

Lithostratigraphy, petrology and sedimentary facies of the Late Cretaceous-Palaeocene Ispikan Group, southwestern Makran, Pakistan

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Abstract

An isolated outcrop, comprising a 300 m thick succession of the Late Cretaceous-Palaeocene Ispikan group, is exposed as a thrust-bound inlier within the Oligocene-Miocene succession of the Panjgur Formation, 3 km to the northeast of the Ispikan village, in south-western Makran, Pakistan. The group is divisible into two lithostratigraphic units; 1) the Late Cretaceous Ispikan group in lower part; comprising mudstone, shale, siltstone and sandstone; and 2) Palaeocene Ispikan Conglomerate in upper part; comprising very coarse pebbly sandstone and conglomerate.

The Ispikan conglomerate is composed of pebbles of a variety of igneous, sedimentary and metamorphic rocks. Sandstone also dominantly comprises igneous and metamorphic rock fragments. Detrital modes of the sandstone suggest a recycled orogenic source, most probably the Himalayan-Karakorum-Hindukush collision orogen.

The group comprises 9 distinct facies, organized as 2 facies associations including the inner-fan channel facies association and the basin-plain facies association, which were parts of the earliest fan system of the Khojak-Panjgur submarine fan complex.

The petrology and provenance of the Ispikan group resemble with those of the surrounding younger submarine fan succession of the Oligocene-Miocene Panjgur Formation, however, its stratigraphic and palaeogeographic relationship with the surrounding succession still remains speculative needing further investigation.

Keywords: Lithofacies; Detrital modes; Provenance; Makran accretionary wedge; Submarine fan complex.

1. Introduction

The Late Cretaceous-Palaeocene Ispikan group (Kassi et al., 2007) is exposed as an isolated thrust-bound inlier (1 km long, 300 m wide) comprising thick succession of sandstone, conglomerate, mudstone and shale, within the Oligocene-Miocene Panjgur Formation near the Ispikan village of the southwestern Makran, Pakistan (Fig. 1). The group is named (Kassi et al., 2007) to represent the Late Cretaceous Ispikan formation; comprising cream, purple and varicolored mudstone, shale, siltstone and sandstone in its lower part, and Palaeocene

Ispikan Conglomerate (Hunting Survey Corporation, 1961); comprising thick bedded, very coarse pebbly sandstone and conglomerate in its upper part.

The succession is part of the emergent Makran Accretionary Wedge, which formed in response to the northward subduction of the oceanic crust of the Gulf of Oman under the southern margin of the Afghan Block of the Eurasian Plate (White and Clift, 1976; Farhadi and Karig, 1977; Jacob and Quittmeyer, 1979; White, 1979; Platt et al., 1985; Platt and Leggett, 1986; McCall, 2003).

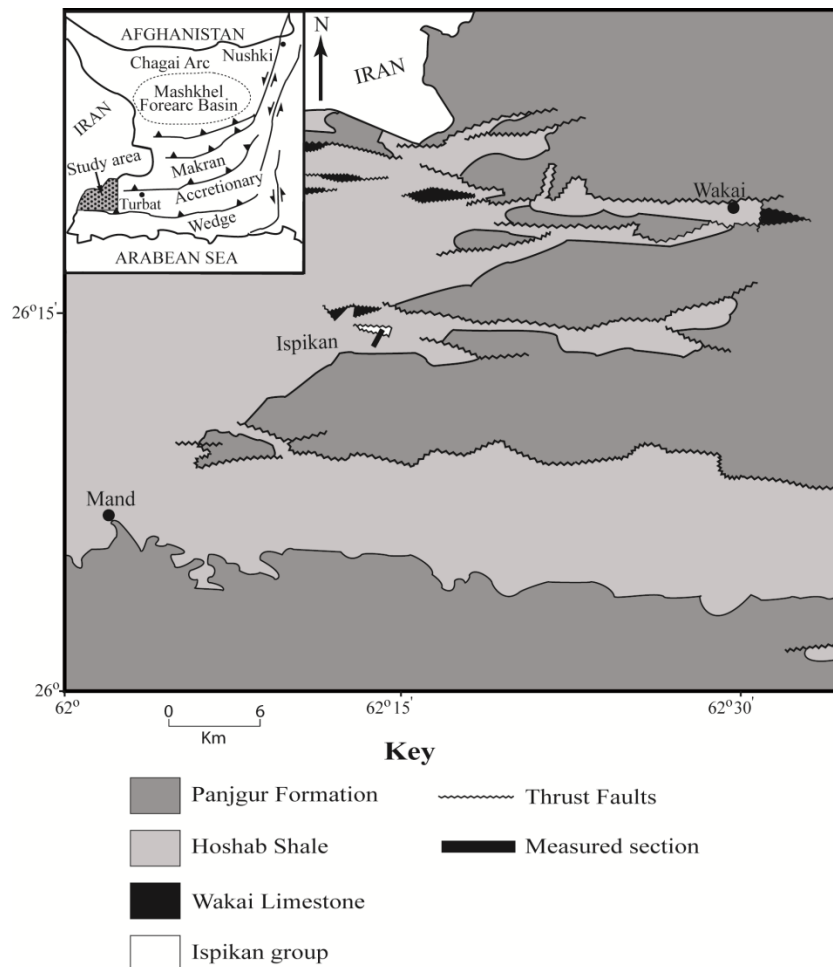


Fig. 1. Location and geological map of the Ispikan and surrounding area, showing studied localities.

The Hunting Survey Corporation (1961) mapped and briefly described the Palaeocene Ispikan Conglomerate in their reconnaissance report; however, they have not described the conformably underlying sandstone and shale succession. They have assigned a Palaeocene age to the Ispikan Conglomerate on the basis of its stratigraphic position, as its lower part, the Ispikan formation of Kassi et al. (2007), is of Late Cretaceous age. Stratigraphic and palaeogeographic relationship of the Ispikan group (Kassi et al., 2007) with the surrounding Oligocene-Miocene Panjgur Formation is enigmatic because its upper and lower contacts are thrust (Hunting Survey Corporation, 1961).

The present paper describes stratigraphy, petrology, facies and facies associations and provenance of the Late Cretaceous-Palaeocene Ispikan group (Kassi et al., 2007), compares it with

the surrounding Oligocene-Miocene Panjgur Formation and attempts to provoke discussion on its provenance, age and the importance of its palaeogeographic position. Bed thickness is categorized according to the classification scheme of Ingram (1954) and grain size according to the classification scheme of Wentworth (1922). Facies and their associations have been described and interpreted in view of the classification schemes of Mutti and Ricci Lucchi (1972), Walker and Mutti (1973), Walker (1978), Underwood and Bachman (1982) and Pickering et al. (1986).

2. Lithostratigraphy

Kassi et al. (2007) proposed the names Wakai and Ispikan groups for the Cretaceous-Palaeocene successions of the Ispikan-Wakai area of southwestern Makran (Table 1). Lithostratigraphy of the Late Cretaceous Ispikan group is described below:

2.1. *The Ispikan group*

The Ispikan group (Table 1, Figs. 2 and 4) has been classified (Kassi et al., 2007) into two formations; 1) the Ispikan formation in lower part and, 2) Ispikan Conglomerate (Hunting Survey Corporation 1961) in upper part, which are described below:

2.1.1. *Ispikan formation*

Named after Kassi et al. (2007), is a 50 m thick succession, comprising cream, purple and varicolored mudstone, shale, siltstone and medium to thin bedded sandstone (Table 1, Fig. 2b). Mudstone is massive to very finely laminated, very thin to very thick bedded and highly bioturbated (Kassi et al., 2007). Shale is massive, highly bioturbated, purple, red, brown and varicoloured, very thinly to very thickly bedded with sharp upper and lower contacts and planar geometry. Sandstone is very thinly bedded, very fine grained and occurs in the form of sandstone/siltstone and mudstone couplets.

Lower contact of the formation is thrust over the Oligocene-Miocene Panjgur Formation and upper contact with the Ispikan Conglomerate is transitional and conformable. The formation is assigned a Late Cretaceous age (Hunting Survey Corporation, 1961; Kassi et al., 2007).

2.1.2. *Ispikan Conglomerate*

Named after the Hunting Survey Corporation (1961), comprises about 250 m succession of sandstone and conglomerate (Fig. 2c). Sandstone is very coarse, pebbly, thinly to very thickly bedded (up to several meters thick), poorly sorted, matrix-supported with or without the mudstone/siltstone intraclasts of the underlying succession. Clasts are generally pebbly and reach up to several centimetres in length.

Conglomerate is generally moderately to well-sorted, clast supported, rounded to well rounded having clasts of pebble to boulder sizes. Some very thick bedded conglomerate is generally very poorly sorted, matrix supported and has subrounded to rounded pebbles. Clast size of pebbles mostly vary between 2 and 40 cm, whereas, maximum clast size reaches up to 110 cm.

The Hunting Survey Corporation (1961) assigned Palaeocene age to the Ispikan Conglomerate on the basis of its stratigraphic position, because it overlies the Late Cretaceous succession, now named (Kassi et al., 2007) as the Ispikan formation.

3. **Petrology and provenance**

The conglomerate and pebbly sandstone (Figs. 2c, e and f) are composed of a variety of igneous, metamorphic and sedimentary rock fragments (Table 2). The igneous fragments include various types of granite, rhyolite, basalt, volcanic glass, trachyte and serpentine. The metamorphic fragments include quartzite, schist, gneiss, phyllite, slate and marble. The sedimentary fragments include limestone, sandstone and chert.

Sandstone of the Ispikan group (Figs. 2a, d and e) is composed of quartz, feldspar, biotite, muscovite, chlorite, heavy minerals, opaque minerals and carbonaceous matter. Quartz is commonly of unstrained, strained and polycrystalline varieties. Some quartz grains have inclusions of biotite, zircon, rutile and apatite. Feldspar includes orthoclase, microcline, sodic plagioclase and perthite. Heavy minerals are sparsely present and include chrome spinel (picotite), garnet and tourmaline. Several varieties of igneous, sedimentary and metamorphic rock fragments (Table 2; Fig. 2a) are also present. Among the igneous rock fragments granite, rhyolite, and basic volcanic are common. The metamorphic rock fragments include quartzite, muscovite-schist, phyllite and gneisses. Quartzite fragments include a highly tectonized variety of highly strained quartz grains having preferred orientation. Some quartzite fragments display gneissose structure of alternate bands of the finely and coarsely crystalline textures. Among the sedimentary rock fragments various types of limestone and chert are common. Chert fragments commonly contain remains of radiolaria. Cementing material is mainly calcite with minor amount of chlorite. Calcite cement occurs in the form of finely crystalline aggregates with patches of sparry texture corroding the detrital grains around their boundaries. Matrix ranges between 2% and 5% of the total material.

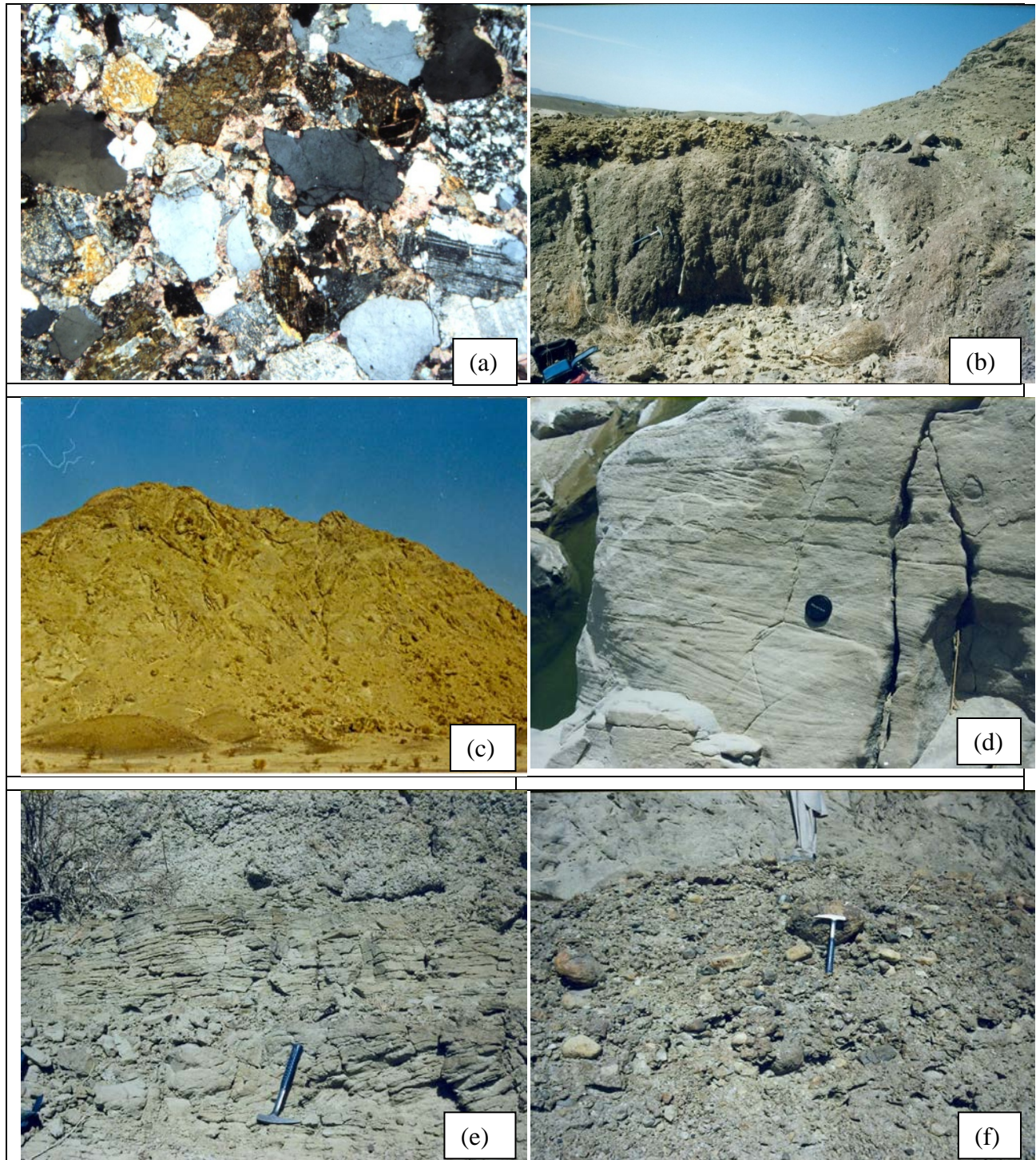


Fig. 2. Photomicrographs and field photographs of the Ispikan group: (a) Photomicrograph of the sandstone of the Ispikan formation showing, quartz, plagioclase and granitic fragments. Note the presence of k-feldspar (stained yellow) within the granitic rock fragments, crossed polars; (b) Outcrop of the Ispikan formation showing shale interbedded with thin sandstone beds; (c) Distant view of the Ispikan Conglomerate; (d) Close up view of the cross-bedded sandstone of the Ispikan Conglomerate; (e) Another view of the parallel- and cross-bedded sandstone of the Ispikan Conglomerate and (f) Close up view of the conglomerate succession of the Ispikan Conglomerate.

Table 1. Newly proposed scheme of stratigraphic succession of the south-western Makran, modified after the Hunting Survey Corporation (1961) and Cheema et al. (1977).

Age	Group	Formation	Lithology
Pleistocene to Holocene	Makran Group	Jiwani Formation	Shelly and reefoid limestone, sandstone and conglomerate
Late Pliocene		Unconformity	
		Gawadar Formation	Soft and poorly consolidated mudstone with minor sandstone
Early Pliocene		Unconformity	
Late Miocene Early Miocene	Turbat Group	Chatti Formation	Calcareous shale and marl
		Talar Formation	Cyclic succession of sandstone and shale
		Parkini Mudstone	Mudstone with occasional thin sandstone
Oligocene-Early Miocene		Panjgur Formation	Sandstone interbedded with shale
Late Eocene-Early Oligocene		Hoshab Shale	Shale with occasional thin bedded sandstone
Thrust			
Eocene		Wakai Limestone	Highly fossiliferous to reefoid limestone
Thrust			
Palaeocene	Ispikan group	Ispikan Conglomerate	Conglomerate interbedded with very coarse pebbly sandstone
Late Cretaceous		Ispikan Formation	Interbedded shale, mudstone and thin bedded fine grained sandstone and siltstone
Thrust			
Cretaceous	Wakai group	Undifferentiated	Agglomerate, purple shale, marl, chert, biomicritic limestone and mafic and ultramafic rocks

Table 2. List of varieties of rock fragments present in sandstone of the Palaeocene Ispikan formation.

Igneous	Metamorphic	Sedimentary
Granite	Quartzite	Limestone
Muscovite granite	Gneissose quartzite	Sandstone
Muscovite-biotite granite	Epidote quartzite	Chert (radiolarian)
Rhyolite	Muscovite-biotite-chlorite schist	
Basalt	Gneiss	
Volcanic glass	Phyllite	
Trachyte	Slate	
Serpentine	Marble	

Point counting of the sandstone of the Ispikan group shows that they are mostly composed of extra-basinal grains of non-carbonate types and minor proportions of carbonate grains of both intra- and extra-basinal origins. They have an average composition of $Qt_{52}-F_{33}-L_{15}$ (Table 3, Fig. 3a), which suggests derivation of the extra-basinal components from a recycled and mixed orogenic source (Dickinson and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985). The Qm-F-Lt plot (Table 3; Fig. 3b) of the sandstone samples shows that they fall into the fields of mixed and basement uplift source terrains. These plots, along with the list of rock fragments (Table 2), suggest that source area contained high- to low-grade metamorphic rocks, granitic intrusions and minor

proportions of basic volcanic and sedimentary successions. The averages $Qp_3-Lvm_{62}-Lsm_{35}$ and $Lm_{26}-Lv_{65}-Ls_9$ (Kassi et al., 2003) indicate the importance of the igneous and metamorphic source area along with a combination of magmatic arcs and ophiolites. The average $PtMt_{90}-Av_7-Bv_3$ (Kassi et al., 2003), indicate that plutonic and metamorphic rocks were the dominant source contributors, whereas, a volcanic source terrain was contributing lesser quantities. The plots (Figs. 3a and b) suggest that both sandstones of the Ispikan group and Panjgur Formation have comparable provenance of recycled and mixed terrains, most plausibly the Himalaya-Karakorum-Hindukush orogens and associated magmatic arcs of Kohistan and Chagai-Raskoh and Bela-Muslimbagh-Waziristan ophiolites.

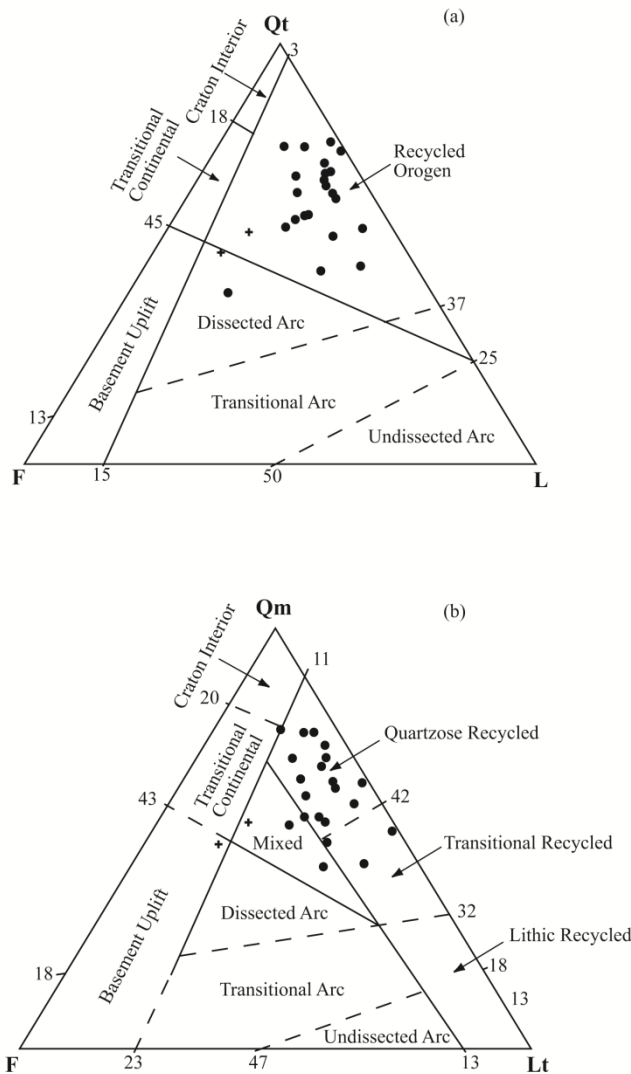


Fig. 3. (a) Qt-F-L plot of the sandstone samples of the Ispikan group and Panjgur Formation and (b) Qm-F-Lt plot of the sandstone samples of the Ispikan group and Panjgur Formation.

Table 3. List of point-count parameters determined for classification of sandstone (after Dickinson and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985).

$Qt = Qm + Qp$	where	Qt = total quartzose grains Qm = monocrystalline quartz grains Qp = polycrystalline aphanitic quartzose grains
$F = P + K$	where	F = total feldspar grains P = plagioclase-feldspar grains K = potassium-feldspar grains
$Lt = Lm + Lv + Ls$	where	Lt = total unstable aphanitic lithic grains Lm = metamorphic aphanitic lithic grains Lv = volcanic and hypabasal aphanitic lithic grains Ls = sedimentary aphanitic lithic grains + extrabasinal carbonate grains
$L = Lvm + Lsm$	where	Lvm = volcanic, hypabasal and metavolcanic aphanitic lithic grains Lsm = sedimentary and metasedimentary aphanitic lithic grains
$PtMt = Pt + Mt$	where	Pt = plutonic grains Mt = metamorphic grains

4. Facies

Nine distinct facies (Table 4) are identifiable within the Ispikan group, which are described below:

4.1. *Isp-1 (Normally graded pebbly sandstone)*

The normally graded pebbly sandstone (Isp-1) is the most common facies of the Ispikan Conglomerate (Table 4; Fig. 4). It comprises, thickly to very thickly (up to several meters thick) bedded, very coarse pebbly sandstone with or without the mudstone/siltstone intraclasts of the underlying succession. Clasts are generally pebbly and reach up to several centimetres in length. The sandstone is poorly sorted, matrix-supported, normally graded, have sharp erosive bases and generally gradational contacts with overlying facies. These characteristics resemble with facies A, A2.5 and “graded-bed” of Mutti and Ricci Lucchi (1972), Pickering et al. (1986) and Walker (1978), respectively, and indicate rapid grain-by-grain deposition from suspension with rapid burial.

4.2. *Isp-2 (Stratified pebbly sandstone)*

This is a common facies of the Ispikan Conglomerate (Table 4; Fig. 4), which comprises

thickly to very thickly bedded, very coarse pebbly sandstone (maximum clast size: 2cm) with erosive bases and normal grading from very coarse and pebbly to medium grained sandy texture towards top. It generally shows 30-40 cm thick solitary or composite sets of cross-bedding and parallel lamination (Figs. 2d and e). These characteristics resemble with the facies A and A2.7 of Mutti and Ricci Lucchi (1972) and Pickering et al. (1986), respectively, and indicate traction bed-load or traction carpet at the base of high-concentration turbidity current. Facies Isp-1 and Isp-2 are mostly, but not exclusively, related; Isp-2 gradationally overlies the Isp-1 and their combination represents the “graded-stratified bed” of Walker (1978).

4.3. *Isp-3 (Normally graded conglomerate)*

Isp-3 is also a commonly occurring facies of the Ispikan Conglomerate (Table 4; Figs. 2e and f), generally comprising well-sorted, clast supported, rounded to well rounded, pebble to boulder conglomerate. Average size of the clasts of various beds varies between 2 and 10 cm, whereas, their maximum clast sizes range between 10 and 20 cm. Beds are generally normally graded, however, inverse grading may also be found in some beds. Their lower contacts are mostly sharp and erosive and upper contacts

gradational with the overlying facies. Beds are mostly lenticular and range between 200 and 500 cm in thickness. These characters resemble with the A and A2.3 facies of the Mutti and Ricci Lucchi (1972) and Pickering et al. (1986), respectively, and indicate rapid deposition from high-concentration turbidity currents. Facies Isp-3 represents the “graded-bed” and “inversely-to-normally graded bed” of Walker (1978).

4.4. *Isp-4 (Disorganised conglomerate and pebbly sandstone)*

This is the least commonly occurring facies of the Ispikan Conglomerate (Table 4; Figs. 2c, e and f). It comprises very thickly bedded, generally very poorly sorted, matrix supported and subrounded to rounded pebble conglomerate. Average size of gravel clasts in various beds varies between 2 and 40 cm and maximum clast size reaches up to 110 cm. Beds generally do not show any grading. Lower contacts are mostly sharp and the upper contacts gradational with the overlying facies. Beds are irregular to lenticular and their thicknesses range between 200 and 500 cm. These characters resemble the facies A and A1.4 of the Mutti and Ricci Lucchi (1972) and Pickering et al. (1986), respectively, and indicate long-distance transport by debris flows and/or high-concentration turbidity currents and finally rapid collective deposition of a pebble-sand mixture. Facies Isp-4 represents the disorganized-bed of Walker (1978).

4.5. *Isp-5 (Biogenic cream coloured mudstone)*

A commonly occurring facies in the Ispikan formation (Table 4; Fig. 2b) comprises massive to very finely laminated, very thinly to very thickly bedded and highly bioturbated biogenic mudstone of cream to white colour. Contacts with underlying and overlying facies are sharp to gradational. Beds are mostly planar and laterally continuous for long distances. These characters resemble the G and G2 facies of the Mutti and Ricci Lucchi (1972) and Pickering et al. (1986), respectively, and indicate deposition by mixed hemipelagic and very low concentration turbidity currents.

4.6. *Isp-6 (Varicoloured mudstone and shale)*

This is also a commonly occurring facies of the Ispikan formation (Table 4; Fig. 2b). It

comprises massive, highly bioturbated, purple, red, brown and varicoloured mudstone and shale, which is very thinly to very thickly bedded with sharp upper and lower contacts and planar geometry. These characters resemble the facies G of Mutti and Ricci Lucchi (1972) and G1.1 and G1.2 of Pickering et al. (1986) respectively and indicate very slow accumulation by pelagic-hemipelagic settling.

4.7. *Isp-7 (Very fine sandstone/siltstone-mudstone couplets)*

This facies is mostly associated with the Isp-5 (biogenic cream coloured mudstone facies) (Table 4; Fig. 2b). It comprises very thinly bedded, very fine sandstone/siltstone and mudstone couplets. Sandstone/siltstone beds have planar geometry, sharp bases, gradational tops and parallel- to cross-laminated (Tcde and Tde of Bouma, 1962). These characters resemble the facies D of Mutti and Ricci Lucchi (1972) and D2.2 and D2.3 of Pickering et al. (1986) respectively and indicate deposition by mixed low-concentration turbidity currents and hemipelagic sedimentation.

4.8. *Isp-8 (Very coarse sandstone-mudstone couplets)*

This facies comprises very thick-bedded and very coarse-grained sandstone and mudstone couplets, which are normally graded (Table 4). The sandstone beds have sharp erosive bases, gradational tops, lenticular morphology and possess Tabcde sequences of Bouma (1962). These characters resemble the facies C of Mutti and Ricci Lucchi (1972) and C2.1 of Pickering et al. (1986), respectively, and indicate deposition by high-concentration turbidity currents.

4.9. *Isp-9 (Exotic clasts in mudstone/siltstone matrix)*

This facies comprises very thick-bedded layers containing disorganized exotic clasts of intra- and extra-basinal origins within a mudstone, siltstone or very fine sandstone matrix (Table 4). The units have sharp erosive bases and tops and irregular morphology. These characters resemble the facies F of Mutti and Ricci Lucchi (1972) and F1.1 of Pickering et al. (1986), respectively, indicating deposition by slumps or debris flows.

Table 4. Characteristics of the lithofacies observed in the Late Cretaceous-Palaeocene Ispikan group.

Lithofacies codes	Lithology	Sedimentary structures	Bouma divisions	Bounding surfaces	Thickness	Geometry	Trace Fossils	Process of deposition	Facies codes of other workers*
Isp-1	Pebbly sandstone	Normally graded sand, poorly sorted	None	Sharp to erosive base, gradational top	Very thick, up to several meters	Lenticular	Rare	Rapid grain by grain deposition from suspension, with rapid burial	A, A2.5,
Isp-2	Pebbly sandstone	Parallel- to cross-stratified	None	Sharp to erosive base, gradational top	Very thick, up to several meters	Lenticular	Rare	Traction bed load or traction carpet at the base of a high-concentration turbidity current	A, A2.7
Isp-3	Conglomerate	Normally graded with / without reverse grading at the base	None	Sharp to erosive base, gradational top	Very thick, up to several meters	Lenticular	Rare	Rapid suspension from high concentration turbidity current	A, A2.3
Isp-4	Conglomerate to pebbly sandstone	Disorganised, poorly sorted with sandy matrix	None	Sharp to erosive base, gradational top	Very thick, up to several meters	Lenticular to irregular	Rare	High concentration turbidity currents or debris flows and finally rapid collective deposition of pebble-sand mixture	A, A1.4
Isp-5	Biogenic mudstone	Massive to very finely laminated, bioturbated	Td, Te	Sharp	Very thin to very thick	Planar	Common	Mixed hemipelagic to very low concentration turbidity currents	G, G2
Isp-6	Purple, brown, red and varicoloured shale	Massive, bioturbated	None	Sharp	Very thin to Very thick	Planar	Common	Pelagic to Hemipelagic	G, G1.1, G1.2
Isp-7	Very fine sandstone – siltstone/mudstone couplets	Parallel and cross-laminated	Tcde, Tde	Sharp bases and gradational tops	Thin to very thin bedded	Planar	Rare	Mixed low concentration turbidity currents and hemipelagic sedimentation	D, D2 D2.3
Isp-8	Very thick bedded sandstone – shale couplets	Normally graded	Tabcde	Sharp erosive base and gradational top	Very thick bedded	Lenticular	Rare	High concentration turbidity currents	C, C2.1
Isp-9	Exotic clasts in mudstone-sandstone matrix	Disorganized	None	Sharp bases and tops	Very thick bedded	Irregular	Rare	Slumps / debris flows	F, F1.1

* A modified after Mutti and Ricci Lucchi (1972), Pickering et al. (1986) and Walker (1978).

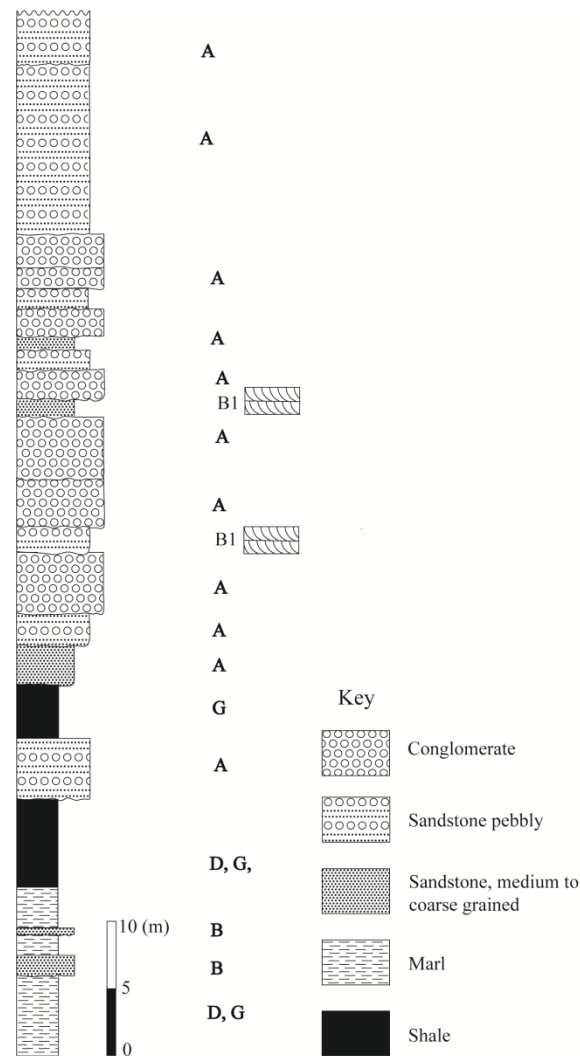


Fig. 4. Sedimentary log of the Ispikan group showing various facies exposed at the outcrop. Letters A, B, D and G refer to the facies codes of the Mutti and Ricci Lucchi (1972) and Pickering et al. (1986).

5. Facies associations

The facies described in the previous section are organized into the basin plain and inner-fan channel facies associations, which pertain to the Ispikan formation and Ispikan Conglomerate, respectively. Facies associations are described as under:

5.1. Inner-fan channel facies association

The inner-fan channel facies association, comprising the Ispikan Conglomerate, is represented by medium to very coarse pebbly sandstone and conglomerate characterized by combination of facies Isp-1, Isp-2, Isp-3 and Isp-4

(Table 4; Fig. 4), which represent facies A of Mutti and Ricci Lucchi, (1972), disorganized beds, inversely- to normally-graded beds, graded beds and graded-stratified beds of Walker (1978) and facies A2.3, A2.5, A2.7 and A1.4 of Pickering et al. (1986). Facies Isp-9, representing facies F of Mutti and Ricci Lucchi (1972) and F1.1 of Pickering et al. (1986), is also present in the lower part of this association. However, its stratigraphic relationship to the rest of the association cannot be ascertained due to thrusting. The succession is organized into fining-upward couplets of conglomerate/very coarse pebbly sandstone and coarse to medium grained sandstone, which has erosive bases. Some structures, like the foreset beds and low-angle cross-lamination (Figs. 2d and

e), within the coarse sandstone beds and their vertical organization and geometry resemble typically with the braided channel deposits. Such features may have formed by the migration of channel thalweg.

5.2. Basin-plain facies association

The basin-plain facies association, comprising the Ispikan formation, is represented mainly by alternations of biogenic cream and varicoloured pelagic and hemipelagic mudstone and shale interbedded with very thin-bedded sandstone/siltstone i.e. Bouma (1962) Tcde, Tde sequences of turbidites (Table 4). This association comprises Isp-5 to Isp-8 facies, representing facies G, D and C of Mutti and Ricci Lucchi (1972) and facies G1.1, G1.2 and G2 of Pickering et al. (1986), which is characteristic of the basin-floor environment.

6. Discussion

Thrust-bound inliers of the Cretaceous-Palaeocene age comprise minor proportion of the vast area of the Makran Accretionary Wedge. However, they make an important part of the geological history of the Makran area and their understanding is very important for proper understanding of the geotectonic history of the Makran Accretionary Wedge. The inliers in the study area and surroundings occur within the thick succession of the Late Eocene-Miocene Hoshab Shale and Panjgur Formation, which have not been studied/described since the reconnaissance report of the Hunting Survey Corporation (1961), however, the siliciclastic succession the Oligocene-Miocene Panjgur Formation has been studied (Critelli et al., 1990; Kassi et al., 2003; Grigsby et al., 2004; Kassi et al., 2007; Kassi et al., 2011).

The variety of rock fragments within the conglomerate and sandstone of the Ispikan group (Kassi et al., 2007; Tables 2-3; Figs. 2-3) suggests a source terrain comprising mostly high-grade metamorphic, acidic igneous and sedimentary rocks. The mineralogical composition of the sandstone indicates that they are mostly meta-sedimentary litharenites. Their quartzose nature and low percentage of feldspars supports the suggestion that sediments are from recycled source and their Qt-F-L plot (Fig. 3a) suggests a

collision orogen as the main source terrain for the sandstone. The Qm-P-K plot (Fig. 3b) shows that the sandstone has very high percentages of monocrystalline quartz (Qm), as compared to plagioclase (P) and K-feldspar (K), which provides additional evidence to suggest recycled siliciclastic detritus. We suggest that the most likely source is the Himalayan-Karakorum-Hindukush collisional orogen.

Sandstone of the surrounding Oligocene Panjgur Formation, exposed in a vast area of the Makran Accretionary Wedge, are also composed of high proportions of quartz and metamorphic, igneous and sedimentary rock fragments (Table 2), which also have a recycled quartzose detrital mode (Critelli et al., 1990; Kassi et al., 2003; Grigsby et al., 2004). Varieties of the rock fragments within the sandstone of the Panjgur Formation also suggest derivation from the Himalayan-Karakorum-Hindukush orogen and associated suture belts, ophiolites, mélanges and volcanic arcs. Qayyum and Naim (2001) consider the Himalayan orogenic belt as the most likely provenance for sandstone of the Khojak Formation of the Katawaz Basin of Pakistan and Afghanistan, which is the Oligocene-Miocene deltaic and shallow marine equivalent of the Panjgur Formation. They observed compositional and provenance changes within the succession of the Khojak Formation, which they related to the gradual uplift of the Himalayan orogen due to thrusting and progressive erosion of the elevated thrust sheets and unroofing of the Himalayan orogen. They have proposed that volcanic fragments within the sandstone of the Khojak Formation were derived from the Himalayan suture zone, where basic igneous rocks of the Kohistan Island Arc were also exposed. Their proposed palaeogeographic model also indicates the Bela-Muslimbagh ophiolites, and also perhaps the Kirther-Sulaiman belt, as the source area for their “Katawaz Delta” and “Khojak Submarine Fan”. Critelli et al. (1990) imply that reworking of the co-eruptive products such as the Chaghai volcanic arc has produced volcanic detritus of the Panjgur sandstone. We propose a combined source of the Himalayan suture zone for the high-grade metamorphic and acidic igneous detritus and Bela-Muslimbagh ophiolites, and possibly the Chaghai-Raskoh volcanic arc, for the basic/ultrabasic detritus. We think that most of the

low- to high-grade metamorphic, granitic and part of basic detritus have been derived from the Himalayan-Karakorum-Hindukush orogen, whereas part of the basic and ultrabasic detritus was derived from the Bela-Muslimbagh Ophiolites and Chaghai-Raskoh Volcanic Arc. Although ultrabasic material is not very common in the sandstone and conglomerate of the Ispikan and Panjgur formations, occasional grains of chrome spinel (picotite) and serpentinite suggest derivation from the ophiolitic belts.

Qayyum and Naim (2001) have shown that during Palaeogene only sedimentary and low-grade metamorphic rocks were exposed in the Himalayas, however, at a later stage, high-grade metamorphic rocks were also exposed and started contributing their detritus, a shift that may be attributed to the progressive unroofing of the Himalayas. This notion does not fit with the composition of sandstone and conglomerate of the Late Cretaceous-Palaeocene Ispikan group and Oligocene-Miocene Panjgur Formation, which contain varieties of igneous and high-grade metamorphic fragments including gneisses and granites and indicate unroofing of the source area during the Early Palaeocene. In view of the remarkable similarities of petrology and provenance between the Late Cretaceous-Palaeocene Ispikan group and Oligocene-Miocene Panjgur Formation of the Makran Accretionary Wedge and Khojak Formation of the Katawaz Basin, we suggest that their detritus has been derived from similar source areas, most likely the Himalaya-Karakorum-Hindukush orogenic belt and associated ophiolitic and sedimentary belts (Kassi et al., 2003; Qayyum and Naim, 2001; Critelli et al., 1990).

Our data suggest that the early Himalayan-Karakorum-Hindukush orogenic highlands to the north and Kirther-Sulaiman belt to the east of the Katawaz remnant ocean had formed during the Early Palaeocene and has been shedding detritus ever since (Beck et al., 1995; Garzanti et al., 1996; Qayyum et al., 1996a, 1996b, 1997a, 1997b; Kassi et al., 2003). Siliciclastic sediments were dispersed to the Katawaz remnant ocean to form the Kkojak-Panjgur delta-submarine fan complex, which comprises the Late Eocene to Oligocene Khojak Formation in the Katawaz area, and the Late Cretaceous-Palaeocene Ispikan group

and Late Eocene-Miocene succession of the Hoshab/Siahan shale and Panjgur Formation in the Makran area (Qayyum et al., 1996a, 1996b, 1997a, 1997b; Kassi et al., 2003). Longitudinal ridges and flute marks at the base of Ispikan Conglomerate, observed in one locality, show orientation of N 60W and flow direction towards NW, which is also compatible with the general palaeoflow trend of the Panjgur Formation (Kassi et al., 2011, 2013).

Facies and facies associations of the Late Cretaceous-Palaeocene Ispikan group indicate deposition in inner-fan channels and basin-floor, which were parts of the earliest submarine fan system of the complex. The Oligocene-Miocene Panjgur Formation was also deposited in a very large submarine fan complex, in which several fan components/facies associations of the submarine fan systems, such as middle-fan channels, outer-fan lobes, fan-fringe and basin-plain, are recognizable (Kassi et al., 2003; Kassi et al., 2011). Although, the inner-fan channel facies were not observed in the studied sections of the Oligocene-Miocene Panjgur Formation it is anticipated that they are present east-northeastward in the proximal parts of the complex, which have not yet been studied. The dominant westward palaeocurrent pattern, as shown by the Panjgur succession (Kassi et al., 2003), is parallel to the regional trend and trench axis, which is characteristic of trenches where abyssal plains are incorporated into the accretionary wedges (Dickinson, 1982; Nilsen and Zuffa, 1982; De Roza et al., 1986; Lash, 1986, 1987). The “Khojak-Panjgur Submarine Fan Complex” has been interpreted as the present day analogue of the Indus Fan (Critelli et al., 1990; Qayyum et al., 1997a, 1997b; Kassi et al., 2003). Qayyum et al. (1996a) suggest that the Murgha Faqirzai and Shaigalu members of the Khojak Formation comprises subaqueous to subaerial facies typical of a fluvial-dominated and wave-modified delta that axially fed their “Khojak Submarine Fan” to the southwest. Kassi et al. (2003) proposed that the Ispikan and Panjgur successions were the further ocean-ward continuum of the Katawaz delta of Qayyum et al. (1997a, 1997b), which they named as the “Khojak-Panjgur Submarine Fan Complex”. It developed in the Katawaz remnant ocean that existed between the Afghan Block of the Eurasian

Plate and the western margin of the Indian Plate and continued further south-westward in the Gulf of Oman abyssal plain. We support the notion of Critelli and De Rosa (1987) and Critelli et al. (1991) that sediment transport was mainly controlled by the Chaman-Ornach Nal Transform System and initially detritus was transported generally southwards along the Chaman-Ornach Nal Transform System and then turned westward and parallel to the present active margin of the Makran Accretionary Wedge.

Despite the age contrast and thrust-boundary relationship the Late Cretaceous-Palaeocene Ispikan group and Late Eocene-Miocene Panjgur Formation and Siahn Shale share the characters of being components of a submarine fan complex that had started to establish during the Early Palaeocene and continued to evolve during Palaeocene through Miocene. However, the stratigraphic relationship of the Ispikan group with the surrounding Oligocene-Miocene Panjgur Formation and palaeogeographic position of the Ispikan group is still enigmatic because of their thrust contacts. In the studied areas no flysch succession of Eocene age has been mapped, however, the Raskoh Flysch Belt located to north of the Mashkhel Trough, is older and may be the possible equivalent succession. Also westwards across the Iranian border McCall (2003) have mapped Early Eocene-Early Oligocene- Miocene flysch turbidites north of the town of Pishin. We propose that further detailed work, especially on biostratigraphy of both the formations, as well as the Raskoh Flysch Belt may be carried out in order to ascertain their stratigraphic relationship.

7. Conclusions

Sandstone and conglomerate of the Late Cretaceous-Palaeocene Ispikan group of the Makran Accretionary Belt are composed of high proportions of metamorphic, acidic igneous and lesser proportions of sedimentary rock fragments and shows a recycled detrital mode. Varieties of the rock fragments, especially of the high-grade metamorphic origins, within the conglomerate and sandstone, suggest that material was derived from the Himalayan-Karakorum-Hindukush orogen and associated suture belts, ophiolites, mélanges and volcanic arcs. Their characters resemble with those of the surrounding succession of the

Oligocene- Miocene Panjgur Formation and the up-current deltaic equivalent, the Khojak Formation of the Katawaz Basin, which also indicates comparable detrital modes.

The Late Cretaceous-Palaeocene Ispikan group comprises nine distinct facies organized into the inner-fan channels and basin-plain facies associations of the submarine fan complex. The surrounding succession of the Oligocene-Miocene Panjgur Formation is also a deposit of a submarine fan complex, showing of the middle- to lower-fan and basin-plain facies associations/fan components.

Although the petrology, provenance and depositional environments of both the Ispikan group and Panjgur Formation are comparable, their stratigraphic relationship and palaeogeographic positions are still enigmatic, as the Ispikan group is an inlier having thrust contacts with the Panjgur formation. Further biostratigraphic work is needed to establish their stratigraphic relationship and palaeogeographic positions.

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