DEPOSITIONAL HISTORY AND PALEOGEOGRAPHY OF THE LOWER PALEOCENE REDBEDS IN EASTERN KOPET-DAGH BASIN NORTHEASTERN IRAN

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Abstract

After the Middle Triassic orogeny (early Kimmerian), the Kopet-Dagh basin was formed in northeastern Iran. From the Jurassic period through to the Miocene epoch, this basin was a site of relatively continuous sedimentation, which was recorded by five major transgressive-regressive sequences. Close to the end of the Cretaceous period through to the Early Paleocene epoch, the epicontinental sea regressed toward the northwest and a thick interval of the Lower Paleocene redbed siliciclastic sediments were deposited in fluvial environments. Facies analysis of Lower Paleocene redbeds allow subdivision into three distinct facies assemblages. The lower and upper facies consist mainly of gypsiferous mudrock and evaporites with a few beds of fine to medium-grained sandstone that were deposited in the lowland area in marginal lacustrine and playa lake environments. The middle facies is composed mainly of sandstone and conglomerate that were deposited as sheet-like bodies in low sinuosity, coarse-grained braided stream systems. A thinning of the coarser-grained sediment toward the north and north-west indicates that the source for these siliciclastic sediments was to the south and southeast of the basin. The results of this study can be used to achieve a further understanding of the geologic history of this important petroleum producing basin.

Introduction

The Kopet-Dagh basin is located in northeastern Iran and contains more than 6000 meters of Mesozoic and Cenozoic sediments (Figure 1). In the eastern part of the basin, rocks pertaining to the Jurassic through to the Tertiary periods crop out of an eastward-plunging anticline. The Lower Paleocene redbeds of the Pestehleigh Formation are well exposed on the northern flank of this anticline in the area under study (Figure 1).

Keywords: Redbeds; Fluvial deposits; Lower Paleocene; Kopet-Dagh basin; Iran

The purpose of this study is to determine the nature and origin of Lower Paleocene redbed siliciclastic sediments in northeastern Iran and interpret their depositional history and paleogeography. Since the Kopet-Dagh is a petroliferous basin and these siliciclastic rocks have not been studied in detail before, this study will further the understanding of the history of the Kopet-Dagh basin in northeastern Iran.

The major portion of data for this study is derived from four measured stratigraphic sections in the study area (Figure 1). The thickness of the Pestehleigh

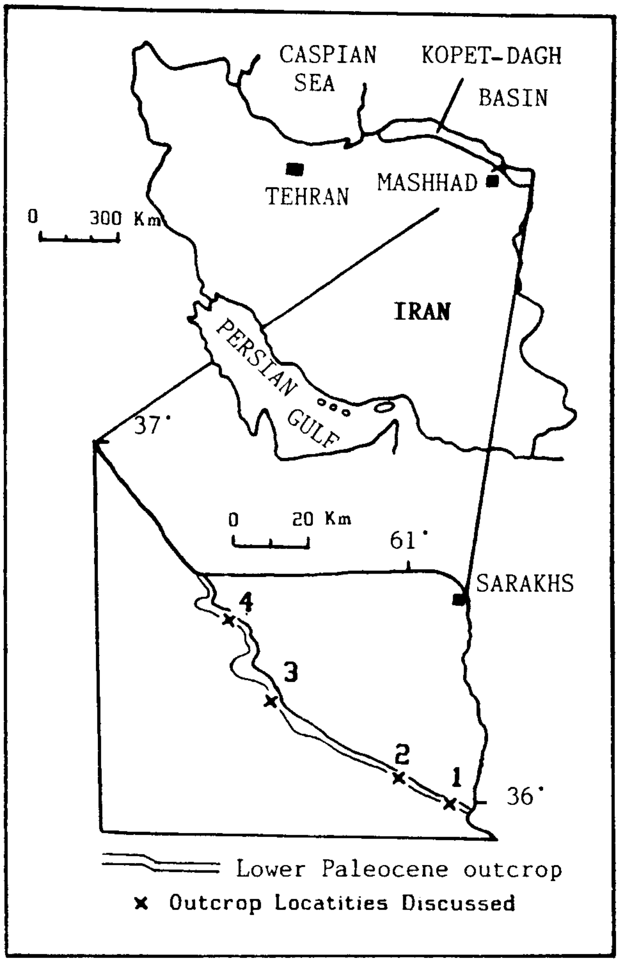


Figure 1. Index and generalized geologic map of the eastern part of the Kopet-Dagh basin (modified from Huber, [17] showing location of measured stratigraphic sections(x)

redbeds decreases from 315 meters in the southeast (section 1) to 190 meters in the northwest (section 4). It also decreases to the north and has a thickness of less than 100 meters in the subsurface of the Khangiran and Gonbadli gas fields in the Sarakhs area. The Pestehleigh Formation displays lateral changes from coarser-grained sediment in the southeast to finer-grained sediment in the north and northwest portions of the study area.

Regional Geologic Setting

After the Middle Triassic orogeny (early Kimmerian) in northeastern Iran, the Hercynian ocean closed, and the Kopet-Dagh basin was formed in northeast Iran as an intracontinental basin [7]. From the Jurassic through to the Eocene, the Kopet-Dagh was a site of relatively continuous sedimentation, which was recorded by five major transgressive-regressive sequences (Figure 2) [2, 3, 4, 18, 19]. Based on surface and subsurface study, Moussavi-Harami and Brenner [30] analysed the geohistory of the eastern part of the Kopet-Dagh basin and concluded that since the Middle Early Cretaceous epoch, the major factor for subsidence in this part of the basin was sediment loading rather than tectonic subsidence.

During the Early Jurassic, the sea moved from northwest toward the southeast across the study area, and a thick sequence of siliciclastic sediment was deposited, in deltaic and marine environments, unconformably above Triassic rocks (Figure 2) [22]. This angular unconformity can be seen in the Aq-Darband area in the easternmost part of the basin. During the Late Jurassic epoch, the whole basin was a site of marine carbonate sedimentation, except for the easternmost part of the basin where siliciclastic sediments were deposited in shoreline environments [28]. Based on geochemical study (oxygen and carbon isotopes), Adabi and Rao [1] concluded that the Upper Jurassic carbonates (Mozduran Formation) of the eastern Kopet-Dagh basin were deposited in tropical warm-waters.

Close to the end of the Jurassic period through to the Lower Cretaceous epoch (Neocomian), the sea withdrew toward the northwest and a thick interval of redbed siliciclastic sediment was deposited in a fluvial system that flowed across the study area from the south to the southwest [27, 29]. The presence of a few marine limestone beds in central and western Kopet-Dagh basin within the Lower Cretaceous rocks indicates that sometimes during the Neocomian, a marine environment was established to the west of the study area [3, 18].

During the Aptian, the sea transgressed toward the southeast and marine environments were established across the study area (Figure 2). This situation continued through the Late Cretaceous, except for a short period of time during Turonian (Figure 2). Close to the end of Cretaceous through the Lower Paleocene, the sea regressed toward the northwest, and a thick interval of red siliciclastic sediment of the Pestehleigh Formation was deposited in continental environments (mostly fluvial systems) in northeast Iran. The Early Paleocene regression was followed by the transgression of the sea and deposition of marine sediment of the Chehel-Kaman Formation which overlies Pestehleigh (Figure 2). Repeated transgression and regression continued through the Miocene epoch, when the basin was folded during the late Alpine orogeny. Anticlines formed during this orogeny created structural traps that are responsible for the Khangiran and Gonbadli gas fields in northeastern Iran.

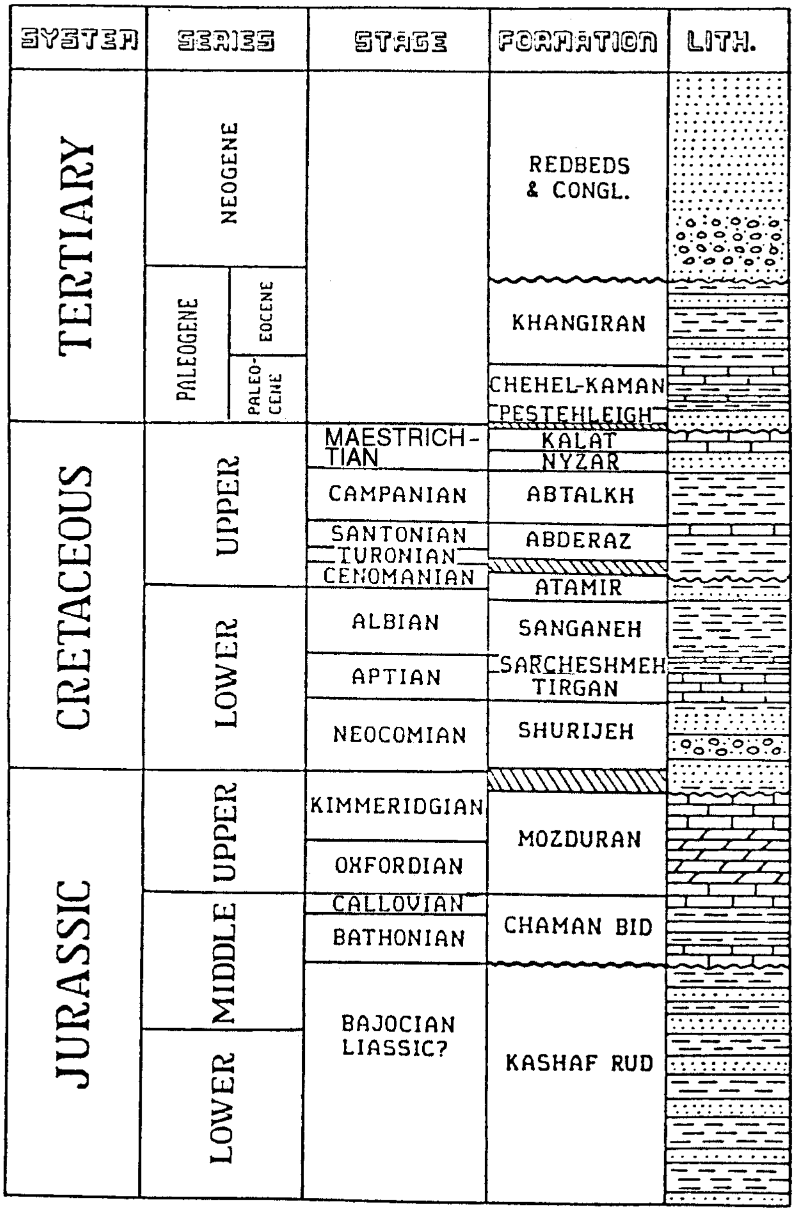


Figure 2. Generalized stratigraphic column of Jurassic through Tertiary strata in eastern Kopet-Dagh basin, northeastern Iran. Modified from Kalantari [19]. Wavy lines separate 5 major transgressive-regressive sequences

Facies Analysis

Lithofacies Description

Eleven lithofacies and six sedimentary elements were identified in the Lower Paleocene Pestehleigh redbeds in the eastern Kopet-Dagh basin (Tables 1 and 2). For the sake of simplicity, a modified version of lithofacies code, that was established by Miall [23, 25, 26], Rust [33], Rust and Koster [35], Smith [36], DeCelles [11] and McCarthy [21] is used (Table 1). Each lithofacies will be described in detail:

Massive to Horizontal-Bedded Conglomerate (Lithofacies Gm):

This lithofacies consists mostly of massive to horizontally bedded, clast-supported conglomerate (Figures 3 and 4). The conglomerate is moderately to poorly sorted. The matrix between pebbles consists mostly of

Table 1. Summary of lithofacies of the Lower Paleocene of eastern Kopet-Dagh basin. Modified from Miall [23], Rust [33], Rust and Koster [35], Smith [36], DeCelles [11], and MacCarthy [21]

Lithofacies	Description	Interpretation
Gm	Massive to horizontal-bedded conglomerate	Longitudinal gravel bar and channel lag
Gt	Trough cross-bedded conglomerate	Three dimension large-scale ripple, channel-fill
Gp	Planar cross-bedded conglomerate	Linguoid and straight crested transverse bar
St	Trough cross-bedded sandstone	Lower flow regime, sinuous crested dune or transverse bar
Sp	Planar cross-bedded sandstone	Lower flow regime, straightcrested transverse and linguoid bars,
Sh	Horizontally laminated sandstone	Lower and upper flow regimes
Sr	Sandstone with ripple cross-lamination	Lower flow regime
Sl	Low angle cross-bedded sandstone	Scour-fill
Se	Sandstone with intra-clasts and erosional scour	Scour-fill
Fl	Laminated sandstone, siltstone and mudstone	Interfluvial overbank and marginal lake
Fm	Laminated silty and clayey shale and evaporite	Interfluvial overbank and playa lake

fine to coarse-grained sand. Clasts are mostly subangular to subrounded, but some are very well rounded. Clast size ranges from 2 to 120 mm with an average of 15 mm. In each cycle, the size of clasts decrease upward. Some of the platy shape gravel (mostly sandstone pebbles) are slightly imbricated. The presence of *Orbitolina koniida* within a few limestone pebbles indicates that the Lower Cretaceous Tirgan Formation (Figure 2) was exposed to erosion during deposition of this unit. The presence of quartz conglomerate pebbles within this lithofacies also indicates that the Shurijeh Formation (Neocomian) was another source for this

Table 2. Summary of architectural element of the Lower Paleocene of eastern Kopet-Dagh basin. Modified from Miall [25]

Element	Principal Lithofacies	Geometry and Relation
Gravel bars and bed forms (GB)	Gm, Gp, Gt	Lens, blanket, usually tabular and some interbedded with SB
Sandy bed-forms (SB)	St, Sp, Sh, Sr, Se	Lenses, sheets, blankets and wedges
Downstream (DA)	St, Sp, Sh, Sl, Sr, Se	Lens lying on a flat or channelled base with convex upward third-order internal and upper bounding surfaces
Channels (CH)	any combination	Finger, lens or sheet; concave-upward erosion base; scale and shape highly variable; internal secondary erosion surface common
Laminated sand sheet (LS)	Sh, Sl, St, Sp, Sr	Sheet, blanket
Overbank fines (OF)	Fm, Fl	Thin sheets to thick blankets of mudrock and evaporites; commonly interstratified with sandy bedform (SB)

conglomerate. Dolomite and some limestone pebbles may have been derived from the Upper Jurassic Mozduran Formation in the south. The basal contact of this lithofacies is erosional wherever observed and the upper contact is gradational to finer-grained conglomerate and pebbly sandstone. Sometimes many mudstone pebbles are present above the erosional contact and form an intraformational conglomerate. Some lenses of cross-bedded, coarse-grained pebbly sandstone and a few laminated, medium to coarse-grained sandstone are present within this lithofacies. This conglomerate dominates the formation in the southeast and thins toward the north and northwest where it is mostly replaced by sandstone (Figure 3).

Trough Cross-Bedded Conglomerate (Lithofacies Gt):

This lithofacies consists mainly of clast-supported

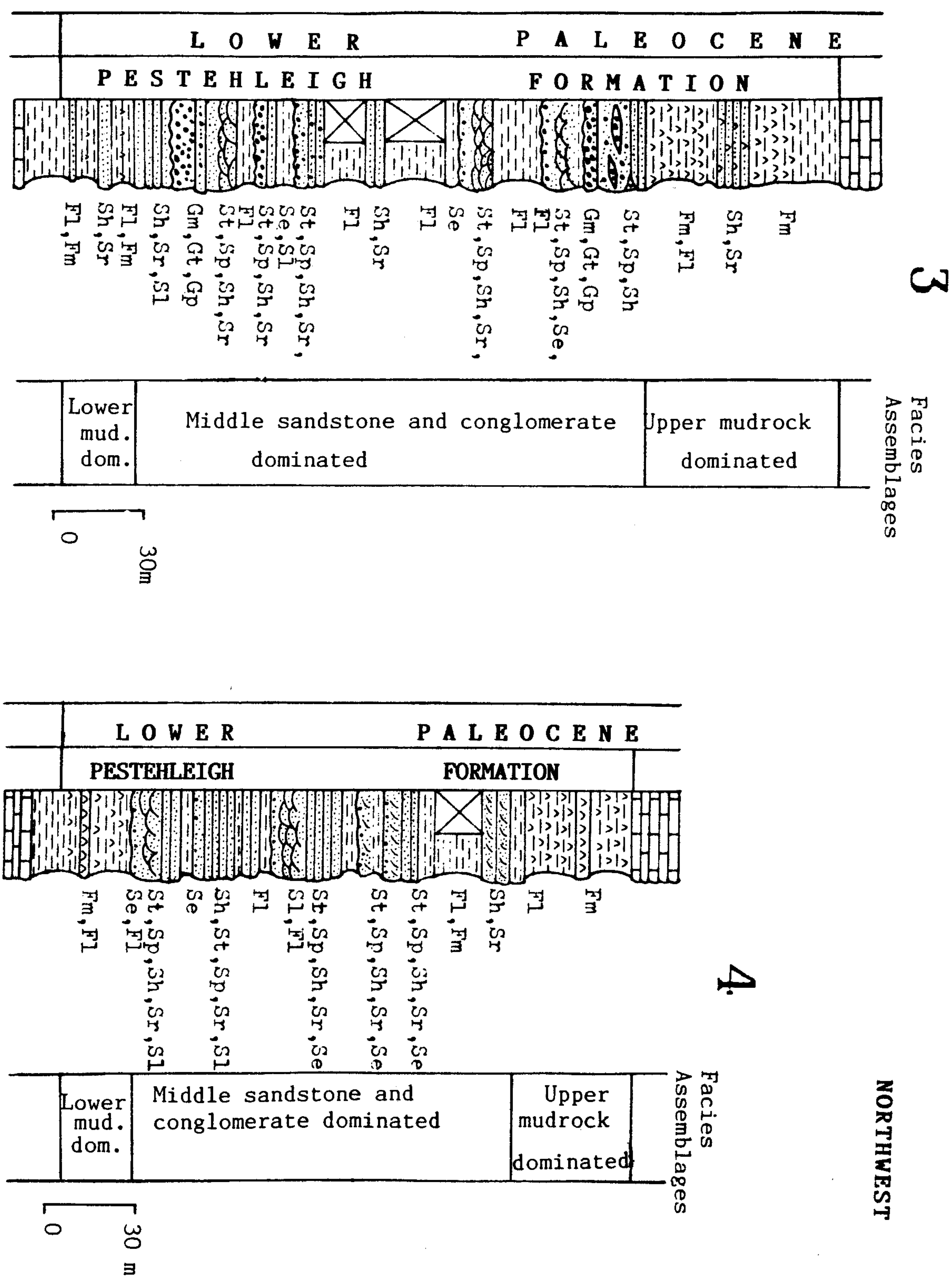
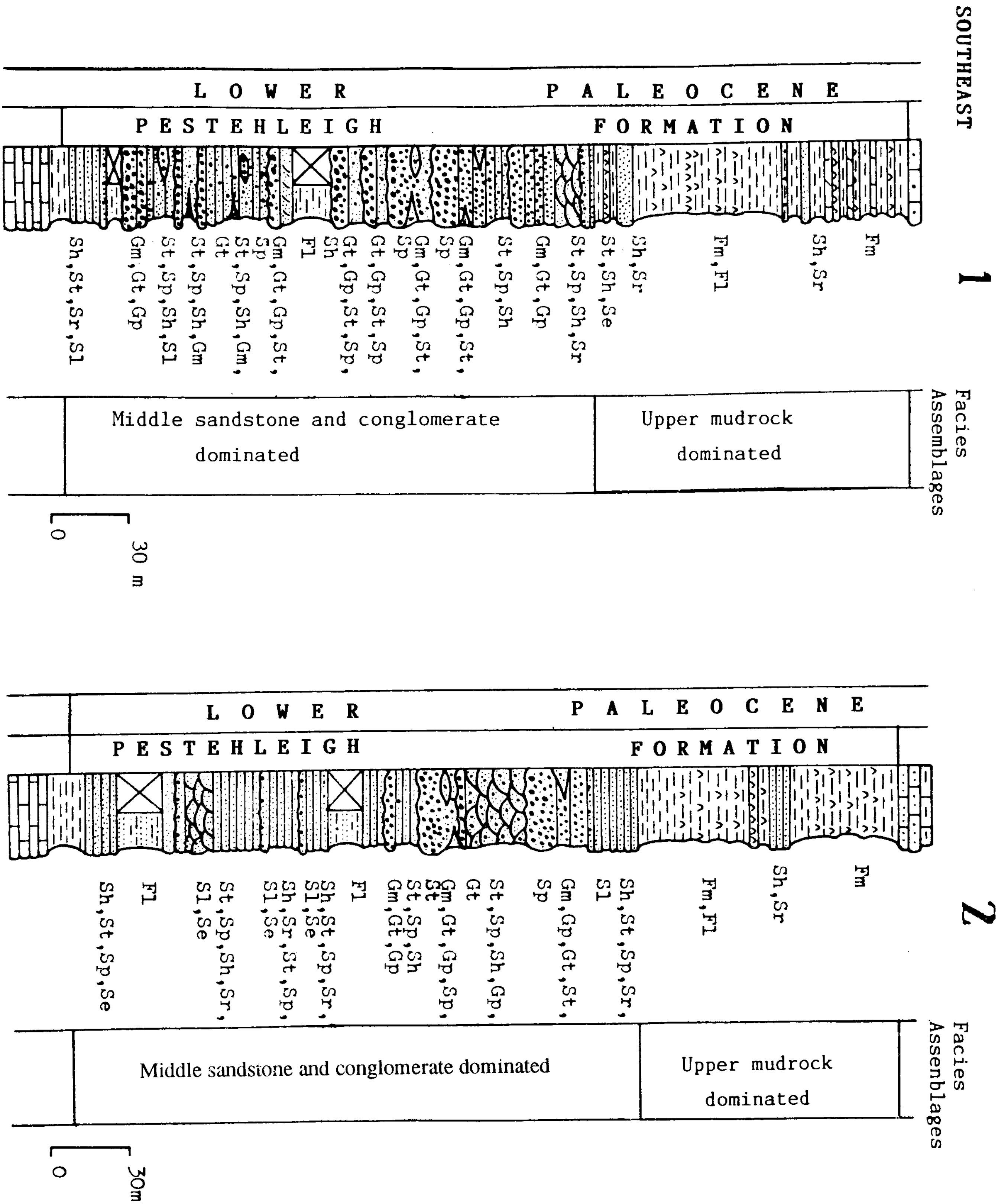


Figure 3. Columnar sections of the Lower Paleocene Pestehleigh Formation at localities 1, 2, 3 and 4 (see Figure 1).



Note that total interval thickness and amounts of coarse-grained siliciclastic sediments decrease from east to west stratified conglomerate with sets of trough cross-beds (Figures 3 and 5). This conglomerate is generally moderately to poorly sorted. The cross-bedded sets are usually graded. Trough sets are up to 40 to 60 cm thick and about 1 to 2 m wide. Paleocurrent of trough axis directions are generally towards the north and northwest. Lenses of cross-bedded, pebbly to very coarse-grained sandstone are present within this unit (lithofacies Sp and St). In some places, the basal contact of this unit is erosional. Clast size is smaller than in the massive conglomerate, with an average size of 5 mm. A few lenses of horizontal pebbly medium to coarse-grained sandstones (lithofacies Sh) are present in this unit. Lithofacies Gt is also very common in the southeast (Figure 3).

Planar Cross-Bedded Conglomerate (Lithofacies Gp):

This lithofacies is composed mostly of clast-supported conglomerate with tabular cross-beds. The thickness of each set is generally between 50 to 70 cm, with foreset dips ranging from 10° to 25° degrees. The foreset dip is generally toward the north and northwest. The basal contact of this lithofacies is both erosional and nonerosional. Cross-bed sets generally show normal or reverse clast size grading. The average pebble size is about 5 mm. Some lenses of cross-bedded, pebbly to very coarse-grained sandstone (lithofacies Sp and St) are present within this conglomerate. Lenses of horizontal pebbly medium to coarse-grained sandstone are also present in this lithofacies. Gp is also very common in the southeast (Figure 3).

Trough Cross-Bedded Sandstone (Lithofacies St):

This lithofacies consists mainly of medium to coarse-grained, trough cross-bedded sandstone (Figures 3 and 6). Sets of trough cross-beds vary in thickness from 15 to 100 cm. Texturally, these sandstone units are submature to mature. Some of these sandstone units contain scattered quartz pebbles. Some beds of horizontal laminated sandstone and siltstone are present within this lithofacies. A few lenses of conglomerate are also present in this unit.

Planar Cross-Bedded Sandstone (Lithofacies Sp):

This lithofacies consists mostly of medium to very coarse-grained, planar cross-bedded sandstone (Figures 3 and 7). Scattered quartz pebbles are present in some beds and form pebbly sandstone. Lenses of conglomerate and conglomeratic sandstone are also present within this lithofacies. The average pebble size is about 5 mm. Most foresets fine upward and dip toward the north and northwest.

Horizontally-Laminated Sandstone (Lithofacies Sh):

This lithofacies is composed of fine to very coarse-grained laminated sandstone to pebbly sandstone (Figures 3, 8a and b). In most parts of the measured sections, this unit consists of fine to medium-grained sandstone. This lithofacies is interstratified with all sandstone lithofacies. In some beds, current ripples are present within very fine-grained sandstone. Parting lineations are formed at the surface of very fine to fine grain sandstone beds (Figure 9). Sh dominates toward northwest (Figure 3).

Ripple Cross-Laminated Sandstone (Lithofacies Sr):

This lithofacies consists mainly of very fine to medium-grained sandstone (Figures 3 and 10). Ripple cross-lamination and climbing ripples are present within this unit. Also, a minor amount of cross-laminated siltstone and mudstone drapes are found in this lithofacies. The ripples are asymmetrical and are formed by unidirectional currents. This facies is commonly interstratified with Sh lithofacies.

Low Angle Cross-Bedded Sandstone (Lithofacies Sl):

This facies consists mostly of very fine to medium-grained sandstone with low-angle cross-beds (Figures 3 and 11). This unit is mostly formed within the scour-fills with intraclasts at the basal part of the unit. It is commonly found throughout the interval.

Sandstone with Intraclasts and Erosional Scours (Lithofacies Se):

This lithofacies is composed mostly of sandstone with erosional surface at the base and scattered intraclasts within the sandstone unit (Figures 3 and 11). The clasts are composed mainly of mudstone and are mostly concentrated above the basal contact. Because of the concentration of intraclast above the erosional contact, the basal part is essentially conglomeratic sandstone.

Laminated Sandstone, Mudrocks and Evaporites (Lithofacies Fl and Fm):

These lithofacies are composed mostly of interbedded very fine-grained sandstone, siltstone and silty to clayey shale (Table 1). A few beds of laminated unfossiliferous limestone (calcilutite), dolomite and gypsum with interstratified mudstone are present within the mudrock facies assemblage in the upper part of the interval. Stratification within some mudstone layers has been destroyed by bioturbation. Some gypsum and calcitic nodules are present in the Fm lithofacies. Lithofacies Fl and Fm are abundant toward the central

Figure 4. Massive, very poorly to poorly sorted clast-supported conglomerate (lithofacies Gm) at section 1

Figure 5. Trough cross-bedded conglomerate (lithofacies Gt) at section 1

Figure 6. Trough cross-bedded coarse-grained sandstone (lithofacies St) at section 1. Hammer is close to the axis of trough. Below is fine to medium-grained horizontally laminated sandstone (lithofacies Sh)

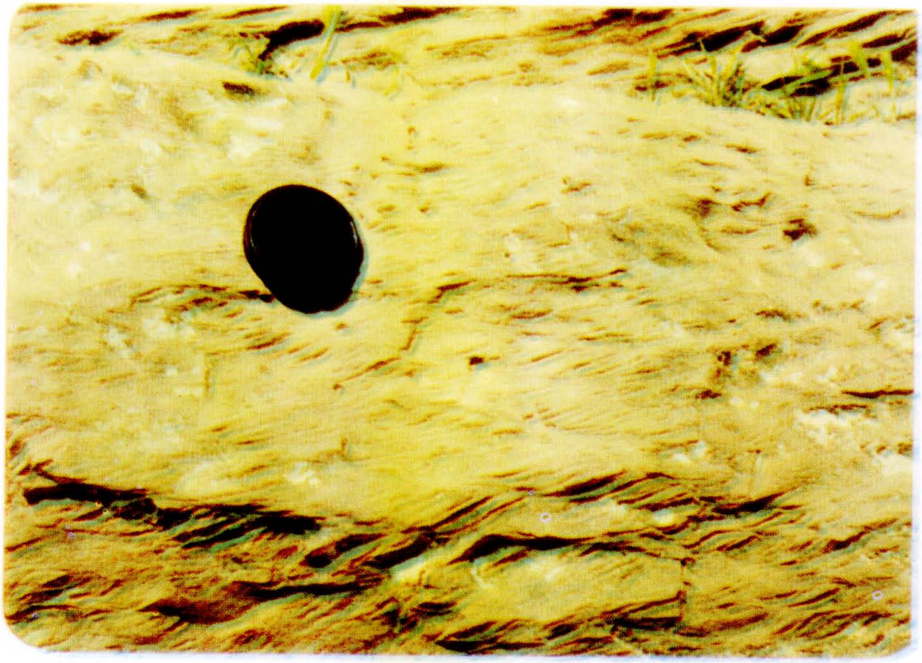


Figure 7. Stack of planar cross-bedded sandstone (lithofacies Sp) at section 2. Diameter of lens cap about 6 cm.

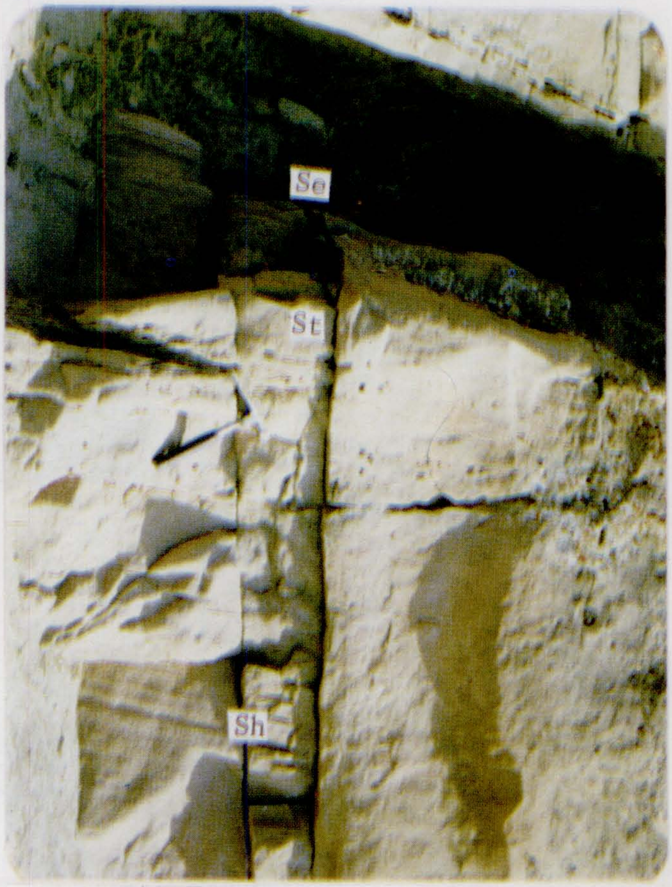


Figure 8. (A) Horizontal laminated very fine-grained sandstone and siltstone (lithofacies Sh) at section 3. (B) Horizontal laminated sandstone (Sh) overlain by trough x-bedded sandstone at the top (St). Upper surface of these units were eroded and filled with massive conglomerate and conglomeratic sandstone (Se)

Figure 9. Parting lineation at the surface of very fine-grained horizontal laminated sandstone (Sh) at section 3

Figure 10. Fine-grained sandstone with ripple cross-lamination (lithofacies Sr) at section 3

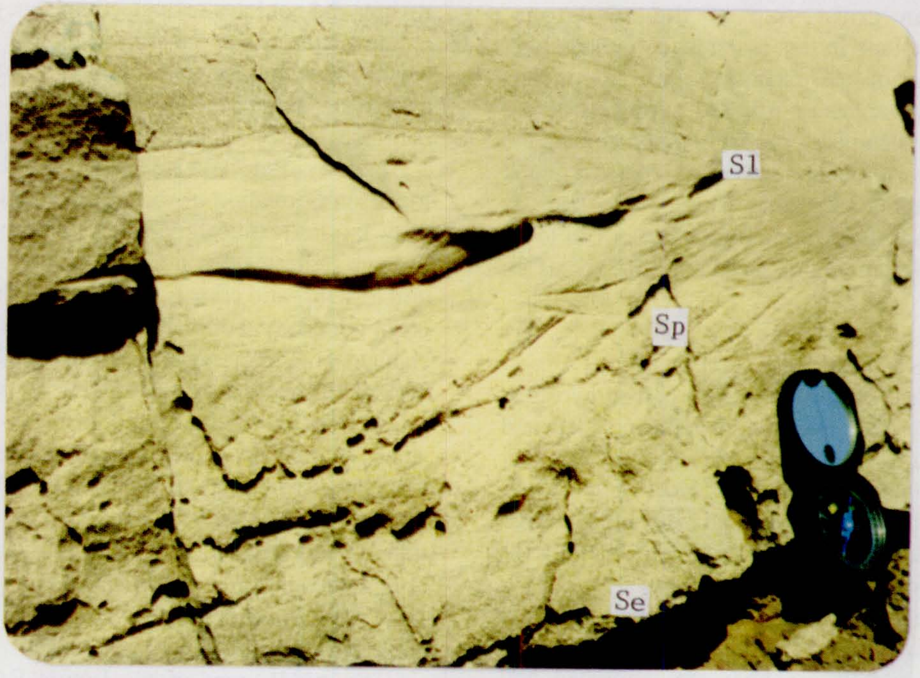


Figure 11. Fining-upward sequence from conglomeratic sandstone with an erosional basal contact (Se) to medium-grained cross-bedded sandstone (lithofacies Sp and Sl)

and northwestern portions of the study area, and can also be seen throughout the interval. The basal part of these units are gradational with underlying facies, and upper contacts are usually erosional and very sharp.

Facies Assemblages

Based on measured stratigraphic sections and field observations, the Lower Paleocene redbed siliciclastic sediments of the eastern Kopet-Dagh basin can be divided into three distinct facies assemblages in ascending order (Figure 3): Lower mudrock-dominated, middle sandstone and conglomerate-dominated, and upper mudrock-dominated facies assemblages.

Lower Mudrock-Dominated Assemblage:

This assemblage is composed mainly of structureless gypsiferous mudstone and laminated to cross-laminated shale and siltstone (Figure 3). A few interstratified cross-bedded very fine to medium-grained sandstone are present in this assemblage. The main lithofacies in this portion include Fl, Fm with a minor amount of Sh and Sr lithofacies. Scattered gypsum and calcitic nodules and a few thin beds of laminated gypsum are present in this mudstone facies in measured section 4. The basal contact of sandstone with shale, in this assemblage, is sharp and the upper contact is gradational. Sometimes the basal contact is erosional and shale intraclasts are present above the contact. This facies assemblage is mostly present in the western part of the study area (measured section 4) and changes to coarser-grained siliciclastic sediment in the basal part of the middle facies assemblage in the east (measured section 1).

Middle Sandstone and Conglomerate-Dominated Assemblage:

This assemblage consists mainly of sandstone, pebbly sandstone and conglomerate (lithofacies Gm, Gp, Gt, Sp, St and Sh) with a few interstratified siltstone shale (lithofacies Fl) (Figure 3). This part of the interval is thicker in the southeast and thins toward the north and northwest. Sandstone and conglomerate units commonly show fining-upward sequences with an erosional basal contact (lithofacies Se).

This assemblage can be divided into two distinct portions of sandstone and conglomerate, respectively. In the lower portion, the major sandstone units commonly fine upward from lithofacies Se to St and Sp, to Sr and Sh (alternating) to less F1 (Figure 3).

The finer-grained rocks in sandstone units consist of drapes or wedges of mudrock . This causes upward fining in units of the sandstone assemblage, together with ripple cross-lamination and climbing ripples (lithofacies Sr) was formed during the waning of the flood stage in the lower flow regime. Lithofacies Sl is also found in the lower part of the interval.

A thick sequence of stacked cross-bedded sandstone in this portion of the middle interval suggests the SB element (sandy bedforms) of Miall [25, 26] which is characteristic of fluvial deposits and is separated by mudrock and very fine grain ripple cross-laminated sandstone (element OF). Fining-upward cycles extending from very thin Gm lithofacies with basal erosional contact up to St, Sp, Sh and Sr lithofacies are present in this part of the interval. Lateral migration of the channel and discharge fluctuation can produce such fining-upward sequences. Lateral continuity of most sandstone beds in this portion indicates that they were formed as sheet-like sand bodies (DA element, Table 2). These sediments were probably deposited in distal parts of low sinuosity, sandy braided streams that flowed north and northwest across the study area. Many channel cut-and-fills with basal erosional contact are also present in this sequence (element CH, Table 2). The absence of much fine-grained sediment resulted from channel migration, which eroded most of the overbank fines and deposited sheet or blanket-like, coarse-grained sediment. Based on the information presented above, this portion of the interval was deposited in low sinuosity sandy braided streams very similar to fining-upward sequences of the South Saskatchewan River deposits described by Cant and Walker [10] and model 10 of Miall [25] for fluvial deposits.

The upper portion of the middle interval consists mostly of conglomerates and medium to coarse-grained pebbly sandstones. The main lithofacies in this portion are Gm, Gp, Gt with minor amounts of sandstone. During the highest stages of flooding, the Gm lithofacies was deposited as a channel lag or longitudinal bars. This lithofacies is mostly clast supported, but some grains are present as a matrix within coarser-grained (gravel size) sediment. This sand grain matrix may have been infiltrated within the open space between gravel grains, probably during a lower flow stage subsequent to the high flow stage responsible for gravel deposition, as described by Rust [34] and Anketell and Rust [6] for the Devonian conglomerates of Quebec, Canada.

A slight imbrication in the gravel-size sediment of the conglomerate indicates very rapid deposition of this unit. Lenses of very coarse-grained to pebbly sandstone within this lithofacies indicate periods of decreased stream competency that were accompanied by finer-grained traction load deposition. This part of the interval thins toward the north and northwest where it is replaced by sandstone and mudrocks. This indicates that the source point for siliciclastic sediment was to the south and southeast of the study area. This conglomerate (Gm) has the characteristics of gravel bars as described by Hein [16]. The Gm lithofacies formed a sheet-like massive unit in the eastern part of the study area very similar to that described by Kerr [20] for the Early Neogene conglomerate of the western Salton Trough in California, and by Ramos and Sopena [32] for Permian and Triassic conglomerates of central Spain. This unit also has characteristics very similar to those of sheet flood deposits described by Friend [12] as well as to the Jurassic-Lower Cretaceous conglomerates of Mexico, which have been interpreted as proximal sheet flood deposits by Blair [8].

The Gt lithofacies was formed as a result of the migration of sinuous-crested megaripple or dune and channel-fill. This lithofacies formed when the stream discharge was very high. The Gp lithofacies was formed during the migration of linguoid and transverse bars in the deeper part of a channel. Gradual decreases in stream competency and current velocity, indicated by a fining upward of clast size, could have caused the development of leeside separation eddies that resulted in the growth of foresets and the development of a transverse bar (Miall, [25]). When stream discharge was very high, the coarse-grained sediment was deposited and planar cross-bedded conglomerate formed. St lithofacies is present within these conglomerate lithofacies (Gp and Gt). These sandstone lenses represent periods of reduced stream competency and the deposition of finer-grained sediment. The foreset dips of cross-beds are toward the north and northwest, again implying that the source point for siliciclastic sediment was to the southeast of the study area.

The Sp lithofacies formed as a result of the migration of linguoid or straight-crested transverse bars. Also, the migration of sinuous-crested dunes or sinuous bars probably produced St lithofacies. These lithofacies formed when sand was dominant within the active channel [25]. Erosional contacts at the base of each cross-bed set represent the time of flooding that eroded some parts of finer-grained sediment. The presence of mudstone intraclasts above the erosional contact can support this interpretation. A few lenses of Sh lithofacies, present within coarser-grained sediment, may have been formed in the turbulent boundary layer of the upper flow regime [5].

Based on the information presented above, the thick sequence of coarse-grained sediments in the upper portion of the middle interval in the Lower Paleocene redbed siliciclastic in the eastern Kopet-Dagh basin represents a combination of elements GB (gravel bar and bedforms) and SB (sandy bedforms) (Table 2), characteristic of fluvial deposits as described by Miall [25]. The upper part of this coarse-grained sediment interval consists mainly of lithofacies Sh that can be traced laterally as sheet sandstone bodies (element LS). Some overbank fines (OF elements) are present within this interval. These sediments were deposited in low sinuosity, coarse-grained braided streams that flowed north and northwest. Sedimentary characteristics of this portion of the interval are very similar to the Donjek River deposits of Yukon [37, 23, 24]. The absence of finer-grained sediment probably resulted from the migration of channels, which eroded finer-grained sediments and deposited coarser material as a sheet or blanket.

The upper part of the Lower Paleocene interval consists mainly of gypsiferous mudrock with minor amouts of sandstone and evaporite, and a few beds of laminated gypsum and calcilutite with scattered ostracods and gastropods. Argillaceous limestone and dolomite were also formed in the middle portion of the upper part. A few beds of very fine to medium-grained sandstones are present in the lower portion of this part and are gradationally overlain by mudrocks and evaporites that may have been deposited in playa lakes. These sandstones may have been deposited in the margins of playa lakes very similar to those described by Brady [9] from the Neogene of southern Death Valley, California. The mudrocks and evaporites were deposited in a topographic depression within a mud flat and lacustrine basin. Because the streams flowed toward the north and northwest, the thickness of the evaporites in the western part of the study area is more than in the east, this indicates that the basin center was probably toward the northwest.

Paleogeography:

Paleogeography reconstruction for the Lower Paleocene redbeds of the eastern Kopet-Dagh basin can be derived from the measured stratigraphic sections (Figure 3) and the field observations interpreted above. Close to the end of the Cretaceous period and through the Early Paleocene epoch, the epicontinental sea regressed toward the northwest and a thick interval of redbed siliciclastic sediments of the Lower Paleocene were deposited in fluvial systems in NE Iran.

During the deposition of the lower part of the interval, streams began flowing toward the northwest, and coarser-grained sediments were deposited in fluvial channels in the eastern part of the study area (Figure 12 A). At the same time, saline (playa lakes) was present to the northwest and evaporite and gypsiferous mudrock formed in the lowland area under arid and semi-arid climatic conditions. As the alluvial plain prograded toward the north and northwest, the whole study area was a site of fluvial sedimentation and coarser-grained sediments (mostly conglomerate and sandstone) were deposited in low sinuosity coarse-grained braided streams close to the source area and finer-grained sediments (mainly sandstone with minor amounts of mudrocks) were deposited in distal parts of low sinuosity braided streams (Figure 12 B). As sediment supply from the source area decreased, the coarser-grained sediments were deposited to the south of the study area and a lowland playa was established in NE Iran (Figure 12C). A thick sequence of gypsiferous mudrocks and evaporites with a few beds of sandstones in the upper part of the interval were deposited in marginal lacustrine mud flats and playa lakes. The upper part of the Lower Paleocene redbed deposition was terminated as the sea transgressed southeastward across the study area and marine sedimentation was established (Figure 12D). During the Middle to Upper Paleocene, a thick carbonate interval of the Chehel-Kaman Formation was deposited in shallow marine environments.

Conclusion

The redbed siliciclastic sediments of the Pestehleigh Formation (Lower-Paleocene (in NE Iran were deposited in fluvial systems under arid to semi-arid climatic conditions. These sediments can be divided into three distinct facies assemblages.

The lower mudrock assemblage consists mostly of gypsiferous mudstone and shale with scattered calcite and gypsum nodules and a few beds of laminated gypsum and very fine to medium-grained sandstone (mainly Fl and Fm lithofacies). This assemblage was deposited in a playa lake environment within a lowland area.

The middle sandstone and conglomerate assemblages can be divided into two portions. The lower portion is composed mainly of fine to very coarse-grained to pebbly sandstone (St, Sp, Sh, Sr and Gm) deposited as sheet-like sand bodies in a distal portion of a low sinuosity sandy braided stream system. The upper portion of the middle interval consists mainly of conglomerate and sandstone (Gm, Gp, Gt, St, Sp and Sh lithofacies) which were deposited as a gravel sheet in a low sinuosity proximal braided-stream system.

The upper mudrock assemblage is mainly composed of gypsiferous mudstone and shale with a few beds of laminated gypsum, limestone, dolomite and very fine to medium-grained sandstone (mostly Fl and Fm with minor amounts of Sr lithofacies). This assemblage was deposited in a lowland area in marginal lacustrine mud flats and playa lakes.

The thinning of coarse-grained sediments toward the north and northwest along with paleocurrent features oriented in the same direction indicate that the source of

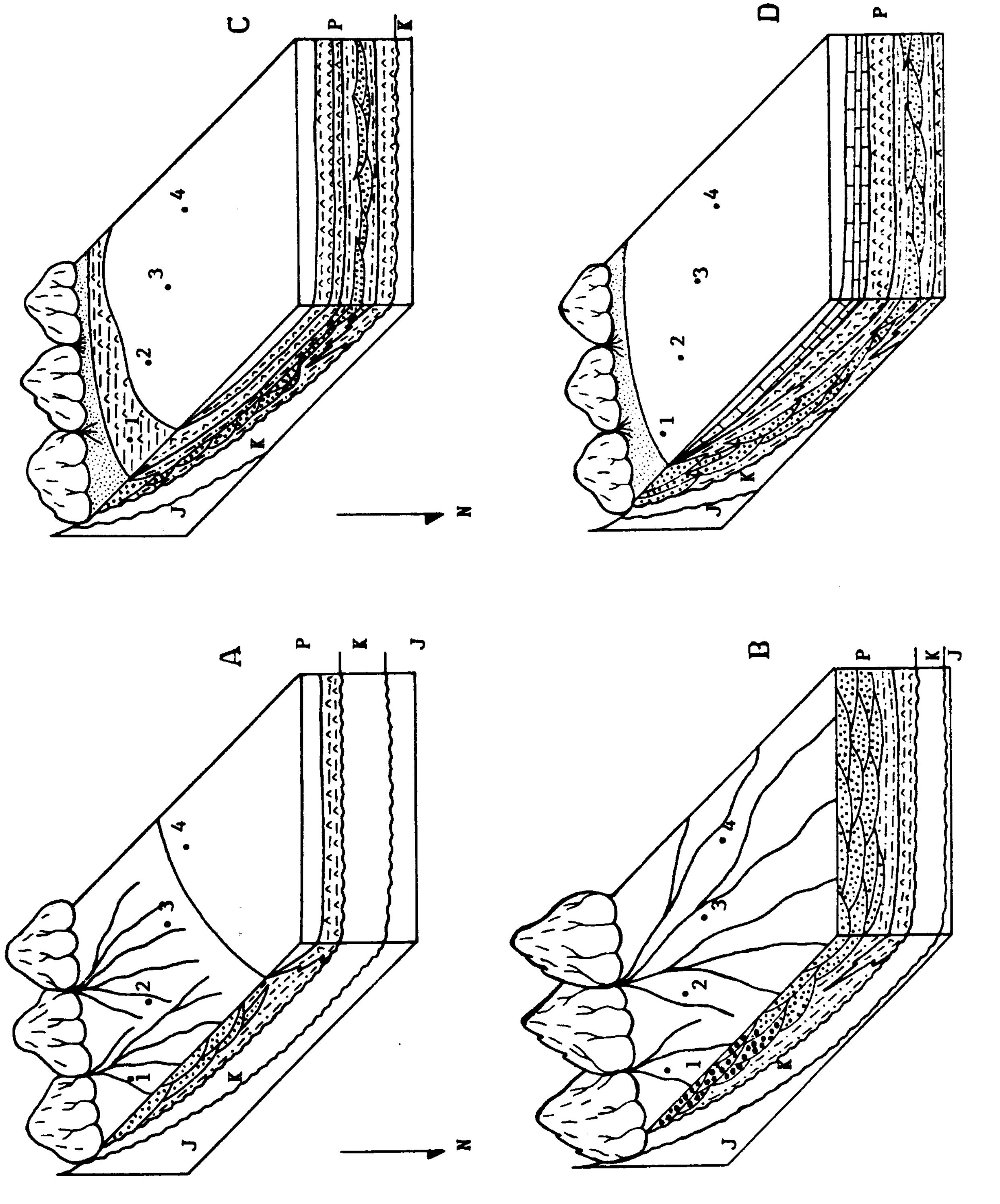


Figure 12. Block diagrams showing depositional history and paleogeography of the eastern Kopet-Dagh basin during the Early Paleocene
(A) Lower mudrock facies assemblage of the Pestehleigh Formation showing deposition in the lowland area within playa lake
(B) Middle sandstone and conglomerate facies assemblage of the Pestehleigh Formation showing deposition of coarser-grained sediment in low-sinuosity sandy braided stream and proximal braided streams, respectively
(C) Upper mudrock facies assemblage of the Pestehleigh Formation showing deposition in the lowland area in marginal lacustrine (mud flat) and playa lake
(D) Post Pestehleigh transgressive carbonate deposition

siliciclastic sediment was to the south of Aq-Darband southeast of the Sarakhs area. Compositional characteristics of pebbles in the conglomerates indicate that the source for these Lower Paleocene siliciclastic sediments was the Upper Jurassic and Cretaceous sedimentary rocks.

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