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GEOLOGIC MAP OF THE ISLAMABAD-RAWALPINDI AREA, PUNJAB, NORTHERN PAKISTAN

by

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and

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Base Credit:
Base from Survey of Pakistan,
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Place names used in this report
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DESCRIPTION OF MAP UNITS

Qal **Stream-channel alluvium (Holocene)**--Unconsolidated gravel, sand, and silt that is subject to stream transport each year. Poorly to moderately sorted and low-angle crossbedding. Generally without soil or vegetation. Forms low islands and bars within braided and meandering stream channels. Maximum thickness about 3 m

Qfp **Flood-plain and fan alluvium (Holocene)**--Moderately bedded and sorted, sand and gravel channel and debris-flow deposits overlain by thin veneer of sandy silt and clay from overbank flooding and slope-wash deposition. Typically deposited adjacent to streams or in fan-shaped bodies at mouth of canyons or gullies. Maximum thickness beneath flood plains about 6 m and beneath fans about 20 m

Qas **Alluvium and windblown silt, undifferentiated (Holocene and upper Pleistocene)**--Eolian silt and stream-channel, flood-plain, terrace, and slope-wash alluvium intermixed in small areas that cannot be depicted separately at map scale. Such deposits typically occupy small depressions in the Margala Hills. Less than 10 m thick

Qp **Potwar Clay (Holocene and Pleistocene)**--Windblown silt and clay and subordinate amounts of alluvial gravel. Sediment is light brown to gray, very fine grained, hard, compact, and calcareous. Windblown sediment averages 71-74 percent silt-size and 15-16 percent clay-size material. Unit is 14-18 percent calcium carbonate. Mineral composition is predominantly quartz, but subordinate amounts of feldspar and clay minerals, such as kaolinite and illite, are present (Rendell, 1988, p. 392). The well-developed vertical partings and lack of bedding suggest that much of the sediment is atmospheric dust, but stratification of some of the sediment indicates partial reworking by surface wash and streams. Locally, silt is intercalated with crossbedded lenses of sand and gravel and with the Lei Conglomerate. Thermoluminescence ages of loess from the Rawat area range from 20 to 132 thousand years (ka) from near the surface to 11-m depth, and greater than 170 ka for more deeply buried loess beneath a gravel facies. Calculated accumulation rates range from 6 to 27 centimeters per thousand years (cm/1,000 yr)(Rendell, 1988, p. 393). The silt and clay beds are very erodible; hence deep, steep-sided gullies and badlands are extensive. Unit subject to loss of bearing strength when wet. Thickness is highly varied, depending on relief of underlying unconformity. Exposed thickness 1-35 m. Similar deposits intercalated with Lei Conglomerate extend to a depth of 152 m (Ashraf and Hanif, 1980)

Terrace alluvium (Holocene and Pleistocene)--Gravel, clay, and silt locally cemented by calcium carbonate. Includes clast-supported boulders, cobbles, and pebbles of sedimentary rocks in a sandy and clayey matrix. These former stream-channel and flood-plain deposits no longer receive sediment because subsequent downcutting by streams has left them high above flood level. Repeated episodes of uplift or climate change and erosion have left terrace deposits at several levels. Unit resembles Lei Conglomerate but is younger and retains depositional form

Qty **Younger terrace alluvium (Holocene and upper Pleistocene)**--Terrace alluvium whose depositional surface is less than 5 m above modern flood level. Generally forms benches along sides of modern stream valleys. Thickness about 3 m

Qto **Older terrace alluvium (Pleistocene)**--Terrace alluvium whose depositional surface is more than 5 m above modern flood level. Generally preserved as discontinuous remnants of gravel capping ridges and flat-topped hills. Maximum thickness about 3 m

Ql **Lei Conglomerate (middle Pleistocene)**--Carbonate-cemented cobble conglomerate consisting of 93 percent subangular limestone clasts intercalated with and grading laterally into weakly consolidated silt, sand, and clay. Clasts are 5 percent older Siwalik Group sedimentary rocks, 2 percent quartzite, and trace amount of igneous rocks (Gill, 1951; Raynolds, 1980). Generally flat lying, but locally folded and faulted. Overlies rocks of Siwalik and Rawalpindi Groups upon an angular unconformity. At Shahpur (lat 33° 30.8' N., long 73° 04' E.), fine overbank sediments are preserved beneath an erosional disconformity at base of conglomerate and above angular unconformity. Volcanic ash from sediments older than the Lei Conglomerate and younger than the Soan Formation has been dated by the fission-track method at 1.6±0.18 Ma, representing a local maximum age for the Lei Conglomerate (Johnson and others, 1982). Interpreted as an alluvial basin-fill sequence of coarse, angular gravel derived from the uplifting Margala Hills to the north interbedded with finer sediment derived from sandstone and shale of the Rawalpindi Group and windblown silt. Deposited along the axis of the subsiding Soan syncline. Cemented conglomerate beds are resistant to erosion and form ledges and hills. Uncemented conglomerate beds are the most important ground-water aquifer in the area. Exposed thickness 106 m, but drill hole FC-12 southwest of Saidpur (grid G-3) penetrated more than 152 m of interbedded clay (72 percent) and gravel (28 percent) (Ashraf and Hanif, 1980). In this drill hole the average thickness of gravel beds is 6 m and of clay beds is 14 m

Siwalik Group (Pleistocene? and Neogene)

Nss **Soan Formation (lower Pleistocene(?) and Pliocene)**--Conglomerate and subordinate interbeds of sandstone, siltstone, and claystone. Conglomerate clasts range in size from pebbles to boulders and consist of about 80 percent rounded quartzite, about 10 percent fine-grained volcanic trap rock, and 10 percent metamorphic rocks combined with sedimentary rocks of the Siwalik Group. Clasts are cemented in a calcareous sandy matrix. Sandstone is greenish gray, coarse grained, and soft. Claystone is orange, brown, and pale pink and soft. Exposed thickness is 200-300 m. Upper contact beneath the Lei Conglomerate and younger sediments is an unconformity older than 1.6±0.18 Ma (Johnson and others, 1982). Base locally rests on an unconformity dated by fission-track dating of volcanic ash at 1.9±0.4 Ma (Raynolds, 1980, p. 190)

Nsd **Dhok Pathan Formation (Pliocene and upper Miocene)**--Sandstone and claystone containing lenses of conglomerate in upper part. Sandstone is light gray, fine to medium grained, medium bedded, and crossbedded. Claystone is orange red and chocolate brown, hard, and compact. Measured thickness is 500-825 m. Unit is overlain unconformably by the Soan Formation. Near type locality base was dated by fission-track dating at about 8.5 Ma (Johnson and others, 1985)

Nsn **Nagri Formation (upper Miocene)**--Sandstone and subordinate claystone and conglomerate. Sandstone is gray, greenish gray, and brownish gray; medium to coarse grained; thick bedded; crossbedded; calcareous; and has a salt-and-pepper pattern that is produced by magnetite and ilmenite. Claystone is brown, reddish gray, and orange and is sandy or silty. Thickness is 500-900 m. Contact with overlying Dhok Pathan Formation is conformable. Near type locality base was dated by fission-track dating of volcanic ash at about 10.8 Ma (Johnson and others, 1985)

Nsc **Chinji Formation (upper and middle Miocene)**--Claystone and sandstone. Claystone is brick red, friable, hard, and intercalated with sandstone. Sandstone is dark gray to brownish gray, medium to thick bedded, soft, and crossbedded. Thickness varies from

880 to 1,165 m. Upper contact with the Nagri Formation is conformable. Near type locality base was dated by fission-track dating of volcanic ash at about 14.3 Ma (Johnson and others, 1985)

Rawalpindi Group (Miocene)

Nrk **Kamlial Formation (middle and lower Miocene)**--Sandstone and claystone. Sandstone is purple, gray, and dark brick red; medium to coarse grained; thick bedded; micaceous; jointed; and calcareous. Interbeds of hard purple claystone; some claystone beds are weathered and have yellow mottles. These weathered beds resemble conglomerate. Unit is distinguished from underlying Murree Formation by its spheroidal weathering. Measured thicknesses range from 1,200 to 1,600 m. Upper contact beneath the Chinji Formation is conformable. Near the village of Chinji, base was dated by fission-track dating of volcanic ash at about 18.3 Ma (Johnson and others, 1985)

Nrm **Murree Formation (lower Miocene)**--Continental sandstone and claystone. Sandstone is reddish gray to purple gray, fine to medium grained, thick bedded, micaceous, crossbedded, jointed, and calcareous. Claystone is purple to dark red and contains mottled lenses of pseudoconglomerate. Epidote is common in sandstone of the Murree Formation. Contact with overlying Kamlial Formation is conformable. Measured thickness ranges from 2,000 to 2,895 m in the area

Cherat Group (lower Eocene)

Pεck **Kuldana Formation**--Marine claystone, marl, limestone, and minor sandstone. Claystone is variegated in color and has gypsum intercalations. Marl is pale gray to brownish gray, thin to medium bedded, and contains fibrous gypsum. Limestone is white to very pale brown. Sandstone is brownish gray, fine grained, and calcareous. Measured thickness is 60-120 m. Unit unconformably underlies Murree Formation

Pεcc **Chorgali Formation**--Marine shale, limestone, and marl. Formation is divisible into lower and upper parts. Lower part consists of shale that is olive green and greenish orange, splintery, and intercalated with lenticular thin limestone beds and coquina beds composed of large foraminifers. Upper part consists of limestone that is gray to light gray and white to grayish yellow, thin to medium bedded, flaggy, cherty, and fossiliferous. Marl is light gray to gray and thinly bedded. Measured thickness ranges from 30-120 m. Unit is conformable with overlying Kuldana Formation

Pεcm **Margala Hill Limestone**--Marine limestone and subordinate marl and shale. Limestone is dark gray to pale gray, medium to thick bedded, nodular, and fossiliferous. Marl is gray to brownish gray and hard. Shale is greenish gray and reddish brown and splintery. Measured thickness 60-90 m. Unit is conformable with overlying Chorgali Formation

Makarwal Group (Paleocene)

Pεmp **Patala Formation**--Shale and subordinate limestone and marl. Shale is green gray to brownish gray, thinly laminated, splintery, and calcareous; grades into siltstone and sandstone. Limestone is gray to light gray, thinly bedded, and fossiliferous. Marl is dark gray and fossiliferous. Mixed continental and marine deposition. Measured thickness is 70-80 m. Unit is conformable with overlying Margala Hill Limestone

Pεml **Lockhart Limestone and Hangu Formation, undivided**--These units are combined on the geologic map of the study area (Williams and others, in press)

Lockhart Limestone--Marine limestone and subordinate marl and shale. Limestone is pale gray to dark gray, medium grained, thick bedded, in part nodular, hard, bituminous, and fossiliferous. Marl is grayish black and fossiliferous. Shale is olive gray to greenish gray and has weakly developed cleavage. Thickness ranges from 70 to 280 m. Unit conformably underlies the Patala Formation

Hangu Formation--Continental claystone, sandstone, and intercalated shale. Claystone and shale are red, brown, and greenish gray; thinly laminated to thin bedded; silty; sandy; hematitic; and bauxitic. Sandstone is reddish brown and grayish black, thin to thick bedded, brittle, oolitic, ferruginous, and quartzitic. Unit consists of highly weathered sediments deposited in humid, tropical, continental environment. Thickness ranges from 2 to 8 m. Unit conformably underlies marine Lockhart Limestone

Surghar Group (Lower Cretaceous and Jurassic)

KJsl **Lumshiwal and Chichali Formations, undivided (Lower Cretaceous and Upper Jurassic)**

Lumshiwal Formation (Lower Cretaceous)--Marine sandstone and subordinate limestone and shale. Sandstone is dark brown and greenish gray, thin to thick bedded, and consists of quartz and glauconite. Shale is silty and glauconitic. Limestone is yellowish orange, arenaceous, shelly, thinly bedded, and hard and contains ammonoids and brachiopods. Limestone is intercalated with marl in places. Unconformably underlies the Hangu Formation. The Upper Cretaceous Kawagarh Formation, which overlies the Lumshiwal Formation immediately north of map boundary, was eroded from map area before deposition of the Hangu Formation. Unit erodes into steep slopes and escarpments. Thickness is 10-50 m

Chichali Formation (Lower Cretaceous and Upper Jurassic)--Shale and sandstone. Shale is dark gray, brownish gray, and dark olive gray; splintery; thinly bedded; calcareous; and contains ferruginous and phosphatic nodules. Sandstone is dull greenish gray, thin to medium bedded, fine grained, and glauconitic. Subordinate thin limestone bands are dark gray. Unit contains belemnites and ammonoids. Unit conformably underlies the Lumshiwal Formation. Measured thickness is 34-50 m. Age is Late Jurassic (Tithonian) to Early Cretaceous (Neocomian)

Jss **Samana Suk Formation (Middle Jurassic)**--Fossiliferous limestone and subordinate marl. Limestone is dark gray, brownish gray, and mottled yellowish orange; medium to thick bedded; micritic to oolitic and pelletal; at places shelly; and has dolomitic and sandy beds. Marl is light olive gray to greenish gray, laminated, thinly bedded, and splintery. Unit forms escarpments and steep slopes. Exposed thickness ranges from 200-250 m. Contact with overlying Chichali Formation is unconformable. Base is not exposed

DISCUSSION

INTRODUCTION

Islamabad, the capital of Pakistan (fig. 1), is a planned city constructed since about 1960 at the foot of the Margala Hills that is located just north of the old city of Rawalpindi. Rapid growth of both Islamabad and Rawalpindi to a combined population near 1.3 million has made ever-increasing demands for natural resources and caused adverse effects on the environment. To maintain the quality of the capital, municipal authorities need information on the physical environment to guide future development. This map summarizes information on the geology of the Islamabad-Rawalpindi study area that was collected by a cooperative project of the U.S. Geological Survey and the Geological Survey of Pakistan, supported by the U.S. Agency for International Development.

GEOLOGIC SETTING AND TERRAIN

The sedimentary rocks exposed in the Islamabad-Rawalpindi study area (fig. 1) record 150 m.y. (Middle Jurassic to Quaternary) of gentle geologic fluctuations and slow deposition while the Indian tectonic plate drifted northward across the Indian Ocean, followed by much more vigorous tectonic processes and rapid deposition in the shorter period since the Indian and Eurasian plates converged. The period from about 150 to 24 Ma was characterized by slow, primarily marine deposition, and little tectonic activity; that from 24 to 1.9 Ma by rapid, voluminous, continental deposition, and slow subsidence; and that since 1.9 Ma by intense tectonism, extensive erosion, and subordinate local deposition of coarse clastic continental sediment (fig. 2).

The terrain of the study area consists of plains and mountains whose total relief exceeds 1,175 m. Three general physiographic zones trend generally east-northeast. The northern part of the area lies in the mountainous terrain of the Margala Hills, a part of the lower and outer Himalayas, which also includes the Hazara and Kala Chitta Ranges. The Margala Hills, which reach 1,600-m altitude near Islamabad, consist of many ridges of Jurassic through Eocene limestone and shale that are complexly thrusted, folded, and generally overturned.

South of the Margala Hills is a southward-sloping piedmont bench underlain primarily by folded sandstone and shale of the Miocene Rawalpindi Group. Buried ridges of sandstone are generally covered by interbedded sandy silt and limestone gravel that locally exceed 200 m in thickness; these deposits, in turn, have been dissected and then buried under a layer of eolian loess and reworked silt that locally exceeds a thickness of 40 m. West of Rawalpindi, plains of thick, easily eroded loess are extensively dissected into shallow badland valleys. East of Rawalpindi, the folded ridge of Rawalpindi Group rocks rise above the alluvial cover to form prominent hills. Urban development is concentrated in the piedmont bench area, which is little dissected in its northern part, where Islamabad is located, but is more deeply dissected toward the south near the Soan River, where Rawalpindi is located.

In the southernmost part of the area, the Soan River valley extends generally along the axis of the Soan syncline at an altitude of about 425 m. The Soan is incised more than 40 m below the level of extensive silt-covered plains north and south of the river. Beds of fluvial sandstone, mudstone, and conglomerate of the Pliocene to Pleistocene(?) Siwalik Group underlie the southern area and crop out along the many steep-sided stream valleys that dissect the land. The beds dip steeply on the north limb of the syncline north of the Soan River, and more gently on the south limb. The piedmont bench and Soan valley make up the northern edge of the Potwar Plateau, which extends southwestward for 150 km.

GEOLOGIC HISTORY

The oldest rocks exposed in the map area are Jurassic marine limestone and dolomite that were deposited on a continental shelf along the north edge of the continental part of the Indian tectonic plate as it migrated northward before converging with the Eursian plate. The oolitic, biomicritic, and intrasparitic limestone in the Samana Suk Formation indicates different amounts of energy in the various carbonate depositional environments. A short break in deposition during the Late Jurassic is represented by the unconformity between the Samana Suk and Chichali Formations. From the Late Jurassic to Early Cretaceous, anaerobic bottom conditions and chemically reducing environments accompanied deposition of the glauconitic shale and sandstone of the Chichali Formation. During the Early Cretaceous, conditions changed to a slightly saline, shallow-water, reducing environment when the glauconitic sandstone of Lumshiwal Formation was deposited. The calcareous facies of Lumshiwal Formation are nearshore, shallow-water deposits. Emergence of the area above sea level during the mid-Cretaceous is indicated by the unconformity between the Lumshiwal and Kawagarh Formations (the latter is missing in the Islamabad area). During the early Late Cretaceous, the sea transgressed again, and the limestone and marl of the Kawagarh Formation were deposited in shallow- to deep-marine water.

During the Late Cretaceous to Paleocene, the area rose again above sea level. The exposed surface of the marine Kawagarh Formation was first eroded and then buried beneath highly weathered continental sediments of the Hangu Formation. In the map area, the Kawagarh was entirely removed; thus the Hangu unconformably lies on the Lumshiwal Formation. Intense lateritic and bauxitic weathering of the Hangu Formation reflects the equitorial latitude of the Indian tectonic plate during the Paleocene. Following deposition and weathering of the Hangu, marine conditions returned and persisted through the early Eocene. Calcareous and argillaceous sediments of the Lockhart Limestone, Patala Formation, Margala Hill Limestone, and Chorgali Formation were deposited during this time. This marine depositional sequence was followed by alternate marine and continental environments during which the Kuldana Formation was deposited. During the middle Eocene, initial contact of the Indian plate with Asia elevated the region above sea level and produced the unconformity beneath the continental Murree Formation.

By Miocene time the sea had completely receded south of the map area, and during the Miocene and Pliocene, very thick continental deposits of the Rawalpindi and Siwalik Groups accumulated in the subsiding Himalayan foredeep region. These deposits consist of sediments eroded from highlands to the north that were uplifted and deformed by tectonic forces in the zone of convergence. The south margin of the deformed zone migrated southward into the Islamabad area, where it first caused coarser sedimentation but eventually so deformed and uplifted the area that deposition drastically decreased and erosion became the predominant sedimentary process. The tectonic migration that began during the Eocene continues to the present. The estimated average rate of southward migration during the Pliocene was 3 cm/1,000 yr, and the average accumulation of mud, sand, and gravel in the subsiding foredeep region was about 28 cm/1,000 yr (Raynolds, 1980, p. 191).

During the Pliocene, sedimentation was controlled by an eastward-flowing river system (Raynolds, 1980). The conglomerate of the Soan Formation that was deposited by that river system during the late Pliocene consists chiefly of quartzite and metamorphic clasts eroded from the Himalayan core and is similar to clasts in modern Indus River gravels. Local sedimentation stopped about 3-1 Ma, when the Hazara fault zone developed, when limestone of the Margala Hills was thrust up along the north border of the study area, and when the sandstone and mudstone of the Rawalpindi and Siwalik Groups were folded and faulted throughout the area. The eastward-flowing river system was disrupted and superseded by the much smaller, southward-flowing Soan River system, and locally derived limestone gravel became the dominant component of the Lei Conglomerate; this conglomerate accumulated most thickly over the Soan Formation and other upturned Siwalik Group rocks along the axis of the subsiding Soan syncline at the south edge of the map area.

During the Quaternary, climatic fluctuations along with tectonic uplift caused periodic incision of the drainage south of the Margala Hills and alternate periodic accumulations of silt and alluvial gravel from the Margala Hills, which filled the valleys and spread laterally to form wide plains of low relief. A great influx of windblown silt probably was blown from the braided outwash channel that originated in the highly glaciated headwaters of the Indus River. This eolian silt formed the thick deposits of loess that mantle the landscape and contribute to the burial of preexisting valleys. Loess deposition was probably most rapid during the glacial maximums, but it continues despite the present interglacial climate because very large glaciers still exist in the Indus River basin and contribute large amounts of fine-grained sediment, which causes the Indus to form a braided channel below the mountain front 50 km long and 10 km wide. Calculated rates of loess accumulation during the period from 170 to 20 ka range from 6 to 27 cm/1,000 yr (Rendell, 1988, p. 393).

Strongly developed soils are scarce in the Islamabad area, perhaps because of the seasonally dry climate and the lack of stable surfaces caused by alternation of erosion and loess deposition. Some paleosols, however, are preserved within the loess.

Pleistocene stream and fan-terrace deposits along the mountain front, preserved as much as 30 m above present drainage levels, reflect stream incision and a provide a measure of continued tectonic uplift of the piedmont zone since their deposition. Distant tectonic events may also have affected the balance of aggradation and degradation. Tectonic tilting and uplift across the course of the Indus River (McDougall, 1989) near the gorge at Kalabagh, 200 km to the west, have caused major shifts in the course of the Indus and affected the base level of the Soan River.

Active tectonism across the area continues in the form of folding, thrust faulting, and seismicity. A very large earthquake in A.D. 25 destroyed the Buddhist community at Taxila, about 25 km west-northwest of Islamabad. The most recent damaging earthquake (Modified Mercalli VII) was in the area centered along the Gumreh Kas (stream) about 7 km northeast of Rawalpindi in February 1977 and had a Richter magnitude of 5.8.

GEOLOGIC STRUCTURE

The Islamabad-Rawalpindi study area can be divided into three structural zones, trending generally east-northeast, that reflect compression and movement oriented S. 20° E. (1) In the north the mountainous Margala Hills consist of Jurassic through Eocene limestone and shale that are complexly folded and thrust along the Hazara fault zone. Uplift of these mountains probably formed a major topographic barrier during the last 1 million yr. (2) South of the mountains, a southward-sloping piedmont bench, the Piedmont fold belt, is underlain primarily by truncated folds in the sandstone and shale of the Rawalpindi Group. (3) In the southernmost part of the area, the Soan River flows generally along the axis of the Soan syncline. Cross sections *A-A'* and *B-B'* depict interpretations of the geologic structure slightly modified from previous interpretations shown in cross sections drawn by Naeem and Bhatti (1985) and Pasha and Bhatti (in press). Islamabad is on the south margin and leading edge of the Hazara fault zone. All the faults in the map area, except those south of Rawalpindi, are part of this fault zone. This zone consists of an arc of thrusted and folded rocks about 25 km wide and 150 km long that is convex to the south and extends west-southwestward away from the Himalayan syntaxis. More than 20 individual thrust sheets have been identified across the 25-km-wide zone north of Islamabad, but only 5 major thrusts lie within the map area. In the Islamabad area, some of the thrust faults are slightly oblique to the front of the Margala Hills; hence, they project west-southwestward beneath the cover of the piedmont fold belt. The extensions of these faults are prominent north of Fetehjang, 25 km west of Rawalpindi, where they form the south margin of the Kala Chitta Range, which is an en echelon extension of the structural pattern of the Margala Hills.

The thrust and fold structure of the Margala Hills immediately north of Islamabad is complex. The Margala Hills consist of at least five principal thrust sheets that repeat the pre-Miocene marine section. The structurally lowest sheet dips generally northward at about 30°, and the higher thrust sheets dip progressively more steeply, so that the northernmost and structurally highest are overturned and dip southward at about 85°. The thrusts have most commonly broken through the beds within or just beneath the Samana Suk Formation, although almost all preMiocene units are cut at some place in the study area. Higher in the section, thrusts are common at the base of the Margala Hill Limestone (probably within the shale of the Patala Formation) and within the overlying Chorgali Formation.

According to interpretations shown in cross sections *A-A'* and *B-B'*, beds within the thrust sheets are commonly not parallel to the bounding faults, but instead are intensely folded, both isoclinally and disharmonically. Beds within the thick thrust sheet composing most of the south slope of the Margala Hills are generally in stratigraphic order, but repetition through internal folding has tectonically thickened the section to 5 times normal thickness. Tight folds that originally were probably overturned southward now appear to be overturned northward because of northward rotation of the entire thrust sheet during the formation of lower, younger thrusts. Northward decrease in rock age combined with southward dips produce an impression of overturning of the section and general horizontal axis rotation of about 120° to the north. Only about half the beds, however, are presently overturned, although those that appear to be upright were probably overturned during an earlier phase of the deformation and have been turned upright by later northward rotation. The geometry suggests that the locus of thrust ramping has migrated southward through time, and the formation of each successive ramp has rotated the overlying thrust sheet back toward the north.

Steeply dipping Pleistocene gravel sparsely exposed south of the mountain front indicates that the structurally lower thrusts may have the potential for renewed movement; it is likely that tectonically generated stresses would be absorbed by movement along low-dipping faults before a stress level high enough to reactivate the higher, overturned thrusts would be reached. Therefore, the overturned thrusts are unlikely to have substantial recurrent movement.

The faults and folds in the piedmont zone south of the mountain front probably have high potential activity, although definitive exposures are sparse and discontinuous. The Pleistocene Lei Conglomerate, overlying sandstone of the Murree Formation (lower Miocene), is folded in the broad anticline at Shakar Parian Park (grid G-4) in Islamabad. The Lei Conglomerate also is tilted 80° southward along a thrust fault in the Kuldana Formation (lower Eocene) north of Golra (grid E-4), about 17 km northwest of Rawalpindi. The fault at Golra may be an eastward projection of the southward overthrusting of the mountain front along the south face of the Kala Chitta Range (grid A-6), a major range that begins about 25 km west of Rawalpindi and extends westward south of the Margala Hills. Major faults bounding the Khairi Murat Range (grid A-10, B-10), about 15 km south of the Kala Chitta Range, may also extend northeastward toward Rawalpindi, concealed beneath Quaternary eolian and alluvial deposits.

The Soan syncline is an asymmetric, faulted fold of regional extent, plunging west-southwestward, in which fluvial sandstone, claystone, and conglomerate of the Siwalik Group dip 60°-85° toward the axis of the syncline on the north limb and 45°-70° on the south limb. The maximum width of the syncline in the map area is about 11 km, but the fold extends 100 km to the southwest. About 38 km southwest of the map area the maximum width is 22 km. Along the south limb, two splays of a northwest-dipping thrust fault, at least 32 km long, trend generally parallel to the fold axis. The throw on the north splay is greater than on the south splay, and the north splay displaces about 1,600 m of the Kamlial Formation (middle and lower Miocene).

Seismic data (Baker and others, 1988; Pennock and others, 1989; Burbank and Beck, 1991) suggest that the north limb of the syncline is underlain at depth by a northward backthrust over an antiformal stack of sedimentary rocks repeated by complex southward thrust faulting. Such a backthrust has not been identified in outcrop, perhaps because the area is generally covered by Quaternary deposits. If such an interpretation is correct, most tectonic shortening across the Soan syncline would be absorbed by thrust faults beneath the syncline. The surface block containing the syncline would behave as a pop-up structure, accounting for the relatively simple deformation in the syncline as compared with the surrounding terrain.

Adhami and others (1980?) interpreted tilted Quaternary conglomerate along the south side of the Soan River east of the Grand Trunk Road and a bedrock shear zone that seems to wedge into Holocene alluvium along the Ling River near Kahuta (0.8 km east of the east border of the study area) as indicating continued folding and faulting along the Soan syncline through the late Pleistocene.

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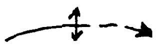
EXPLANATION OF MAP SYMBOLS

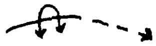
 **Contact**--Boundaries of surficial deposits approximately located

 **Fault**--Dashed where approximately located

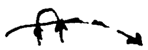
 **Thrust fault**--Dashed where approximately located; dotted where concealed. Sawteeth on upper plate. In cross sections, half arrows indicate direction of relative movement

 **Transcurrent fault**--Dashed where approximately located. Half arrows indicate direction of relative movement. In cross section: T, toward observer; A, away from observer

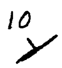
 **Anticline**--Showing trace of axial plane and direction of plunge of axis; dashed where approximately located

 **Overturned anticline**--Showing trace of axial plane, direction of dip of limbs, and direction of plunge of axis; dashed where approximately located

 **Syncline**--Showing trace of axial plane and direction of plunge of axis; dashed where approximately located

 **Overturned syncline**--Showing trace of axial plane, direction of dip of limbs, and direction of plunge of axis; dashed where approximately located

Strike and dip of beds



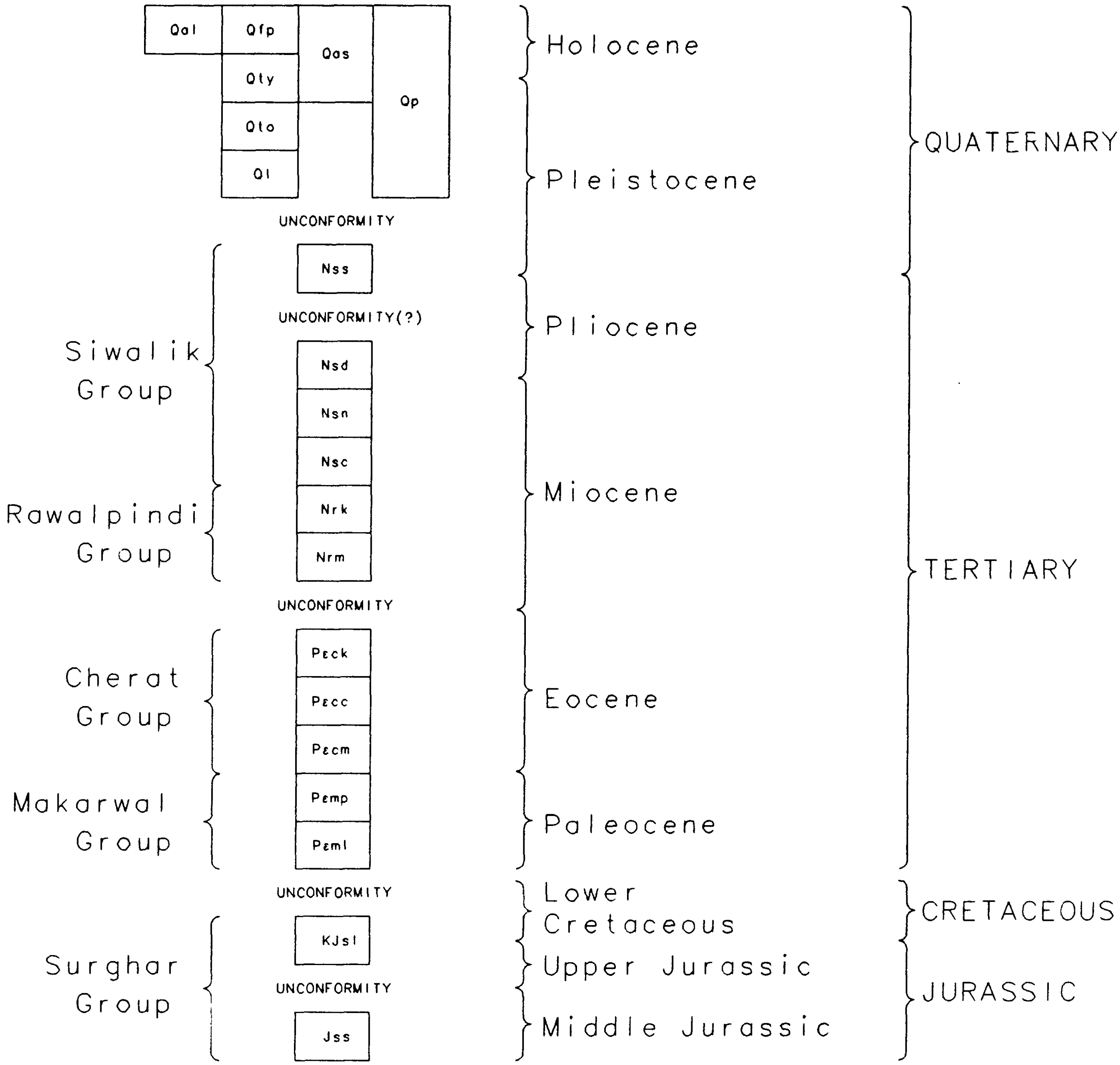
Inclined

Overturned

 Vertical

 Horizontal

CORRELATION OF MAP UNITS



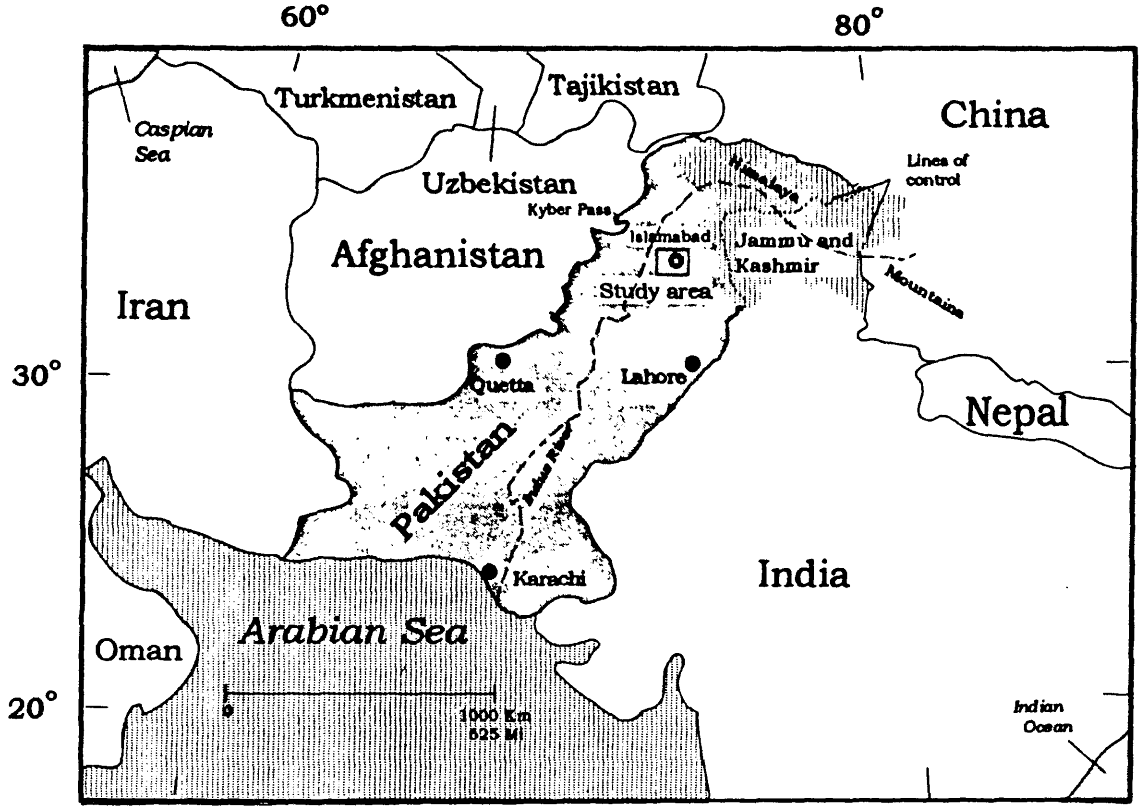


Figure 1. Map showing the location of the Islamabad-Rawalpindi study area and selected regional features.

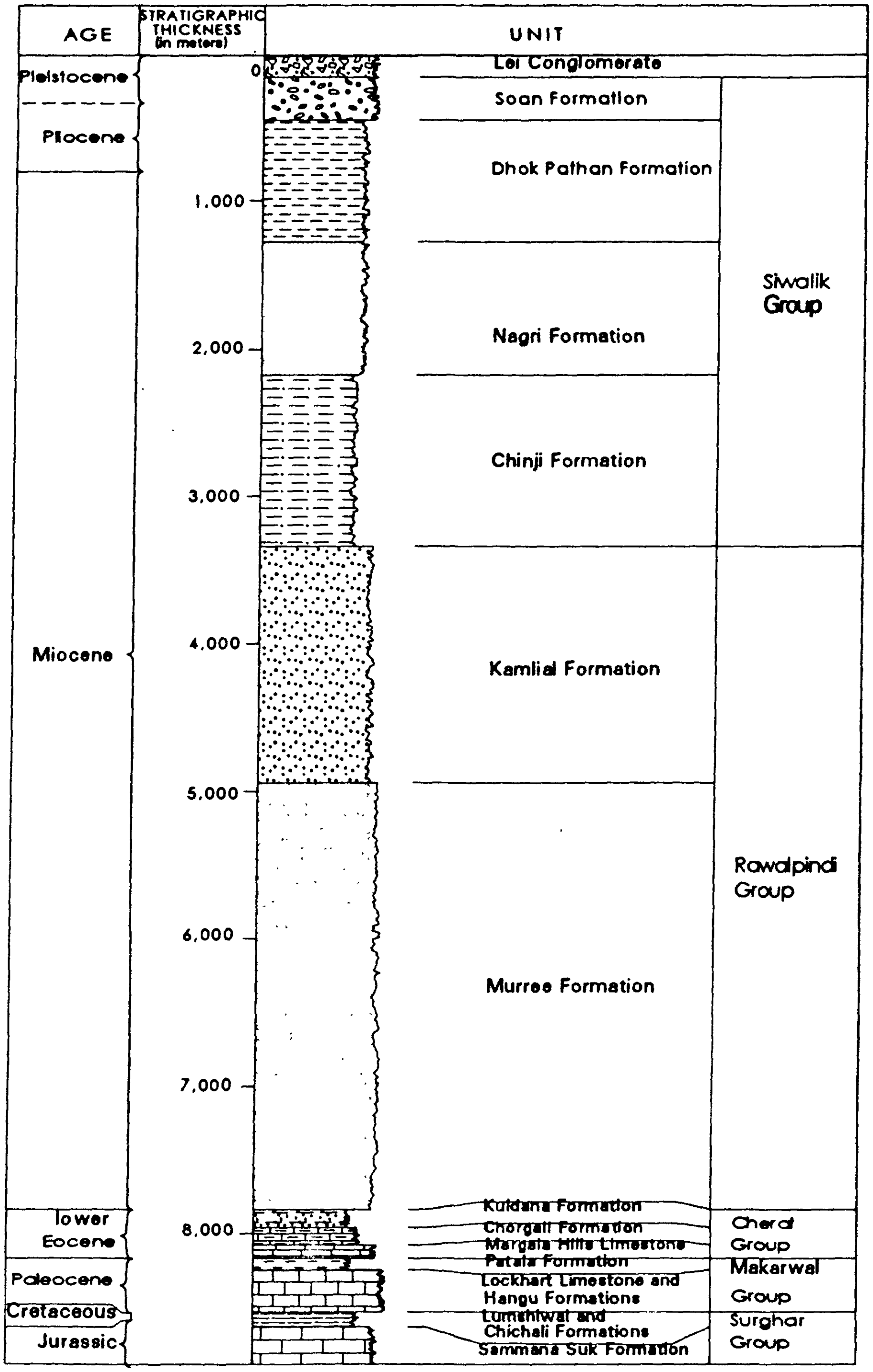
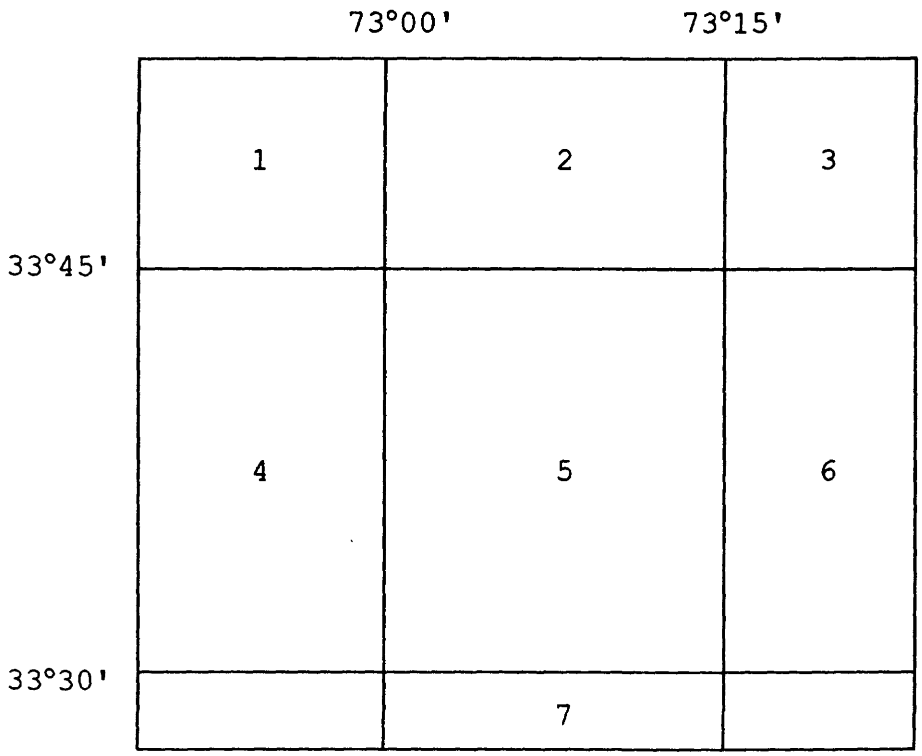


Figure 2. Generalized composite stratigraphic section of consolidated rocks in the Islamabad-Rawalpindi area.



SOURCES OF GEOLOGIC MAPPING

1 Bhatti and others (in press)

2 Pasha and Bhatti (in press)

3 Akhtar and others (in press)

4 Akhtar and Bhatti (in press)

5 Naeem and Bhatti (1985)

6 Kauser (in press)

7 Akhtar and Bhajawa (in press)

Figure 3. Diagram showing the sources of geologic mapping data for this report