Aspects of the Cenozoic stratigraphy of the Northern Sulaiman Ranges, Pakistan

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ABSTRACT - The results of micropalaeontological, nannopalaeontological and palynological analyses of Cenozoic sections from the Northern Sulaiman Ranges in Pakistan are discussed. They are in keeping with previously published results (though in some cases significantly more refined). They enable placement of most of the sampled lithostratigraphic units in a global bio- and sequence-stratigraphic framework. Limestones appear to be associated with essentially transgressive global sequences, shales with essentially regressive sequences. Palaeoenvironmental interpretations indicate a range of depositional settings from continental through shallow marine to basinal. A number of shallow marine carbonate platform sub-environments are recognized over the Palaeocene–Eocene section J. Micropalaeontol. 16(1): 51–58, May 1997.

INTRODUCTION
BP has recently undertaken a field survey of part of the Northern Sulaiman Ranges in Pakistan (Fig. 1). The primary objective of the survey was to log selected sections and to collect samples for geochemical, sedimentological and palaeontological analysis in order to identify any resource (source, reservoir and seal) potential. The secondary objective was to obtain enough structural geological information to construct a cross-section through the mountain-front to constrain appropriate source maturation and migration models. Structural aspects are discussed by Banks & Warburton (1986) and Jadoon et al. (1994).

Samples were made available for palaeontological analysis from the Dunghan, Ghazij, Kirthar and Chitanwata Formations and the Siwalik Group of the Zam Tower, Zor Shahr, Domanda, Toi River and Baska sections (Fig. 1). Particular emphasis was placed on the Eocene Baska and Kirthar Formations (Fig. 2), which, by analogy with the Potwar Basin to the northeast (Brown & Dey, 1975; Khan et al., 1986) were perceived to have the most resource potential.

Micropalaeontological analyses were undertaken by the author (calcareous algae and foraminifera) and John Athersuch (ostracods), nannopalaeontological analyses by Ted Finch and Julie Pearce, and palynological analyses by Bob Ravn, Paul Ventris and John Williams.

RESULTS AND DISCUSSION
Results are summarized on Fig. 3, and discussed in more detail (in ascending stratigraphic order) below.

Dunghan Formation
The dominant lithology was bioclastic limestone. Micropalaeontological analyses were undertaken on three samples (18, 44 and 45).
Results. The microfauna is moderately rich and diverse, and included benthonic and planktonic foraminifera, calcareous algae, and bryozoan and miscellaneous macrofossil debris. The benthonic foraminifera include ?Dictyoconus sp. and indeterminate miliolids and rotaliids. The planktonic foraminifera include Globorotalia (Morozovella) ex gr. angulata/conicotruncata, G. (M). ex gr. subbotinae and G. (M). sp. The calcareous algae include Amphiroa, sp., Archaeolithothamnium, sp., indeterminate codiaceans and dasycladaceans, Distichoplax biseriatalis, Lithothamnium sp., Mesophyllum and rhodoliths.

Discussion. Stratigraphy – A Late Palaeocene to Early Eocene age is indicated by the occurrences of the planktonic foraminifera Globorotalia (Morozovella) ex gr. angulata/conicotruncata (Zones P3–P5 of Blow, 1979) and and G. (M). ex gr. subbotinae (P6–P8). Published information supports this interpretation (see, for instance, Samanta, 1972, 1973; Kureshy, 1978a, 1984).

Paleoenvironmental Interpretation – Micropalaeontological evidence points to a warm, shallow carbonate platform. The presence of codiacean, dasycladacean and rhodophytic algae indicates a setting within the euphotic zone (no deeper than 5–15 m).

Ghazij Formation

The dominant lithology was mudstone. Palynological analyses were undertaken on four samples (46, 120, 124 and 130).

Results. The in situ palynoflora is impoverished, and includes only rare pollen (flowering-plant (angiosperm) and grass (Gramineae) pollen) and spores (Callialasporites). Reworked...
Early Cretaceous dinoflagellate cysts are also present.

Discussion. Stratigraphy – No conclusions can be drawn with regard to age. Published information indicates Early Eocene (see, for instance, Gill, 1953; Haque, 1956; Nagappa, 1959; Latif, 1961; Siddiqui, 1971; Samanta, 1972, 1973; Dorreen, 1974; Kureshy, 1978a,b, 1985a).

Palaeoenvironmental interpretation – The absence of marine palynomorphs provides negative evidence of a non-marine palaeoenvironment.

Baska Formation

The dominant lithology is mudstone. Micropalaeontological and palynological analyses were undertaken on eight samples (95, 106, 118, 115–116, 119 and 181).

Results. The microfauna is moderately rich and diverse, and includes benthonic and planktonic foraminifera, ostracods, gastropods, and bryozoan, echinoderm and miscellaneous macrofossil debris. The benthonic foraminifera include Miliolida (Archaias sp., ?Peneroplis sp., Quinguelculina sp.), Bulimini (Brizalina sp.), smaller Rotaliida (anomalids, discorbids, ?Nonion sp.) and larger Rotaliida (Assilina maior punctulata, Dictyoconoides cooki, Nummulites sp.). The planktonic foraminifera (Globigerinida) include ‘Globigerina’ lozanoi and Globorotalia (Acarinina) ex gr. pentacamerata. The ostracods include Alocopocythere sp., bairdiids, cyprids, Gyrocystere exaggerata, Krithie sp., ?Ocullitocythereis sp., Pontocythere sp., trachyleberidids and Xestoleberis cf. globosa.

The palynoflora is also moderately rich and diverse, and includes marine dinoflagellate cysts and terrestrially derived pollen and spores. The dinocysts include Achomosphaera sp., Areoligerum sp., Cordosphaeridium sp., Diphyes cf. colligerum (?D. fucoides), ?Impletosphaeridium sp., ?Systematophora placacantha and Thalassiphora sp.

Discussion. Stratigraphy – An age in the range latest Early–earliest Middle Eocene is indicated by the occurrences of the larger benthonic nummulitid foraminifer Assilina maior punctulata (Cuisien Superieur – Lutetien Basal of Schaub, 1981; calcareous nannoplankton Zones NP14–NP15 of Martini, 1971) and the planktonic foraminifera ‘Globigerina’ lozanoi (Zones P8–P10 of Blow, 1979) and Globorotalia (Acarinina) ex gr. pentacamerata (P8–?P9). Published information supports this interpretation (see, for instance, Siddiqui, 1971).

The Baska Formation appears to be associated with the essentially regressive global third-order (eustatically mediated) sequence TA3.1 of Haq et al. (1987).

Palaeoenvironmental interpretation – Microfaunal evidence points to a low-energy back-bank lagoon characterized by Miliolida. The presence of sea-grasses is indicated by the presence of epiphytic discorbids, the influence of the open ocean by rare globigerinids.

The depth of depositional environment is difficult to determine, because it would have been determined not by the foraminifera themselves but by the photosynthetic algal symbionts to which they acted as host. Modern Archaias aduncus, Cyclorobiculina compressa and Peneroplis proteus contain photosynthetic green algae which restrict them to between 0–15 m (e.g. Murray, 1973; Reiss & Hottinger, 1984; Hallock, 1988).

Habib Rahi Limestone Member (Kirthar Formation)

Lithology ranged from nummulitic and nummulithoclastic grainstone carbonate to laminated shale. Micropalaeontological, nannopalaeontological and palynological analyses were undertaken on 38 samples (58, 59, 68, 69, 80, 82, 83, 85–87, 91–94, 131, 132, 136, 141–143, 150, 152, 155–157, 174–177, 179, 180, 182–185, 188, 194 and 195). The majority of the micropalaeontological analyses were undertaken on random thin-section samples.

Results. The microfauna is moderately rich and diverse, and included benthonic and planktonic foraminifera, and bivalve, bryozoan and miscellaneous macrofossil debris. The benthonic foraminifera include Bulimina (Brizalina sp., Loxostomum sp., Stainforthia sp., Uvigerinella sp.), smaller Rotaliida (Cibicidoides sp.) and larger Rotaliida (Assilina maior punctulata, Dictyocohnoides sp., Discocyclina sp., Lockhartia sp., Nummulites). The planktonic foraminifera (Globigerinida) include indeterminate globigerinids.

The nannoflora is also moderately rich and diverse, and included Braarudosphaera bigelowi, Chiasmolithus grandis, C. formosus, Cocolithus eopelagicus, C. pelagicus, Discoaster barbadiensis, D. binodosus, D. deflandrei, D. saipanensis, Helico- sphaera lophota, H. seminulum, Lanterninthis minutus, Markalus inversus, Micranolithus sp., Nannotetoria sp., Femma angulatum, P. sp., Reticulofenestra dictyoa, Rhabdolithus tenuis, Sphenolithus moriformis, S. pseudoradians, S. radians, S. spiniger/orphankollenis, S. sp. and Zygrabdlithus bijugatus.

The palynoflora is also moderately rich and diverse, and includes marine dinoflagellate cysts and terrestrially derived pollen and spores. The dinocysts include Achomosphaera sp., Cordosphaeridium sp., Diphyes colligerum (?D. fucoides), Impletosphaeridium sp., Systematophora sp. and Thalassiphora sp.

Discussion. Stratigraphy – An early Middle Eocene is indicated by the occurrences of the larger benthonic nummulid foraminifer Assilina maior punctulata (Cuisien Superieur – Lutetien Basal of Schaub, 1981; calcareous nannoplankton Zones NP14–NP15 of Martini, 1971) and the calcareous nannofossils Discoaster saipanensis (calcareous nannoplankton Zones NP15–NP20 of Martini, 1971), Nannotetoria sp. (NP14–NP15), Sphenolithus pseudoradians (NP15–NP23), and S. spiniger/orphankollenis (Zones NP13–NP15). Published information suggests an essentially Middle–Late Eocene age for the Kirthar Formation (see, for instance, Gill, 1953; Nagappa, 1959; Latif, 1961; Khan, 1967; Siddiqui, 1971; Samanta, 1972, 1973; Dorreen, 1974; Kureshy, 1978a,b, 1985b).

The Habib Rahi Member appears to be associated with the essentially transgressive global third-order (eustatically mediated) sequences TA3.2–TA3.3 of Haq et al. (1987).

Palaeoenvironmental interpretation – Microfaunal evidence points to a range of carbonate platform and associated basinal sub-environments. Proximal high-energy bank and fore-bank (nummulitic and nummulithoclastic grainstone) sub-environments are characterized by Rotaliida (nummulitids and discocyclinids, respectively) (cf. Henson, 1950; Das Gupta, 1975; Ghose, 1977; Decrouez & Lanterno, 1979; Philobos & Keheila, 1979; Benjamini, 1981; Luterbacher, 1984; Reiss & Hottinger, 1984; Serra Kiel & Regaunt, 1984; Singh, 1984; Moody, 1987; Pautal, 1987; Hallock, 1988; Buxton & Pedley, 1989). Distal
basinal (laminated shale) sub-environments are characterized by stress-tolerant Buliminida (as in the Palaeogene of Tunisia (Bou Dagher, 1987), large-pored Rotaliida (again as in the Palaeogene of Tunisia (Keller, 1988) and Globigerinida.

The depth of depositional environment is again difficult to determine, because it would have been determined not by the foraminifera themselves but by the photosynthetic algal symbionts to which they acted as host. Modern nummulitids (e.g. Amphistegina, Operculina, Operculinella) contain photosynthetic B-2 and B-3 diatoms whose light requirements are non-specific and which therefore enable them to range down to the light floor (usually ± 130 m) (e.g. Murray, 1973; Reiss & Hottinger, 1984; Hallock, 1988). The optimum development of the modern nummulitids is between 50 and 70 m (Murray, 1973; Reiss & Hottinger, 1984; Hallock, 1988), whereas the optimum development of Eocene pustulose nummulitids in the Jaisalmer Basin in India has been estimated at around 20 m (Singh, 1984).

The nummulitid populations in the studied samples are characteristically dominated either by large B-forms or by small A-forms. Aigner (1982, 1983, 1985) has argued that this is a function of hydrodynamic sorting, and that B-form dominated populations are characteristic of autochthonous and A-form dominated populations of allochthonous accumulations. This has been disputed by various others authors (e.g. Wells, 1986). However, it seems reasonable to interpret A-form dominated assemblages associated with planktonic foraminifera as al-

Cenozoic stratigraphy

Fig. 4. Ternary plot of foraminiferal 'morphogroups' illustrating discrimination of standard facies (after Hallock & Glenn, 1986). M & R = Milolida and smaller Rotaliida; L & S = lenticular and subspher-oidal larger Rotaliida; P & F = planktonic foraminifera (Globigerinida) and flattened larger Rotaliida. 1-8 = standard facies of Wilson (1975) (1 = basin; 2 = open shelf; 3 = toe of slope; 4 = foreslope; 5 = ecologic reef; 6 = shelf sand; 7 = open platform; 8 = restricted platform). A-form dominated nummulitid populations from the Habib Rahi Member of the Kirthar Formation fall in the 'toe of slope' field.

Micropalaeontological and palynological analyses were undertaken on two samples (56 and 57).

Results. The microfauna is impoverished, and includes only rare benthonic and planktonic foraminifera, ostracods, gastropods, and bivalve, echnidnoid and miscellaneous macrofossil debris. The benthonic foraminifera include Lituolida (lituolids), Milolida (Alveolina elliptica, alveolinids, miliolids, soritids) and Rotaliida (anomalinids). The ostracods include Cyprididae. The palynoflora is also impoverished, and includes only rare marine dinoflagellate cysts and terrestrially derived pollen and spores. The dinocysts include Achnomosphaera sp., Areoligeria, Diphyes coligerm (?D. fuscoides), Glaephyrocysta sp.

Discussion. Stratigraphy – A 'mid' Middle Eocene age was indicated by the occurrence of the larger benthonic alveolinid foraminifer Alveolina elliptica (Lutetian Basal – Moyen (2) of Schaub, 1981; calcareous nanoplankton Zones NP15–NP16/17 of Martini, 1971). Published information suggests an essentially Middle-Late Eocene age for the Kithhar Formation (see, for instance, Gill, 1953; Nagappa, 1959; Latif, 1961; Khan, 1967; Siddiqui, 1971; Samanta, 1972, 1973; Dorreen, 1974; Kureshy, 1978a,b, 1985b).

The Domanda member appears to be associated with the essentially regressive global third-order (?eustatically mediated) sequence TA3.4 of Haw et al. (1987).

Palaeoenvironmental interpretation – Microfaunal evidence points to a low-energy back-bank lagoon characterized by Milolida. The depth of depositional environment is difficult to determine, because it would have been determined not by the foraminifera themselves but by the photosynthetic algal symbionts to which they acted as host. Modern Alveolina quaui contains photosynthetic B-3 diatoms which restrict it to between 15 and 75 m, with optimum development between 30 and 50 m (e.g. Reiss & Hottinger, 1984; Murray, 1973; Hallock, 1988).

Pir Koh Limestone Member (Kirthar Formation)

Lithologies ranged from laminated shale through mudstone to limestone. Micropalaeontological, nannopalaeontological and palynological analyses were undertaken on five samples (54, 55, 144, 147 and 149).

Results. The microfauna is moderately rich and diverse, and includes benthonic and planktonic foraminifera, calcareous algae, ostracods, radiolarians, and miscellaneous macrofossil debris. The benthonic foraminifera include Lituolida (Clavulinoide sp.), Milolida (miliolids, soritids), Nodosariida (Lenticulina sp.), Buliminida (Brizalina sp., eouvigerinids), smaller Rotaliida (Cibicidoides sp., discorbids, Gyroidina sp., Nonion sp.) and larger Rotaliida (Assilina exponens, A. sp., Asterocyclina spp., Dictyocyclina cooki, D. sp., Discoyclina spp., Linderina spp., Nummulites baumonti, N. nanngoelani (N. mamilla auctt.), N. cf. obtusus, N. sp., Sphaerogypsina sp.). The planktonic foraminifera (Globigerinida) include Globigerina (Subbotina) ex gr. linaperta, ?Globigerinatheka sp., globigerinids/ tenulilletids, Globorotalia (Acarinina) ex gr. bulbrokii, G. (A.) spp., G. (Morozovella) spinulosa, G. (M.) sp., G. (Turborotalia) centrals, Hankeiina spp., Orbulingoides beckmanni and Truncoro-
taloides toplensis. The calcareous algae include Dictichopax biserialis. The ostracods include Alacopocysther sp., bairdiids, cyprids, Cytherella sp., Krihe sp., Occulticythereis sp. and

Domanda Shale Member (Kirthar Formation)

Lithology ranged from mudstone to bioclastic limestone.
trachyleberidids.

The nannoflora is also moderately rich and diverse, and includes *Braarudosphaera bigelowi*, *Chiasmolithus grandis*, *Coccolithus pelagicus*, *Discoaster barbadiensis*, *D. saipanensis*, *Helicosphaera* sp., *Sphenolithus moriformis*, *S. predistensus* and *S.* spp.

The palynoflora is also moderately rich and diverse, and includes marine dinoflagellate cysts and terrestrially derived pollen and spores. The dinocysts include *Achromocephera* sp., *Areoligeras* sp., *Cordosphaeridium* sp., *Diphyes* sp., *Impleto-sphaeridium* sp., *Lepidodinium* sp., *Nematocystaphora* sp., *Pithanoperidinium* sp., *Spinitertes* sp. and *Wetzelia* sp.

**Discussion. Stratigraphy** – A ‘mid’ Middle Eocene age is indicated by the occurrences of the larger benthonic nummulitid foraminifera *Assilina exponens* and *Nummulites beaumont*, (Lutetien Moyen – Bariariantien of Schaub, 1981; calcareous nannoplankton Zones NP15–NP18 of Martini, 1971), the planktonic foraminifera *Globorotalia* (Acarinina) *ex gr. bullbrookii* (Zones P8b–P12 of Blow, 1979) and *Orbulinoides beckmanni* (P13), and the calcareous nannofossils *Chiasmolithus grandis* (calcareous nannoplankton Zones NP11–NP17 of Martini, 1971) and *Sphenolithus predistensus* (NP17–NP24). Published information suggests an essentially Middle–Late Eocene age for the Kirthar Formation (see, for instance, Gill, 1953; Nagappa, 1959; Latif, 1961; Khan, 1967; Siddiqui, 1971; Samanta, 1972, 1973; Dorreyn, 1974; Kureshy, 1978a,b, 1985b).

The Pir Koh Member appears to be associated with the essentially transgressive global third-order (eustatically mediated) sequence TA3.6 of Haq et al. (1987).

**Palaeoenvironmental interpretation** – Microfaunal evidence points to a range of carbonate platform and associated basinal sub-environments.

**Discussion. Stratigraphy** – No conclusions can be drawn with regard to age. Regional evidence indicates Oligocene.

**Palaeoenvironmental interpretation** – Palynological evidence points toward a continental environment characterized by a forested (?montane) hinterland. Published information indicates a shallow marine environment for the essentially age-equivalent Muree Formation (Bossart & Ottiger, 1989). These formations collectively can be regarded as representing a diachronous foreland basin megasequence younging from northeast to southwest.

**Siwalik Group**

The dominant lithology was mudstone. Palynological analyses were undertaken on two samples (159 and 163), both of which were barren. No conclusions can be drawn with regard to age or depositional environment. Published information indicates a Neogene–Pleistocene age and a range of continental depositional environments (see, for instance, Gill, 1953).

**CONCLUSIONS**

The results of palaeontological analyses of samples from sections from the Northern Sulaiman Ranges in Pakistan are in keeping with previously published information (though in some cases, including that of the prospective Kirthar Formation, significantly more refined). They enable placement of most of the sampled lithostratigraphic units in a global bio-
Cenozoic stratigraphy

sequence-stratigraphic framework. The limestones appear to be associated with essentially transgressive global sequences, the shales with essentially regressive sequences.

Paleoenvironmental interpretations indicate a range of depositional settings from continental through shallow marine to basinal. A number of shallow marine carbonate platform subenvironments are recognized over the Paleocene–Eocene section (essentially back-bank lagoon, bank and fore-bank).

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