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Lithofacies, Depositional Environments, and Regional Stratigraphy of the Lower Eocene Ghazij Formation, Balochistan, Pakistan

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Cover. Exposures of the lower Eocene Ghazij Formation along the northeast flank of the Sor Range, Balochistan, Pakistan. Photograph by Stephen B. Roberts.

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By Edward A. Johnson, Peter D. Warwick, Stephen B. Roberts, *and* Intizar H. Khan

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Lithofacies, Depositional Environments, and Regional Stratigraphy of the Lower Eocene Ghazij Formation, Balochistan, Pakistan

By Edward A. Johnson, Peter D. Warwick, Stephen B. Roberts, *and* Intizar H. Khan[1]

ABSTRACT

The coal-bearing, lower Eocene Ghazij Formation is exposed intermittently over a distance of 750 kilometers along the western margin of the Axial Belt in north-central Pakistan. Underlying the formation are Jurassic to Paleocene carbonates that were deposited on a marine shelf along the pre- and post-rift northern margin of the Indian subcontinent. Overlying the formation are middle Eocene to Miocene marine and nonmarine deposits capped by Pliocene to Pleistocene collision molasse.

The lower part of the Ghazij comprises mostly dark gray calcareous mudrock containing foraminifers and rare tabular to lenticular bodies of very fine grained to fine-grained calcareous sandstone. We interpret the lower portion of this part of the Ghazij as outer-shelf deposits, and the upper portion as prodelta deposits. The middle part of the formation conformably overlies the lower part. It comprises medium-gray calcareous mudrock containing nonmarine bivalves, fine- to medium-grained calcareous sandstone, and rare intervals of carbonaceous shale and coal. Sandstone bodies in the middle part, in ascending stratigraphic order, are classified as Type I (coarsening-upward grain size, contain the trace fossil *Ophiomorpha*, and are commonly overlain by carbonaceous shale or coal), Type II (mixed grain size, display wedge-planar cross stratification, and contain fossil oyster shells and *Ophiomorpha*), and Type III (fining-upward grain size, lenticular shape, erosional bases, and display trough cross stratification). These three types of bodies represent shoreface deposits, tidal channels, and fluvial channels, respectively. Mudrock intervals in the lower portion of this part of the formation contain fossil plant debris and represent estuarine deposits, and mudrock intervals in the upper portion contain fossil root traces and represent overbank deposits. We interpret the middle part of the Ghazij as a lower delta plain sequence. Overlying the middle part of the Ghazij, possibly unconformably, is the upper part of the formation, which comprises calcareous, nonfossiliferous, light-gray, brown, and red-banded mudrock, and rare Type III sandstone bodies. Much of the mudrock in this part of the formation represents multiple paleosol horizons. Locally, a limestone-pebble conglomerate is present in the upper part of the formation, either at the base or occupying most of the sequence. We interpret all but the uppermost portion of the upper part of the Ghazij as an upper delta plain deposit.

Thin sections of Ghazij sandstones show mostly fragments of limestone, and heavy-liquid separations reveal the presence of chromite. Paleocurrent data and other evidence indicate a northwestern source area.

During earliest Eocene time, the outer edge of the marine shelf off the Indian subcontinent collided with a terrestrial fragment positioned adjacent to, but detached from, the Asian mainland. This collision caused distal carbonate-platform deposits to be uplifted, and an intervening intracratonic sea, the Indus Foreland Basin, was created. Thus for the first time, the depositional slope switched from northwest facing to southeast facing, and a northwestern source for detritus was provided. We conclude that the Ghazij was deposited as a prograding clastic wedge along the northwestern shore of this sea, and that the formation contains sedimentologic evidence of a collisional event that predates the main impact between India and Asia.

INTRODUCTION

The lower Eocene Ghazij Formation is one of the most significant lithostratigraphic units in Pakistan. First of all, the formation contains a considerable amount of minable coal, and this commodity is of particular importance in a country whose energy resources are limited. Secondly, the Ghazij was deposited during the initial stages of collision between India and Asia; thus the formation contains the first sedimentologic record of this important event. Of special

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interest to geologists is the formation's enigmatic depositional setting, which seems to change with every area of exposure.

LOCATION OF THE STUDY

The Ghazij Formation is exposed within a sigmoidally shaped mountain belt that covers much of northeastern Balochistan. As shown in figure 1, Balochistan is the largest province in Pakistan; it contains only 5 percent of the country's population, however. Most of the region is arid with an average annual rainfall of less than 250 mm. Elevations in the province range from sea level to over 3,500 m. We used the provincial capital of Quetta as a base from which to conduct our study because of its proximity to good exposures of the Ghazij and for logistical reasons. In addition, Quetta is the national headquarters of the Geological Survey of Pakistan. In the late 1980's Quetta had a population of about 100,000, but this number has increased dramatically by an influx of refugees. Figure 2 is a detailed map of north-central Pakistan showing the locations of most of the place names used in our report.

Although we examined the Ghazij over a broad area of Balochistan, we concentrated our efforts in four specific areas: Pir Ismail Ziarat, the Sor Range, Mach, and Johan. Each of these areas is within a day's travel of Quetta, and each exhibits good exposures of the Ghazij; most are the site of an existing coal-mining effort.

SPONSORSHIP AND PURPOSE OF THE REPORT

This report resulted from a joint effort between the U.S. Geological Survey and the Geological Survey of Pakistan. The study was sponsored by the Government of Pakistan and the U.S. Agency for International Development (USAID). Funding was provided by USAID through Project 391-0478: Energy Planning and Development Project, Coal Resource Assessment Component 2a; Participating Agency Service Agreement (PASA) No. 1PK-0478-P-IC-5068-00.

By mutual decision of the two geologic organizations, the Ghazij Formation in Balochistan was selected for study because it is known to contain a considerable amount of coal, and because a comprehensive investigation of its regional geologic character had not previously been undertaken. As a result of our study, a better understanding of the depositional setting, regional stratigraphic framework, and coal potential of the formation can be presented. Moreover, both geologic organizations benefited greatly from the interactions between participating geologists.

PREVIOUS STUDIES

Short reports discussing the presence of coal-bearing strata in Balochistan appeared in the literature as early as the 1880's. More detailed reports on the Ghazij Formation were published by the pre-partition Geological Survey of India during the first half of the 20th century; references to this early work appear throughout our report. During the 1950's geologists working for Hunting Survey Corporation, Limited, conducted an extensive geologic reconnaissance of a large part of West Pakistan. This work was financed by the Government of Canada under a Colombo Plan Co-operative Project. As part of this effort, the Ghazij was examined regionally for the first time, and this accounting of the formation remains a major source of information on the unit (Hunting Survey Corporation, 1960). During the 1960's John Reinemund of the U.S. Geological Survey and geologists from the Geological Survey of Pakistan conducted a detailed study of the Ghazij in the Sor Range coal field centered about 17 km southeast of Quetta (fig. 2), and this effort resulted in a geologic map of the area (Reinemund and others, no date). In addition to the work just listed, the Geological Survey of Pakistan has published several important reports on the Ghazij, and these are referenced in our report.

METHODS OF INVESTIGATION

Because of time and logistical constraints, the task of investigating the Ghazij Formation was divided among the authors. Johnson, Khan, and Warwick measured and described in detail the Ghazij at five widely spaced locations in order to better interpret regional changes in the depositional facies. Warwick took the lead in examining the formation in reconnaissance over a broad area of Balochistan. Roberts studied the detailed lateral variations of the formation in the Sor Range by measuring a set of closely spaced stratigraphic sections.

Stratigraphic sections were measured using a Jacob's staff or tape and compass. Standard lithofacies descriptions such as color, grain size, and lithology were recorded, and special attention was directed toward describing bedding characteristics and sedimentary structures. Lateral changes defining the geometry of sandstone bodies were also noted. Where available, measurements of paleocurrent indicators were taken, and pebble counts were conducted on conglomerates. Rock samples were collected from critical units along the line of section for petrographic and paleontologic studies. Petrographic studies involved the microscopic examination of thin sections, X-ray diffraction analyses, and work with the scanning electron microscope (SEM). Some mudrock samples were submitted for Rock-Eval analysis, and some limestone samples were submitted for insoluble residue

Figure 1. Map of Pakistan showing provincial boundaries. Also shown is a general outline of the study area. N.A., Northern Area; N.W.F.P., North West Frontier Province; I, Islamabad; Q, Quetta; K, Karachi.

determinations. Samples collected for paleontologic analyses were submitted to paleontologists at the U.S. Geological Survey.

ACKNOWLEDGMENTS

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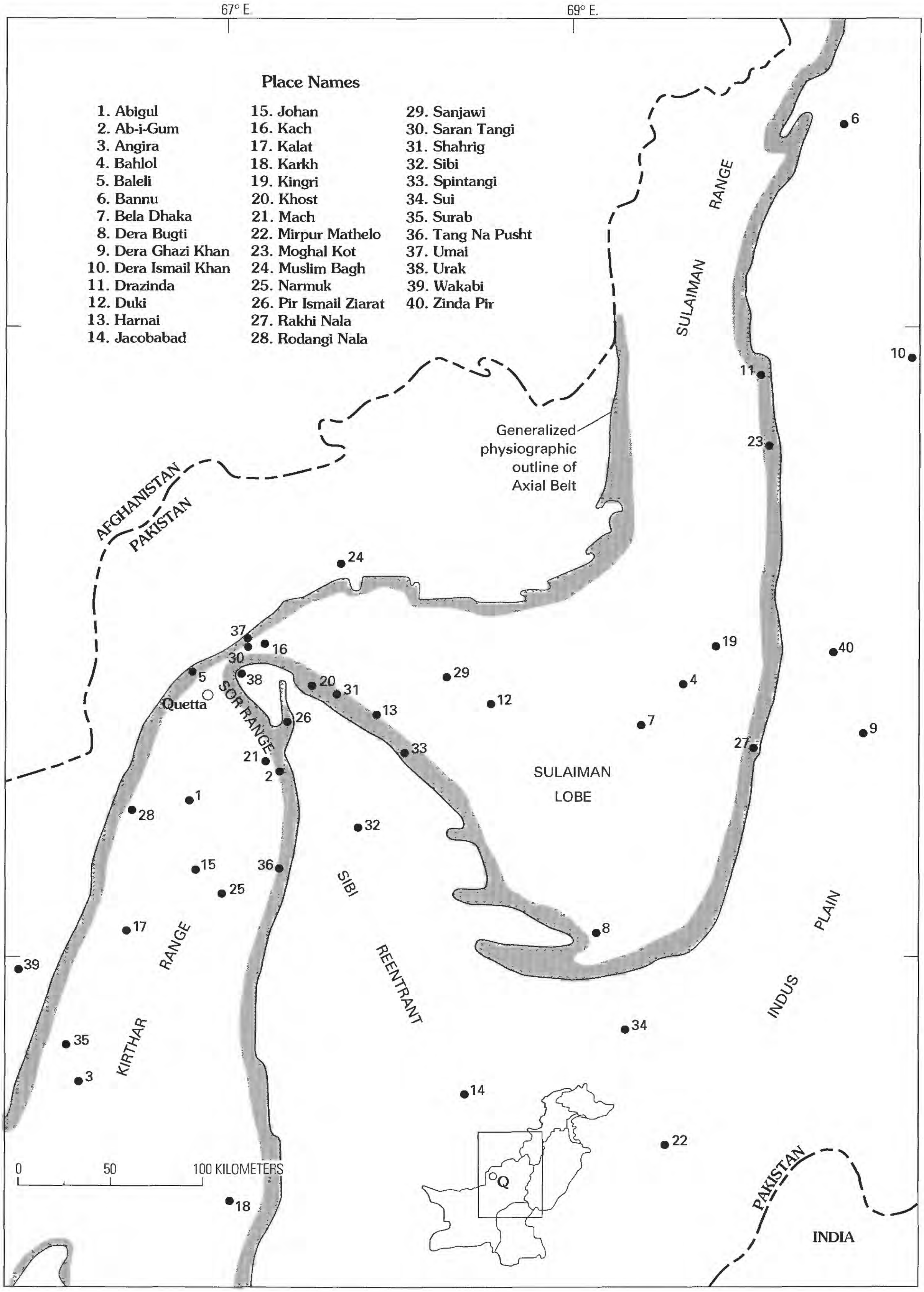


Figure 2. Map of north-central Pakistan showing major physiographic elements and Balochistan provincial capital of Quetta. Most place names mentioned in text are listed and positioned on map by number.

those officials in the Balochistan provincial government who made our field activities possible, and the U.S. Agency for International Development staff at Quetta, now disbanded, for their logistical support.

GEOLOGIC FRAMEWORK OF NORTHEASTERN BALOCHISTAN

Northeastern Balochistan is a land of arid plains, dry river beds, and abruptly uplifted mountain ranges. The lack of vegetation affords the observer a clear, unobstructed view of the structural and sedimentologic complexities of the geologic record contained in the rocks. We can scarcely overstate the high degree of tectonism the region has been subjected to. For example, overturned unconformities and folded thrust faults are not uncommon, and Zarghun Peak at 3,580 m, the highest elevation in Balochistan, contains folded Pleistocene conglomerate at its summit.

STRUCTURAL FEATURES

As shown in figure 2, a significant mountain belt occupies the central part of northeastern Balochistan. The northern segment of this belt is the Sulaiman Range, which seems to swing westward in the Sulaiman lobe, and continue south as the Kirthar Range. This mountain belt is part of a classic foreland fold-and-thrust belt caused by the ongoing collision of the Indian subcontinent with the Asian mainland (hereafter often referred to as simply the collision). That portion of the belt present in northeastern Balochistan thus represents a part of the southern extension of the Himalayan orogen. Hunting Survey Corporation (1960) referred to this feature in Balochistan as the Axial Belt, literally, a belt of axes. For simplicity of discussion, we will continue this usage. Powell (1979) reported that during the early Eocene, just after the initial collision, India apparently rotated about 9° counterclockwise, and this action might have set the stage for the north-northeast orientation of the belt in north-central Pakistan. The bend in the belt represented by the Sulaiman lobe represents a type of orocline, and this particular one is named the Quetta syntaxis. Powell (1979) also stated that since the early Eocene, India has rotated a total of about 29° counterclockwise. This continuing counterclockwise rotation is probably responsible for creating a complicated belt of regional, left-lateral shear in the area of north-central Pakistan, and the Quetta syntaxis might then be an expression of this transpression (see Abel-Gawad, 1971; Klootwijk and others, 1981; Farah and others, 1984).

Figure 3 is a simplified geologic map of the same area shown in figure 2. Fold axes (not shown on map) and the trends of fault traces generally follow the sigmoidal trend of the Axial Belt. The axial planes of folds are usually east vergent in the Sulaiman and Kirthar Ranges, and south vergent in the Sulaiman lobe. Many individual mountains within the belt are anticlinal in structure, and the fold axis in many of these cases is doubly plunging. It is common to observe steeply dipping strata adjacent to relatively undersized alluvial fans at the mountain-valley break in slope, indicating that the mountain had been domed in rapid fashion. Most of the faults in the Sulaiman and Kirthar Ranges are low-angle thrusts with fault planes dipping less than 45°. Some faults in the Sulaiman lobe are high-angle reverse types. Fault planes are vergent in the same directions as the folds. From the geometry of these compressional structures, it is apparent that tectonic transport is in directions away from the orogen (see Banks and Warburton, 1986). High-angle normal faults are rare and strike-slip faults are uncommon throughout the Axial Belt. For more details on the structural geology of northeastern Balochistan, consult maps by Bannert (1992) and Maldonado and others (1998).

The western swing of the Axial Belt in the Sulaiman lobe is only apparent. Actually, the feature is caused by that part of the belt being detached at depth, and gliding southward in response to the present oblique convergence of the Indian subcontinent and the Asian mainland. The lobe is composed of a series of arcuate compressional structures that represent a maximum of 378 km of crustal shortening since the beginning of the Miocene (Jadoon and others, 1990; Humayon and others, 1991; and Jadoon and others, 1994). A prominent left-lateral strike-slip fault on the east side of the lobe (fig. 3) trending north-northwest supports this model, but no corresponding fault has been mapped on the western margin of the lobe. However, Shahid H. Khan and Jan M. Mengel of the Geological Survey of Pakistan (oral commun., 1990) reported that subtle changes in structural trends on the western margin indicate tectonic movement that fits the model (see also Kazmi, 1979). The mechanism involved is thought to involve either (1) a single decollement at depth, perhaps moving within a layer of ductile Eocambrian salt separating higher rocks in the lobe from the crystalline basement, or (2) several relatively smaller thrusts moving within thick shale sequences of the Cretaceous Sembar Formation or the Ghazij Formation (fig. 4). The front of the lobe is tectonically active, as indicated by seismicity (Quittmeyer and others, 1979), but no frontal thrust has broken the surface. This same tectonic situation is apparently operating in the Salt Range in Punjab Province where the frontal thrust has come to the surface (Gee, 1989). However, in the Salt Range the cover rocks are known to be gliding across a thin layer of Eocambrian salt, and there is no hard evidence of this lithology in the Sulaiman lobe. For more detailed discussions of the mechanisms involved in the evolution of the lobe, consult Sarwar and DeJong (1979), Jadoon and others (1990), and Humayon and others (1991). In closing this short discussion of the compressional tectonics of the belt, we stress that, in general, the folding, faulting, and formation of the Quetta syntaxis have, since the Miocene, all occurred simultaneously.

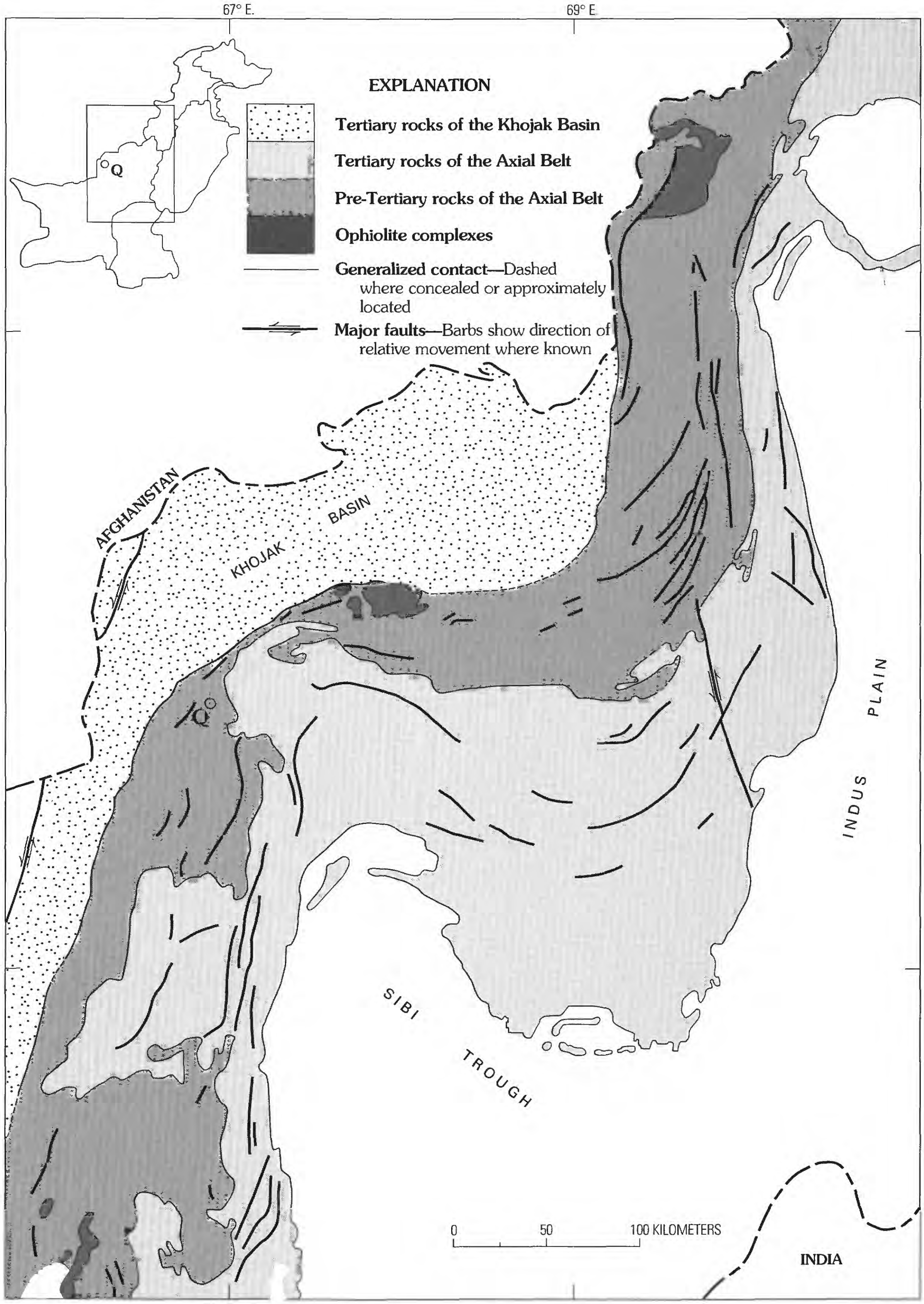


Figure 3. Simplified geologic map of northeastern Balochistan. Q, Quetta. Modified from Bakr and Jackson (1964) and Kazmi and Rana (1982). Fold axes are not shown.

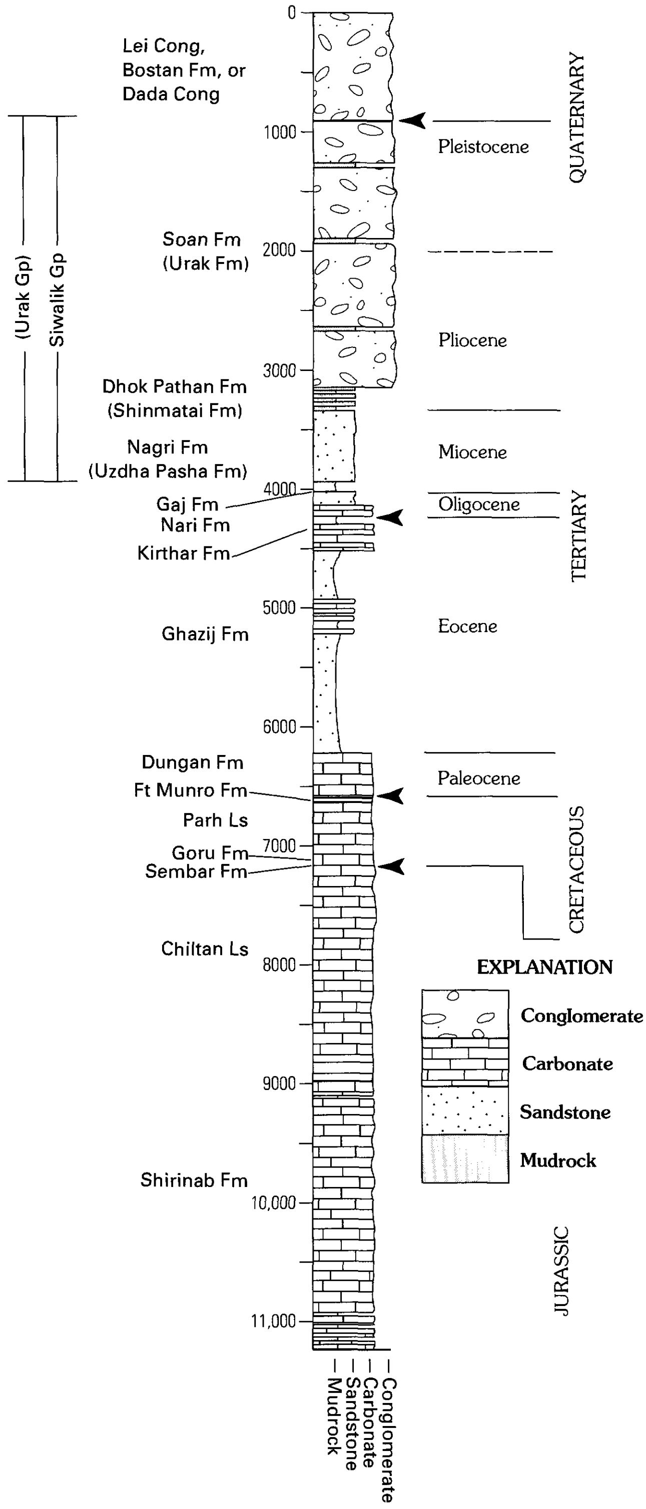


Figure 4. Generalized stratigraphic section of exposed Phanerozoic rocks in the Quetta area. Arrowheads on right side of column represent positions of major unconformities; dashed line, approximate boundary separating Pliocene and Pleistocene. Names in parentheses associated with the Siwalik Group are more applicable in middle and southern parts of study area. Gp, Group; Fm, Formation; Ls, Limestone; Cong, Conglomerate. Compiled from Hunting Survey Corporation (1960) and Shah (1977). Thickness, in meters, indicated to left of section.

The geologic boundary separating the Axial Belt from the Khojak Basin (fig. 3) is significant. Ophiolitic complexes consisting of basic and ultrabasic igneous rocks, and tectonic melanges containing ocean-floor sedimentary rocks such as radiolarian chert and pelagic limestone, along with various thrust faults and unconformities, form a discontinuous zone several tens of kilometers wide. The ophiolitic rocks on the east side of the zone indicate that the boundary represents a suture zone, and that the sedimentary deposits in the Khojak Basin are actually affiliated with another geologic terrain.

The northeast-trending fault shown on the westernmost edge of the area of figure 3 is a segment of the Chaman transform fault. This left-lateral strike-slip fault connects the northern Himalayan convergence zone to the north with the Makran convergence zone to the south. Lawrence and Yeats (1979) stated that this intracratonic plate boundary is as wide as 1 km and can be traced for over 800 km; total displacement is at least 155 km.

AREAL DISTRIBUTION OF SEDIMENTARY ROCKS

Almost all of the rocks exposed in northeastern Balochistan are sedimentary. Very small amounts of ultramafic intrusive rocks are present in relatively small ophiolite complexes (fig. 3), and basaltic volcanic rocks are present but rare in certain Cretaceous carbonate sequences. In figure 3 one can see that, in general, the eastern portion of the Axial Belt contains younger rocks than the western portion. This pattern results from tectonism associated with the ongoing Himalayan orogeny, which is migrating eastward with time; compressional structures in the western portion of the belt have been affected by tectonism for a longer period of time, thus allowing deeper parts of the crust to be uplifted and exposed by erosion. Seismicity associated with this ongoing tectonism is well documented. All of the Mesozoic and lower Cenozoic sedimentary rocks in the Axial Belt are contained in the Calcareous zone of Hunting Survey Corporation (1960). West of the Axial Belt, the Khojak Basin contains Paleogene flysch deposits (Jadoon and others, 1990) that are depositionally unassociated with any deposits in the Axial Belt. These rocks are contained in the Arenaceous zone of Hunting Survey Corporation (1960). To the east of the Axial Belt, strata plunge under the Indus Plain, and the same sequence of rocks observed in the mountain ranges can be identified in drill holes. Southeast of Quetta in the Sibi Reentrant (fig. 2) is a thick wedge of mostly Neogene clastic rocks that attains a thickness of perhaps as much as 8,500 m (Movshovitch and Malik, 1965). This molasse basin, referred to as the Sibi trough (fig. 3), might be a northwestern extension of the northwest-trending Cambay graben in India, which contains as much as 5,000 m of similar rocks, as suggested by Auden (1974).

VERTICAL DISTRIBUTION OF SEDIMENTARY ROCKS

Despite the significant tectonism, rocks older than Permian are not exposed in northeastern Balochistan. Moreover, Permian and Triassic rocks are themselves volumetrically insignificant, making Jurassic rocks the essential base of the exposed sedimentary pile. Sedimentary rocks exposed in this region amount to more than 11,000 m (fig. 4), and this sequence can be divided into three parts based on general lithology. The lower part consists of 5,000 m of marine carbonate that was deposited prior to the collision. Except for the Paleocene strata at the top of this interval, these rocks are generally exposed along the west side of the Axial Belt (fig. 3). The middle part comprises 3,000 m of mostly mudrock and lesser amounts of sandstone and carbonate that were deposited during or just after the initial collision. The Ghazij Formation occupies the lower half of this interval. The upper part of the sequence consists of 3,000 m of conglomerate deposited in response to radical uplift associated with the Himalayan orogeny. Rocks of both the middle and upper parts of the sequence are generally exposed along the east side of the Axial Belt, and within the Sibi trough (fig. 3). Significant unconformities in the exposed section are present between Jurassic and Cretaceous strata, Cretaceous and Paleocene strata, Eocene and Oligocene strata, and separating Pleistocene conglomerate of the Siwalik Group from younger conglomerates (fig. 4).

PRE-GHAZIJ GEOLOGIC HISTORY

Nowhere is the history of the Ghazij Formation adequately described in a single publication. Rather, it is scattered about as small bits and pieces in numerous publications, either stated or implied, and in the heads of many geologists. Because of the incredible amount of tectonism this region has been subjected to, one never knows how much structural rotation and (or) transport has affected the rocks studied. This is especially true of rocks in the Sulaiman lobe. Because of this fact, assigning compass directions for source areas and paleoslopes is an educated guess, at best.

PRE-GHAZIJ PLATE TECTONICS

The geologic history of this region cannot be told without first describing the significant role that plate tectonics has played. At about 130 Ma, during the Early Cretaceous, the Indian subcontinent separated from Gondwana (Scotese and others, 1988), and proceeded northward toward the Asian mainland. Oceanic crust at the leading edge of the Indian plate was probably subducted either (1) beneath oceanic crust positioned in front of the Asian mainland with an associated island arc, or (2) directly under the continental crust of the Asian mainland. From about 130 to 80 Ma (Early Cretaceous to Late Cretaceous) the Indian subcontinent continued to move northward at a rate of 3–5 cm/yr (Powell, 1979) as the southern Tethys Sea began to close. From 80 to 53 Ma (Late Cretaceous to early Eocene) the Indian subcontinent's progress accelerated to perhaps 20 cm/yr (Powell, 1979). Sometime during Late Cretaceous to Paleocene time, the leading edge of the marine shelf that was positioned off the Indian subcontinent approached the subduction zone, and sea-floor material in the form of submarine volcanic rocks and deep-water sediments were obducted onto carbonate-platform deposits (McCormick, 1989). Many workers (Powell, 1979; Besse and others, 1984; Patriat and Achache, 1984; Searle and others, 1987; Scotese and others, 1988; Ricou, 1994) have placed the initial collision between 55 and 50 Ma (early Eocene). Klootwijk and Peirce (1979) placed the event generally within this range based on polar wandering paths, and Powell (1979) reported that the rate of northward movement of the Indian subcontinent decreased to 4–6 cm/yr at about 53 Ma, which fits this timing. Evidence from the Ghazij Formation contained in our report favors 55 Ma for the initial collision. The initial collision was probably between the Indian subcontinent and a terrestrial fragment, such as a microcontinent or island arc, positioned just off the Asian mainland (see Powell, 1979; Klootwijk and others, 1981; Waheed and Wells, 1990; Bannert and others, 1992; Kemal and others, 1992). A variation of this scenario was proposed by Garanti and others (1996). These workers proposed that the initial collision was with the leading edge of the Asian mainland. In either case, it was probably during this time that the northward subduction of oceanic crust ceased, and what remained of the southern Tethys Sea closed. An important question is, "What became of the terrestrial fragment?" Perhaps the eastern part of this mysterious terrain lies under the Eocene to Miocene flysch deposits of the Khojak Basin, and the west side of the terrain was transported out of the region by the Chaman fault. (See Wells, 1984; Waheed and Wells, 1990.)

PRE-GHAZIJ DEPOSITION

A shallow-marine shelf supporting a carbonate platform existed along a portion of coastal Gondwana from at least the Permian, and when the Indian subcontinent separated from the supercontinent in the Early Cretaceous, this environment accompanied the subcontinent northward. As the Indian plate proceeded north during the remainder of Cretaceous and Paleocene time, this carbonate platform continued to accumulate carbonate sediments on the passive continental margin of the Indian subcontinent. Toward the north lay the open ocean of the southern Tethys Sea and toward the south lay the nonmarine environments of the subcontinent (fig. 5). It was on this platform that the pre- and post-rift, Jurassic through Paleocene carbonates that dominate the lower part of the stratigraphic column (fig. 4) were deposited. Of volumetric importance in the Quetta area are the Jurassic Shirinab Formation and Chiltan Limestone, the Cretaceous Parh Limestone, and the Paleocene Dungan Formation. This sequence also contains some limited amounts of clastic rocks such as the mudrock in the Cretaceous Sembar Formation and the sandstone in the Cretaceous Pab Sandstone (a unit at the top of the Cretaceous strata that is present in some areas of the Sulaiman and Kirthar Ranges; not shown in fig. 4). According to Kemal and others (1992), the carbonate rocks were deposited during long periods of marine highstand, and the clastic rocks were deposited during periods of marine lowstand. Two significant periods of erosion, or nondeposition, are evident in this sequence: one between Jurassic and Cretaceous strata, and another between Cretaceous and Paleocene strata (fig. 4). These two surfaces define a major transgressive-regressive event during the Cretaceous that culminated locally with the progradational Pab Sandstone. Another period of erosion is indicated by the local presence of an unconformity between Paleocene and Eocene strata. The presence of this surface indicates that another transgressive-regressive event probably occurred during the Paleocene.

In the southern part of the Kirthar Range, volcanic material is present in association with post-rift carbonate rocks. This thick sequence, known as the Bela Volcanic Group, contains basaltic pillow lava, tuff, and agglomerate interbedded with mudrock, carbonate, conglomerate, and radiolarian chert (Hunting Survey Corporation, 1960). Auden (1974) reported the rocks to be Early to middle Cretaceous in age, and therefore older than the latest Cretaceous to earliest Paleocene Deccan Basalt of India and southern Pakistan. The history of the Bela volcanics is poorly understood, but they might have been emplaced when the carbonate platform passed over a hot spot in the mantle as the Indian plate moved northward. McCormick (1989) supported this idea, and referred to the rocks as within-plate alkali basalts associated with volcanic islands.

Any clastic material entering the pre- and post-rift depositional system probably did so from the south, southeast, or east. Waheed and Wells (1990) reported that paleocurrent data from the Pab Sandstone in the southern part of the Sulaiman Range indicate paleoflow toward the northwest, and in the northern part of the range, toward the southwest. Moreover, they reported that these same sandstones are quartz arenites, which might have been derived from exposed Precambrian shield rocks on the Indian subcontinent. Meissner and Rahman (1973) studied Paleocene rocks from exposures in the Axial Belt and from information obtained from drill holes under the Indus Plain. They reported that Paleocene rocks contain more sandstone toward the east, suggesting a clastic source in that direction.

Toward the southeast and east, the thick sequence of pre-Ghazij Formation carbonates apparently thins, and the

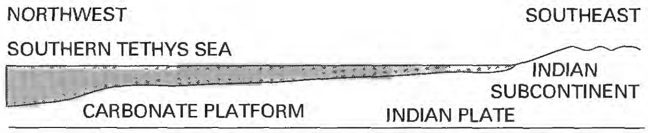


Figure 5. Schematic cross section of post-rift, pre-collision passive margin of the Indian subcontinent. No scale implied.

rocks in the sequence were probably deposited in shallower water settings in these directions. In discussing the more than 8,000 m of Mesozoic rocks in the Sulaiman Range, Humayon and others (1991) reported that the carbonates were deposited in relatively shallow water, and at least some of the mudrocks were deposited in deeper water. They went on to report that toward the east on the east side of the Indus Plain, information from a drill hole documents that these same Mesozoic rocks have thinned to 750 m, and evidence from this hole suggests that some of the sandstones and mudrocks contained in the sequence were deposited in a nearshore setting. The eastward thinning of the pre-Ghazij carbonates is also supported by Kemal and others (1992). Meissner and Rahman (1973) reported that carbonates in the Paleocene deposits increase toward the west, indicating deeper water conditions in that direction. In addition, toward the southeast in Sindh Province, Paleocene strata include fluvial deposits and a considerable amount of coal. Sediments now contained in these units might well have prograded in a westerly direction, to be deposited on the northwest edge of the Indian subcontinent. (See also Sahni and Kumar, 1974.)

EARLY EOCENE DEPOSITIONAL SETTING

Sometime just before or just after the beginning of the Eocene, the depositional setting in what is now northeastern Balochistan changed dramatically. As discussed previously, apparently the leading edge of the marine shelf that extended off the Indian subcontinent came in contact with some type of terrestrial fragment that was close to, but separated from, the Asian mainland. The compass direction of the long axes of these physiographic elements might never be known with any certainty, but we favor a simple northeast trend as a first approximation. As a result of tectonism associated with this event, a topographically positive area developed just northwest of the main part of the marine shelf. This uplifted area consisted of carbonate-platform deposits that had accumulated on the distal part of the platform. This feature was referred to by Hunting Survey Corporation (1960) as the Central and Las Bela geanticlines. Thus for the first time, a northwestern source area for clastic sediments was created, and the depositional slope changed from northwest facing to southeast facing (fig. 6 *A*). Evidence supporting this paleogeography is presented herein.

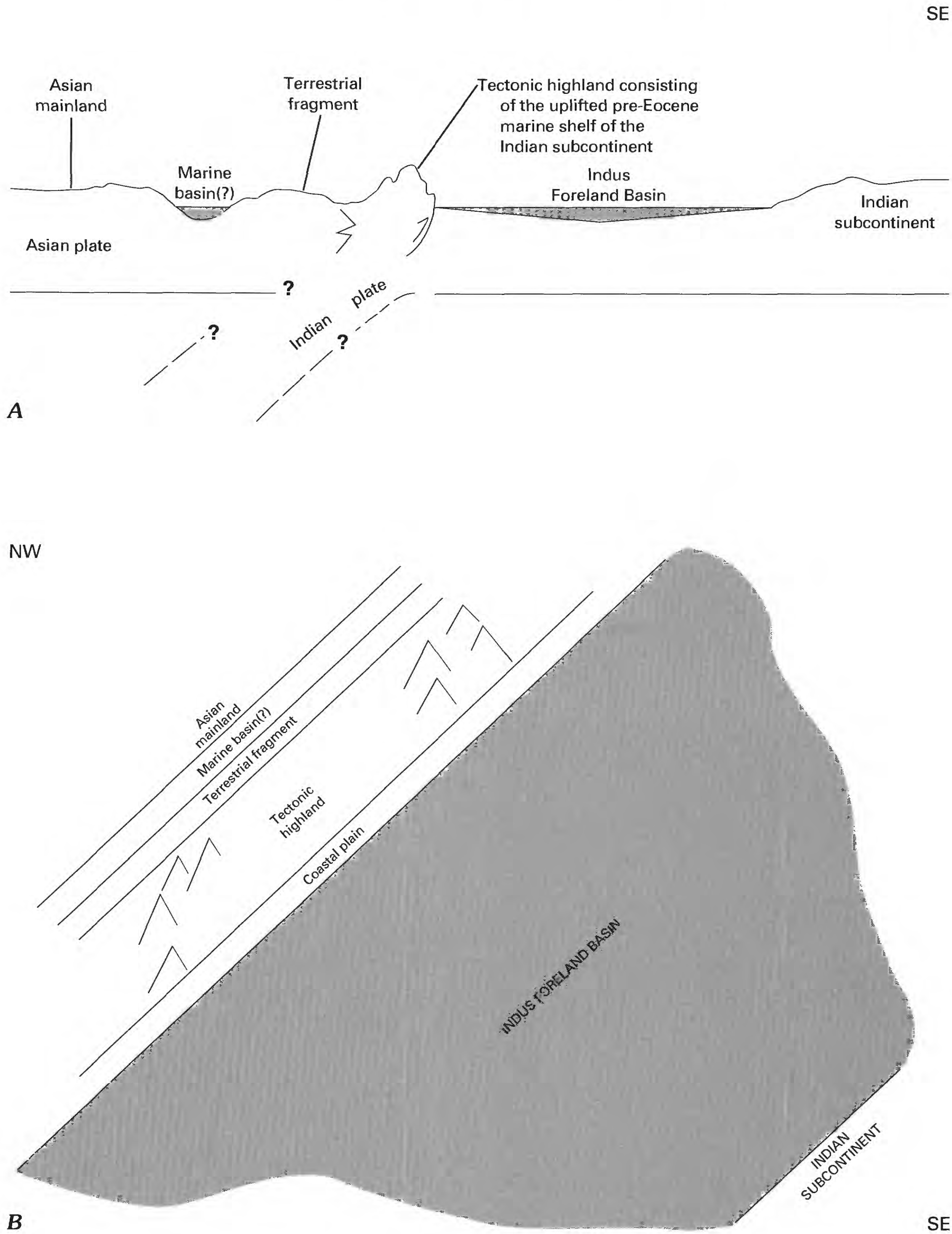


Figure 6. Conditions just after the initial collision of Indian subcontinent and Asian mainland. *A*, Schematic cross section. *B*, Generalized plan view of physiographic elements of area depicted in *A*. No scale implied.

The sudden presence of elevated topography northwest of the main part of the marine shelf created a generally northeast trending foreland basin with a tectonic highland to the northwest and the exposed Indian craton to the southeast. Thus, the embryonic Indus Foreland Basin was formed. The relatively shallow intracratonic sea that occupied the basin was undoubtedly somewhat connected with the open seaway, at least toward the south. During early Eocene, the Ghazij Formation was deposited on the west side of the basin. The lower part of the Ghazij was probably deposited offshore, but the middle and upper parts of the formation were apparently deposited higher on the depositional slope, near the shoreline and on the coastal plain, respectively (fig. 6*B*).

Lower Eocene deposits in Sindh Province are mostly marine carbonates suggesting that the pre-Eocene carbonate platform persisted on the east side of the basin. Clastic material interbedded with the carbonates in this area was probably derived from the east off the Indian shield.

The Indus Foreland Basin was divided by the northwest-trending Sargodha high into a northern part and a southern part. An isopach map (fig. 7) of Eocene deposits in south-central Pakistan shows that basin-floor irregularities existed. Of particular importance is the northwest-trending Jacobabad high that separated the southern part of the basin into two subbasins now known as the Kirthar and Sulaiman provinces. The Ghazij was deposited in both of these provinces. Small ephemeral irregularities north of the Jacobabad high might have resulted in areas of restricted marine circulation, which could explain the presence of rare evaporites in the upper part of the Ghazij in the southern Sulaiman Range.

According to Powell (1979), India has migrated from about lat 30° S. to about lat 30° N. since the Late Cretaceous. Powell further calculated that during the formation of Pakistan's Paleocene and Eocene coal deposits, the region was approximately at the equator. Klootwijk and others (1981) placed this region slightly north of this position.

LOWER EOCENE SEDIMENTARY ROCKS

Lower Eocene sedimentary rocks in north-central Pakistan are contained within the Ghazij Formation. The Ghazij is intermittently exposed throughout the Axial Belt (fig. 8) from the vicinity of Bannu 440 km northeast of Quetta in the northern Sulaiman Range, to the vicinity of Karkh about 350 km south of Quetta in the central Kirthar Range. North of Bannu, lower Eocene strata are included in other formations, and south of Karkh the formation is no longer recognized, probably because of a facies change. In the Quetta region, exposures of the formation are limited on the west by a significant north-trending fault, the Ghazaband fault (Bannert, 1992). East of the Axial Belt, the formation is recognized in the subsurface of the Indus Plain as far east as Mirpur Mathelo (fig. 2), 340 km southeast of Quetta.

Regionally, the Ghazij Formation is mainly an argillaceous deposit that contains increasing amounts of sandstone toward the west, and increasing amounts of carbonate toward the east. Based on this generality, Hunting Survey Corporation (1960) divided the Ghazij into two major lithologic groups: the complex assemblage on the west and the simple assemblage on the east. These workers also subdivided the complex assemblage into lower, middle, and upper zones (parts).

The Ghazij Formation comprises a crudely shaped clastic wedge that, in general, thins toward the east. Hunting Survey Corporation (1960) reported the thickness of the Ghazij to range from 305 to 3,353 m, and Shah (1977) reported the range to be from 160 to 3,330 m. These differences in thickness range are difficult to interpret. They might reflect differential subsidence in the depositional basin, or they might simply be the measurements of incomplete stratigraphic sections. Complete sections of the formation are rarely exposed, and because of compressional tectonics and the great amount of soft mudrock in the formation, thickness measurements of even so-called complete sections are questionable. Williams (1959) reported the Ghazij to be almost 600 m thick at its type locality near Spintangi, about 110 km southeast of Quetta.

HISTORY OF STRATIGRAPHIC NOMENCLATURE

The first mention of the term Ghazij was by R.D. Oldham (Oldham, 1890a). In a short note, he first mentioned that at least 600 m of shale overlies the "Dungan limestone" just northwest of Spintangi (about 110 km southeast of Quetta). Later in the same note, he described an anticlinal structure in the Kipar Valley where "Ghazij shales" are exposed. His accompanying sketch map shows this structure on the north side of the northwest-trending Kipar Valley, 11 km southeast of Spintangi, and "Ghazij Group," as listed in his index (explanation), is shown exposed in the core. Ghazij N., a northwest-flowing tributary to Kipar Valley, is shown on his sketch map just north of the anticline. Later in that year, Oldham more closely defined his usage of the term Ghazij in a slightly longer note (Oldham, 1890b). In this note, Oldham described the "Ghazij group" as a great thickness of gray and olive-green shale with subsidiary beds of lime (sic), sandstone, and, locally, coal, all sandwiched between the "Dungan limestone" and the "Spintangi group." He stated that the unit is named after the valley that runs down from near Dungan Mountain to Spintangi. Maps of this area show this drainage as either Ghazij Nala or Ghazij Rud.

In the Kirthar Range, Vredenburg (1909) described a shaly sequence underlying the upper and middle "Kirthar

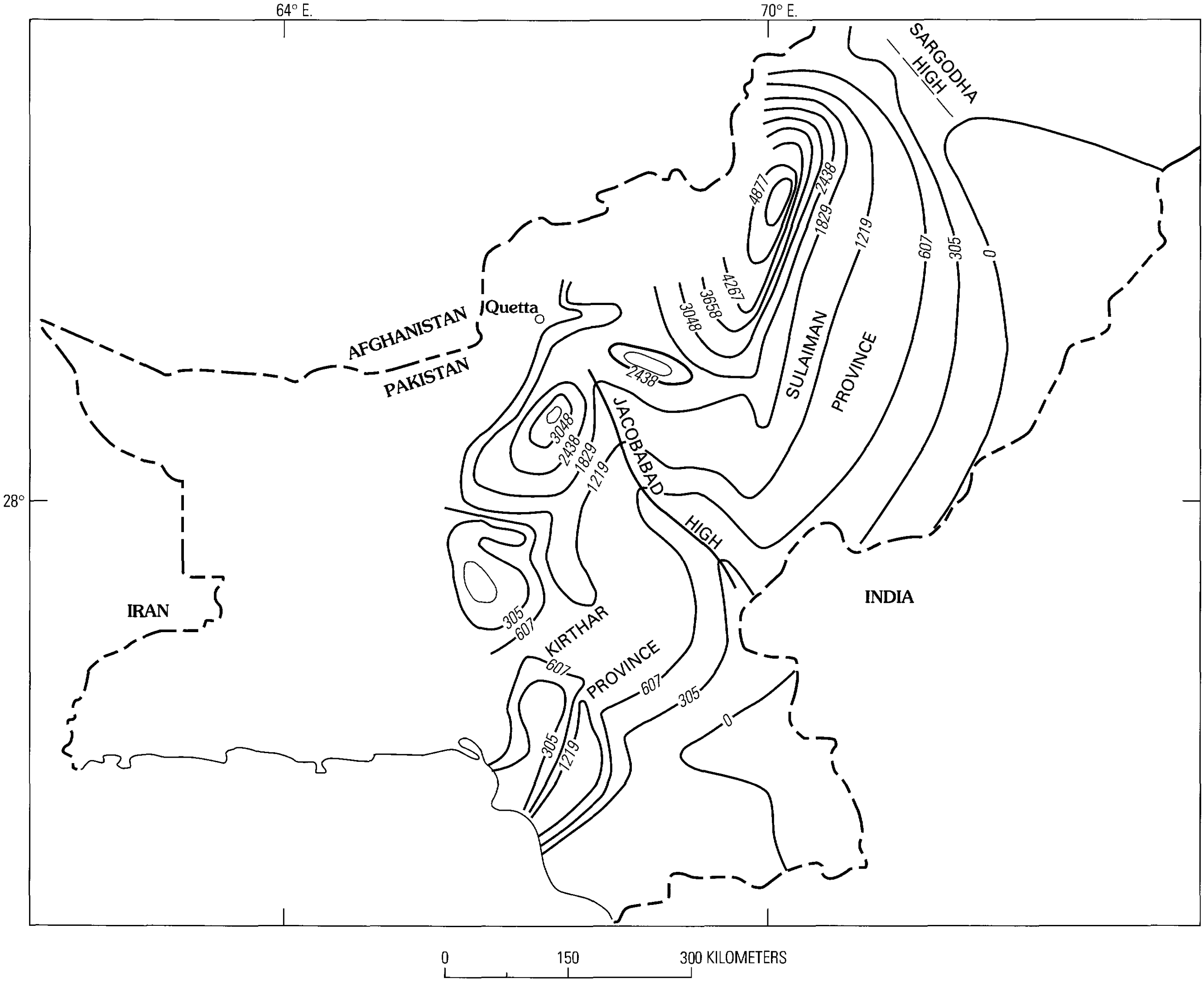


Figure 7. Isopach map of total Eocene deposits in south-central Pakistan. Axis of Sargodha high approximate. Contours in meters. Modified from Ahmad (1982).

limestone," and he divided the sequence into "lower Kirthar shales" in the upper part and "Ghazij beds" in the lower part. Eames (1952a) and Nagappa (1959) presented detailed nomenclature for lower Eocene rocks in the Sulaiman Range that included and limited the term "Ghazij Shales." Williams (1959) was the first to use the word "formation" in association with the Ghazij. Following Oldham's work, he redescribed the unit as the Ghazij Formation and redesignated Spintangi as the type locality. Hunting Survey Corporation (1960) preferred the term "Ghazij Shale," and included in the unit the "lower Kirthar shales" of Vredenburg (1909). Shah (1977) and Iqbal and Shah (1980) returned to the term Ghazij Formation and tightened the definition of the formation by accounting for the terms introduced by Eames (1952a), Nagappa (1959), and Hunting Survey Corporation (1960).

PRINCIPAL REFERENCE SECTIONS

During the course of our study, we measured and described in detail five stratigraphic sections of the Ghazij Formation in four widely spaced areas to serve as stratigraphic anchor points: one in the Sor Range, one near Pir Ismail Ziarat, two in the vicinity of Mach, and one near Johan (fig. 9). The first three of these four areas are the sites of ongoing coal mining activity, and the fourth area has the potential, although low, for such activity. Measuring sections of the Ghazij can be quite difficult. Because of the high percentage of mudrock in the formation, the unit commonly forms valleys where the rocks are poorly exposed. Moreover, faults and the axial planes of folds are often parallel to bedding, making their presence difficult to detect. Therefore, in each of these areas, we selected exposures where the

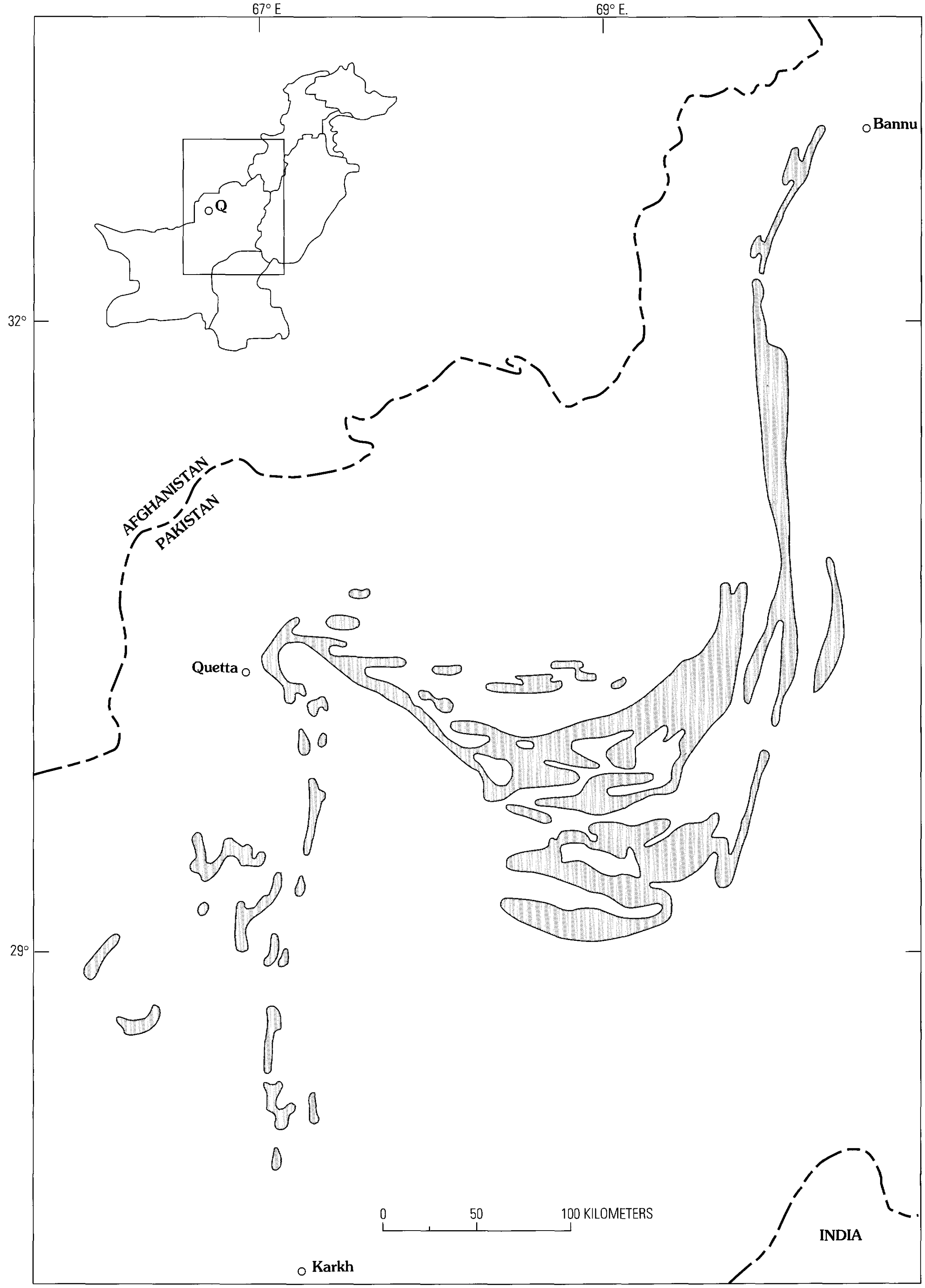


Figure 8. Large exposures of the Ghazij Formation (patterned) in north-central Pakistan. Modified from Bakr and Jackson (1964).

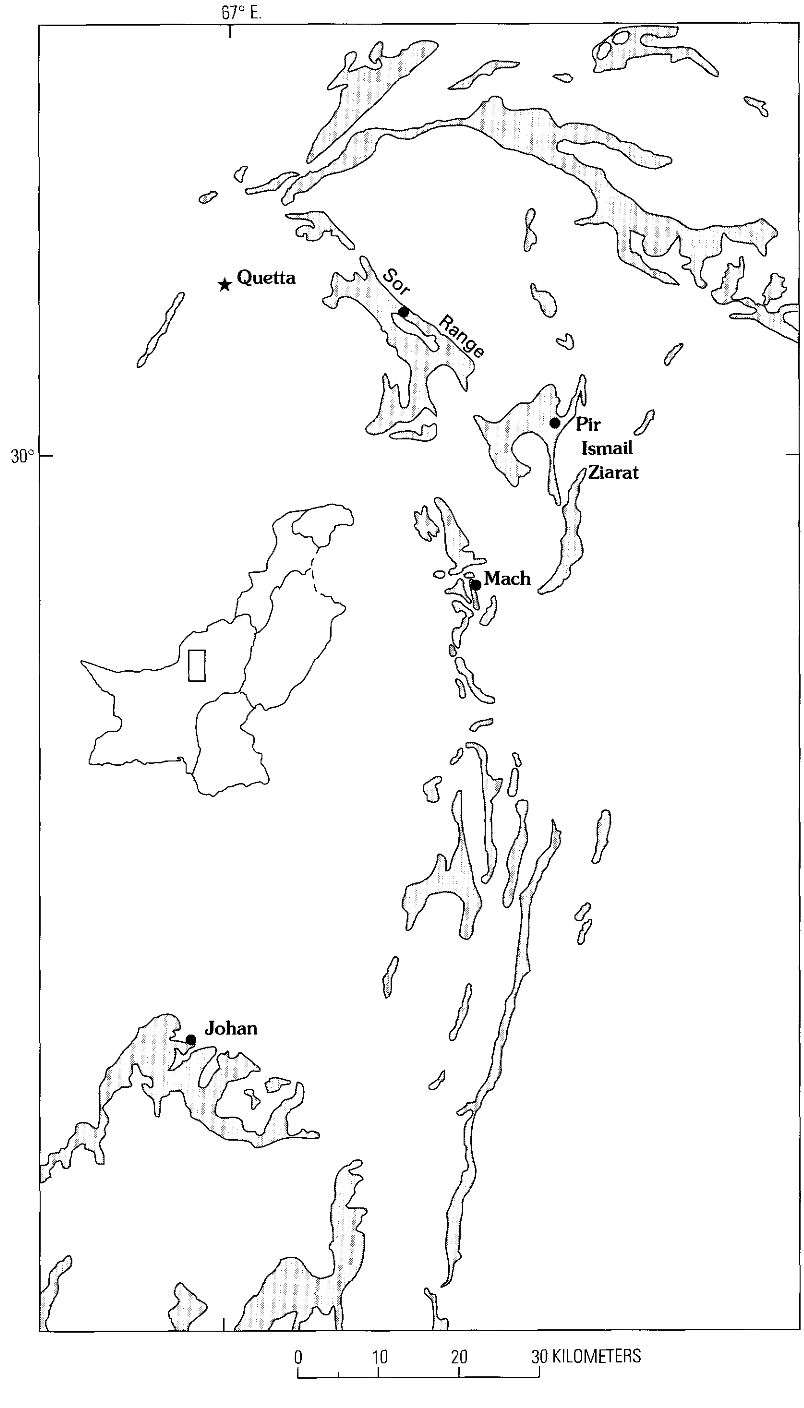


Figure 9. Exposures of Ghazij Formation (patterned) and sites of principal reference sections. Modified from Hunting Survey Corporation (1960).

most complete section could be measured, and where the strata seemed relatively undeformed. It is from these five sections that much of our understanding of the Ghazij stems. Plate 1 shows small-scale versions of these five sections. On this plate, in some of the figures, and in the text, we often use the term mudrock, which as defined by Lundegard and Samuels (1980) includes siltstone, shale, mudstone, and claystone. Each of our five sections has been published separately at a much larger scale as a U.S. Geological Survey Miscellaneous Field Studies Map, and the reader is encouraged to consult these publications for a more detailed display of the sections. In addition to these reference sections, numerous shorter sections and outcrop observations are discussed in this report.

SHIN GHWAZHA MINE

The Shin Ghwazha mine section was measured near an active coal mine of the same name located in the central part of the Sor Range coal field, about 20 km east of Quetta. This coal field is the most active of the four fields we visited. The 483 m of strata in our section dip southwest, and make up part of the northeastern limb of a regional, doubly plunging syncline. All of the upper and middle parts of the Ghazij Formation were measured, but only a few meters of the lower part were measured. See Johnson and Khan, 1994a.

ABRAHAM MARRI MINE

We measured the Abraham Marri mine section about 2 km northwest of the village of Pir Ismail Ziarat near an active coal mine of the same name. The Pir Ismail Ziarat coal field, located about 45 km southeast of Quetta, is the most recently developed of the four fields we visited. Strata in this section dip northeast. The section totals 536 m, and contains portions of the lower and upper parts of the Ghazij, and all of the middle part. See Johnson and Khan, 1994b.

GISHTARI NALA

The Gishtari Nala section was measured about 2.9 km west-southwest of the town of Mach. Coal mining in the Mach area, 48 km southeast of Quetta, predates mining in all of the other areas visited. Our section contains 385 m of northeast-dipping strata. Portions of the middle and upper parts of the Ghazij were measured. See Warwick and others, 1994.

MOGHAL MINE

The Moghal mine section was measured about 2.9 km south of Mach near an active coal mine of the same name. Rocks in this 463-m thick section dip northeast. Portions of the middle and upper parts of the Ghazij were measured. See Johnson, Warwick, Khan, and Kazim, 1994.

SARAWAN RIVER

Our farthest south section, Sarawan River, was measured on the south side of the river of the same name, several kilometers west of the village of Johan, 93 km south of Quetta. Coal mining in the Johan area has been small scale and unprofitable, and at the time of our visit no mining activity was apparent. This southeast-dipping, 674 m of strata is our thickest section. All of the upper part of the Ghazij, and a portion of the main body of the formation were measured. See Johnson, Warwick, Khan, and others, 1994.

VERTICAL SUBDIVISIONS AND LITHOFACIES OF THE GHAZIJ FORMATION

In the Sulaiman lobe and northern Kirthar Range, the Ghazij Formation can be easily divided into three parts: lower, middle, and upper (fig. 10). In general, the lower part (more than 1,000 m thick) consists of greenish-gray mudrock with uncommon isolated sandstone bodies. The middle part (about 30–300 m thick) consists of gray mudrock with subordinate sandstone bodies, and locally present carbonaceous shale, coal, and limestone. The upper part (as thick as 533 m) consists of multicolored mudrock with uncommon isolated sandstone bodies, and locally, a conglomerate unit at the base. In most places the lower part of the formation is the thickest followed by the upper part and then the middle part. Hunting Survey Corporation (1960) recognized these three natural subdivisions but referred to them as zones. Basically, the Ghazij is a regressive unit going from marine in the lower part, to paralic in the middle part, to nonmarine in most of the upper part. Officially, these three parts of the formation have never been designated as members, but we believe that their regional predictability qualifies them for formal recognition.

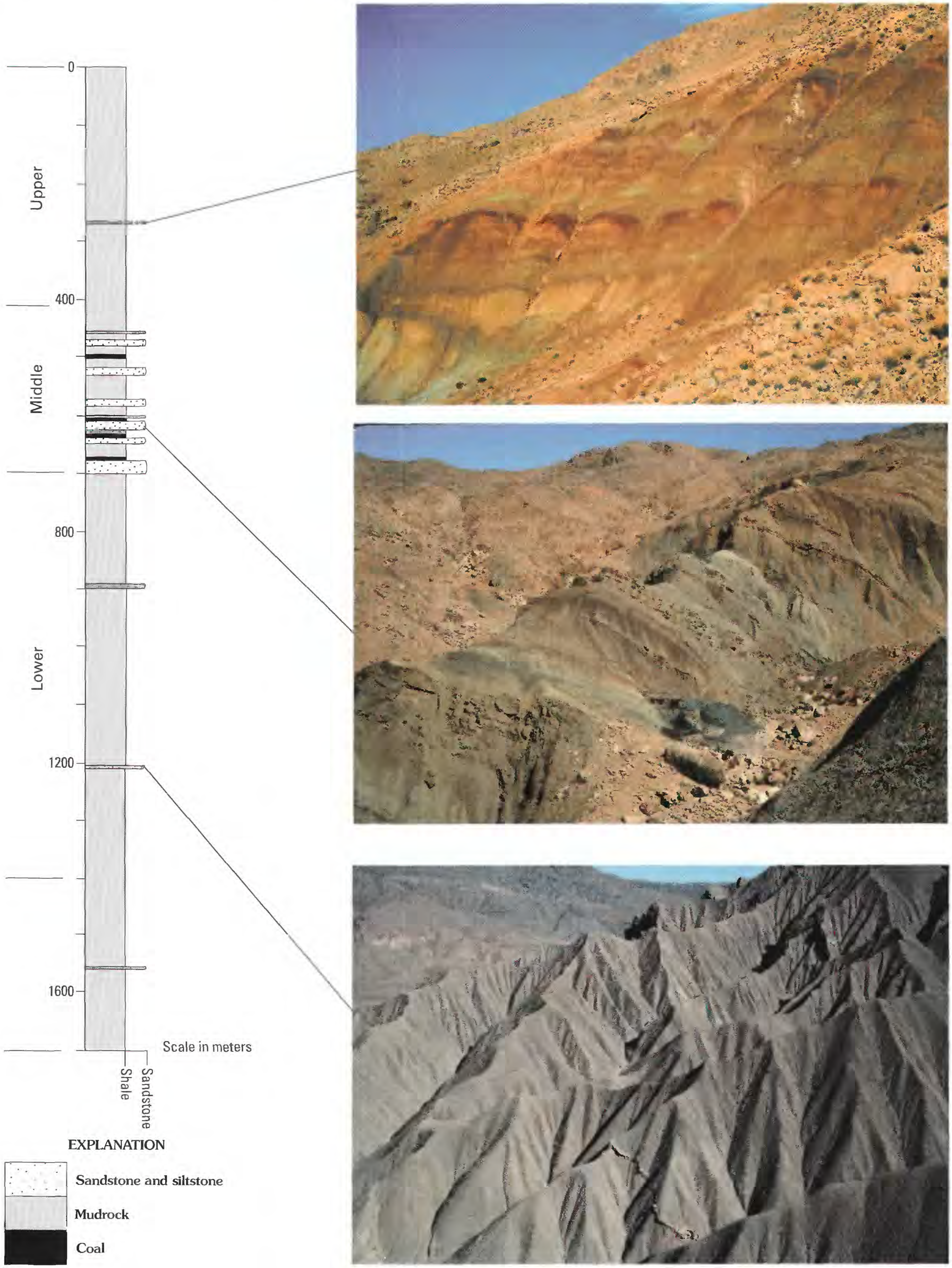
LOWER MUDDY MARINE PART

The lower part of the Ghazij Formation is the thickest subdivision of the formation. According to Hunting Survey Corporation (1960), this part of the Ghazij ranges in thickness from 914 m near Duki to 2,134 m near Johan. The lower part is not exposed in its entirety at any of our measured section localities, but 166 m is included in the lower part of our Abraham Marri mine section (pl. 1*B*), and a minimum of 1,000 m was measured, but not included in, our Shin Ghwazha mine section. The lower part of the formation is particularly susceptible to regional compressional tectonics, and as a result, bedding-plane faults and isoclinal folds are very common and difficult to detect. In general, the lower part consists of a thick sequence of mudrock with a few isolated sandstone bodies (fig. 10).

LITHOFACIES

MUDROCK

The mudrock in the lower part of the Ghazij Formation consists mostly of calcareous mudstone and shale. Some mudrock is sandy, and very fine grained sandstone is present as laminae or, locally, in very thin beds in the mudrock. Both fresh and weathered surfaces are medium to light gray. Bedding planes and joint surfaces are often stained very dark


0
400
800
1200
1600
Upper
Middle
Lower
Scale in meters
Shale
Sandstone
EXPLANATION
Sandstone and siltstone
Mudrock
Coal

gray, probably by films of carbonaceous material or manganese-bearing minerals. From a distance, this part of the Ghazij in many places appears to have a green tinge. Fossil plant debris is common as isolated fragments or concentrated on lamina surfaces. Coaly carbonaceous material is very rare as very thin laminae; however, one lamina several millimeters thick was observed in the Sor Range. Body fossils were not observed. Ahmed and others (1985) X-rayed samples of this mudrock collected near Chappar Rift, about 16 km northwest of Khost. They reported that clays from the rocks consist of 50–60 percent illite, 26 percent mixed layered, and 14 percent magnesium-rich chlorite. Samples of the mudrock were collected at three locations and analyzed for Rock-Eval pyrolysis to determine the characteristics of the hydrocarbon content and source-rock potential. Two of the locations are in the Sor Range, one below our Shin Ghwazha mine section and the other near Sinjidi several kilometers southeast of our section, and the third is in the Pir Ismail Ziarat area. At each site, we collected a sample from the lower, middle, and upper thirds of the sequence. The results of these analyses appear in table 1. Because of the low total organic carbon values (< 0.50 weight percent), the lower part of the formation is not a very likely source rock for hydrocarbons. Moreover, the low total organic carbon values of all of the samples make the other Rock-Eval indices unreliable, and this precludes using these data for interpreting source-rock quality and depositional environments.

SANDSTONE

Sandstone is a relatively rare lithology in the lower part of the Ghazij Formation. This lithology is present in either laterally extensive, single-bedded tabular bodies, mostly less than 0.5 m thick, or as larger, very broad lenticular bodies, mostly less than 2.5 m thick. The rocks are calcareous and mostly very fine to fine grained; medium-grained sandstone is present locally in the Sor Range. In most cases, grain size is evenly distributed within the bodies, but coarsening-upward or, less frequently, fining-upward bodies of the larger type are known (see pl. 1*B*). Fresh surfaces are light gray; weathered surfaces are mostly light brown to light orangish brown. From a distance, some of these rocks appear green tinged. The sandstones consist primarily of subangular to subrounded grains of light-colored carbonate rock fragments and lesser amounts of green lithic fragments. Mudrock chips, as impressions or actual fragments, are also common. Fossil plant debris is abundant, but whole leaf or stem impressions are extremely rare. Vertical and horizontal fossil burrows, most about pencil size in diameter, are common. Almost all are simple in structure, but in some very rare cases, larger burrows are pellet packed and resemble *Ophiomorpha*. Body fossils were not observed. The thin, single-bedded tabular bodies are usually structureless or parallel laminated, and both the upper and lower contacts are sharp; sole marks are common on basal surfaces. The larger bodies have sharp bases, commonly exhibiting sole marks or subtle erosional relief, and the upper contacts are sharp, or less frequently, gradational. Bedding is mostly very thin to thin, but medium to thick bedding is present, locally. Upper and lower surfaces of individual beds are sharp. Many of these bodies exhibit partings of mudrock, some of which are carbonaceous (in extremely rare instances, even coaly); other partings comprise poorly cemented, very fine grained sandstone. Small-scale, low-angle, wedge-planar cross stratification is common; small-scale trough cross stratification is rare. Ripple marks, commonly interference type, are common, especially on the top surface of the bodies. In some cases, partings in these bodies are thick enough that "sandstone interval" might be a more appropriate term (fig. 11).

Figure 10 (facing page). Composite stratigraphic column of the Ghazij Formation showing lithologic character of lower, middle, and upper parts of the formation. Thicknesses shown (in meters) are averaged from stratigraphic sections studied in this report. Top photograph, upper part near Pir Ismail Ziarat; middle photograph, middle part at Abraham Marri section, Pir Ismail Ziarat; lower photograph, lower part in the Sor Range.

LOWER CONTACT

In our study area, the Ghazij Formation overlies carbonate rocks of the Paleocene Dungan Formation, or its stratigraphic equivalents. The contact is commonly sharp, but Hunting Survey Corporation (1960) reported it to be transitional at Mach and Narmuk, and Shah (1990) reported it as gradational at Khost, Shahrig, Harnai, and Duki (see also Qureshi and others, 1987). Near Chappar Rift, we examined this contact, and found that, locally, mudrock of the Ghazij interfingers with carbonate rocks of the Dungan through a stratigraphic distance of several tens of meters. Some workers, such as Williams (1959) and Kassi and others (1987), stated or implied that the contact is always conformable. However, this contact can be locally unconformable (Hunting Survey Corporation, 1960; Shah, 1977).

Hunting Survey Corporation (1960) described the contact as conformable near Angira, Bahlol, Duki, Harnai, Kingri, Mach, Moghal Kot, Narmuk, Sanjawi, Spintangi, and Tang Na Pusht.

Unconformable contacts have been reported at the following localities. At Rakhi Nala and near Zinda Pir, Eames (1952a) reported the contact to be unconformable based on field evidence and sudden faunal changes. Hunting Survey Corporation (1960) described the contact as unconformable with underlying Paleocene rocks in the Sor Range, and stated that the base of the Ghazij contains rusty (sic) grit and Paleocene foraminifers. Near Wakabi and 6 km northeast of Baleli, these workers reported that the Ghazij is

Table 1. Rock-Eval pyrolysis data.

[Tmax, temperature at which maximum yield of hydrocarbons occurs during pyrolysis; S1, integral of first peak (existing hydrocarbons volatilized at 250°C for 5 minutes); S2, integral of second peak (hydrocarbons produced by pyrolysis of solid organic matter between 250° and 550°C); S3, integral of third peak (CO_2 produced by pyrolysis of kerogen between 250° and 390°C); PI, production index (S1/S1+S2); TOC, total organic carbon; HI, hydrogen index (S2/TOC); OI, oxygen index (S3/TOC)]

Sample No.	Locality	Tmax (°C)	S1 mg/g	S2 mg/g	S3 mg/g	PI	TOC wt.%	HI	OI
SR-U1/3-91	Shin Ghwazha	0	0.	0.08	0.66	0.	0.42	19	157
SR-M1/3-91	Shin Ghwazha	0	0.	0.07	0.58	0.	0.43	16	134
SR-L1/3-91	Shin Ghwazha	444	0.01	0.17	0.58	0.06	0.4	42	145
SIN-U1/3-91	Sinjidi	442	0.	0.07	1.27	0.	0.26	26	488
SIN-M1/3-91	Sinjidi	450	0.	0.11	0.9	0.	0.38	28	236
SIN-L1/3-91	Sinjidi	454	0.	0.12	0.59	0.	0.38	31	155
PIZ-U1/3-91	Pir Ismail Ziarat	430	0.	0.18	0.41	0.	0.41	43	100
PIZ-M1/3-91	Pir Ismail Ziarat	433	0.	0.14	0.3	0.	0.43	32	69
PIZ-L1/3-91	Pir Ismail Ziarat	443	0.	0.04	0.47	0.	0.32	12	146

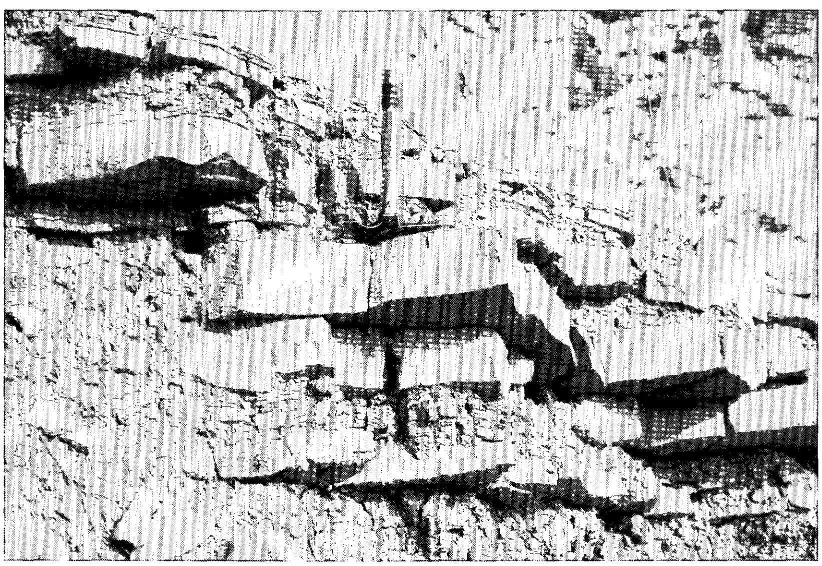


Figure 11. Typical sandstone sequence in lower part of the Ghazij Formation, Abraham Marri mine section, Pir Ismail Ziarat.

unconformable on the Cretaceous Parh Limestone, and near Abigul they reported that the Ghazij is unconformable on the Jurassic Chiltan Limestone. Iqbal (1969) reported that near Murree Brewery, located on the western outskirts of Quetta, not only is the contact unconformable, but some angularity is locally apparent. The most striking unconformable contact is present just west of the village of Umai where the Ghazij is reported to rest with angularity on older rocks (Blanford, 1883; Hunting Survey Corporation, 1960; Khan, Abbas, and others, 1986). According to Hunting Survey Corporation (1960), the underlying rocks, Paleocene, Cretaceous, and Jurassic carbonates, are folded and are discordant (as much as 90°) with the overlying Ghazij. The basal Ghazij at this locality consists of green, cross-stratified, pebbly sandstone and white, quartz-rich sandstone containing fragments of older limestone. Other lithologies present include nodules, irregular patches and layers of red and yellow ochre (pedogenic?), rusty brown grit containing Paleocene foraminifers, and mottled and burrowed lateritic shale. The carbonate rocks directly below the unconformity are also commonly burrowed.

Another type of contact is present in some areas of the northern Sulaiman Range. Shah (1990) reported that in these areas the Dungan can be absent apparently because of depositional pinch-out, and where this happens the Ghazij rests conformably on rocks older than the Dungan.

According to Florian Maldonado (U.S. Geological Survey, oral commun., 1995), many Ghazij-Dungan contacts that appear sedimentary are actually tectonic.

UPPER CONTACT

The top of the lower part of the Ghazij Formation can be in either sharp or gradational contact with the overlying middle part of the Ghazij. We placed this contact at the base of the lowest significant sandstone body or sandy interval of the middle part of the formation. Some workers have drawn the contact at the base of the lowest coal bed in the middle part of the formation, but this placement is problematic in areas where the coal is poorly exposed or where there is no coal in the middle part. Moreover, our placement of the contact facilitates the field mapping of the contact.

MIDDLE COAL-BEARING PART

The middle part of the Ghazij Formation has the most variable thickness of the three parts of the formation. The thinnest we can confirm is 16 m at the north end of the Sor Range, and the thickest is 291 m near Pir Ismail Ziarat. Hunting Survey Corporation (1960) reported a maximum thickness of 2,438 m near Bahlol, but this seems unreasonably thick considering our findings. In general, the middle part of the Ghazij consists of thick sequences of mudrock and thinner tabular to lenticular bodies of sandstone. The middle part also commonly contains carbonaceous shale and coal, and, locally, thin beds of limestone. In some areas, such as Pir Ismail Ziarat, the middle part appears greenish when viewed from a distance (fig. 10).

LITHOFACIES

MUDROCK

Calcareous mudrock is the most common lithology in the middle part of the Ghazij Formation. Mudstone is the usual variety of mudrock, with lesser amounts of shale and siltstone. Very thin sandstone or limestone beds are present locally. Fresh surfaces of the mudrock are typically medium gray, and weathered surfaces are most commonly light to medium gray or greenish gray; in addition, some weathered surfaces have a yellow or brown tinge. Secondary gypsum is very common, and orange-sized tan-weathering limy concretions are present in the Johan area. Hunting Survey Corporation (1960) reported that in the Khost-Shahrig-Harnai area, mudrock of the middle part in the Ghazij locally contains large concretions. Almost all of the mudrock in our study area contains carbonaceous material ranging from isolated specks to very thin layers on laminae and bedding planes. Some of this material is clearly identifiable as fossil plant debris. In addition, thin carbonaceous shale layers and, rarely, thin coaly layers are present. Fossil root traces are common. Locally, the mudrock can be quite fossiliferous, even to the point of forming a thin coquina. Most common are small bivalves and snails, but oysters and other large clams, and large high-spiral gastropods are present in some units. Ostracodes are also abundant locally.

Units of mudrock range in thickness from 8 cm to 54 m. Some mudrock units, such as in the lower part of the Gishtari Nala section, coarsen upward with an increase in silt content. The upper part of some units contains numerous fossil-root-trace horizons, particularly just below the top surface. In some areas, such as at the Moghal mine section, the topmost layer is commonly carbonaceous shale. The lowermost part of some units contains increased amounts of fossils, silt, or sand. Coquina or fossil plant debris forms a thin basal layer of some units.

SANDSTONE

Sandstones in the middle part of the Ghazij Formation are mostly very fine to fine grained, with lesser amounts of medium-grained varieties. Exceptions to this are at the Gishtari Nala and Sarawan River sections where the sandstones are mostly fine to medium grained. The rocks are calcareous and very frequently contain fossil plant debris. Fresh surfaces of the sandstone are light gray, and weathered surfaces are most commonly light yellowish gray. Exceptions to this color are two unique sandstone bodies at the Abraham Marri mine section, and two bodies at the Moghal mine section; these sandstones weather greenish gray. Because sandstone bodies form such an important component of the middle part of the Ghazij, we have subdivided them into three primary types, which we call Type I, Type II, and Type III.

TYPE I SANDSTONE BODIES

Type I sandstone bodies are the least common, and, if present, they tend to occur stratigraphically low in the middle part of the Ghazij Formation. They can be single bodies, or can be part of a mudrock sequence containing several such bodies (fig. 12). In the areas that we examined, most bodies range in thickness from about 1.25 to 7.25 m, but one sequence of three bodies at the Abraham Marri mine section is 22.5 m thick (pl. 1*B*). All Type I sandstone bodies are laterally extensive. Although each of these bodies is unique, some characteristics are common to many. In most cases, these bodies coarsen upward in grain size: from very fine to fine at the Shin Ghwazha mine and Abraham Marri mine sections, and fine to medium at the Gishtari Nala section.

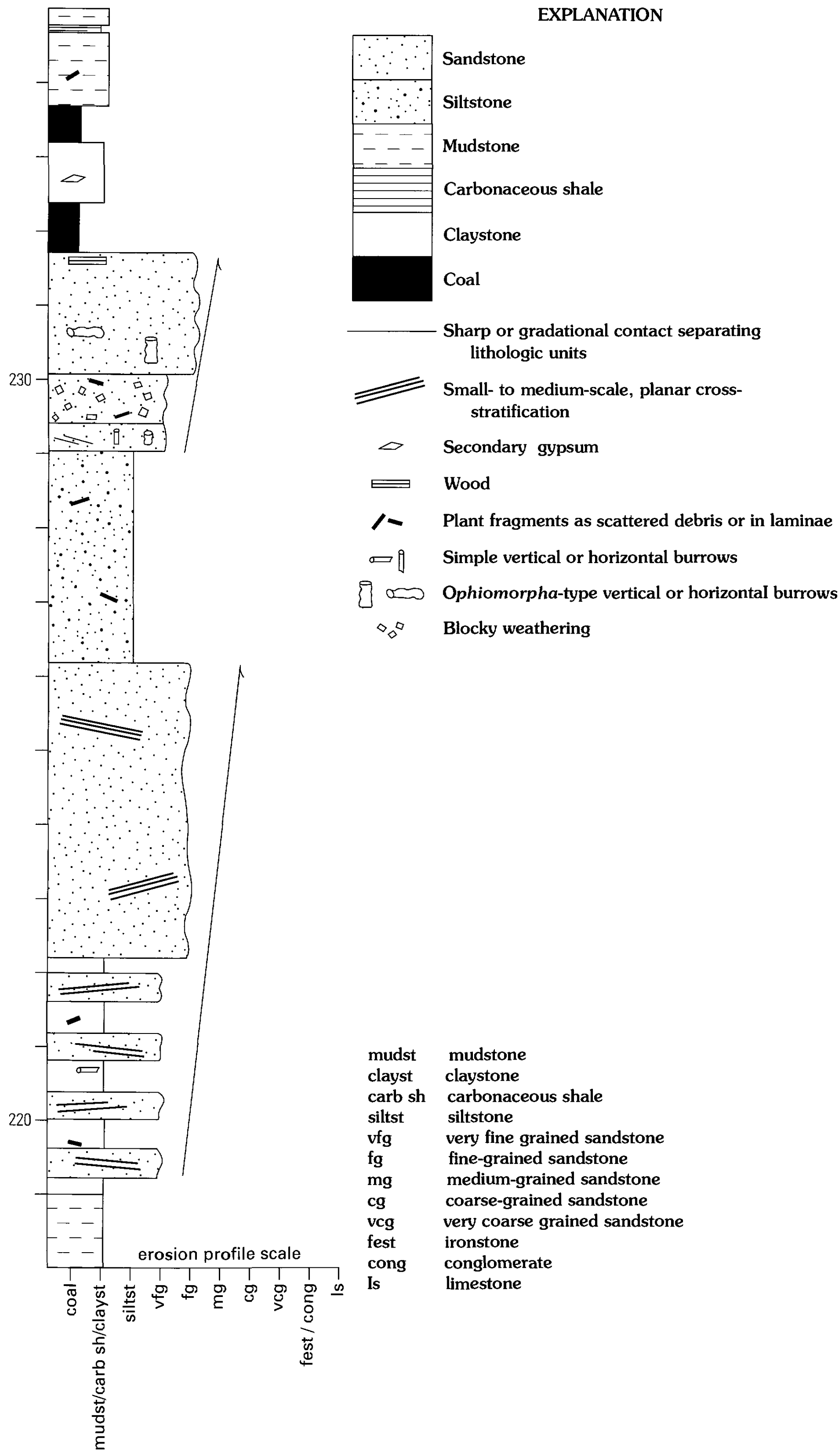


Figure 12. Two consecutive, coarsening-upward sequences (indicated by sloping arrows) containing Type I sandstone bodies in basal portion of the middle part of the Ghazij Formation, Abraham Marri mine section. Scale in meters above base of measured section.

Mudrock interbeds are common, and where present, they tend to decrease in thickness and in number upward. Bed thickness is quite variable, ranging from very thin to thick or massive, but several bodies exhibit an upward increase in bed thickness. The upper and lower contacts of the bodies are almost everywhere sharp. Sandstones in the uppermost part of some bodies are ripple laminated, stained orange, or contain fossil root traces. Coal or carbonaceous shale rests directly on top of some bodies, and interbedded sequences of sandstone and mudrock directly underlie some bodies.

Medium-scale, low-angle, wedge-planar cross stratification is very common. Also very common are horizontal and vertical fossil burrows; some of these are simple in structure and resemble *Thalassinoides*, whereas others are pellet packed and resemble *Ophiomorpha*. Body fossils are generally absent.

TYPE II SANDSTONE BODIES

Type II sandstone bodies are more difficult than Type I bodies to define. Where Type I bodies are present, Type II bodies are found either (1) within a mudrock sequence stratigraphically above the Type I bodies, such as at the Shin Ghwazha mine and Abraham Marri mine sections, or (2) commingled with the Type I bodies in a mudrock sequence such as at the Gishtari Nala section. Type II sandstone bodies range in thickness from 0.50 to 3 m; rarer bodies, especially at the Sarawan River section, can range from 3 to 5 m. The sandstones are very fine to fine grained, but some at the Gishtari Nala and Sarawan River sections are medium grained. Most bodies are of uniform grain size, but about 25 percent fine upward. Bedding thickness ranges from very thin to medium, and mudrock partings are common. Many bodies display small-scale, low-angle, wedge-planar cross stratification; trough cross stratification is less common. Vertical and horizontal fossil burrows are abundant. Burrows with simple structures resemble *Thalassinoides* (fig. 13), and pellet-packed varieties resemble *Ophiomorpha*. Other features typical of Type II sandstones bodies are fossil plant debris, mudrock chips, oyster shells, and, especially in the upper part of the bodies, ripple laminations. Lower contacts are almost always sharp, and upper contacts are sharp or, less frequently, gradational.

Figure 13. Simple-structured horizontal and vertical burrows, resembling *Thalassinoides*, on top surface of a sandstone bed in a Type II sandstone body, middle part of the Ghazij Formation, Abraham Marri mine section. U.S. penny for scale (arrow).

TYPE III SANDSTONE BODIES

Type III sandstone bodies, where present, are found stratigraphically high in the middle part of the Ghazij Formation. These bodies range in thickness from 0.5 to 12 m and can be either laterally continuous sandstone sheets, or laterally discontinuous lenticular bodies. Grain size ranges from very fine to medium, and bodies are of uniform grain size or fine upward. Internally, the bodies are very thin to medium bedded, with bed thickness often decreasing upward. Small- to medium-scale, trough cross stratification is common (fig. 14), but low-angle, wedge-planar cross stratification was also noted. In addition, some bodies also display numerous internal erosion surfaces. Most bodies contain carbonaceous material ranging from fossil plant debris to fossil logs. Locally, the upper parts of bodies contain mudrock partings, ripple laminations, and ripple marks. Body and trace fossils are in most places absent. The upper surfaces of these bodies are sharp or gradational, but all lower surfaces are sharp, and some display erosional relief of as much as 60 cm. Mudrock chips and fossil wood fragments are present just above some lower surfaces.

Many of the mudrock sequences that contain Type III sandstone bodies contain a few thin tabular sandstone bodies, typically 0.5 m thick. These bodies are commonly thin bedded, and locally are ripple laminated, display fossil root traces, and contain abundant fossil plant debris.

CARBONACEOUS SHALE

Carbonaceous shale is present in all exposures of the middle part of the Ghazij Formation. Units of this lithology range in thickness from 10 cm to 2 m. These rocks are dark brown on fresh surfaces and weather medium to light brown. Where observed in active mine dumps, these rocks are greenish gray and display parallel laminations and pyrite

Figure 14. Typical trough cross stratification in a Type III sandstone body in middle part of the Ghazij Formation, Abraham Marri mine section. Hammer for scale.

globules. Secondary gypsum, fossiliferous horizons, and coaly streaks are common. In some cases, such as at the Shin Ghwazha mine and Gishtari Nala sections, some carbonaceous shale units are at a stratigraphic level that can be correlated laterally with a coal bed that is being extracted at a nearby mine.

COAL

Coal beds are present in the middle part of the Ghazij Formation in the Shin Ghwazha mine, Abraham Marri mine, and Moghal mine measured sections. The beds range in thickness from 7 cm to almost 1 m. Coal miners report that beds can thicken considerably over short distances because of tectonic squeezing (see Hunting Survey Corporation, 1960). Mudrock or carbonaceous shale typically overlies and underlies coal beds, but at the Abraham Marri mine section, beds of white claystone or coquina are present above or below some coal beds, and in two places at the Abraham Marri mine section, some coal rests directly on sandstone. Locally, some freshly mined coal contains pyrite as coatings on cleat surfaces, or as concretions ranging in diameter from a few millimeters to several centimeters. The only evidence of naturally burned coal that we observed was several large patches of reddish-stained mudrock along a known coal horizon near the Abraham Marri mine stratigraphic section.

Two interesting coal localities merit special mention. The first is coal from the Gishtari mine just north of the Gishtari Nala section. Here, we observed coal in active stockpiles that contained common, whole specimens of fossil bivalves and snails disseminated randomly throughout hand samples. The second locality is a coal outcrop at Sharan Tangi several kilometers southeast of Shahrig in the northwestern Sulaiman lobe. Here, coal is rhythmically interbedded with very fossiliferous limestone over a stratigraphic interval of about 1 m (fig. 15). The limestone weathers very light gray and is present in beds that range from about 2 to 10 cm thick. Coal units are about 3–15 cm thick, and can contain very thin partings of limestone or fossil shell hash. (See Appendix for a more detailed account of coal in the Ghazij.)

LIMESTONE

The middle part of the Ghazij Formation contains a significant amount of limestone in the Mach and, to a lesser degree, Johan areas. Fresh surfaces of the limestone are light gray, and weathered surfaces are usually orangish gray or orangish brown. Most of the limestones appear very muddy, and it is tempting to refer to them as limy mudrocks. However, laboratory tests reveal that they contain less than 5 percent insoluble residue. The limestones are present as single units (fig. 16) isolated within thick mudrock sequences, which also contain Type II sandstone bodies. The limestone units range in thickness from 5 cm to 2.33 m, and they can be traced laterally for considerable distances. Internally, the units are very thin bedded to medium bedded, and can contain mudrock or carbonaceous shale partings. Simple-structured vertical and horizontal fossil burrows are locally rare to abundant.

The most striking feature of these rocks is their fossil content (fig. 17). Ranging from fossiliferous to coquinas, the units contain abundant small bivalves and larger clams, small snails and larger, high-spiral gastropods, and ostracodes and foraminifers. Oysters are rare. At the Moghal mine section,

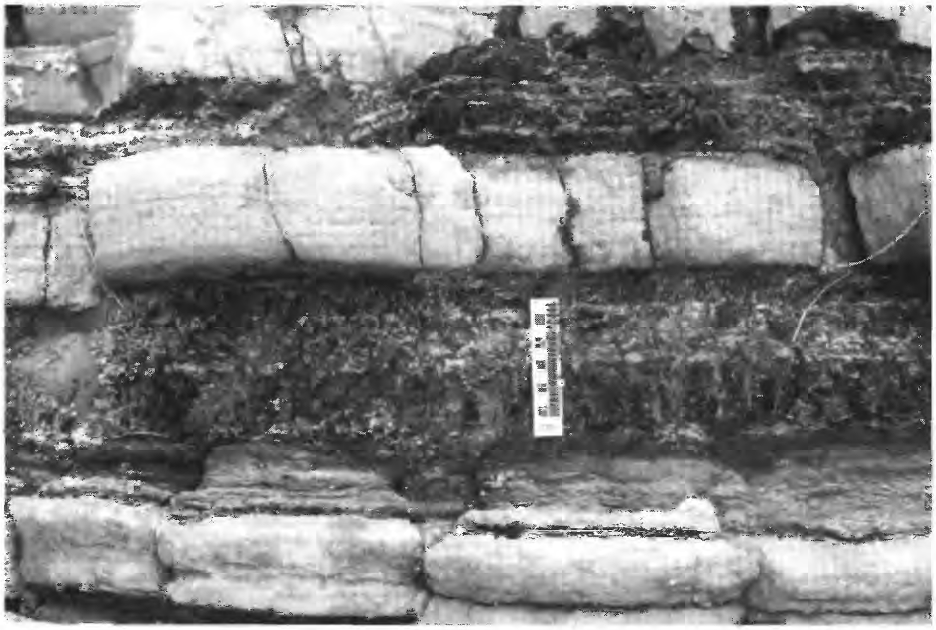


Figure 15. Interbedded fossiliferous limestone and coal, middle part of the Ghazij Formation near Shahrig.

Figure 16. Thin limestone bed typical of middle part of the Ghazij Formation in Mach area. Photograph taken at the Gishtari Nala section. Penny for scale.

horizons of closely packed yellowish-brown-weathering, limy concretions are also present. These elliptical bodies range in thickness from 15 to 70 cm and can be as long as 1 m. Locally, the concretions have fossils sprinkled on their top surfaces, and can have centers of brecciated fragments separated by calcite crystals.

Hunting Survey Corporation (1960) reported that limestone beds are present in the middle part of the Ghazij Formation in the Khost-Shahrig-Harnai area in the northwestern Sulaiman lobe. In addition, limestone is also known to be present in the middle part of the formation at Rakhi Nala and near Kingri in the southern Sulaiman Range.

WHITE CLAYSTONE

At the Abraham Marri mine section, units of white claystone are present either directly over or under some coal beds. The units range in thickness from 7 to 87 cm. Fresh surfaces are very light gray, and weathered surfaces are light brownish gray or light yellowish brown. The claystone is noncalcareous and contains abundant fossil plant debris and, less commonly, very thin beds of carbonaceous shale. Most exposures display patches of boxlike weathering structure with associated yellow mineralization. Rarer features are secondary gypsum, fossil root traces, and possible fossil burrows.

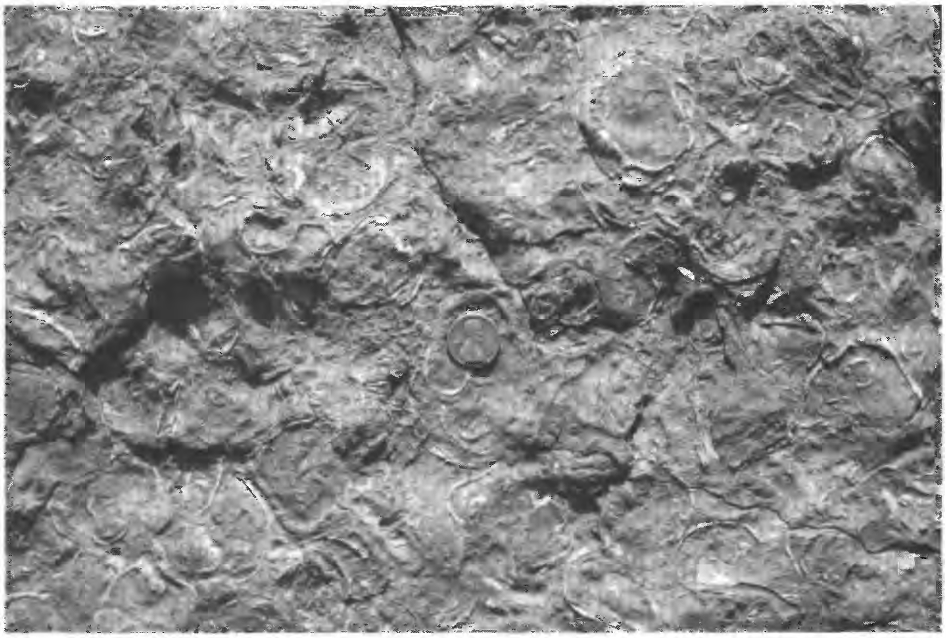


Figure 17. Abundant fossil hash (bivalves) commonly found in limestones of middle part of the Ghazij Formation in Mach area. Photograph taken at the Moghal mine section.

COQUINA

Also present at the Abraham Marri mine section are units of coquina. These rocks are a very light pink on fresh and weathered surfaces, and the unit thicknesses range from 2 to 16 cm. Most of the larger fossil material has been abraded to hash, but ostracodes and small bivalves and gastropods can be recognized.

UPPER CONTACT

We place the contact between the middle and upper parts of the Ghazij Formation at the stratigraphic level that separates gray mudrock of the middle part from lighter, variegated mudrock of the upper part. In most areas, this color difference is quite distinct, and the contact can usually be placed within a meter. Some workers place the contact on the top of the highest coal bed, but we know of examples, such as the Pir Ismail Ziarat and Mach areas, where coal is present in the upper part of the formation. Where conglomerate is present in the base of the upper part of the formation, we place the contact at its lower surface. In areas where the conglomerate is usually present but is locally represented by a sandstone unit that is clearly a lateral facies of the conglomerate, such as in the southern Sor Range, the contact is placed at the base of the sandstone.

In some areas the boundary between the middle and upper parts of the Ghazij Formation might be an unconformity. The erosional surface underlying the conglomerate that is present in the base of the upper part of the formation at some localities is a good candidate for such a boundary. (See also Kazim and others, 1991.) Where the conglomerate is not present, evidence for an unconformity is generally lacking. However, at the Moghal mine section, a mudrock bed, 15 cm thick, directly below the mudrock color change weathers white and contains what appears to be pedogenic structures; this unit might represent a significant paleosol horizon, and possibly a subtle unconformity.

In contrast to a relatively sharp boundary between the middle and upper parts of the Ghazij Formation based on mudrock color, we know of two sites where gray and variegated mudrocks appear to interfinger, forming a transitional boundary. At the Moghal mine section this transition covers 59 m, and at the Sarawan River section it covers 20 m. We placed the contact at these two sites at the top of the transitional sequence. We also suspect that the boundary separating these two parts of the Ghazij at the Abraham Marri mine section might also be transitional in a similar manner.

Placing the contact between the middle and upper parts of the Ghazij Formation at the Gishtari Nala section is problematic. We placed the contact at a stratigraphic level separating gray mudrock below from light-brownish-gray mudrock, most of which is claystone, above. However, just above this level several minable coal beds are present and carbonaceous shale is fairly common to the top of the section. Moreover, fossiliferous mudrock and, near the top of the section, thin, fossiliferous limestone is also present. Despite the fact that the above-mentioned lithologies are usually not associated with the upper part of the formation, and that possibly only the middle part of the formation is represented in this section, we believe that our contact placement is justified.

UPPER MUDDY NONMARINE PART

The upper part of the Ghazij Formation is perhaps the most interesting subdivision of the formation. Both the thinnest and thickest measurements of the upper part of the formation that we know of are in the Sor Range. In the northwestern part of the range, the upper part is about 215 m thick, and in the southeastern part of the range it is about 533 m thick; we measured 407 m at the Shin Ghwazha mine section. The upper part of the formation is 251 m thick at the Sarawan River section near Johan. Two problems complicate measuring the thickness of this part of the Ghazij. (1) At many localities the uppermost part of the formation is incomplete because of Neogene erosion and subsequent molasse deposition; this is the case at the Gishtari Nala section. (2) At many localities large limestone slide blocks of the overlying Kirthar Formation are observed floundering in the relatively soft mudrock at the top of the upper part of the Ghazij, making a correct measurement impossible; this is the case at the Moghal mine section. In general, the upper part of the formation consists of light, variegated mudrock and less common sandstone bodies. Other lithologies are rare. Body and trace fossils as well as fossil plant debris are generally not observed in this part of the formation.

LITHOFACIES

MUDROCK

As with other parts of the Ghazij Formation, calcareous mudrock is the most common rock type in the upper part of the Ghazij. Locally, the mudrock is sandy. Fresh colors are medium gray or medium brown, and weathered colors are light gray or light brown, with significant local tinges of green, yellow, red, and maroon. The rocks are commonly mottled, and many exposures are color banded in units 1–2 m thick (fig. 10). Mudrock sequences range in thickness from 15 cm to as much as 61 m. Most of the rock is clay rich, resulting in case hardening and a distinctive popcornlike weathering surface. Gene Whitney (U.S. Geological Survey, oral commun., 1994) analyzed the clays from a sample of mudrock collected from this part of the formation near Harnai, and reported the presence of detrital illite. Very fine grained sandstone in very thin beds is locally present, and in some mudrock sequences the silt content increases upward. Carbonaceous material is very rare. At the Shin Ghwazha mine section, one sequence of mudrock contains disseminated granule- to pebble-sized masses of white clay material that increase upward within several intervals. Mudrock at the Gishtari Nala section is quite unique for this part of the formation. Here, fossil plant debris is very abundant, and fossil root traces, especially in the upper part of individual sequences, are common. Fossil shell debris and fossil burrows are locally common.

SANDSTONE

Sandstone is present in the upper part of the Ghazij Formation as lenticular bodies or, less commonly, as laterally continuous sheets, bounded by mudrock. The sandstones are calcareous, and usually fine to medium grained; some sandstones are very fine grained at the Abraham Marri mine section, and most sandstones at the Moghal mine section are coarse grained to very coarse grained. Most fresh surfaces are light gray, and weathered surfaces vary among light yellowish gray, light brownish gray, and very light brown. With two exceptions, all sandstone bodies in the upper part of the Ghazij in the Quetta region resemble the Type III bodies described in the middle part of the formation, and this terminology will be continued. Most of the bodies in the upper part of the formation are between 1 and 3 m thick. The largest single body we measured was 6.51 m thick at the Shin Ghwazha mine section. Also present in this section are several sandstone complexes as thick as 13.85 m consisting of amalgamated Type III bodies. Common features of Type III bodies are lenticular shape, fining-upward grain size, an increase in mudrock partings in the upper part, and a decrease in bed thickness in the upper part. Upper contacts are mostly sharp, and lower contacts are sharp and commonly display erosional relief. Mudrock chips are commonly observed just above the basal surface. Small- to medium-scale, trough and planar-tabular cross stratification is common in the lower part of bodies, and ripple laminations are common in the uppermost part. At least one Type III body, stratigraphically above the Abraham Marri mine section, and another such body in the Sarawan River section, contain pellet-packed fossil burrows that resemble *Ophiomorpha*. Less common, much thinner, tabular sandstone bodies are also present in the upper part of the formation. These bodies average less than 1 m thick, and most are very thin to thin bedded. Upper and lower contacts can be either sharp or gradational. Ripple lamination and simple, horizontal and vertical fossil burrows are common.

CONGLOMERATE

In the Sor Range a conglomerate unit occupies the lowermost portion of the upper part of the Ghazij Formation (pl. 2; fig. 18). The rock consists of poorly sorted pebbles and cobbles of limestone and subordinate chert (fig. 19). In general, the conglomerate is clast supported, but matrix-supported intervals are common. The matrix is calcareous and consists of poorly sorted, subangular, medium-grained sandstone of a composition similar to that of the clasts. The unit can be traced laterally for 12 km, and according to Hunting Survey Corporation (1960) the unit's thickness commonly ranges from 9 to 60 m. The unit has a sharp top and an erosional base with as much as 22 m of relief over a distance of 0.5 km. Mudrock of the middle part of the Ghazij nearly everywhere underlies the conglomerate. Many outcrops of the conglomerate appear massive, but, locally, faint horizontal stratification and trough cross stratification, normal grading, and clast imbrication are observed. Internal erosion surfaces are locally present. Some outcrops display discrete lenticular bodies of conglomerate averaging 1 m in thickness. The unit also contains lenses of pebbly, medium-grained, trough and wedge-planar cross stratified sandstone of the same composition as the matrix. At several locations in the Sor Range, a medium- to coarse-grained sandstone unit lies directly on top of the conglomerate (fig. 18). This sandstone unit typically fines upward in grain size, is trough cross stratified, and contains horizontal bedding near the top.

The conglomerate is absent in the southeastern part of the Sor Range, and in some nearby areas, such as Pir Ismail Ziarat, where the conglomerate is not present, a coarse-grained sandstone occupies this stratigraphic position.

North of the Sor Range in the Sulaiman lobe from Shahrig to Harnai, a similar conglomerate is present at the base of the upper part of the Ghazij Formation. West of Shahrig near Khost, a sandstone occupies this stratigraphic position (Khan and others, 1972). Along the outcrop belt from Shahrig to Harnai, the unit averages 6 m in thickness (Shah, 1990). Kazi (1968) reported the unit to be 11 m thick at Harnai. Near Shahrig the unit is 4 m thick, and the conglomerate appears to have a higher percentage of chert relative to the Sor Range conglomerate. Far to the north near Moghal Kot, conglomerate is reported to be present in small amounts in the upper part of the lower Eocene interval (Hemphill and Kidwai, 1973). South of the Sor Range, conglomerate is absent from the formation near Mach and Johan. However, south of Johan conglomerate again becomes an important component of the upper part of the formation. These rocks will be discussed in a forthcoming section of this report.

Traditionally, the conglomerate has been placed in the top of the middle part of the Ghazij Formation. The unit, however, is more closely associated with the upper part of the formation, where we have placed it. For example, in the Sor Range the sandstone unit that locally rests directly on top of the conglomerate (fig. 18) has traditionally been placed in the upper part of the Ghazij, but this sandstone appears to be part of the same depositional package as the conglomerate and should be included with that unit. Moreover, thinner, less spectacular conglomerate beds are present stratigraphically higher in the lower portion of the upper part of the formation. A further reason to place the conglomerate in the upper part of the formation is that in certain areas near Shahrig multicolored mudrock, usually associated with the upper part of the formation, is present just below the conglomerate.

OTHER LITHOLOGIES

Carbonaceous shale is present in small amounts in the upper part of the Ghazij Formation at the Abraham Marri mine and Moghal mine sections. However, at the Gishtari Nala section, this lithology is common. Here, the carbonaceous shale is present in beds 3–70 cm thick, and coaly partings are common. One thin coal bed is present at the Abraham Marri mine section, and at the Gishtari Nala section two coal intervals are present, and one 37-cm-thick bed is being mined nearby. A few thin fossiliferous limestone units are present at the Gishtari Nala section.

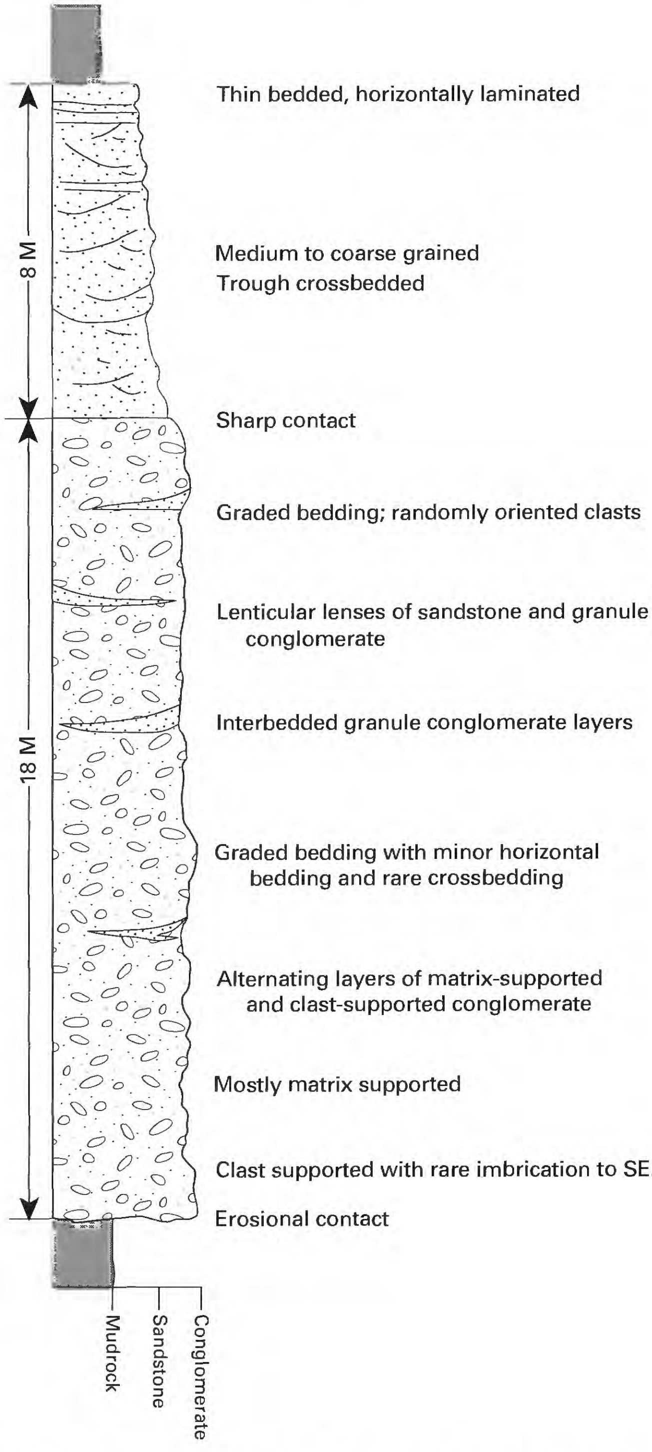


Figure 18. Composite stratigraphic section showing characteristics typical of conglomerate facies of upper part of the Ghazij Formation in Sor Range.

UPPER CONTACT

The contact between the Ghazij Formation and the overlying Kirthar Formation, or its stratigraphic equivalents, is covered in many places by large blocks of limestone shed from the topographically higher cliffs of Kirthar.

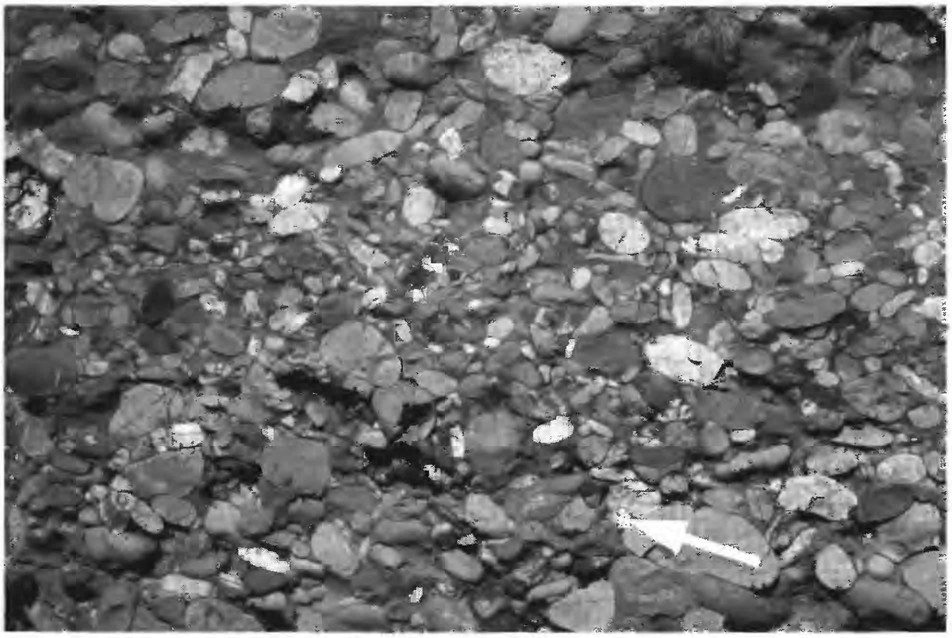


Figure 19. Typical outcrop of conglomerate facies at base of upper part of the Ghazij Formation in Sor Range. U.S. penny for scale (arrow, lower right side of view).

The contact is generally conformable, but locally can be disconformable. Hunting Survey Corporation (1960) reported it to be conformable, and some places transitional, near Moghal Kot, Kingri, Harnai, Umai, Quetta, Tang Na Pusht, Wakabi, and Karkh.

At the Shin Ghwazha mine section (pl. 1*A*), the two formations appear to interfinger within a stratigraphic interval of 32 m. Here, overlying an extensive covered interval near the top of the upper part of the Ghazij Formation, a unique limestone unit 5.86 m thick appears to be lithologically associated with the Kirthar, yet has certain characteristics not found in that formation. The lower 3.56 m of the limestone is thin to medium bedded, and the rock weathers light yellowish gray; some exposures appear pinkish white from a distance. The upper 2.30 m is very thin to thin bedded, and is fissile in the uppermost part. This somewhat silty rock weathers light orangish brown. Above this limestone unit is a sequence of calcareous mudrock 15.31 m thick. The lower 4.60 m of the sequence is silty, very thin bedded, and weathers orangish brown. Fresh surfaces appear brick red. The upper 10.71 m is similar to the lower part but weathers yellowish green and appears to contain foraminifers. None of this mudrock resembles any of the mudrock elsewhere in the upper part of the Ghazij. Above the mudrock is a covered interval about 11 m thick overlain by the base of the Kirthar cliff. A similar situation is present along the road to Quetta just west of the village of Pir Ismail Ziarat, where a 4-m-thick bed of limestone identical to that in the overlying Kirthar is present near the top of the upper part of the Ghazij separated from the Kirthar by 6 m of mudrock. In both of these cases, we placed the contact between the two formations at the base of the main body of Kirthar limestone.

The Ghazij-Kirthar contact was reported by the Hunting Survey Corporation (1960) to be locally disconformable near Mach, Narmuk, and Angira. These workers went on to say that where a lateritic unit at the very top of the Ghazij directly underlies the Kirthar, the contact is certainly disconformable. This is apparently the case in the Shahrig area where a red-weathering, very fine grained sandstone unit 1.5 m thick near the top of the Ghazij has the appearance of a laterite. Above this red-tinged sandstone is a unit of black-weathering shale 2.30 m thick, which is overlain by a spectacular layer of large simple horizontal burrows on the basal surface of the Kirthar. Just west of Harnai, the Ghazij-Kirthar contact takes on yet another appearance. Here, a sequence several meters thick near the top of the Ghazij consists of quartz-rich sandstone with a chert-rich, limonitic conglomerate bed near the middle of the sequence. Above these rocks is a sequence several meters thick consisting of marl overlain by nodular, thin-bedded limestone, all of which has been assigned to the Kirthar. Above this is the main body of the Kirthar.

DISCUSSION

The vertical arrangement of lithofacies and contact relations just described is typical for the Ghazij Formation in those areas of the Axial Belt that are marginal to the Sibi trough. From south to north, this part of the belt defines a regional strip that extends north from Johan through Mach and the Sor Range to the vicinity of Kach and then turns east along the Sulaiman lobe to as far east as Duki (fig. 2). All of the Ghazij exposed along this trend falls within the complex assemblage as defined by Hunting Survey Corporation (1960). The overall characteristics of the formation are similar throughout this area, but subtle vertical and lateral differences are apparent, and these variations are described in this

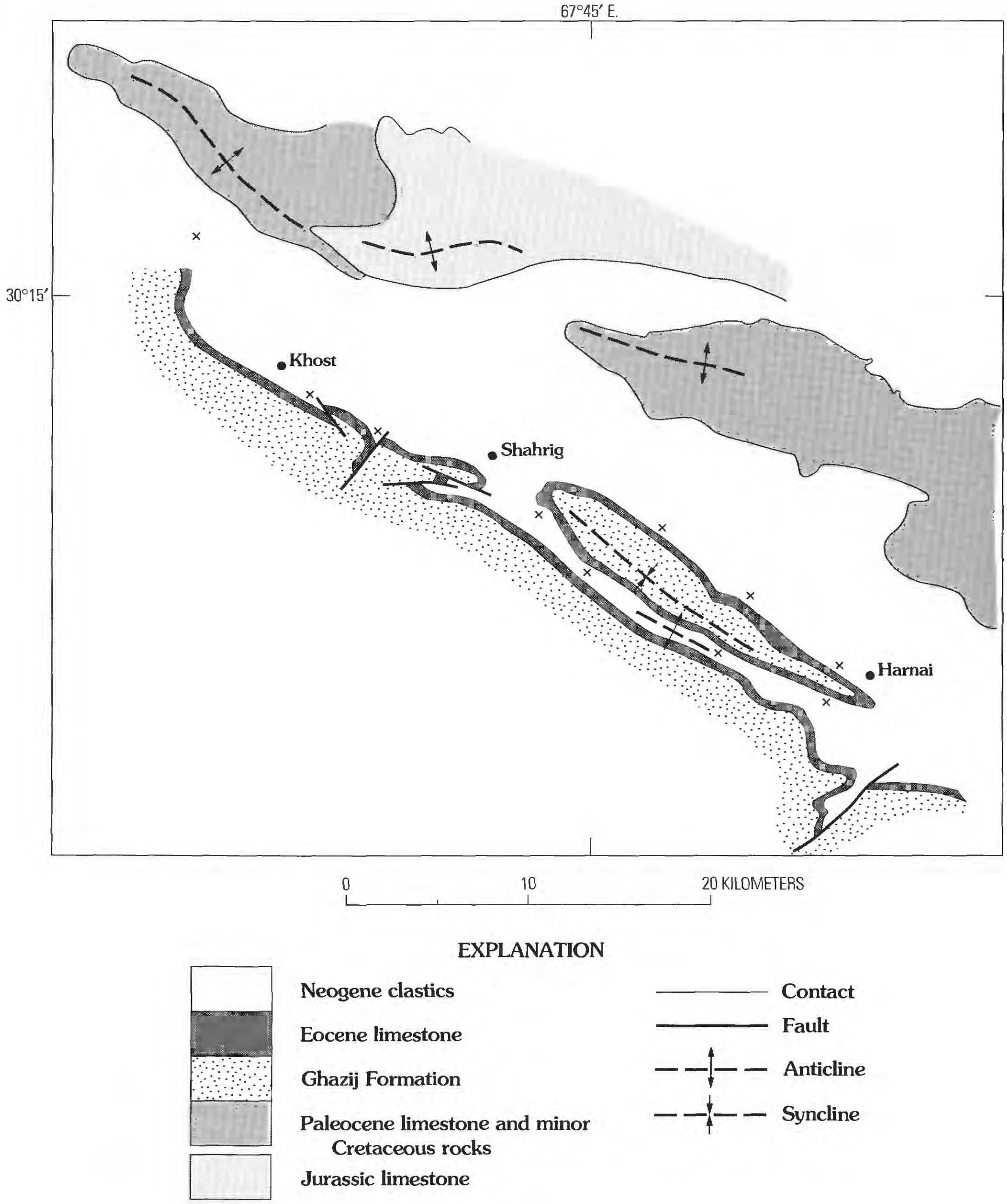


Figure 20. Generalized geology of Khost-Shahrig-Harnai segment. ×, coal mine. Quaternary alluvial deposits not shown. Modified from Hunting Survey Corporation (1960).

section of our report. Although we might not have measured a stratigraphic section at some of the sites mentioned, one or more of us have knowledge of the formation in the area discussed.

NORTHWESTERN SULAIMAN LOBE

In the northwestern part of the Sulaiman lobe, the Ghazij Formation is exposed near Umai, Saran Tangi, Kach, Khost, Shahrig, Harnai, Sanjawi, and Duki, a total distance of about 130 km. Thanks to the narrow-gauge railroad that once ran parallel to this trend, the Ghazij and its coal resources have been reported on since the latter part of the 19th century (Blanford, 1882, 1883; King, 1889; Oldham, 1890a, 1890b, 1892; Griesbach, 1893). Shah (1977) stated that along this outcrop belt, the formation thickens toward the east, and within the formation, limestone increases toward the east and conglomerate increases toward the west. Also, the amount of quartz grains in sandstones increases eastward, and dramatically so from Harnai to Duki.

Of the localities just listed, the Khost-Shahrig-Harnai segment (fig. 20), about 40 km long, has been the most thoroughly studied. Here, the Ghazij Formation is exposed along the southern limb of a regional, northwest-trending anticlinorium. According to Shah (1965), the Ghazij ranges in thickness from 700 to 800 m along the segment, and beyond the east end of the segment in the area just southeast of Harnai, Hunting Survey Corporation (1960) reported the formation to range from 900 to 1,500 m thick. The lower part of the formation is about 600 m thick just northwest of Khost. The upper portion of the lower part of the formation along the segment is commonly characterized by a relatively thin sequence containing green-weathering sandstone overlying yellow-weathering, sandy limestone. Sandstones below this interval weather a lighter shade of green, but all of the sandstones in the lower part of the formation appear greener than sandstones in the lower part to the south, in the Pir Ismail Ziarat and Sor Range areas. The middle part of the formation is reported to average about 150 m thick along the segment (Ahmad and others, 1986), but near Shahrig it is about 203 m thick (fig. 21*A*). As compared to the Pir Ismail Ziarat and Sor Range areas, the middle part of the formation along the segment contains more limestone units and the mudrocks are more calcareous (Hunting Survey Corporation, 1960). Sandstones in the middle part of the formation contain more quartz grains than sandstones in the middle part anywhere to the south. In general, the amount of sandstone in the middle part of the formation along the segment increases westward toward Khost (Hunting Survey Corporation, 1960). East of the segment toward Duki, sandstone bodies increase significantly in number and thickness, and consequently, the middle part of the formation thickens in this direction. The upper part of the formation is about 140 m thick near Shahrig (fig. 21*B*). Southeast of Harnai, the upper part of the formation contains some white, primary gypsum, and, in the uppermost portion, some gypsiferous limestone.

West of the Khost-Shahrig-Harnai segment, Hunting Survey Corporation (1960) reported the Ghazij Formation to be at least 900 m thick in the Saran Tangi area, and to consist of green-weathering mudrock with a few green-weathering sandstone bodies and minor pebbly conglomerate. The green coloration of the sandstones in this region results from an increased percentage of green rock fragments (Kassi, 1986), and the significance of this will be discussed later in this report.

East of the Khost-Shahrig-Harnai segment, the Ghazij Formation is well exposed in the area of Duki. Here, the lower and middle parts of the Ghazij occupy the center of the east-trending Duki syncline. The upper part of the formation in this area has been eroded. According to Hunting Survey Corporation (1960), the Ghazij near Duki contains more sandstone and fossiliferous limestone in its middle part than do exposures of this part to the west. They also mentioned that a curious maroon-weathering mudrock unit is present at the base of the lower part of the formation. Sandstones in the middle part of the formation are quartz rich, and Shah (1990) reported them to contain 70–80 percent quartz grains. The rocks are fine to medium grained, but locally they are coarse grained to pebbly. Sandstone bodies are often cross stratified, and the limestone units are sandy and contain abundant foraminifers. The lower and middle parts of the formation are thicker in this area than in areas to the west. Khan, Abbas, and others (1986) reported that at Jar Manda near Duki, the lower part is 960 m thick, and the middle part is more than 1,080 m thick. Moreover, the number of individual coal beds in the middle part of the formation near Duki is greater than in areas to the west.

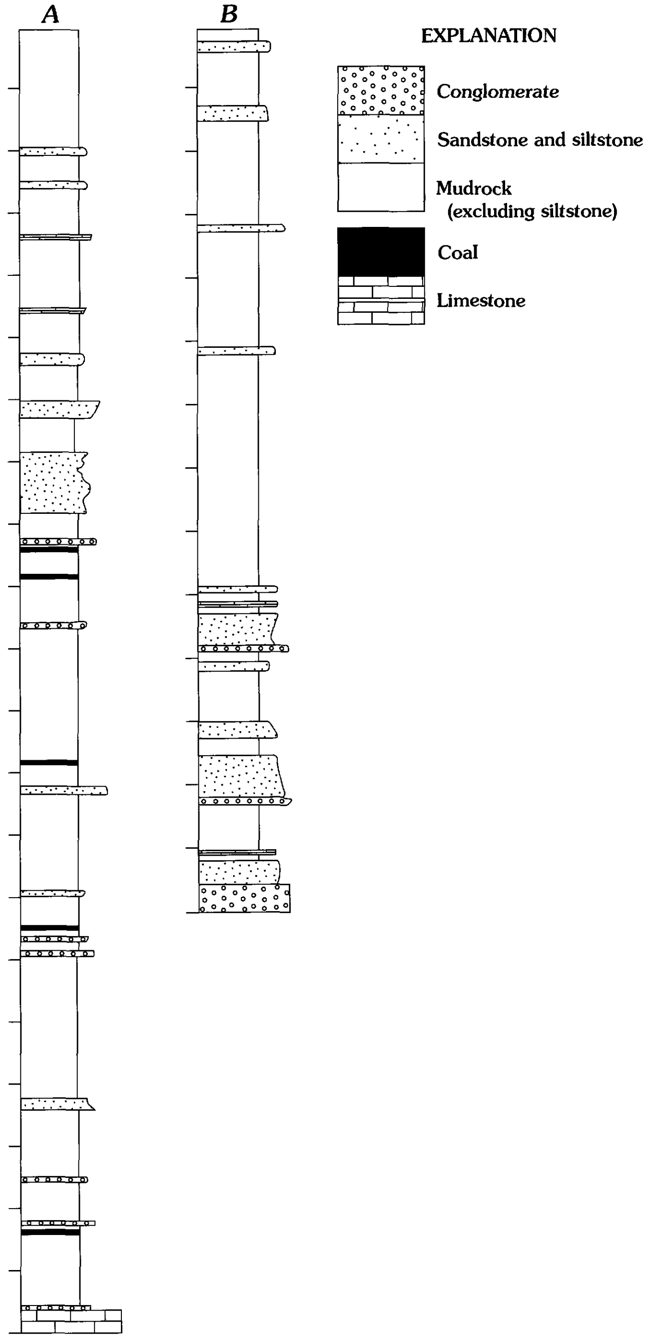


Figure 21. Stratigraphic section of a portion of the Ghazij Formation at PMDC (Pakistan Mineral Development Corporation) mine, several kilometers southeast of Shahrig. *A*, middle part of the formation; *B*, upper part of the formation. Modified from a section provided by the Geological Survey of Pakistan. Scale in 10 m increments.

MURREE BREWERY

Just west of the western suburbs of Quetta, a northeast-trending sliver of Ghazij Formation extends for 9 km along the eastern margin of the Chiltan Mountains (Khan, Younas, and others, 1986; Kazim and others, 1987). This is the westernmost exposure of the Ghazij in the Quetta region. Here, about 640 m of the lower part of the formation is present above the Dungan Formation. The stratigraphic top of the exposure is in thrust fault contact with the Chiltan Limestone. Carbonaceous shale is rumored to be present somewhere along this exposure, and if this is true, then perhaps some of the middle part of the formation is also represented. That part of the formation that is present consists of mudrock and lesser amounts of sandstone; both lithologies weather green. The sandstone is coarse grained, but locally it is gritty, or in rare cases, conglomeratic. Kassi (1986) reported that the sandstone is particularly rich in basic igneous rock fragments.

SOR RANGE

Just east of Quetta, a large expanse of the Ghazij Formation is exposed in the core of the northwest-trending Obashtaki anticline (fig. 22). Because the Ghazij is relatively soft, the structure has been breached, and the formation now occupies a northwest-trending valley. To the south, the doubly plunging Sor Range syncline forms the next fold in the series. Here, thick limestone of the Kirthar Formation protects the syncline from erosion, and the structure is maintained as a small mountain range. All three parts of the formation are present in this area, but because the lower part rolls over along the axial trace of the anticline, the lower portion of this part of the formation is not exposed. The middle and upper parts of the formation are well exposed along the northern slope of the Sor Range tucked under the Kirthar cliff, and it is along this trend that coal mining is most intense.

The Ghazij Formation has been studied in detail in the Sor Range because of its good exposures, economic significance, and close proximity to Quetta. The lithology of the Ghazij here fits the general description presented in previous sections of this report. Hunting Survey Corporation (1960) reported the formation ranges from about 900 to 1,200 m thick, but Khan and others (1972) thought it might be as thick as 1,800 m. Kazim and others (1991) reported that the middle part of the formation ranges in thickness from 30 to 75 m, and, in general, thickens toward the south. The reader should keep in mind that all of the above workers included the conglomerate unit in the middle part, so these values are thicker than we would report. The thinnest middle part that we measured was 16 m at the north end of the range (pl. 2). Our thickest value, measured in the central part of the range, was 75 m (pl. 2). At the Shin Ghwazha mine section (pl. 1*A*) the middle part is 54 m thick. These values confirm that the middle part of the formation is quite thin in the Sor Range when compared to regional thicknesses. It is tempting to relate this thinness to the presence of the conglomerate facies at the base of the upper part of the formation, and indeed erosion at the base of the conglomerate might have removed considerable amounts of the middle part of the formation. However, in the southern part of the range, south of Sinjidi, where the conglomerate is not represented, the middle part of the formation is also thin. The question here is, does the erosional surface observed under the conglomerate in the main part of the range extend to the south, into areas where the conglomerate is not present, and become so subtle that it goes undetected?

Kazim and others (1991) reported that the upper part of the Ghazij Formation ranges in thickness from 127 m near the north end of the range to 375 m in the central part of the range. Again, these workers placed the conglomerate unit in the middle part of the formation, so these values are thinner than we would report. We measured 419 m at the Shin Ghwazha mine section, and this part might be as thick as 533 m in the southern part of the range near Daghari.

PIR ISMAIL ZIARAT

About 24 km east of the Sor Range, the Ghazij Formation is exposed in the core of a generally north trending anticline that extends for about 40 km (fig. 23). The largest exposure of Ghazij is present in the southern part of the structure in the Pir Ismail Ziarat area. Hunting Survey Corporation (1960) referred to this area as the Narwari Valley, but they provided very little geologic data. At the Abraham Marri mine section (pl. 1*B*), only 166 m of the lower part of the formation is measurable, and we included only 79 m of the upper part of the formation. However, all of the middle part of the formation is represented, and we recorded a thickness of 291 m.

The lithologic character of the Ghazij Formation in the Pir Ismail Ziarat area generally fits the regional description. The total thickness of the lower part of the Ghazij is probably unmeasurable, but it appears to be about half as thick as it is in the Sor Range. Type I sandstone bodies in the lower portion of the middle part of the formation are better developed in the Pir Ismail Ziarat area than anywhere else in Balochistan. At the Abraham Marri mine section, two green-weathering sandstone bodies are present in the middle part of the formation, and at least two more can be observed in the upper part of the formation, stratigraphically higher than the top of our measured section. This is a unique color for Ghazij sandstones south of the northwestern Sulaiman lobe. The contact between the middle and upper parts of the formation at the Abraham Marri mine section is interesting. Based on a general color change between mudrock units in the two parts, a sharp contact can easily be placed. But a problem arises when one views the upper part of the formation from a

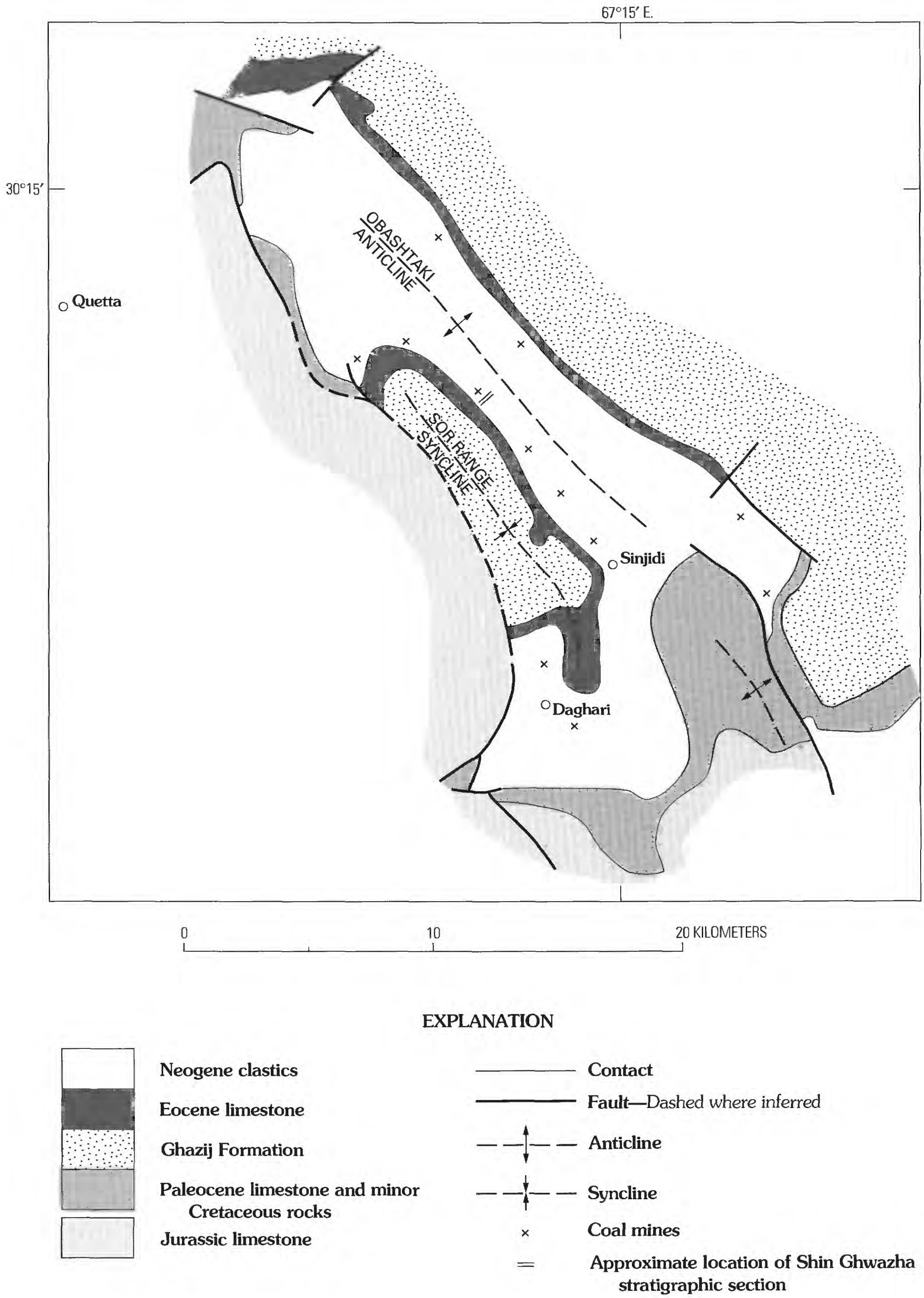


Figure 22. Generalized geology of Sor Range area. ×, coal mines. Quaternary alluvial deposits not shown. Modified from Hunting Survey Corporation (1960). See Kazim and others (1987) and Reinemund and others (no date) for smaller scale geologic maps of the Sor Range area.

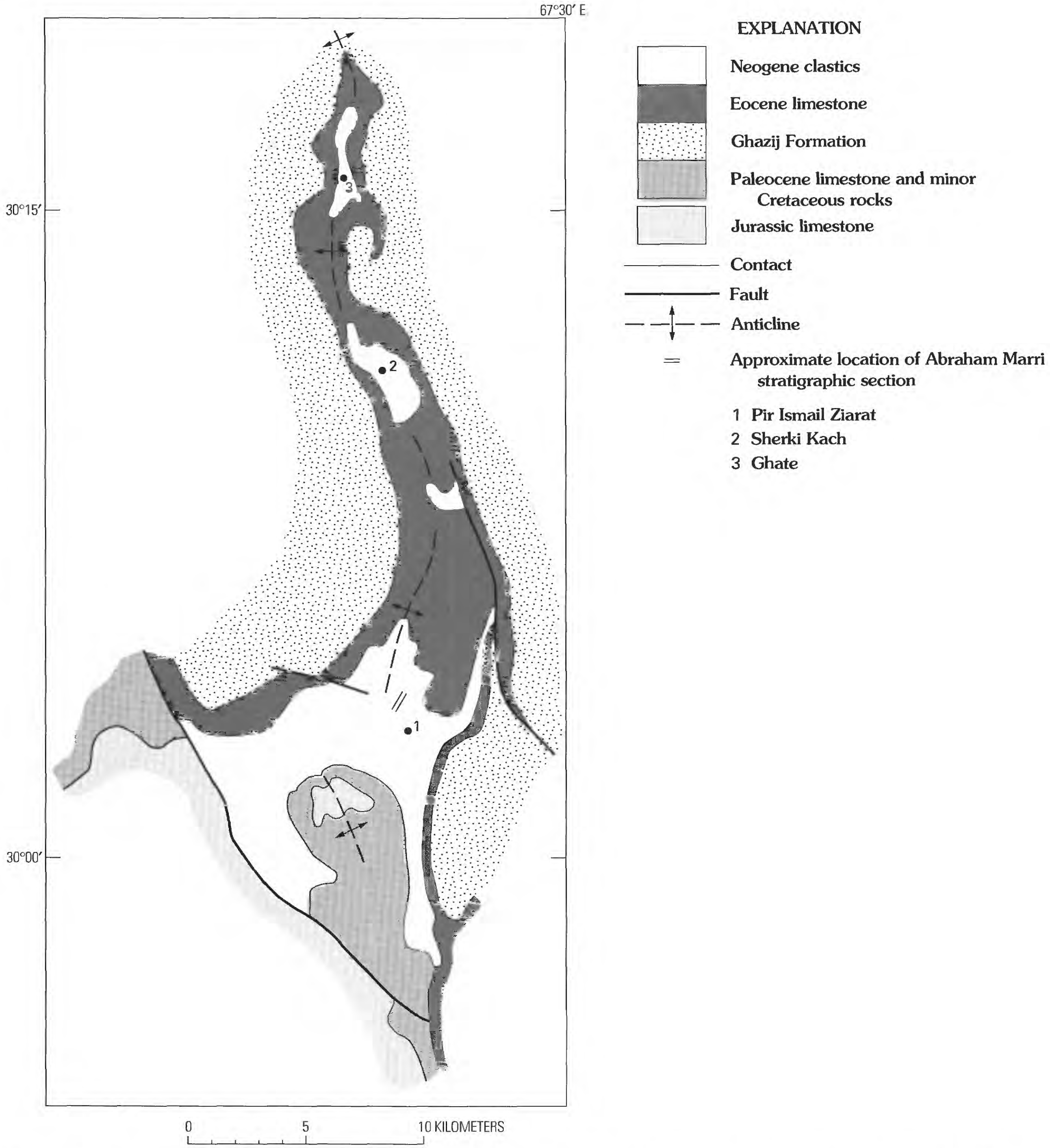


Figure 23. Generalized geology of Pir Ismail Ziarat-Sherki Kach-Ghate segment. Quaternary alluvial deposits not shown. Modified from Hunting Survey Corporation (1960).

distance. Several significant units of dark-gray mudstone, carbonaceous shale, and green sandstone are seen to be interbedded with the light-colored mudrock typical of the upper part. We suspect that either the contact in this area is highly transitional, or compressional tectonics has shuffled units from the middle part of the formation into the upper part of the formation.

North of the Pir Ismail Ziarat area, along the axial trace of the anticline, several large exposures of Ghazij Formation surrounded by limestone of the Kirthar Formation are present (fig. 23). The southernmost exposure, known as Sherki Kach, is about 13 km north of Pir Ismail Ziarat, and the northernmost exposure, known as Ghate, lies about 10 km farther to the north. Both of these exposures contain coal. At Ghate, the coal beds appear to be stratigraphically higher in the section than the coal beds near Pir Ismail Ziarat. Also, two or three green-weathering sandstone bodies are present, and these could correlate roughly with the green sandstone bodies in the upper part of the Ghazij at our Abraham Marri mine section, assuming that these latter bodies are in place. However, the Ghazij at Ghate also looks similar to the middle part of the formation to the northwest, near Kach.

MACH

The Ghazij Formation in the Mach area has been reported on since the late 1880's because of its coal content and the importance of this resource to the railroad that passes through the region (Griesbach, 1881; Blanford, 1882, 1883). The Ghazij in this area occupies the axial portion of a broad, ill-defined syncline that generally strikes north-northwest (fig. 24). Hunting Survey Corporation (1960) reported the formation to be 1,500–2,700 m thick. They also thought that the middle part of the formation was thick by regional standards, and Ahmad and others (1986) reported it to be more than 300 m thick. At our two measured sections, Gishtari Nala and Moghal mine (pl. 1*C* and 1*D*), we recorded a minimum of 241 m and 334 m for the middle part, and a minimum of 129 m and 114 m for the upper part, respectively.

In general, the lithology of the Ghazij Formation in the Mach area fits the regional description, but some features warrant mentioning. The lower part of the Ghazij has been deformed by compressional tectonics and is poorly exposed; its total thickness is probably unmeasurable. However, if the formation is as thick as Hunting Survey Corporation (1960) estimated, then the lower part of the formation must be abnormally thick. One of the truly unique features of the Ghazij in this area is the abundance of thin limestone beds in the middle part of the formation. These beds are quite common at the Moghal mine section. At this same section, two sandstone bodies in the middle part of the formation weather a unique green color. It is tempting to think of these two bodies as perhaps distal representatives of two similar sandstone bodies in the middle part of the formation in the Pir Ismail Ziarat area, 22 km to the northwest. As discussed in a previous section of this report, locally the upper part of the formation in the Mach area seems to have some sedimentary features that are more typical of the middle part of the formation. Hunting Survey Corporation (1960) came close to recognizing this fact in stating that the upper part of the formation was in many places either missing or unrecognizable.

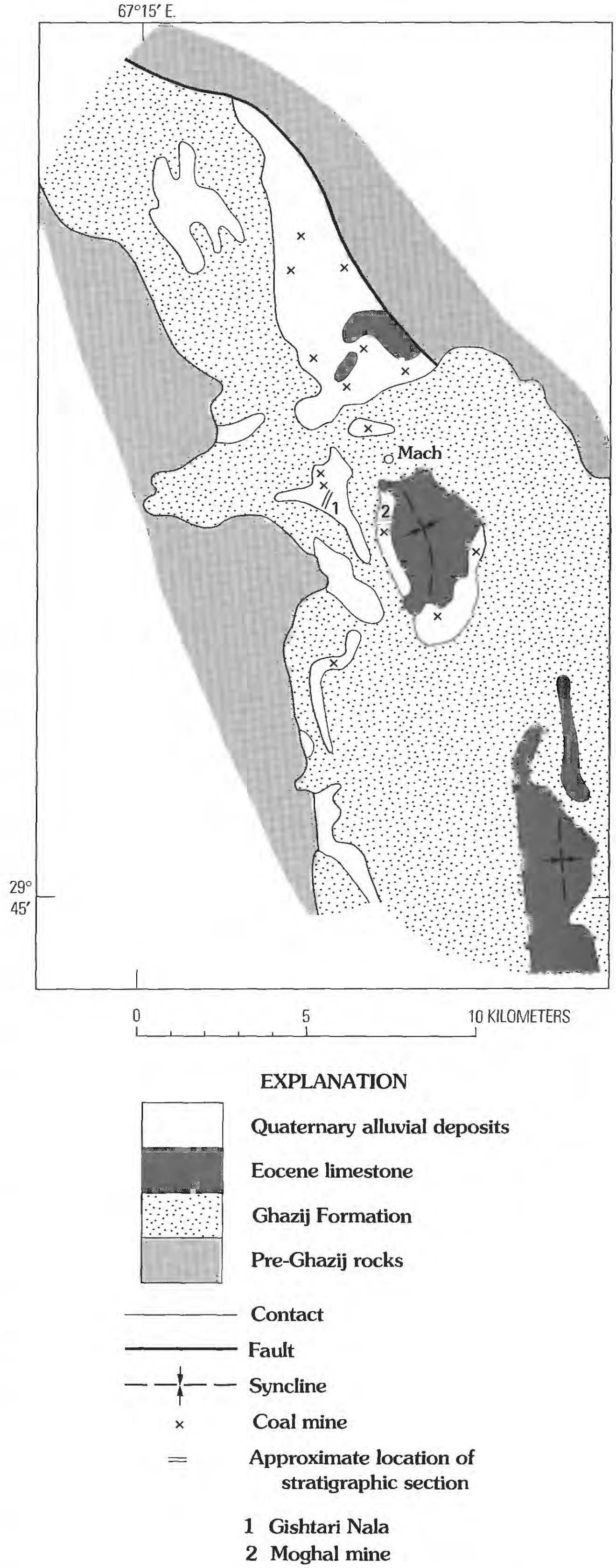


Figure 24. Generalized geology of greater Mach area. Modified from Hunting Survey Corporation (1960).

RODANGI NALA

A curious lithostratigraphic unit is present about 75 km southwest of Quetta. Vredenburg (1909) mentioned that coal had been reported in the area, and while falling short of confirming its presence, he did state that "Ghazij shales" were present. Actually, the Ghazij Formation is not present in this area, but what is present is a structurally complicated sequence of limestone and minor mudrock that contains at least three beds of coaly carbonaceous shale. Hunting Survey Corporation (1960) named these rocks the Rodangi Formation, and stated that the limestone looked like the Cretaceous Parh Limestone, and that the mudrock looked like the Ghazij; no mention was made of any coal. The limestone is dense (sublithographic) and medium bedded, weathers a cream color, and contains black-weathering chert lenses and rusty-weathering lenses and pods of foraminiferal limestone. The mudrock is calcareous, weathers greenish gray, and is present in sequences as thick as 6 m. Sandstone associated with the mudrock also weathers greenish gray. Rocks of the Jurassic Shirinab Formation unconformably underlie the Rodangi, and Eocene limestone, probably equivalent to the Kirthar Formation, unconformably overlies the Rodangi. Hunting Survey Corporation (1960) estimated the Rodangi Formation to be about 150–250 m thick, and they thought the unit might be late Paleocene to early Eocene in age.

We visited this area and measured a short stratigraphic section that includes three coaly carbonaceous shale horizons (fig. 25). The limestone in the section weathers yellowish light gray, is medium bedded with mostly flat bedding surfaces, and contains horizontal, pencil-sized, simple fossil burrows. Partings in the limestone units are as much as 13 cm thick, and consist of light-greenish-gray-weathering, very thin bedded limestone or limy mudrock. The mudrock in the section weathers light greenish gray, is calcareous, and contains ostracodes. The coaly carbonaceous shale units contain gray-weathering calcareous mudrock partings, and the units vary in thickness along strike. Exactly how the Rodangi correlates with the Ghazij is unclear, but the presence of coaly rocks intimately associated with relatively thick sequences of limestone is quite interesting from both a depositional environment and a paleogeographic aspect.

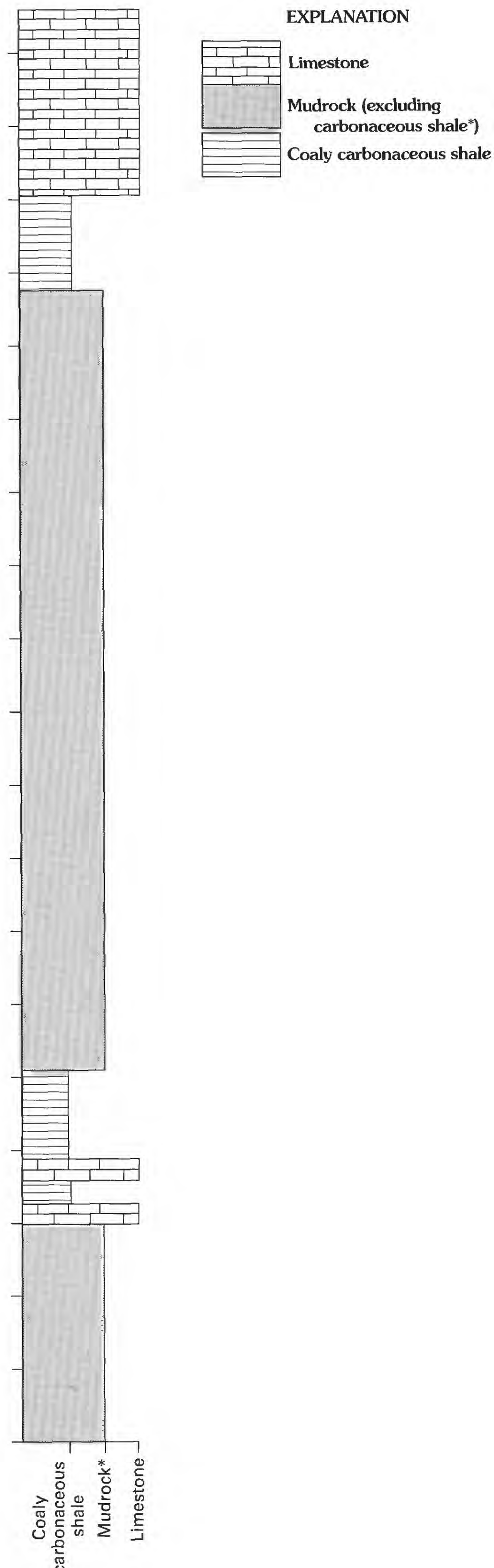


Figure 25. Stratigraphic section showing an interval of the upper Paleocene to lower Eocene(?) Rodangi Formation containing units of coaly carbonaceous shale. Scale in 1 m increments.

JOHAN

In the Johan area the Ghazij Formation crops out as an irregular, arcuate belt wrapping around the north end of the Kalat Plateau (fig. 26). South of this area, coal ceases to be a mentionable component of the Ghazij. Moreover, the three-fold division of the formation that is easily recognized in the Quetta region is less distinct in the Johan area. The upper part of the formation is clearly identifiable, and the base of the upper part is easily placed. But rocks below this stratigraphic level are poorly exposed and appear to have a nearly uniform lithology, so assigning a stratigraphic level

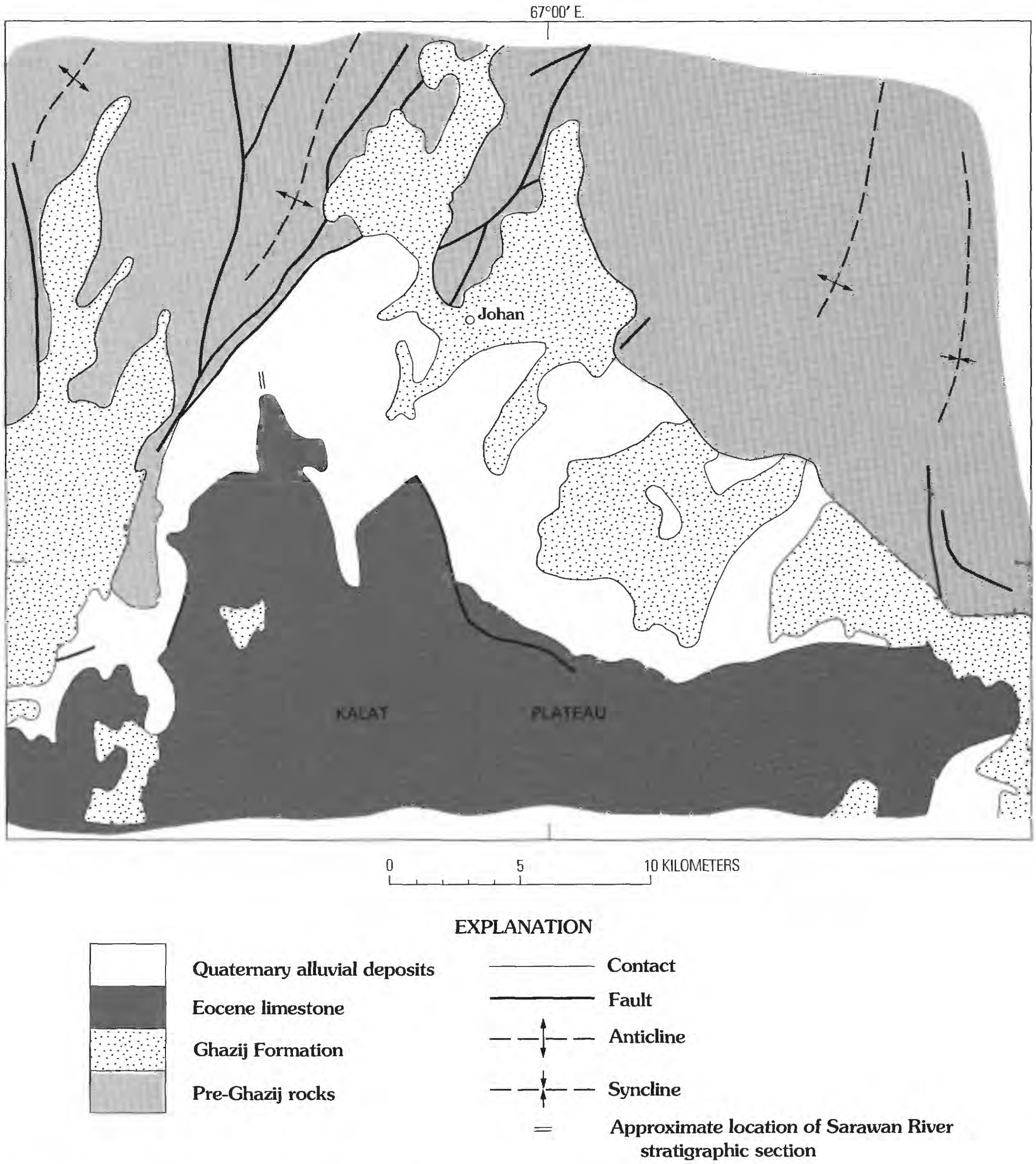


Figure 26. Generalized geology of the greater Johan area. Modified from Hunting Survey Corporation (1960).

that would separate a middle and lower part of the formation is difficult. Thus, we propose that in the Johan area, those rocks below the upper part of the formation be referred to as the main body of the Ghazij Formation. The upper part of the Ghazij in the Johan area appears similar to the upper part in areas to the north. The main body of the formation consists of a thick section of greenish-gray, calcareous mudrock with locally abundant fossil plant debris and secondary gypsum, and isolated tabular bodies of brown-weathering sandstone that display sharp upper and lower contacts and contain local, pellet-packed fossil burrows that resemble *Ophiomorpha*. The upper portion of the main body of the formation contains rare thin units of carbonaceous shale (generally less than 20 cm), very rare coal beds (generally less than 3 cm), and some fossil oyster shell fragments. This interval most likely corresponds to the middle part of the Ghazij in areas to the north. The total thickness of the formation in the Johan area might never be known with certainty, but past workers have estimated it to exceed 1,000 m (Shah, 1965; Ghaznavi, 1990). At the Sarawan River section (pl. 1*E*), we measured all 251 m of the upper part of the formation, and the top 413 m of the main body of the formation.

THE ALTERNATE NOMENCLATURE OF SHAH

Shah (1990) proposed a different nomenclature for lower Eocene rocks in northeastern Balochistan. He raised the term Ghazij to group status and subdivided it into three formations. In ascending order these are the Shaheed Ghat Formation, the Drug Formation, and the Toi Formation. Although Shah applied his scheme to rocks from Moghal Kot to Mach, all three of his type sections are in the Sulaiman Range, and his scheme has the most usefulness in certain areas of this region. Shah's Shaheed Ghat Formation is roughly equivalent to the lower part of the Ghazij Formation. The Drug Formation appears to be restricted to certain areas of the Sulaiman Range, and probably has no lithostratigraphic equivalent in the Ghazij. The Toi Formation is probably equivalent to the middle and upper parts of the Ghazij (fig. 27). Combining the middle and upper parts of the Ghazij Formation into one single formation might prove to be inconvenient if a significant unconformity is eventually identified between these two parts of the Ghazij. Shah's classification has not been widely accepted, and we prefer retaining the traditional subdivisions.

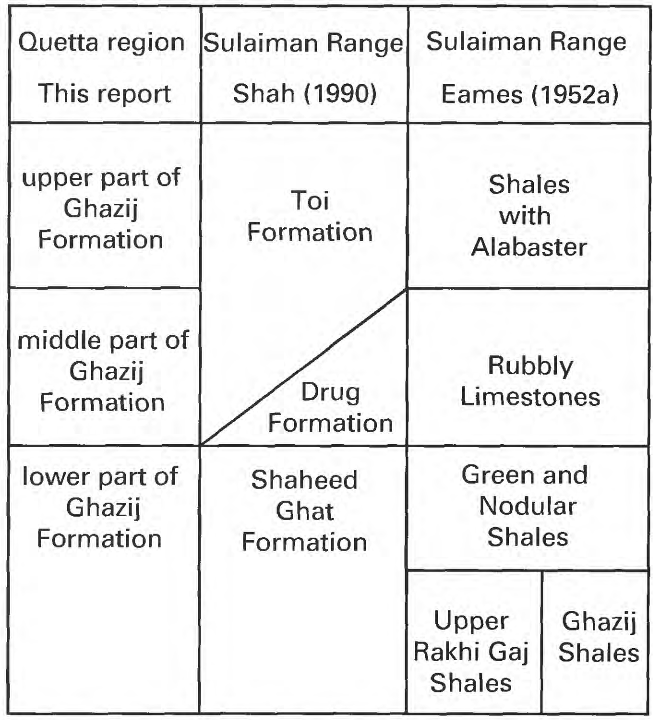


Figure 27. Comparison of three-part division of the Ghazij Formation in Quetta region with lower Eocene nomenclatures of Shah (1990) and Eames (1952a) in Sulaiman Range. No scale implied.

REGIONAL VARIATIONS OF THE GHAZIJ FORMATION

Beyond that part of the Axial Belt that borders the Sibi Reentrant, the Ghazij Formation begins to undergo facies changes that alter the lithologic characteristics of the formation. In some areas, this has led previous workers to propose different nomenclature schemes. Although we consider the areas described in this section to be within our general study area (fig. 1), only a few were visited by Warwick, and most of the information discussed was taken from the literature.

SULAIMAN RANGE

BALA DHAKA-BAHLOL-KINGRI BELT

Eighty kilometers east of Duki in the northeastern part of the Sulaiman lobe, or the south end of the Sulaiman Range, lies a northeast-trending belt of exposures of the Ghazij Formation that extends for about 65 km. The Ghazij near Bala Dhaka, near the southwest end of the belt, is reported by Hunting Survey Corporation (1960) to contain a minor amount of coal, and this is probably the southernmost locality for Ghazij coal in the Sulaiman Range. Evidently the Ghazij is poorly exposed here, for little has been reported concerning the characteristics of the formation in this area. To the northeast, near Bahlol, all three subdivisions of the Ghazij are present, and the middle part of the formation is probably thicker here than anywhere else in northeastern Balochistan (Hunting Survey Corporation, 1960). Shah (1990) reported that the Ghazij in this area looks similar to the formation's appearance near Duki. The middle part of the formation contains coal, and although the Ghazij is present in areas to the east, Bahlol represents the easternmost locality for coal in the formation. According to Hunting Survey Corporation (1960), a 150-m-thick unit of brown-weathering, cross-stratified, coarse-grained sandstone is present at the top of the formation. This sandstone unit is thus in the same stratigraphic position as the sandstone observed at the top of the formation just west of Harnai. Hunting Survey Corporation (1960) reported that the Ghazij ranges from about 1,500 to 2,900 m thick in the Bahlol area. All three subdivisions of the Ghazij are present at Kingri near the northeast end of the belt, but the lithologic details are different. The lower part of the formation is similar to that in areas to the west. The middle part of the formation is more than 300 m thick, and contains mudrock in the upper portion and abundant Type I and Type III sandstone bodies in the lower portion. The upper part of the formation is about 300 m thick and contains abundant Type III sandstone bodies, most of which are 12–18 m thick and medium to coarse grained. According to Hunting Survey Corporation (1960), the Ghazij is about 1,200 m thick in this area.

South of the Bala Dhaka-Bahlol-Kingri belt, in the Marri Bugti Hills near Dera Bugti, Hunting Survey Corporation

(1960) reported that the Ghazij Formation contains rocks consistent with their simple assemblage, that is, a shale-dominated sequence that contains some limestone units that increase in number upward, and minor sandstone. These workers also reported that the formation is thin in this area as compared to its thickness in areas to the west. The formation in the Marri Bugti Hills is also reported to contain some gypsum in its uppermost part (Hemphill and Kidwai, 1973).

RAKHI NALA AND ZINDA PIR

East and north of the Bala Dhaka-Bahlol-Kingri belt, the Ghazij Formation loses its three-fold divisional characteristic, and other subdivisions have been applied to lower Eocene strata. Eames (1952a) measured a 1,106-m-thick stratigraphic section of lower Eocene strata near Rakhi Nala about 67 km east of Bala Dhaka, and another 1,240-m-thick section of these rocks near Zinda Pir about 69 km east of Kingri. In ascending order, Eames divided the lower Eocene section at Rakhi Nala into Upper Rakhi Gaj Shales (he also included the very uppermost part of the Lower Rakhi Gaj Shales), Green and Nodular Shales, Rubbly Limestones, and Shales with Alabaster (fig. 28). At Zinda Pir, about 68 km to the northeast, he divided the lower Eocene section into Zinda Pir Limestones (upper part), Ghazij Shales, Green and Nodular Shales, Rubbly Limestones, and Shales with Alabaster.

Eames' descriptions of the upper three formations for both localities are as follows. The Green and Nodular Shales unit is a sequence of gray calcareous shale interbedded with layers of green nodular sandy shale, which becomes more common toward the top of the unit. The Rubbly Limestones unit is a sequence of interbedded calcareous gray shale and white-weathering nodular limestone. Some of the rocks contain foraminifers. Locally, the ratio of shale to limestone varies, as do the bed thickness and silt content of the limestone. The Shales with Alabaster unit consists mostly of green, gray, and brown calcareous shale with abundant thin limestone beds containing numerous fossil mollusks. At least two horizons of gypsum are present, one about 6 m thick near the top of the unit, and a thinner horizon about 61 m below that. In the Rakhi Nala area, the Upper Rakhi Gaj Shales are composed of green- and gray-weathering shale with very rare thin beds of limestone in the lower 18 m. Foraminifers are locally common. In the Zinda Pir area, the Ghazij Shales are also composed of green- and gray-weathering shale but lack the limestone beds in the basal part. In descending order, the Zinda Pir Limestones (upper part) consist of a discontinuous white-weathering limestone, a brown-weathering dense limestone, and 6–14 m of shale similar to the overlying Ghazij Shales.

The Zinda Pir Limestones (upper and lower parts) are possibly equivalent to the Paleocene Dungan Formation. Nagappa (1959) reported that the Rakhi Gaj Shales and

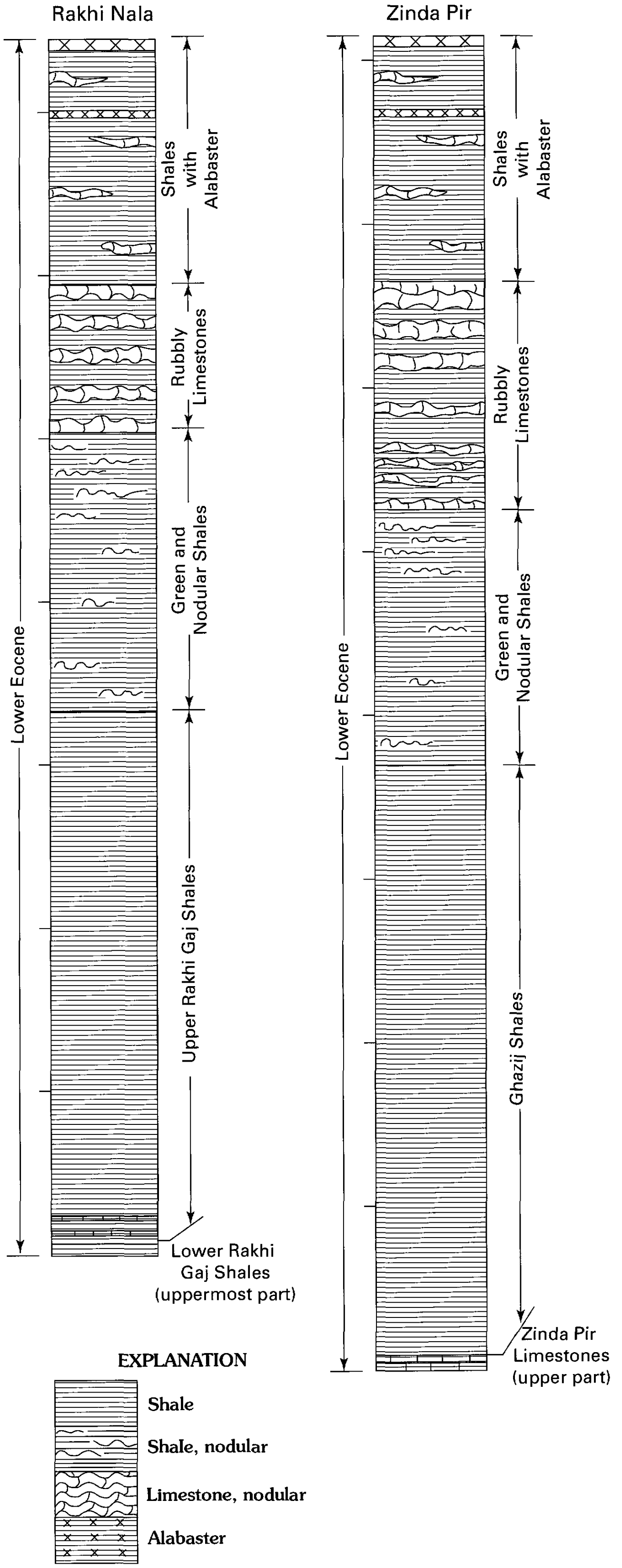


Figure 28. Stratigraphic columns for lower Eocene deposits at Rakhi Nala and Zinda Pir. Generalized from Eames (1952a). Vertical scale in 500-ft (approx. 150 m) intervals.

Ghazij Shales as described by Eames are equivalent. The Upper Rakhi Gaj Shales and Ghazij Shales, and the overlying Green and Nodular Shales are probably equivalent to the lower part of the Ghazij Formation to the west (fig. 27); the Rubbly Limestones probably has no lithostratigraphic equivalent in the Ghazij; and the Shales with Alabaster is probably equivalent to the upper part of the Ghazij. The coal-bearing middle part of the Ghazij Formation in the Quetta region is evidently not present in the Rakhi Nala and Zinda Pir areas. If an unconformity exists between the middle and upper parts of the Ghazij Formation, then the boundary between the Shales with Alabaster and the Rubbly Limestones in the Zinda Pir and Rakhi Nala areas might also be unconformable. Correlating the subdivisions of Shah (1990) with those of Eames (1952a) is difficult. Perhaps Shah's Shaheed Ghat Formation is equivalent to the Upper Rakhi Gaj Shales and Ghazij Shales, and the Green and Nodular Shales (fig. 27), the Drug Formation is equivalent to the Rubbly Limestones, and the upper part of the Toi Formation is equivalent to the Shales with Alabaster.

Qureshi and others (1987), in their study of the stratigraphy of the Sulaiman Range in the general vicinity of Rakhi Nala and Zinda Pir, presented yet another nomenclature for lower Eocene rocks in this area. They proposed including all of the lower Eocene strata in the Ghazij Formation, and divided it into three members. In ascending order these are: Rakhi Gaj Shale, Drug Limestone, and Baska Shale. This nomenclature was also used by Akhtar and Masood (1991).

MOGHAL KOT AND DRAZINDA

About 130 km north of Zinda Pir, in the Moghal Kot and Drazinda area, Hemphill and Kidwai (1973) divided the lower Eocene section, in ascending order, into Ghazij Shale and Baska Shale (fig. 29). They reported the Ghazij Shale to be about 2,740 m thick and divided it into two parts. The lower part consists of green- and dark-gray-weathering, locally carbonaceous mudrock and subordinate sandstone. The upper part consists of red- and maroon-weathering mudrock, with coarse-grained sandstone and conglomerate near the top. Foraminifers are locally common throughout the Ghazij Shale. The Baska Shale consists of 49–189 m of green- to greenish-gray-weathering mudrock that contains alabaster both as nodules and in beds as thick as 9 m. Near the base of the formation, the mudrock is sandy and weathers red and maroon, and the contact with the underlying Ghazij Shale is sharp where sandstone occupies the upper part of the Ghazij Shale. Locally, gypsiferous limestone containing large foraminifers is present near the top of the Baska Shale. Hemphill and Kidwai (1973) stated that the formation thins toward the north, and extends south along the east edge of the Sulaiman Range perhaps as far as Dera Bugti. Although Hemphill and Kidwai intended the Baska Shale to replace the Shales with Alabaster of Eames (1952a), the two type areas are separated by about 150 km. The reddish upper part of their Ghazij Shale might actually be equivalent to Eames'

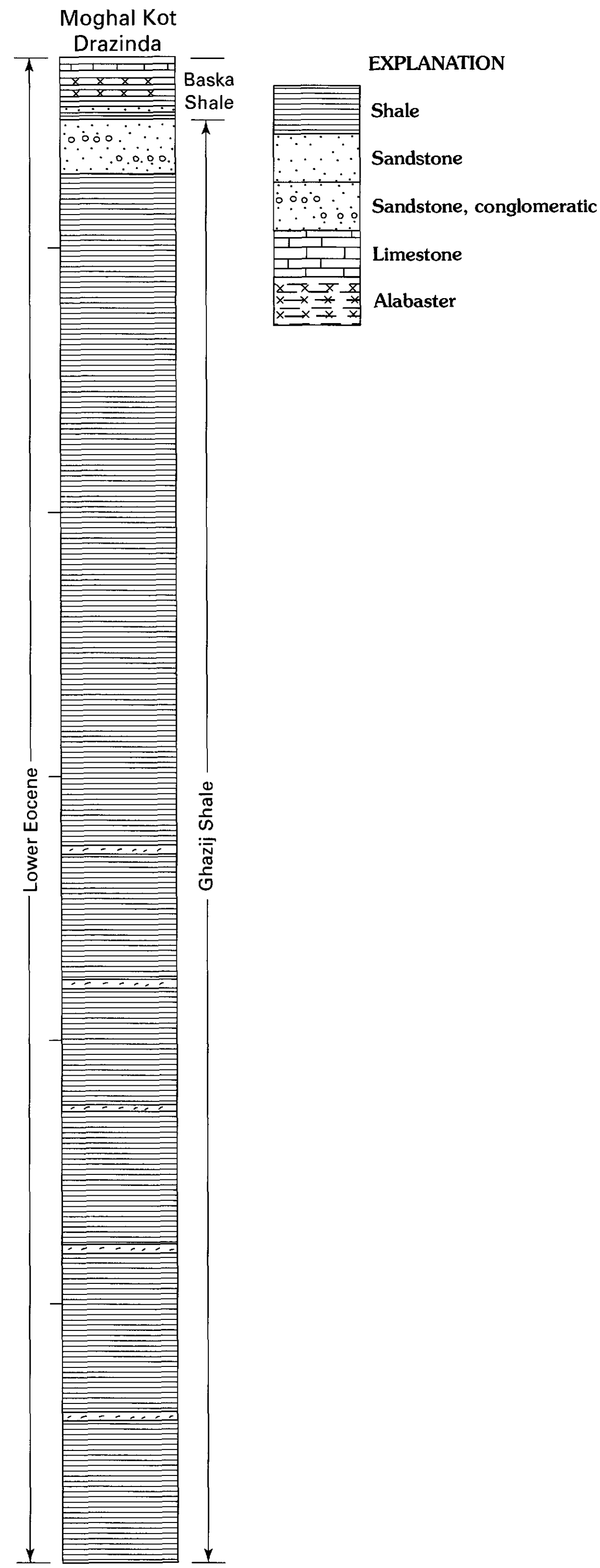


Figure 29. Lower Eocene stratigraphy in Moghal Kot and Drazinda areas. Modified from Hemphill and Kidwai (1973). Vertical scale in 500-m intervals.

Shales with Alabaster, and the Baska Shale could be a completely different unit. If this is the case, then the lower part of the Ghazij Shale of Hemphill and Kidwai would be equivalent to all of the lower Eocene strata below the Shales with Alabaster, as described by Eames.

KIRTHAR RANGE

Exposures of the Ghazij Formation are common in the northern Kirthar Range from Johan south to Karkh. Twenty-two kilometers south of Karkh, the southernmost exposure of Ghazij is truncated by a fault. South of this location rocks equivalent to the Ghazij were included in the Jamburo Group (Hunting Survey Corporation, 1960), but Fritz and Khan (1966) identified early Eocene foraminifers from well cuttings near Karachi and extended the term Ghazij into this area. On the west side of the Kirthar Range south of Surab, the Ghazij grades into the Upper Cretaceous to lower Eocene Gidar Dhor Group (Hunting Survey Corporation, 1960). In most of the Kirthar Range the Ghazij is underlain by the Dungan Formation and overlain by the Kirthar Formation, or their stratigraphic equivalents (Hunting Survey Corporation, 1960). However, in the vicinity of Surab, the Ghazij is underlain by the Gidar Dhor Group, or by formations older than this group.

The Ghazij in the Kirthar Range lacks a distinctive middle part such as it has in the Quetta region. In the Johan area we have divided the formation into a main body and an upper part, but south and east of this area the formation is dominated by dark-colored mudrock and is apparently indivisible. Although the Ghazij is usually dominated by mudrock in the Kirthar Range, a west-to-east decrease in grain size of the subordinate lithologies is apparent. Exposures in the western part of the range are more likely to include some conglomerate and sandstone, whereas exposures in the eastern part are usually limited to mudrock and limestone, or to just mudrock. For example, Hunting Survey Corporation (1960) described the Ghazij near Angira on the west side of the range as comprising shale with minor conglomerate, limestone, and sandstone—their complex assemblage. On the east side of the range between just south of Karkh and an area just north of Tang Na Pusht, they described the formation as containing mostly shale—their simple assemblage. Coal is not reported in the Ghazij south of the Johan area. In general, the thickness of the Ghazij increases from west to east. For example, the formation is reported by Hunting Survey Corporation (1960) to be 457 m thick near Angira and 762 m thick near Karkh. Thirty-five kilometers northeast of Karkh, on the east edge of the Kirthar Range, unpublished company data on file with the Geological Survey of Pakistan in Quetta cite the formation to have a minimum thickness of more than 1,200 m.

One of the most significant lithologic features of the Ghazij in the Kirthar Range is the conglomerate facies that locally dominates the formation in the Kalat-Surab area. This lithofacies is so distinctive that it has been assigned its own name, the Marap Conglomerate.

MARAP CONGLOMERATE

The name Marap Conglomerate was introduced by Hunting Survey Corporation (1960) to designate a thick sequence of conglomerate in the district of Marap, about 19 km northwest of Surab. They intended the Marap to have formational status, and defined the reference locality as the northwest edge of the Marap Valley. Shah (1977) later redefined the Marap Conglomerate as a member of the Ghazij Formation. According to Hunting Survey Corporation (1960) and Shah (1977), the Marap is about 910 m thick at the reference locality and is composed almost entirely of conglomerate. The rock weathers reddish brown and is poorly sorted. Clasts are well rounded, and consist of pebbles to boulders of gray, white, and pink limestone, and lesser amounts of maroon and green marl, green shale, and sandstone. Locally, the conglomerate is interbedded with shale, sandstone, and limestone that appear similar to rocks in other parts of the Ghazij Formation. Toward the east, the unit pinches out or grades into finer grained rocks of the Ghazij. In some areas, the Marap occupies the entire Ghazij interval; where it occupies less of the interval, it is found at various stratigraphic levels in the upper part of the Ghazij. Where the Marap occurs at the top of the Ghazij, it is overlain by the Kirthar Formation or its stratigraphic equivalent. Where the Marap takes up the entire Ghazij interval, it is underlain by a variety of units including the Shirinab Formation, the Parh Limestone, and the Gidar Dhor Group. The Marap is not present north of an area just south of Johan. No fossils have been recovered from the Marap, but it is assumed to be early Eocene age because of its association with the Ghazij.

HARBOI HILLS

The Marap Conglomerate Member is well exposed and easily accessible on the west side of the Harboi Hills, 16 km east of Kalat. Here, the unit occupies the upper part of the Ghazij interval and crops out on the west side of a breached, northeast-trending anticline. We measured a stratigraphic section of the Marap in this area and found the main mass of the unit to be 286 m thick (fig. 30). However, the conglomerate is interbedded with finer grained rocks of the Ghazij 49 m below and 28 m above the main mass. The top of the main mass lies 56 m below the base of the Kirthar Formation, and a sequence of green- and red-weathering mudrock, 29 m thick, is present at the top of the Ghazij. On the east side of the anticline, several kilometers away, no conglomerate is present in the Ghazij, so the Marap must pinch out or grade into finer grained rocks over this distance.

Exposures of the Marap weather light to dark brown, and where thick intervals are well exposed, the unit is composed of amalgamated sequences of tabular to lenticular bodies averaging 2 m thick, separated by finer grained rocks (fig. 31). Some inclined surfaces are present. The conglomerate is poorly sorted, but a few exposures display crude horizontal stratification and normal grading. Most of the conglomerate is clast supported, but intervals of matrix-supported rock are common. Pebbles are the most common size clasts, but cobbles are present and boulders are rare. The clasts are composed mostly of medium- to light-gray-weathering limestone, with lesser amounts of yellow- or brown-weathering chert. Limestone clasts are mostly well rounded; chert clasts are usually subrounded to subangular. Matrix material is poorly sorted, fine- to coarse-grained sandstone composed of limestone and chert grains. Locally, pebbly sandstone beds are interbedded with the conglomerate. These rocks are medium to very coarse grained, have a composition similar to that of the conglomerate matrix, and are commonly small scale, trough cross stratified.

The conglomerate in the Harboi Hills appears very similar to the conglomerate in the Sor Range, 137 km to the north. However, the stratigraphic position and depositional architecture of the conglomerates are different. In the Harboi Hills, the Marap is wedge shaped and occupies much of the upper part of the Ghazij, whereas in the Sor Range the conglomerate is more tabular in shape and restricted to the base of the upper part of the formation.

SURAB

Another well-exposed sequence of Marap Conglomerate Member is located in a south-facing slope near a microwave station about 8 km south of Surab. The unit appears similar to that in the Harboi Hills but subtle differences can be observed. Overall, the conglomerate near Surab is somewhat coarser grained than that in the Harboi Hills, and boulder-size clasts are more common. Clasts of red chert and quartzite, both of which are rare in the Harboi Hills, are common near Surab. In addition, finer grained intervals separating amalgamated sequences of conglomerate are less common near Surab than in the Harboi Hills, and where present, they are thinner.

The top of the Ghazij interval near Surab is mostly covered by limestone debris from the overlying cliff of Kirthar Formation, but red-weathering mudrock can be observed in the uppermost few meters of the formation; locally, the Kirthar is reported to rest directly on the Marap. The Surab site is located at the west end of a sinuous, generally east trending escarpment that is held up by the Kirthar. When the escarpment is viewed from a distance, the Marap

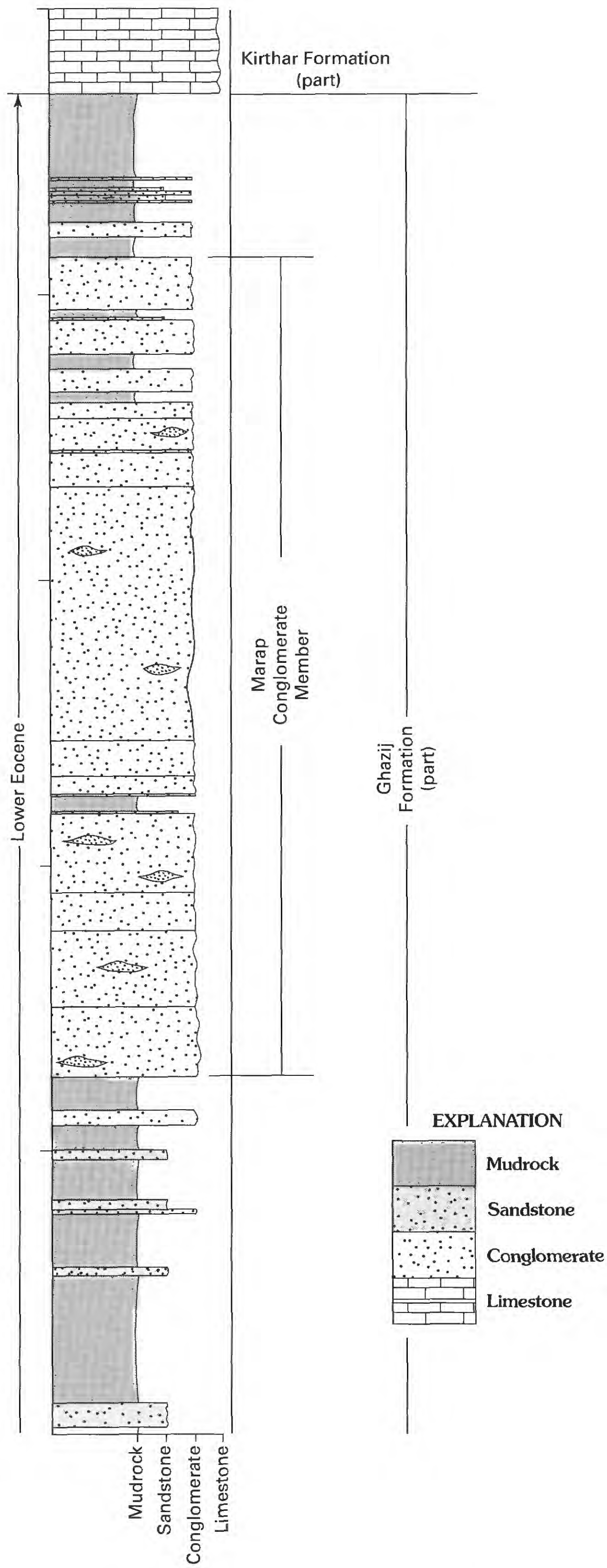


Figure 30. Stratigraphic section of the Marap Conglomerate Member of the Ghazij Formation in the Harboi Hills 16 km east of Kalat. Vertical scale in 100-m intervals.

Figure 31. Typical exposure of Marap Conglomerate Member of the Ghazij Formation in the Harboi Hills. Architectural elements include amalgamated tabular sandstone bodies and accretion surfaces. Total conglomerate package shown in photograph is about 12 m thick.

is seen to thin toward the east over a distance of several kilometers.

The Geological Survey of Pakistan has measured a stratigraphic section of the Ghazij in this area and reported it to be 426 m thick (oral commun., 1991). Although conglomerate is present throughout most of the interval, this lithology decreases downward and only the top 183 m of the formation is composed more or less totally of conglomerate, and warrants the name Marap.

SIBI TO THE INDUS RIVER

All the information on the Ghazij Formation east of the Axial Belt comes from subsurface data. In 1952 gas was discovered in lower Eocene strata in the vicinity of Jacobabad, and since that time electric logs and cutting records from numerous exploration wells have provided data that characterize this part of the stratigraphic section. From these data two important observations can be made: (1) almost no detrital rocks coarser grained than siltstone are present, and (2) a significant amount of limestone is locally present in the lower part of the sequence. Figure 32 shows the lower Eocene section as interpreted from subsurface data in the Sui No. 1 well. This sequence is typical for the area, and the lithostratigraphic terms assigned by petroleum geologists working in the area are shown. Lower Eocene strata are overlain by the Kirthar Formation, and are underlain by rocks of the Paleocene Ranikot Group, a term correlated into the area from Sindh Province to the south. In ascending order, the lower Eocene sequence comprises "Sui Main Limestone" (this is the major gas reservoir in the area), Ghazij Shale (uncharacteristically thin), "Shale with Nodular Limestone" (the lower part of which locally contains the "Sui Upper Limestone"), and the "Lower Alabaster Shale" (despite the fact that gypsum is rarely present). Figure 33 shows the areal distribution of drill-hole data in the vicinity of Jacobabad that was available to us. Three oil and gas wells northwest of the village of Sui (Sui No. 1, Uch No. 1, and Zin) encountered the Sui Main Limestone; other wells in the region did not. This pattern, supported by a simple north-south cross section (fig. 34), demonstrates that the presence of the Sui Main Limestone is restricted to a specific area. This isolated patch of limestone surrounded by shale would undoubtedly provide a nearly perfect stratigraphic trap for hydrocarbon accumulation. Another well, Pak Pet Ltd and Hunt No. 1, 150 km to the southwest, encountered limestone at the same stratigraphic level as the Sui Main Limestone. The limestone in this well is probably part of a patch similar to that of the Sui Main Limestone. The Sui Main Limestone was probably deposited on a carbonate platform that was isolated in the middle of the early Eocene Indus Foreland Basin. Perhaps the position of this feature was somehow controlled by differential movement associated with an ancestral

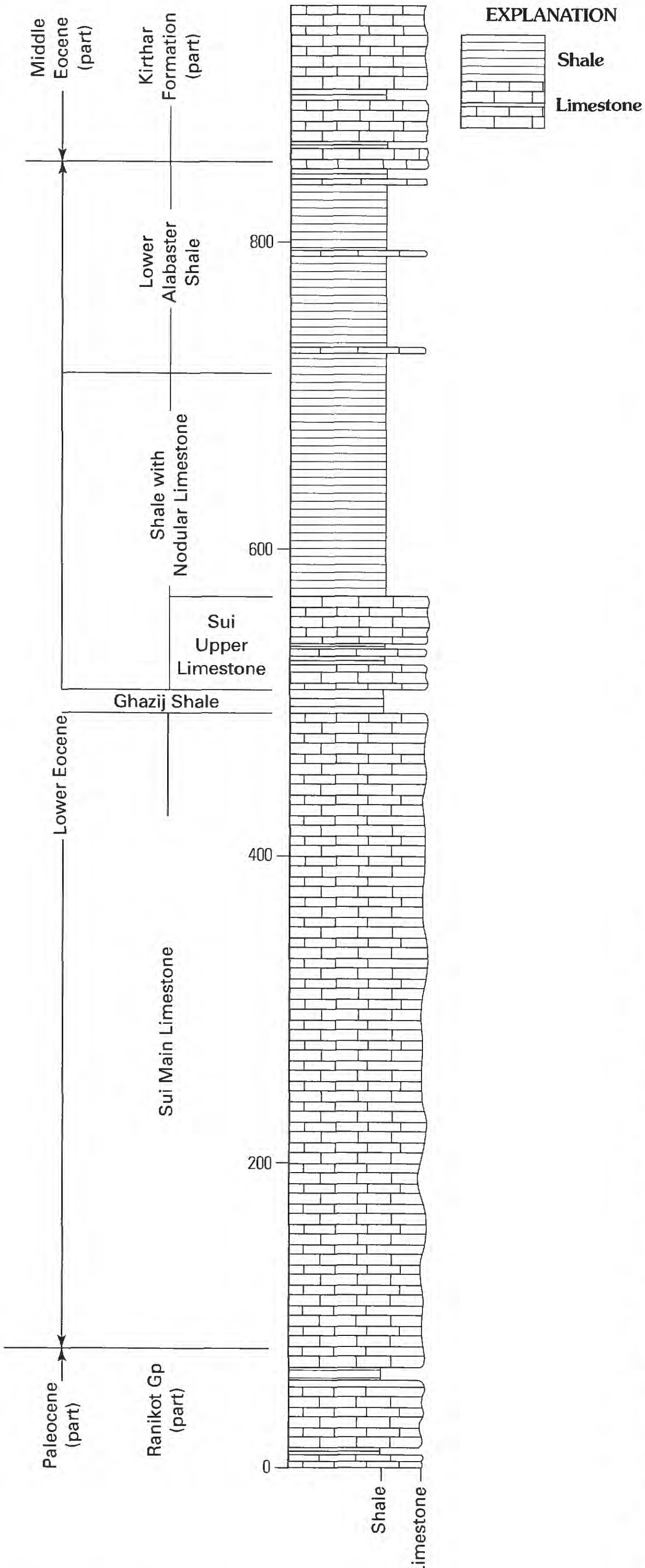


Figure 32. Stratigraphic section of lower Eocene rocks encountered in drill hole Sui No. 1. See figure 33 for location. Data provided by the Geological Survey of Pakistan. Vertical scale in meters.

version of the Jacobabad high, a subsurface structural element that is now prominent in the area (fig. 7).

The lithologies represented in the lower Eocene sequence in the Sui area seem to reflect an interfingering of eastern and western depositional influences within the Indus Foreland Basin. For example, the Sui Main Limestone is probably related to depositional conditions that were present along the east side of the basin, whereas the Ghazij Shale is more closely associated with depositional conditions that existed along the west side of the basin.

PETROGRAPHIC CHARACTERISTICS OF THE GHAZIJ FORMATION

Petrographic information concerning the Ghazij Formation in this report comes from three sources: (1) observations recorded from the viewing of thin sections of sandstone samples, (2) analysis of heavy-mineral separations obtained from sandstone samples, and (3) clast counts of conglomerate units. More generalized petrographic information based on hand-sample observations are available in Hunting Survey Corporation (1960).

SANDSTONE PETROGRAPHY

Only two petrographic studies of sandstones from the Ghazij Formation have been published to 1997. Kazi (1968) reported on 10 sandstone samples from the middle and upper parts of the formation near Harnai. To study the components of these rocks, Kazi disaggregated each of them with hydrochloric acid, passed the resulting fragments through a series of sieves, and mounted a selected fraction on glass slides. With the use of a binocular microscope, he reported that quartz made up 60 percent of the detrital grains from the middle part of the formation and 55 percent of the grains from the upper part of the formation. Rock fragments, the next most abundant component, made up 15 percent of the grains from the middle part and 30 percent from the upper part. These latter components represent mostly extrusive igneous rocks. The fact that carbonate grains were not reported is probably the result of their solution by the acid that Kazi used to break down his samples. With the use of a petrographic microscope, Kassi (1986) studied thin sections of 10 sandstones collected at several sites in the general vicinity of Quetta, and reported that in the sections he examined, rock fragments were the most common detrital grains. Limestone made up from 12 to 98 percent of the grains. Chert made up 3–60 percent of the grains and appeared red or gray in plane light. Some chert grains contained spherical structures (radiolarian?). Subordinate amounts of basic volcanic rock grains were also present. In addition to the rock fragments, quartz grains made up 0.4–14 percent of the grains and feldspar

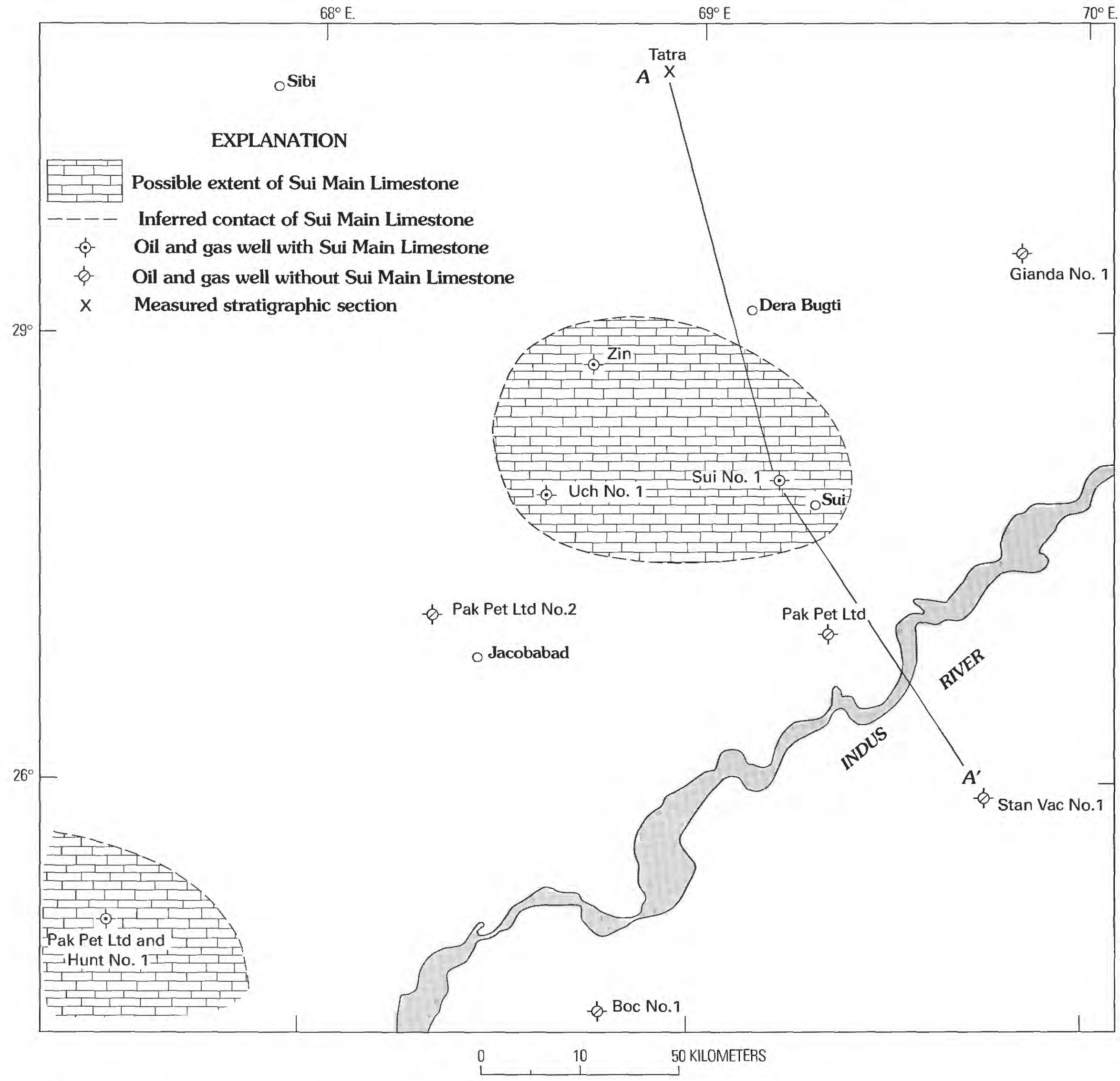


Figure 33. Areal distribution of some drill holes and possible distribution of Sui Main Limestone, greater Jacobabad region. Map modified from Kemal (1964) and Shah (1965).

(mostly plagioclase) made up less than 2.6 percent of the grains. Rarely present were reddish-brown biotite, and blue, yellow, or green chlorite. Calcite cement accounted for 7–35 percent of the rocks.

As part of our study of the Ghazij, we made thin sections of 31 sandstone samples collected at Kingri (one from the middle part of the formation and two from the upper part), Duki (two from the middle part), Pir Ismail Ziarat (four from the lower part, nine from the middle part, and one from the upper part), Sor Range (one from the middle part and three from the upper part), Mach (four from the middle part and one from the upper part), and Johan (three from the main body of the formation). The samples collected from the last four areas listed were taken from stratigraphic sections that we measured in those areas, and the exact geographic and stratigraphic positions of these samples appear in the appropriate publications cited previously in this report in the section on principal reference sections. Clearly, 31 samples collected over an area of thousands of square kilometers do not constitute an adequate petrographic study of Ghazij sandstones. However, this "quick look" does confirm what is already reported about Ghazij sandstones from hand-sample observations, and it does reveal some important petrographic trends.

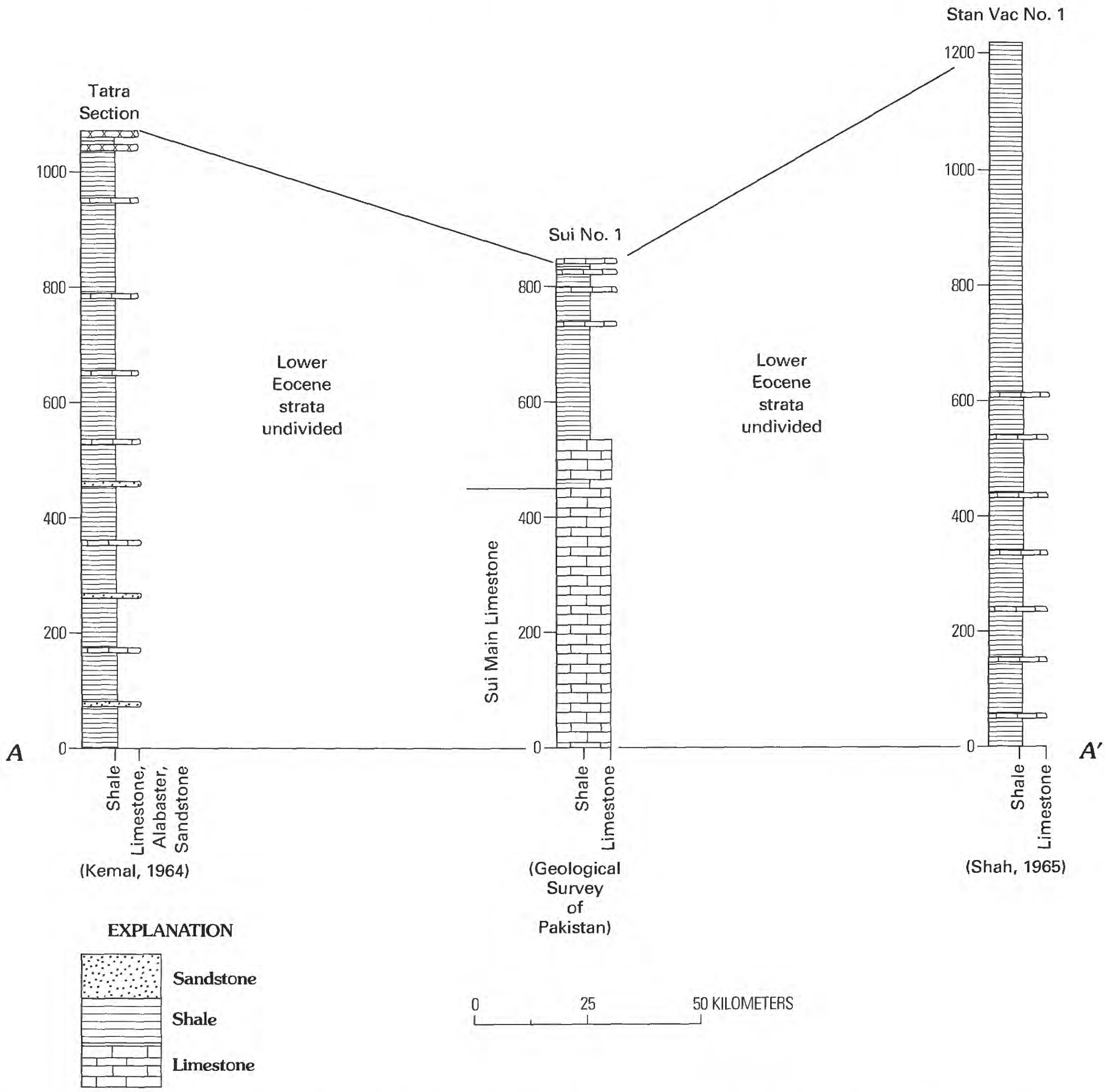


Figure 34. Cross section showing isolated character of the Sui Main Limestone. See figure 33 for line of section. Vertical scale in meters.

The rocks were impregnated with blue-dyed epoxy, and the sections were stained for calcite, potassium feldspar, and iron. The red stain for calcite did not take well, making the distinction between calcite and dolomite difficult. However, X-ray analysis of selected samples did not indicate the presence of dolomite, so we assume that all of the carbonate is limestone. The yellow stain for potassium feldspar was never observed, nor were any other types of feldspar identified. Moreover, X-ray analysis did not indicate the presence of any feldspar. The blue stain for iron-bearing carbonate was useful in identifying ferron calcite, which was present as detrital grains and as a cementing agent in some thin sections.

Examination of the sections revealed that all the components could fit into one of 10 categories:

cryptocrystalline limestone
microcrystalline limestone
sparite
chert (non-green)
chert (green)
quartz
rock fragments (non-green)
rock fragments (green)
other
cement

At least 300 framework grains were identified and counted on each thin section, and the following information is based on these observations.

Cryptocrystalline limestone.—These well-rounded, dark, cloudy grains are the most common component of the rocks. Although crystallinity is difficult to detect, some areas of the grains do show interference colors typical of carbonates. Outlines of microfossils, especially foraminifers, are commonly observed within the grains. These grains are interpreted as fragments of lime mudstone or micrite.

Microcrystalline limestone.—These subrounded grains probably represent fragments of finely crystalline limestone.

Sparite.— This material is often difficult to distinguish from sparry cement but appears as subrounded grains optically separate from the cement. We interpret these grains to be fragments of coarsely crystalline limestone.

Chert (non-green).—Almost all the subangular to subrounded chert grains appear transparent in plane light.

Chert (green).—These grains are extremely rare and are present only in those few sandstones that appear green in hand specimens.

Quartz.—Almost all the subangular quartz grains are monocrystalline, but rare grains are polycrystalline; all the grains display undulatory extinction.

Rock fragments (non-green).—Most of these subangular to subrounded grains are probably fragments of basic extrusive rock, but some are undoubtedly fragments of argillaceous sedimentary rock.

Rock fragments (green) .— These grains are less abundant than the non-green varieties and are most common in rocks that appear green in hand specimens. Almost all of these grains are assumed to be fragments of basic extrusive rock.

Other.—Included in this category are (1) detrital microfossils filled with microcrystalline calcite, (2) green detrital chlorite, and (3) translucent to opaque fragments of brown unidentifiable material. None of these grains are common. Some microfossils are present in almost all of the rocks; the chlorite was only observed in rocks that appeared green in hand specimens; and the dark-colored unidentifiable material is rare but is more common in the finer grained sandstones. An exception to this latter statement is a medium-grained sandstone from the Johan area that contains an abundance of such material.

Cement.—All the rocks are cemented with coarsely crystalline calcite, and some of this is ferron calcite. Matrix material with a green cast, present in very small amounts and thus too rare to warrant a separate category, was counted with the cement.

Figures 35 and 36 are photomicrographs showing the grains in some of our thin sections.

Plotting the results of our observations on a traditional quartz-feldspar-rock (QFR) triangular diagram is inappropriate because we identified no feldspars in our thin sections. Therefore, we chose to plot our data on a limestone-quartz-rock (LQR) diagram (fig. 37). Because we believe that the non-green chert grains came from the same rock source as the limestone grains, we included the relatively small number of these chert grains (most rocks averaging about 8 percent) with the limestone grains when constructing our LQR diagrams.

As hand-specimen observations indicate and the previous study by Kassi (1986) confirms, most of the grains in Ghazij sandstones are limestone (fig. 37). Except for the Duki and Kingri samples, and two green sandstone samples from Pir Ismail Ziarat, limestone grains in the sandstones range from 51 to 98 percent with an average of nearly 80 percent. These values are for framework grains; when the calcite cement is also considered, the amount of calcium carbonate contained in these rocks is quite high. Because limestones are usually defined as containing greater than 50 percent calcium carbonate, these rocks are actually clastic limestones or limy sandstones rather than just sandstones (unqualified) as we traditionally think of them. At first we considered using the term calcarenite, but this term allows for the inclusion of limestone fragments that formed within the environment of accumulation (intraclasts). Because we believe that these grains originated outside of the environment of accumulation (extraclasts) as a result of erosion of older limestone units, we prefer the term calclithite, which limits the grains to this origin. Another term that could be applied to these rocks is lime grainstone. As shown on a triangular diagram of limestone types (fig. 38) with cryptocrystalline limestone, microcrystalline limestone, and sparite on the corners, micrite is the most common limestone grain, followed by finely crystalline limestone and coarsely crystalline limestone.

The Duki and Kingri samples contain a surprising amount of quartz (fig. 37). Samples from Duki and Kingri average 69 and 88 percent quartz, respectively. Our findings support the high percentage of quartz in the middle part of the Ghazij at Duki as reported by Shah (1990). The samples from these two areas are best classified as litharenites and sublitharenites, respectively.

The two samples of green sandstone collected from two separate sandstone bodies in the middle part of the Ghazij at the Abraham Marri mine section near Pir Ismail Ziarat are interesting. Thin sections reveal a high percentage of rock fragments when compared to other Ghazij sandstones (fig. 37). Rock fragments average 40 percent and limestone grains average 36 percent. Of the rock fragments, non-green varieties average 59 percent and green varieties average 41 percent. One of the sandstones contains 8 percent chert, all of which is non-green; the other sample contains 18 percent chert, and 85 percent of this is green. Also present are about 3 percent detrital chlorite grains. The green color of the samples results from the high percentage of green rock fragments, green chlorite, and green chert.

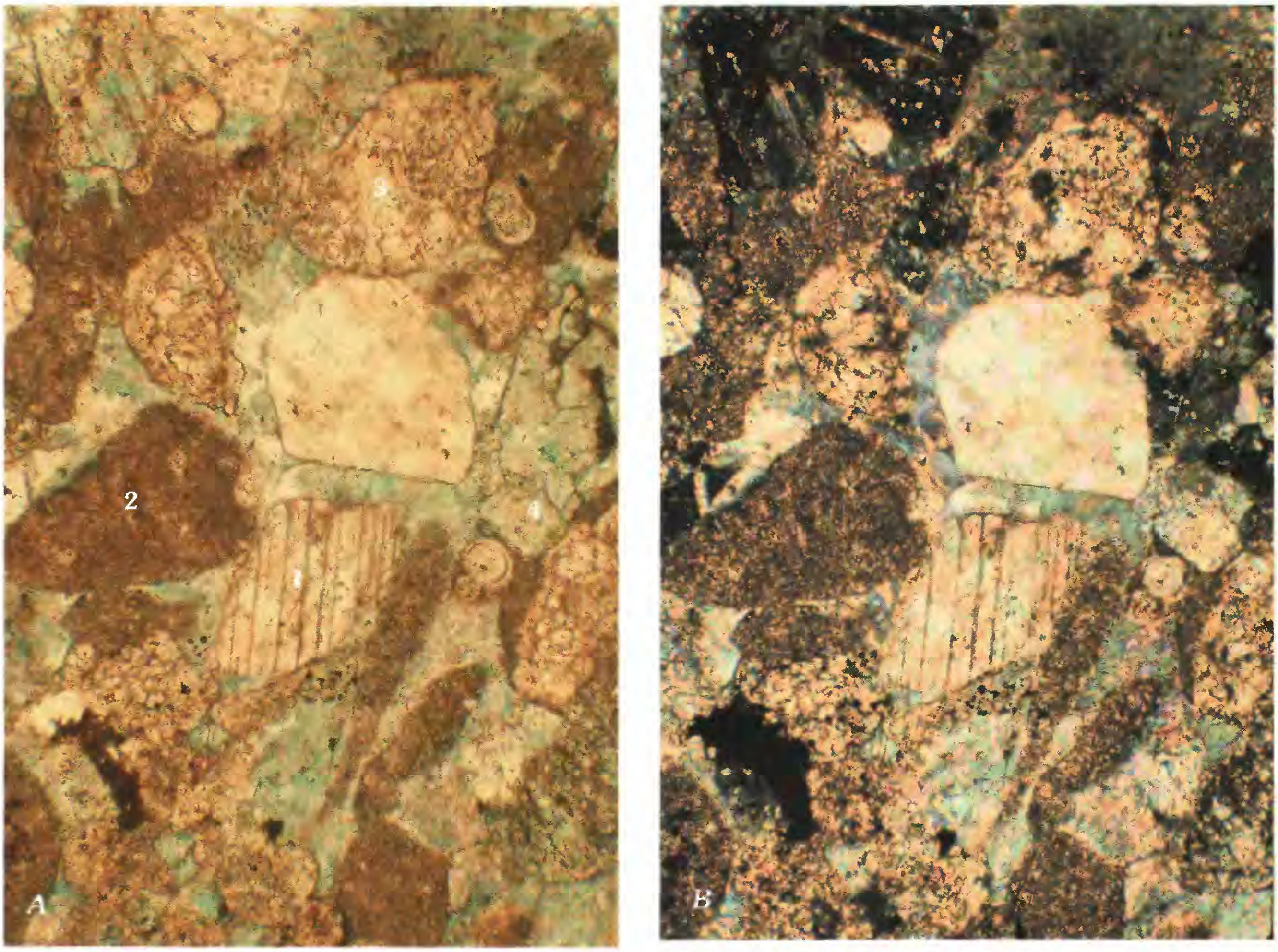


Figure 35. Photomicrograph of thin section cut from sandstone sample A-12-90 collected at Abraham Marri mine stratigraphic section near Pir Ismail Ziarat (Johnson and Khan, 1994b) showing typical limestone grains. *A*, plane light; *B*, crossed nicols; field length 0.87 mm. Specific grains are 1, sparite (twinned); 2, cryptocrystalline limestone; 3, microcrystalline limestone; 4, ferron calcite cement stained blue. Note the many microfossils in the cryptocrystalline limestone.

HEAVY MINERALS

We submitted 30 sandstone samples for heavy-mineral separation. These samples were taken from the same rocks that were thin sectioned for petrographic examination. The samples were crushed and sized using standard methods, and the 50- to 200-mesh fraction added to heavy liquids, either sodium polytungstate or lithium polytungstate. Prior to mounting the recovered material on glass slides (without cover slips), some samples were X-rayed.

Based on microscopic observations and X-ray analysis, the following minerals were identified:

amphibole (?)
apatite
barite
calcite
chlorite
dolomite
ilmenite
magnetite
olivine (?)
pyroxene
spinel group
quartz
zircon (trace)

Of particular interest is the presence of a specific mineral within the spinel group. Using a scanning electron microscope (SEM), we were able to confirm the presence of chromite in samples from the Sor Range, Pir Ismail Ziarat, and Mach (L.F. Ruppert, oral commun., 1994). Chromite was particularly abundant in the samples from Pir Ismail Ziarat, and both high aluminum and high aluminum and magnesium types were detected. Samples from Duki and Kingri did not contain chromite, and the samples from Johan were not studied with the SEM. The SEM work also revealed that some of the calcite and quartz grains have framboids of iron-bearing minerals (hematite?) on their surfaces, which might explain why these two minerals ended up among the more traditional heavy minerals.

Kassi (1986) also detected heavy minerals in the sandstones he studied, and he reported the presence of chromite, tourmaline, and apatite.

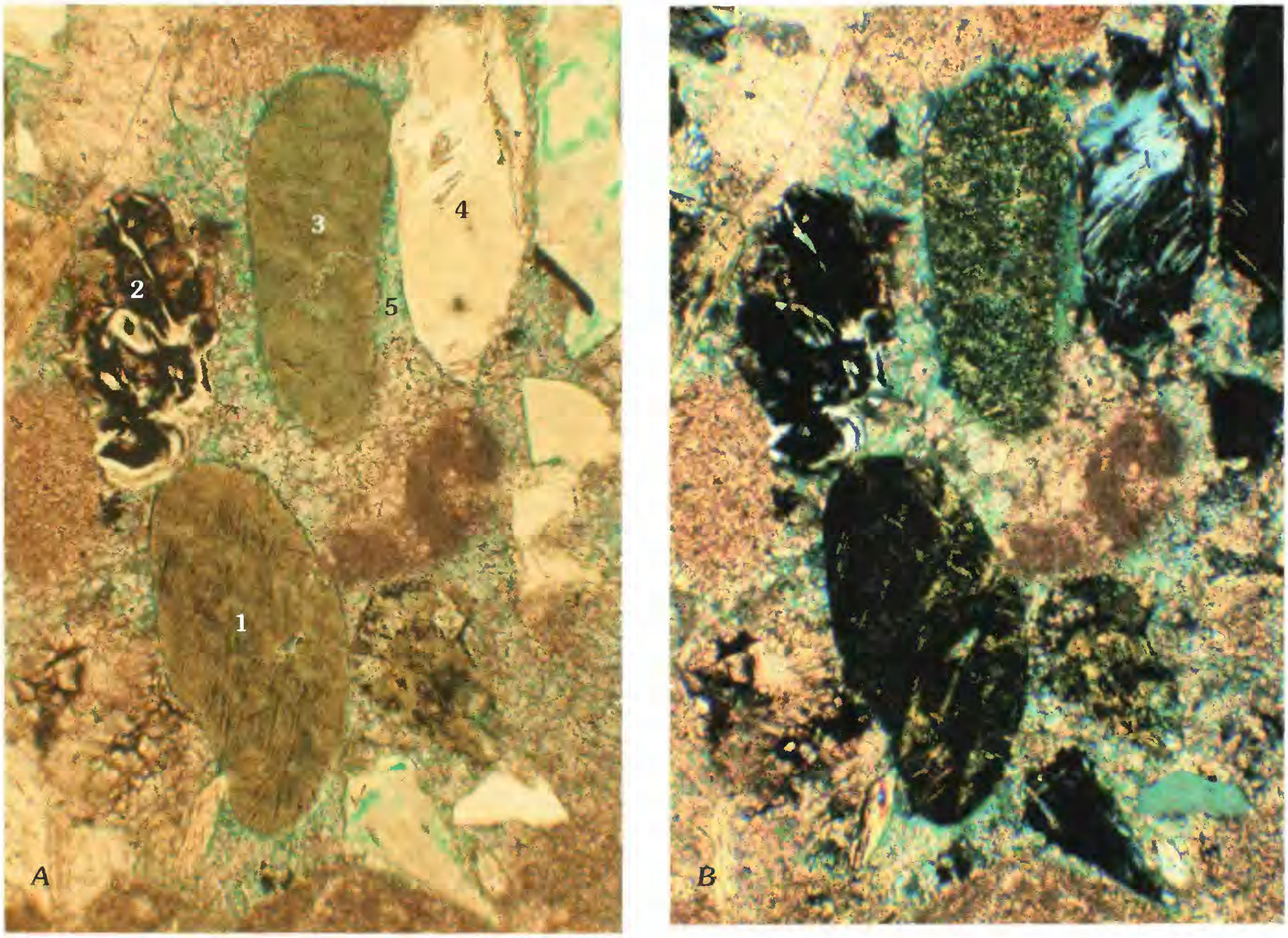


Figure 36. Photomicrograph of thin section cut from sandstone sample A-26-90 collected at Abraham Marri mine stratigraphic section near Pir Ismail Ziarat (Johnson and Khan, 1994b) showing typical green lithic grains. *A*, plane light; *B*, crossed nicols; field length 1.08 mm. Specific grains are 1, green rock fragment; 2, non-green rock fragment; 3, green rock fragment (chert?); 4, non-green rock fragment; 5, ferron calcite cement stained blue.

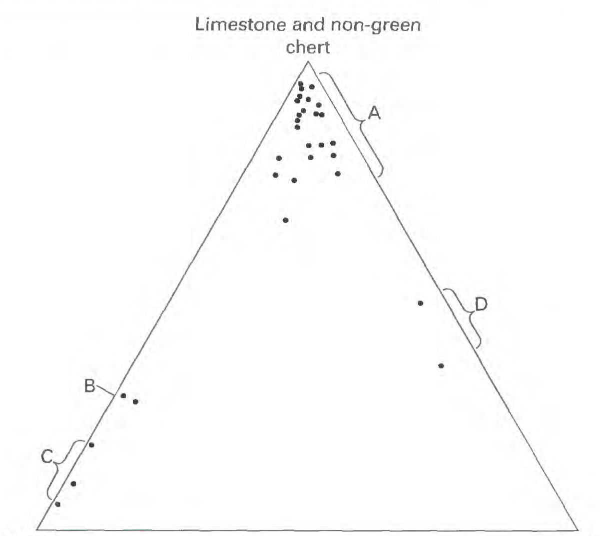


Figure 37. Limestone and non-green chert, quartz, and rock (LQR) diagram with points representing all sandstone thin sections studied. A, Sor Range, Pir Ismail Ziarat (non-green sandstones), Mach, and Johan; B, Duki; C, Kingri; D, Pir Ismail Ziarat (green sandstones).

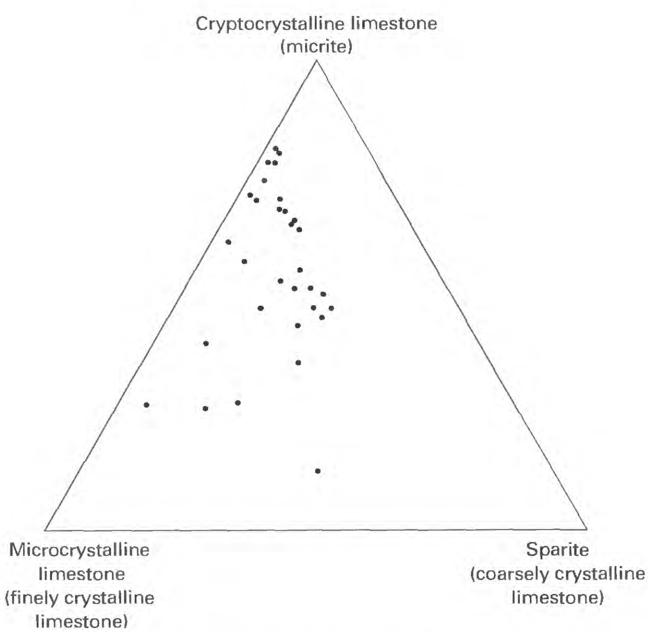


Figure 38. Limestone-type diagram with points representing all sandstone thin sections studied.

CONGLOMERATE CLAST COUNTS

In order to better understand the specifics of the conglomeratic facies of the Ghazij Formation, we conducted clast-count studies at two localities, the Sor Range and the Harboi Hills. As discussed in a previous section of this report, conglomerate is locally present in the Ghazij either as a single, tabular body at the base of the upper part of the formation, or as a much thicker mass that takes up most of the upper part of the formation, the Marap Conglomerate Member. We chose the Sor Range and Harboi Hills because they best represent these two depositional modes, respectively. At each of these two localities, we selected three equally spaced sites, thus providing a broad sampling of the facies. At each of these sites we counted 300 clasts, and recorded such characteristics as clast size, rock type, and color.

In the Sor Range, where the conglomerate is present as a tabular body, we spaced our three sites along depositional strike in order to better sample the facies. We selected a site on the nose of the Sor Range syncline near the Surab Jee mine, a middle site, several kilometers to the east near the Amin mine, and a third site several kilometers to the south of that. The conglomerate is composed of 84 percent limestone clasts and 16 percent chert clasts. Pebbles accounted for 85 percent of the clasts, and cobbles the other 15 percent.

Limestone clasts are mostly well rounded and distributed as follows:

55 percent light gray
21 percent off white
12 percent brown
8 percent medium gray
1 percent dark gray
3 percent other

Chert clasts are mostly subangular and distributed as follows:

55 percent yellow
16 percent brown
11 percent light gray
8 percent off white
5 percent dark gray
4 percent green
1 percent other

In the Harboi Hills, where the conglomerate is present as a thick wedge, we selected the three sites in a vertical manner so as to better sample the lower, middle, and upper thirds of the facies. We conducted our study in the same area that we measured our stratigraphic section of the Marap Conglomerate Member (fig. 30), on the west side of the Harboi Hills, 16 km east of Kalat. The conglomerate is composed of 93 percent limestone clasts and 6 percent chert clasts; sandstone clasts make up less than 1 percent. Pebbles accounted for 86 percent of the clasts, and cobbles the other 14 percent. This is remarkably close to the sizes recorded in the Sor Range.

Limestone clasts are mostly well rounded and distributed as follows:

29 percent light gray
49 percent medium gray
15 percent brown
5 percent dark gray
2 percent other

Chert clast are mostly subangular and distributed as follows:

48 percent yellow
38 percent brown
14 percent red

In summation, limestone clasts in the Sor Range tend to be lighter in color than those in the Harboi Hills, Sor Range conglomerates contain more chert than those in the Harboi Hills, the variety of chert colors is greater in Sor Range as compared to the Harboi Hills, and sandstone clasts and red chert are rare in the Sor Range, but are slightly more common in the Harboi Hills.

PROVENANCE

SANDSTONE

The high percentage of limestone grains in Ghazij Formation sandstones indicates that extensive limestone terranes were present in the source area. As shown in figure 4, the pre-Ghazij stratigraphic section contains thousands of meters of carbonate, and a process of uplift, weathering, and erosion of these rocks provides the simplest explanation for the abundant limestone grains contained in Ghazij sandstones. We make no attempt at assigning specific limestone types to specific pre-Ghazij limestone formations, but Kassi (1986) suggested that, based on physical similarities, the cryptocrystalline limestone might be derived from the Cretaceous Parh Limestone, and the sparite might be derived from the Paleocene Dungan Formation. Because the pre-Ghazij carbonates are known to contain varying amounts of primary chert (Hunting Survey Corporation, 1960), we believe that the non-green chert grains observed in our thin sections were also derived from these rocks. When samples are grouped by area on a LQR diagram, no meaningful conclusions concerning differing source areas can be drawn, except, of course, for Duki and Kingri, and for the two green sandstones from Pir Ismail Ziarat (see section on sandstone petrography). However, when the same samples are grouped on a limestone-type diagram (fig. 39) four main groups can be recognized: (1) the Sor Range, Mach, and Johan, (2) Pir Ismail Ziarat, (3) Duki, and (4) Kingri. We believe these groupings are significant enough to indicate subtle differences in the rocks exposed in the source areas. LQR and limestone-type diagrams were constructed that grouped samples from the lower, middle, and upper parts of the Ghazij to see if any differences in source areas could be detected. Possibly because of the limited number of samples, no meaningful trends were identified. The same set of diagrams were constructed for the Pir Ismail Ziarat samples, less the two green sandstones. On these diagrams we grouped the samples by their depositional environments, and, as would be expected, differences were noted. However, these differences probably reflect the energy of deposition rather than differences in source areas. Because, in general, the grain size of Ghazij rocks decreases in an easterly direction (Hunting Survey Corporation, 1960), we believe that the detrital grains now contained in Ghazij sandstones entered the depositional system from a westerly direction.

The high percentage of quartz grains in the Duki and Kingri samples indicates a source area rich in that mineral, and the percentage increase from Duki to Kingri might indicate that the source area was located toward the east. We can think of two possible sources of the quartz. The Upper Cretaceous Pab Sandstone is known to be present in the Sulaiman Range (Hunting Survey Corporation, 1960), and uplift and erosion of this unit might have provided the quartz. Uplift and erosion of Precambrian acidic crystalline rocks could also have provided the quartz, but no such rocks are known to have been present to the west during the Eocene. The eastward increase in quartz from Duki to Kingri makes the Indian Precambrian shield a tempting candidate, but paleocurrent data collected from Duki and Kingri do not support an easterly source. Lacking any definitive proof, we must assume that the quartz entered the system from the same direction as the limestone grains, that is, from a general westerly direction. Whether the source area for the Duki and Kingri quartz and the less common quartz present in other Ghazij sandstones was the same remains an unanswered question.

The source of the green sandstones in the middle part of the Ghazij at Pir Ismail Ziarat is intriguing. Northwest of Pir Ismail Ziarat, the amount of green sandstone in this part of the formation is known to increase toward Kach. To the southeast at the Moghal mine stratigraphic section near Mach, two bodies of green sandstone are present at about the same stratigraphic level as those at Pir Ismail Ziarat. The similar stratigraphic position coupled with the fact that the bodies near Mach are thinner than those at Pir Ismail Ziarat suggests that the bodies near Mach could represent a more distal position of the same depositional system that deposited the bodies near Pir Ismail Ziarat. In any case, the regional increase in green sandstone toward the northwest indicates a source area in that general direction. The rock fragments contained in the sandstones are probably fragments of basic extrusive rocks, as reported by Kassi (1986) for sandstones in the Kach area, and the grains of green chert might be of deep marine origin. Both of these possible parent materials are commonly present in ophiolite complexes. An alternate source of the basic extrusive fragments could be the Bela Volcanic Group, a local unit consisting mostly of basaltic rocks that is generally considered to be a part of the Parh Limestone (Hunting Survey Corporation, 1960). In addition, the Parh is known to include local accumulations of conglomerate containing high percentages of basic igneous clasts. At one such locality in the vicinity of Kach, 30 km northwest of Pir Ismail Ziarat, the conglomerate is as thick as 762 m (Blanford, 1883; Williams, 1959; Hunting Survey Corporation, 1960). We believe that the rock fragments of the green sandstones and the much less common rock fragments found in other Ghazij sandstones had a similar source. What remains unanswered is what kind of unique conditions resulted in the deposition of the two bodies of green sandstone at Pir Ismail Ziarat within a stratigraphic sequence dominated by carbonate-rich sandstone.

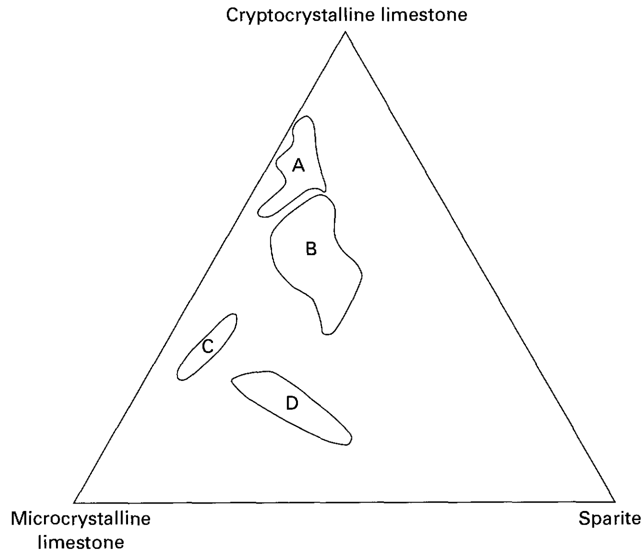


Figure 39. Limestone-type diagram showing groupings of data points by area. A, Sor Range, Mach, and Johan; B, Pir Ismail Ziarat; C, Duki; D, Kingri.

Another question about the sandstones is a more concrete one: where are the feldspar grains? Perhaps the rocks in the source area simply did not contain any such minerals. More likely, though, detrital feldspars were initially deposited but subsequently altered to other minerals. It is known that feldspars, especially the calcium-rich varieties, that are subjected to either deep burial or high tectonic stress are quite susceptible to diagenetic process. Because these rocks have experienced extreme amounts of tectonism associated with continental collision, the original feldspars could have converted in place to calcite, or, if altered to calcium carbonate and mobilized, could be present as a contributor to the calcite cement. Conversely, the original feldspars could have gone into solution and simply left the system. We note that many of the sparite crystals display strong calcite twinning that could be mistaken for plagioclase twinning. This might explain the feldspars reported by Kassi (1986).

HEAVY MINERALS

The presence of chromite in some of the sandstones has a profound implication on source area. With little doubt, these grains were originally contained in ultrabasic rocks. The most likely source of the chromite, and the basic extrusive rock and green chert fragments observed in thin section, is one or more ophiolite complexes similar to those now exposed sporadically along the western margin of the Axial Belt (fig. 40). Ophiolite complexes contain an admixture of former sea-floor sediments, basic oceanic lavas, and ultrabasic upper-mantle rocks that were "scraped off" the upper part of an oceanic plate as it was being subducted beneath an adjacent plate. When continental masses riding on these two plates collided, the ophiolitic material was obducted onto the continent riding the plate being subducted. Thus, an ophiolite complex represents a suture zone between welded continental masses. In the case of the Eocene collision between the terrestrial fragment and the Indian subcontinent, the ophiolitic material was thrust southeastward over platform carbonates that were present off the northwestern coast of the Indian subcontinent.

As shown in figure 40, a large ophiolite complex is presently exposed north of Quetta in the south end of the Zhob Valley near Muslim Bagh. Rocks contained in this complex include dunite, gabbro, harzburgite, peridotite, pyroxenite, basic volcanic rocks (pillow lavas), red siliceous limestone, and red and green radiolarian chert (DeJohn and Farah, 1976; Ahmad and Abbas, 1979; Gansser, 1979). Chromite is a common component of the dunite and harzburgite, and many mines in the area extract this mineral (Rossman and others, 1971; Ahmad and Abbas, 1979). The complex overlies a tectonic melange that includes garnet amphibolite, green schist, serpentinite, and autochthonous platform carbonates in a matrix of highly sheared shale (Ahmad and Abbas, 1979). According to Rossman and others (1971), Allemann (1979), and Ahmad and Abbas (1979), the youngest rocks included in this melange are latest Late Cretaceous (Maastrichtian) in age. Locally, the top surface of the ophiolites shows evidence of erosion, dissection, and laterization (Rossman and others, 1971; Allemann, 1979; Powell, 1979). The oldest rocks to be deposited over this unconformity are limestones of the middle Eocene Kirthar Formation (implied by Rossman and others, 1971; Ahmad and Abbas, 1979; Allemann, 1979; and Powell, 1979). In addition, a local unit in the Zhob Valley, the lower Eocene to lower Oligocene Nisai Group, overlies the ophiolites at some localities and contains pebbles of peridotite (Auden, 1974). Thus, the ophiolites must have been emplaced between Late Cretaceous and early Eocene time. Although the present-day Muslim Bagh ophiolite complex might not have been exposed and shedding sediments into the Ghazij depositional area during early Eocene, a similar complex likely was present during this time, and did provide the chromite and basic igneous rock fragments to the Ghazij depositional system. Subsequently, such a complex could have been eroded away or transported out of the area by tectonism.

CONGLOMERATE

By considering only the major limestone and chert colors, and adjusting their totals to 100 percent, we constructed trigonal diagrams showing the distributions of clast colors for conglomerates in the Sor Range and in the Harboi Hills (fig. 41). As shown in this figure, the colors of limestone clasts from the Harboi Hills are about equally distributed, whereas those from the Sor Range show a high percentage of light-gray and off-white colors. Chert clasts from the Sor Range come in a variety of colors, including light gray and off white, whereas those from the Harboi Hills come in fewer colors and lack light-gray or off-white varieties. These data demonstrate that differences exist between the types of clasts present in the Sor Range and in the Harboi Hills (fig. 41; Johnson and others, 1993). Considering that these two areas are separated by 137 km, this is not unexpected. All of the limestone and chert clast colors can be accounted for as coming from pre-Ghazij carbonate units (fig. 4). Determining the particular pre-Ghazij unit that might have provided the clasts is more difficult because all the colors represented in the limestone clasts are common in many pre-Ghazij units. The high percentage of light-gray and off-white limestone clasts in the Sor Range probably came from exposures of the Parh Limestone, a unit particularly rich in those colors. The presence of Parh clasts in the Sor Range is supported by Iqbal (1969), who reported the presence of Cretaceous limestone clasts in this area.

Oldham (1890b) observed the conglomerate at the base of the upper part of the Ghazij near Shahrig and Harnai, and reported the presence of clasts of Cretaceous limestones. Kazi (1968) also examined the conglomerate near Harnai and recognized clasts from Jurassic units and from the Paleocene Dungan Formation. The conglomerate in the Ghazij near Urak was reported by Hunting Survey Corporation (1960) to contain clasts from the Jurassic Chiltan Limestone, the Parh Limestone, and the Paleocene Brewery Limestone (a local equivalent of the Paleocene Dungan). To the south, Shah (1977) confirmed the presence of clasts as old as the Jurassic Shirinab Formation in the Marap Conglomerate Member.

Geologists with the Geological Survey of Pakistan stated that in the conglomerate facies of the Ghazij in the Sor Range, clasts of Parh Limestone are common but limestone clasts of Dungan Formation are rare or absent. This seems supported by Fritz and Khan (1975), who reported that among the foraminifers recovered from the Ghazij in the Sor Range, reworked Late Cretaceous varieties are common but reworked Paleocene foraminifers are absent. This implies that in the Sor Range's source area Upper Cretaceous rocks were exposed but Paleocene rocks were not. Hunting Survey Corporation (1960) reported evidence of inverse order of deposition in the Marap Conglomerate by noting that Shirinab clasts are more common in the upper part of the deposit and Parh clasts are more common in the lower part of the deposit. For more details on the types of chert available

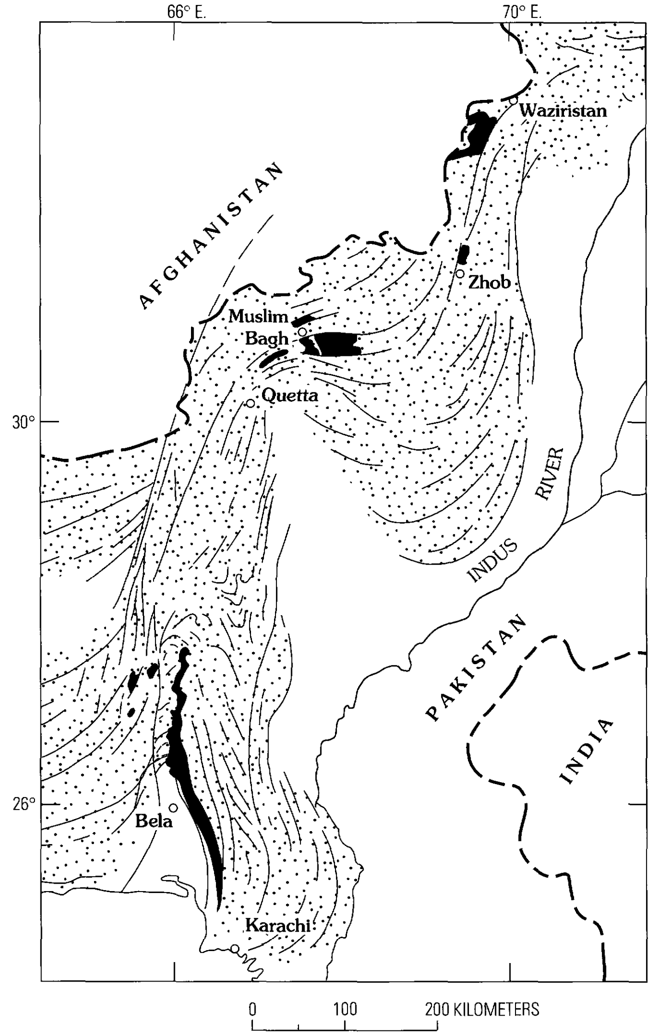


Figure 40. Map showing ophiolite complexes (black pattern) in central Pakistan. From north to south, Waziristan, Zhob, Muslim Bagh, and Bela. Curved lines are structural trends, dashed where inferred (in Afghanistan). Dot pattern, Axial Belt. Modified from Asarullah and others (1979).

from pre-Ghazij formations, consult Aubry and others (1988).

Sandstone clasts are rare in the Sor Range conglomerate, but Hunting Survey Corporation (1960) thought that some of those observed might have come from sandstone bodies in the lower part of the Ghazij.

BIOSTRATIGRAPHY OF THE GHAZIJ FORMATION

Locally, the Ghazij Formation is rich in gastropods, pelecypods, foraminifers, corals, echinoids, algae, and nannofossils. Fossil plant impressions and trace fossils are also locally abundant. Vertebrate fossils have not been described from the Ghazij, but workers at a coal mine in the Pir Ismail

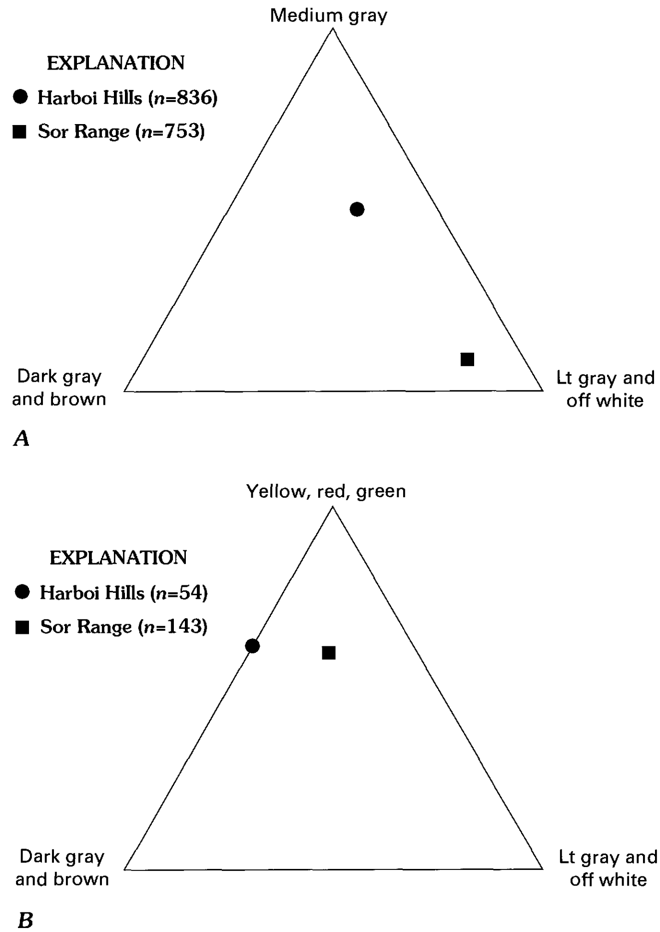


Figure 41. Trigonal diagrams showing distribution of clast types in conglomeratic facies of the Ghazij Formation in the Sor Range and in the Harboi Hills; *n*, number of clasts counted. *A*, limestone clasts; *B*, chert clasts.

Ziarat area reported the finding of a lower jaw with a tooth in a coal bed. Many of the earlier workers who studied the Ghazij collected and identified numerous fossils from the formation, and lists of their findings can be found in the literature. See Eames (1951, 1952a, 1952b, 1952c), Haque (1959), Hunting Survey Corporation (1960), Latif (1962, 1964), Fritz and Khan (1975), and Iqbal (1969). The reader should be aware that although most of the fossil names listed in these reports are still valid, many names have been superseded by newer names. Furthermore, more recent studies have placed many of these fossils into time stratigraphic units that differ from those originally published.

VERTICAL SUBDIVISIONS OF THE GHAZIJ FORMATION

LOWER PART

We did not observe any body fossils in the lower part of the Ghazij Formation. However, based on published studies of microfossils, especially foraminifers, microfossils are quite common in this part of the Ghazij. Many of the sandstone bodies contain trace fossils, including simple vertical and horizontal burrows, and a variety of tracks and trails on bedding surfaces. Almost every hand sample contains carbonized fragments of fossil plant debris, including stem fragments, leaf parts, and rare fruiting bodies. At Pir Ismail Ziarat we observed impressions of whole leaves in a sandstone body more than 166 m below the top of this part of the formation. In addition, whole leaves are reported to be present in the upper portion of the lower part of the formation near Kach, and we observed their presence at this same stratigraphic interval in the Sor Range.

Fritz and Khan (1975) identified 37 genera and about 100 species of foraminifers in the lower part of the Ghazij in the Sor Range. Both benthonic (large and small types) and planktonic varieties were observed. These workers reported that reworked Cretaceous foraminifers are quite common in this part of the section, and that horizons rich in the reworked foraminifers contain very few Eocene foraminifers, and vice versa. That is, horizons rich in Eocene ones contain very few reworked ones. They attributed this to the fact that during intense erosion of Cretaceous rocks in the source area, increased amounts of sediment, including foraminifer tests, clouded the Ghazij depositional environment. Because foraminifers require clear water to thrive, live Eocene varieties could not exist. As erosion in the source area slowed, water in the environment cleared, Eocene foraminifers thrived, and their tests could again dominate the deposited foraminifer assemblage. Gibson and others (1992) have reported on foraminifers in the lower portion of this part of the formation, and their work is discussed in an upcoming section of this report.

MIDDLE PART

Body fossils are quite common in the middle part of the Ghazij Formation. In almost all the areas we examined, this part of the section contains layers of fossiliferous sandstone or mudrock, and the fossils locally reach such density that some layers qualify as coquinas. Gastropods and pelecypods are the most common fossils. We also found a few foraminifers and ostracodes in some units. Trace fossils are locally common in sandstone bodies toward the base of this part of the Ghazij in some areas, and at least one variety closely resembles *Ophiomorpha*. *Thalassinoides* is also probably present. Much of the mudrock in this part of the formation contains fossil root traces, and most of the mudrock and finer grained sandstones contain fossil plant debris in the form of stem fragments, leaf parts, and rare fruiting bodies.

Despite the abundance of fossils in this part of the Ghazij, few studies of them have been published. Iqbal (1969) studied fossils from the middle part of the formation in the Sor Range and near Shahrig. He reported 17 species of foraminifers, 5 species of coral, and 27 species of mollusks.

UPPER PART

For the most part, fossils are very rare to absent in the upper part of the Ghazij Formation. In all the areas that we examined, we did not observe a single body fossil in this part of the Ghazij. Of particular interest is the fact that almost all the mudrock is barren of any fossil plant debris. Fritz and Khan (1975) reported that all types of foraminifers are rare in the upper part of the formation in the Sor Range. However, Haque (1959) recovered foraminifers from several beds stratigraphically high in the upper part of the formation in the Sor Range. And, we collected samples of mudrock high in the Shin Ghwazha mine stratigraphic section in the Sor Range from which nannofossils were recovered. Both Haque's work and the results of our sample analyses are discussed in the next section of this report.

AGE OF THE GHAZIJ FORMATION

Based on fossil evidence, the Ghazij Formation is mostly early Eocene (Ypresian) in age. This age has been established or confirmed by such workers as Eames (1951, 1952a, 1952b, 1952c), Haque (1959), Williams (1959), Hunting Survey Corporation (1960), Latif (1962, 1964), Fritz and Khan (1966), Iqbal (1969); Shah (1977), Iqbal and Shah (1980), and Kassi and others (1987).

Paleocene fossils have been collected from the lowermost portion of the Ghazij in the area of Umai (Hunting Survey Corporation, 1960). T.G. Gibson (U.S. Geological Survey, oral commun., 1992) identified late Paleocene foraminifers from shale samples collected from the lowermost portion of the formation just above the Paleocene Dungan Formation near Chappar Rift, 16 km northwest of Khost (see also Gibson and others, 1992). However, in another set of samples collected by us at the same locality, Gibson identified only early Eocene foraminifers. J.M. Self-Trail (U.S. Geological Survey, written commun., 1994) examined both sets of samples and was able to identify late Paleocene and early Eocene nannofossils, respectively. All this implies that at this locality the Dungan-Ghazij contact is very close to the Paleocene-Eocene boundary. The fact that the lower contact of the Ghazij might transgress a time boundary was first mentioned by Oldham (1890b). This fact was also recognized by Hunting Survey Corporation (1960), and they presented evidence that the base of the formation became younger toward the east. Moreover, stratigraphic relations shown on one of their geologic maps (Geologic Map No. 15) imply that the base of the Ghazij might also become younger toward the south.

On several diagrams in Williams (1959), the upper contact of the Ghazij is shown to transgress the early-middle Eocene time line, and this was also reported by Hunting Survey Corporation (1960) and implied by Gingerich and others (1979). In the Sor Range at the Shin Ghwazha mine stratigraphic section, the Ghazij and the overlying Kirthar Formation seem to interfinger over a stratigraphic interval of about 32 m. As shown on plate 1*A*, a limestone unit about 6 m thick is present near the top of the upper part of the Ghazij. This is the only limestone in the Ghazij in this section, and it appears different from any limestone observed in the Ghazij elsewhere. Although the limestone is also unlike any limestone observed in the overlying Kirthar, it appears more closely associated with this formation than with the Ghazij. Overlying this limestone unit is a partly covered mudrock sequence about 26 m thick tucked under the Kirthar cliff. This circumstance poses a question: should the contact between the two formations be drawn at the base of the 6-m-thick limestone unit, or at the base of the cliff? Because formations are defined as mappable units, we would place the contact at the base of the cliff. We collected two samples (SG-18-91 and SG-19-91; Johnson and Khan, 1994a) from the mudrock interval between the 6-m-thick limestone unit and the Kirthar cliff, and according to J.M. Self-Trail (written commun., 1994) they contain late Eocene nannofossils. Haque (1959) recovered 108 species of foraminifers from five samples collected within a 25-m-thick shale interval just below the Kirthar cliff several kilometers northwest of our stratigraphic section. Although he did not mention a lower limestone unit, such a unit might be covered or missing in the area he sampled. Haque reported the age of these foraminifers to be middle to late Eocene, and stated that some of the foraminifers were also present in the "White Marl Band" and "Upper Chocolate Clays" of the Kirthar Formation in the Rakhi Nala area as described by Eames (1952a). L.M. Bybell (U.S. Geological Survey, oral commun., 1994) reported that late-middle Eocene nannofossils have also been identified from the upper part of the Ghazij near Shahrig. Thus, evidence indicates that at least the uppermost part of the Ghazij is middle to late Eocene in age. The question is, where within the Ghazij is the lower-middle Eocene boundary?

DEPOSITIONAL FACIES OF THE GHAZIJ FORMATION

Overall, the Ghazij Formation comprises a shallowing-upward sequence. This was also the understanding of Hunting Survey Corporation (1960), as indicated by their statement that the depositional environments of the Ghazij progressed from marine to brackish to fresh in an upward direction. In detail, the formation, especially the middle part, probably records deposition under complex conditions of repeated minor marine transgression and regression. Distant views of the Ghazij in areas where all three subdivisions are exposed are reminiscent of views of the Upper Cretaceous Mancos Shale and Mesaverde Group in the Western United States, which contains rocks deposited under similar depositional conditions.

VERTICAL SUBDIVISIONS OF THE GHAZIJ FORMATION

In the following text, we discuss the depositional facies of each of the three subdivisions of the Ghazij Formation. We discuss the conglomerate and evaporite facies of the formation in separate sections, because of their complex nature.

LOWER PART

An overwhelming body of evidence supports a marine depositional setting for the lower part of the Ghazij. Almost all of this part of the formation consists of mudrock, probably greater than 1,000 m in thickness, and an environment other than marine where this much mud could accumulate is difficult to imagine. Sandstone bodies in the lower part of the formation can be divided into two broad categories: (1) thin, laterally extensive, tabular bodies, and (2) thicker, broad, lenticular bodies. The tabular bodies with their sharp upper and lower contacts and sole marks are interpreted as having been deposited as wave base lowered during periods of storm activity. This resulted in sand being transported down slope into environments of finer grained sediments. The origin of the larger sandstone bodies is problematic. Most likely they represent submarine-channel or submarine-fan deposits. Curiously, some of these bodies, especially in the Sor Range, are as coarse as medium grained, and a submarine channel moving nearshore sediments into deeper water might explain the presence of this grain size. Some bodies, especially in the Pir Ismail Ziarat area, coarsen upward, and these could conceivably represent minor shoreface deposits developed during short periods of lower sea level.

The presence of abundant foraminifers in the mudrock of this part of the formation is ample evidence of deposition in a marine environment. In addition, marine ostracodes have been identified from this part of the formation (E.M. Brouwers, U.S. Geological Survey, oral commun., 1992). Gibson and others (1992) collected mudrock samples from the lowermost beds of the lower part of the formation near Chappar Rift, 16 km northwest of Khost. From these samples they extracted certain benthonic foraminifers that suggest deposition in middle-bathyal waters 300–550 m deep. Fritz and Khan (1966) collected planktonic and benthonic foraminifers from the lower part of the formation in the Sor Range and concluded that the presence of the planktonic varieties indicated an open-ocean environment. These workers also noted the presence of a zone containing the large benthonic foraminifer *Nummulites* in the uppermost mudrock just below the base of the middle part of the formation. They interpreted the present of this fauna as evidence of warm, shallow-water deposition, perhaps in water as shallow as 30 m or less. In addition, samples we collected (A-4-90 and A-9-90, Johnson and Khan, 1994b) from the upper portion of the lower part of the formation at the Abraham Marri mine stratigraphic section near Pir Ismail Ziarat contained marine ostracodes characteristic of deposition in shallow-water environments (E.M. Brouwers, oral commun., 1992). Thus, there is evidence for shoaling depositional conditions in the upper portion of this part of the formation just prior to the deposition of the middle part of the formation.

We believe that the lower part of the Ghazij can be divided into a lower portion, representing relatively deep water deposition on the outer shelf, and an upper portion, representing shallower deposition on the inner shelf. The time of shallowest marine deposition occurred during the final stage of lower Ghazij accumulation.

MIDDLE PART

The middle part of the Ghazij Formation contains rocks that show characteristics of marine, paralic, and fluvial depositional environments. Sandstone bodies in the middle part of the formation can be divided into three types. Type I sandstone bodies, most of which coarsen upward in grain size, display an upward decrease in mudrock interbeds, and contain trace fossils resembling *Ophiomorpha,* are interpreted to be shoreface deposits. This assignment is supported by the fact that some of these bodies also display orange stain and fossil root traces in their uppermost few centimeters, and the fact that coal or carbonaceous shale is present directly on or just above many of them. In addition, Type I bodies, where present, are always positioned stratigraphically at or near the base of the middle part of the formation. Assuming that the lower part of the formation has a marine origin, this position of Type I bodies is consistent with a prograding shoreface setting.

In areas where Type I sandstone bodies are particularly common in the middle part of the formation, the presence of a nearby point source for sand entering the depositional system is suspected. Therefore, in these sand-rich areas, Type I sandstone bodies could represent delta-front deposits. If this is correct, then the upper portion of the lower part of the formation is a prodelta deposit.

Type II sandstone bodies are more difficult to interpret. In areas where Type I bodies are present near the base of the middle part of the formation, Type II bodies tend to be positioned stratigraphically above them. Where Type I bodies are absent, Type II bodies occupy the lower part of the sequence. Characteristics of Type II bodies vary considerably, but the common presence of wedge-planar cross stratification, trace fossils resembling *Ophiomorpha,* and local concentrations of fossil oyster shells suggests that these bodies are some type of paralic deposit associated with tidal processes and brackish conditions. Some Type II bodies might represent tidal channels cutting through older deposits; others might represent bay-head deltas or crevasse splays debouching sand into brackish bays or estuaries.

Type III sandstone bodies were most certainly deposited under fluvial conditions. Evidence pointing to this environment includes the common presence of (1) erosional bases typically underlying a layer of mudrock chips and wood impressions, (2) fining-upward grain size, (3) upward decrease in bed thickness, (4) trough cross stratification and internal erosion surfaces, especially in the lower part of the bodies, and (5) mudrock partings and ripple laminations in the upper part of the bodies. Some bodies appear laterally continuous and are interpreted to be sheet-flood deposits, whereas other bodies are lenticular and interpreted to be channel-fill deposits. Almost all Type III bodies are positioned stratigraphically in the upper portion of the middle part of the formation. Thinner, laterally continuous sandstone bodies in the upper portion of the middle part probably represent crevasse-splay deposits.

Mudrock intervals stratigraphically above the shoreface sandstones probably represent lagoonal deposits, whereas mudrock intervals associated with the paralic sandstones are interpreted to be bay-fill or estuarine deposits. Mudrock intervals associated with the fluvial sandstones higher in the section are interpreted to be overbank accumulations such as levee and flood plain deposits.

Coal in the middle part of the formation indicates the past presence of peat swamps in areas where the water table was at or very close to the ground surface. Moreover, the presence of coal implies a fresh-water environment, no matter how close the swamp was to the shoreline, and a climate where precipitation exceeded evaporation. As noted by Hunting Survey Corporation (1960), those areas where the middle part of the formation is the thinnest, such as in the Sor Range and at Khost and Harnai, have the thickest coal deposits. They believed that the thinness of the middle part in these areas resulted from their depositional position near the heads of deltas where clastic accumulation was less because of sediment bypass. And, because these areas were the first environments to form on the deltas, peat had the most time to accumulate. In contrast to this idea, we suggest that coal associated with Type I sandstone bodies most certainly represents peat accumulation low on the coastal plain, and the coal beds in the Mach area seem to represent peat accumulation near the very front of the coastal plain. Most likely peat accumulated under a variety of conditions throughout the coastal area.

Some of the coals in the middle part of the formation are relatively high in sulfur. A high sulfur content is believed by many to indicate a marine influence, and this feature might further support the interpretation of peat accumulation adjacent to the shoreline. Ghaznavi (1990) used the relation of high sulfur and marine influence to create a depositional model for the middle part of the Ghazij in the Khost-Shahrig-Harnai area. He suggested that the high sulfur content in his middle coal bed near Shahrig indicated a close proximity of the sea. The high sulfur content in his top coal bed near Harnai was interpreted as evidence that the marine influence had shifted east into this area by the time this coal bed was deposited.

Numerous reports of marine fossils in certain stratigraphic horizons in the middle part of the formation indicate a depositional environment influenced by frequent incursions of sea water. Iqbal (1969) studied fossils collected from the middle part of the formation near Sinjidi in the Sor Range and from near Shahrig. Iqbal identified numerous foraminifers, gastropods, and pelecypods, and concluded that they were all marine. In addition, he observed an interesting limestone bed in the middle part of the formation near Sinjidi. From this bed he identified five species of corals, and speculated that they probably lived in warm, clear marine water of the sublittoral zone between 46 and 61 m deep. E.M. Brouwers (oral commun., 1992) reported the presence of shallow-marine ostracodes in samples we collected (A-11-90 and A-13-90, Johnson and Khan, 1994b) from the lower portion of the middle part of the formation at the Abraham Marri mine stratigraphic section near Pir Ismail Ziarat. A close proximity of the sea is also supported by the presence of trace fossils resembling *Ophiomorpha* in sandstone bodies in the lower portion of the middle part of the formation. Oyster shells are a common fossil in the middle part of the formation, and these fauna are good indicators of brackish conditions. Nonmarine environments are evident higher in the middle part of the formation as reported by E.M. Brouwers (oral commun., 1992), who recovered nonmarine ostracodes from samples of mudrock we collected (A-23-90, A-34-90, and A-41-90, Johnson and Khan, 1994b) high in the middle part of the formation.

We conclude that most of the middle part of the Ghazij was deposited in the lower reaches of a coastal plain of very low relief that experienced frequent marine incursions. In detail, the middle part of the formation probably contains a complex mixture of marine, brackish, and fluvial depositional facies. In areas such as Pir Ismail Ziarat where the middle part of the formation is especially well developed, it is apparent that this part contains the deposits of a prograding coastal package as evidenced by the upward succession of shoreface, brackish, and fluvial facies. In other areas, however, such clear evidence of depositional history is lacking.

UPPER PART

In regard to depositional setting, the upper part of the Ghazij Formation is the most enigmatic. Taking no chances, Hunting Survey Corporation (1960) stated that it was of "semiterrestrial, paludal, fluvial, or marine origin." The first thing one notices about the upper part of the Ghazij is its color. Although gray is still the primary color of the mudrock, such tones as maroon, red, orange, and yellow are very common. These colors along with their banded appearance suggest sequences dominated by multiple paleosol horizons. This association was also noted by Hunting Survey Corporation (1960) in their occasional use of the term "lateritic" when describing this part of the formation.

Almost all the sandstone bodies in the upper part of the formation appear to be Type III. These bodies contain the same features that identify Type III bodies in the middle part of the formation as fluvial deposits, but in the upper part of the formation these bodies tend to contain a larger number of fluvial characteristics than do the bodies below. Most of the fluvial sandstones seem to be channel-fill deposits; sheetflood deposits are rare. Although sandstone is not a common lithology in the upper part of the formation, those channel-fill deposits that are present can be quite spectacular. At the Shin Ghwazha mine stratigraphic section in the Sor Range (pl. 1*A*), sandstone units in the upper part of the formation are thicker than any other sandstone units in the section. The same situation exists at the Moghal mine section near Mach (pl. 1*C* and 1*D*).

The upper part of the formation is practically devoid of fossil animal or plant remains. This phenomenon is probably the result of post-deposition oxidation rather than an original absence of life forms in the depositional setting. An exception to this is the presence of foraminifers and nannofossils in the uppermost portion of the upper part at several localities in the Sor Range. Haque (1959) reported planktonic foraminifers in this stratigraphic interval and interpreted a warm-water environment that might have been as deep as 730 m. In addition, E.M. Brouwers (oral commun., 1994) identified marine ostracodes from this part of the section near Shahrig. We observed trace fossils resembling *Ophiomorpha* in the upper part of the formation in a sandstone body stratigraphically above the Abraham Marri mine stratigraphic section near Pir Ismail Ziarat, and in a sandstone body high in the Sarawan River section near Johan (pl. 1*D*). The presence of this trace fossil indicates at least brackish conditions, if not totally marine, and implies that at least some marine transgression followed deposition of the middle part of the formation.

Most of the upper part of the Ghazij was probably deposited under fluvial conditions high on a coastal plain. The apparent interfingering of the middle and upper parts of the formation near Pir Ismail Ziarat and Mach probably represents a transition zone between lower and upper depositional settings on the coastal plain. The presence of relatively deep water foraminifers in the uppermost part of the sequence in the Sor Range and at Shahrig seems to indicate that a major marine flooding event occurred sometime prior to the deposition of the overlying Kirthar Formation. If such an event did occur late in Ghazij time, then the sandstone and conglomerate present at the very top of the formation near Harnai could represent a subsequent localized regression prior to the Kirthar transgression. Finally, we note that the middle and upper parts of the Ghazij contain the first nonmarine sediments to be deposited in this area of the Indus Foreland Basin.

SPECIFIC SITES

SOR RANGE

As mentioned before, the middle part of the Ghazij Formation in the Sor Range (pl. 1*A*) is abnormally thin, probably because the upper portion was removed by erosion prior to the deposition of the conglomerate facies, which now occupies the basal portion of the upper part of the formation. Most of the sandstone bodies present in the middle part of the formation appear to be of paralic origin. Shoreface sandstones are present at the base of the middle part, but only locally (fig. 42).

PIR ISMAIL ZIARAT

The best developed shoreface sandstone at the base of the middle part of the Ghazij Formation is present in the Pir Ismail Ziarat area. In fact, as shown on plate 1*B*, two such deposits, each overlain by a coal-bearing interval, are present at the Abraham Marri stratigraphic section. This implies an initial regression and subsequent progradation, a short-lived transgression, followed by another regression and progradation. We believe that the lower portion of the middle part of the formation, just above the stratigraphically highest shoreface sandstone, might have been deposited in a broad tidally dominated delta, which would explain the close association of marine and nonmarine rocks observed in this part of the section. By this depositional model, the mudrock intervals would represent bay-fill or estuarine deposits, and the paralic sandstone bodies would represent bay-head deltas or large crevasse splays. If this model is correct, then where were the rivers that fed the delta? Most likely they existed to the northwest beyond the western limit of present-day Ghazij outcrops. The upper portion of the middle part of the formation at this site contains fluvial sandstone bodies, and these could indicate that with time, the river systems that fed the delta eventually prograded across the top of the paralic deposits.

MACH

In the middle part of the Ghazij Formation, near Mach, relatively thin coal beds and thin limestone beds containing high-spiral marine gastropods (R.M. Forester, U.S. Geological Survey, oral commun., 1993) are intercalated in the same sequence (pl. 1*C* and 1*D*). Moreover, some of the coal beds contain concentrations of isolated fossil mollusks of probable marine or brackish affinity. We interpret the close association of coal and marine limestone to deposition on a very flat surface where peat was accumulating directly adjacent to the shoreline. As a result of relatively frequent but minor fluctuations in sea level, a mixing of marine and nonmarine environments caused these two lithofacies to be closely deposited. This general interpretation was also expressed by Hunting Survey Corporation (1960), who noted that the thin coal beds in this area probably resulted from the relatively short periods of peat accumulation between frequent shifts in the shoreline (see also Ahmad and others, 1986). Conversely, the association of these two lithologies could represent changes in climate. Although well displayed in the Mach area, the best example of the intercalation of these two lithologies is in the middle part of the Ghazij near Shahrig (fig. 15).

We believe that the fossiliferous coal is the result of storm activity that washed marine or brackish shell material landward into the peat swamps.

JOHAN

The fact that the middle part of the Ghazij Formation is less recognizable in the Johan area probably results from the fact that this area was farther away from the deltaic source of sand-size sediments than areas to the north (see also Ahmad and others, 1986). As a result, sandstone bodies are generally absent in the upper portion of the main body of the formation in this area. Because the area lacked a sand-supported depositional platform during middle Ghazij time, peat swamps were more ephemeral and as a result, coal beds are few and thin in the Johan area.

CONGLOMERATE FACIES

The abrupt appearance of a conglomerate facies in the otherwise finer grained Ghazij Formation is perhaps the most intriguing feature of the formation. This facies is limited to the westernmost margin of the early Eocene Indus Foreland Basin, an area perhaps best described as a mountain-front foreland basin. As previously discussed, conglomerate is found in the Ghazij (1) locally, at the base of the upper part of the formation in the greater Quetta region, and (2) taking up much of the upper part of the formation in the greater Kalat region—the Marap Conglomerate Member of the Ghazij.

It is our opinion that all the conglomerates in the Ghazij represent the bed-load deposits of gravel-dominated, low-sinuosity (braided) streams flowing, in general, from

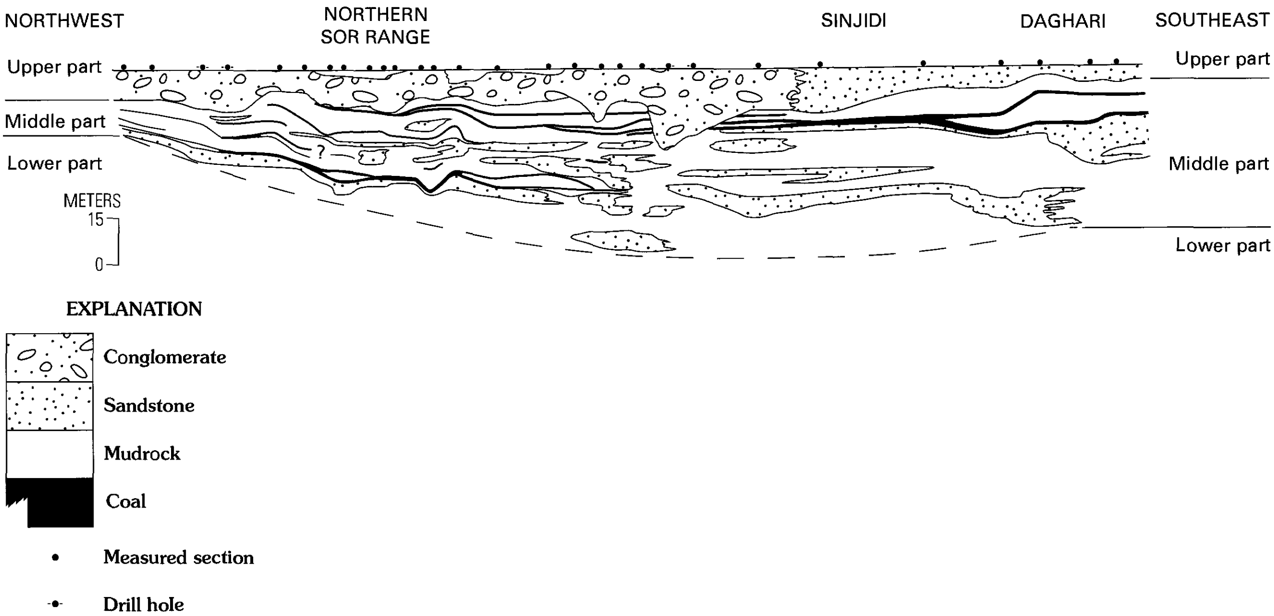


Figure 42. Generalized cross section of middle part of the Ghazij Formation and its relation to the conglomerate unit in basal portion of the upper part of the formation along the length of the Sor Range. Also shown are interpreted geometries of sandstone bodies in middle part of the formation and their relation to major coal beds. Datum is top of conglomerate unit. Dots representing measured sections and drill holes are named and located on plate 2. Length of cross section approximately 23 km.

northwest to southeast (Johnson and others, 1993). The riverine conclusion is supported by the following observations:

1. The widespread presence of amalgamated lenticular bodies with erosional bases, representing deposition in individual channels.
2. The clast-supported fabric, indicating hydrologic segregation of gravel and sand in a bed-load stream.
3. The weakly developed, horizontal stratification resulting from traction processes in a bed-load stream.
4. The presence of imbricated clasts resulting from saltation processes in a bed-load stream.
5. The presence of inclined surfaces representing accretion associated with migrating bar forms.
6. The presence of isolated lenses of small-scale, trough cross stratified sandstone.
7. The commonly observed normal grading, or fining-upward grain size, indicative of a decrease in flow velocity as vertical accretion culminated.

The low-sinuosity conclusion seems to be the only possibility considering the stream velocity needed to transport the size of clasts in the deposit.

QUETTA REGION

Where present in the Quetta region, in the Sor Range and in the Shahrig-Harnai area, the conglomerate occupies a series of channels, the lowest of which have cut into the top of the middle part of the formation. The absence of the conglomerate in the southeastern part of the Sor Range more likely occurred because the area was beyond channel margins, rather than because of a simple pinchout or gradation into finer grained rocks in that direction. The relative thinness of the conglomerate in the Quetta region seems to indicate a single, relatively ephemeral riverine stage early in the history of upper Ghazij deposition in this area. Because the conglomerate is not present everywhere, the riverine system (or systems) must have been somewhat fixed in position although individual streams probably exhibited considerable lateral mobility. Post-depositional tectonic transport in conjunction with the present-day limited exposures of the Ghazij makes it difficult to tell just how interconnected these patches of conglomerate were, but subtle differences in overall lithology indicate that at least the Sor Range and Shahrig-Harnai deposits had different source areas. In the Sor Range, a sandstone unit overlies the conglomerate at several localities, and based on the sedimentologic characteristics of the sandstone it appears to have accumulated during the final stage of the same depositional event that deposited the underlying conglomerate. This depositional association of sand following gravel fits nicely with the decrease in flow velocity that occurs during the waning stage of riverine deposition.

KALAT REGION

In the Kalat region, conglomerate constitutes a much higher percentage of the upper part of the Ghazij and can be present at any stratigraphic level in the interval. In some areas, the conglomerate makes up all of the upper part of the formation, and at the type area of the Marap Conglomerate

Member, conglomerate makes up most of the formation. This implies that riverine conditions were more common and more intense in the Kalat region. Regionally, the lithofacies is more wedge shaped in this area compared with the broad sheetlike deposits in the Quetta region.

DISCUSSION

It is tempting to assume that the relatively thin conglomerates in the Quetta region are simply the distal edge of the more massive conglomerates of the Marap in the Kalat region. However, the northernmost exposure of Marap and the southernmost exposure of the Quetta conglomerates are about 80 km apart creating a broad belt where similar conglomerate is not present in the upper part of the Ghazij (fig. 43). This fact leads to the realization that instead of one regional package of conglomerate, at least four depocenters or lobes of conglomerate can be identified: from south to north, the Kalat lobe, the Sor Range lobe, the Shahrig-Harnai lobe, and, far to the north, the Moghal Kot lobe (fig. 43). Of course, some of these lobes might have been connected at some distance to the west, in an area now unavailable for inspection because of erosion or tectonic transport. The Sor Range, Shahrig-Harnai, and Moghal Kot lobes, with their relatively thin, blanketlike geometry, probably represent simple coarse deposition in minor paleovalleys incised into the early late Ghazij coastal plain. The Kalat lobe, however, with its thick amalgamated channel deposits, probably represents a complex system of one or more stream-dominated alluvial fans. Each of these lobes represents a separate depositional system, but the basic depositional process was the same—riverine. The differences in stratigraphic position and total clast volume between the Kalat lobe and the three lobes to the north probably reflect more proximal versus more distal depositional positions, respectively, on different depositional systems. For example, the Kalat lobe might represent midfan deposition, the three lobes to the north distal deposition. The coarse-grained sandstone bodies observed at the stratigraphic level of the conglomerate east of the Sor Range would thus have been deposited in even more distal areas of the fans. We found it interesting that the conglomerate in the Sor Range and the lowest conglomerate in the Harboi Hills are at about the same stratigraphic level (fig. 44), suggesting that the depositional episode that emplaced the conglomerate began at about the same time in both areas.

SOME QUESTIONS AND ANSWERS

How did gravel come to be deposited in an environment of finer grained sediment? We believe that most of the upper part of the Ghazij Formation was deposited on a coastal plain of very low relief. Apparently limestone terranes of significant height developed directly adjacent to this depositional setting (fig. 45). High-velocity streams originating in these highlands had enough hydrologic head to move coarse-grained detritus out into the low-energy environment near the base of the uplift. As these streams quickly lost their gradient and dispersed radially, hydrologic energy decreased and gravel accumulated as a basin-margin deposit.

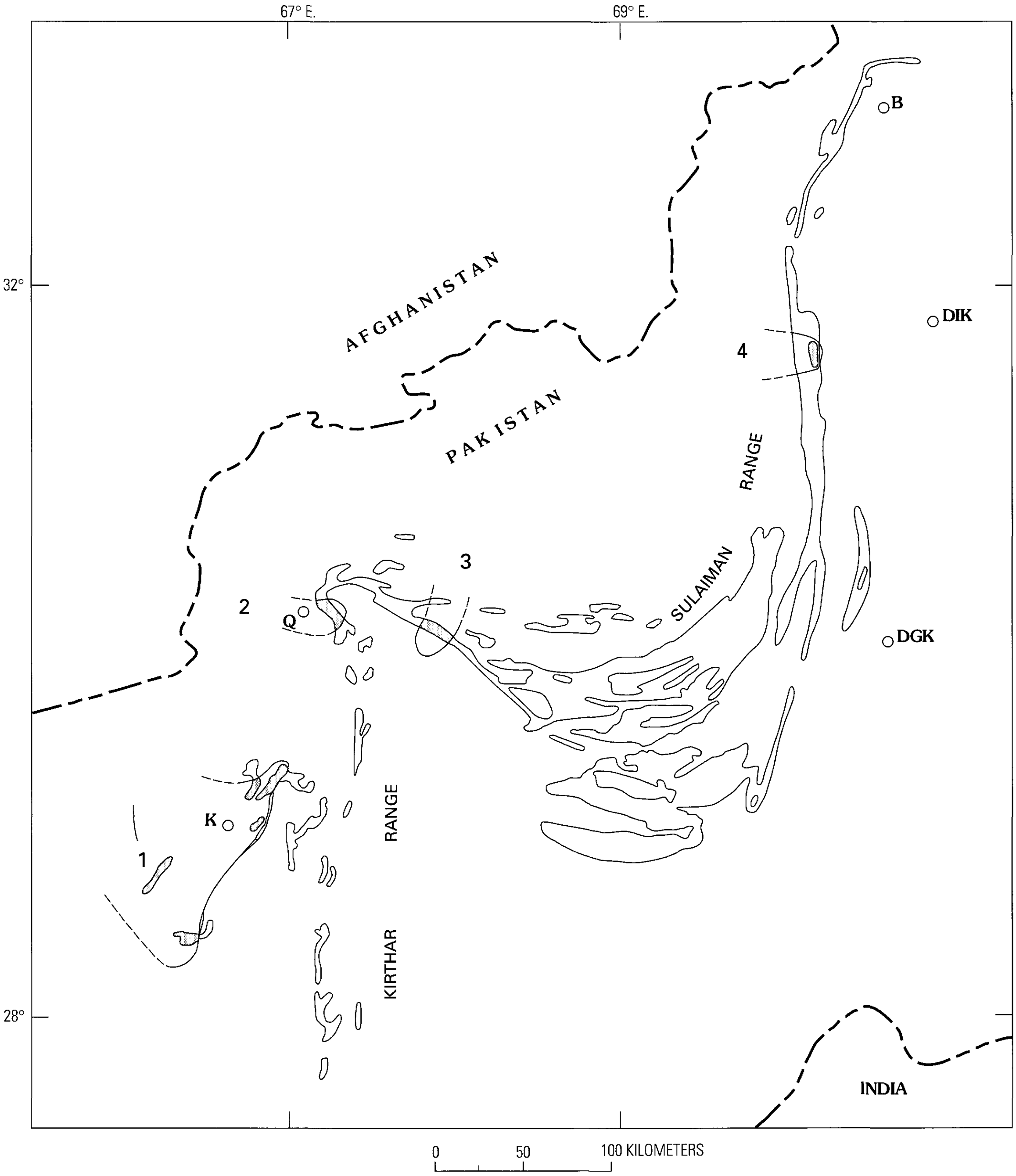
How and where did the clasts get so well rounded? Because calcite is relatively soft, clasts of limestone can become well rounded during one sedimentary cycle. Thus, these clasts could have obtained their roundness over a relatively short distance of fluvial transport while moving along a system of tributary and trunk streams within the highlands. It is possible, of course, that some of these clasts were stored during their transport history in river terraces within catchment basins, and then remobilized, perhaps during a period of high discharge associated with intense precipitation and runoff, and dumped suddenly onto the edge of the coastal plain.

If stream transportation is responsible for rounding the clasts, then why are the rocks so poorly sorted? The poor sorting observed in the conglomerates is probably a function of flash-flood discharge that moved the coarse detritus out beyond the topographic front.

EVAPORITE FACIES

Of major importance to our discussion is the depositional setting of the evaporite facies that is present, but poorly described, in the upper part of the lower Eocene interval in the Sulaiman Range. The rocks could have been deposited in a coastal setting in areas where circulation of marine water was somehow restricted. Evaporation exceeding the influx of normal sea water could have caused hypersaline conditions and led to the establishment of a sabkha environment. Conversely, the rocks could have been deposited in a separate closed basin where evaporation coupled with the lack of incoming normal sea water resulted in hypersaline conditions. Some gypsiferous limestones in the Baska Shale are reported to contain foraminifers (Hemphill and Kidwai, 1973), and this is evidence of some marine influence.

Figure 43 (facing page). Present-day distribution of Eocene sedimentary rocks in north-central Pakistan and location of conglomerate facies of the Ghazij Formation or its equivalent. 1, Kalat lobe; 2, Sor Range lobe; 3, Shahrig-Harnai lobe; 4, Moghal Kot lobe. Outlines of conglomerate facies are approximate and in some cases drawn larger than their actual distribution for emphasis. Outlines of individual lobes (solid and dashed lines) are entirely hypothetical. Geology modified from Bakr and Jackson, 1964.



EXPLANATION

Eocene sedimentary rocks

Conglomerate facies of the Ghazij Formation

B	Bannu
DIK	Dera Ismail Khan
DGK	Dera Ghazi Khan
Q	Quetta
K	Kalat

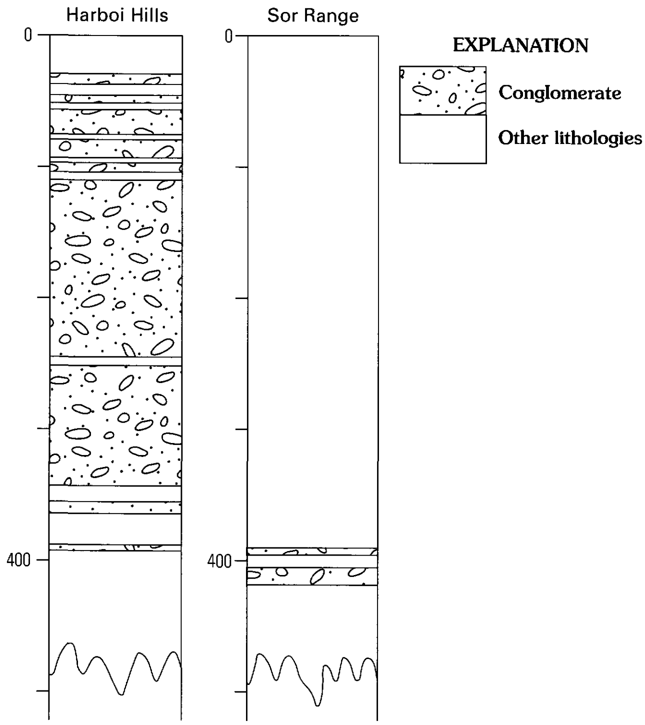


Figure 44. Stratigraphic columns showing conglomerate intervals in top 500 m of the Ghazij Formation in Harboi Hills and Sor Range. Stratigraphic level of conglomerate facies in Sor Range is about the same as that of lowest conglomerate in the Harboi Hills.

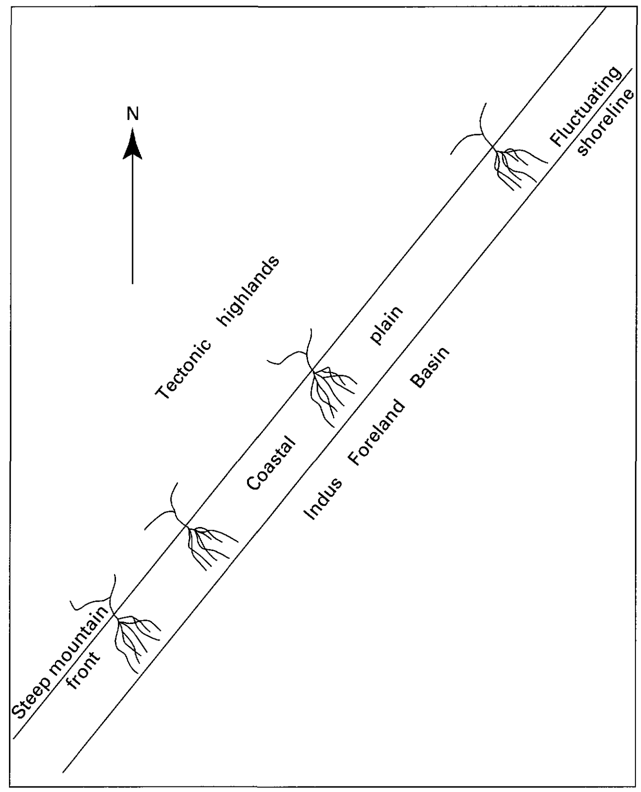


Figure 45. Depositional model showing possible distributary stream systems on the late Ghazij coastal plain, whose gravelly bed load is now represented by the conglomerate facies found in the upper part of the Ghazij Formation. No scale implied.

Because humid conditions probably prevailed during middle Ghazij time, as indicated by the presence of coal in this part of the section, a climate change must have occurred during late Ghazij time to account for the deposition of evaporite minerals.

PALEOCURRENT INDICATORS FROM THE GHAZIJ FORMATION

Only a few paleocurrent studies have been conducted on the Ghazij Formation, and all of these were small parts of broader investigations. Thus, too few data points are available to make any definitive statement about early Eocene paleoflow in this part of the Indus Foreland Basin.

We took 15 paleocurrent measurements from individual sandstone bodies in the middle part of the Ghazij along the length of the Sor Range. Almost all of the measurements were of cross stratification, and in each case we measured the three-dimensional orientation of a foreset surface. Because the strata dip at low angles in this area, no correction for structure was necessary. Directional data from this effort are quite variable, but there is a slight preference for northwest and southwest paleoflow. We also collected paleocurrent information from the conglomerate facies at the base of the upper part of the formation. These data were collected from clast imbrication and from cross-stratified foresets in sandstone lenses within the conglomerate facies. The data, consisting of 10 measurements, appear random.

As part of our examination of the Ghazij at the Abraham Marri mine stratigraphic section near Pir Ismail Ziarat, we collected paleocurrent data from five individual sandstone bodies in the middle part of the formation. At each site we measured the three-dimensional orientation of foreset surfaces from at least 12 individual trough limbs. Because the strata dip at high angles in this area, all values were corrected for structure. Rose diagrams displaying these data show paleoflow toward the south-southwest, west-northwest, north-northeast, southeast, and south-southeast. We also recorded the long-axis orientations of symmetrical ripple marks from four marine sandstone bodies in the lower part of the formation. All four axial values were toward the northeast. In present-day marine settings the axes of symmetrical ripple trains are developed subparallel to shoreline. Based on this, our paleogeographic model for the early Eocene Indus Foreland Basin with its northeast-trending western margin seems supported by the data.

We recorded 16 paleocurrent measurements from foreset surfaces in cross-stratified sandstone bodies in the Kingri area. Measurements were taken in three dimensions and corrections were made for structure. Most values indicate paleoflow toward the east-northeast.

Kazi (1968) studied the Ghazij near Harnai and reported a southeast paleoflow for the middle part of the formation, and a south-southeast paleoflow for the upper part of the formation. Kazi determined these orientations from measurements of cross stratification, but his report gave no details on methodology. Based on the orientations of sole marks observed on the bottoms of Ghazij sandstone bodies in the Kach area, Kassi and others (1987) determined that paleoflow was toward the southwest and, to a lesser extent, toward the southeast. These workers also did not mention methodology. Ghaznavi (1990) studied the Ghazij in the Khost-Shahrig-Harnai area and reported mostly south and southeast paleoflow. Again, no mention was made of methodology. In the Sulaiman Range, Waheed and Wells (1990) conducted a detailed study of paleoflow indicators in rocks ranging in age from Cretaceous to Pliocene. As part of this study, they collected data from the Ghazij west of Dera Ismail Khan and found that paleoflow was toward the north at one site and toward the southeast at another site. They attributed this disparity to different depositional positions on two separate delta lobes. These workers described their methodology in detail.

The wide range in compass directions just cited is not surprising considering the variability in stream orientation on a relatively flat fluvial setting, and the variability in the direction of dune migration within individual stream channels. Moreover, regional and local tectonic disruptions have most likely rotated strata from their original orientation. Collecting good-quality paleocurrent data is dependent on correct procedures, especially observing features in three dimensions and correcting for structure where necessary. Any carelessness in technique can result in erroneous paleoflow interpretations.

EARLY EOCENE PALEOGEOGRAPHY

Any reconstruction of the paleogeography that existed during deposition of the Ghazij Formation is constrained by the following two facts, both of which were discussed by Hunting Survey Corporation (1960). First, overall grain size in the Ghazij decreases in an easterly direction, that is from shale, sandstone, and conglomerate to shale and limestone, which suggests a westerly source for the detritus. The total thickness of the Ghazij thins toward the east, which also supports a westerly source area. Moreover, in the Sulaiman Range, Akhtar and Masood (1991) reported that the Ghazij onlaps the Paleocene Dungan Formation from west to east, and this phenomenon requires a westerly source area. And second, the depositional facies of the Ghazij become more marine in an easterly direction, which suggests that water depth increased in that direction. Fritz and Khan (1966) reached the same conclusion from their work with Ghazij foraminifers from the Sor Range.

As stated previously, we believe that sometime near the beginning of early Eocene time the distal edge of the marine shelf that was attached to the leading edge of the Indian subcontinent made contact with a terrestrial fragment that was positioned adjacent to, but separated from, the Asian mainland. This timing fits nicely with the emplacement of the ophiolites (Humayon and others, 1991). As a first approximation, we assume that the long axes of these colliding physiographic elements were oriented northeast. The collision caused a relatively sudden reversal in the depositional slope of the marine shelf from northwest facing to southeast facing, and for the first time the region had a clastic source toward the northwest (see Waheed and Wells, 1990, for a contrasting opinion of the timing of this slope reversal). One of the initial effects of this collision was to uplift distal portions of the marine shelf exposing its carbonate-platform deposits to weathering and erosion. Evidence for this is contained in the sandstones of the lower part of the Ghazij, which are composed almost solely of limestone fragments. The topographic depression known as the Indus Foreland Basin developed between the Indian subcontinent and the tectonic highlands uplifted by the collision, and during the time between early Eocene and late Miocene this basin contained an epicontinental sea. The great thickness of lower Eocene to upper Miocene strata in the region indicates that the depositional basin subsided with time. It is probable that the floor of the basin had some amount of topographic relief caused by differential structural movements, and such features as the present-day Jacobabad high might have been present during the early Eocene, dividing the basin into a series of subbasins. (See Auden, 1974.)

We postulate that the rocks now contained in the Ghazij were deposited along the northwest side of the Indus Foreland Basin, which is best described as a mountain-front foreland basin. We visualize a series of broad deltas, each associated with a major drainage system coming from the tectonic highlands (fig. 46). The lower part of the Ghazij was deposited seaward of these deltas, the middle part of the formation was deposited within the deltas or along interdelta stretches of the coastline, and the upper part of the formation was deposited landward of the deltas.

The broader aspects of the early Eocene paleogeographic model suggested by Hunting Survey Corporation (1960) is expectedly similar to our model. However, their model was conceived during the late 1950's, a time that predates the understanding of plate tectonics. For example, their discussion of the tectonic highlands, or hinterland as they called it, as related to sediment source is made complex by their lack of understanding of modern tectonic theory. Also, not realizing that vast areas could be moved great distances by tectonics, such as with the southern advance of the Sulaiman lobe, these workers simply took the present-day outcrop belt of the Ghazij and constructed their coastal outline to fit this pattern. Hence, this part of their model has

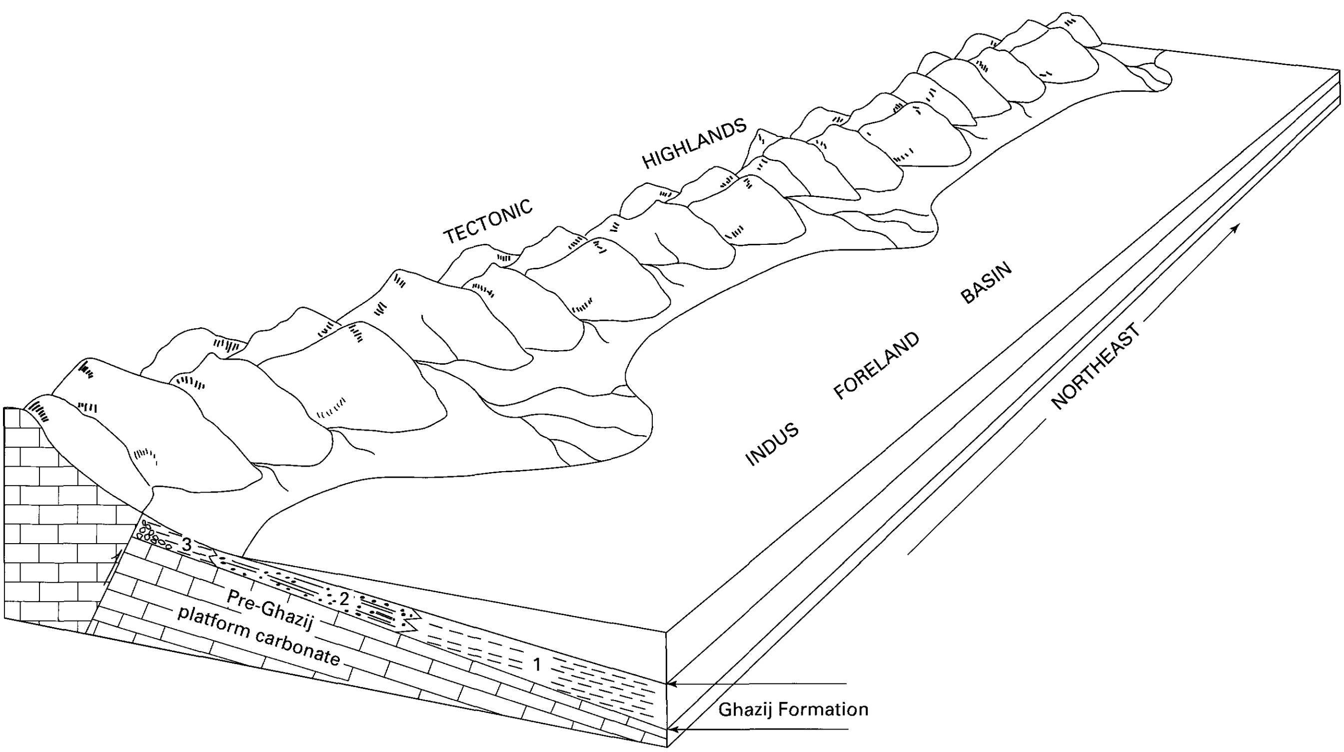


Figure 46. Interpretive sketch of northwest edge of the early Eocene Indus Foreland Basin showing deltas positioned along a southeast-prograding shoreline. Deposition of the three parts of the Ghazij Formation resulted from this progradational process. 1, Mudrock deposited in a prodelta (lower part of the formation). 2, Mudrock, sandstone, and coal deposited on lower delta plain and near shoreline (middle part of the formation). 3, Mudrock and conglomerate deposited on upper delta plain (upper part of the formation). No scale implied. Barb indicates relative direction of movement on range-front fault.

little merit today. In contrast, we assume, as a first approximation, that the coastline was relatively straight.

Current thinking (Jadoon and others, 1990, 1994; Humayon and others, 1991) has the Sulaiman Lobe moving southward since the Ghazij was deposited in early Eocene time. Therefore, exposures of the formation now located within the lobe, such as at Khost, Shahrig, Harnai, and Duki, and to a lesser extent, Kingri, Rakhi Nala, and Zinda Pir, must have been deposited to the north some unknown distance. In addition to simple southern transport, some unknown amount of rotation undoubtedly has occurred. All of this makes unraveling the details of early Eocene paleogeography in this area very difficult. Exposures of the Ghazij south of the lobe front, such as at Pir Ismail Ziarat, the Sor Range, Mach, and Johan, are probably close to their original depositional orientation, although they might have been transported at high angles away from the Himalayan orogen some unknown distance. The same can be said of Ghazij exposures along the northern part of the Sulaiman Range, such as at Moghal Kot and Drazinda.

We believe that the amount of sandstone and coal contained in the middle part of the Ghazij is directly related to proximity to delta complexes. With this in mind, we have named these the Kingri delta, the Khost-Duki delta, and the Pir Ismail Ziarat delta. The original positions of the Kingri and Khost-Duki deltas are unknown, but we believe that the Pir Ismail Ziarat delta was positioned south of these two. The delta complex that we are the most familiar with is Pir Ismail Ziarat. As the name implies, we believe that the depocenter of this complex existed somewhere in this area. We visualize a broad feature, probably tidally dominated, and believe that the Sor Range, Mach, and Johan represent increasingly distal areas of this depositional system. Hunting Survey Corporation (1960) also considered the Johan area distal to a delta setting.

DEPOSITIONAL HISTORY OF THE GHAZIJ FORMATION

In general, the vertical lithologic and biologic characteristics of the Ghazij Formation are those of a shallowing-upward sequence. We postulate that, overall, the Ghazij represents, in ascending order, marine shelf, beach, estuary, and coastal-plain deposition.

As pointed out by Gibson and others (1992), the presence of deep-water foraminifers in the lowest strata of the formation just above the shallower water limestones of the

Paleocene Dungan Formation indicates a significant increase in water depth. This requires a rise in sea level (transgression) resulting in a major marine flooding event at the beginning of the Eocene.

The general shallowing-upward conditions recorded in the upper portion of the lower part and in the middle part of the formation must have resulted from a relative lowering of sea level (regression) and the gradual withdrawal of marine water from the region. Progradation associated with this event resulted in the deposition of shoreface deposits in the lower portion of the middle part of the formation. In areas where the middle part of the formation is particularly well developed, such as at Pir Ismail Ziarat, strata in the upper portion of the middle part of the formation indicate that the progradational event progressed to the point of fluvial deposition.

One of the major unknowns concerning the Ghazij is whether a regional unconformity exists between the middle and upper parts of the formation. Where the conglomerate facies is present at the base of the upper part of the formation in the Quetta region, an unconformity is suspected at the base of the conglomerate. The same tectonism that uplifted the source area and provided the gravel could also have caused regional erosion. But in areas where the conglomerate is not present at this stratigraphic level, little evidence for an unconformity is noted. If an unconformity does exist at this level, then a continued lowering of sea level is indicated, and the conglomerate represents incised-valley-fill deposits occupying depressions that were cut during the fall in base level. In contradiction, the conglomerates in the upper part of the Ghazij to the south in the Kalat region do not seem to fit this model. Here the conglomerates seem less likely to represent a single valley-fill event because they make up much of the upper part of the formation. Unable to prove the presence of a regional unconformity, we accept the assumption that coastal-plain deposition continued into late Ghazij time.

The presence of trace fossils resembling *Ophiomorpha* in sandstone bodies in the middle portion of the upper part of the Ghazij near Pir Ismail Ziarat and near Johan indicates brackish, if not totally marine conditions. Allowing that the upper portion of the middle part of the formation was deposited under mostly fluvial conditions and that at least the lower portion of the upper part of the formation was deposited fluvially, then some amount of sea level rise (transgression) and resulting marine flooding is required to move brackish or marine environments landward across the fluvial deposits. Moreover, based on the presence of deep-water foraminifers recovered from the upper portion of the upper part of the formation in the Sor Range, this rise in sea level apparently continued into latest Ghazij time. This seems supported by the upward progression from brackish to marine ostracodes in the upper portion of the upper part of the formation near Shahrig, as reported by E.M. Brouwers (oral commun., 1994). Because a laterite is locally present at the very top of the Ghazij, a major lowering of sea level (regression) culminating with a withdrawal of marine water from the area is suspected. If this was the case, then the event is represented by a subtle regional unconformity between the Ghazij and the overlying middle Eocene Kirthar Formation. The limestones in the lower part of the Kirthar formed in relatively shallow marine water, which indicates that a rise in sea level (transgression) resulted in yet another marine flooding event at the beginning of Kirthar time.

In summary, deposition of the Ghazij seems to have been influenced by several major fluctuations in sea level (fig. 47). These fluctuations could have occurred in response to the nearby tectonism associated with the collision, or they could have been part of a worldwide eustatic event. Nagappa (1959) used foraminifer data to define four transgressive-regressive cycles affecting the deposition of Upper Cretaceous through Eocene strata in the India-Pakistan-Burma region; our model is somewhat similar to his third cycle.

ABOUT THE CONGLOMERATE FACIES

We postulate that during late Ghazij time the early Eocene collisional event culminated with intensified uplift of the Indian subcontinent's former marine shelf on the west side of the Indus Foreland Basin exposing even more of the shelf's carbonate-platform deposits to weathering and erosion. Significant relief, perhaps the scarps of high-angle reverse faults, directly adjacent to the west edge of the late Ghazij coastal plain provided coarse sediment to an otherwise low-energy depositional environment (Johnson and others, 1993). Geographic irregularities along the collisional front resulted in a unique pattern of uplifts, which then provided coarse sediment to a corresponding irregular pattern of southeast-prograding alluvial lobes. These various lobes are now represented by the conglomerate facies in the Ghazij.

CORRELATION OF THE GHAZIJ FORMATION WITH EOCENE SEDIMENTARY ROCKS IN ADJACENT REGIONS

Much work remains to be done before unequivocal correlations can be made between the Ghazij Formation and lower Eocene sedimentary rocks in adjacent regions. This work will involve studies on biostratigraphy and depositional settings that will ultimately lead to a better understanding of the small-scale paleogeographic subtleties that existed during this epoch.

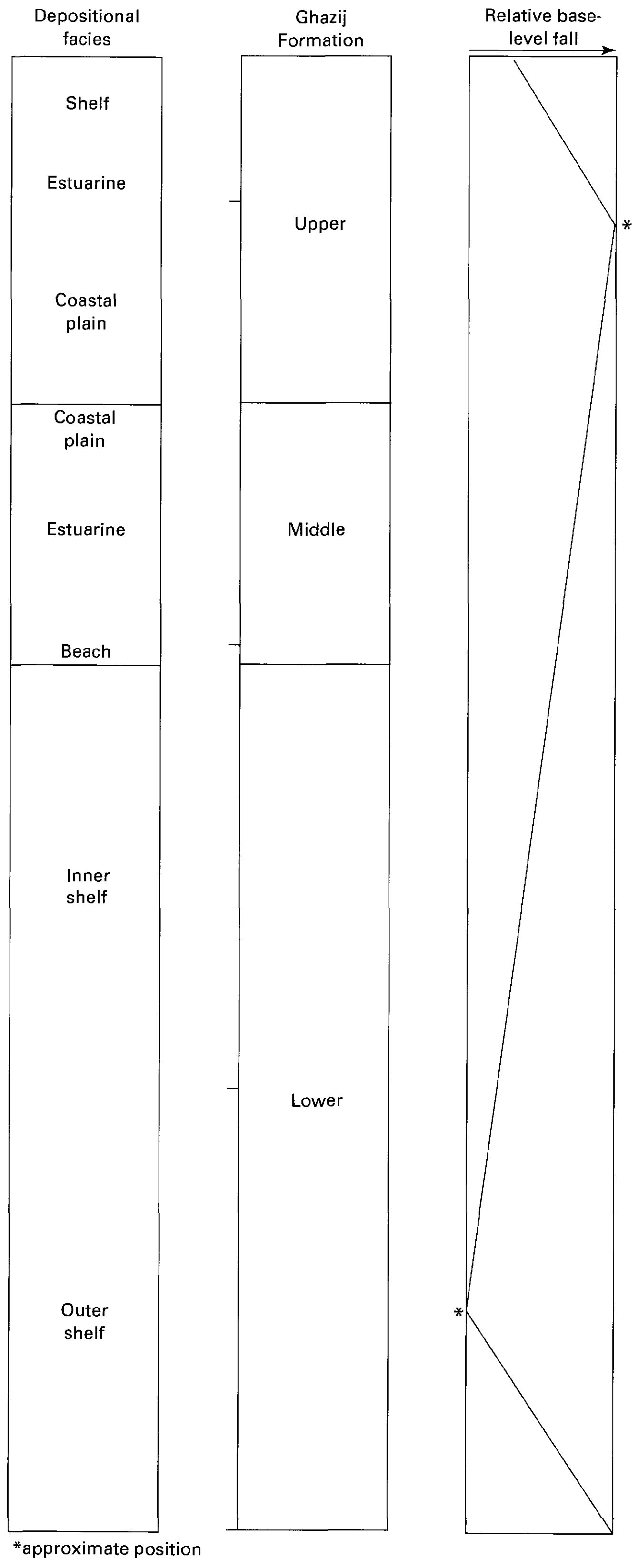


Figure 47. Depositional environment of the lower Eocene Ghazij Formation as compared to base-level fluctuations. Scale in 500-m increments.

TOWARD THE NORTH—NORTH WEST FRONTIER PROVINCE

Along the eastern flank of the northern part of the Sulaiman Range between latitudes 31°00′ and 33°00′ N., Hemphill and Kidwai (1973) mapped three Eocene units, Ghazij Shale, Baska Shale, and Kirthar Formation. The Ghazij Shale and the Baska Shale are thought to be equivalent to the Ghazij Formation in the Quetta region (fig. 48). On their maps, outcrop patterns of these two units trend north, generally between longitudes 70°00′ and 70°15′ E. The Baska Shale is not shown north of about lat 32°30′ N., but the Ghazij Shale is shown extending to the north edge of the area of their northernmost map. The abrupt termination of the outcrop pattern at this edge implies that the unit continues beyond the northern limit of their mapping. However, the name Ghazij is not used in publications concerning lower Eocene strata in areas beyond lat 33°00′ N., which happens to be the latitude of Bannu (fig. 49).

THAL-KOHAT AREA

North and northeast of Bannu in the Thal-Kohat area (fig. 49), Eocene rocks have been mapped and described by Meissner and others (1974) and by Meissner and others (1975). The usual ascending sequence is Panoba Shale, Mami Khel Clay, and Kohat Formation. By direction of the Stratigraphic Committee of Pakistan (Shah, 1977), the Mami Khel Clay has been renamed the Kuldana Formation. Throughout the region the Panoba and Kuldana are separated by an unconformity. The Kuldana and Kohat are separated by an unconformity on the west side of the area, but on the east side the contact is conformable. In the southeastern part of the region, in an apparently more basinward direction, the Shekhan Limestone intervenes between the Panoba and the Kuldana, and no unconformities are present in the Eocene sequence. Farther to the southeast, facies changes have resulted in the Bahadur Khel Salt replacing the upper part of the Panoba, and the Jatta Gypsum replacing the Shekhan. Throughout the Thal-Kohat area the Eocene sequence is underlain conformably by the Paleocene Patala Formation, and unconformably overlain by the Miocene Murree Formation.

The pattern labeled Ghazij Shale that terminates against the northern border of the area of the map by Hemphill and Kidwai (1973) at lat 33°00′ N. is shown on the southern border of the area of a map by Meissner and others (1975) to continue as the Panoba Shale. Both Hemphill and Kidwai, and Meissner and others agreed that the two lithostratigraphic units are equivalent. B.R. Wardlaw and others observed and measured parts of the lower Tertiary sequence in this region in 1991. In an unpublished trip report outlining their activities, Wardlaw (written commun., 1991) indicated on a figure that the Panoba Shale in this area is equivalent to

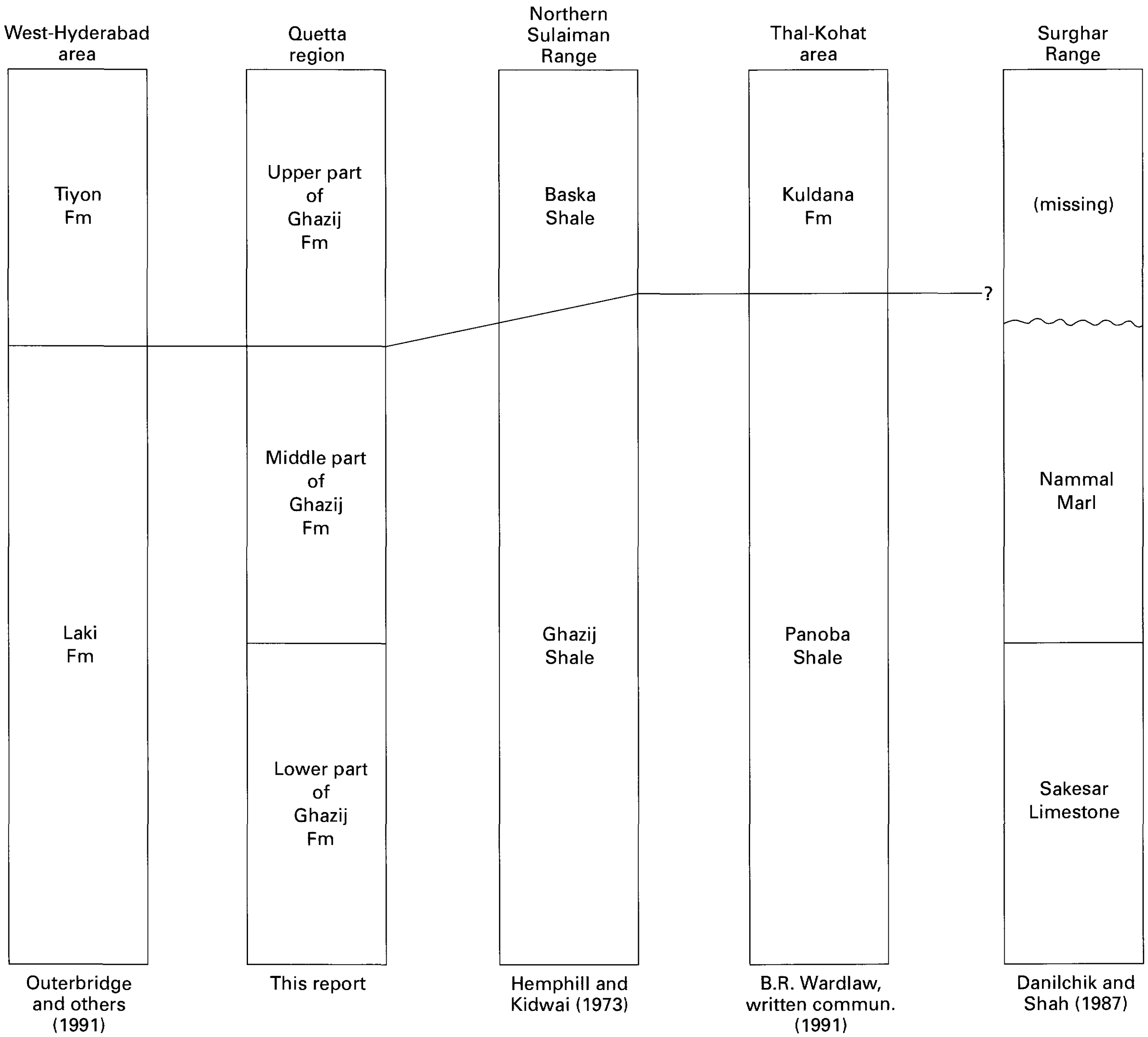


Figure 48. Diagram correlating lower Eocene strata in the Quetta region with lower Eocene strata in selected areas of North West Frontier Province and Sindh Province. No scale implied.

the lower part of the Ghazij Formation in the Quetta region (fig. 48). Moreover, one of his measured sections containing the Panoba shows an interval of sandstone and conglomerate about 60 m thick at the top of the formation that he interpreted as a deltaic deposit. Although the middle part of the Ghazij as it is known in the greater Quetta region pinches out at some latitude north of Kingri, the deltaic unit just mentioned probably accumulated in a paleogeographic setting similar to that of the middle part of the Ghazij in the Quetta region. Also in this trip report, Wardlaw stated his belief that the Kuldana Formation, Baska Shale, and the upper part of the Ghazij Formation in the greater Quetta region were all stratigraphic equivalents. In contrast to this, Hemphill and Kidwai (1973) believed that the Baska simply pinched out toward the north within the area of their mapping. We note that Gingerich and others (1979) reported the presence of middle Eocene fossil vertebrate remains in the Kuldana Formation near Kohat. If the upper part of the Ghazij and the Baska Shale are lower Eocene, as usually cited, then the depositional facies must become younger toward the north for the upper Ghazij-Baska-Kuldana correlation to be valid.

SURGHAR RANGE

East of Bannu near Makarwal in the Surghar Range (fig. 49), Eocene rocks have been mapped and described by Danilchik and Shah (1987). Here, only two units are recognized, Nammal Marl and Sakesar Limestone. This

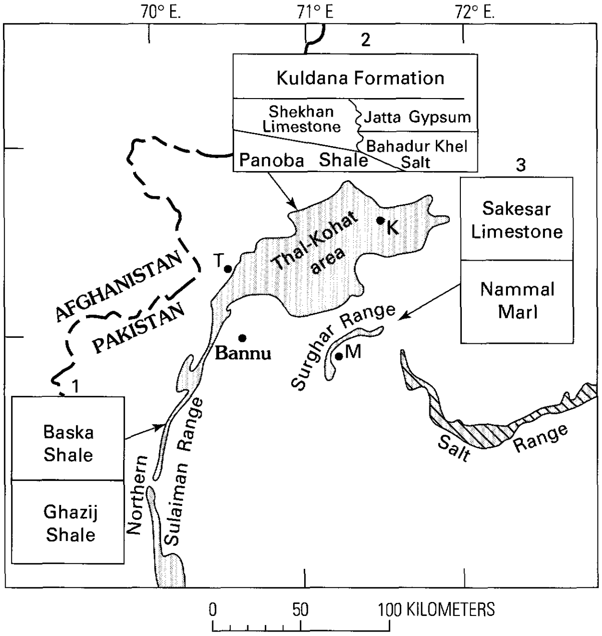


Figure 49. Lithostratigraphic units in northern Sulaiman Range and to north that possibly correlate with the Ghazij Formation in Quetta region. Shaded pattern encloses exposures of Eocene rocks. T, Thal; K, Kohat; M, Makarwal. 1, northern Sulaiman Range; 2, Thal-Kohat area; 3, Surghar Range. No vertical scale implied. Modified from Bakr and others, 1964.

sequence is underlain conformably by the Paleocene Patala Shale and overlain unconformably by the Oligocene to Miocene Mitha Khatak Formation.

According to Meissner and others (1974) the lower two thirds of the Sakesar is equivalent to the Panoba Shale, and the upper third is equivalent to the Shekhan Limestone. If this is correct then the Sakesar, and probably the Nammal, are time-stratigraphic equivalents of the Ghazij Shale near Bannu (fig. 48) and, by inference, the lower and middle parts of the Ghazij Formation in the greater Quetta region (see also Iqbal, 1969; Shah, 1977, 1990). The fact that the Surghar units are carbonates indicates a more basinward depositional position. Because the Sakesar is overlain by an unconformity in the Surghar Range it is impossible to tell if a time-stratigraphic equivalent to the Baska Shale was removed by erosion or simply never deposited.

TOWARD THE SOUTHEAST—SINDH PROVINCE

South along the Kirthar Range, the Ghazij Formation crops out intermittently to a point 23 km south of Karkh at about lat 27°30′ N., where the farthest-south exposure is terminated by a fault (Hunting Survey Corporation, 1960). In this part of the Kirthar Range, the Ghazij is composed almost exclusively of mudrock, and the formation is underlain by the Paleocene Karkh Group and overlain by the mostly Eocene Brahma Limestone; both of these are local units roughly equivalent to the Paleocene Dungan Formation and the middle Eocene Kirthar Formation, respectively.

HYDERABAD

In the southern part of Sindh Province west of Hyderabad, rocks of Eocene age are well exposed over a broad area (fig. 50). This area is centered about 240 km south-southeast of the southernmost exposure of Ghazij Formation in the central Kirthar Range. The Eocene sequence is composed of the following units, in ascending order: Laki Formation, Tiyon Formation, and Kirthar Formation (Kazmi and others, 1990; Outerbridge and others, 1991). This sequence is underlain conformably by the Paleocene Sohnari Formation, and overlain unconformably by the Oligocene Nari Formation.

The time-stratigraphic equivalent of the Ghazij Formation is probably contained in the sub-Kirthar part of the sequence, namely the Laki (Shah, 1977; Hunting Survey Corporation, 1960) and Tiyon Formations. But because the closest exposures are separated by 240 km, a more specific correlation based on lithofacies is probably impossible. This apparent limitation does not, however, prohibit speculative comments. Based on stratigraphic position we postulate that the mostly nonmarine Sohnari is perhaps the time-stratigraphic equivalent of at least part of the Paleocene Dungan Formation in Balochistan (see also Hunting Survey Corporation, 1960). Outerbridge and others (1991) suggested that the Sohnari probably represents a minor regressive event. If this is correct, then the associated slight fall in sea level might have affected shallower parts of the marine shelf positioned close to the India subcontinent, while having only minor effects on carbonate deposition farther out on the shelf toward the northwest. The marine transgression indicated by the deposition of marine rocks of the Meting Limestone Member of the Laki Formation, which overlies the Sohnari, might be associated with the transgressive event in Balochistan that caused deep-water mudrock in the lower portion of the lower part of the Ghazij to be deposited over shallow-water carbonates in the Dungan. Based on lithology, the Tiyon might possibly represent another minor regressive event. Adding this hypothesis to the formation's stratigraphic position, one might argue that the Tiyon is somehow related to the regressive event that affected the deposition of the upper part of the Ghazij in Balochistan (fig. 48). This leaves the Laki as the most likely candidate for equivalence to the lower and middle parts of the Ghazij (see also Iqbal, 1969).

POST-GHAZIJ GEOLOGIC HISTORY

POST-GHAZIJ PLATE TECTONICS

By the middle Eocene the effects of the initial collision had subsided, and between middle Eocene and earliest

Miocene time, the Indian subcontinent made its final approach to the Asian mainland. Thus, the distance between the terrestrial fragment and the mainland is accounted for. Actual docking of the two landmasses must have occurred between earliest Miocene and earliest Pliocene time, but the full impact of the collision did not occur until later in the Pliocene when the ongoing Himalayan orogeny began. Currently, the convergence rate is about 4 cm/yr (Powell, 1979) as the Indian subcontinent tries to underthrust, perhaps obliquely, the Asian mainland. Estimates of total crustal shortening since the beginning of the Himalayan orogeny range from 600 km (Butler and Coward, 1989) to 2,000 km (Patriat and Achache, 1984).

POST-GHAZIJ DEPOSITION

Following the initial collision and the deposition of the Ghazij Formation, the area that is now northeastern Balochistan entered a period for which the geologic setting is poorly understood. This period is represented by the rocks contained in the middle part of the stratigraphic column (fig. 4) above the Ghazij and below the conglomerates of the collision molasse.

PREOROGENIC MARINE DEPOSITS

Rocks just above the Ghazij Formation are mostly marine, and were deposited in a variety of specific environments. The strata probably accumulated on a south- or southeast-facing depositional slope that received clastic input from the north or northwest. During this period, it is possible that several transgressive-regressive events occurred (Nagappa, 1959), and by the orientation of the depositional slope we propose, the sea would have approached and retreated from the south or southeast, but there is no evidence to support this conclusion. The following brief lithologic descriptions are based primarily on Hunting Survey Corporation (1960) and Shah (1977).

Overlying the Ghazij is the middle to upper Eocene Kirthar Formation (Spintangi Limestone of Hunting Survey Corporation, 1960). This unit contains locally abundant marine fossils, and is divided into four members that define two depositional cycles, each consisting of shallow-water limestone overlain by shale. Bedded gypsum, as thick as 6 m, is locally present in the lower part of the formation and probably represents deposition in areas of restricted-marine circulation.

Above the Kirthar is the Oligocene Nari Formation. This unit consists mostly of cross-stratified, ripple-laminated, medium- to coarse-grained sandstone interbedded with minor amounts of shale. Limestone containing marine fossils and interbedded with shale and sandstone is commonly present in the lower part of the formation. The Nari signals the end of post-Ghazij carbonate deposition, and the large amount of sand in the formation represents the first major influx of clastic detritus to enter the depositional environment since Ghazij time; its presence might be a precursor to later events.

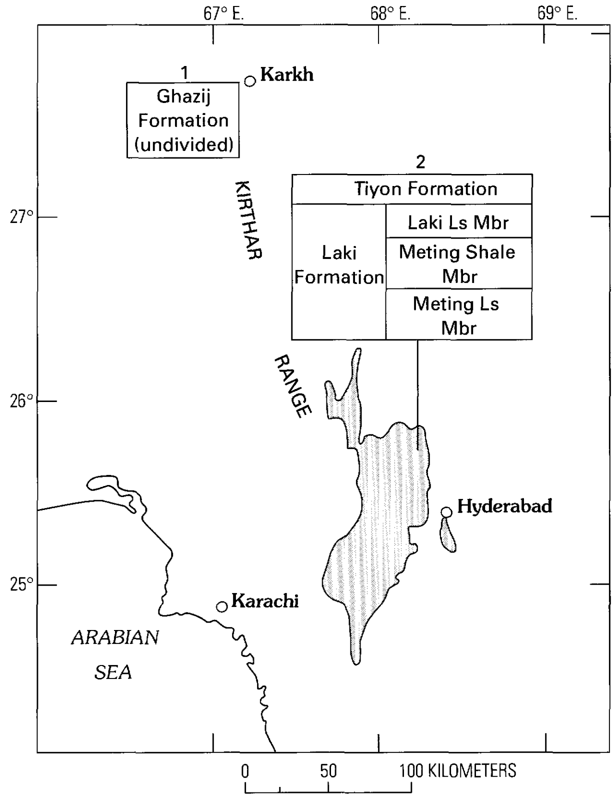


Figure 50. Lithostratigraphic units in Sindh Province that possibly correlate with the Ghazij Formation in Quetta region. Shaded pattern encloses exposures of Eocene rocks west of Hyderabad. 1, Central Kirthar Range south of Karkh; 2, West-Hyderabad area. No vertical scale implied. Modified from Bakr and Jackson, 1964.

The last marine unit to be deposited is the Miocene Gaj Formation; it is not present in most areas north of Quetta. This unit consists of shale with subordinate amounts of sandstone and limestone, all of which contain marine fossils. However, in the uppermost part of the formation in the northern part of the Kirthar Range, sedimentary features are reported that suggest fluvial deposition (Hunting Survey Corporation, 1960).

PREOROGENIC NONMARINE DEPOSITS

The first truly nonmarine unit to be deposited in the region is the upper Miocene Nagri Formation of the Siwalik Group. The Nagri consists of green and blue, medium- to coarse-grained sandstone with subordinate amounts of shale and conglomerate, the latter containing pebbles of igneous rock and limestone. Terrestrial vertebrate fossils are abundant, and Waheed and Wells (1990) reported fossil root traces and pedogenic features.

The lowest Pliocene Dhok Pathan Formation of the Siwalik Group was the last relatively fine grained continental unit to be deposited prior to the arrival of the collision molasse. This unit consists of multiple cycles of sandstone and shale with some layers and lenses of conglomerate in the upper part. Terrestrial vertebrate fossils are very common.

SYNOROGENIC DEPOSITS

The beginning of coarse-grained molasse deposition did not occur until later in the Tertiary after the full impact of the main collision had initiated the Himalayan orogeny. Starting in the earliest Pliocene, radical uplift associated with the orogeny provided a source of gravelly sediments that were transported by braided streams (Waheed and Wells, 1990) away from the tectonism and eventually deposited in foredeep basins that developed subparallel to the tectonic front. The conglomerates shown in the upper part of the stratigraphic column (fig. 4), the Pliocene-Pleistocene Soan Formation, and Pleistocene Lei Conglomerate, Bostan Formation, and Dada Conglomerate, were deposited by this process. Waheed and Wells (1990) collected paleocurrent data from post-Oligocene deposits at two widely spaced sites in the Sulaiman Range. Although data from the northern part of the range indicate paleoflow generally toward the southeast, which seems to fit the regional model of molasse deposition, data from the southern part of the range indicate a paleoflow toward the southwest, which seems at variance to the model.

Since the early Pliocene, tectonism has apparently proceeded toward the south in the Salt Range (fig. 49) and Sulaiman lobe, and toward the east in the Sulaiman and Kirthar Ranges, away from the main orogen. This tectonic progression is evident by the development of small folds within the foredeep just off the main tectonic fronts. Good examples are the Zinda Pir anticline east of the Sulaiman Range, and the Sui and Uch anticlines south of the Sulaiman lobe (Jadoon, 1991; Humayon and others, 1991). Accompanying this tectonic migration, depocenters of the associated foredeeps have moved in the same direction as sediments prograde away from the approaching tectonic fronts. The fact that the molasse sequence generally coarsens upward seems to support this concept. Raynolds and Johnson (1985) reported that a vertical sedimentation rate of 20–30 cm per 1,000 years, and a horizontal depocenter migration rate of 20 m per 1,000 years, are typical for these deposits.

Earthquakes are common events in northeastern Balochistan, and one such event near Quetta in 1935 registered at least 7 on the Richter Scale. Thus it is clear that the Himalayan orogeny continues into the present, and associated seismicity is recognized throughout Pakistan.

SELECTED REFERENCES

Abdel-Gawad, Monem, 1971, Wrench movement in the Baluchistan arc and relation to Himalayan-Indian Ocean tectonics: Geological Society of America Bulletin, v. 82, no. 5, p. 1235–1250.

Adams, L.D., and Carter, J.M.L., 1997, Influence of synsedimentary tectonics on hydrocarbon systems; three examples from Balochistan Province, Pakistan [abs.]: American Association of Petroleum Geologists, 1997 Annual Convention, Official Program, p. 1.

Ahmad, Habib, 1982, Isopach map showing thickness and distribution of Cretaceous and Eocene sedimentary rocks in Pakistan, *in* Kazmi, A.H., and Rana, R.A., compilers, Tectonic map of Pakistan: Geological Survey of Pakistan, scale 1:2,000,000.

Ahmad, S.A., and Kazim, M.A., 1987, Geology of coal-bearing "Ghazij Formation" of Mach area, Baluchistan, Pakistan: Acta Mineralogica Pakistanica, v. 3, p. 69.

Ahmad, Waheeduddin, Gauhar, S.H., and Siddiqi, R.A., 1986, Coal resources of Pakistan: Geological Survey of Pakistan, Records, v. 73 (73), 55 p.

Ahmad, Zaki, and Abbas, S.G., 1979, The Muslim Bagh ophiolites, *in* Farah, Abul, and DeJong, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 243–249.

Ahmed, F., Khan, M.K., and Hamid, I., 1969, Geology of Rodho anticline Safed Koh Range, special territory of D. G. Khan District, Multan Division Western Pakistan: Oil and Gas Development Corporation, Report on work carried out by geological party no. 1 during the first half field season 1968–69, 16 p. (on file with the Geological Survey of Pakistan, Quetta).

Ahmed, Jawed, Moore, D.M., and Ahmed, Zulfiqar, 1985, The nature of clay minerals from a section of Ghazij Shale Formation in Chappar Valley near Mangi Kach, Baluchistan: Acta Mineralogica Pakistanica, v. 1, p. 74–77.

Ahmed, Riaz, and Ahmad, Jalil, 1991, Petroleum geology and prospects of Sukkur rift zone, Pakistan with special reference to Jaisalmer, Cambay and Bombay high basins of India: Pakistan Journal of Hydrocarbon Research, v. 3, no. 2, p. 33–41.

Ahmed, Riaz, and Ali, S.M., 1991, Tectonic and structural development of the eastern part of the Kirthar Fold Belt and its hydrocarbon prospects: Pakistan Journal of Hydrocarbon Research, v. 3, no. 2, p. 19–31.

Ahmed, W., and Gauhar, S.H., 1986, Plate tectonics, crustal evolution and metallogeny of Pakistan: Lahore, Pakistan, Punjab University, Institute of Geology, First Advanced School in Geology, Himalayan Research Centre, Khanspur, Volume of Abstracts, no. 7, p. 8–9.

Ahmed, W.A., Gauhar, S.H., and Siddiqui, R.A., 1986, Coal resources of Pakistan: Records of the Geological Survey of Pakistan, v. 73, 55 p.

Akhtar, Muhammad, and Masood, Tariq, 1991, Guide book to geology of Sulaiman Range: Geological Survey of Pakistan, Information Release No. 342, 24 p.

Allemann, Franz, 1979, Time of emplacement of the Zhob Valley ophiolites and Bela ophiolites, Baluchistan (preliminary report), *in* Farah, Abul, and DeJong, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 215–242.

Asarullah, Ahmad, Zaki, and Abbas, S.G., 1979, Ophiolites in Pakistan; an introduction, *in* Farah, Abul, and DeJong, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 181–192.

Aubry, Thierry, Ahmed, Zulfiqar, and Baloch, M.K., 1988, A preliminary study of cherts from Balochistan: Acta Mineralogica Pakistanica, v. 4, p. 102–112.

Auden, J.B., 1974, Afghanistan-West Pakistan, *in* Spencer, A.M., ed., Mesozoic-Cenozoic orogenic belts: The Geological Society of London Special Publication 4, p. 235–254.

Bakr, M.A., and Jackson, R.O., compilers, 1964, Geological map of Pakistan: Geological Survey of Pakistan, scale 1:2,000,000.

Banks, C.J., and Warburton, J., 1986, Passive-roof duplex geometry in the frontal structures of the Kirthar and Sulaiman mountain belts, Pakistan: Journal of Structural Geology, v. 8, nos. 3/4, p. 229–237.

Bannert, Dietrich, in cooperation with Cheema, Amjed, Ahmed, Abrar, and Schaffer, Uwe, 1992, The structural development of the western fold belt, Pakistan: Geologisches Jahrbuch Reihe B, Heft 80, 60 p.

Beck, R.A., Burbank, D.W., Sercombe, W.J., Riley, G.W., Barndt, J.K., Berry, J.R., Afzal, Jamil, Khan, A.M., Jurgen, Hermann, Metje, Jogen, Cheeman, Amjed, Shafique, N.A., Lawrence, R.D., and Khan, M.A., 1995, Stratigraphic evidence for an early collision between northwest India and Asia: Nature, v. 373, p. 55–58.

Bender, F.K., 1995, Palaeogeographic and geodynamic evolution, *in* Bender, F.K., and Raza, H.A., eds., Geology of Pakistan: Berlin, Gebruder Borntraeger, p. 162–181.

Besse, J., Courtillot, V., Pozzi, J.P., Westphal, M., and Zhou, Y.X., 1984, Palaeomagnetic estimates of crustal shorting in the Himalayan thrusts and Zangbo suture: Nature, v. 311, no. 5987, p. 621–626.

Blanford, W.T., 1882, Note on the coal of Mach (Much) in the Bolan pass, and of Sharag or Sharigh on the Harnai route between Sibi and Quetta: Records of the Geological Survey of India, v. 15, pt. 3, p. 149–153.

———1883, Geological notes on the hills in the neighbourhood of the Sind and Punjab frontier between Quetta and Der Ghazi Khan: Memoirs of the Geological Survey of India, v. 20, pt. 2, p. 105–240.

Butler, Rob, 1995, When did India hit Asia?: Nature, v. 373, p. 20–21.

Butler, R.W.H., and Coward, M.P., 1989, Crustal scale thrusting and continental subduction during Himalayan collision tectonics on the NW Indian plate, *in* Sengor, A.M.C., ed., Tectonic evolution of the Tethyan region: Kluwer Academic Publishers, p. 387–413.

Crookshank, H., (and Heron, A.M.), 1954, Directory of economic minerals of Pakistan: Records of the Geological Survey of Pakistan, v. 7, pt. 2, 146 p.

Danilchik, Walter, and Shah, S.M.I, 1987, Stratigraphy and coal resources of the Makarwal area, Trans-Indus Mountains, Mianwali District, Pakistan: U.S. Geological Survey Professional Paper 1341, 38 p.

DeJohn, K.A., and Farah, Abul, 1976, Geodynamic significance of ophiolites in Baluchistan, Pakistan, *in* Michot, P., organizer, Geology and petrology of the crystalline domains of the earth's crust: International Geological Congress, Abstracts, v. 3, Symposium 102.1, p. 701.

Eames, F.E., 1951, A contribution to the study of the Eocene in Western Pakistan and western India—B, The descriptions of the Lamellibranchia from standard sections in the Rakhi Nala and Zinda Pir areas of the western Punjab and in the Kohat District: Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, v. 235, no. 627, p. 311–482.

———1952a, A contribution to the study of the Eocene in Western Pakistan and western India—A, The geology of standard sections in the western Punjab and in the Kohat District: The Quarterly Journal of the Geological Society of London, v. 107, p. 159–171.

———1952b, A contribution to the study of the Eocene in Western Pakistan and western India—C, The descriptions of the Scaphopoda and Gastropoda from standard sections in the Rakhi Nala and Zinda Pir areas of the western Punjab and in the Kohat District: Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences, v. 236, no. 631, p. 1–162.

———1952c, A contribution to the study of the Eocene in Western Pakistan and western India—D, Discussion of the faunas of certain standards, and their bearing on the classification and correlation of the Eocene in Western Pakistan and western India: The Quarterly Journal of the Geological Society of London, v. 107, p. 173–200.

Farah, Abul, and DeJong, K.A., eds., 1979, Geodynamics of Pakistan: Geological Survey of Pakistan, 361 p.

Farah, Abul, Lawrence, R.D., and DeJong, K.A., 1984, An overview of the tectonics of Pakistan, *in* Haq, B.U., and Milliman, J.D., eds., Marine geology and oceanography of Arabian Sea and coastal Pakistan: New York, Van Nostrand Reinhold, p. 161–176.

Fritz, E.B., and Khan, M.U., 1966, Stratigraphy and paleontology of coal beds in the Ghazij Shale, Sor Range-Daghari coal fields, Quetta Division, West Pakistan: U.S. Geological Survey Administrative Report PK–15, 16 p.

———1975, Stratigraphy and paleontology of coal beds in the Ghazij Shale, Sor Range-Daghari coal fields Quetta Division, Pakistan: U.S. Geological Survey Open-File Report 75-274, 16 p.

Gansser, Augusto, 1979, Reconnaissance visit to the ophiolites in Baluchistan and the Himalaya, *in* Farah, Abul, and Dejong, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 193–213.

Garzanti, E., Salvatore, C., and Ingersoll, R.V., 1996, Paleogeographic and paleotectonic evolution of the Himalayan Range as reflected by detrital modes of Tertiary sandstones and modern sands: Geological Society of America Bulletin, v. a108, no. 6, p. 631–642.

Gee, E.R., 1945, Coal: Records of the Geological Survey of India, v. 76, no. 16, 84 p.

———1950, The mineral resources of north western India: Records of the Geological Survey of Pakistan, v. 1, pt. 1, 25 p.

———1989, Overview of the geology and structure of the Salt Range, with observations on related areas of northern Pakistan, *in* Malinconico, L.L., and Lillie, R.J., eds., Tectonics of the western Himalayas: Geological Society of America Special Publication 232, p. 95–112.

Geological Survey of Pakistan and U.S. Geological Survey, 1988, National coal exploration plan: U.S. Geological Survey Open-File Report 88-251, 81 p.

Ghaznavi, M.I., 1990, Characterization of the coals of Harnai-Shahrig-Khost area, Balochistan, Pakistan: Carbondale, Ill., Southern Illinois University Ph. D. thesis, 358 p.

Gibson, Thomas, Khan, Intizar, and Fatmi, Farah, 1992, Paleobathymetric changes in uppermost Paleocene strata in Pakistan: First South Asia Geological Congress, Abstracts, Islamabad, Pakistan, p. 56.

Gibson, T.G., 1994, Foraminiferal evidence for Paleocene-Eocene boundary tectonism in northwestern Pakistan, *in* Langer, M.R., and Harmeet, B., eds., Forams '94, international symposium on Foraminifera [abs.]: PaleoBios, v. 16, supplement to no. 2, p. 32.

Gingerich, P.D., Russell, D.E., Sigogneau-Russell, Denise, and Hartenberger, J.L., 1979, *Chorlakkia Hassani*, a new middle Eocene Dichobunid (*Mammalia, Artiodactyla*) from the Kuldana Formation of Kohat (Pakistan): Ann Arbor, Mich., University of Michigan Contributions from the Museum of Paleontology, v. 25, no. 6, p. 117–124.

Griesbach, C.L., 1881, Report on the geology of the section between the Bolan Pass in Biluchistan and Girishk in southern Afghanistan: Memoirs of the Geological Survey of India, v. 18, p. 1–60.

———1893, On the geology of the country between Chappar Rift and Harnai in Balochistan: Records of the Geological Survey of India, v. 26, pt. 4, p. 113–147.

Haque, A.F.M.M., 1959, Some middle to late Eocene smaller Foraminifera from the Sor Range, Quetta District, West Pakistan: Memoirs of the Geological Survey of Pakistan, Palaeontologia Pakistanica, v. 2, pt. 2, 79 p.

Hemphill, W.R., and Kidwai, A.H., 1973, Stratigraphy of the Bannu and Der Ismail Khan areas, Pakistan: U.S. Geological Survey Professional Paper 716–B, 36 p.

Humayon, Mansoor, Lillie, R.J., and Lawrence, R.D., 1991, Structural interpretation of the eastern Sulaiman foldbelt and foredeep, Pakistan: Tectonics, v. 10, no. 2, p. 299–324.

Hunting Survey Corporation, Limited, 1960 [1961], Reconnaissance geology of part of West Pakistan; a Colombo Plan Cooperative Project: Toronto, Canada, Government of Canada; Oshawa, Ontario, Maracle Press, 550 p.

Husain, F., Shah, S.M.I., Rauf, M.A., and Bhatti, N.A., 1985, Geologic Map of Daghari: Geological Survey of Pakistan, Balochistan Map Series, Sheet 97, scale 1:7,423.

Iqbal, M.W.A., 1969, Mega-fauna from the Ghazij Formation (lower Eocene) Quetta Shahrig area, West Pakistan: Memoirs of the Geological Survey of Pakistan, Palaeontologia Pakistanica, v. 5, 40 p.

Iqbal, M.W.A., and Shah, S.M.I., 1980, A guide to the stratigraphy of Pakistan: Records of the Geological Survey of Pakistan, v. 53, 34 p.

Jadoon, I.A.K., 1991, The style and evolution of foreland structures; an example from the Sulaiman Lobe, Pakistan: Pakistan Journal of Hydrocarbon Research, v. 3, no. 2, p. 1–17.

Jadoon, I.A.K., Lawrence, R.D., and Lillie, R.J., 1990, Balanced retrodeformed geological cross-section from frontal Sulaiman lobe, Pakistan; duplex development in the thick strata along the western margin of the Indian Plate, *in* McClay, K.R., ed., Thrust tectonics: London, Chapman and Hall, p. 343–356.

———1994, Seismic data, geometry, evolution, and shorting in the active Sulaiman fold-and-thrust belt of Pakistan, southwest of the Himalayas: American Association of Petroleum Geologists Bulletin, v. 78, no. 5, p 758–774.

Johnson, E.A., and Khan, I.H., 1994a, Principal reference section for part of the Eocene Ghazij Formation, Shin Ghwazha mine area, Sor Range coal field, Balochistan, Pakistan, U.S. Geological Survey Miscellaneous Field Studies Map MF–2263–B.

———1994b, Principal reference section for part of the Eocene Ghazij Formation, Abraham Marri mine area, Pir Ismail Ziarat coal field, Balochistan, Pakistan: U.S. Geological Survey Miscellaneous Field Studies Map MF–2263–A.

Johnson, E.A., Warwick, P.D., Khan, I.H., and Kazim, M.A., 1994, Principal reference section for part of the Eocene Ghazij Formation, Moghal mine area, Mach coal field, Balochistan, Pakistan: U.S. Geological Survey Miscellaneous Field Studies Map MF–2263–D.

Johnson, E.A., Warwick, P.D., Khan, I.H., Rana, A.N., and Kazim, M.A., 1994, Principal reference section for part of the Eocene Ghazij Formation, Sarawan River area, Johan coal field, Balochistan, Pakistan: U.S. Geological Survey Miscellaneous Field Studies Map MF–2263–E.

Johnson, E.A., Warwick, P.D., Roberts, S.B., and Khan, I.H., 1993, Limestone-pebble conglomerate facies of the Eocene Ghazij Formation, Balochistan, Pakistan; evidence for collision-related tectonism on the northwestern margin of the Indian Plate [abs.]: American Association of Petroleum Geologists, 1993 Annual Convention Program, p. 124.

Kassi, A.M., 1986, Sandstone petrology of Ghazij Formation of Degari, Kach, Murree Brewery, and Bib Nani areas, northeast Baluchistan: Geological Bulletin, University of Peshawar, v. 19, p. 77–82.

Kassi, A.M., Qureshi, A.R., and Kakar, D.M., 1987, Sedimentology of the Ghazij Formation, Kach area, Baluchistan: Geological Bulletin, University of Peshawar, v. 20, p. 53–62.

Kazi, A., 1968, Sedimentology of the Ghazij Formation, Harnai, Balochistan, *in* Bulman, O.M.B., Nockolds, S.R., and Harland, W.B., eds., Geological Magazine: Caxton Hill, England, Mimram Books, v. 105, no. 1, p. 35–45.

Kazim, M.A., Rana, A.N., Memon, A.R., Saleem, M., and Khan, A.L., 1991, Coal resources of Sor-Range Block, Sor-Range-Daghari coal field, Balochistan, Pakistan: Geological Survey of Pakistan, Information Release No. 463, 18 p.

Kazim, M.A., Younas, Mohammad, and Hussain, S.A., 1987, Urban geologic map of the Quetta valley: Geological Survey of Pakistan, Urban Geologic Map of Pakistan Baluchistan Series, Map-1, scale approximately 1:62,500.

Kazmi, A.H., 1962, Stratigraphy of the Ghazij shales: Geological Society, University of Karachi, The Geologist, v. 1, no. 1, p. 27–40.

———1979, Active fault systems in Pakistan, *in* Farah, Abul, and DeJong, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 285–294.

Kazmi, A.H., and Rana, R.A., compilers, 1982, Tectonic map of Pakistan: Geological Survey of Pakistan, scale 1:2,000,000.

Kazmi, A.H., and Siddiqi, R.A., eds., 1990, Significance of the coal resources of Pakistan: Geological Survey of Pakistan and U.S. Geological Survey, 269 p.

Kazmi, A.H., Khan, M.S., Khan, I.A., Fatmi, S.F., and Fariduddin, M., 1990, Coal resources of Sindh, Pakistan, *in* Kazmi, A.H., and Siddiqi, R.A., eds., Significance of the coal resources of

Pakistan: Geological Survey of Pakistan and U.S. Geological Survey, p. 27–61.

Kemal, A., 1964, Geology of Pir Koh anticline Marri-Bugti area District Sibi West Pakistan: Oil and Gas Development Corporation, Report on work carried out by the geological party no. 1 field season 1963–64, 11 p. (on file with the Geological Survey of Pakistan, Quetta).

Kemal, Arif, and Malik, M.A., 1987, Geology and gas resources of Mari-Bugti agency, Pakistan: Acta Mineralogica Pakistanica, v. 3, p. 72–81.

Kemal, Arif, Balkwill, Hugh, Stokes, Frank, and Campbell, Clarence, 1992, Indus Basin, Pakistan hydrocarbon plays [abs.]: American Association of Petroleum Geologists, 1992 Annual Convention Official Program, p. 64.

Khan, G.S., 1994, Coal for power in Balochistan: Pakistan Mine Owners Association, Quetta, 4 p.

Khan, M.Y., Landis, E.R., and Reinemund, J.A., 1972, Coal resources of Pakistan: U.S. Geological Survey Project Report, Pakistan Investigations, PK-61, 126 p.

Khan, N.M., 1950, A survey of coal resources of Pakistan: Geological Survey of Pakistan, v. 2, pt. 2, 11 p.

Khan, S.N., Abbas, S.G., Sultan, Muzaffar, Khan, I.H., and Shah, S.M.I., 1986, Coal resources of Duki and adjoining regions, Loralai District, Baluchistan, Pakistan: Geological Survey of Pakistan, Records, v. 74, 22 p.

Khan, S.N., Younas, Muhammad, Kazim, M.A., and Hussain, S.A., 1986, Environmental geology, mineral, raw materials, and aggregate resources of Quetta Valley, Baluchistan, Pakistan: Geological Survey of Pakistan, Records, v. 76, 44 p.

King, William, 1889, Abstract report on the coal outcrops in the Sharigh Valley, Baluchistan: Records of the Geological Survey of India, v. 22, pt. 3, p. 149–153.

Klootwijk, C.T., and Peirce, J.W., 1979, India's and Australia's pole path since the late Mesozoic and the India-Asia collision: Nature, v. 282, no. 5739, p. 605–607.

Klootwijk, C.T., Nazirullah, Russel, DeJohn, K.A., and Ahmed, H., 1981, A paleomagnetic reconnaissance of northeastern Baluchistan, Pakistan: Journal of Geophysical Research, v. 86, no. B1, p. 289–306.

Knipper, A., Ricou, L.-E., and Dercourt, J., 1986, Ophiolites as indicators of the geodynamic evolution of the Tethyan ocean: Tectonophysics, v. 123, p. 213–240.

Landis, E.R., ed., 1994, Reconnaissance of coal areas in Balochistan Province, Pakistan: Government of Pakistan, Ministry of Petroleum and Natural Resources, Geological Survey of Pakistan, Project Report (IR)PK–112, 91 p.

Landis, E.R., Reinemund, J.A., Schlick, D.P., and Kebblish, W., 1971, Analyses of Pakistan Coals: U.S. Geological Survey Project Report, Pakistan Investigations, PK–58, 71 p.

Latif, M.A., 1962, The use of pelagic Foraminifera in the subdivisions of the Paleocene-Eocene of the Rakhi Nala, West Pakistan: Punjab University Geology Bulletin, no. 2, p. 31–45.

———1964, Variations in abundance and morphology of Pelagic foraminifera in the Paleocene-Eocene of the Rakhi Nala, West Pakistan: Punjab University Geology Bulletin, no. 4, p. 29–109.

LaTouche, T.D., 1893, Geology of the Sherani Hills: Records of the Geological Survey of India, v. 26, pt. 3, p. 77–96.

Lawrence, R.D., and Yeats, R.S., 1979, Geological reconnaissance of the Chaman fault in Pakistan, *in* Farah, Abul, and DeJong, K. A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 351–357.

Lillie, R.J., Lawrence, R.D., Humayon, Mansoor, and Jadoon, Istiaq, 1989, The Sulaiman thrust lobe of Pakistan; early-stage underthrusting of the Mesozoic rifted margin of the Indian subcontinent: Geological Society of America Abstracts with Programs, v. 21, no. 6, p. 318.

Lundegard, P.D., and Samuels, N.D., 1980, Field classification of fine-grained sedimentary rocks: Journal of Sedimentary Petrology, v. 50, p. 781–786.

Maldonado, Florian, Khan, S.H., and Mengal, J.M., 1993, Structural elements related to plate convergence of the Quetta-Muslim Bagh-Sibi region, Balochistan Province, Pakistan: Geological Society of America Abstracts with Programs, v. 25, no. 6, p. 482.

———1994, Preliminary geologic map of parts of Loralai, Sibi, Quetta, and Khuzar Divisions, Balochistan Province, west-central Pakistan: U.S. Geological Survey Open-File Report 94-689, 29 p., scale 1:250,000.

Maldonado, Florian, Khan, S.H., and Mengal, J.M., and Thomas, Jean-Claude, 1998, Geologic map and landsat image of parts of Loralai, Sibi, Quetta, and Khuzar Divisions, Balochistan Province, west-central Pakistan: U.S. Geological Survey Miscellaneous Investigations Series Map I–2549, scale 1:250,000.

Malik, A., 1968a, Geology of Afiband structure tribal area of Der Ghazi Khan District West Pakistan: Oil and Gas Development Corporation, Report on work carried out by geological party no. 2 during the field season 1967–68, 19 p. (on file with the Geological Survey of Pakistan, Quetta).

———1968b, Report on geological party no. 2 on the central part of Zinda Pir structure tribal area—Der Ghazi Khan District—West Pakistan field season 1967–68: Oil and Gas Development Corporation, 18 p. (on file with the Geological Survey of Pakistan, Quetta).

McCormick, G.R., 1989, Geology of the Baluchistan (Pakistan) portion of the southern margin of the Tethys sea, *in* Sengor, A.M.C., ed., Tectonic evolution of the Tethyan region: London, Kluwer Academic Publishers, p. 277–288.

Meissner, C.R., Jr., and Rahman, Habib-ur, 1973, Distribution, thickness, and lithology of Paleocene rocks in Pakistan: U.S. Geological Survey Professional Paper 716–E, 6 p.

Meissner, C.R., Master, J.M., Rashid, M.A., and Hussain, Muzaffar, 1974, Stratigraphy of the Kohat quadrangle, Pakistan: U.S. Geological Survey Professional Paper 716–D, 30 p.

Meissner, C.R., Hussain, Muzaffar, Rashid, M.A., and Sethi, U.B., 1975, Geology of the Parachinar quadrangle, Pakistan: U.S. Geological Survey Professional Paper 716–F, 24 p.

Movshovitch, E.B., and Malik, M.A., 1964, Geology of the Kot Anticline, Sibi reentrant region of Kalat Division, West Pakistan: Oil and Gas Development Corporation, Report on work carried out by geological party no. 2 during field season 1963–64, 14 p. (on file with the Geological Survey of Pakistan, Quetta).

———1965, Thickness and facies variations of molasse sediments of the Sibi re-entrant, West Pakistan: Lahore, Pakistan, Punjab University, Geological Bulletin, v. 5, p. 31–42.

Nagappa, Yedatore, 1959, Foraminiferal biostratigraphy of the Cretaceous-Eocene succession in the India-Pakistan-Burma region: Micropaleontology, v. 5, p. 145–179.

Oldham, R.D., 1890a, Special report on the most favourable sites for petroleum exploration in the Harnai district Baluchistan: Records of the Geological Survey of India, v. 23, pt. 2, p. 57–59.

———1890b, Report on the geology and economic resources of the country adjoining the Sind-Pishin railway between Sharigh and Spintangi, and of the country between it and Khattan: Records of the Geological Survey of India, v. 23, pt. 3, p. 93–110.

———1892, Report on the geology of Thal Chotiali and part of the Mari country: Records of the Geological Survey of India, v. 15, pt. 1, p. 18–29.

Opdyke, N.D., compiler, 1982, The geochronology and biochronology of the Siwalik Group, Pakistan: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 37, p. 1–130.

Otsuki, K., Hoshino, K., Anwar, M., Mengal, J.M., Fatmi, A.N., and Okimura, Y., 1989, Breakup of Gondwanaland and emplacement of ophiolitic complex in Muslim Bagh area of Balochistan, Pakistan, *in* Okimura, Y., and Fatmi, A.N., eds., Tectonic and sedimentation of the Indo-Eurasian colliding plate boundary region and its influence on the mineral deposits in Pakistan: Hiroshima, Japan, Hiroshima University, p. 33–57.

Outerbridge, W.F., Frederiksen, N.O., Khan, M.R., Khan, R.A., Qureshi, M.J., Khan, M.Z., Niamatullah, and Khan, S.A., 1991, The Sohnari Formation in southern Pakistan: U.S. Geological Survey Bulletin 1935, p. 27–34.

Patriat, Philippe, and Achache, Jose, 1984, India-Eurasia collision chronology has implications for crustal shortening and driving mechanism of plates: Nature, v. 311, no. 5987, p. 617–621.

Pinfold, E.S., no date, The Dunghan Limestone and the Cretaceous-Eocene unconformity in north-west India: Records of the Geological Survey of India, v. 74, pt. 2, p. 189–198.

Pivnik, D.A., 1994, Eocene closure of Tethys as recorded in NW Pakistan: Geological Survey of America Abstracts with Programs, v. 26, no. 7, p. 181.

Powell, C.McA., 1979, A speculative tectonic history of Pakistan and surroundings; some constraints from the Indian Ocean, *in* Farah, Abul, and DeJohn, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 5–24.

Pryor, W.A., 1978, Cyclic sedimentation in the Cretaceous-Paleocene sequence in west-central Pakistan: Geological Society of America Abstracts with Programs, v. 10, no. 7, p. 474.

Quittmeyer, R.C., 1978, The Quetta-Sibi (Pakistan) syntaxis; evidence for its origin from seismicity and plate tectonics: Eos, v. 59, no. 4, p. 323.

Quittmeyer, R.C., Farah, Abul, and Jocob, K.H., 1979, The seismicity of Pakistan and its relation to surface faults, *in* Farah, Abul, and DeJong, K. A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 271–284.

Qureshi, M.K.A., Abbas, S.Q., and Bhatti, M.A., 1987, Stratigraphy of part of Sulaiman Range: Punjab University, Institute of Geology, Bulletin 22, p. 76–91.

Rana, A.N., and Khan, A.L., 1990, A note on the geological investigation for Ghazij coal in the Kalat-Johan areas, Balochistan, Pakistan: Geological Survey of Pakistan, unpublished report, 20 p. (on file with Geological Survey of Pakistan, Quetta).

Raynolds, G.H., and Johnson, G.D., 1985, Rates of Neogene deposition and deformational processes, north-west Himalayan foredeep margin, Pakistan, *in* Snelling, N.J., ed., The chronology of the geological record: British Geological Survey Memoir 10, p. 297–311.

Reinemund, J.A., Khan, M.Y., Hussain, F., and Usmani, A.H., no date, Geologic map of Sor Range-Daghari: Geological Survey of Pakistan, scale approximately 1:32,000.

Ricou, Luc-Emmanuel, 1994, Tethys reconstructed; plates, continental fragments and boundaries since 260 Ma from central America to south-central Asia: Geodinamica Acta, v. 7, no. 4, p. 169–218.

Rossman, D.L., Ahmad, Zaki, and Rahman, Hamidur, 1971, Geology and economic potential for chromite in the Zhob Valley ultramafic rock complex, Hindubagh, Quetta Division, West Pakistan: U.S. Geological Survey Project Report, Pakistan Investigations (IR) PK-50, 63 p.; also published as U.S. Geological Survey Open-File Report 71-242, 63 p.

Sahni, Ashok, and Kumar, Vilmal, 1974, Palaeogene palaeobiogeography of the Indian Subcontinent: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 15, p. 209–226.

Sarwar, Ghulam, and DeJong, K.A., 1979, Arcs, oroclines, and syntaxes; the curvatures of mountain belts in Pakistan, *in* Farah, Abul, and DeJong, K.A., eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 341–349.

Scotese, C.R., Gahagan, L.M., and Larson, R.L., 1988, Plate tectonic reconstructions of the Cretaceous and Cenozoic ocean basins: Tectonophysics, v. 155, p. 27–48.

Searle, M.P., Windley, B.F., Coward, M.P., Cooper, D.J. W., Rex, A.J., Rex, D., Tingdong, Li, Xuchang, Xiao, Jan, M.Q., Thakur, V.C., and Kumar, S., 1987, The closing of Tethys and the tectonics of the Himalaya: Geological Society of America Bulletin, v. 98, no. 6, p. 678–701.

Shah, S.H.A., 1965, Preliminary geological report about structure, history, and petroleum prospects of the Sibi reentrant and surrounding regions, western province, Pakistan: Oil and Gas Development Corporation, Report on work carried out by geological party no. 2 during the field season 1963–64, 57 p.

———1990, Coal resources of Balochistan, *in* Kazmi, A.H., and Siddiqi, R.A., eds., Significance of the coal resources of Pakistan: Geological Survey of Pakistan and U.S. Geological Survey, p. 63–92.

Shah, S.M.I., ed., 1977, Stratigraphy of Pakistan: Memoirs of the Geological Survey of Pakistan, v. 12, 138 p.

Siddiqui, N.K., 1992, Sui Main Limestone, regional geology and pressure analysis of a closed system [abs.]: First South Asia Geological Congress (GEOSAS), Abstracts, Islamabad, Pakistan, p. 39.

Singh, N.P., 1984, Additions to the Tertiary biostratigraphy of Jaisalmer Basin: Petroleum Asia Journal, p. 106–127.

Sokolov, B.A., 1964, Geology of the Sor anticline (Sibi reentrant) Bolan Pass, District Kalat, West Pakistan: Oil and Gas Development Corporation, Report on work carried out by geological party no. 2 during field season 1963–64, 7 p. (on file with the Geological Survey of Pakistan, Quetta).

Subhani, A.M., Jaleel, Asad, and Durrazai, M.I., 1986, Suture associated metallogeny in LasBela-Khuzdar-Baluchistan: Lahore, Pakistan, Punjab University, Institute of Geology, First Advanced School in Geology, Himalayan Research Centre, Khanspur, Volume of Abstracts, no. 29, p. 28–89.

Vredenburg, E.W., 1909, Report on the geology of Sarawan, Jhalawan, Mekran and the State of Las Bela, considered principally from the point of view of economic development: Records of the Geological Survey of India, v. 38, pt. 3, p. 189–215.

Waheed, Abdul, and Wells, N.A., 1990, Changes in paleocurrents during the development of an obliquely convergent plate boundary (Sulaiman fold-belt, southwestern Himalayas, west-central Pakistan): Sedimentary Geology, v. 67, p. 237–261.

Warwick, P.D., and Javed, Shahid, 1990, Quality and character of Pakistan coal, *in* Kazmi, A.H., and Siddiqi, R.A., eds., Significance of the coal resources of Pakistan: Geological Survey of Pakistan and U.S. Geological Survey, p. 127–135.

Warwick, P.D., Javed, Shahid, Mashhadi, T.A., Shakoor, Tariq, Khan, A.M., and Khan, A.L., 1995, Lithofacies and palynostratigraphy of some Cretaceous and Paleocene rocks, Surghar and Salt Range coal fields, northern Pakistan: U.S. Geological Survey Bulletin 2096, 35 p.

Warwick, P.D., Johnson, E.A., and Khan, I.H., 1993, Paralic and marine facies of the Ghazij Formation; evidence for Eocene tectonism along the northwestern margin of the Indian Plate: Society for Sedimentary Geology, Stratigraphic Record of Global Change, Abstracts with Program, p. 60.

Warwick, P.D., Johnson, E.A., and Khan, I.H., 1998, Collision-induced tectonism along the northwest margin of the Indian subcontinent as recorded in the upper Paleocene to middle Eocene strata of central Pakistan (Kirthar and Sulaiman Ranges): Palaeogeography, Palaeoclimatology, Palaeoecology (PALAEO), v. 142, p. 201–216.

Warwick, P.D., Johnson, E.A., Khan, I.H., and Kazim, M.A., 1994, Principal reference section for part of the Eocene Ghazij Formation, Gishtari Nala area, Mach coal field, Balochistan, Pakistan: U.S. Geological Survey Miscellaneous Field Studies Map MF–2263–E.

Warwick, P.D., and Wardlaw, B.R., 1992, Paleocene-Eocene stratigraphy in northern Pakistan; depositional and structural implications [abs.]: Programme and Abstracts, 7th Himalaya-Karakoram-Tibet Workshop, April 6–8, 1992, Department of Earth Science, Oxford University, England, p. 97.

Warwick, P.D., and Wardlaw, B.R., eds., in press, Potwar regional framework assessment studies, Pakistan: U.S. Geological Survey Project Report (IR)PK–109, and U.S. Geological Survey Bulletin 2078.

Wells, N.A., 1984, Marine and continental sedimentation in Early Cenozoic Kohat Basin and adjacent northwestern Indo-Pakistan: Ann Arbor, Mich., University of Michigan Ph. D. thesis, 465 p.

Williams, M.D., 1959, Stratigraphy of the lower Indus Basin, West Pakistan: Proceedings of the Fifth World Petroleum Congress, Geology and Geophysics, Section I, Paper 19, p. 377–394.

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APPENDIX. COAL DEPOSITS OF NORTHEASTERN BALOCHISTAN

Pakistan contains three main coal-mining regions: (1) the Surghar Range and Potwar Plateau in the North West Frontier and Punjab Provinces, which are typified by the activities west of Makarwal and along the Salt Range; (2) the Quetta region in Balochistan Province stretching from Mach to Duki; and (3) the area west of Hyderabad in Sindh Province. In addition to these three regions, coal has recently been discovered in the subsurface of the Thar Desert in eastern Sindh Province. With the exception of the Eocene coal in Balochistan, all the coal currently mined in Pakistan is Paleocene in age. Non-economic coal is locally present in Permian strata in the Salt Range, and rarely present in Miocene strata in the Sulaiman Range.

Coal is present in the middle part of the Ghazij Formation throughout the greater Quetta region. However, in only a few areas is the coal of sufficient thickness to warrant commercial extraction. According to Ahmad and others (1986), the coal-bearing part of the Ghazij covers about 10,000 km^2. Coal rank ranges from subbituminous B to high-volatile B bituminous, with averages of ash 13.59 percent, sulfur 4.99 percent, and heat value 9,816 Btu/lb (Warwick and Javed, 1990). Most of the place names mentioned in this discussion can be found in figure 2.

According to Khan and others (1972), coal was first discovered in Balochistan in 1870 by Sir R. Sandeman in the Chamalang River valley near Bahlol. Coal was next discovered in areas adjacent to the valley that connects Khost, Shahrig, and Harnai, and with the western extension of a narrow-gauge railroad through this area in the 1880's, coal mining became an important commercial endeavor. With the exception of the Pir Ismail Ziarat coal field, mining in most other areas had commenced by the turn of the century.

Coal from Balochistan is considered the best in Pakistan because of its relatively high rank. But why is the rank so high in this region? Three processes are generally thought to account for increase in coal rank: (1) tectonic squeezing, (2) depth of burial, and (3) proximity to an igneous intrusion. In support of the first process, Hunting Survey Corporation (1960) reported that coal rank in Balochistan increases with structural deformation. As mentioned by Ahmad and others (1986), compressional forces expel moisture and volatile matter, and in so doing might increase the carbon content. This process could explain the northwest increase in coal rank in the Khost-Shahrig-Harnai area, as discussed by Ghaznavi (1990); this area lies in the general direction of increased tectonism from the Himalayan orogeny. In regard to process 2, Ghaznavi (1990) estimated that the Ghazij Formation in the Khost-Shahrig-Harnai area could have been buried under as much as 6,000 m of younger rocks in the past, and that even a geothermal gradient as low as 2° C per 100 m could result in increased maturation. Igneous intrusions (factor 3) are generally absent from Balochistan.

The validity of some reported coal quality values cited herein must be viewed with caution. Because of differences in sampling techniques, shipping methods, and laboratory procedures, it is problematic to compare one set of values with another set. Also, only the salient values are mentioned. For more details on the analyses, consult the references provided.

SPECIFIC COAL FIELDS

Coal has been extracted from many sites throughout Balochistan, but in this report we summarize only the major deposits. For a more complete listing refer to Hunting Survey Corporation (1960).

DUKI

The Duki coal field is centered southwest of Duki about 60 km east northeast of Harnai. The coal field trends northwest and extends for about 16 km. According to Khan (1994), the field covers about 100 km^2. Although the presence of coal has been known since 1892, coal remained unmined as late as Hunting Survey Corporation's work in the late 1950's. The coal field has been discussed by Hunting Survey Corporation (1960), Khan and others (1972), Ahmed and others (1986), Khan and others (1986), Shah (1990), and Khan (1994). The most comprehensive study is by Khan and others (1986) and Khan (1994), and much of the information given herein is from their work.

The coal is exposed in the north-dipping limb of a west-plunging syncline. There are reported to be as many as 17 coal beds, the most beds present in any coal field in Pakistan, and these are grouped into four coal zones. Fifteen of the beds are minable. Bed thickness ranges from about 15 cm to 1.15 m.

On an as-received basis, Khan and others (1986) cited average ranges as follows: moisture 4–8 percent, volatile matter 38–50 percent, fixed carbon 28–42 percent, ash 5–24 percent, and sulfur 4–6 percent. Calorific value ranges from 7,992 to 11,706 Btu/lb with an average of about 9,739. Most of the coal is subbituminous B and C.

KHOST-SHAHRIG-HARNAI

In the northwest corner of the Sulaiman lobe, coal is exposed along a northwest-trending belt of interconnecting valleys that stretches for about 100 km. Most of the commercial coal is contained in the Khost-Shahrig-Harnai coal field, which extends from near Khost on the northwest to near Harnai on the southeast, a distance of about 56 km (fig. 20). According to Khan (1994), the field covers about 200 km^2. Although Khost is only 54 air kilometers east of Quetta, the only approach from this city involves a circuitous road trip involving almost a day's travel. A railroad extends from Khost southeast to Sibi and beyond. Mining has occurred in this area since 1885, and the area contains one of the largest concentrations of coal mines in Pakistan. The coal field has been discussed by Gee (1945, 1950), Khan (1950), Crookshank (1954), Hunting Survey Corporation (1960), Kazi (1968), Landis and others (1971), Ahmad and others (1986), Shah (1990), Ghaznavi (1990), and Khan (1994). The most comprehensive study of the coal in this field was conducted by Ghaznavi (1990) as a Ph. D. dissertation at Southern Illinois University, and much of the information contained in this section comes from his work. The work of Khan (1994) was also used in this section.

Coal beds in the Khost-Shahrig-Harnai coal field range from about 8 cm to 2.30 m thick. Although as many as seven coal beds have been reported, only three are generally thought to be of economic significance. These are referred to as the bottom, middle, and top beds. Most coal is mined from the middle and top beds. As reported by Ghaznavi (1990), the top bed is the most laterally extensive, and ranges from 23 to 67 cm thick. It is best developed near Shahrig; mudrock partings in the bed increase toward both Khost and Harnai. The middle bed ranges from 23 to 69 cm thick. It lies from 30 to 50 m below the top bed near Khost, from 75 to 80 m below the top bed near Shahrig, and from 10 to 15 m below the top bed near Harnai. Mudrock partings are present near Khost and Harnai, and these increase from both directions toward Shahrig. In general, the partings are thinner than those in the top bed, and some partings consist of sandstone.

Coal from this field is relatively high in ash and sulfur. Ghaznavi (1990) reported as-received values from 35 samples taken from the middle and upper beds. Ash averages 21 percent with a maximum of 25 percent, and sulfur averages 8.8 percent with a maximum of 17 percent. The coal is also comparatively high in volatile matter, hydrogen, and nitrogen. Calorific values range from 6,773 to 13,023 Btu/lb with an average of 10,114. This coal field contains the highest rank coal in Pakistan. In general, the coal is high-volatile C bituminous near Harnai, high-volatile B bituminous near Shahrig, and high-volatile A bituminous near Khost. Coal petrography reveals that vitrinite group macerals are abundant and inertinite macerals are quite rare (Ghaznavi, 1990).

SOR RANGE

The northwest-trending Sor Range is about 21 km long and, structurally, consists of a northwest-plunging syncline involving the Ghazij and Kirthar Formations in the limbs, and Neogene deposits in the core. The southwest side of this structure has been cut by a range-parallel fault that is partly covered by Quaternary deposits. As viewed from the northeast, resistant limestone of the Kirthar forms a semicontinuous cliff along the top of the range, and softer mudrock of the Ghazij makes up the lower slopes. The Sor Range coal field is spread along the northeastern flank of the range, and is generally thought of as including three areas: the northern and central part of the range, Sinjidi, and Daghari (fig. 22). According to Khan (1994), the field covers about 50 km^2. The north end of the coal field lies only 13 km east of Quetta, and Daghari, at the south end of the coal field, lies about 27 km southeast of Quetta. Some coal has been mined east of Sinjidi near the village of Margat (Khan and others, 1972), but this area is usually not considered part of the Sor Range coal field. The Sor Range coal field has been discussed by Gee (1945, 1950), Khan (1950), Crookshank (1954), Hunting Survey Corporation (1960), Landis and others (1971), Khan and others (1972), Ahmed and others (1986), Shah (1990), Kazim and others (1991), and Khan (1994). The most recent study of this coal field is that by Kazim and others (1991), and much of the information following is from their report.

Plate 2 shows stratigraphic sections of the middle part of the Ghazij along the entire length of the Sor Range. In this stratigraphic framework, the spatial relations between mudrock intervals, sandstone bodies, and coal beds are easily seen. Kazim and others (1991) reported the presence of as many as five coal beds in the Sor Range ranging from a few centimeters to 8.5 m thick. Only two of these are minable, and are referred to as the bottom bed and the top bed. According to Hunting Survey Corporation (1960), the thickness of these two beds ranges from about 0.6 m to 2.74 m with the bottom bed averaging about 1.37 m and the top averaging about 0.76 m. Most coal is extracted from the bottom bed.

Coal from the Sor Range is relatively low in sulfur and ash. Landis and others (1971) reported on the analyses of 28 coal samples collected from the Sor Range between 1956 and 1969. On an as-received basis, ash ranges from 2.7 to 14.1 percent and sulfur ranges from 0.4 to 5.6 percent. Khan and others (1972) reported that averages from 22 of these samples are ash 6.7 percent and sulfur 2.6 percent. Calorific values as reported by Landis and others (1971) range from 8,690 to 10,900 Btu/lb with an average of 10,098. Most of the coal is subbituminous A. Kazim and others (1991) noted that the coal contains from 75 to 85 percent vitrain, from 5 to 12 percent durain, from 5 to 8 percent clarain, and from 3 to 8 percent fusain.

PIR ISMAIL ZIARAT

The Pir Ismail Ziarat coal field is located about 45 km southeast of Quetta in the Narwari Valley (fig. 23), and is the newest coal mining area in Pakistan. According to Khan (1994), the field covers about 20 km^2. Several small-scale enterprises extracted coal for local use during the 1950's, but larger mining efforts did not begin until the late 1960's. The coal field has been discussed by Ahmed and others (1986), Shah (1990), Landis (1994), and Khan (1994). Of these, Landis (1994) contains the most useful data, and much of the information in this section comes from his report.

Because Pir Ismail Ziarat is a relatively new coal field, details of the coal are still quite sketchy. For example, it is still uncertain how many coal beds are present. Most workers think the number of minable beds is between two and five. Landis (1994) reported that in the southern part of the coal field two coal beds are mined. The lower bed averages 0.75 m in thickness, and the upper bed, 180–300 m higher in the stratigraphic section, averages about 0.6 m. In the northern part of the coal field near the village of Pir Ismail Ziarat, detailed work by Johnson and Khan (1994b) revealed the presence of 10 coal horizons, each consisting of one or two beds. The stratigraphic separation between the base of the lowest bed and the top of the highest bed is 262 m. Bed thickness ranges from 6 to 92 cm and at least three beds are minable.

Coal is present north of the main part of the coal field at two sites, Sherki Kach and Ghate (fig. 23). In the Sherki Kach area only one coal bed, about 1 m thick, is mined. In the Ghate area two beds are present, but only the upper bed is mined. This bed is locally as thick as 2.4 m, but it is usually less than 1 m thick.

According to Landis (1994), as-received analyses of 13 samples collected from the Pir Ismail Ziarat coal field revealed that the coals are medium to high in ash and high in sulfur. Ash content ranges from 3.7 to 37.1 percent with an average of 13 percent, and sulfur content ranges from 2.2 to 6.0 percent with an average of 4.3 percent. Calorific value ranged from 7,450 to 10,840 Btu/lb with an average of 10,100. Coal from the southern part of the field is high-volatile C bituminous, and coal from the northern part, including the Sherki Kach and Ghate areas, is subbituminous A.

MACH

The town of Mach is located about 48 km southeast of Quetta, and coal is mined to the south, west, and north of this community. A railroad connecting Quetta with Sibi runs through Mach. Coal is also mined near Ab-i-Gum about 10 km to the southeast, but this area is not usually considered part of the Mach coal field. According to Shah (1990), the field covers about 50 km^2. The coal field has been discussed by Gee (1945, 1950), Khan (1950), Hunting Survey Corporation (1960), Khan and others (1972), Ahmad and others (1986), Ahmad and Kazim (1987), Shah (1990), and Khan (1994).

According to Shah (1990) as many as 17 coal beds might be present in this area, ranging in thickness from a few centimeters to 1.5 m, but only two or three beds, usually less than 1 m thick, are being mined.

The most recent coal quality data appears in Shah (1990), but it is unclear who conducted the analyses. On an as-received basis, ash content ranges from 9.6 to 20.3 percent, sulfur ranges from 3.2 to 7.4 percent, and calorific value ranges from 9,900 to 10, 500 Btu/lb. Coal rank ranges from subbituminous C to subbituminous B.

LESS SIGNIFICANT SITES

Coal has been reported in the Ghazij Formation just north of Bahlol about 80 km east of Duki (Crookshank, 1954; Hunting Survey Corporation, 1960; Khan and others, 1972; Shah, 1990). Only a few beds are present, and their thicknesses range from 3 to 76 cm. Minor coal is also reported near Bela Dhaka about 30 km northeast of Bahlol (Hunting Survey Corporation, 1960).

Northwest of the Khost-Shahrig-Harnai coal field, the Ghazij is exposed in the core of an anticline that extends northwest almost to Kach before turning southwest and continuing to within 10 km of Quetta. Some minor coal mining is conducted along this trend. Landis (1994) reported the mining of one bed about 1 m thick near the west end of the trend. Near the east end of the trend, two beds are present, an upper bed about 1 m thick and a lower bed about 75 cm thick. At the time of Landis' visit only the lower bed was being mined. As-received analyses of three coal samples collected from the western part of the trend are high in ash, about 18 percent, and high in sulfur, about 5.6 percent. Calorific value is about 10,320 Btu/lb on an equilibrium moisture basis, and the coal has a rank of high-volatile C bituminous. Two samples collected from the eastern part of the trend were considered unreliable by Landis, but a rank of high-volatile A or B bituminous was suggested for this area.

Vredenburg (1909) and Hunting Survey Corporation (1960) mentioned the presence of coal near the small village of Abigul about 60 km south of Quetta. Landis (1994) reported that a small patch of Ghazij is exposed in the area, and that the analyses of two samples revealed one to be coaly carbonaceous shale and the other to be lignite A.

Coal is present in the Ghazij near the village of Johan about 93 km south of Quetta. Mention of this was made by Vredenburg (1909), Crookshank (1954), Khan and others (1972), and Hunting Survey Corporation (1960). According to the Geological Survey of Pakistan, coal beds in this area are strongly lenticular, and the maximum thickness is 26 cm. Except for one small entry on a 2.5 cm bed, we observed no evidence of mining. Landis (1994) commented that what coal is present is too weathered for meaningful chemical analysis.

Of special interest is the rumored presence of coal in Rodangi Nala about 75 km southwest of Quetta, in the Paleocene and Eocene Rodangi Formation. Landis (1994) reported that during a short reconnaissance of the area, only three beds of coaly carbonaceous shale could be found.

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