Environmental Geology of the Islamabad-Rawalpindi Area, Northern Pakistan

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Chapter G of

Regional Studies of the Potwar Plateau Area, Northern Pakistan

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Abstract

Islamabad, the capital of Pakistan, is a planned city constructed since about 1960 at the foot of the Margala Hills 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 on 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. Major environmental concerns are (1) availability of building materials, (2) environmental degradation from extraction and processing of building materials, (3) availability of surface and ground water, (4) pollution of water by waste disposal, (5) geologic hazards, and (6) engineering characteristics of soil and rock. This report summarizes information on the environmental geology of the Islamabad area that has been collected by a cooperative project of the Geological Survey of Pakistan and the U.S. Geological Survey, supported by the U.S. Agency for International Development.

Many of the interpretations in this report are based on the geologic map of the Islamabad-Rawalpindi area at 1:50,000 scale that was compiled by the first three authors of this report and released separately (Williams and others, 1999, U.S. Geological Survey Open-File Report 99–0047). A 1:100,000-scale map plate included with this report shows environmental map units that are based on the geology, landforms, and slopes; resources of construction materials; engineering conditions; and geologic hazards. This approach is one example of how geologic information can be organized to aid urban planning in the south Asia region.

Introduction

The metropolitan area of Islamabad-Rawalpindi lies between longs 72°45′ and 73°30′ E. and lats 33°30′ and 33°50′ N. in the Islamabad District, the Rawalpindi District of the Punjab, and the Abbottabad District of North-West Frontier Province, Pakistan (figs. G1 and G2, pl. G1). Islamabad is the national capital and the hub for all governmental activities; Rawalpindi is an older and much larger city and is a center of industrial, commercial, and military activity.

Rawalpindi lies along the ancient trade route from Persia and Europe across the Khyber Pass to India (fig. G1). The area has been a cultural meeting place and invasion route for millennia and was visited by Alexander the Great, Genghis Khan, the Moghul conquerors, and other prominent historical figures. Rawalpindi itself was settled around 1765 and grew to importance during the late 1800's, when it became an important staging ground for the British Afghan campaigns. Today it remains the site of a major military cantonment and headquarters of the Pakistan Armed Forces.

Islamabad is a planned city in a beautiful setting at the foot of the mountains immediately north of Rawalpindi, constructed to serve as capital of the newly independent country of Pakistan. Construction began in the early 1960's, following extensive surveys and planning. Since then, rapid growth of both Islamabad and Rawalpindi to a combined population estimated at 1.3 million has made ever-increasing demands on natural resources and caused adverse effects on the environment. As of 1981, the population of Islamabad was estimated as 201,000 and that of Rawalpindi as 806,000 (Survey of Pakistan, 1982). To maintain the quality of the capital, municipal authorities need information on the physical environment to guide future development.

Potential environmental problems are (1) providing additional resources of ground water, (2) extensive pollution of surface water and of ground water by improperly disposed solid waste, (3) continued availability of geologic construction materials, (4) effects of mining of limestone, sand, gravel, and clay, (5) potential subsidence of building foundations caused by instability of loess, (6) control of gully erosion, (7) danger of debris flows from the mountain canyons and floods along the streams, and (8) earthquake hazards. This report is a summary of earth science information in the Islamabad area that can be applied to these problems.

This report is based on a geologic map of the area at a scale of 1:50,000 (Williams and others, 1999) and an environmental geologic map at a scale of 1:100,000 (pl. G1) that delineates (1) environmental units that are based on geology, landforms, and slopes, (2) resources of construction materials, and (3) engineering conditions and geologic hazards. These

Figure G1. Location map showing the Islamabad-Rawalpindi study area (box) and selected regional features.

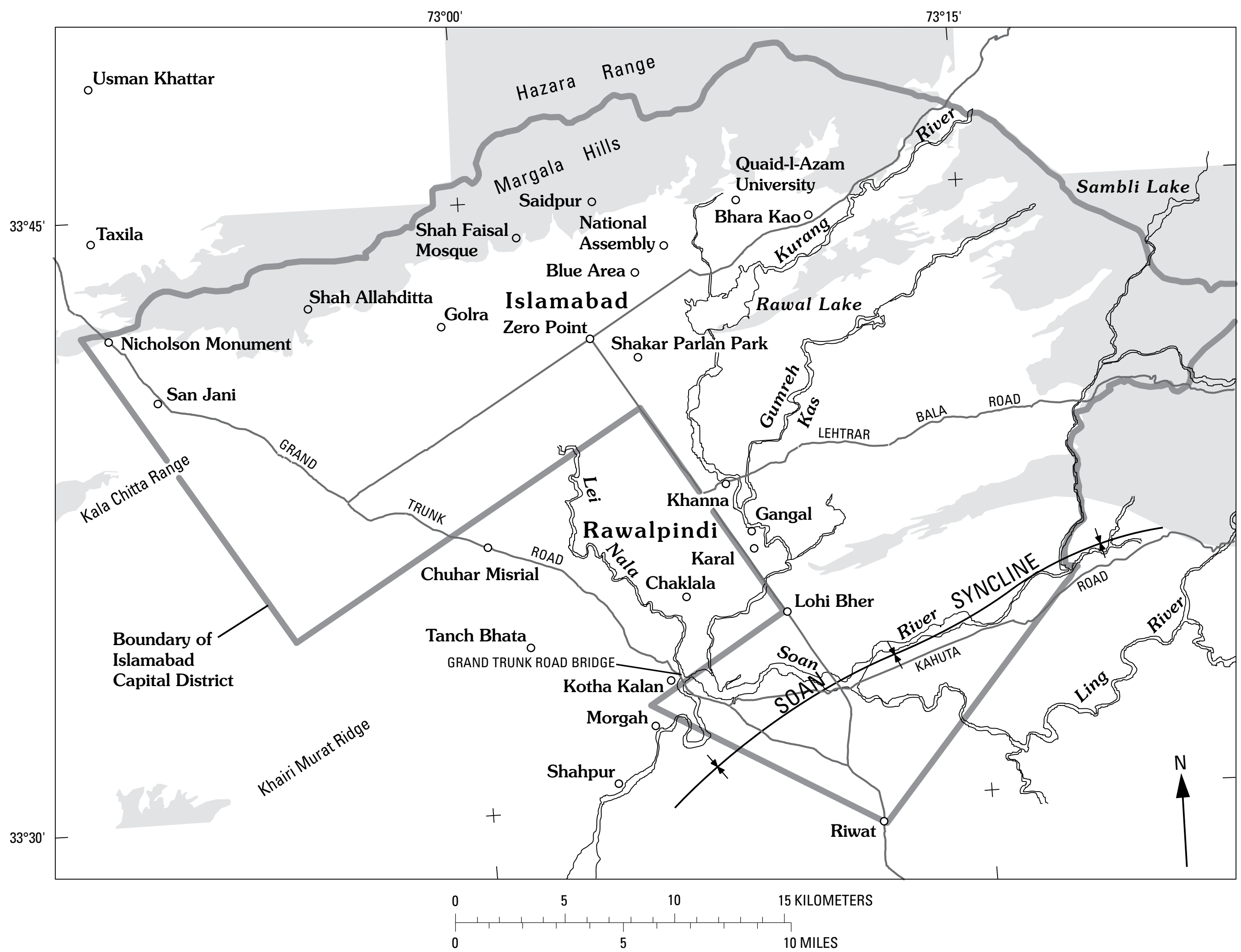


Figure G2. Location map of Islamabad-Rawalpindi study area showing cultural and geographic places mentioned in the report. Mountainous areas are shaded.

data are compiled on the 1:50,000-scale topographic map of "Islamabad and Surroundings" (Survey of Pakistan, 1985), which delimits the study area. Figure G2 locates cultural and geographic places within the study area that are mentioned in the text.

Tables G1, G2, and G3, which define and describe the units shown on the environmental geologic map (pl. G1), summarize the characteristics of the geologic materials in the Islamabad-Rawalpindi study area. Table G1 describes lithology and landform; table G2 describes engineering properties, hazards, and hydrology; and table G3 describes resources and land-use considerations. This information has been derived from geologic and topographic maps, aerial photographs, satellite images, laboratory testing of geologic samples, and review of previous studies. All of this information has been collected and synthesized by a cooperative project of the Geological Survey of Pakistan (GSP) and the U.S. Geological Survey (USGS), supported by the U.S. Agency for International Development (USAID). Figure G3 shows the sources of the basic geologic mapping.

Acknowledgments

This work was supported by the U.S. Agency for International Development. The various agencies and individuals who generously allowed us access to unpublished data include the Capital Development Authority, National Engineering Services of Pakistan, the National Logistic Cell, the Pakistan Army, Syed Najmul Hasan of the National Highways Board, and the Pakistan Department of Meteorology. Akram Bhatti of the Geological Survey of Pakistan and many of his colleagues who have been working in the Islamabad area for many years contributed greatly to this report by sharing their observations and work in progress.

Climate

Records for the Islamabad station of the Pakistan Department of Meteorology (written commun., 1988) (fig. G4) indicate a monsoonal climate of rainy hot summers and cool dry winters; precipitation is characteristic of the semiarid zone of Pakistan. The monsoon rains usually start in June, peak in August, and end by September. A much smaller winter monsoon peaks in March. The four monsoon summer months always have some precipitation, but any of the other months can be completely dry. Annual rainfall of only 249.1 millimeters (mm) was recorded in 1982. The high of 1,732 mm was recorded in 1983. The average for 1931–87 was 1,055 mm. The maximum recorded temperature was 45.9 degrees Celsius (°C) in June 1972, and the minimum was –3.9°C in one January before 1961. Freezing temperatures are rare and have been recorded only in November, December, and January. There is no record of snow (Pakistan Department of Meteorology, written commun., 1988).

Hydrology

The Soan and Kurang Rivers are the main streams draining the area. Their primary tributaries are the Ling River, draining northwestward into the Soan; Gumreh Kas, draining westward into the Kurang from the area between the Kurang and Soan; and Lei Nala, draining southward into the Soan from the mountain front and urban areas. The Kurang and Soan Rivers are dammed at Rawal and Sambli Lakes, respectively, to supply water for the urban area. Extensive forest reserves in the headwaters of the Kurang and Soan Rivers benefit the quality and quantity of supply. A supplemental network of municipal and private wells as deep as 200 meters (m) produces ground water primarily from Quaternary alluvial gravels. The altitude of the water table decreases from about 600 m at the foot of the Margala Hills to less than 450 m near the Soan River, so that the saturated zone generally lies 2–20 m below the natural ground surface (Ashraf and Hanif, 1980). Lei Nala carries most of the liquid waste from Rawalpindi and contributes greatly to the pollution of the Soan River below their confluence. Solid-waste disposal practices threaten the quality of ground-water reserves.

Landforms

General Terrain

The terrain in the metropolitan area of Islamabad-Rawalpindi 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 metropolitan 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 (fig. G2). The Margala Hills, which reach 1,600-m altitude near Islamabad, consist of many ridges of Jurassic through Eocene limestones and shales that are complexly thrusted, folded, and generally overturned.

South of the Margala Hills is a southward-sloping piedmont bench underlain primarily by folded sandstones and shales of the Rawalpindi Group (Miocene). Although the relief of the piedmont area is generally low and dominated by extensive plains of windblown silt, the piedmont area also includes many ridges and valleys that have been buried by alluvial deposits from the hills. 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. The gravel and loess are especially

Table G1. Geology and geomorphology of environmental map units shown on plate G1.

Environmental unit (pl. G1) Symbol	Unit name	Geologic unit[1]	Lithology	Landform
		Loose sediment		
S	Stream-channel alluvium.	Quaternary stream-channel alluvium.	Unconsolidated, channel-crossbedded, moderately sorted channel and bar deposits of sand and gravel.	Streambeds, low islands, and bars within braided or meandering stream channels.
F	Flood-plain alluvium.	Quaternary flood-plain alluvium.	Unconsolidated, channel-crossbedded, moderately sorted channel and bar deposits of sand and gravel, overlain by relatively thin veneer of silt, clay, and organic material.	Stream flood plains. Low stream terraces having very gentle slopes.
T	Stream-terrace alluvium.	Quaternary stream and fan terraces.	Unconsolidated, channel-crossbedded, moderately sorted channel and bar deposits of sand and gravel, overlain by relatively thin veneer of silt, clay, and organic material.	Stream and fan terraces. Stream terraces are former flood plains now above the general level of flooding because of lowering of the streambed, uplift, or decrease in stream size. Gently sloping with steep slopes along eroded margins.
A	Fan alluvium	Quaternary fan alluvium.	Primarily unconsolidated sand and gravel of a mixture of the lithologies found in the tributary watershed. The surface may be covered with thin soil of silt and clay. Poorly sorted and bedded. Debris-flow deposits are common.	Alluvial fans. Sediments deposited where streams emerge from confining valleys and shift radially. Slopes less than 15% except in gullies or eroded margins. Usually the major stream flowing across the fan is braided.
P	Undissected windblown silt.	Quaternary Potwar Clay.	Thick, massive loess. Well-sorted grains of eolian silt held together in an openwork pattern by films of clay and carbonate. Low bulk density. Commonly reworked by water, so crossbedded channel fills of sand and gravel are present.	Loess plains. The depositional surface forms gently rolling low hills sloping less than 15%, mantling a more rugged, buried topography. Steep at eroded margins and gullies. Patches in valley bottoms within mountains.
B	Dissected windblown silt	Quaternary Potwar Clay.	Loess. Well-sorted grains of eolian silt held together in an openwork pattern by films of clay and carbonate. Low bulk density. Commonly reworked by sheet wash and small streams, so crossbedded channel fills of sand and gravel are present.	Loess badlands and gullies. A dense network of steep-sided gullies eroding silt deposits so that the depositional surface is destroyed and most land slopes steeply.
		Weak rock		
H	Undissected, unconsolidated or very weakly consolidated mudstone and sandstone.	Chinji, Nagri, and Dhok Pathan Formations of the Siwalik Group.	Unconsolidated or very weakly consolidated mudstone and sandstone. Moderately bedded and sorted.	Gentle hill slopes with angular clasts. Gently sloping table lands with wide benches and low steps between levels. Covered with a residual soil formed from weathering of the underlying rock.
X	Crystalline gravel conglomerate.	Soan Formation of the Siwalik Group.	Rounded cobbles as large as 30 cm in diameter of metamorphic and igneous rocks from a distant source in a sandy matrix. Weakly cemented to noncemented.	Gentle hill slopes with rounded clasts. Moderately sloping, rolling hills with steep slopes at eroded margins. May cap ridges or hogbacks.
G	Eroded, unconsolidated or very weakly consolidated sandstone, mudstone, and conglomerate.	Siwalik Group and Lei Conglomerate.	Unconsolidated or very weakly consolidated sedimentary rock. Moderately bedded and sorted.	Bedrock badlands and gullies. Steep to moderate hill slopes covered by sparse soil and vegetation.

Table G1. Geology and geomorphology of environmental map units shown on plate G1.—Continued

Environmental unit (pl. G1) Symbol	Unit name	Geologic unit[1]	Lithology	Landform
		Moderately strong rock		
C	Limestone gravel conglomerate.	Lei Conglomerate	Subangular cobbles of Eocene limestone as large as 30 cm. Matrix of reworked eolian silt. Conglomerate is thickly interbedded with sandy silt beds.	Moderately sloping, rolling hills and plains. Eroded into steeper slopes near the Soan River.
M	Interbedded sandstone and shale.	Murree and Kamlial Formations of the Rawalpindi Group.	Consolidated sandstone beds that are relatively resistant to erosion interbedded with less resistant, poorly consolidated rocks such as claystone.	Rocky ridges and pinnacles. Moderate to steep hill slopes with stairstep alternation of cliffs and benches.
L	Limestone	Surghar, Makarwal, and Cherat Groups.	Thickly bedded, gray, fossiliferous marine limestone and dolomite interbedded with minor shale and sandstone. Intensely folded, faulted, and sheared in the Margala Hills.	Steep rocky hill slopes. Cliffs and benches in mountains.

[1]See Williams and others, 1999.

Table G2. Engineering properties, hazards, and hydrology of environmental map units shown on plate G1.

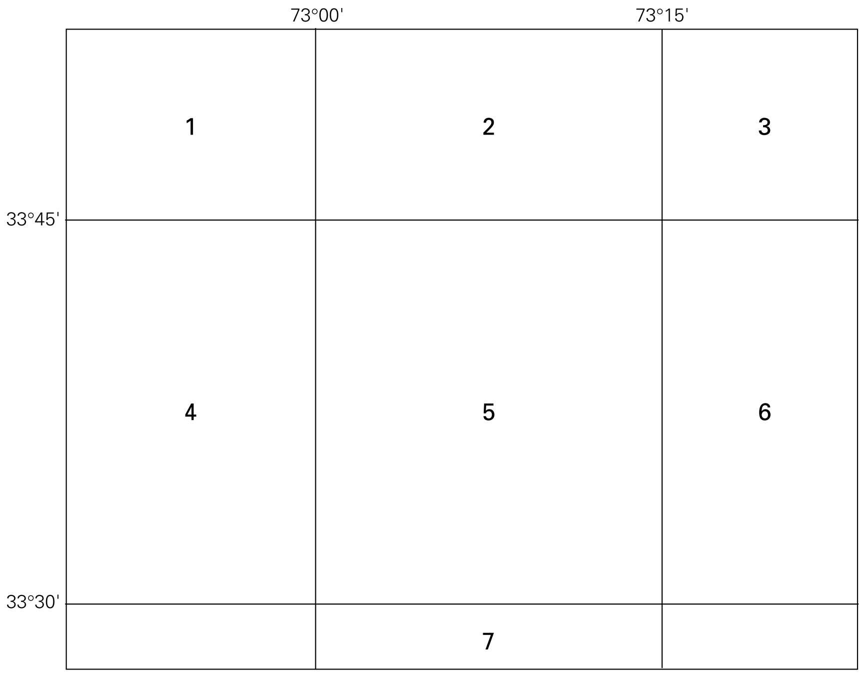
Environmental unit (pl. G1) Symbol	Unit name	Engineering properties	Limitations and hazards	Surface and ground water
		Loose sediment		
S	Stream-channel alluvium.	Low to moderate bearing capacity. Subject to subsidence, liquefaction, failure of cutbanks, stream erosion. High water table. Easy to moderate excavation.	Flooding, erosion of banks, depositional burial, subsidence under load, liquefaction during earthquakes.	Surface water, good ground water at shallow depth, high permeability, poor drainage. Any disturbance affects quality of surface and ground water.
F	Flood-plain alluvium.	Low to moderate bearing capacity. Subject to subsidence, liquefaction, failure of cutbanks, stream erosion. High water table. Easy to moderate excavation.	Flooding, erosion of banks, depositional burial, subsidence under load, liquefaction during earthquakes.	Surface water, good ground water at shallow depth, high permeability, poor drainage. High permeability and shallow ground water make flood-plain alluvium unfavorable for waste disposal.
T	Stream-terrace alluvium.	Moderate bearing capacity. Subject to slumping along edge. Moderate to easy excavation.	Lower terrace flooding. Undercutting by stream erosion. Liquefaction during earthquakes.	Surface water and shallow ground water available. High permeability and shallow ground water make stream-terrace alluvium unfavorable for waste disposal.
A	Fan alluvium	Moderate bearing capacity. Moderate to easy excavation.	Debris flows, sheet floods, and gully erosion. Liquefaction during earthquakes.	Surface water and shallow ground water available. High permeability and shallow ground water make fan alluvium unfavorable for waste disposal.
P	Undissected wind-blown silt.	Moderate bearing capacity when dry, but may lose most strength when wet under load or subject to earthquake shear. Easy excavation. Very erodible.	Very erodible by streams or wind. May collapse under structures when wet. May collapse into flowing landslides under earthquake shock. Excavated caves may collapse under earthquake shock.	Rapid runoff and high sediment yield degrade surface streams. Generally yields little ground water but may contain gravel aquifers.

Table G2. Engineering properties, hazards, and hydrology of environmental map units shown on plate G1.—Continued

Environmental unit (pl. G1) Symbol	Unit name	Engineering properties	Limitations and hazards	Surface and ground water
		Loose sediment—Continued		
B	Dissected windblown silt.	Moderate bearing capacity when dry, but may lose most strength when wet under load or subject to earthquake shear. Easy excavation. Unstable slopes. Very erodible.	Very erodible by streams or wind. May collapse under structures when wet. May collapse into flowing landslides under earthquake shock. Gullies subject to flash floods. Excavated caves may collapse under earthquake shock.	Rapid runoff and high sediment yield degrade surface streams. Generally yields little ground water but may contain gravel aquifers.
		Weak rock		
H	Undissected, unconsolidated or very weakly consolidated mudstone and sandstone.	Low bearing capacity. Unstable slopes subject to creep and earthflow. Very erodible by water or wind. May include expansive clays. Easy excavation.	Erosion, slope failure, subsidence under load, expansive soils.	Sandy units may be good aquifers. Artesian pressure is possible.
X	Crystalline gravel conglomerate.	Moderately high bearing capacity. Natural slopes are well drained and relatively stable but will not support steep cut slopes unless cemented. Excavation may be difficult.	Poor agricultural soil, poor moisture-holding capacity.	High infiltration rate and transmissivity make the unit a good ground-water recharge medium and aquifer. Surface streams are likely to be small and widely spaced. Surface soil is dry and difficult to irrigate. Unsuitable for waste disposal.
G	Eroded, unconsolidated or very weakly consolidated sandstone, mudstone, and conglomerate.	Low bearing capacity. Unstable slopes subject to creep and earthflow. Very erodible by water or wind. May include expansive clays. Easy excavation.	Erosion, slope failure, mudflows, flash floods, subsidence under load, expansive soils.	Sandy units may be good aquifers. Artesian pressure is possible.
		Moderately strong rock		
C	Limestone gravel conglomerate.	Moderately high bearing capacity. Natural slopes are well drained and relatively stable but will not support steep cut slopes unless cemented. Excavation may be difficult.	Poor agricultural soil	High infiltration rate and transmissivity make the unit a good ground-water recharge medium and aquifer. Surface streams are likely to be small and widely spaced. Unsuitable for waste disposal.
M	Interbedded sandstone and shale.	Shales are weak, but thick sandstones have moderate bearing capacity. Slopes are unstable because erosion of the shale undermines the stronger sandstones. Where dip is toward the slope, sandstone may slide on the shale. Excavation difficult.	Block-slip landslides on dip slopes. Rockfall and rotational block slides on slopes opposite to dips. Debris flows.	Surface water may be difficult to obtain in rugged areas. Sandstones may be favorable as aquifers but require mechanical drilling; shales are unfavorable. Artesian conditions may exist.
L	Limestone	Good bearing capacity but may have concealed cavities subject to collapse; moderately stable slopes where dip is into slope. Subject to block slip on dip slopes. High fracture permeability makes the unit unfavorable for waste disposal. Difficult excavation.	Dip slope landslides, ground collapse	Good ground-water recharge medium and aquifer. Flow rates are high and filtration low, so pollution spreads rapidly. Few surface streams cross the limestone, but large springs may occur near the base.

Table G3. Resources and land-use considerations of environmental map units shown on plate G1.

Environmental unit (pl. G1) Symbol	Unit name	Resources	Land-use considerations
		Loose sediment	
S	Stream-channel alluvium	Gravel, sand	No major structures affected by flooding. Regulate extraction of sand and gravel to minimize disturbance of stream equilibrium and degradation of water quality. No disposal of toxic waste.
F	Flood-plain alluvium	Gravel, sand, some brick clay, farming soil.	Minimize residential use, preserve for cropland. Favorable for irrigation but may be subject to high ground water. Protect structures from shifting channels. No major structures affected by flooding.
T	Stream-terrace alluvium	Gravel, sand, silty clay, farming soil	Lower terraces subject to same limitations as flood plains. Higher terraces suitable for many uses but unfavorable for waste disposal. Risk from stream erosion must be controlled or avoided.
A	Fan alluvium	Gravel, sand, silty clay, farming soil	Fan surfaces suitable for many uses, but unfavorable for waste disposal. Potential debris flows affecting the apical area must be controlled or avoided.
P	Undissected windblown silt	Good source of brick clay. Good farming soil. Can be carved into caves for lodging or livestock.	Erosion of gullies must be controlled, building foundations protected from excessive wetting. Vegetation should be protected, farmers should use measures to prevent soil erosion.
B	Dissected windblown silt	Possible source of brick clay. Can be carved into caves for lodging or livestock. Can be graded and compacted into suitable building sites.	Attempt reclamation by revegetation and protection from erosion. Farming and grazing should be restricted. At critical locations, erosion control structures and dams may be necessary.
		Weak rock	
H	Undissected, unconsolidated or very weakly consolidated mudstone and sandstone.	Sand or clay	Suitable for most uses with proper design of structures.
X	Crystalline gravel conglomerate.	Good source of gravel for aggregate	Near urban areas, planning should allow for sequential land use. Value of aggregate resource should be evaluated before residential development is permitted. Residential use can be postponed until mining and reclamation are completed.
G	Eroded, unconsolidated or very weakly consolidated sandstone, mudstone, and conglomerate.	Sand or clay	Unsuitable for most uses because of rapid erosion and poor soil. Has potential for reclamation because the topography can be modified with earth-moving equipment.
		Moderately strong rock	
C	Limestone gravel conglomerate.	Good source of gravel for aggregate	Near urban areas, planning should allow for sequential land use. Value of the aggregate resource should be considered before residential development is permitted. Residential use can be postponed until mining and reclamation are completed.
M	Interbedded sandstone and shale.	Sandstone building stone	Care must be taken to avoid destabilizing slopes during construction. Design foundations to avoid differential settlement problems.
L	Limestone	Important source of crushed aggregate, feedstock for cement manufacture. Some limestones form oil reservoirs at depth.	Makes excellent watershed, especially when vegetation can be maintained. Mining on dip slopes may be dangerous.



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 G3. Sources of geologic mapping data for this report.

important to the environmental geology because they form most of the building foundations and because gravel is the primary ground-water aquifer. West of Rawalpindi, plains of thick, easily eroded loess are extensively dissected into shallow badland valleys. East of Rawalpindi, the folded ridges 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.

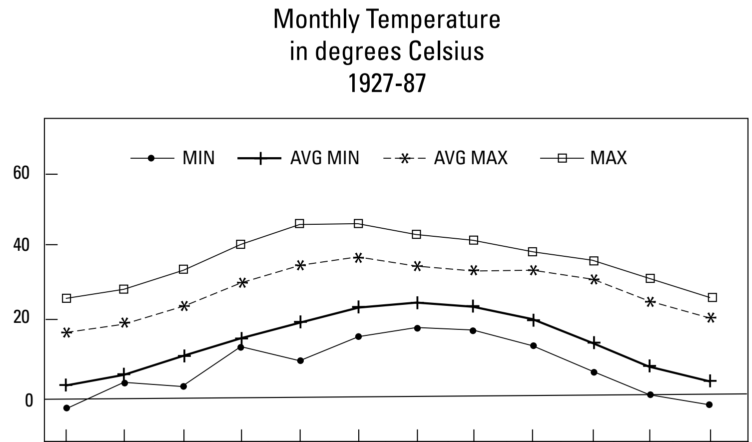
In the southernmost part of the area, the Soan River valley extends generally along the axis of the Soan syncline at an altitude of about 425 m. The Soan is incised more than 40 m below the level of extensive silt-covered plains north and south of the river. Southeast of Rawalpindi, upstream from the Grand Trunk Road bridge, the Soan channel and flood plain extend 1.5 kilometers (km) across the valley floor. Elsewhere, the valley bottom is much narrower. Beds of fluvial sandstone, mudstone, and conglomerate of the Siwalik Group of Neogene to Pleistocene(?) age 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 (see Warwick, this volume, chap. A, fig. A2), which extends southwestward for 150 km.

Descriptive Outline of Landforms

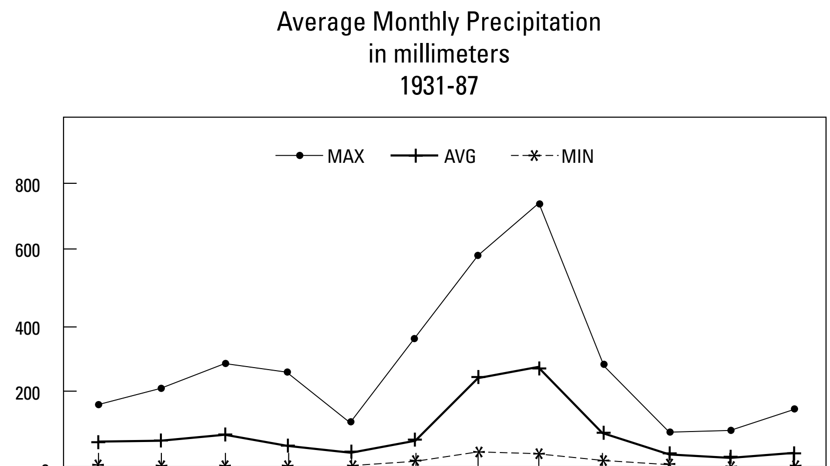
Landforms mapped (pl. G1) in the Islamabad-Rawalpindi area can be subdivided into those constructed by deposition of sediment and those carved by erosion. Each landform has a characteristic range of slopes, soil types, and active geologic processes that may limit its suitability for various uses.

Depositional Landforms

Streambeds, low islands, and bars.—Low land in valley bottoms that is generally covered and reshaped by flowing water each year. These features are formed by braided



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MIN	-3.9	3.4	2.2	13.0	8.9	15.0	18.0	17.2	13.3	6.4	-0.2	-2.8
AVG MIN	2.5	5.5	10.2	15.1	19.0	23.7	24.6	23.6	20.5	14.0	7.2	3.1
AVG MAX	17.0	19.1	23.8	29.8	35.1	37.1	34.9	33.3	33.3	30.9	25.1	20.0
MAX	26.1	28.3	33.3	40.6	45.6	45.9	43.3	41.4	38.1	36.1	31.0	26.0



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MAX	167	209	282	265	116	344	580	730	282	95	96	152
AVG	61	70	81	52	34	59	239	277	92	24	16	29
MIN	0	0	0	0	0	3.6	30.7	28.1	9.4	0	0	0

Figure G4. Temperature and precipitation data for Islamabad. Data from Pakistan Department of Meteorology (written commun., 1988).

or meandering streams. The surface is generally sand and gravel, and there is little or no soil development. The surface is unstable and lacks vegetation except for quick-growing grass. Slopes are less than 4 percent.

Stream flood plains.—Low benches slightly above the stream channels in valley bottoms. They are above water level most of the year but are commonly flooded whenever the streams overtop their banks. The surface is generally fine sand, silt, and clay with a relatively high organic content and fertile soil. Slopes are less than 4 percent.

Stream and fan terraces.—Lower terraces form wide benches along the sides of modern stream valleys similar to flood plains, but the terraces are higher above the stream and are seldom flooded. Higher terraces form gravel-capped ridges and flat-topped hills that never flood. Terraces are dissected relict flood plains; uplift of the old depositional surface and erosional lowering of streambeds have left the terrace surfaces above the reach of most floods. The highest terraces are along the mountain front in stream valleys and alluvial fans and generally are preserved where limestone gravel that was cemented by calcium carbonate from ground water forms hard layers resistant to erosion. Under the terrace surface, a thin layer of fine-textured soil generally overlies channel deposits of sand and gravel. The terrace surfaces generally slope less than 10 percent, but erosional scarps on the side of the terrace slope steeply.

Alluvial fans.—Fan-shaped bodies of gravel-rich alluvium deposited near the mountain front where streams emerge from steep canyons. Streams on the fan surface commonly shift their courses laterally; floods and debris flows episodically cover parts of the fan surface with water and thick layers of sediment. The time interval between major debris flows may be tens of years, so the hazard is commonly underestimated. Cemented limestone gravel in the alluvium may make excavation difficult. Slopes are less than 15 percent.

Loess plains.—Plains and gently sloping hills of fine silt and clay built up from airborne dust burying preexisting hills and valleys. The landscape has also been smoothed by thin sheets of rainwater flowing across the surface. The soil is fertile and easily tilled but is easily eroded by water and wind. The geologic formation underlying these plains is the Quaternary Potwar Clay. Slopes are less than 15 percent.

Erosional Landforms

Loess badlands and gullies.—Steep-sided but generally shallow ravines eroded in soft loess (windblown silt and clay of the Potwar Clay). These gullies tend to grow and coalesce through headward erosion. Growth of loess badlands can be controlled, and some of the land can be reclaimed through conservation measures. Loess badlands are especially extensive south and west of Rawalpindi.

Bedrock badlands and gullies.—Areas of generally parallel, deep ravines eroded in steeply dipping soft mudstone and sandstone of the Siwalik Group. Most of the gullies have formed along the strike of weakly consolidated beds separated by ridges of resistant, cemented sandstone. This landform develops from loess badlands and gullies when streams cut down through the base of the loess into steeply dipping bedrock. Such terrain is extensive west of Riwat on either side of the Soan River. Bedrock badlands are more difficult to reclaim than loess badlands. Slopes are 50–100 percent.

Gentle hill slopes with angular clasts.—Rolling hills generally sloping more than 15 percent but less than 75 percent. Some ledges of rock may crop out, but the surface generally is covered with thin soil of sand, clay, and broken rock derived from weathering of the underlying bedrock. This type of slope is generally found on low hills underlain by sandstones of the Rawalpindi and Siwalik Groups.

Gentle hill slopes with rounded clasts.—Rolling hills generally sloping more than 15 percent but less than 100 percent. Some ledges of rock may crop out, but the surface generally is covered with thin sandy soil derived from weathering of the underlying rock; the soil contains rounded cobbles from a distant source. This type of slope is generally found on low hills underlain by conglomerates of the Soan Formation (Pliocene and lower Pleistocene(?)) or Lei Conglomerate (middle Pleistocene).

Rocky ridges and pinnacles.—Low hills, abundant rock outcrops, and thin sandy soil formed primarily on resistant, steeply dipping sandstone beds of the Kamlial Formation (lower and middle Miocene). The beds typically erode into a band of parallel, low sandstone walls. Excavation and agriculture are difficult. Average slope is less than 15 percent but may include vertical rock walls several meters high.

Steep, rocky hill slopes.—Mountain slopes 20 percent to vertical, and many rock ledges. Parts of rock slopes are covered by boulders and finer rock debris; soil is sufficient in places to support partial cover. Includes most of the Margala Hills, where Paleocene marine limestones have been deeply eroded.

Geology

The dominant factor controlling the geology of the Islamabad-Rawalpindi area is the convergence of the Pakistan-India and Eurasian tectonic plates and the collision between the plates that began about 20 million years ago. This process produced complex structure and stratigraphy in the Islamabad-Rawalpindi area that have been studied by many Pakistani and foreign geologists. Most of the individual quadrangle maps comprising the study area have been mapped by the Geological Survey of Pakistan (fig. G3), although many have not yet been published. This mapping has been interpreted and compiled by the first three authors of this report into a map at 1:50,000 scale (Williams and others, 1999) of the same area covered by plate G1. Plate G1 shows some of the information on the geologic map, but many geologic units of various ages have been grouped together on the basis of their physical properties, and much of the structural detail has been omitted. This discussion of the geology of the Islamabad-Rawalpindi area will be best understood by reference to the geologic map (Williams and others, 1999).

Descriptive Outline of Rock Units

The sedimentary rocks of the Islamabad area record a long period of gentle geologic fluctuations and slow deposition while the Pakistan-India tectonic plate drifted northward across the Indian Ocean, followed by much more vigorous tectonic processes and rapid deposition in the shorter period since the Pakistan-India and Eurasian plates converged. Consequently, the 150-million-year (m.y.) period from deposition of the Samana Suk Formation (Middle Jurassic) to the beginning of deposition of the Murree Formation (lower Miocene) is represented by only about 675 m of primarily marine sedimentary rocks, whereas the last 20 m.y. are represented by more than 7,572 m of continental sedimentary rock (fig. G5).

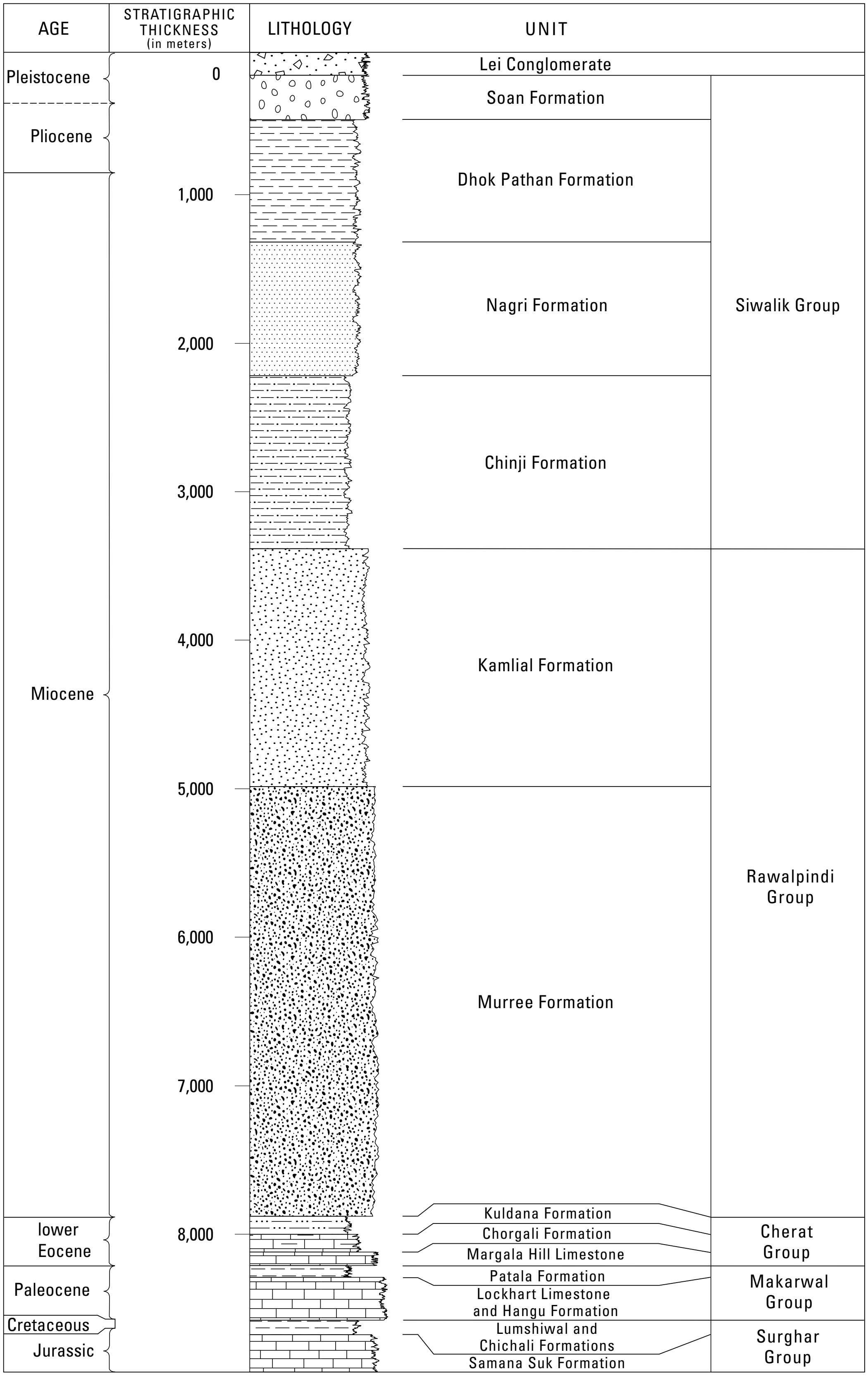


Figure G5. Generalized composite stratigraphic section of consolidated rocks in the Islamabad-Rawalpindi study area. See text for exact ages and generalized lithologic descriptions. Dashed boundaries are approximate.

During the uplift and structural deformation of the last 1.5 m.y., erosion has dominated over deposition, so that the only sediments preserved are thin, discontinuous bodies of alluvium and eolian silt.

Surghar Group (Jurassic and Lower Cretaceous)

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

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

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

Makarwal Group (Paleocene)

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

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

Patala Formation.—Shale and subordinate limestone and marl. The shale is greenish gray to brownish gray, thinly laminated, splintery, and calcareous; it grades into siltstone and sandstone. The limestone is gray to light gray, thinly bedded, and fossiliferous. The marl is dark gray and fossiliferous. The Patala Formation represents primarily marine deposition. The measured thickness is 70–80 m. The unit is conformable with the overlying Margala Hill Limestone.

Cherat Group (Lower Eocene)

Margala Hill Limestone.—Marine limestone and subordinate marl and shale. The limestone is dark gray to pale gray, medium to thick bedded, nodular, and fossiliferous. The marl is gray to brownish gray and hard. The shale is greenish gray and reddish brown and splintery. The measured thickness ranges from 60 to 90 m. The unit is conformable with the overlying Chorgali Formation.

Chorgali Formation.—Marine shale, limestone, and marl. The formation is divisible into lower and upper parts. The 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. The upper part consists of limestone that is gray to light gray and white to grayish yellow, thin to medium bedded, flaggy, cherty, and fossiliferous. The marl is light gray to gray and thinly bedded. The measured thickness ranges from 30 to 120 m. The unit is conformable with the overlying Kuldana Formation.

Kuldana Formation.—Marine and continental claystone, marl, limestone, and minor sandstone. The claystone is variegated in color and has gypsum intercalations. The marl is pale gray to brownish gray, is thin to medium bedded, and contains fibrous gypsum. The limestone is white to very pale brown. The sandstone is brownish gray, fine grained, and calcareous. The measured thickness is 60–120 m. The unit unconformably underlies the Murree Formation.

Rawalpindi Group (Miocene)

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

Kamlial Formation (lower and middle Miocene).—Sandstone and claystone. The sandstone is purple, gray, and dark brick red; medium to coarse grained; thick bedded; micaceous; jointed; and calcareous. The Kamlial Formation contains interbeds of hard purple claystone; some claystone beds are weathered and have yellow mottles. These weathered beds resemble conglomerate. The unit is distinguished from the underlying Murree Formation by its spheroidal weathering. Measured thicknesses range from 1,200 to 1,600 m. The upper contact beneath the Chinji Formation is conformable. Near the village of Chinji, 115 km southwest of Islamabad, the base was dated by fission-track dating of volcanic ash at about 18.3 million years ago (Ma) (Johnson and others, 1985).

Siwalik Group (Neogene and Pleistocene(?))

Chinji Formation (middle and upper Miocene).—Claystone and sandstone. The claystone is brick red, friable, hard, and intercalated with sandstone. The sandstone is dark gray to brownish gray, medium to thick bedded, soft, and crossbedded. The thickness ranges from 880 to 1,165 m. The upper contact with the Nagri Formation is conformable. Near the type locality, the base was dated by fission-track dating of volcanic ash at about 14.3 Ma (Johnson and others, 1985).

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

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

Soan Formation (Pliocene and lower Pleistocene(?)).—Conglomerate and subordinate interbeds of sandstone, siltstone, and claystone. The 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 and sedimentary rocks of the Siwalik Group. Clasts are cemented in a calcareous sandy matrix. The sandstone is greenish gray, coarse grained, and soft. The claystone is orange, brown, pale pink, and soft. The exposed thickness is 200–300 m. The upper contact beneath the Lei Conglomerate and younger sediments is an unconformity older than 1.6±0.18 Ma (Johnson and others, 1982). The base locally rests on an unconformity dated by fission-track dating of a volcanic ash at 1.9±0.4 Ma (Raynolds, 1980, p. 190).

Surficial Units (Pleistocene and Holocene)

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. Other clasts are 5 percent older Siwalik Group sedimentary rocks, 2 percent quartzite, and trace amount of igneous rocks (Gill, 1951; Raynolds, 1980). The Lei Conglomerate is generally flat lying, but locally it is folded and faulted. It overlies rocks of the 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 the base of the conglomerate and above the 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).

The Lei Conglomerate is 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. The unit was 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. The exposed thickness is 106 m, but drill hole FC–12 southwest of Saidpur (fig. G2) 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 that of clay beds is 14 m.

Potwar Clay (Pleistocene and Holocene).—Windblown silt and clay and subordinate amounts of alluvial gravel. Sediment is light brown to gray, very fine grained, hard, compact, and calcareous. The windblown sediment averages 71–74 percent silt-size and 15–16 percent clay-size material. The unit is 14–18 percent calcium carbonate. The mineral composition is predominantly quartz, but subordinate amounts of feldspar and clay minerals are present, such as kaolinite and illite (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, the silt is intercalated with crossbedded lenses of sand and gravel and with the Lei Conglomerate.

Thermoluminescence ages of loess from the Potwar Clay in the Riwat area range from 20 thousand to 132 thousand years ago (ka) from near the surface to 11-m depth and are 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. The Potwar Clay is subject to loss of bearing strength when wet. Its thickness is highly varied, depending on the relief of the underlying unconformity. The exposed thickness is 1–35 m. Similar deposits intercalated with the Lei Conglomerate extend to a depth of 152 m (Ashraf and Hanif, 1980).

Terrace alluvium (Pleistocene and Holocene).—Gravel, clay, and silt locally cemented by calcium carbonate. Clast-supported boulders, cobbles, and pebbles of sedimentary rocks enclose 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. The terrace-alluvium unit resembles the Lei Conglomerate but is younger and retains its depositional form. The unit is divided into older and younger subunits.

Older terrace alluvium (Pleistocene).—Terrace alluvium whose depositional surface is more than 5 m above modern flood level. The older terrace-alluvium unit is generally preserved as discontinuous remnants of gravel capping ridges and flat-topped hills. The maximum thickness is about 3 m.

Younger terrace alluvium (upper Pleistocene and Holocene).—Terrace alluvium whose depositional surface is less than 5 m above modern flood level. The younger terrace alluvium generally forms benches along the sides of modern stream valleys. The thickness is about 3 m.

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

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

Stream-channel alluvium (Holocene).—Unconsolidated gravel, sand, and silt that is subject to stream transport each year. The stream-channel alluvium is poorly to moderately sorted and contains low-angle crossbedding. The alluvium is generally without soil or vegetation. It forms low islands and bars within braided and meandering stream channels. The maximum thickness is about 3 m.

Geologic History

Sedimentary rocks exposed in the Islamabad area (fig. G1) record 150 m.y. of geologic history from the Middle Jurassic to the Quaternary. 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 subordinant local deposition dominated by coarse clastic continental sediment.

The oldest rocks exposed in the study area are Jurassic marine limestone and dolomite that were deposited on a continental shelf along the northern edge of the continental part of the Pakistan-India tectonic plate as it migrated northward before converging with the Eurasian plate. The oolitic, biomicritic, and intrasparitic types of limestone in the Samana Suk Formation indicate 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 the 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 the Lumshiwal Formation was deposited. The calcareous facies of the 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 north of the map area (the Kawagarh is missing from the study 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 equatorial latitude of the Pakistan-India 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 Pakistan-India 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 consisted chiefly of quartzite and metamorphic clasts eroded from the Himalayan core and is similar to clasts in modern Indus River (pl. A1) gravels. Local sedimentation stopped between 3 Ma and 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 southern 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 (pl. A1). 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 (Warwick, this volume, chap. A, pl. A1, fig. A2). 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 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 (pl. A1, fig. A2), have caused major shifts in the course of the Indus and affected the base level of the Soan River (pl. A1).

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 intensity VII) was in the area centered along the Gumreh Kas (stream) about 7 km northeast of Rawalpindi (fig. G6) in February 1977 and had a Richter magnitude of 5.8.

Geologic Structure

The Islamabad-Rawalpindi 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 m.y.

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″*, *A′–A″*, and *B–B′* (figs. G7–G9) depict interpretations of the geologic structure slightly modified from previous interpretations shown in sections by Naeem and Bhatti (1985) and Pasha and Bhatti (in press).

Hazara Fault Zone

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.

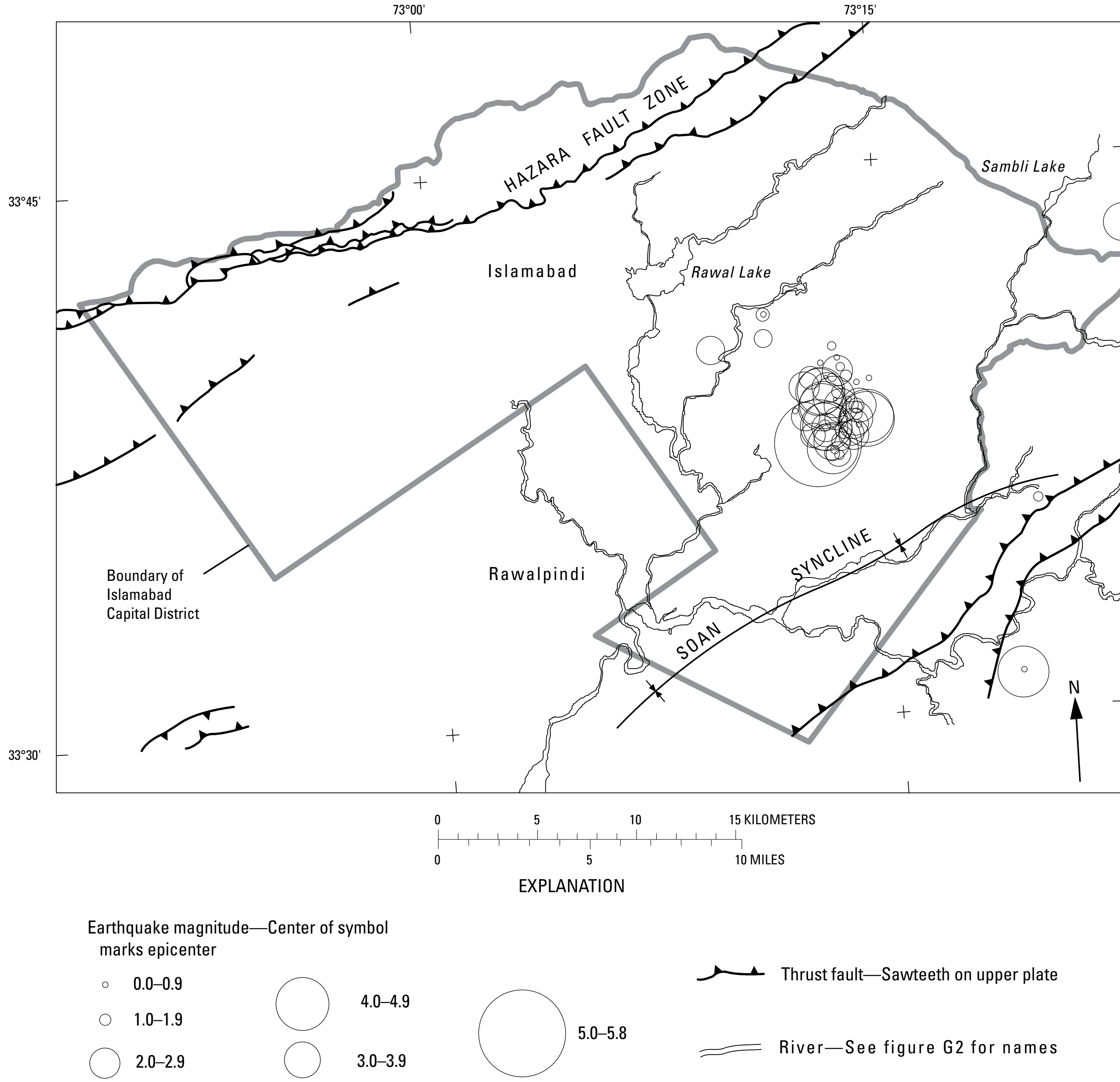


Figure G6. Earthquake magnitudes between January 26, 1977, and April 30, 1978 (from Adhami and others, 1980), and potentially active faults in the Islamabad-Rawalpindi study area. Centers of circles are epicenters, and radii of circles are proportional to magnitude.

The thrust and fold structure of the Margala Hills immediately north of Islamabad is complex (fig. G8). 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 pre-Miocene 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″*, *A′–A″* (figs. G7 and G8), and *B–B′* (fig. G9), 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 five 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 decreases 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 and are not shown in figure G6.

Piedmont Fold Belt

The faults and folds in the piedmont fold belt south of the mountain front probably have high potential activity, although definitive exposures are sparse and discontinuous. The Pleistocene Lei Conglomerate, overlying the sandstone of the Murree Formation (lower Miocene), is folded in the broad anticline at Shakar Parian Park (fig. G2) in Islamabad. The Lei Conglomerate also is tilted 80° southward along a thrust fault in the Kuldana Formation (lower Eocene) north of Golra, 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, a major range that begins about 25 km west of Rawalpindi and extends westward south of the Margala Hills. Major faults bounding the Khalri Murat Range (figs. A2, G2), about 15 km south of the Kala Chitta Range (figs. A2, G1), may also extend northeastward toward Rawalpindi, concealed beneath Quaternary eolian and alluvial deposits.

Soan Syncline

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 that 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) have 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) (pl. A1) as indicating continued folding and faulting along the Soan syncline through the late Pleistocene.

Geologic Hazards

Seismic Risk

The Islamabad-Rawalpindi area lies in a tectonically active zone, where faulting, folding, and earthquakes have been frequent in the recent geologic past. Quaternary deposits are tectonically deformed throughout the map area. In A.D. 25, the Buddhist monasteries at Taxila, 25 km west-northwest of Islamabad, were destroyed by an earthquake estimated at Modified Mercalli intensity IX. More recently, a Richter magnitude 5.8 earthquake on February 14, 1977, centered 7 km northeast of Rawalpindi (fig. G6), caused damage indicating Modified Mercalli intensity VII near the epicenter (Adhami and others, 1980).

The focus of the 1977 earthquake was estimated to be at 14- to 18-km depth and could not be definitely associated with any of the known surface faults in the map area. Although earthquake shaking is not confined to areas near surface faults, the risk of surface rupture is greater where the surface has been broken previously. Only those faults estimated as most likely to rupture during earthquakes are shown in figure G6, along with epicenters and magnitude of earthquakes in the Islamabad area between January 26, 1977, and April 30, 1978, from data of Adhami and others (1980, p. 72–81).

Studies by National Engineering Services of Pakistan (NESPAK) indicated that a realistic seismic factor for building design should probably be higher than that indicated on

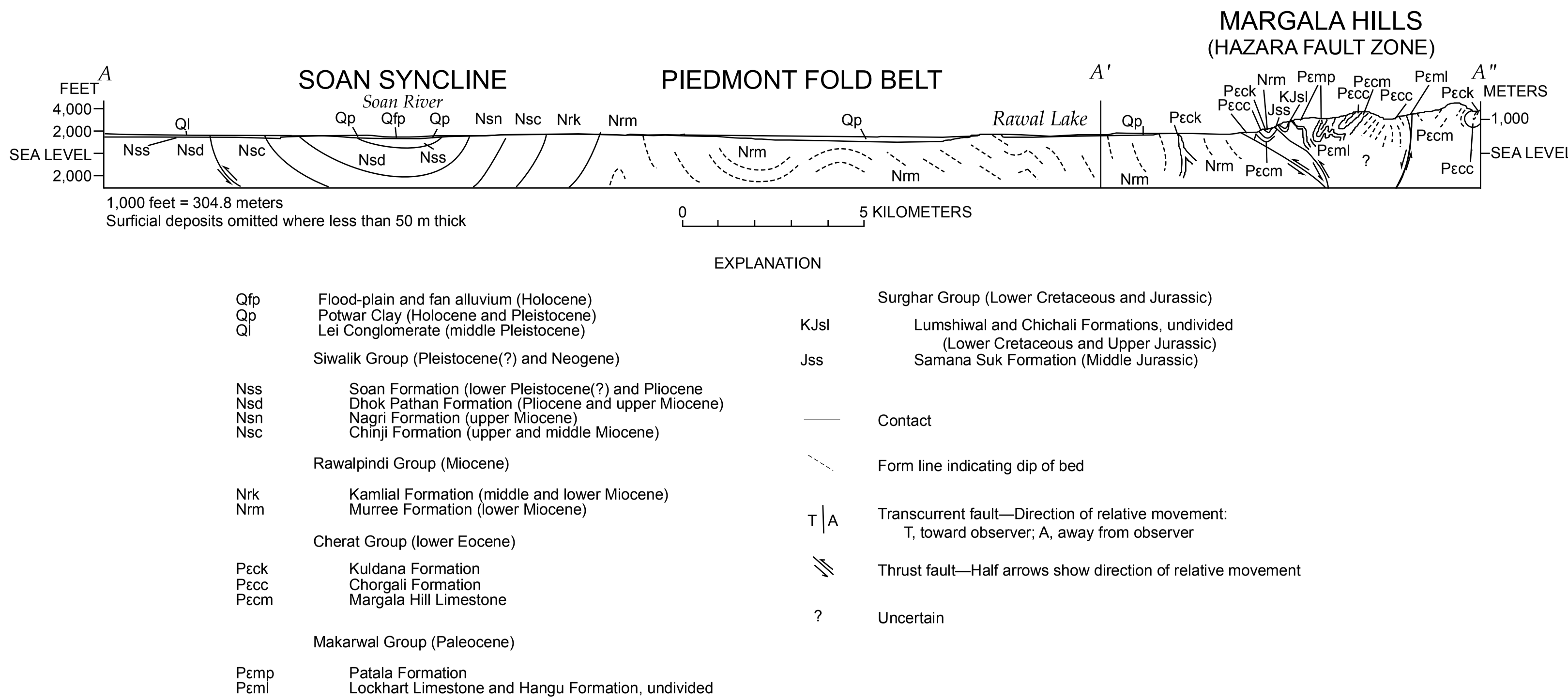


Figure G7. Geologic cross section *A–A″* in the Islamabad-Rawalpindi study area (modified from Williams and others, 1999, whose section was modified from those by Naeem and Bhatti (1985) and Pasha and Bhatti (in press)). See plate G1 for location.

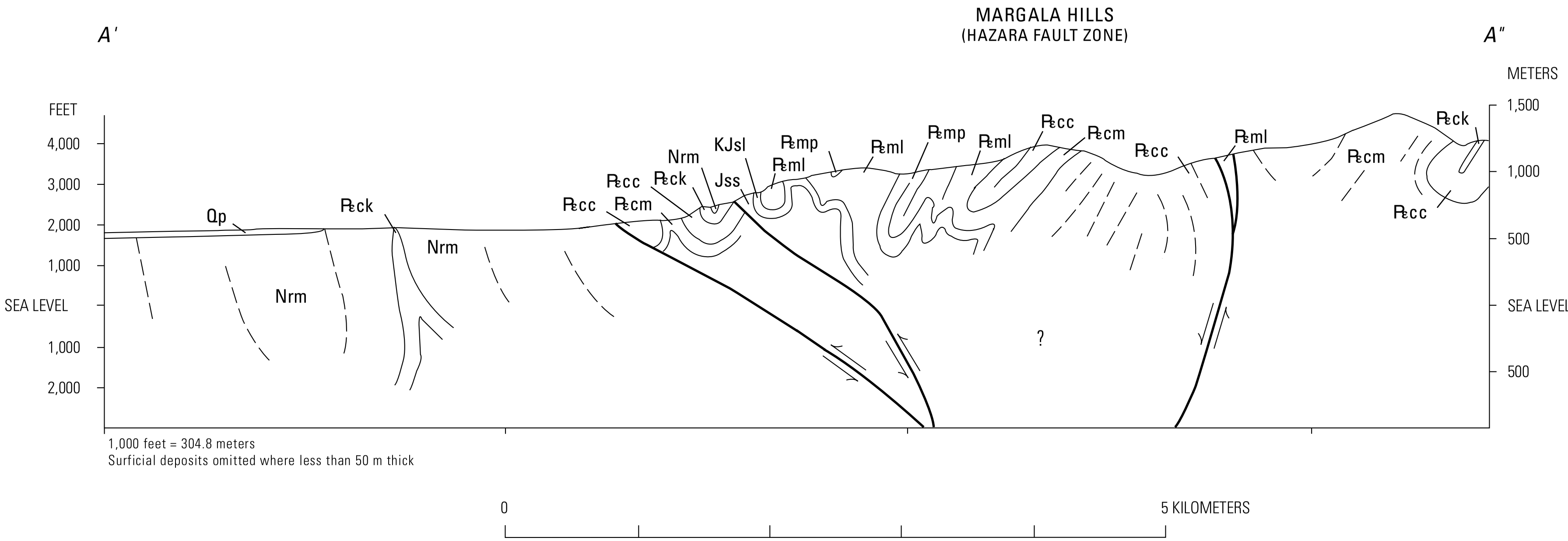


Figure G8. Enlargement of the north end (*A′–A″*) of the geologic cross section *A–A″* in the Islamabad-Rawalpindi study area (modified from Williams and others, 1999, whose section was modified from those by Naeem and Bhatti (1985) and Pasha and Bhatti (in press)). See figure G7 and plate G1 for location; see figure G7 for explanation of geology.

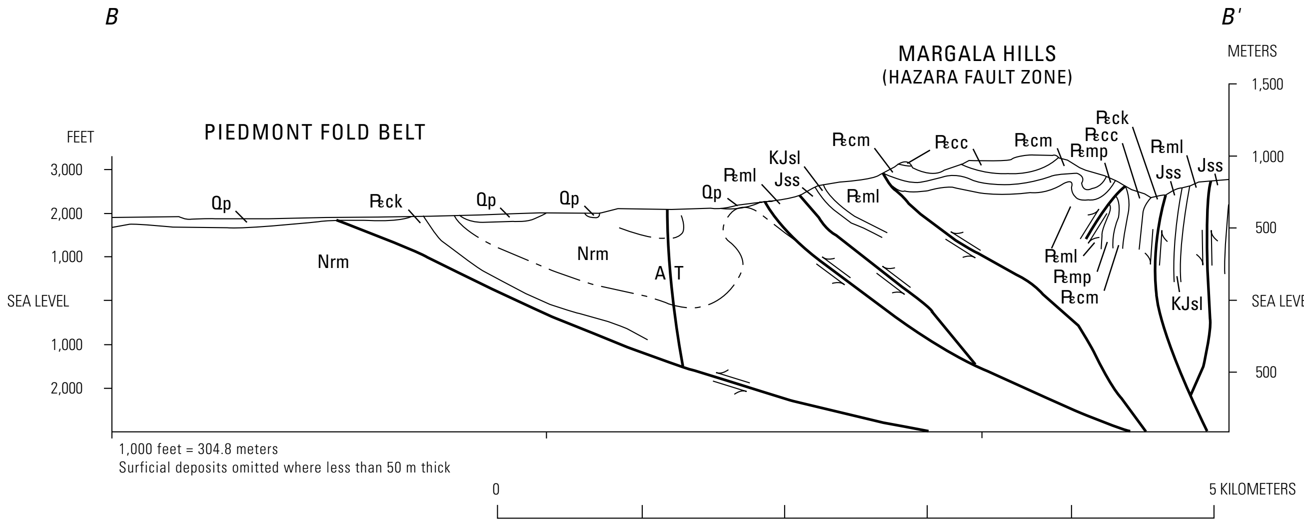


Figure G9. Geologic cross section *B–B′* in the Islamabad-Rawalpindi study area (modified from Williams and others, 1999). See plate G1 for location and figure G7 for explanation of geology.

the seismic zoning map of Pakistan (Adhami and others, 1980, p. 133). They recommended design for 0.125-*g* (gravitational acceleration) horizontal acceleration for ordinary structures, and for 0.2 *g* without collapse for important structures. For sensitive structures, site-specific designs are required that take into account the strength of the underlying soil and bedrock and the distance from probable earthquake sources (Adhami and others, 1980, p. 137).

NESPAK (Adhami and others, 1980, p. 131) estimated that each year there is a 50 percent chance of a Richter magnitude 4 earthquake, an 8.33 percent chance of magnitude 5, a 1.67 percent chance of magnitude 6, a 0.26 percent chance of magnitude 7, and a 0.11 percent chance of magnitude 7.5 (recurrence intervals of 2, 12, 66, 380, and 912 years, respectively). A complicating factor in estimating probable seismic accelerations in the Islamabad area is the irregularity of the bedrock surface buried beneath Quaternary silt and gravel. Capital Development Authority (CDA) test hole 18, 1.8 km south of the zero-point road intersection in Islamabad (fig. G2, pl. G1), penetrated more than 140 m of unconsolidated gravel and clay (probably including interbedded conglomerate and silt of the Lei Conglomerate) without reaching bedrock (fig. G10). Depths to bedrock exceeding 100 m are common over much of the area, even close to outcrops. In the southern part of the area, Siwalik Group bedrock is commonly near the surface, but it is little stronger than the alluvial cover. Thick, unconsolidated deposits tend to amplify earthquake shocks, and uncompacted eolian silt, such as parts of the Potwar Clay, may collapse or even liquefy if the bonds between the grains are destroyed.

Flooding

Lei Nala heads in the Margala Hills and passes through the center of Rawalpindi, where homes and lives have been lost to flooding in low-lying areas. Although the stream is relatively small, it is entrenched, so floodwaters are confined to the narrow flood-plain zone at the valley bottom. This confinement increases the depth and suddenness of flooding in the small area affected but protects most of the population, who live above flood level. If continued losses are to be minimized, land use in the affected areas may have to be changed. Wide flood plains along the Soan River above the Grand Trunk Road bridge are subject to flooding but are not densely populated. Expansion of residential or industrial development onto the Soan flood plain should be carefully controlled, although dams on tributaries to the Soan help to reduce potential problems.

Debris Flows

Debris flows issuing from mountain canyons onto alluvial fans at the mountain front create another flooding hazard that is less easily recognized than most conventional flood hazards. Infrequent, extreme precipitation events may trigger such flash floods of mud, boulders, and water, but during the periods between events, sediment accumulates in the mountain canyons, and the longer the time between flushing events, the more violent may be the final release. Deposits from such events seem to occur in northern Islamabad in parts of municipal blocks F6, E8, F8, E9, F9, and E10 (block grid of master plan of Islamabad, Survey of Pakistan, 1982).

General Engineering Characteristics

Foundation conditions in Islamabad and Rawalpindi vary greatly. The bedrock surface consists mostly of folded and faulted sandstone and claystone of the Rawalpindi Group, some soft sandstone and claystone from the Kuldana Formation, harder limestone from the Chorgali Formation toward

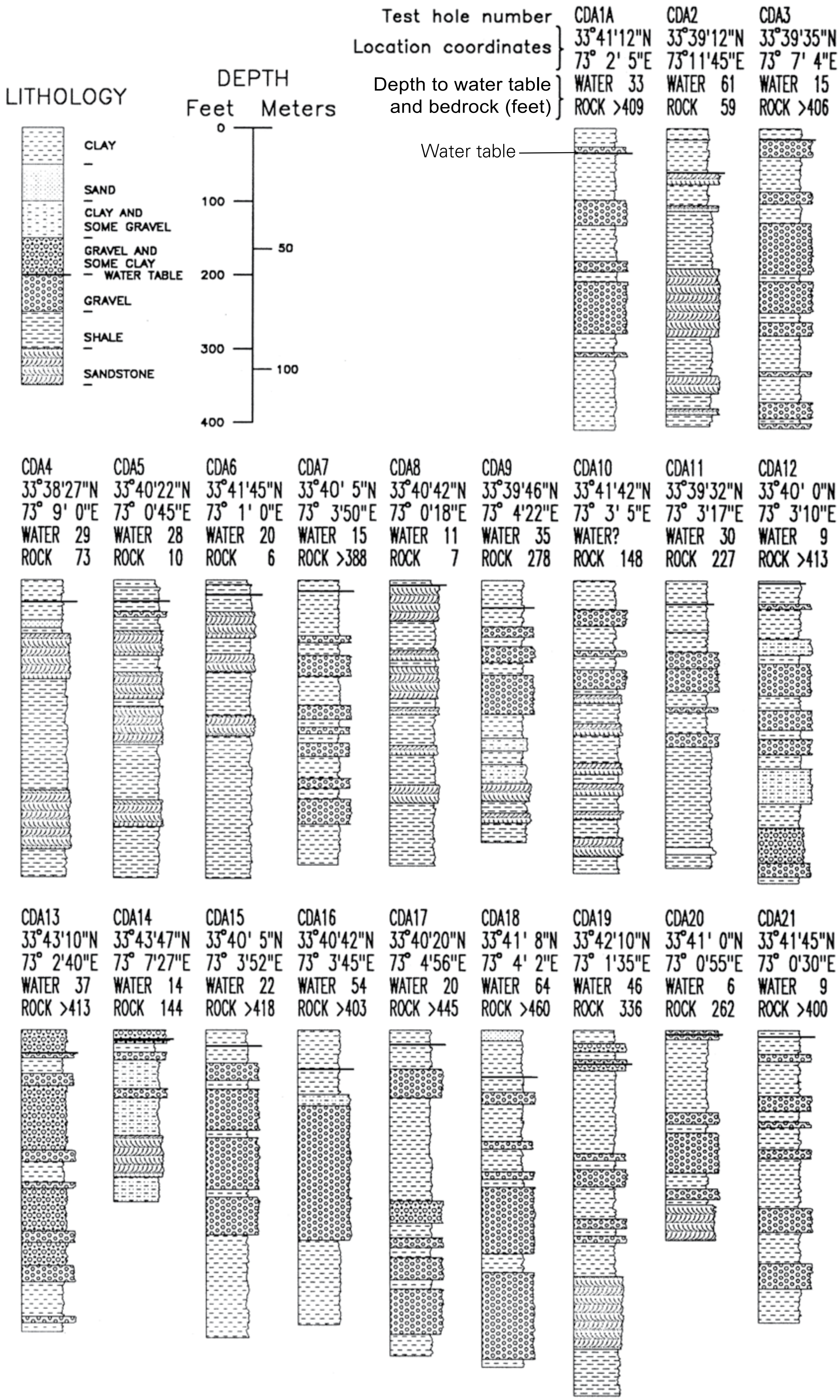


Figure G10. Logs of the Capital Development Authority (CDA) hydrologic test holes around Islamabad. See plate G1 for locations of test holes (plotted without CDA prefix). Data from Ashraf and Hanif (1980).

the north, and some Siwalik Group sandstone and claystone toward the south. These rocks have been deformed and eroded into a highly irregular surface, and they have been partly buried beneath alternating layers of silt and sandy, locally cemented, limestone gravel in the Lei Conglomerate, Potwar Clay, and younger stream deposits. The Pleistocene deposits generally lie flat, but locally they also are tectonically deformed. Between bedrock outcrops, a flat plain of silt may conceal bedrock ridges just below the surface, hard, cemented limestone conglomerate, or loose silt and gravel more than 100 m thick.

In general, all the natural foundation materials are weak, including the bedrock. The exceptions are the limestone beds of the Chorgali Formation, some cemented sandstone beds in the Murree and Kamlial Formations of the Rawalpindi Group, and the cemented limestone gravel in the Lei Conglomerate and stream-terrace deposits. The uncompacted eolian silt covering many upland surfaces has moderate bearing capacity when dry, but it is subject to sudden loss of strength and collapse when wetted under loads of about 1–3 kilograms per square centimeter (kg/cm^2) (Rendell, 1985, p. 766). The silt is very easily excavated, but where cemented gravel lies close to the surface, excavation may be much more difficult and expensive than anticipated (Khan and others, 1987).

Table G4 tabulates the range of values and averages for various physical properties of soil and rock samples from the Islamabad-Rawalpindi area as generalized categories of sandstone, mudstone, gravel, sand, and silt plus clay. Categories for unconsolidated samples signify the particle-size range making up the greatest weight percent of the sample. Most of the samples are poorly sorted, so some of the gravel samples contain as much as 18 percent silt and clay, and some of the samples classified as silt plus clay contain as little as 40.5 percent silt and clay. Liquid limit, plastic limit, and plastic index are determined on the portion of the sample finer than 0.42 mm, so the values reported for gravels reflect properties of the matrix sand, silt, and clay. This tabulation does not represent a systematic areal collection but is a random collection of all the available data that could be located (74 samples), supplemented with analyses of 11 samples collected specifically for this study (3–01 to 3–11, pl. G1).

Samples from building sites of the Pakistan Overseas Foundation office building (pl. G1, 1–1) and the Pakistan Engineering Council (pl. G1, 2–1) near the Blue Area in central Islamabad (fig. G2) provided data on water content, bulk density, specific gravity, liquid limit, plastic limit, plastic index, consolidation, direct shear, unconfined compression, point load, organic-matter content, sulfate content, pH, percent gravel, percent sand, and percent silt plus clay. Samples 3–01 to 3–03 (pl. G1) of loess surface soil from Islamabad and Riwat provided data on water content, specific gravity, liquid limit, plastic limit, plastic index, organic-matter content, sulfate content, sodium chloride content, total dissolved solids, optimum moisture content, maximum dry density, percent gravel, percent sand, and percent silt plus clay. Sample 3–04 from a brick clay pit (pl. G1) provided data on organic-matter content, sulfate content, total dissolved solids, percent gravel, percent sand, and percent silt plus clay. Samples 3–05 to 3–09 of building sand from Lawrencepur (50 km northwest of Islamabad) provided data on specific gravity, organic-matter content, sulfate content, sodium chloride content, total dissolved solids, percent gravel, percent sand, and percent silt plus clay. Samples 3–10 and 3–11 (pl. G1, 3–10) are crushed limestone from a quarry near Nicholson Monument (fig. G2). They were analyzed for data on specific gravity, abrasion resistance, moisture absorption, percent gravel, percent sand, and percent silt plus clay.

A series of 21 hydrologic test holes drilled by the Capital Development Authority across Islamabad (pl. G1) provides information on depth to bedrock, depth to the water table, and some physical properties of subsurface materials. Samples from these holes were measured to determine natural water content, dry bulk density, specific gravity, porosity, permeability, percent gravel, percent sand, and percent silt plus clay. Logs of these holes are summarized in figure G10; they were constructed from information in the report of Ashraf and Hanif (1980).

The rest of the physical properties data is from route studies along roads outside the study area, but in the same geologic materials that occur in the study area. These provided data on specific gravity, liquid limit, plastic limit, plastic index, California bearing ratio, optimum moisture content, maximum dry density, percent gravel, percent sand, and percent silt plus clay. There is no certainty that the data from the 85 samples summarized in table G4 are typical of the Islamabad-Rawalpindi area, but they do indicate part of the range of possible values.

Most of the large structures in Islamabad and Rawalpindi are less than 10 stories high, although some higher than 20 stories have been completed and others are under construction (pl. G1), primarily in the Blue Area (fig. G2), near the National Assembly building. The minarets of Shah Faisal Mosque are also very tall, slender structures, and the main building is massive. All the tall structures are underlain by silt, conglomerate, and bedrock of folded Murree sandstone and mudstone.

Waste Disposal

Disposal of the large quantities of liquid and solid waste generated by the combined populations of more than 1.3 million people in Rawalpindi and Islamabad is a major problem that presently causes extensive pollution of ground water, surface water, and air. Islamabad has one of the most modern sewage treatment plants in Pakistan; sewage is carried by pipes to a disposal plant just north of Rawalpindi, where it is treated and the relatively clean effluent passes into a tributary of Lei Nala. Immediately downstream, however, waste water of all types enters Lei Nala as it passes through Rawalpindi. On the south side of Rawalpindi, Lei Nala enters the Soan River as a putrid stream covered with brown foam. Toxic waste may

Table G4. Physical properties of geologic materials in the Islamabad-Rawalpindi study area.

[Samples are described in the text under "General Engineering Characteristics." wt %, weight percent; g/cm^3, grams per cubic centimeter; kg/cm^2; kilograms per square centimeter; deg, degrees; —, no data available]

Property	Sand-stone	Mud-stone	Gravel	Sand	Silt plus clay
Water content (wt %)					
Average	8.90	7.73	5.70	7.07	15.19
Maximum	15.12	12.88	8.70	13.67	29.20
Minimum	1.40	2.40	4.59	4.65	1.74
No. of samples	6	6	8	25	11
Dry bulk density (g/cm^3)					
Average	1.79	1.97	1.69	1.62	1.64
Maximum	2.52	2.45	2.00	1.69	2.00
Minimum	1.42	1.47	1.56	1.53	1.40
No. of samples	8	6	8	25	8
Specific gravity					
Average	2.58	2.64	2.65	2.63	2.64
Maximum	2.66	2.70	2.70	2.72	2.73
Minimum	2.46	2.57	2.57	2.56	2.47
No. of samples	5	3	10	30	9
Porosity (%)					
Average	40.21	39.86	37.85	38.32	41.82
Maximum	42.19	42.63	39.39	40.44	43.22
Minimum	38.13	38.11	37.43	36.41	39.92
No. of samples	5	3	7	25	3
Permeability (darcies)					
Average	1.62	1.51	8.64	11.74	.20
Maximum	5.36	2.37	20.51	30.61	.44
Minimum	.14	.69	.32	.38	.04
No. of samples	5	3	8	25	3
Silt plus clay content (%)					
Average	—	—	4.78	9.20	80.50
Maximum	—	—	18.00	35.20	99.00
Minimum	—	—	.00	1.40	40.50
No. of samples	—	—	13	37	14
Liquid limit (% water)					
Average	—	—	20.00	31.00	33.70
Maximum	—	—	21.00	35.00	40.00
Minimum	—	—	19.00	25.00	23.00
No. of samples	—	—	2	4	10
Plastic limit (% water)					
Average	—	—	14.50	20.75	21.00
Maximum	—	—	15.00	24.00	26.00
Minimum	—	—	14.00	17.00	16.00
No. of samples	—	—	2	4	10
Plastic index					
Average	—	—	5.50	10.25	12.70
Maximum	—	—	6.00	13.00	20.00
Minimum	—	—	5.00	6.00	7.00
No. of samples	—	—	2	4	10
Consolidation:					
Void ratio (%)					
Average	—	—	—	—	0.603
Maximum	—	—	—	—	.650
Minimum	—	—	—	—	.570
No. of samples	—	—	—	—	3
Compression index					
Average	—	—	—	—	0.15
Maximum	—	—	—	—	.20
Minimum	—	—	—	—	.10
No. of samples	—	—	—	—	3
Direct shear:					
Cohesion (kg/cm^2)					
Average	—	—	—	—	0.29
Maximum	—	—	—	—	.30
Minimum	—	—	—	—	.28
No. of samples	—	—	—	—	2
Angle of friction (deg)					
Average	—	—	—	—	11.50
Maximum	—	—	—	—	18.00
Minimum	—	—	—	—	5.00
No. of samples	—	—	—	—	2
Unconfined compression:					
Unconfined compressive strength (kg/cm^2)					
Average	109.50	31.96	6.20	—	2.41
Maximum	315.00	90.27	6.20	—	8.40
Minimum	6.00	1.09	6.20	—	.60
No. of samples	3	3	1	—	5
Strain at failure (%)					
Average	0.95	—	1.20	—	5.12
Maximum	1.00	—	1.20	—	9.10
Minimum	.90	—	1.20	—	1.40
No. of samples	2	—	1	—	5
Point load (kg/cm^2)					
Average	57.50	41.50	—	—	—
Maximum	57.50	63.00	—	—	—
Minimum	57.50	14.00	—	—	—
No. of samples	1	3	—	—	—
Organic-matter content (%)					
Average	—	—	—	0.04	0.59
Maximum	—	—	—	.05	1.83
Minimum	—	—	—	.01	.16
No. of samples	—	—	—	5	6
Sulfate (%)					
Average	—	—	—	0.001	0.039
Maximum	—	—	—	.001	.114
Minimum	—	—	—	.001	.001
No. of samples	—	—	—	5	6

Table G4. Physical properties of geologic materials in the Islamabad-Rawalpindi study area.—Continued

Property	Sand-stone	Mud-stone	Gravel	Sand	Silt plus clay
Sodium chloride (%)					
Average	—	—	—	0.002	0.047
Maximum	—	—	—	.005	.137
Minimum	—	—	—	.001	.002
No. of samples	—	—	—	5	3
Total dissolved solids (%)					
Average	—	—	—	0.091	0.446
Maximum	—	—	—	.120	.748
Minimum	—	—	—	.065	.175
No. of samples	—	—	—	5	4
pH					
Average	6.5	—	7.6	—	7.0
Maximum	6.5	—	7.6	—	7.0
Minimum	6.5	—	7.5	—	7.0
No. of samples	1	—	2	—	2
California bearing ratio unsaturated					
Average	—	—	—	38.23	—
Maximum	—	—	—	57.40	—
Minimum	—	—	—	15.20	—
No. of samples	—	—	—	6	—
California bearing ratio saturated					
Average	—	—	—	18.92	—
Maximum	—	—	—	38.10	—
Minimum	—	—	—	6.60	—
No. of samples	—	—	—	6	—
Optimum moisture content (%)					
Average	—	—	—	10.28	15.87
Maximum	—	—	—	10.81	16.60
Minimum	—	—	—	8.71	15.00
No. of samples	—	—	—	4	3
Maximum dry density (g/cm^3)					
Average	—	—	—	2.33	1.82
Maximum	—	—	—	3.08	1.86
Minimum	—	—	—	2.08	1.78
No. of samples	—	—	—	4	3

be part of the mixture, as Lei Nala passes through industrial areas, and the Rawalpindi area lacks an organized facility for disposal of toxic waste.

Solid waste is also dumped into Lei Nala and at various sites in the surrounding countryside (pl. G1). These sites are generally unsuitable for agriculture, either because of bedrock outcrops or because of gullies in the silt. The waste is spread, burned, and, in some places, covered with a thin layer of soil. These practices represent an attempt to reclaim waste land, and in a few places, crops are planted over the buried waste. Air pollution results from the burning in either case, but potential problems with pollution of surface and ground water are more severe in the bedrock outcrop areas. There is no impermeable barrier between the waste and the exposed bedding planes of steeply dipping permeable sandstone of the Murree Formation, so leachate from the waste can move rapidly into the ground-water flow system. Also, steep slopes in bedrock areas combined with lack of adequate cover material and drainage control structures allow leachate to move rapidly into surface streams. During the summer monsoon, leaching of waste is accelerated by precipitation averaging more than 250 mm/month and maximum temperatures averaging more than 34°C. Control of ground-water pollution is important because municipal and private wells are used extensively in Islamabad and Rawalpindi to supplement supplies from the Rawal and Sambli Lakes.

Potentially favorable sites for waste disposal near Rawalpindi exist in exhausted clay pits within the Potwar Clay. Compacted clay-rich silt has low permeability, and areas of silt suitable for cover can usually be found. When properly engineered, filled, and covered, the reclaimed pits may be suitable for low-intensity uses such as agriculture, storage yards, or parks and recreation.

Urban Mineral Resources

The most important mineral resources in the Islamabad-Rawalpindi urban area are construction materials: limestone for cement; aggregate for concrete; sand for mortar; and clay for bricks, tiles, and pottery. All of these resources are quite abundant and have been heavily exploited. Most aggregate is quarried and crushed from limestone bedrock or dug from alluvial gravel in modern and ancient stream deposits. General-purpose sand is taken locally from modern streambeds, and higher quality sand is brought in from pits at Lawrencepur, about 50 km northwest of Islamabad. Brick clay is dug from pits scattered around the Islamabad-Rawalpindi area wherever the surficial cover of Potwar Clay (primarily windblown silt) is sufficiently thick and clay rich.

Aggregate

Aggregate is in heavy demand in the Islamabad-Rawalpindi area for use in concrete construction and road building. There are two principal sources. Most of the supply is obtained by quarrying and crushing limestone from the Margala Hills, but a secondary source is alluvial gravel, either taken directly from the stream channel or dug from terrace deposits. Other potential sources are little exploited.

Table G5 lists the locations and estimated quantity of important aggregate resources. The areas of outcrop were measured from the environmental geologic map (pl. G1), but the estimated reserve (in metric tons) was calculated by using assumptions about thickness and bulk density. The symbols in table G5 appear on plate G1 to identify the areas measured in each category. Those symbols consist of the basic environmental geologic map unit letter symbol plus a number that is appended to indicate the resource area. For example, the letter C indicates the areas of Lei Conglomerate outcrop not included in aggregate-reserve calculations; on plate G1, sym-

Table G5. Estimated reserves of aggregate in the Islamabad-Rawalpindi study area.

[Assumptions used to calculate reserves are explained in the text in the "Aggregate" section. Areas of reserves are shown on plate G1. Availability: a, already active; b, potentially available; c, beneath superior agricultural land; d, beneath urban development; e, beneath protected parkland or reserved forest; f, beneath important structures]

Map symbol (pl. G1)	Availability	Area (ha)	Reserve (millions of metric tons)	Location
		Limestone bedrock		
L1	b	142	103.8	NE end of Khairi Murat Ridge.
L2	b	369	270.2	NE end of Kala Chitta Range.
L3	a	668	488.5	Margala Hills near Grand Trunk Road.
L4	b	231	168.7	Margala Hills E of Sang Jani and W of Shah Allahditta.
L5	a	282	206.5	Margala Hills N of Shah Allahditta.
L6	b	898	657.2	Margala Hills E of Shah Allahditta and W of quarries near Islamabad.
L7	b	87	63.7	Small low foothills just W of Islamabad.
L8	a	736	538.0	Margala Hills NW of Islamabad.
L9	e	5,155	3,770.9	Margala Hills N of Islamabad.
L10	b	1,879	1,374.5	Margala Hills NE of Islamabad.
Subtotal		10,447	7,642.0	
		Limestone gravel from the Lei Conglomerate		
C1	e	79	7.5	Shakar Parian Park.
C2	b	197	21.6	Isolated outcrops SW of Rawalpindi.
C3	d	1,271	338.0	Large outcrops N of Soan River.
C4	b	655	71.9	Scattered outcrops S of Soan River.
C5	b	1,410	1,546.8	Thick hill SE of Soan River.
Subtotal		3,612	1,985.8	
		Crystalline conglomerate of the Soan Formation		
X1	b	308	84.5	N of Soan River.
X2	b	998	273.9	S of Soan River.
Subtotal		1,306	358.4	
		Terrace gravel		
T1	b	594	45.9	W of Shah Allahditta.
T2	b	169	13.1	Along stream bank at Sang Jani-Grand Trunk Road.
T3	f	163	12.6	Near National Assembly building.
T4	b	916	70.8	E of Islamabad.
T5	f	331	25.5	At Quaid-l-Azam University.
Subtotal		2,173	167.9	
		Flood-plain sand and gravel		
F1	c	218	21.9	Soan River flood plain below Grand Trunk Road bridge.
F2	c	11	1.1	Soan River flood plain above Grand Trunk Road bridge.
Subtotal		229	23.0	
		Unmined stream-channel sand and gravel		
S1	b	247	12.4	Above Rawal Lake.
S2	b	92	4.6	Gumreh Kas.
S3	b	90	4.5	Soan River below Grand Trunk Road bridge.
S4	b	573	28.8	Soan River above Grand Trunk Road bridge.
Subtotal		1,002	50.3	
		Actively mined stream-channel sand and gravel		
S5	a	194	9.7	Below Rawal dam.
S6	a	219	11.0	Soan River near Grand Trunk Road bridge where mined.
Subtotal		413	20.7	
Grand total		19,182	10,248.1	

bols C1–C5 also appear, because part of unit C was subdivided into five geographic areas for calculating aggregate reserves. Location is a critical factor in the economics of aggregate resources, because of the low value of the product relative to the transportation cost. Assumptions used to calculate the reserves in table G5 are discussed below for each potential source of aggregate:

1. Limestone bedrock. The reserve tonnage of limestone bedrock was calculated by assuming mining to an average depth of 30 m and a bulk density of 2.4 g/cm^3. The steeply dipping limestone beds extend to a great depth, and mining to depths greater than 30 m is possible. Environmental impact, mine safety, and economics are the primary limitations on production of aggregate from limestone, rather than the extent of the raw material.

2. Limestone gravel from the Lei Conglomerate. The Lei Conglomerate was estimated to have an average minable thickness of 6 m and a bulk density of 1.8 g/cm^3. It is not much used as a source of aggregate at present, perhaps because the limestone gravel commonly is cemented and interbedded with silt.

3. Crystalline conglomerate of the Soan Formation. The crystalline conglomerate of the Soan Formation was estimated to have an average minable thickness of 7.5 m and a bulk density of 1.8 g/cm^3. This unit is a possible source of high-strength aggregate but may prove difficult to crush because it contains clasts of strong crystalline rock.

4. Terrace gravel. Terrace gravels were estimated to have an average minable thickness of 3 m and a bulk density of 1.7 g/cm^3. They are widely distributed along the mountain front, but because individual deposits are scattered, reserves at any one locality are generally small. Many deposits are covered by urban development and major structures. Northeast of Islamabad, at Bhara Kao, some of the larger terrace deposits are presently being mined.

5. Flood-plain sand and gravel. Flood-plain alluvium along the Soan River was estimated to have an average minable thickness of 6 m and a bulk density of 1.7 g/cm^3, but little of it has been mined. The land is fertile and easily irrigated and, consequently, is quite valuable for agriculture. If pumping or dredging is required, the high water table beneath the flood plain may make excavation more expensive than for other sources of aggregate.

6. Stream-channel sand and gravel. Stream-channel alluvium was estimated to have an average minable thickness of 6 m and a bulk density of 2.0 g/cm^3. The thickness estimate is nearly meaningless because material removed during the dry season is replaced by deposition during the monsoon. Alluvium is generally not mined under water but is excavated from dry bars exposed during the dry season. The bulk density estimate is high because of many cobbles of crystalline rocks.

Limestone is quarried mostly from the Lockhart Limestone and Samana Suk Formation but may also be obtained from the Margala Hill Limestone. Most of the quarries are at the foot of the Margala Hills, where access is easy and where mining and crushing are facilitated by the extensive shearing that has accompanied thrust faulting (pl. G1). Two samples of Lockhart Limestone from the quarries at soil sample site 3–10 (pl. G1), near Nicholson Monument, have an average Los Angeles abrasion test value of 22.79 percent loss for 500 revolutions. The average apparent specific gravity of the crushed rock is 2.69, and the average absorption is 0.625 percent.

Immediately north of Islamabad, mining at the mountain front is prohibited within reserved forests that protect the scenic backdrop of the capital. The greatest concentration of limestone quarries in the metropolitan area extends along the mountain front from the forest boundaries westward for about 20 km. On either side of the Grand Trunk Road at Nicholson Monument, 15 km northwest of Rawalpindi, quarries are nearly continuous, and very little of the hill slopes remains undisturbed. Dust pollution there seriously restricts visibility, and the closeness of uncoordinated mining operations increases the substantial hazard to the miners.

Control of the mining area is split between Rawalpindi and Islamabad administrative authorities and the Punjab Provincial Government. The Capital Development Authority controls about 600 hectares (ha) on either side of the Grand Trunk Road at Nicholson Monument, where about 217 crushers are working. The limestone is crushed on a single-shift basis, and about 36 metric tons per day is the average production of each crusher, which means total production of aggregate from this area is about 2.5 million metric tons per year.

In the Punjab Provincial Government area, an automatic crusher and 40 hand-fed crushers are in operation. The hand-fed crushers produce almost the same tonnage as described for the Capital Development Authority areas, but the automatic plant, at Shah Allahditta, produces about 91 metric tons per day, which is used to feed the adjacent cement factory.

The alluvial gravel is commonly quite coarse and the clasts are well rounded, so crushing is needed to optimize size and increase angularity. Most of the crushers are scattered along the Soan River and its tributaries, where they take gravel directly out of the streambed or dig it from terraces. The main production centers have five crushers on the Soan River near the Grand Trunk Road bridge, six on terraces at Bhara Kao, and five along the Kurang River below Rawal Lake and above the Baroher Kahuta Road. Potential undesirable effects of stream-channel mining are excessive siltation and degradation of water quality downstream and accelerated erosion of streambeds and banks upstream.

Sand

Of about 1,500 ha leased for sand production as of 1989, 90 percent is along the Soan River and along the Haro River at Usman Khattar, and 10 percent is in the Kotha Kalan and

Morgah areas. Other localities supplying Rawalpindi and Islamabad are south of the area along the Grand Trunk Highway near Gujar Khan (pl. A1 of Warwick, this volume, chap. A). Sand from Lawrencepur, about 50 km to the northwest, is cleaner, coarser, and more angular than the local sand, and it has the quality required for multistory construction. At Lawrencepur, the sand is about 7 m thick beneath 70 cm of loessic silt. Five samples of sand (3–05 to 3–09) collected for this study from Lawrencepur sand pits averaged 94 percent sand, 4 percent silt, and 2 percent gravel. They contain some iron particles and average 0.376 percent organic matter, 0.09 percent total dissolved solids, 0.00084 percent sulfate, and 0.0012 percent sodium chloride. The average apparent specific gravity is 2.77, and average absorption is 0.916 percent.

Brick Clay

The Potwar Clay, used for making bricks, is a thick blanket of wind-deposited dust that has settled and accumulated over thousands of years and now covers most of the gently sloping parts of the Islamabad-Rawalpindi metropolitan area and extensive parts of the Potwar Plateau. It is widely exposed and covers about 30 percent of the total map area. It consists of silt, clay, and sand. Silt and sand predominate at some places, whereas clay predominates at others. Brick kilns are widely spread across the Islamabad-Rawalpindi area wherever the clay content of the Potwar Clay (loessic silt and clay) is sufficient for making bricks (pl. G1). A sample (3–04, pl. G1) taken for this study from an operating clay pit contained 79 percent clay, 20 percent silt, and 1 percent sand, although most Potwar Clay deposits in the Islamabad area probably average about 75 percent silt and 15 percent clay-size particles (Rendell, 1988, p. 392). Kaolinite and illite are the most common clay minerals, but most of the fine particles are quartz. The brick clay sample had 0.2 percent organic material, 0.64 percent total dissolved solids, and 0.114 percent sulfur dioxide content.

Although all of the digging of clay and the molding, stacking, and firing of bricks are done by hand, the number of kilns is so large that production is sufficient for the substantial requirements of the Islamabad-Rawalpindi metropolitan area. About 375 brick kilns (Brick Kilns Association of Rawalpindi, written commun., 1989) are scattered in areas where the loess is especially fine and rich in clay. The localities listed in table G6 produce significant quantities of bricks for Islamabad and Rawalpindi, although some are outside the study area. The number and exact location of brick kilns fluctuate constantly, but concentrations of brick kilns that were observed in the study area are shown on plate G1.

There is no system for regulating or leasing clay pits and brick kilns. Wherever the clay deposits are of sufficient thickness and quality, the owner of the land may dig a pit and construct a brick kiln. Each kiln and the surrounding clay pit occupy about 10,000 square meters (m^2); each operation has an average production life of about 10 years. Bricks are produced in cycles lasting about 3 months. About 300,000 bricks are produced in each run, and about 12 million over the life of the pit.

Table G6. Number of brick kilns operating in major clay-mining areas in or near the Islamabad-Rawalpindi study area.

[Brick Kilns Association of Rawalpindi (written commun., 1989). For locations, see figure G2]

Location	Number of kilns
Chaklala	30
Tarnool[1] (16 km W)	45
Chuhar Misrial	8
Karal	5
Lohi Bher	10
Taxila	100
Tanch Bhata	25
Khanna	8
Chakri[1] (53 km SW)	5
Lehtrar Bala Road	13
Gangal	20
Fatehjang[1] (40 km WSW)	50

[1]Located outside but near the study area. Distances and directions are from the zero-point road intersection in Islamabad (fig. G2).

Generally, two sizes of bricks are manufactured. For walls, the brick size is 22 cm by 11 cm, which weighs about 2.5 kilograms (kg). For ceilings, the brick size is 15 cm by 30 cm, weighing about 3 kg.

In the metropolitan area, about 375,000 m^2 (37.5 ha) of land per year is consumed for the manufacture of bricks (Rawalpindi Industries Department, written commun., 1989). This land is not necessarily lost to other uses because abandoned clay pits may be reclaimed for residential use or for solid-waste disposal followed sequentially by agricultural, forestry, or parkland use.

Brick kilns are fired with subbituminous coal trucked to the Islamabad-Rawalpindi area from near Quetta (fig. G1). Each truck carries about 20 metric tons, and 14–15 trucks are needed for each kiln run of about 275,000 bricks, or about 1 kg of coal per brick (Brick Kilns Association of Rawalpindi, written commun., 1989). About 450,000 metric tons of coal per year is thus burned in the Islamabad-Rawalpindi area for brick production, and the sulfurous smoke emitted by the many primitive kilns surrounding Rawalpindi is an important factor in degrading the quality of air.

References Cited

Adhami, N.Z., Ilyas, M., and Ahmad, M., [1980?], Seismotectonic studies of the Rawalpindi region: Islamabad, National Engineering Services of Pakistan (NESPAK) Limited, Pakistan Atomic Energy Commission, 139 p. (Undated, published about 1980.)

Akhtar, M., and Bhajawa, M. Saleem, in press, Geologic map of 43 G/3 quadrangle: Geological Survey of Pakistan Geologic Map Series, scale 1:50,000.

Akhtar, M., and Bhatti, M. Akram, in press, Geologic map of 43 C/14 quadrangle: Geological Survey of Pakistan Geologic Map Series, scale 1:50,000.

Akhtar, M. Kaleem, Khan, A.A., and Abass, S.Q., in press, Geologic map of 43 G/5 quadrangle: Geological Survey of Pakistan Geologic Map Series, scale 1:50,000.

Ashraf, K.M., and Hanif, Mohammad, 1980, Availability of ground water in selected sectors/areas of Islamabad—Phase I and II: Pakistan Water and Power Development Administration Ground Water Investigation Report 35, 30 p.

Baker, D.M., Lillie, R.J., Yeats, R.S., Johnson, G.D., Yousuf, Mohammad, and Zamin, A.S.H., 1988, Development of the Himalayan frontal thrust zone—Salt Range, Pakistan: Geology, v. 16, no. 1, p. 3–7.

Bhatti, M. Akram, Choudary, T.M., Choudary, R.A., and Pasha, M.K., in press, Geologic map of 43 C/13 quadrangle: Geological Survey of Pakistan Geologic Map Series, scale 1:50,000.

Burbank, D.W., and Beck, R.A., 1991, Rapid, long-term rates of denudation: Geology, v. 19, p. 1169–1172.

Gill, W.D., 1951, The stratigraphy of Siwalik series in the northern Potwar, Punjab, Pakistan: Geological Society of London, Quarterly Journal, pt. 4, v. 10, no. 248, p. 375–394.

Johnson, N.M., Opdyke, N.D., Johnson, G.D., Lindsay, E.H., and Tahirkheli, R.A.K., 1982, Magnetic polarity stratigraphy and ages of Siwalik Group rocks of the Potwar Plateau, Pakistan: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 37, no. 1, p. 17–42.

Johnson, N.M., Stix, John, Tauxe, Lisa, Cervany, P.F., and Tahirkheli, R.A.K., 1985, Paleomagnetic chronology, fluvial processes, and tectonic implications of the Siwalik deposits near Chinji Village, Pakistan: Journal of Geology, v. 93, no. 1, p. 27–40.

Kauser, A.B., in press, Geologic map of 43 G/6 quadrangle: Geological Survey of Pakistan Geologic Map Series, scale 1:50,000.

Khan, K.S.I., Khan, F., and Arsgad, Fayaz, 1987, Description and evaluation of the soil materials along the Margala and Faisal Avenues near the Faisal Mosque, Islamabad: Geological Survey of Pakistan Information Release 319, 22 p.

McDougall, J.W., 1989, Tectonically induced diversion of the Indus River west of the Salt Range, Pakistan: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 71, nos. 3–4, p. 301–307.

Naeem, M.M., and Bhatti, M. Akram, 1985, Geologic map of Islamabad: Geological Survey of Pakistan Geologic Map Series, v. IV, sheet 9, scale 1:50,000.

Pasha, M.K., and Bhatti, M. Akram, in press, Geologic map of 43 G/1 quadrangle: Geological Survey of Pakistan Geologic Map Series, scale 1:50,000.

Pennock, E.S., Lillie, R.J., Zaman, A.S.H., and Yousaf, Mohammad, 1989, Structural interpretation of seismic reflection data from eastern Salt Range and Potwar Plateau, Pakistan: American Association of Petroleum Geologists Bulletin, v. 73, no. 7, p. 841–857.

Raynolds, R.G.H., 1980, The Plio-Pleistocene structural and stratigraphic evolution of the eastern Potwar Plateau, Pakistan: Hanover, New Hampshire, Dartmouth College, Ph.D. dissertation, 264 p.

Rendell, H.M., 1985, The precision of water content estimates in the thermoluminescence dating of loess from northern Pakistan: Nuclear Tracks and Radiation Measurements, v. 10, nos. 4–6, p. 763–768.

Rendell, H.M., 1988, Environmental changes during the Pleistocene in the Potwar Plateau and Peshawar Basin, northern Pakistan: Proceedings of the Indian National Science Academy, ser. A, v. 54, no. 3, p. 390–398.

Survey of Pakistan, 1982, Islamabad/Rawalpindi guide map: scale 1:30,000.

Survey of Pakistan, 1985, [Topographic map of] Islamabad and surroundings: scale 1:50,000.

Williams, V.S., Pasha, M.K., and Sheikh, I.M., 1999, Geologic map of the Islamabad-Rawalpindi area, Punjab, northern Pakistan: U.S. Geological Survey Open-File Report 99–0047, 16 p., 1 oversize sheet, scale 1:50,000.