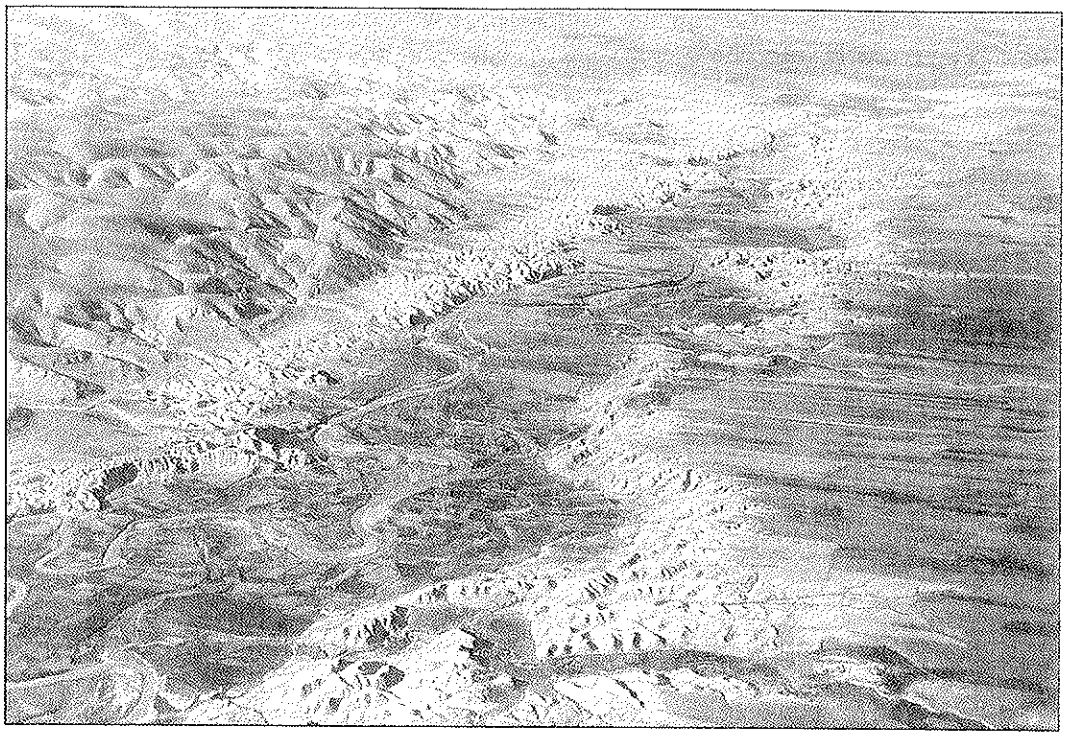


FIGURE 2–5 The Jordan River meandering across its floodplain (*al-Zor*), flowing sluggishly from upper right (from the Sea of Galilee, just out of the picture) to lower left. The higher terrace level is *al-Ghor*.

nantly basement rocks. These ancient crystalline rocks are part of the Nubian Shield, corresponding to the Arabian Shield east of the Red Sea. Unlike the exposed Red Sea Hill rocks, the shield west of the Nile, in the Western Desert, is blanketed with relatively thin sedimentary strata to the south and additional, thicker, younger strata to the north. Along the contact between the two different sets of thicknesses of sedimentary cover, depressions cradle five oases, and the profound Qattara Depression in the north descends 436 ft./133 m below sea level. The significance of these depressions is examined in Chapter 17. The Nile River flows along the separation between the two major deserts, and its great delta lies in a former embayment of the Mediterranean coast.

Central Areas. The same general sedimentary sequence found in the eastern Arabian Peninsula overlies the basement rocks in the Fertile Crescent and Syrian Desert areas in the heart of the Middle East. However, strata in the central area are more level, and large expanses of eastern Jordan, eastern and southern Syria, and western Iraq show level to undulating surfaces of Cretaceous limestones.

Jordan Valley and Related Features. A major geomorphic feature of the western Fertile Crescent is the Levant Rift System, a great trench that extends from the northwestern end of the Red Sea up the Gulf of Aqabah and along the axis of the Wadi al-Arabah, Dead Sea, Jordan Valley, and Bekaa of Lebanon to the Ghab Depression in northwestern Syria (Figs. 2–2 and 2–5). This feature is primarily a transform fault, similar to the San Andreas Fault in California, that resulted chiefly from counterclockwise rota-

tion of the Arabian Plate away from the African Plate.

The system, referred to by various other names—Dead Sea Fault, Jordan–Dead Sea Rift, West Arabian Fault Zone, and others—is a left-lateral fault (showing a leftward shear when viewed across the fault line) that resulted in a total horizontal displacement of 66.5 miles/107 km during two main stages. Thus, the igneous and metamorphic rocks north of Aqabah were formerly adjacent to the center of the east coast of the Sinai Peninsula. The four deeper basins along the fault—the Gulf of Aqabah, Dead Sea, Sea of Galilee, and Huleh Basin—are "pull-apart zones" in which elongated depressions were formed as local grabens. The bottom of the trench is below sea level from well south of the Dead Sea to north of the Sea of Galilee, with the steadily shrinking Dead Sea the lowest body of water on the globe (see "Middle East Lakes" section later in this chapter).

The first of the rift system's three main segments comprises the trench and related features extending from the Gulf of Aqabah north to and including the Huleh Basin. A second segment, the most seismically active of the three, begins at the southern border of Lebanon, where the Levant Rift bends to the northeast. This segment consists of a less profound trench but still constitutes a prominent linear depression through eastern Lebanon, the Bekaa. In the third segment, beginning at the northern border of Lebanon, the fault zone turns north again and finally disappears just beyond the Ghab Depression in northwestern Syria, the northernmost feature of the system (pictured in Fig. 5–4).

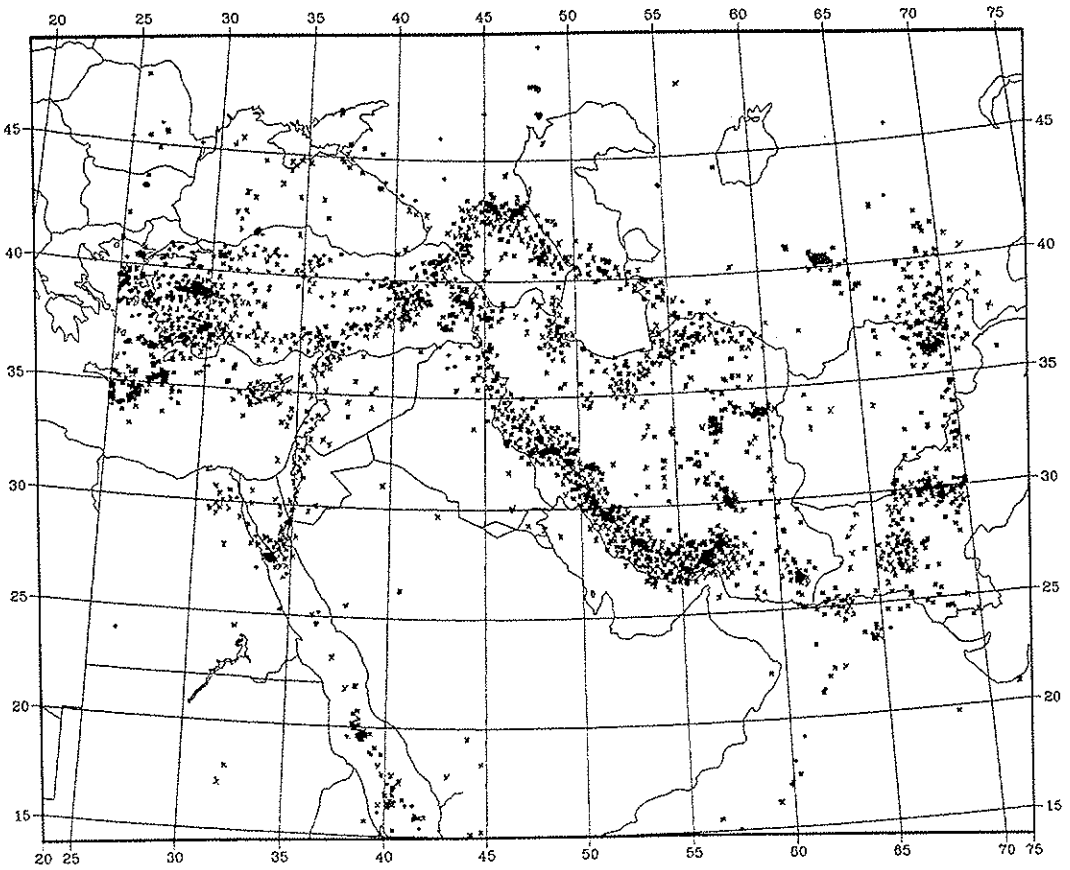
The linear belt between the Mediterranean and the three-segment rift is upwarped along a north-south axis for most of its length and is considered by some geologists to be a sliver subplate related to the African Plate. The highlands formed by the upfolded and faulted structures in the belt include, from south to north, the Judean and Samarian hills, the upper Galilee highlands, Mount Lebanon, and the Jabal al-Nusayriyah (sometimes Jabal al-Ansariyah, but officially Jabal al-Sahiliyah). East of the Bekaa are the Anti-Lebanon Mountains, beyond which extend the prominent splayed ridges of the Palmyra Folds, crumpled up and faulted by the counterclockwise rotation of the Arabian Plate.

Mobile Belt

The Mobile Belt (or Fold Belt) is a continuous band of folded, faulted, and compressed mountains extending from western to eastern Anatolia and then southeastward across Iran and eastward into the Pamirs and Himalayas. This belt, the middle segment of the vast east-west Alpine-Himalayan mountain system, makes Turkey, northeastern Iraq, and Iran structurally extraordinarily complex. Some of the folding and complex structures may be seen in Figure 2–1.

Asia Minor (Anatolia) and Cyprus. South of and generally parallel to the Black Sea coast, the Pontic Mountains (5,000–13,000 ft./1,524–3,962 m) stretch virtually the full length of Turkey. For much of their extent, they lie north of the great North Anatolian Transform Fault (Map 2–2), the eastern end of a 4,000-mile/6,440-km fault zone that begins at the Mid-Atlantic Rift and transits the northern Maghrib. Periodic slippage along this right-lateral fault has produced devastating earthquakes, the most disastrous of which in the Middle East occurred south of Istanbul on August 17, 1999 (see Chap. 18).

Rimming the southern side of Asia Minor are the Taurus Mountains (7,000–9,000 ft./2,135–2,745 m), whose complexity reflects the severity of the compression that formed them. The slightly offset Anti-Taurus Mountains extend eastward to merge with folds that in turn bend southeastward to become the Zagros Mountains. The Anti-Taurus generally parallel the East Anatolian



MAP 2–3 Major Middle East earthquakes, 1966–2004 (magnitude of more than 4.5 and depth less than 31 miles/50 km). Note the concentration of seismicity along the Zagros Fold and Overthrust Belt and in western and eastern Anatolian Turkey. Compare with Map 2–2. Boundaries as shown on NEIC compilation. (Updated from USGS Web site on earlier map by special courtesy of National Earthquake Information Center, U.S. Geological Survey)

Transform Fault, which in turn partially parallels the Southeast Anatolian Suture Zone between the former northern edge of the Arabian Plate and the southeastern edge of the Anatolian subplate (see Map 2–2).

At its southwestern end, the East Anatolian Transform Fault links with both the northern end of the Levant Rift System and the eastern end of the Cyprus Subduction Zone. At its northeastern end, it intersects the North Anatolian Fault. The proximity of these several seismic belts results in frequent and severe earthquakes (Map 2–3), such as the three catastrophic quakes in the Erzincan area in 1938, 1983, and 1992. South of the suture zone is a complex foreland in which moderate Border Folds merge into the Harran Plain along the Turkish-Syrian boundary.

Located in the junction of these several fault zones, the East Anatolian Accretionary Complex is a jumble of mountains and tilted plateaus (Fig. 2–6), where compression at the junction of plates creates severe seismic movements. Volcanic vents have also opened and are now marked by massive volcanoes (Mount Ararat near the Turkish-Iranian border reaches 16,948 ft./5,166 m), crater lakes, cinder cones, and lava flows. Mineralization along these various plate contacts gives

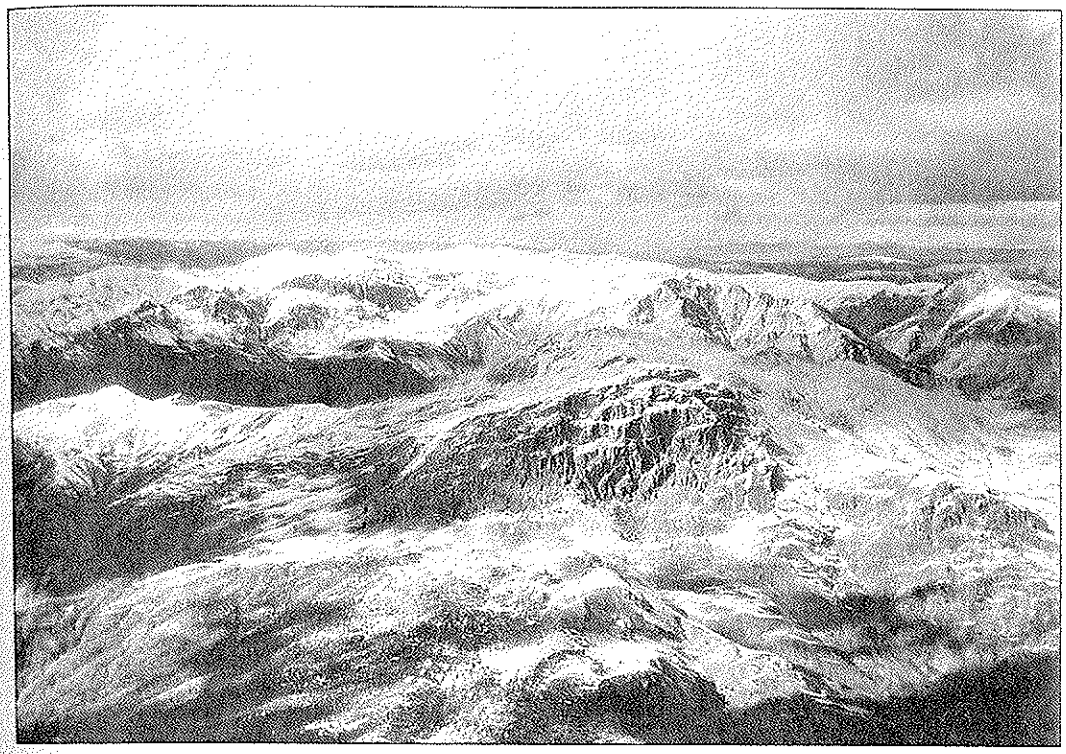


FIGURE 2–6 Eastern Anatolian Mountains west of Lake Van—rugged, snow-covered, cloud-shrouded, and geologically very complex. Heavy precipitation makes this mountain area a major hydrographic center spawning such major rivers as the Tigris and Euphrates.

Turkey more nonfuel mineral wealth than any other country in the Middle East, although Iran is similarly wealthy for the same geological reasons. In between this East Anatolian complex and the western mountains is the exceedingly complex central Anatolian intermontane plateau, with its lowest part an almost flat-floored basin occupied by the shallow Tuz Gölü.

More than 600 miles/965 km to the west, the Aegean coastal zone of extreme western Anatolia is an area of block mountains, alternating uplifted and downdropped masses (horsts and grabens). These structures have produced a series of rugged east-west promontories and deeply indented bays on the Aegean coast, which beckoned Ionian Greeks to settle in the sixth century BCE. In the northwest, a large foundered block flooded to form the Sea of Marmara, which links the Aegean and Black seas through flooded valleys to its southwest and northeast.

About 55 miles/88 km off the Mediterranean coast of Turkey, the island of Cyprus is believed to have been formed as a result of the same plate collision that produced the Taurus range on the mainland. An exposed granitic intrusion forms the core of the Troodos (6,407 ft./1,953 m), the highly mineralized mountain mass of southern Cyprus, whereas a linear limestone reef was uplifted to produce the narrow Kyrenia range (3,360 ft./1,025 m), which parallels the northern coast of the island. The depression between the Troodos and Kyrenia highlands is a sediment-filled basin, the Mesaoria, Cyprus's breadbasket.

Iranian Plateau and Ranges. Complex folding in the Mobile Belt extends farther

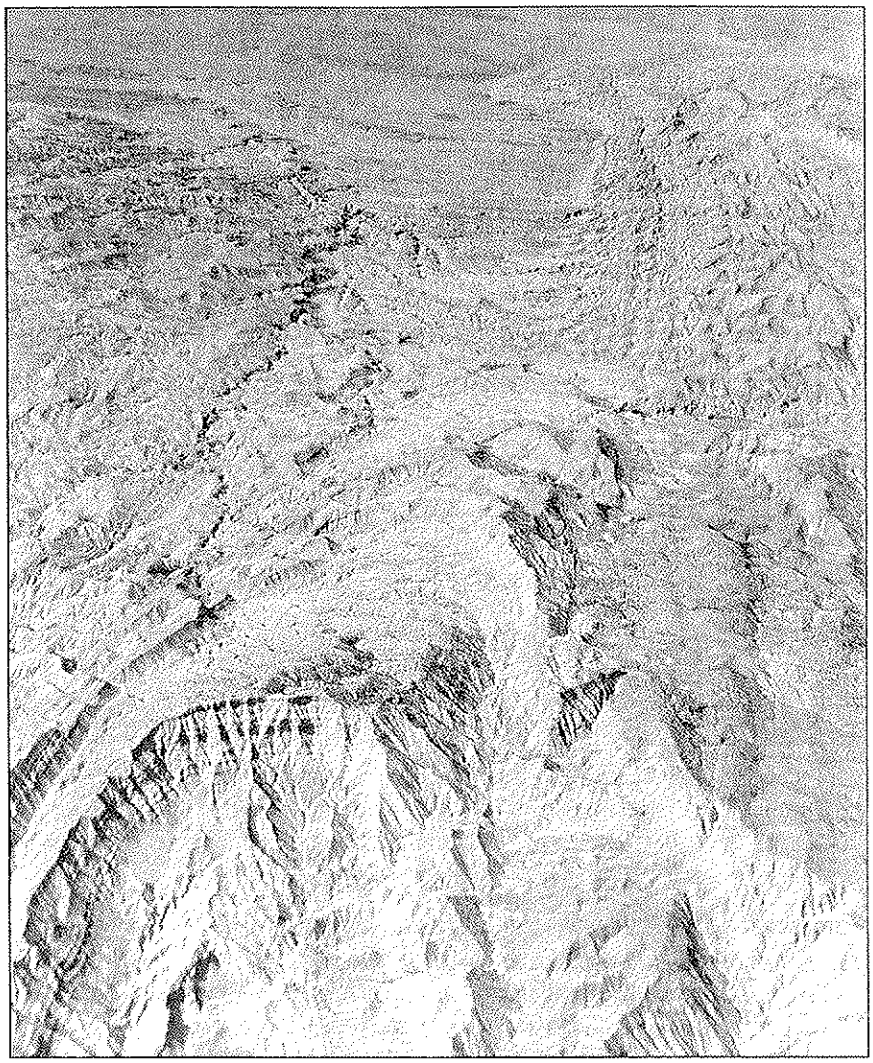


FIGURE 2–7 Denuded pitching anticline in typical structures of the Folded Zagros Mountains of western Iran. In such subsurface folds are found the great petroleum reservoirs of the area. Compare with Figure 8–6, which shows salt domes that also form oil-reservoir structures.

eastward and southeastward from Anatolia into the Iranian mountain and intermontane plateau regions. From the junction of Turkey, Iran, and Iraq to the Arabian Sea, compression and subduction between the Arabian Plate and the Iranian subplate has crumpled, faulted, and thrust-faulted mostly sedimentary rocks along the longest and most prominent fold belt in the Middle East, the Zagros Mountains (10,000–14,000 ft./3,000–4,300 m) (Fig. 2–7: Note caption). In the southern Zagros, scores of salt plugs have been pushed to or near the surface, creating stratigraphic structures that in many instances have entrapped large quantities of petroleum and natural gas. Farther southeast, the Makran range, which lies behind Iran's coast on the Gulf of Oman, is the result of recent uplift of oceanic crust and exhibits forms that are distinctly differ-

ent from the Zagros geomorphology and that are related to the Oman Mountains across the Gulf.

Compressed between the rigid core blocks of Iran and the Russian Platform of the Eurasian Plate, high linear ridges were folded sharply upward across the full extent of northern Iran. The Elburz Mountains south of the Caspian Sea and the series of ridges in the Kopet Mountains along the Iran-Turkmenistan border reach elevations of 12,000–15,000 ft./3,660–4,575 m in the Elburz and somewhat less in the Kopet. As in eastern Turkey, plate collision in the Elburz belt squeezed lava out of volcanic vents, with the towering cone of Mount Damavand (18,600 ft./5,669 m) the highest point in the entire Middle East. Scattered volcanoes—including Iran's only recently active vent—appear along the eastern Iranian border near Afghanistan and Pakistan, and complex fold mountains around the Zahedan Plateau enclose the third side of the triangular Iranian Plateau core. As in central Anatolia, the lowest part of Iran's inner basin contains ephemeral salt lakes (playas), known in Iran as *kavirs*. Compressional highland chains extend still farther eastward into Central Asia, increasing in complexity and elevations to become the globe's mightiest mountain masses—the Hindu Kush, Tien Shan, and Himalayas, with the Pamir Knot tying them together.

Median Trough

The Mesopotamian-Gulf trough, which is technically the northeastern edge of the Stable Interior Province, lies along the median axis between the Arabian Plate and the Iranian subplate and is one of the most conspicuous geomorphic features of the Middle East. It is also the world's greatest petroleum province, a zone of downbuckling and subsidence on the flanks of the Arabian Shield. The northwestern half of the trough, the Mesopotamian Basin, is above sea level and has two subdivisions: a low plateau northwest of Baghdad and an alluvial-deltaic plain from Baghdad to the Gulf. The southeastern half of the structural trough is drowned by the shallow waters of the Gulf, the sea invading from the Indian Ocean through the Strait of Hormuz. One of the world's most strategic chokepoints, the strait is thus as significant physically as it is economically and strategically. The Gulf and its littorals will be discussed in detail in various later sections and chapters.

MIDDLE EAST WATERS

Seas and Gulfs

Even after the sea basins of the main water bodies of the Middle East reached their approximate present contours, major modifications occurred in response to slight crustal adjustments and climatic variations. Especially during the Pleistocene glacial period, the sea fell to more than 395 ft./120 m below its current level during periods of ice advance, when millions of cubic meters of ocean water were frozen into sheets. During those same periods of glacial maxima, the Middle East enjoyed pluvial periods, when precipitation increased appreciably. The increased rainfall charged the regional aquifers and induced environmental conditions more favorable for human cultural development during the long Paleolithic period. Eustatic (sea-level) changes during glacial retreats, when the melting of the ice sheets freed water that had been previously locked in the glaciers, brought seas 180–195 ft./55–60 m higher than at present, giving a total differential of more than 590 ft./180 m over the 1.3 million years of the glacial Pleistocene.

The great drop in sea level during glacial maxima left the straits of the region as dry sills between basins—the Strait of Gibraltar, connecting the Mediterranean and the Atlantic; the Bosporus and Dardanelles,

connecting the Mediterranean and the Black Sea; and the Strait of Hormuz, connecting the Gulf and the Indian Ocean. With their main water supplies cut off, the basins of the three inland seas became extensive deep desert basins, large-scale versions of today's Death Valley in California. Some of the salt deposited in these basins during periods of evaporation still affects the chemical composition of rocks, water, and soil in the region. As the interglacial thaw induced a rise in sea level, the mounting water crested the dried-up straits and roared into the empty basins in thunderous cascades, gradually refilling the huge depressions to their former, and approximately present, configurations.

Red Sea and Gulf of Aden. The Red Sea occupies an elongated, escarpment-bounded depression 1,220 miles/1,965 km long and 155–280 miles/250–450 km wide. Tectonically, it is a northward extension of the great African Continental Rift that has its southern origin in Mozambique and that in turn extends northward through the Levant Rift to Turkey. As was mentioned earlier, rifting opened the Red Sea in two phases several million years ago, and it is still continuing along the sea's entire length. South of 21° N Lat, a narrow inner axial trough within the sea's main trough is about 6,500 ft./2,000 m deep, formed by seafloor spreading processes during the past 4 million years. North of 25°, the inner axial trough is lacking, and the floor has an irregular, faulted surface. Between the shores and the center axis, a narrow continental shelf extends all along both coasts.

Seafloor spreading, especially in the central Red Sea, conveys molten lava into the bottom of the trench. The lava heats the seawater above it and stimulates the formation of hot brines and the development of a sludge with high concentrations of zinc, copper, silver, gold, and other metals. Facing each other across these deeps, Saudi Arabia and Sudan formed a Red Sea Commission in 1975 to consider exploitation of the metals. The sludge is not a commercially feasible source at present, but it may well be a major source for the metals in the future.

Rifting along both branches of the Red Sea at the northern end, along the Gulf of Aqabah east of the Sinai Peninsula and the Gulf of Suez west of the peninsula (Fig. 2–2), is of two different types and ages. With great depths, exceeding 5,900 ft./1,800 m, the Gulf of Aqabah is a pull-apart zone associated with the Levant Rift and is morphogenetically related to the Dead Sea, the Sea of Galilee, and the Huleh Basin. Much shallower, only about 150 ft./45 m, and a much older structure, the Gulf of Suez split from the Red Sea Hills to the west and subsided over a long period.

At the southern end of the Red Sea, the Gulf of Aden opened by seafloor spreading along a rift at right angles to the Red Sea, and it has proceeded further to become an example of a young ocean basin. It exhibits well-defined continental margins, small ocean basins, an oceanic crust floor, an active mid-ocean ridge (Sheba Ridge), and a spreading center characterized by a rift valley and transverse fracture zones. This triple junction of the rifts (see Map 2–2) creates a magnificent laboratory for observing the mechanics and processes of active seafloor spreading, especially in and around Djibouti.

Persian/Arabian Gulf. Lying in a tectonically downfolded basin of Late Pliocene to Pleistocene age, the shallow Gulf (Arabic: *al-Khalij*) is a marginal sea that exhibits striking contrasts with the Red Sea and the Gulf of Aden. It covers approximately 87,000 miles²/226,000 km² and is about 620 miles/1,000 km long and 125–185 miles/201–300 km wide. Although it reaches depths of more than 330 ft./100 m near the Strait of Hormuz, its average depth is only 115 ft./35 m. Since the floor slope and depth are greater on the

Iranian side, the basin has a marked bathymetric asymmetry across its axis, reflecting the downfolding between the Arabian Plate and Iranian subplate. Because the Gulf's elongated axis defines this separation between two different geomorphic provinces, the opposite coasts, Arabia to the west and Iran to the east, reflect the contrasting structures. The low surface of the eastern half of the stable Arabian Shelf is a generally level coastal area that slopes gently under the shallow Gulf waters and is fringed with offshore sand islands and sand spits. One such sand spit is Ras Tanura, the location of three large oil installations on the Saudi coast.

To the east of the anticlinal Qatar Peninsula is a broad, shallow area 33–66 ft./10–20 m deep studded with numerous shoals and salt-dome islands, around which huge petroleum accumulations are exploited. Formerly the world's greatest natural-pearl fishing area, the Great Pearl Bank Barrier extends eastward across this embayment. The concave southern coast of the Gulf is typified by low, evaporitic, supratidal flats (*sabkhahs*), some of which, along the coast of the United Arab Emirates, are more than 6 miles/10 km wide. On the east, in contrast, the Iranian coast rises steeply and quickly merges with the folded ridges of the Zagros Foreland.

The Gulf shows a wide variation in temperature and salinity because of its considerable supply of fresh water, shallowness, and limited connection with the ocean. In summer, the surface waters are warm and evaporation is high. Even in winter, water temperature is about 68°F/20°C. Salinity varies from 7 percent (twice that of average seawater) in protected Arabian lagoons to less than 3.7 percent near the Strait of Hormuz. The major freshwater influx into the Gulf is that of the Shatt al-Arab (the combined Tigris and Euphrates rivers), but water also enters from the Karun River in Iran and from short streams descending the western ridges of the Zagros Foreland. Tidal ranges in the western Gulf are moderate, with average maximums of about 8 ft./2.5 m. When the sea level fell during the later Pleistocene glaciation and the Gulf evaporated, the Tigris-Euphrates river system extended eastward, flowed across the dry basin, and emptied into the Arabian Sea through the Strait of Hormuz. About 18,000 years ago, when sea levels again rose from meltwaters from ice sheets warmed by rising temperatures, seawater poured back into the basin, and the present level was reached about 5,000 years ago.

With more than a score of major oil-export terminals in operation in the Gulf virtually around the clock, and with forty to fifty large tankers sailing up or down the Gulf daily, pollution of the waters and beaches has long been a grave concern around the littoral. Despite government monitoring and caveat, and despite appreciable care taken by oil companies and shippers, as many as a quarter of a million barrels of oil pollute the Gulf annually. The rapidly growing population around the littoral discards many tons of waste into the water daily. However, a pollution crisis occurred in January 1991, when Iraqi forces retreating from Kuwait engaged in ecoterrorism by dumping several million barrels of crude oil (the amount can only be estimated) into the Gulf off the coast of the amirate. This largest oil spill in history spread south to the Qatar coast within sixty days, killing countless fish, shrimp, crabs, and birds, as well as fouling sea-grass beds and beaches and posing a threat to desalination plant intakes. Although reasonable revival took place in less time than was initially forecast, the crisis was a global wake-up call to the potential catastrophe posed by current oil technology.

Mediterranean Sea. Of complex origin, the Mediterranean is partially a western

remnant of the pre-Miocene Tethys Sea and partially a collapsed structure along the collision zone between the African and Eurasian plates. Since its re-creation with the most recent melting of the Pleistocene ice, it has been virtually enclosed (its name means "sea in the middle of the land"), connecting with the global oceans only through the narrow Strait of Gibraltar. An artificial link with the Red Sea opened with construction of the Suez Canal in 1869. The Mediterranean's greatest depth (15,072 ft./4,594 m) is west of Crete, and a basin off the Levant coast is 4,787 ft./1,459 m. Except in the southeast, where Nile sediments are borne seaward and then eastward and northeastward by currents, most Mediterranean coasts descend sharply under the fringing waters. Few ports, therefore, face major dredging problems, unlike virtually all Gulf ports.

The extensive, deep Mediterranean waters exercise profound effects on the climate of much of the Middle East and North Africa, with the elongated basin serving as a conduit for weather-maker low pressure systems. The sea has carried ships of many nations for thousands of years. Such maritime activity has linked North Africa with Europe and the Levant and has encouraged a variety of interrelations among Mediterranean littoral peoples, producing a "Mediterranean" subrace, diet, agriculture, music, and history. Fishing in this virtually inland sea has supplied a crucial element in the diet of the littoral peoples for millennia.

Black Sea. Occupying a deeply foundered subplate, the Black Sea is of major importance to the littoral states that fringe its coasts. Relatively shallow near the Danube Delta in the northwest, the Black Sea depth exceeds 7,000 ft./2,135 m across much of its southern extent. The northern slopes of Turkey's Pontic Mountains plunge steeply into the Black Sea, giving deep water access to Turkey's many northern ports. Receiving a plentiful freshwater inflow from rivers in the north and several smaller rivers in the south, the Black Sea is only moderately salty. Virtually tideless, it overflows freely through the Bosporus into the Sea of Marmara and thence through the Dardanelles into the Aegean. The Black Sea is also known as the Euxine Sea, the ancient Pontus Euxinus. Commonality of certain interests has led the six Black Sea littoral states to concert their planning and actions—for example, in tackling the increasingly serious problem of the basin's pollution. Pollution and other issues have demanded growing attention since the Black Sea, like the Caspian, has become a major factor in the burgeoning oil industry of the region.

Caspian Sea. Unlike the other "seas," the inland Caspian has no outlet, and its surface averages about 92 ft./28 m below sea level. The Caspian bottom has two basins divided by a high sill east of the Baku Peninsula. Its floor built up by Volga sediments, the shallower of the basins lies at the northern end and eastern side; the greatest depth is in the southwestern quadrant, 3,363 ft./1,025 m. With most of the fluviatile inflow coming from the Volga at the northern end, the level of the Caspian slowly dropped until the late 1970s as the Russians increasingly utilized Volga water for irrigation. The trend reversed in 1977, and by 1995 the Caspian had risen by 8 ft./2.4 m before slowly receding. A railroad ferry crosses from Baku to Türkmenbashy, and other freight and passenger ships utilize the sea; however, most vessels on the Caspian are fishing boats seeking especially the famous Caspian sturgeon, source of the valuable Russian and Iranian caviar.

As in the Persian/Arabian Gulf area, the tectonics of the Caspian Basin created structures favorable for huge accumulations of petroleum and natural gas both around and under the sea. Indeed, some of the world's earliest major oil production came