclasts (mainly oval), quartz grains and bioclasts that include

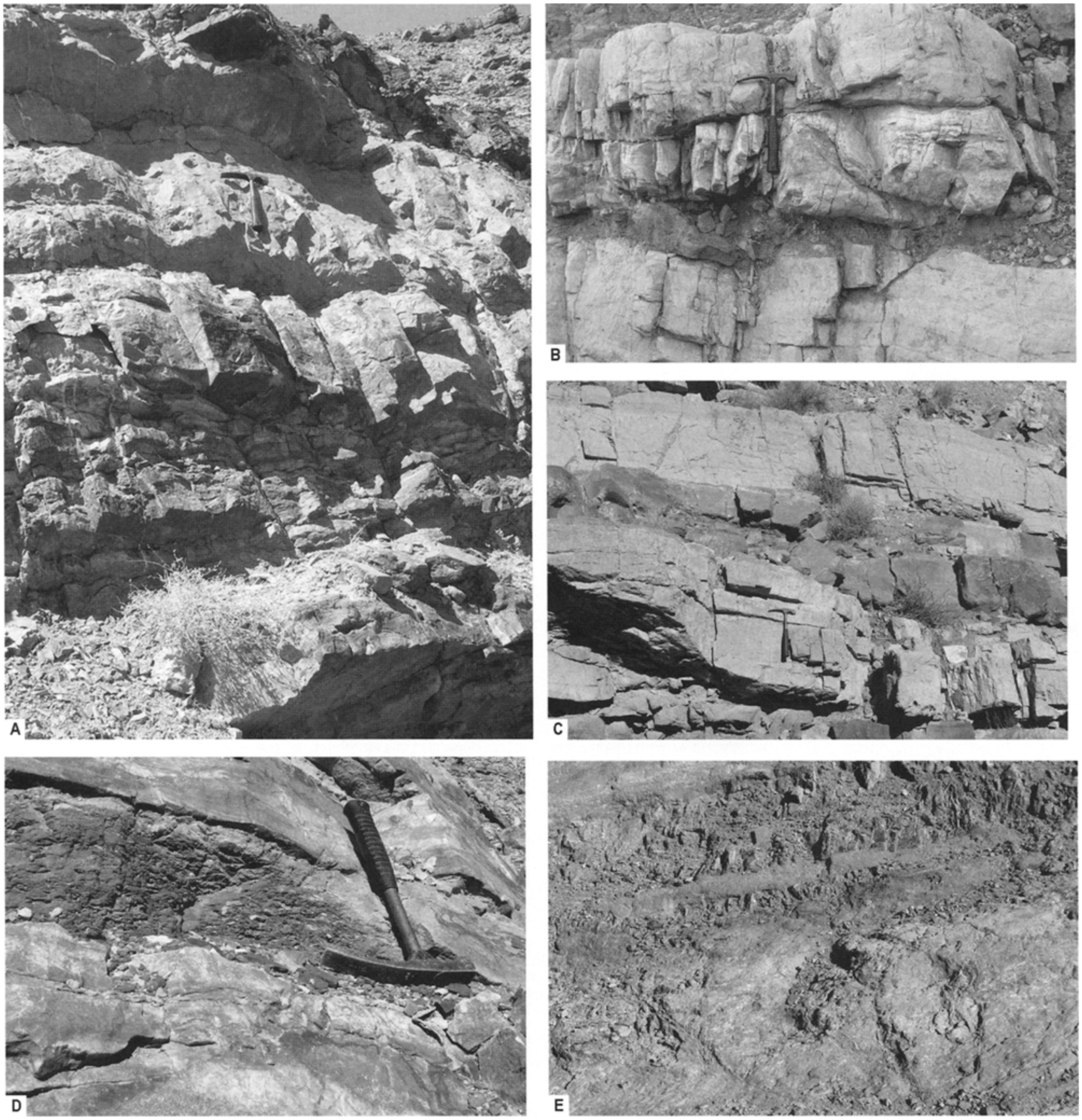

Figure 10. (A-C) Field photographs of tidal flat cycles. (A) A few sharp-based, shallowing-upwards cycles composed of quartzarenite facies related to the lower intertidal setting (hammer for scale). (B and C) Mixed pure carbonate to pure quartzarenite double cycles (sharp-based and top missing). Note the white quartzarenite in the center of photograph in B that is overlain and underlain by carbonate tidal flat facies. The dark red layer in the center of C is diagenetically altered quartzarenite facies. (D) A quartzarenite bed that is diagenetically altered to red shale-like material in the center of the photograph left of the hammer). (E) Gray-white gypsum bed overlain by thin beds of red shale and gray silty lime mudstone interpreted as continental evaporite facies (width of the photograph is 70 cm).

bivalves with prismatic structure (genus *Claraia*) or neomorphic spar filled shells (*Pseudomonotis*), serpulids (genus *Spirobis*), rare echinoderm debris, ostracodes and gastropods (Fig. 11C-F). These components are present in the fair weather facies of the lower limestone member of the Elika Formation. The storm beds commonly fine upward (Fig. 11B) and show a sharp or erosional base with gutter casts (Fig. 11A). They are overlain and underlain by various peritidal facies (Fig. 6) and may occur within any individual facies (Figs. 7A, 8C and 11A); several storm beds

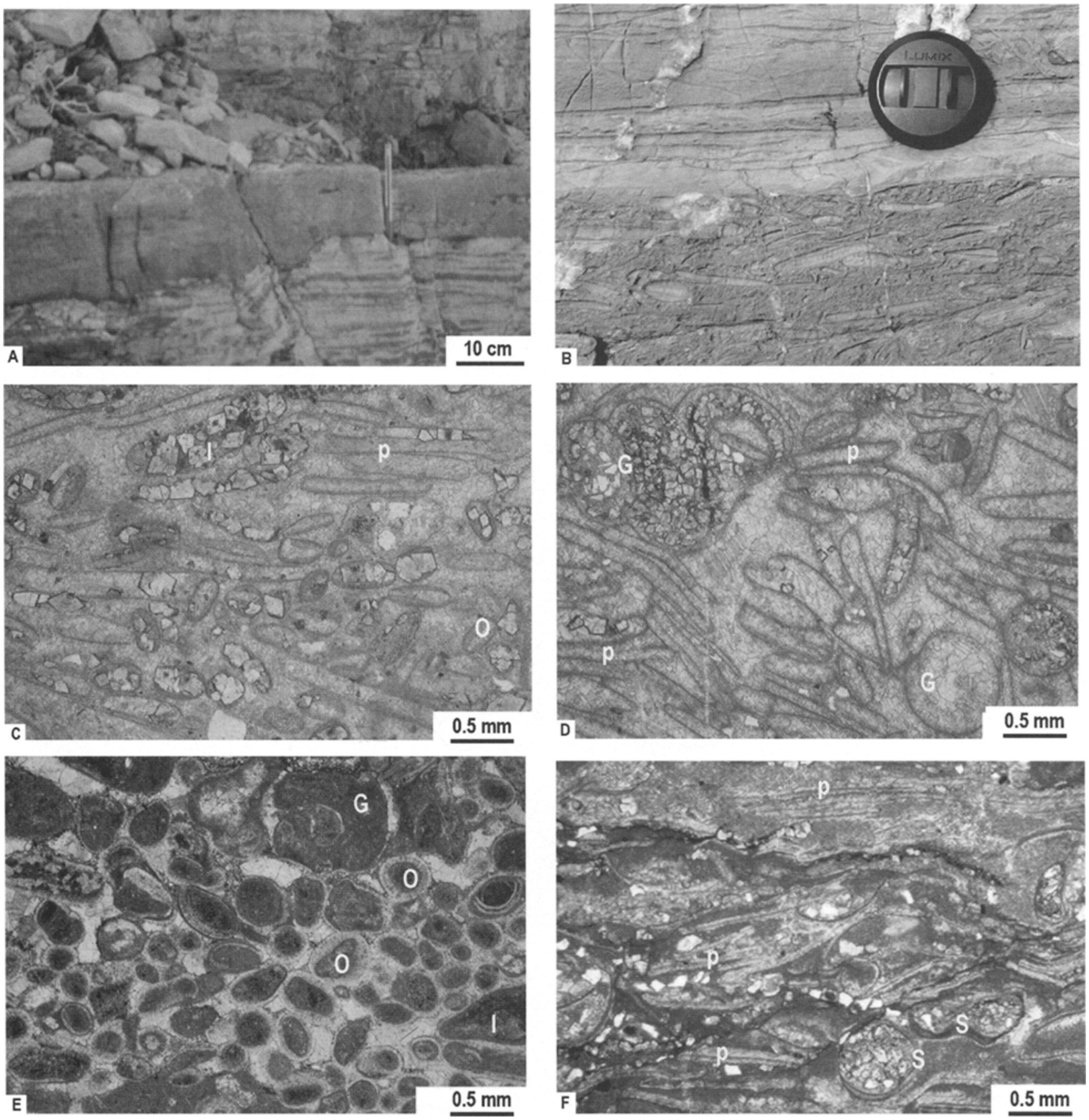

Figure 11. A and B, Field photographs of storm beds. (A) A carbonate storm bed displaying a gutter cast cut into the laminated intertidal facies (length of pen is 15 cm). (B) A fining-upward intraclastic storm bed (lens cap diameter is 5.5 cm). (C-F) Photomicrographs of carbonate storm beds containing bioclasts of mixed fauna, ooids and intraclasts. I, intraclast; O, ooid; G, gastropod; S, Spirobis; P, sparite-filled pelecypods (Photographs C-D) or prismatic (photograph F) pelecypod shell fragments.

may occur within a single tidal flat facies. Current ripples, cross-bedding and imbrication in the storm beds indicate a southward paleocurrent direction. Carbonate storm deposits are absent in the proximal Islamabad section, south of the Tabas Basin (Fig. 6). Their mixed marine components, normal grading, sharp/erosive basal contacts with gutter casts, and interlayering with/or occurrence within any low energy peritidal facies all support formation during storm events (e.g., Aigner 1985). Carbonate storm beds are also present throughout the Elika Formation, the Sorkh Shale equivalent of the Paleotethys margin (Fig. 5).

HIGH FREQUENCY CYCLES

The Sorkh Shale Formation consists primarily of asymmetric, high frequency (4th to 6th-order) shallowing upward peritidal cycles (Fig. 6) (parasequences of Van Wagoner et al. 1988), which consist of genetically-related lithofacies that are bounded by marine flooding surfaces. Each cycle starts with an initial phase of deepening over an underlying cycle with a sharp contact (Figs. 6, 7A, 8A, 9A and 10A). 5th to 6th-order cycles of pure carbonate (Figs. 8A and 9A), pure siliciclastic (Figs. 9E-F and 10A) and mixed pure siliciclastic-pure carbonate double cycles (Fig. 10B-C), which are the building blocks of 4th-order cycles (Fig. 6) are recognized. Pure carbonate parasequences are present in the distally located Godar Sorkh section and in the upper part of the Godar Gachal section (Fig. 6). Each mixed double cycle (5th-order cycle) consists of a basal texturally and compositionally mature quartz sandstone peritidal cycle (Fig. 9C-D) overlain, with an erosive or sharp contact, by a pure peritidal carbonate cycle. The sand grains were probably transported over the tidal flat from adjacent non-marine environments during emergence of the proximal area of the platform and reworked in the intertidal environment during subsequent flooding (e. g., Grammer et al. 2000). The double cycles are present throughout the Formation in the proximal Islamabad section (Fig. 6) and are similar to those described by Goldhammer et al. (1991).

DISCUSSION

Carbonate Platform

The carbonate ramp model (Ahr 1973, 1998; Read 1985; Burchette and Wright 1992) is appropriate for the depositional settings of the Tabas Basin during the Lower Triassic. A ramp or epeiric platform can be subdivided, using the fair weather wave base and storm wave base, into inner-, mid-, and outer-ramp settings with different energy conditions (Burchette and Wright 1992). The Sorkh Shale Formation includes evidence of deposition under arid conditions on a storm-dominated inner-ramp setting. Arid conditions prevailed in the basin during the Lower Triassic as indicated by the presence of numerous red-colored intervals, evaporites that locally exist in the lower part, and the red paleosol at the upper boundary of the formation. This interpretation is in accord with Frakes et al. (1992) who also suggested arid and hot conditions for the Early Triassic time.

Rounded and bimodal sand grains of the texturally and compositionally mature coarse siliciclastics (Fig. 9C-D) interpreted to have been transported to the basin during emergence, display polished (frosted) surfaces indicating the existence of an eolian environment landward of the ramp. The chiefly tidal flat facies of the Sorkh Shale Formation in sections of more than 300 kilometers apart, from Islamabad to the distal Godar Sorkh section (Fig. 1), as well as the northward decrease of coarse siliciclastics (Figs. 5 and 6), suggest deposition in the proximal part of an inner ramp with a very gentle northerly slope that fringed the Tabas Block of east central Iran during the Lower Triassic. Despite the differences in geometry and tectonic settings, the proximal inner-ramp setting of the southern Persian Gulf is a present day analog for the Tabas platform during the Lower Triassic.

Regional Correlation

The Sorkh Shale sequence of the Tabas Basin is correlated with the lower limestone member of the Elika Formation of the Alborz Mountains along the Paleotethys passive margin of northern Iran (Figs. 3 and 5). Paleontological data (e. g., Bronnimann et al. 1973; Seyed-Emami 2003) supports an Early Triassic age (Scythian) for the Sorkh Shale Formation and its equivalent lower Elika Formation. Lower Triassic (Griesbachian) deposits in many parts of the world are characterized by abundant storm beds (e.g.,Wignall and Twitchett 1999). Storm layers are also abundant in the Lower Triassic deposits of the Alborz Mountains and the Tabas Basin (Fig. 5) supporting an early Scythian age for the Sorkh Shale Formation.

The bounding unconformities of the Sorkh Shale formation are traceable across the Cimmerian Plate of central and northern Iran. In Late Permian time, a global sea-level lowstand resulted in the emergence and formation of a well-developed laterite soil horizon on the Permian succession of a vast area of the Cimmerian Plates of Iran (Lasemi 2001) including the Tabas Basin. This unconformity corresponds with the lowest first-order sea-level stand of the Phanerozoic (Golonka and Kiessling 2002). In the Tabas Block, this pre-Triassic laterite separates the Upper Permian Jamal Formation from the Lower Triassic Sorkh Shale Formation (Fig. 4A-B). In other areas of central Iran and in the central and southern Alborz Mountains the Lower Triassic succession overlies, with a well-developed laterite/ bauxite horizon, Permian rocks of different ages (Lasemi 2001; Seyed-Emami 2003; Aghanabati 2004). In parts of the eastern Alborz, the entire Lower to Upper Permian succession is missing (Fig. 3) and the Lower Triassic Elika Formation overlies the Lower Carboniferous Mobarak Formation (Jahani 2000; Lasemi 2001). The Permo-Triassic boundary is conformable only in Jolfa-Amol (in the northern Alborz of northern Iran) (e.g., Alavi-Naini 1993; Lasemi 2001; Aghanabati 2004), the distally located section of the Paleotethys passive margin.

The upper unconformable boundary of the Sorkh Shale Formation coincides with the Lower-Middle Triassic unconformity (Fig. 3), which corresponds with the first-order sequence boundary of Vail et al. (1977). In the Tabas Basin, a distinct paleosol (Fig. 4C-E) separates the Sorkh Shale Formation from the Middle Triassic Shotori

Formation. The same paleosol is present on the lower member of the Elika Formation, the Sorkh Shale equivalent in the Alborz Mountains of northern Iran (Tahmasebi 1998). In the eastern Alborz Mountains, the paleosol is underlain by about 9 meters of quartzarenite facies (Jahani 2000; Lasemi and Jahani 2001). In the southern margin of the Cimmerian Plate (e.g., north of Isfahan in central Iran), a proximal section of the southern part of the Cimmerian Plate, the entire Lower Triassic section is missing and the Middle Triassic mixed siliciclastic-carbonates of the middle Elika Formation (Middle Triassic) overlie the pre-Triassic unconformity (Jahani 2000).

Relation to Paleotethys Passive Margin

The elongate north-south trending Tabas Block (Fig. 1), a part of the Cimmerian Continent, which is located between the Lut Block in the east and the Kalmard Block in the west (Figs.1 and 2) was suggested by Lasemi (1999, 2001) to have been a failed rift basin during Late Paleozoic and Early Mesozoic times. The basin, a part of the central east Iranian micro-continent described by Takin (1972), rests on a structural framework that was developed during a late Precambrian extensional movement (e. g., Stocklin 1968; Nabavi 1976; Berberian and King 1981; Lasemi 2001). Continued tectonic activity along the Nayband and Kalmard-Kuhbanan bounding faults during Paleotethys rifting (Early Ordovician-Silurian) resulted in repeated vertical movement and formation of the Tabas failed rift basin (Lasemi 1999, 2001) that opened northward (present-day coordinates) into the Paleotethys Ocean (Fig. 2). The interpretation is based on regional facies and sequence stratigraphic analyses of the Cambrian through Silurian deposits of northern and central Iran. In the Tabas Block, the Ordovician-Silurian continental to shallow marine succession (the Shirgesht and Niur Formations) in the southern part of the block changes northward to over 1500 meters of chiefly deep marine siliciclastic turbidities. The succession, like the Alborz Mountains in northern Iran, unconformably overlies the Cambrian platform deposits and shows an overall transgressive trend corresponding to the syn-rift phase of the Paleotethys margin (Lasemi 2001). The sedimentary succession of the Tabas Block, like other parts of the Cimmerian Plates of central and northern Iran, consists of the Cambrian platform facies (pre-rift), Ordovician to Silurian siliciclastics and carbonates including basaltic flows (syn-rift) and the Devonian-Upper Triassic platform deposits (post-rift) related to the Paleotethys passive margin (Stampfli et al. 1991; Lasemi 1999, 2001).

The uppermost lithostratigraphic unit of the Paleotethys post-rift sequence corresponds with the unconformity bounded Lower-Upper Triassic Elika Formation of the Alborz Mountains and its equivalent Sorkh Shale and Shotori Formations of the Tabas Block (Fig. 3). Although the nature of the deposits is markedly different, detailed facies and sequence stratigraphic analyses have indicated that the Sorkh Shale Formation of the Tabas Basin and the lower Elika member of the Alborz Mountains (the Paleotethys passive margin of northern Iran) are genetically related and belong to the same tectonic settings. Gray to tan, heavily bioturbated lime mudstone, bioclastic mudstone-packstone, ooid/bioclast grainstone and numerous intraclast-bearing storm beds comprise the bulk of the lower Elika carbonates of the Alborz Mountains (Fig. 5); Tahmasebi 1998; Jahani 2000; Lasemi and Jahani 2001). In contrast to the lower unit of the Elika Formation, the Sorkh Shale is characterized by predominantly red-colored, marginal marine (chiefly peritidal) carbonate and siliciclastic facies containing numerous carbonate storm beds, which include grains of fair weather facies of the Elika Formation (Figs. 5, 6, 7A, 8C, 11A-F).

The constituents of the storm beds, such as, ooids, intraclasts (texturally different from the interbedded facies) and bioclasts (particularly prismatic and sparry calcite-filled pelecypod fragments and *Spirobis*) (Fig. 11B-F) are absent in the fair weather peritidal facies of the Sorkh Shale Formation. These components are present throughout the lower limestone member of the Elika Formation (Figs. 5 and 6). The rounded and oval intraclasts, and the presence of ooids and bioclasts in the storm beds of the Sorkh Shale Formation that are absent in the interbedded fair-weather strata (Fig. 5) suggest transport of these components a considerable distance from the offshore area of the Paleotethys passive margin before deposition. In addition, the northward increase in carbonate content, absence of the storm layers in the southern part of the Tabas Block, and northward paleocurrent directions of the fair weather facies of the Sorkh Shale Formation indicate that the Tabas Basin was tectonically a part of the Paleotethys passive margin and that the low topographic gradient of the ramp in the Tabas failed rift faced the Paleotethys Ocean (Fig. 2), where the storms were generated. Relative sea-level, basin geometry and tectonic movements along the bounding faults played a significant role during deposition of the Sorkh Shale Formation by controlling accommodation space and facies variations in the Tabas failed rift basin.

CONCLUSIONS

1. The Sorkh Shale Formation is composed chiefly of numerous high-frequency (4th to 6th-order) peritidal cycles and was deposited in the low energy settings of a storm-dominated mixed carbonate-siliciclastic inner-ramp with a very gentle slope that fringed east central Iran (Tabas Block) and passed northward (present-day coordinates) into deeper water facies of the Paleotethys passive margin.

2. Arid conditions prevailed during deposition of the Sorkh Shale Formation as indicated by the presence of numerous red colored intervals, thick evaporates and the red paleosol at the upper boundary of the formation.

3. The Tabas Block was a rift basin that developed during Early Ordovician-Silurian Paleotethys rifting and persisted until Late Triassic time. Facies analysis of the Sorkh Shale Formation has revealed additional supporting evidence for interpreting the Tabas Block as a failed rift basin related to the Paleotethys passive margin.

4. Thickness and facies variations (both laterally and vertically) of the Sorkh Shale Formation along the bounding faults of the Tabas Block indicate that relative sea-level, basin geometry and tectonic movements played significant role during deposition of the Sorkh Shale Formation by controlling accommodation space and facies variations along the Tabas failed rift basin.

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REFERENCES

AGHANABATI, S. A., 1977, Etude geologique de la Kalmard (W. Tabas). Geological Survey of Iran Report, no. 35, 230 p.

AGHANABATI, S. A., 2004, Geology of Iran. Geological Survey of Iran, 586 p. (in Persian).

AHR, W. M., 1973, The carbonate ramp: an alternative to the shelf model: *Transactions, Gulf Coast Association of Geol. Scientists*, v. 23, p. 221-225.

AHR, W.M., 1998, Carbonate ramps, 1973-1996: a historical review. In V.P. Wright and T.P. Burchette, eds., Carbonate Ramps. Geological Society of London Special Publication, no. 149, p. 7-14.

AIGNER, T., 1985, Storm Depositional Systems. Springer-Verlag, Berlin, 174 p.

ALAVI, M., VAZIRI, H., SEYED-EMAMI, K., and LASEMI, Y., 1977, The Triassic and associated rocks of the Nakhlak and Aghdarbad area in central and northeastern Iran as remnants of the southern Turanian active continental margin: *Geological Society of America Bulletin,* v. 109, p. 1563-1575.

ALAVI-NAINI, M., 1993, Paleozoic Stratigraphy of Iran. Geological Survey of Iran, Treatise on the Geology of Iran, v. 5, 492 p. (in Persian).

BERBERIAN, M. and KING, G.C.P., 1981, Towards a paleogeography and tectonic evolution of Iran: *Canadian Journal of Earth Sciences,* v. 18, p. 210-265.

BRATASH, V.I., 1975, Kerman-Kashmer Trough, Iran, and the problem of the junction between pre-Jurassic structures of the Turanian plate and the Mediterranean belt: *Geotectonics,* v. 9, p. 101-107.

BRONNIMANN, P., ZANINETTI, L., MOSHTAGHIAN, A., and HUBER, H., 1973, Foraminifera from the Sorkh Shale Formation of the Tabas area, east-central Iran: *Riv. Ital. Paleont.*, v. 79, p. 1-32.

BURCHETTE, T.P. and WRIGHT, V.P., 1992, Carbonate ramp depositional systems: *Sedimentary Geology,* v. 79, p. 3-57.

DAVOUDZADEH, M., SOFFEL, H., and SCHMIDT, K., 1981, On the rotation of the Central East Iran microplate: *Neues Jahrbuch fur Geologie und Palaontologie Monatshefte*, Heft 3, p. 180-192.

DERCOURT, J., RICOU, L.E., and VRIELYNCK, B., eds., 1993, Atlas Tethys Paleoenvironmental Maps. Gauthier-Villars, Paris, 307 p.

DUNHAM, R.J., 1962, Classification of carbonate rocks according to depositional texture. In Ham, W.E., ed., Classification of Carbonate Rocks. American Association of Petroleum Geologists Memoir, no. 1, p. 108-121.

DUNHAM, R.J., 1970, Keystone vugs in carbonate beach deposits (abstract): *American Association of Petroleum Geologists Bulletin*, v. 54, p. 845.

EMBRY, A.F., 1988, Triassic sea level changes: Evidence from the Canadian Arctic Archipelago. In C.K. Wilgus, B.S. Hastings, C.G.St. Kendal, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner, eds., Sea-Level Changes, an Integrated Approach. Society of Sedimentary Geology (SEPM) Special Publication, no. 42, p. 249-259.

FLÜGEL, E., 1982, Microfacies Analysis of Limestones. Springer-Verlag, Berlin, 633 p.

FLÜGEL, E., 2004, Microfacies of Carbonate Rocks. Springer-Verlag, Berlin, 976 p.

FOLK, R.L., 1974, Petrology of Sedimentary Rocks. Hamilton Publ. Co., Austin, Texas, 182 p.

FRAKES, L.A., FRAKES, J.E., and SYKTUS, J.I., 1992, Climate Models of the Phanerozoic. Cambridge University Press, Cambridge, UK, 274 p.

GANSSER, A., 1955, New aspects of geology in Central Iran. Proceedings of the 4th World Petroleum Congress, Rome, Sect. I/A/5, p. 279-300.

GHOMASHI, M., 2007, Depositional environments and sequence stratigraphy of the Sorkh Shale and Shotori Formations (Lower-Middle Triassic) in the Tabas Block. PhD thesis, Department of Geology, Tarbiat Moallem University, Tehran, Iran (in Persian with English abstract), 123 p.

GLAUS, M., 1964, Trias und oberperm in Zentralen Elburs (Persien): *Eclogae. Geol. Helv.*, v. 57, p. 497-508.

GOLDHAMMER, R.K. DUNN, P.A., and HARDIE, L.A., 1991, Depositional cycles, composite sea level changes, cycle stacking patterns and the hierarchy of stratigraphic forcing-examples from platform carbonates of the Alpine Triassic: *Geological Society of America Bulletin*, v. 102, p. 535-562.

GOLONKA, J., 2002, Plate-tectonic map of the Phanerozoic. In W. Kiessling, E. Flügel, and J. Golonka, eds., Phanerozoic Reef Patterns. Society of Sedimentary Geology (SEPM) Special Publication, no. 72, p. 21-75.

GOLONKA, J. and FORD, D., 2000, Pangean (Late Carboniferous-Middle Jurassic) paleoenvironment and lithofacies: *Palaeogeography, Palaeoclimatology, and Palaeoecology,* v. 161, p. 1-34.

GOLONKA, J. and KIESSLING, W., 2002, Phanerozoic time scale and definition of time slices. In W. Kiessling, E. Flügel, and J. Golonka, eds., Phanerozoic Reef Patterns. Society of Sedimentary Geology (SEPM) Special Publication, no. 72, p. 11-20.

GRAMMER, G.M., EBERLI, G.P., VAN BUCHEM, F.S.P., STEVENSON, G.M., and HOMEWOOD, P.W., 2000, Application of high resolution sequence stratigraphy in developing an exploration and production strategy for a mixed carbonate/siliciclastic system (Carboniferous)

Paradox Basin, Utah, USA. In P.W. Homewood and G.P. Eberli, eds., Genetic Stratigraphy on the Exploration and the Production Scales. Elf Exploration Production, France, p. 29-69.

HAQ, B.U., HARDENBOL, J., and VAIL, P.R., 1988, Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In C.K. Wilgus, B.S. Hastings, C.G.St. Kendal, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner,, eds., Sea-Level Changes, an Integrated Approach. Society of Sedimentary Geology (SEPM) Special Publication, no. 42, p. 71-108.

JAHANI, D., 2000, Sedimentary basin analysis of the Elika Formation in central and eastern Alborz. PhD thesis, Dept. of Geology, Science and Research Unit, Azad University, Tehran, Iran (in Persian with English abstract), 313 p.

KLEIN, G.deV., 1977. Clastic Tidal Facies. Continuing Education Publ. Co. Champaign, Illinois, USA, 149 p.

LASEMI, Y., 1995, Platform carbonates of the Upper Jurassic Mozduran Formation in the Kopet-Dagh Basin, NE Iran, Facies, paleoenvironments and sequences: *Sedimentary Geology,* v. 99, p. 151-164.

LASEMI. Y., 1999, Depositional environments of the Ordovician rocks of Iran (syn-rift sequence) and formation of the Paleotethys passive margin. Proceedings of the 17th annual meeting of the Geological Survey of Iran, p. 158-160 (in Persian).

LASEMI, Y., 2001, Facies Analysis, Depositional Environments and Sequance stratigraphy of the Upper Pre-Cambrian and Paleozoic Rocks of Iran. Geological Survey of Iran, 180 p. (in Persian).

LASEMI, Y. and JAHANI, D., 2001. Storm deposits of the lower unit of the Elika Formation (Lower Triassic): *Islamic Azad University Journal of Sciences,* v. 11, p. 3005-3024 (in Persian).

NABAVI, M.H., 1976, An introduction to the geology of Iran. Geological Survey of Iran, 109 p. (in Persian).

PETTIJOHN, F.J., POTTER, P.E., and SIEVER, R., 1987, Sand and Sandstone. Springer-Verlag, New York, 553 p.

PURSER, B.H., 1973, The Persian Gulf, Springer-Verlag, Berlin, 471 p.

READ, J.F., 1985, Carbonate platform facies models: *American Association of Petroleum Geologists Bulletin,* v. 66, p. 860-879.

SCOTESE, C.R. and Langford, R.P., 1995, Pangea and the paleogeography of the Permian. In P.A. Scholle, T.M. Peryt, and D.S. Ulmer-Scholle, eds., The Permian of Northern Pangea, v. 1. Berlin, Springer-Verlag, p. 3-19.

SENGOR, A.M.C., 1984, The Cimmeride orogenic system and the tectonics of Eurasia. Geological Society of America Special Paper, no. 195, 82 p.

SENGOR, A.M.C., ALTINER, D., CIN, A., USTAOMER, T., and HSU, K.J., 1988, Origin and assembly of the Tethyside orogenic collage at the expense of Gondwana Land. In M.G. Audley-Charles and A. Hallam, eds., Gondwana and Tethys. Geological Society of London Special Publication, no. 37, p. 119-181.

SENGOR, A.M.C. and NATALIN, B.A., 1996, Paleotectonics of Asia: fragments of a synthesis. In A. Yin and T.M. Harrison, eds., The tectonic evolution of Asia. Cambridge University Press, p. 486-640.

SEMENIUK, V., 1981, Sedimentology and stratigraphic sequence of a tropical tidal flat, NW Australia: *Sedimentary Geology,* v. 29, p. 195-221.

SEYED-EMAMI, K., 2003, Triassic in Iran: *Facies,* v. 48, p. 91-106.

SHAHRABI, M., 2000, Triassic in Iran. Geological Survey of Iran, 279 p. (in Persian).

SHINN, E. A., 1983a, Tidal flat environment. In P.A. Scholle and R.C.H. Moore, eds., Carbonate Depositional Environments: American Association of Petroleum Geologists Memoir, no. 33, p. 171-210.

SHINN, E.A., 1983b, Birdseyes, fenestrae, shirinkage pores and loferites, a re-evaluation: *Journal of Sedimentary Petrolology,* v. 53, p. 619-629.

SHINN, E.A., 1986, Modern carbonate tidal flats: their diagenetic features: *Quarterly Journal: Colorado School of Mines,* v. 81, p. 7-35.

SOFFEL, H.C. and FORSTER, H.G., 1984, Polar wander path of the Central East Iran microplate including new results: *Neues Jahrbuch fur Geologie und Palaontologie Abhandlungen,* Band 168, p. 165-172.

STAMPFLI, G., MARCOUX, J. and BAUD, A., 1991, Tethyan margins in space and time. *Palaeogeography, Palaeoclimatology, and Palaeoecology,* v. 87, p. 373-409.

STAMPFLI, G. and PILLEVUIT, A., 1993. An alternative Permo-Triassic reconstruction of the kinematics of the Teyhan realm. In J. Dercourt, L.E. Ricou, and B. Vrielynck, eds., Atlas Tethys Paleoenvironmental maps. Paris, Gauthir-Villars, p. 55-62.

STOCKLIN, J., 1968, Structural history and tectonics of Iran- a review: *American Association of Petroleum Geologists Bulletin,* v. 52, p. 1229-1258.

STOCKLIN, J. and SETUDEHNIA, A., 1971, Stratigraphic Lexicon of Iran. Geological Survey of Iran Report, no. 18, 376 p.

STOCKLIN, J., EFTEKHAR-NEZHAD, J., and HUSHMANDZADEH, A., 1965, Geology of the Shotori Range, Tabas area, East Iran. Geological Survey of Iran Report, no. 3, 69 p.

TAHERI, A., 2002, Stratigraphy of the Permian sediments (Jamal Formation) in Tabas Basin. PhD Thesis, Department of Geology, University of Isfahtan, Isfahan, Iran (in Persian with English abstract), 165 p.

TAKIN, M., 1972, Iranian geology and continental drift in the Middle East: *Nature,* v. 235, p. 147-150.

TAHMASEBI, A., 1998, Microfacies, depositional environments and sequence stratigraphy of the lower and middle units of the Triassic Elika Formation in eastern central Alborz. MS thesis, Department of Geology, Tarbiat Moallem University, Tehran, Iran (in Persian with English abstract), 123 p.

TUCKER, M.E. and WRIGHT, V.P., 1990, Carbonate Sedimentology. Blackwell, Oxford, 482 p.

VAIL, P.R., MITCHUM, R.M., TODD, R.G., WIDMIER, J.M., THOMPSON, S. III, SANGREE, J.B., BUBB J.N., and HATLEID, W.G., 1977, Seismic stratigraphy and global changes in sea level. In C.E. Payton, ed., Seismic Stratigraphy, Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir, no. 26, p. 49-212.

VAN WAGONER, J.C., POSAMENTIER, H.W., MITCHUM, R.M., VAIL, P.R., SARG, J.F., LOUTIT, T.S. and HARDENBOL, J., 1988, An overview of the fundamentals of sequence stratigraphy and key definitions. In C.K. Wilgus, B.S. Hastings, C.G.St. Kendal, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner, eds., Sea-Level Changes, an Integrated Approach. SEPM Spec. Publication, no. 42, p.

39-45.

WIGNALL, P.H. and TWITCHETT, R.J., 1999, Unusual intraclastic limestones in Lower Triassic carbonates and their bearing on the aftermath of the end-Permian mass extinction: *Sedimentology,* v. 46, p. 303-316.

WILSON, J. L., 1975, Carbonate Facies in Geologic History. Springer-Verlag, Berlin, 471 p.