

# Chapter 2

## Geography and Geology of the United Arab Emirates: A Naturalist's Introduction



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### 2.1 Introduction

The natural history of the United Arab Emirates (UAE) can be envisioned as a stage drama in which all the plants and animals, even human beings and their different cultures through time, play their parts and live out their lives (Fig. 2.1). Viewed this way, geography and geology are literally the stage sets for the drama of life. They are the physical background where all the different action takes place.

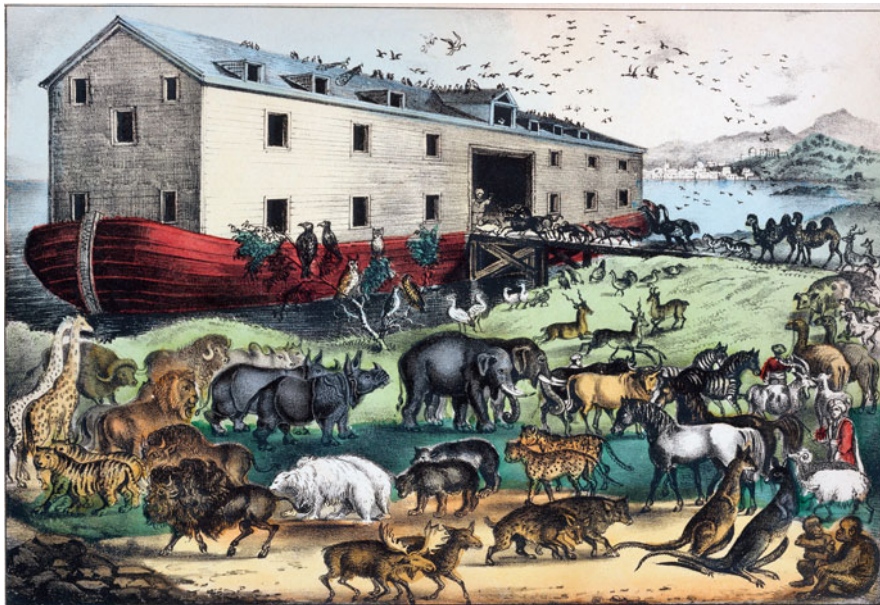
This chapter will introduce the landscapes of the UAE and its many 'stage sets' from a naturalist's perspective. Although the UAE is not a large country, it has many physical environments that are unusual on a global scale, yet at the same time relatively accessible and relatively safe to explore. An added bonus is that the flora and fauna and other phenomena of many of those environments remain to be fully explored, so there are still new discoveries to be made.

The geography of a particular location comprises the different landforms that we can see there and the physical qualities and characteristics that are associated with them, including global geographical position (latitude and longitude), elevation, surface composition (rock, soil, sand, marsh, etc.), slope, surface roughness, hydrology (plumbing) and proximity to major water bodies, as well as climatic factors such as temperature, rainfall, humidity, wind regime and seasonality (discussed in the next paper, Chap. 3). Vegetation cover, height and density are also part of the description of the geography of a place (Fig. 2.2).

One difference between stage sets and the real world is that real world environments typically change continuously through time, sometimes gradually and other times very rapidly. The history of those changes can be read and understood by studying and interpreting the geological and geographical features we see today. The prevailing plant and animal life of a place inevitably changes as the environment

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**Fig. 2.1** “Noah’s Ark”. Hand-colored lithograph by Currier & Ives, 1868–1878. The original is held at The Metropolitan Museum of Art in New York and is reproduced here by courtesy of the Met’s [Open Access](#) policy, modified to remove border

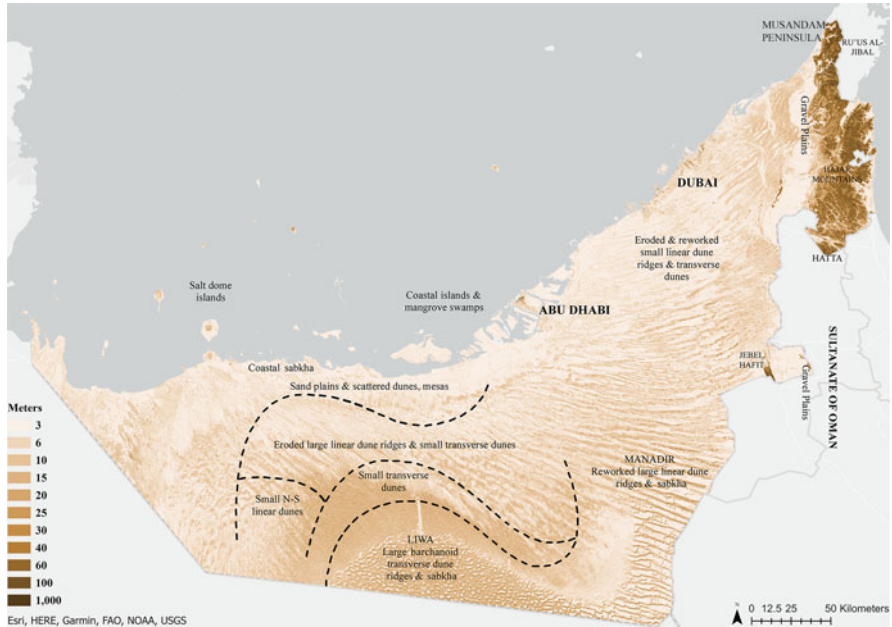
changes, but biological systems often take more time to change, so the geological and geographical history of a place, especially the recent history, can impose limits on current and even future possibilities for the local biosphere.

## 2.2 The Principal Geographical Units of the UAE

The UAE today features four principal geographical divisions (Fig. 2.3):

- (a) the Coastal Plains of the Arabian Gulf and the Gulf of Oman.
- (b) the Sand Deserts of the west, south and central UAE.
- (c) the Mountain Regions of the eastern UAE.
- (d) the Alluvial Plains that flank the mountain regions on the east and west.

These four basic units and some of their most distinctive sub-units are described and discussed below. In general, they correspond to the units that will be discussed from an ecosystem point of view in Chaps. 5, 6 and 13.



**Fig. 2.2** A topographic map of the UAE, annotated to show the variety of UAE landforms. Topographic data from ESRI, created in ArcGIS. Annotations modified from Glennie 1991 and reused with permission

### 2.2.1 *The Coastal Plains*

The coastal plain constitutes the more or less flat topography that, along UAE coastlines, extends inland from the low tide line for up to several kilometers before encountering terrain of more substantial relief, usually sand dunes or, along the East Coast, mountain ridges or foothills.

Prior to modern development, the flat coastal plain along the Arabian Gulf was essentially unbroken between Sha'am in northern Ras Al Khaimah and the Sila'a peninsula at the Saudi Arabian border, except for coastal hills at a few remote places such as Ras Al Aysh and the Shuwaihat peninsula in the west of Abu Dhabi emirate. But the nature of the coastal plain was (and is) far from uniform. Although much of the former coastline has been highly modified, the Coastal Plain still includes all of the following:

- (a) White sand beaches, especially in the area from Ras Al Khaimah to Taweelah (Abu Dhabi) (Fig. 2.4).
- (b) Coastal sabkha, or salt flats, especially along the Arabian Gulf coast west of Abu Dhabi Island, where they are reckoned to be the world's finest examples of this geologically significant environment (Fig. 2.5).



**Fig. 2.3** The four principal geographical divisions of the UAE, which correspond to the four principal terrestrial environments/ecosystems. Image credit: Gary Brown

- (c) Sheltered coastal lagoons (Arabic: *khors*), many of them so shallow that they empty almost entirely at lowest tides, exposing vast mudflats and a rich diversity of associated intertidal marine life, including food resources relied on by hunter-gatherer ancestors (see Chap. 8) (Figs 2.6 and 2.7).
- (d) Mangrove forests, monospecific stands of the local mangrove *Avicennia marina* occupying the intertidal zone, sometimes tall and dense, representing the only true “forests” in the country, most of them associated with coastal lagoons or channels representing the outlets of former terrestrial watercourses debouching to the sea (see Chap. 8) (Fig. 2.8).
- (e) Salt marsh, stands of dwarf shrubs, sedges and grasses occupying the uppermost intertidal zone, typically on the margins of coastal lagoons where freshwater input is localized.
- (f) Remnant outcrops of eroded coastal dunes and shallow marine sediments, mostly Pleistocene and Holocene (Recent) in age, reflecting a long history of repeated emptying and filling of the Arabian Gulf due to ‘Ice Age’ changes in sea level; also more substantial mesas of older, mostly Miocene sedimentary rocks, as at Ras Al Aysh and the Sila’a Peninsula (Fig. 2.9).
- (g) Rocky headlands/cliffs, on the UAE’s East Coast, where salient ridges or foothills of the Hajar Mountains extend to the sea and form headlands at the



**Fig. 2.4** A white sand beach near Saih Shuaib, Dubai, near the Abu Dhabi border. In the distance is a massive artificial headland, built to accommodate planned development. Photo credit: Gary Feulner

water's edge, as at Khor Fakkan, Sharm or Dadnah. In these locations the coastal plain is absent and the beaches adjacent to them may be littered with eroded and wave-tumbled rocks (see Chap. 4) (Fig. 2.10).

Several of the foregoing geographical/ecological units are discussed independently in later chapters of this volume.

## **2.2.2 The Sand Deserts**

### **2.2.2.1 The Sand and its Sources**

The majority of the UAE is covered by sand (technically, rock or mineral particles having dimensions from ca. 0.06 to 2.00 mm) (Fig. 2.3), but the land surface is nevertheless far from uniform. Putting aside smaller-scale local variations, at least three broad trends are evident.

First, the highest dunes and dune ridges are found in the south of Abu Dhabi, and they become smaller towards the Arabian Gulf coast (Figs. 2.11 and 2.12). In the



**Fig. 2.5** Coastal sabkha in the far west of Abu Dhabi emirate. Photo credit: Gary Feulner

south, the sands of the UAE are continuous with the Rub' Al Khali, the famous Empty Quarter, which brings to mind the names of explorers like Bertram Thomas, St. John Philby and Wilfred Thesiger.

Second, the color of the sands changes from reddish inland to white near the coast, primarily as a result of changing mineral composition. Most of the sand in the interior was transported from the northwest, and derives from erosion of the rocks found in the mountains and plateaux of western and central Saudi Arabia, as they have been raised and exposed by the rifting of the Red Sea (Glennie 2001). That sand consists predominantly of quartz ( $\text{SiO}_4$ ) grains and the red color results from trace amounts of iron that has been oxidized to hematite ( $\text{Fe}_2\text{O}_3$ ) (Fig. 2.13). Locally, erosion of outcrops of nearby rocks may contribute to the neighboring sands. Adjacent to the inland Sabkha Matti in western Abu Dhabi, the surface sand occasionally features conglomerates representing paleo-rivers that once traversed the area, probably 5–10 million years ago.

Nearer the Arabian Gulf, today's sands are primarily white calcium carbonate ( $\text{CaCO}_3$ ) grains derived both directly from the broken and weathered shells of marine organisms and from carbonate sediments deposited in the shallow Gulf, many of which incorporate substantial amounts of weathered shell material



**Fig. 2.6** Intertidal mud flats in Umm Al Qaiwain. The hundreds of thousands of dark spots on the mud are intertidal gastropod molluscs, mostly the mudcreeper *Cerithidea cingulata*. The water-filled holes in the foreground are feeding rings left by flamingoes, who can be seen in the distance. Photo credit: Gary Feulner

(Fig. 2.14). These carbonate sand grains are often somewhat flattened or irregular compared to the more equidimensional quartz grains of the interior sands.

Third, in the northeast of the country, where the sands generally meet the alluvial gravel plains bordering the mountains, the dunes are engaged in a ballet of advance and retreat, choreographed by climate and danced in partnership with floodwater runoff and alluvium. In this area the dunes have mostly advanced over the past 6000 years, following deterioration of a previously somewhat wetter climate (Parker 2009; Parker et al. 2004, 2016) (Fig. 2.15) (read more on recent climate change in the UAE in Chap. 3).

#### 2.2.2.2 Rainfall and Temperature

Climatically, the UAE today is very hot and very dry. Basic details are presented here for convenience, but for a more complete understanding the reader should



**Fig. 2.7** An aerial view of Khor Hulaylah, Ras Al Khaimah, north of Al Rams and seaward of Dhayah, viewed from Sal Dhayah at ca. 500 m elevation. This photo was taken in the mid-1990s before construction of free zone infrastructure and residential housing. Photo credit: Gary Feulner

consult Chap. 3. Mean annual rainfall shows a clear geographical gradient, decreasing to the southwest and away from the mountain areas (UAE University 1993). Annual rainfall for most of the south and west of Abu Dhabi is almost invariably less than 40 mm, classifying those areas securely as hyper-arid (Kwarteng et al. 2009). Moreover, rainfall in the sand deserts is notoriously unpredictable and often highly localized. Mean annual rainfall rises to 80–100 mm for much of Dubai emirate and 100–150 mm for the sand desert areas of the northern emirates. Annual variation can be substantial, however, and may be periodic (Feulner 2006).

Mean maximum summer temperature (June, July and August) exceeds 40°C everywhere throughout the sand deserts of the UAE, from Ras Al-Khaimah to the Western Region of Abu Dhabi. Mean minimum winter temperature for all but the coastal margin is below 13°C. Extremes generally increase in a southwesterly direction from Ras Al-Khaimah to the Western Region of Abu Dhabi. Diurnal temperature variation is especially high in sand desert areas; in early summer (June) the diurnal change can reach nearly 25°C in western Abu Dhabi emirate (Bu Hasa), further emphasizing the extreme climate of the desert interior of the country. The past 30 years have been slightly but steadily hotter, with the average temperature rising 0.75°C since 1990, a trend which is expected to continue (Hill 2021). The past 20 years and more have also been markedly drier. The UAE's climate regime and recent changes in temperature and precipitation are described in more detail in Chap. 3.





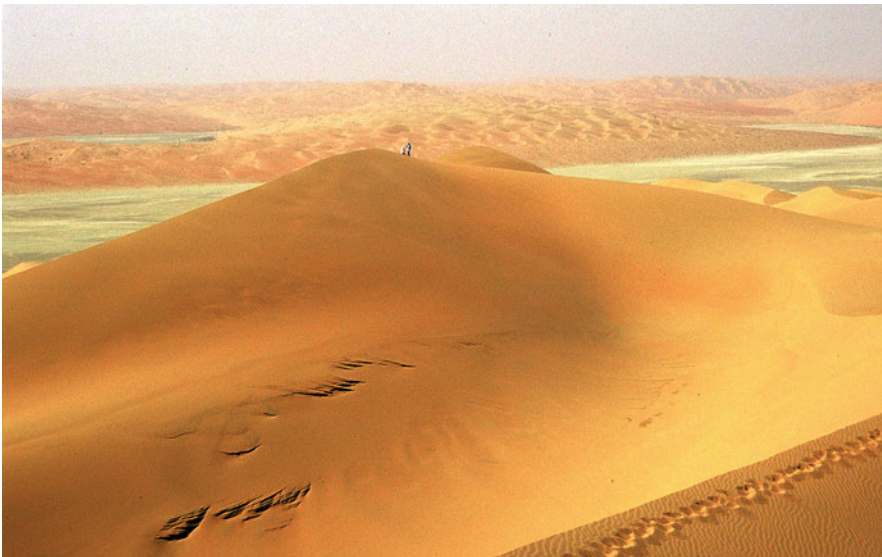
**Fig. 2.8** A peaceful creek within the mangrove forest at Khor Zowra, Ajman, in the early 2000s. The mangrove trees (*Avicennia marina*) are fully exposed by a spring low tide. Photo credit: Gary Feulner



**Fig. 2.9** Eroded recent coastal sediments, inland from Jebel Ali, Dubai. The column consists of 'fossil' dune sands capped by resistant shallow-water marine limestone. Photo credit: Gary Feulner



**Fig. 2.10** A rocky headland on the East Coast, north of Sharm and south of Snoopy Rock, an offshore landmark. Photo credit: Gary Feulner



**Fig. 2.11** In the south of Abu Dhabi, on the edge of the Empty Quarter, huge dune ridges are interspersed with sabkha flats (salt pans). This photo was taken in the eastern half of the Liwa crescent, looking southwest. Photo credit: Gary Feulner



**Fig. 2.12** A small herd of camels crosses a sand-swept salt pan in the Manadir area, east of Liwa. Photo credit: Gary Feulner

These rainfall and temperature conditions, and the southwest to northeast gradient, are reflected in the vegetation of the UAE's sand desert areas, as described in Chap. 5. Nevertheless, temperature and rainfall alone do not tell the entire story of the desert's ability to support life. Humidity can also play a significant role. Relative humidity decreases inland, away from the UAE coasts, and is low in the interior, enhancing the effect of higher temperatures on evapotranspiration (water loss) by plants. But seasonally, especially in late autumn and winter, and occasionally at other times, fog forms even in the interior deserts (Fig. 2.16), and the fog can be so dense that it condenses on the sand surface and on plants, which literally drip with dew, supplying moisture equivalent to a gentle rain (Fig. 2.17). Moreover, if the water which reaches the sand surface is able to percolate to 1.5 to 2.0 m beneath it, it is effectively protected from evaporation and can continue its gravity driven descent until it reaches stable sands at the base of large dune ridges, where established vegetation with sufficient root depth can make use of it (Fig. 2.18). Heavy rain can have an even more dramatic effect (Fig. 2.19).



**Fig. 2.13** Even small dune ripples sort (and re-sort) the sand grains by size and composition. Photo credit: Gary Feulner



**Fig. 2.14** Close-up of white carbonate sand from a Dubai beach. Most of it consists of material derived from the shells of marine invertebrates. The individual grains are often flattened or irregular rather than equidimensional. Photo credit: Gary Feulner



**Fig. 2.15** In the northeast of the country, where the sands meet the alluvial plains bordering the mountains, the dunes advance and retreat in response to climate, mediated in part by floodwater runoff and alluvium. The dunes in this area are reckoned to be no more than about 6000 years old. They commenced their current advance at the end of the Climatic Optimum, a relatively humid interval of about 5000 years. This photo looks northeast; the mid-ground shows the bed of Wadi Faya and in the distance is the foreland ridge of Jebel Faya. Photo credit: Gary Feulner



**Fig. 2.16** Humidity can make a significant contribution to the water budget of sand desert shrubs. Fog sometimes forms, seasonally and occasionally, and condenses as dew, which drips from plants. Shown here is a winter morning in the desert of the Manadir area to the east of the Liwa crescent. Photo credit: Gary Feulner

**Fig. 2.17** Dew dripping from a *Calligonum* shrub on a foggy winter morning in central Liwa in the early 1990s. Photo credit: Gary Feulner



### 2.2.2.3 Regional Variations in the UAE's Sand Desert Landscapes

Huge dune ridges and intervening sabkha flats (salt pans) characterize the south of Abu Dhabi, from the Liwa crescent in the center, where the dunes are arrayed in a pattern of sinuous parallel ridges, each half a wavelength out of phase from the next (Fig. 2.20), to the Manadir area in the southeast, where the dune ridges and pans are elongated in a compass direction of about 110 degrees (Glennie 1991, 1996; Feulner 2005) (Figs. 2.21 and 2.2). Although these areas are ca. 100–150 km inland and although the dune ridges reach ca. 150 m above the adjacent pans (Glennie 2001), the base level of the flats is only ca. 80–90 m above sea level and the areas as a whole are actually slightly lower than the more continuous rolling sands to the north. Moreover, the water table in these areas is less than a few meters below the sabkha surface (Fig. 2.22). The rolling sands of the intermediate desert areas give way seaward to sand plains, which in most places merge gradually into the sand and gravel plains of the Arabian Gulf coast (Figs. 2.23 and 2.24). At that junction, on the



**Fig. 2.18** Vegetation in the deserts in the south of Abu Dhabi is often concentrated on stable sand pediments at the base of steep dune slopes, where it is nourished by rainwater that percolates down through the high dunes. Photo credit: Gary Feulner



**Fig. 2.19** Rare rainfall in the sand deserts can sometimes be heavy. Playa lakes may persist for weeks or months. Seen here are the sabkha flats at Qaraytisah. Photo credit: Gary Feulner



**Fig. 2.20** Within the Liwa crescent, sinuous parallel dune ridges isolate discrete sabkha pans among them. Photo credit: Gary Feulner

gravel plains, fields of individual, mobile barchan (crescent) dunes can be seen in a number of places in the Western Region of Abu Dhabi (Fig. 2.25).

In the east and northeast of the country, the sands are occasionally graced by groves of the ghaf tree *Prosopis cineraria*, sometimes localized on small dunes which the trees themselves may have helped to create, and other times on flats at the base of higher dune ridges, perhaps coincident with remnant water channels in the subsurface (Fig. 2.26). Still further to the northeast, the sands are occasionally punctuated by rocky outcrops of sedimentary ridges raised up by tectonic movements in the foreland of the main mountain front, but at a distance of 15–25 km (Fig. 2.27). Those ridges have been confirmed as the loci of distinctive floral associations (see Chap. 6 and Sect. 2.2.3.3 below).

### 2.2.3 *The Mountain Regions*

The mountains of the UAE are part of the chain of mountains that extends parallel to the Gulf of Oman coast for more than 600 km from the tip of the Musandam





**Fig. 2.21** In the Manadir area in the southeast of Abu Dhabi, the dune ridges and sabkha pans are elongated in a compass direction of about 110 degrees. The sabkha surface is always “puffy” due to the hygroscopic nature of the saline sediment. Photo credit: Gary Feulner



**Fig. 2.22** On inland sabkha flats the water table is no more than a few meters below the surface. Photo credit: Gary Feulner



**Fig. 2.23** A track on sand flats in the western desert of Abu Dhabi, dominated by profuse growth of *Zygophyllum*. This photo was taken south of Umm Al ‘Ashtan in the wet years of the mid-1990s. Photo credit: Gary Feulner

peninsula almost to Ras Al Hadd in Oman, at the southeastern tip of Arabia. These have been called, variously, the Oman Mountains, the Hajar Mountains, and the Oman/UAE mountains. In the UAE, the mountain environment occupies most of Fujairah emirate, much of Ras Al Khaimah, parts of Sharjah, and the Dubai and Ajman enclaves of Hatta and Masfut, respectively.

The mountain areas of the UAE are cooler and wetter overall than the coastal and desert areas to the west (UAE University 1993; Feulner 2011); see also Chaps. 3 and 6. Temperature decreases with elevation and the UAE mountains, like mountains everywhere, induce so-called orographic rainfall by causing passing air to rise and cool, condensing whatever water vapor it carries (Fig. 2.28). In addition, the UAE’s mountains receive life-sustaining moisture from two weather systems—the northwesterly winds of the temperate zone and, less frequently but significantly, southeasterly winds from the tropical Indian Ocean. Annual rainfall over the UAE’s mountain areas is extremely variable but the long-term average is in the range of 160–190 mm per year (UAE University 1993; Feulner 2011), so the mountain climate is classified as arid, but not hyper-arid like most of the rest of the UAE.



**Fig. 2.24** This sand plain in the western desert of Abu Dhabi is relatively flat, firm and deflated by wind. It is colonized almost exclusively by the perennial sedge *Cyperus conglomeratus*. The photo is another taken in the wet years of the mid-1990s. Photo credit: Gary Feulner



**Fig. 2.25** In the Western Region of Abu Dhabi, fields of individual barchan dunes can be found at the geographical boundary where the deflated coastal plain grades inland to sand desert. Photo credit: Gary Feulner

The UAE's mountain areas are much more physically variegated than its desert areas in terms of surface attributes, so they feature a greater diversity of microhabitats. The mountain areas of the UAE constitute only about 5% of its surface area, but the combination of more moderate temperatures, higher rainfall, range of elevations, and diversity of microhabitats gives the mountain areas a disproportionate amount of the country's biodiversity. Approximately 60% of the UAE's native terrestrial plant



**Fig. 2.26** In the east and northeast of the UAE, the sand deserts are occasionally punctuated by groves of ghaf trees *Prosopis cineraria*. Shown here is Wadi Qarhah in the greater Sweihan area in the Eastern Region of Abu Dhabi. Photo credit: Gary Feulner

species are found in mountain areas and many are found only there (see Chap. 6). A similar relationship is estimated for UAE fauna (see, e.g., van Harten 2008, 2009, 2010, 2011, 2014, 2017 Judas 2015).

As a foundation for discussion of the natural history of the UAE, it is advantageous to recognize two main ranges within the mountain areas, which have very different geographical, geological and ecological characteristics, the Hajar Mountains and the Ru'us Al Jibal (see also Chap. 6).

### 2.2.3.1 The Hajar Mountains

The Hajar Mountains stretch southwards from Dibba along the Gulf of Oman coast, through Khor Fakkan and Fujairah to the Oman border (Fig. 2.29). These are the mountains that one crosses en route to or from the east coast. On their west flank they extend, in the UAE, from Tawiyah to the Hatta Road. The mountains do not end at the international border, however; the same range continues unbroken for another 200 km into Oman (where it is called the Western Hajar) until it meets the Jebel Akhdar range west of Muscat.



**Fig. 2.27** In the northeast of the country, mobile sands sometimes lap onto rocky carbonate ridges west of the main Hajar Mountains. Seen here in the background is *Jebel Mleiha, a/k/a Fossil Rock*. The carbonate ridges host floral associations distinct from those of the surrounding desert or the main Hajar Mountains. This photo was taken in the very ‘wet’ years of the mid-1990s; the author is pictured at right. Photo credit: Gary Feulner

Although rugged, the Hajar Mountains in the UAE are the lowest area of the entire chain, with only three scattered peaks and two high ridges reaching as much as 1000 metres. By contrast, in Oman, south of Hatta, summits along the spine of the Western Hajar range from 1400 to 1800 m, culminating to the southeast in the much higher elevations of the *Jebel Akhdar*, which rises to just over 3000 m.

#### 2.2.3.1.1 Hajar Mountain Geology

The rocky hillsides in the Hajar Mountains typically weather reddish-brown, but seen in road cuts they are usually greenish, blackish or pale. They are composed of a suite of interrelated igneous rocks collectively called *ophiolite*. (Igneous rocks are rocks that formed by crystallisation from hot, molten rock. They can sometimes form



**Fig. 2.28** A rainy day in the mountains above Wadi Khabb, in the Ru'us Al Jibal range (the mountains of the Musandam peninsula). Native trees are well established in slope rubble. The large trees at left and right are Sidr *Ziziphus spina-christi* (Rhamnaceae); the smaller tree in the center is Umbrella Thorn *Acacia tortilis* (Fabaceae). Photo credit: Gary Feulner

at the earth's surface, as in the case of volcanic lavas, but more often they form by slow cooling of molten rock deep within the earth.)

Within the ophiolite of the UAE, two rock types predominate: harzburgite and gabbro (Fig. 2.30). Harzburgite, representing exposures of the earth's uppermost mantle, occupies most of the northern areas (north of the Dhaid-Masafi-Fujairah roads, including Wadi Wurayah, Wadi Zikt, Wadi Madha, upper Wadi Shi, upper Wadi Siji, Wadi Asimah and Wadi Maydaq) as well as a narrow belt along the west flank of the mountains. In the southwest, the harzburgite includes minor areas of a rock type called dunite, which differs by only a few percent in its statistical mineral composition. In most areas of harzburgite, the surface rock is highly fractured and forms steep, rubble-covered slopes that are very difficult to climb; the summits are normally narrow, rocky ridges (Fig. 2.31).

The chemical composition of harzburgite is extreme among rocks found at the earth's surface. It is very low in silica ( $\text{SiO}_2$ ), the building block of most igneous rocks (a condition geologists call "ultrabasic" or "ultramafic"). It is also high in magnesium, and high in heavy metals such as chromium and nickel, as a result of which it is considered unfriendly to typical plant life (Harrison and Kruckeberg 2008). Along the west flank of the mountains the harzburgite exposures are almost completely weathered to serpentine, a fibrous clay mineral. Ultrabasic terranes elsewhere, and especially serpentinite terranes, are associated with limited floral diversity but high endemism (Harrison and Kruckeberg 2008; Anacker 2011).



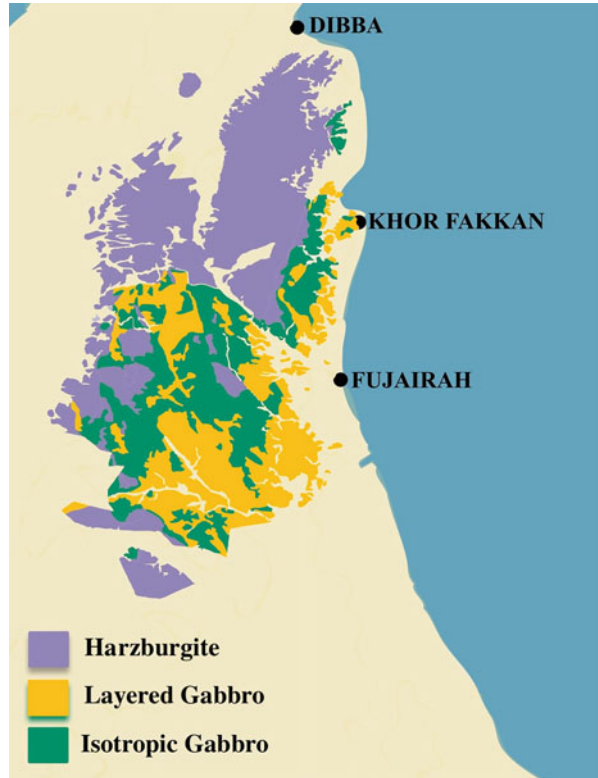
**Fig. 2.29** The Hajar Mountains of the UAE closely parallel the Gulf of Oman coastline. This photo looks out from above the mountains across the broad alluvial fan at the mouth of Wadi Wurayah, the largest of the East Coast wadis. Photo credit: Gary Feulner

In the center and southeast of the UAE's ophiolite terrane (including Wadi Ashwani, Wadi Asfani, Wadi Hiluw, Wadi Safad and Wadi Mayy), gabbro predominates. Gabbro is the principal component of oceanic crust and has a more normal chemistry for surface rocks, equivalent to volcanic basalt. It is visibly coarsely crystalline and weathers in a more blocky fashion, often creating more gentle and somewhat more navigable slopes and summits (Fig. 2.32). Gabbro in the UAE often features conspicuous dark and light banding.

#### 2.2.3.1.2 The Mountain Wadi Environment

Major wadis in the Hajar Mountains can be very stark and the wadi beds may appear to be almost devoid of vegetation, because they are swept clean from time to time by flood waters that are consolidated rapidly from many smaller tributaries (Fig. 2.33). In fact, this is what happens to most of the water that falls during very heavy rains. There is not enough capacity in the gravel wadis, or in the network of subterranean fractures in the bedrock, or in the very limited soils, to soak up all the water that falls in a short time during heavy rain, so much of it flows directly down the wadis and towards the mountain front as muddy, brown, turbulent floodwaters. In recent

**Fig. 2.30** Geological map of the Hajar Mountain ophiolite in the UAE, showing the distribution of the principal rock types. Image credit: Gary Feulner



decades, dams have been built in most Hajar Mountain drainages to try to prevent damage from flood waters and to collect the excess water.

Smaller wadis, on the other hand, including tributaries of larger wadis and the many steep ravines and gulleys that feed the tributaries, can be oases of life (Figs. 2.34 and 2.35). That is partly because the volume of flow in those channels is not so great as to uproot or inundate small shrubs. But equally important is that some of the water that falls as rain enters the shallow subsurface through cracks in the bedrock, scree and gravel terraces of the hillsides, where it resides long enough to nourish the natural, dry-adapted vegetation.

No mountain wadis in the UAE or Oman sustain continuous surface flow along their lengths, but a number of Hajar Mountain wadis have permanent water in pools at discrete locations (Feulner 1998, unpublished data) (Fig. 2.36). This is because rainwater that has entered the groundwater system, if it has not been absorbed by plants (or chemically incorporated into clay minerals that are the subsurface weathering products of the ophiolite rocks), percolates gradually through the bedrock and terraces and into the gravel fill of the main wadi channels. There, it flows slowly downstream through the gravel, saturating the lowest horizons and sometimes appearing intermittently at the surface (see next paragraph), so becoming available for hydrophilic (i.e., water-loving) plants and for selected animals.



**Fig. 2.31** Summits and summit ridges in harzburgite terrane are generally narrow, rocky, barren of vegetation and difficult to traverse. Here, the author overlooks upper Wadi Shees from a ridge ascended via a tributary of Wadi Deftah. Photo credit: Gary Feulner



Figure 2.37 shows cross-sections of a typical Hajar Mountain wadi. The wadi bed is cut into bedrock and filled with coarse gravel. Water flows within the porous gravel, as well as on top of it when flow is sufficient. The wadi bed beneath the gravel is not always smooth and even, however. At intervals, the underlying bedrock is resistant to erosion and punctuates the gravel fill, forming barriers. Pools of water form behind those barriers, and the barriers themselves may become small waterfalls after rain. Larger waterfalls may create deep pools at their base. Although many wadi pools appear calm or stagnant, flow is usually continuous, although very slow, facilitated by fractures in the underlying bedrock and by continuing drainage from the slopes on either side.

The amount of gravel fill in a wadi bed varies greatly from point to point, but it gives a sense of scale to know that in the middle and lower reaches of Wadi Wurayah, early contractors recorded a maximum depth to bedrock of 40 m; beyond the mountain front, but within the alluvial fan, the depth was somewhat more than 90 m (Tourenq et al. 2011). For comparison, Parton et al. (2015) studied a 42-m thick section of an alluvial fan exposed at a quarry west of the mountains near Al Foah,



**Fig. 2.32** A ridgetop at 1000 m in the Olive Highlands, south-west of Fujairah city. Summits in gabbro bedrock are normally somewhat broader and gentler than those in harzburgite. Photo credit: Gary Feulner

north of Al Ain, UAE; there the oldest exposed sediments dated back to (only) ca. 160,000 years.

Apart from downstream drainage, water in mountain wadis is lost by evaporation. This can be substantial at the UAE's high summer temperatures, when shallow pools fully exposed to the sun may shrink by as much as 2 cm depth per day. Within the gravel, however, the water is protected from extreme temperatures (Emirates Wildlife Society–WWF 2006) and, below a depth of about 1.5 to 2.0 m, it is effectively protected from evaporation (Valett 1991). Subterranean flow helps to buffer the temperature of surface pools and streams (Emirates Wildlife Society–WWF 2006).

Today, the greatest threat to the continued presence of surface or near-surface water in most natural wadi environments in the Hajar Mountains is mechanical extraction by pumping.

#### 2.2.3.1.3 Geological 'Windows' Exposing Metamorphic Rocks

The Hajar Mountain region of the UAE includes two areas of generally pale colored, often silvery, metallic-looking rocks—one surrounding Asimah and Tayyibah, north of Masafi, and the other encompassing Wadi Shees, deep within the mountains overlooking the east coast and west of the Oman enclave of Madha (Fig. 2.38). Both areas expose rocks that were originally deposited as sediments on the edge of the Arabian continent and were later deformed and metamorphosed by partial

**Fig. 2.33** Major wadi channels in the Hajar Mountains are often very stark because the vegetation is swept clean by floods from time to time. Shown here is a gorge in the middle reaches of Wadi Wurayah. A tall human figure at lower left emphasizes the scale. Photo credit: Gary Feulner



subduction beneath the ophiolite slab, being the leading edge of the oceanic plate to the east (see Sect. 4.2 below, Emplacement of the ophiolite rocks and creation of the Hajar Mountains). Because those areas allow us to ‘look through’ the ophiolite and see the rocks that underlie them, they are called geological windows. And because of their relationship to the ophiolite, the metamorphic rocks themselves are known collectively to geologists as the Metamorphic Sole.

### 2.2.3.2 The Ru’us Al Jibal

The Ru’us Al Jibal range (the traditional local name for the mountains of the Musandam peninsula) is dramatically different, geographically and geologically, from the Hajar Mountains to the south (Feulner 2011). This is evident even to the casual observer. Ru’us Al Jibal (pronounced *roo-OOS al-ji-BAL*) means, literally, “the Heads of the Mountains” and reflects the fact that the summits in this area are higher than any others for about 275 km to the south (in the Jebel Akhdar region of Oman). Much of the Ru’us Al-Jibal lies within the Musandam province of Oman,



**Fig. 2.34** Smaller mountain wadis, and gentle tributaries of larger wadis, can be genuine oases of life. Photo credit: Gary Feulner

but the margins in the west and south belong to the emirates of Ras Al Khaimah and Fujairah, respectively.

The rocks of the Ru'us Al Jibal comprise a thick pile (ca. 3 km) of relatively flat-lying, greyish, carbonate sedimentary rocks (Fig. 2.39). Physiographically, the Ru'us Al Jibal is characterised by steep-sided, boulder-filled wadis and steep lower slopes, including many sheer cliffs, but culminating in summit areas of rolling, stony plateaux, layered hills and intermittent basins at elevations of 500–1500 m. A handful of ridges and summits exceed 1600 m, of which the highest is Jebel Harim, in Oman, at just over 2000 m. The whole gives the impression of a relatively mature landscape that has been rapidly uplifted as a block (Fig. 2.40).

The Ru'us Al Jibal is separated from the Hajar Mountains by the Dibba Zone, an elongated geographical and geological boundary trending SW-NE and extending from Tawiyah and Jareef in the southwest to Ghub and Dibba in the northeast. The Dibba Zone marks the locus of major tectonic movement and consists of a mixed and colorful array of mostly deep water sedimentary rock units, all now discontinuous and divorced from their original stratigraphic context (Glennie et al. 1974; Feulner 2005; Searle 2019).

The hydrology of the carbonate bedrock of the Ru'us Al Jibal is very different from that of the Hajar Mountains. The carbonate rocks can be dissolved by groundwater, which creates its own network of subterranean drainage channels and even small caves, quickly conveying most excess rainwater to the main wadi systems or deeper underground (Borreguero and Jeannin 1990). As a result, there is almost no



**Fig. 2.35** A third order tributary in Wadi Wurayah National Park, well-vegetated after rain. Photo credit: Gary Feulner

permanent surface water in the wadis of the Ru'us Al Jibal, and few permanent springs.

The Ru'us Al Jibal is also characterized by its distinctive traditional human culture based on the cultivation of wheat and other crops in seasonal agricultural settlements at high elevation, often very picturesque, whereas cultivation in the ophiolite of the Hajar Mountains is invariably along wadi banks at low elevations (Fig. 2.41).

### **2.2.3.3 The Foreland Ridges (Jebel Hafeet et al.)**

Jebel Hafeet, on the outskirts of Al Ain in the Eastern Region of Abu Dhabi emirate, is a foreland ridge set at a distance of ca. 25 km from the main mountain front. It is the largest, by far, of a chain of similar ridges stretching north almost to Dhaid, composed of tightly folded carbonate sediments much younger than those of the Ru'us al-Jibal (Fig. 2.42). Rising to 1200 m, Jebel Hafeet is higher than any of the UAE's Hajar Mountain peaks except Jebel Hatta. It is also 75 km further south. The steep, rocky slopes are relatively barren, but it is nevertheless home to several species of plants that are absent or uncommon elsewhere in the UAE, and to several butterflies associated with those plants or more common to the south, in Oman (see

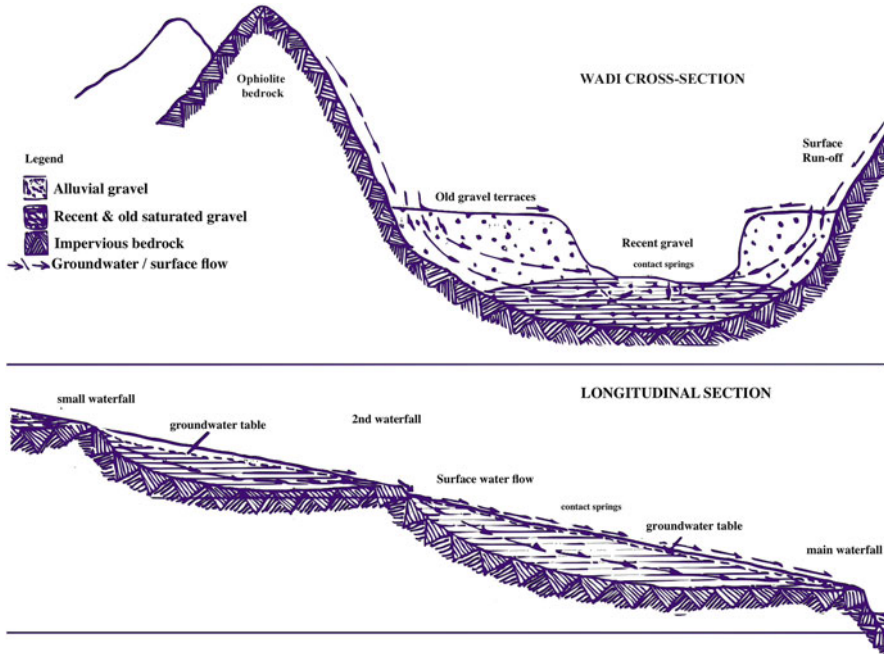
**Fig. 2.36** A number of Hajar Mountain wadis have permanent surface water and can be idyllic in wet years. Unfortunately, the site shown here was later destroyed when a large roadhead farm was created and was permitted to tap the local spring. Some native species, like the wadi fish *Garra barreimiae*, will never return. Photo credit: Gary Feulner



Chap. 6). The smaller and more northerly ridges are mostly situated in Sharjah (Jebel Faya, Jebel Buhais, Jebel Mleiha et al.) and are also associated with distinctive floral elements.

### ***2.2.4 The Alluvial Plains***

Gravel plains flank the mountain regions of the UAE to the east and west. In the extreme northwest of Ras Al Khaimah and along the entire east coast, the gravel plains are equivalent to the coastal plain. Everywhere, the gravel plains consist of alluvium—weathering products from the erosion of the adjacent mountains, washed down the wadis by moving water and eventually deposited in flatter, lower energy



**Fig. 2.37** Schematic cross-section (top) and longitudinal section (bottom) of a typical Hajar Mountain wadi (modified from Emirates Wildlife Society–WWF 2006)

environments beyond the mountain front (Fig. 2.43). The gravel plains inter-finger with the mountain front in the upstream/uphill direction, and with the desert sands or the coastal plain in the other direction (Figs. 2.44 and 2.45). At various times in the past, rainfall and erosion rates have been significantly greater than today. One line of evidence for this conclusion is that outwash gravels from the Hajar Mountains can be found in the subsurface under today's Arabian Gulf coastal cities in the northern emirates, including Dubai (Zander and Brückner 2005).

In Paleolithic (Old Stone Age) times, the alluvial plains to the west of the Hajar Mountains were the locus of human tool industries based on flint resources. Flint is found (i) as scattered concretions within the carbonate rocks of the foreland ridges along the western margin of today's plains, south of Dhaid (Jebel Faya et al.) (Bretzke et al. 2013); and (ii) along the eastern margin of the plains, where pervasive silicification affected the foothills along the main mountain front, from serpentinized ophiolite bedrock hills near Fili in the south to remnant channel deposits of limestone and metamorphic rocks along the southwesterly salient of the Ru'us Al Jibal carbonates, in the area of Khatt and Habhab (Scott-Jackson et al. 2008).

Analysis of the outwash gravels can give us a better understanding of the timing and nature of the uplift and erosion of the Hajar Mountains — which occurred primarily over the past 25 to 30 million years (Glennie 2001) — as well as of the



**Fig. 2.38** A plateau of silvery micaceous schist within the Asimah-Tayyibah metamorphic window—a very unusual mountain landscape for the UAE. The more familiar ophiolite (harzburgite) terrane is seen on the horizon. Photo credit: Gary Feulner

details of paleoclimate (e.g. Parton et al. 2015). However, that potential utility has earned those deposits little respect from the general populace. Today, the gravel plains are almost everywhere degraded by infrastructure construction, quarrying and rampant overgrazing (Fig. 2.46). In recent decades the cutting of live trees has been added to the list of environmental sins visited on these already-insulted lands.

### 2.3 Biogeography

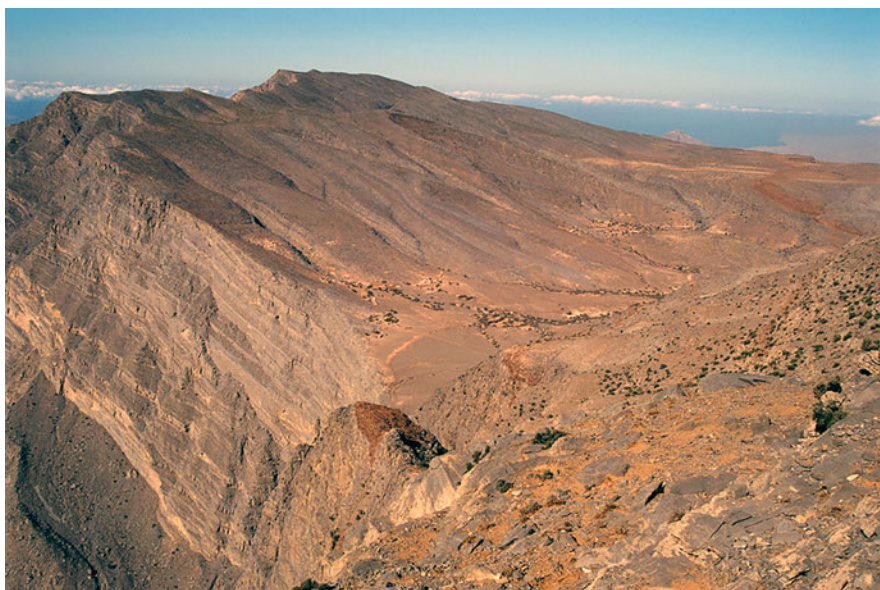
The geography of a place properly includes consideration of its global position in relation to not only climatic boundaries but also biogeographical ones. In the case of the UAE, the country occupies a privileged position at the junction of the three major biogeographical regions of the Old World—the Palearctic, the Afrotropical and the Oriental (Fig. 2.47). As a result, it has received plant, animal and human influences from all three regions. And, of course, the modern UAE receives influences from the entire world.

Currently the mutual boundaries of the three major regions are overlain by what has been called the Eremic zone (Larsen 1984), a climatic belt extending from West Africa to northern India, characterized by substantial aridity, that has developed many of its own distinctive floral and faunal elements. This adds yet a fourth





**Fig. 2.39** The Ru'us Al Jibal range (the mountains of the Musandam peninsula) contrasts greatly with the Hajar Mountains. The rocks of the Ru'us Al Jibal comprise a thick pile of relatively flat-lying carbonate sedimentary rocks. Photo credit: Gary Feulner



**Fig. 2.40** The Ru'us Al Jibal range as a whole gives the impression of a relatively mature landscape that has been rapidly uplifted as a block. Photo credit: Gary Feulner



**Fig. 2.41** The high Musandam has been used for seasonal cultivation for hundreds of years, and features many remote and picturesque settlements. Most are now disused but some have been refurbished in the twenty first century. Photo credit: Gary Feulner

contributor to the biodiversity of the Emirates. Some examples of UAE flora and fauna derived from those four sources are set out in the following paragraphs.

**Afrotropical:** Many of the plant and animal species of the sand deserts and gravel plains of the UAE are of Afrotropical origin—the semi-arid Sahel and savannah regions of West, Central and East Africa. Examples include species such as Umbrella Thorn *Acacia tortilis* and Desert Broom *Leptadenia pyrotechnica* (Fig. 2.48a).

**Oriental:** Mountain Spurge *Euphorbia larica*, a normally leafless, yellow-green shrub that is one of the most common and characteristic plants of Hajar Mountain slopes, has its global distribution in southern and eastern Arabia and the Makran region and across southern Iran, extending eastward from the Hajar Mountains to Baluchistan (Fig. 2.48bi). The ghaf tree *Prosopis cineraria* has a similar native distribution, but extending further eastward to northern India (Fig. 2.48bii).

**Palaearctic/Mediterranean:** The Wild Olive *Olea europaea* is found in discrete high elevation locales in the Hajar Mountains of the UAE and northern Oman (Fig. 2.48c). It is considered native to the Mediterranean region (Palaearctic), but it had spread by the late Pleistocene (tens of thousands of years ago) to the mountains of South Asia and Eastern Arabia, and to East Africa. Today, the closest populations to the UAE and northern Oman are in the Makran region—the coastal mountains of southern Iran, Baluchistan and Pakistan.

**Fig. 2.42** The foreland anticline of Jebel Hafeet rises ca. 800 m from the surrounding plain, ca. 25 km west of the main mountain front. Its slopes and wadis are home to a number of plants and animals rarely seen elsewhere in the UAE. The traditional ascent route, shown here, is formidable. See also Chap. 6, Fig. 6.41. Photo credit: Gary Feulner



Eremic: The Desert White butterfly *Pontia glauconome* is one of the most common butterflies in wild areas of the UAE and is also common elsewhere throughout the Eremic zone (Fig. 2.48di). It is an arid region specialist that has evolved in place to survive as its homeland has dried out. Its larvae can develop on a variety of regional plants in both mountain and sand desert environments, and reportedly can delay emergence of the adult butterfly from the pupal state for up to several years, in order to await favorable conditions (Feulner et al. 2021). Two of the UAE's seven native land snails, *Zootecus insularis* and *Pupoides coenopictus*, are also widespread throughout the Eremic zone, but essentially absent outside it (Feulner and Green 2003) (Fig. 2.48dii).



**Fig. 2.43** Alluvial plains, often composed of coarse gravel, border the mountain regions on the east and west flanks. They represent the outwash from erosion of the mountains. Seen here is the west flank of the Ru'us Al Jibal, north of Khatt. The trees are all *Acacia tortilis*. Photo credit: Gary Feulner

## 2.4 Geological Highlights

Geological processes—all the processes studied by earth scientists generally—ultimately control earth's geography, the oceans, the atmosphere, the cycling and recycling of various chemical and mineral components, and the feedback mechanisms among those interrelated systems. And so, geological processes ultimately control life itself.

The classical bedrock geology of the UAE, however, is seldom exposed to view, except in the mountain regions of the northeast. In addition, with respect to the terrestrial ecosystems of the UAE that are the focus of Section 2 of this volume, the bedrock geology is generally not as important as the various geographical factors discussed above. Again, the mountain regions are a limited exception. For that reason, this section presents only an abbreviated discussion of the most distinctive features of the UAE's physical geology and geological history; the general reader seeking greater detail should consult more specialized non-technical accounts (e.g. Glennie 1992, 2001; Feulner 2005; Thomas and Ellison 2014; Searle 2019).

The treatment below nevertheless attempts to introduce the most important conceptual aspects of the UAE's geological history—those that provide context for understanding the dynamic evolution of both the Arabian landscape and the



**Fig. 2.44** In some places gravel terraces are well developed within the mountain front, as here in the Wadi Ghayl tributary of Wadi Wurayah. Photo credit: Gary Feulner

plants and animals to which it plays host. Figure 2.49 is a simplified geological map of the mountain regions of the UAE and northernmost Oman. Figure 2.50 presents a schematic geological cross-section of the UAE—one of the most useful tools for understanding geological structures and interpreting geological history.

The geology of the UAE is world famous for three main reasons: (1) the country's huge oil reserves; (2) the ophiolite rocks of the Hajar Mountains (extensively exposed in the UAE and Oman); and (3) the modern-day coastal sabkha of Abu Dhabi, mentioned briefly above.

### **2.4.1 Oil Reserves**

The UAE's oil reserves have been tremendously important for the development of the modern nation, but they have not been significant for the evolution of native UAE plant and animal life. As the cross-section shows, most of the UAE (except the mountain areas) is underlain by tens of thousands of meters of relatively undisturbed sedimentary rocks. Most of those sediments were deposited in shallow seas over the past 550 million years, beginning not long before the start of the Cambrian Period, at



**Fig. 2.45** On the west flank of the mountains, the gravel plains merge with the coastal plain to the north and the sand desert to the west. Seen here is Wadi Umm Al Naghool, north of Dhaid. Photo credit: Gary Feulner

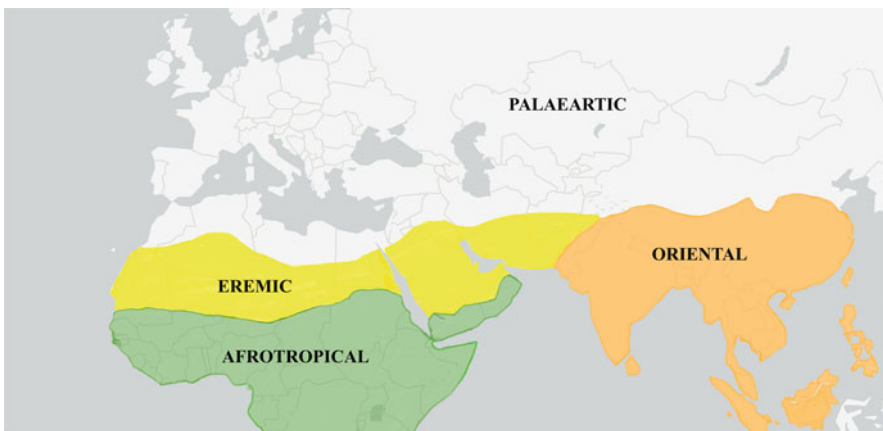
about the same time when fossilizable multicellular life first began to proliferate (Fig. 2.51).

It is in those sedimentary rocks, and mainly under Abu Dhabi emirate, that the UAE's petroleum reserves now reside. Much of those reserves is believed to derive from the decomposition of microscopic marine life from the Silurian Period (ca. 444–419 million years ago) (Glennie 2001). The resulting hydrocarbons migrated slowly upward through porous strata until they were blocked by stratigraphic or structural traps. Many of the traps were created by deformation arising from salt domes rooted in the infra-Cambrian Hormuz Formation, a very thick unit that underlies much of the central and Southern Arabian Gulf (e.g., Glennie 2001); the same salt domes are responsible for most of the UAE's offshore islands. The oil reservoirs and their host rocks now lie out-of-sight, deep underground. However, some of the same strata are exposed (but without oil) and can be studied in the mountains of the Musandam peninsula (Fig. 2.52).

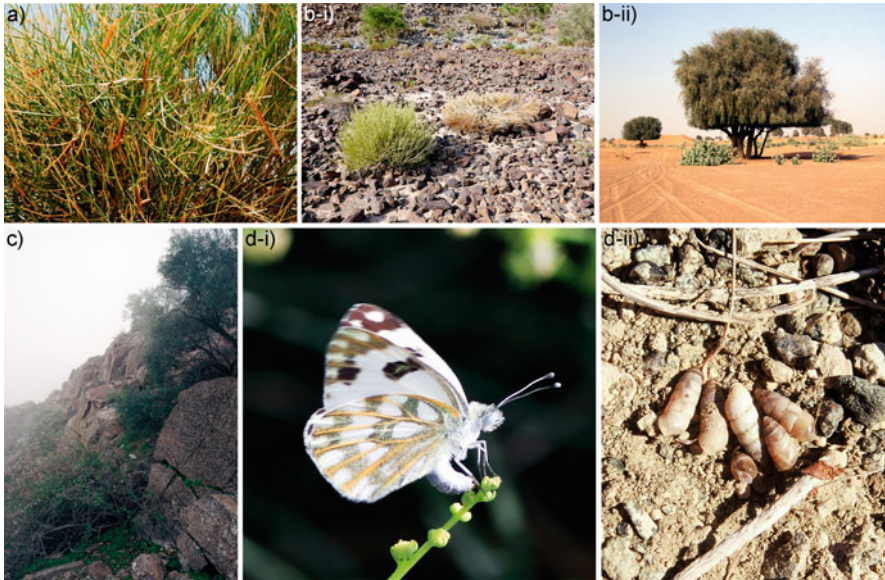
The cross-section also shows that the vast dune sands so prominent in the UAE landscape today, and so characteristic of Abu Dhabi's hinterland, are just a superficial overlay, geologically speaking, being no more than a maximum of about 200 m thick. Inland, they are deposited mostly atop eroded sedimentary bedrock and/or sabkha.



**Fig. 2.46** Almost everywhere, the alluvial plains have been degraded by infrastructure construction and overgrazing. More recently, cutting of live trees has been added to the list of modern environmental sins. Photo credit: Gary Feulner



**Fig. 2.47** The principal biogeographical regions of the Old World. Modified from Feulner et al. (2021) and reused with permission

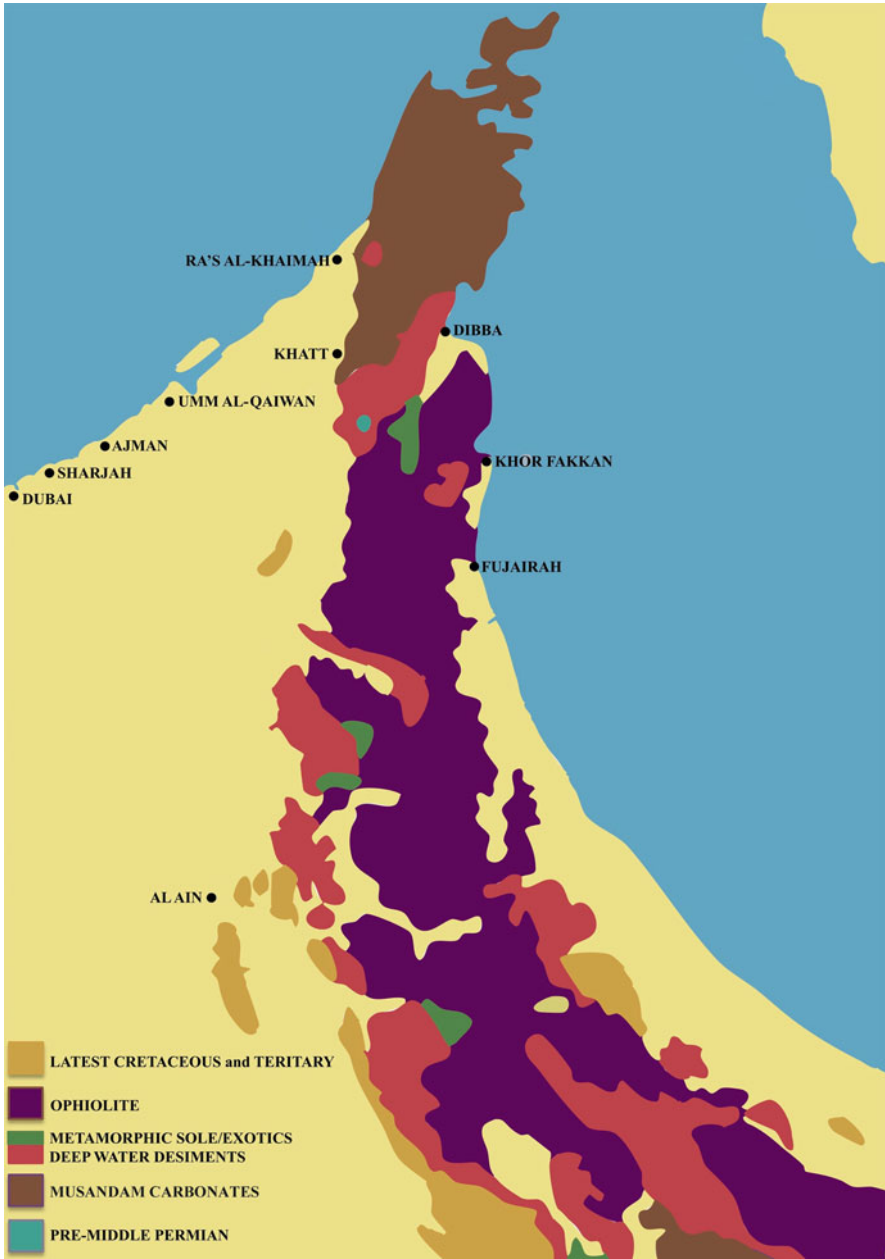


**Fig. 2.48** Some examples of the multiple biogeographical components of the UAE's flora and fauna: (a) Afrotropical: Desert Broom (*Leptadenia pyrotechnica*), a large, leafless milkweed found across the Sahel zone of Africa; it dominates much of the sand desert of inland Dubai. (b) Oriental: (i) Mountain Spurge (*Euphorbia larica*), in life and in death. (ii) Ghaf tree (*Prosopis cineraria*), growing here in the bed of an intermittent sand river. The bottom of the canopy is browsed to the height of an outstretched camel's neck. (c) Palearctic: Wild Olive (*Olea europaea*), part of a relict population that survives in the UAE today only in a high elevation refuge. (d) Eremic: (i) Desert White butterfly (*Pontia glauconome*) (Pieridae). (ii) Land snail *Zootecus insularis* (Achatinidae). Both are widespread throughout the Eremic zone. Photo credits: Gary Feulner (a,b,c,d-ii), Binish Roobas (d-i)

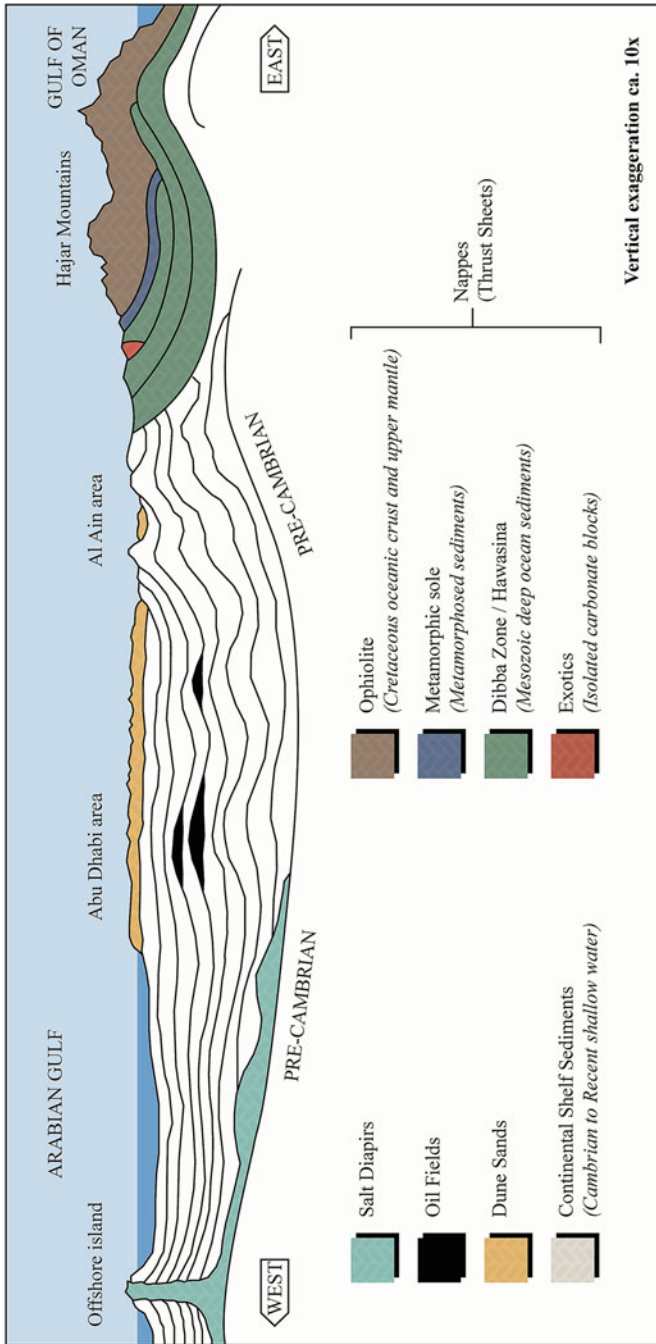
#### 2.4.2 Emplacement of the Ophiolite Rocks and Creation of the Hajar Mountains

The most dramatic event in the geological history of the UAE was the formation of the Hajar Mountains. The rocks that make up most of the mountain chain we see today were not originally part of Arabia. Instead, they began as part of an adjacent tectonic plate consisting of oceanic crust and underlying upper mantle from the deep ocean lying to the east, a precursor of today's Indian Ocean. During the period from about 90 to 70 million years ago, a huge slab of that oceanic plate was slowly slid over the edge of Eastern Arabia, which was beginning to descend into a subduction zone. The overriding slab was subsequently detached and uplifted, and the oceanic crust and mantle rocks, collectively called "ophiolite", are now magnificently exposed on land. They also pushed ahead of them some colorful deep ocean sediments and even remnants of coral atolls, which can be seen today in the Dibba Zone and elsewhere (Fig. 2.53). As described above, geological "windows" in the





**Fig. 2.49** A simplified geological map of the mountain areas of the UAE and northernmost Oman. Modified from Feulner (2005) and reused with permission



**Fig. 2.50** Schematic geological cross-section of the UAE. Modified from P. Vine in Feulner (2005) and reused with permission

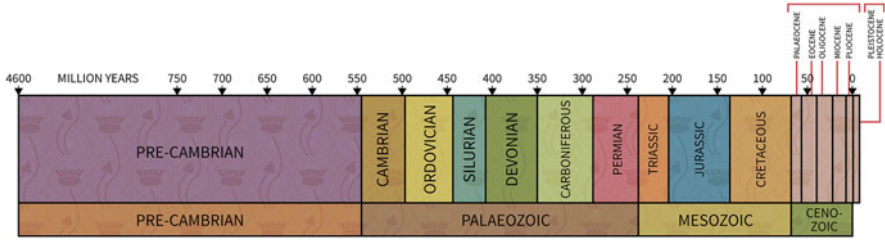


Fig. 2.51 The geological time scale. Modified from Feulner (2005) and reused with permission



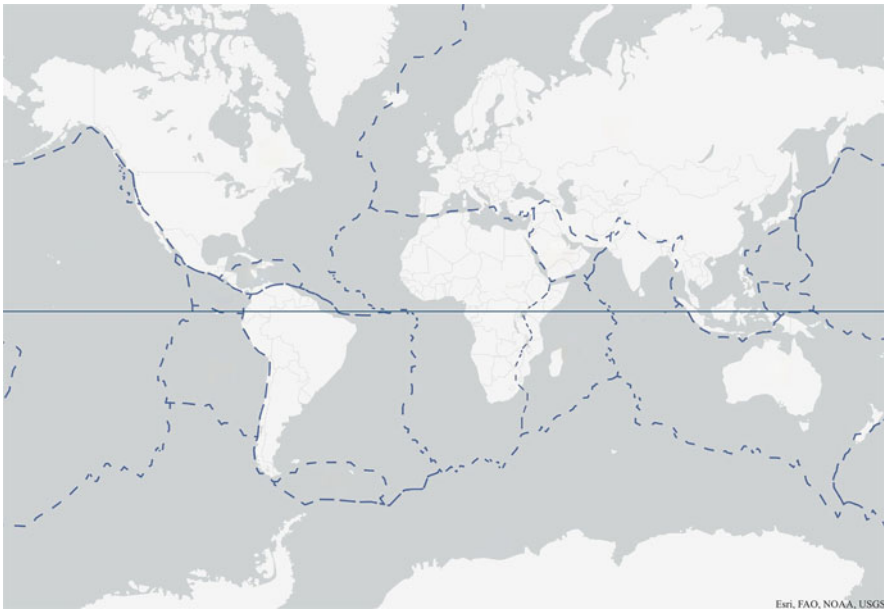
Fig. 2.52 Many of the same strata that host oil reservoirs under Abu Dhabi are exposed for study (but without oil) in the mountains of the Musandam peninsula. Seen here in Wadi Naqab are the dolomitic limestones of the Ghail Formation, the uppermost member of the Permo-Triassic Ru’us Al Jibal Group. Photo credit: Gary Feulner

areas of Asimah/Tayyibah and Wadi Shis expose sedimentary rocks originally deposited on the edge of the Arabian continent that were subducted under the advancing ophiolite and metamorphosed beneath it, creating rocks unlike any others seen today in the Emirates, often silvery and metallic-looking.

Gradually, earth forces pushed the ophiolite rocks and associated sediments further and further over the edge of Arabia, then raised them up, and slowly raised the whole of Arabia as well, all as part of processes which continue today.



**Fig. 2.53** In Wadi Khabb, in the south of the Ru`us Al Jibal, colorful deep ocean sediments (right) that were originally deposited far to the east have been thrust over pale grey carbonates (left) deposited on the Arabian continental shelf. Photo credit: Gary Feulner



**Fig. 2.54** Major tectonic plates of the modern earth



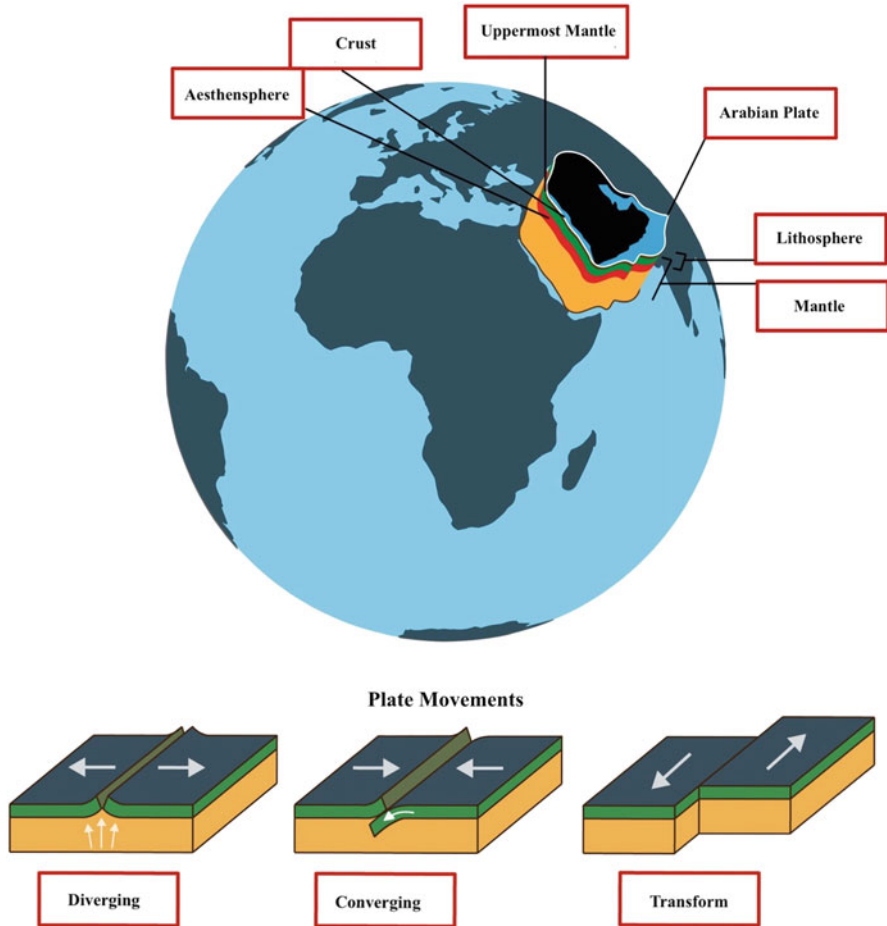
Fig. 2.55 Tectonic plate boundaries surrounding Arabia

## 2.5 Plate Tectonics

Underlying the emplacement of the ophiolite rocks and the formation of the Hajar Mountains is the system of earth movements called “plate tectonics” (Figs. 2.54, 2.55, and 2.56). Plate tectonics shuffles and recycles land masses and ocean basins. It is a continuing process that remains active today and it is a major unifying concept for geological science.

In Arabia, plate tectonics explains not only the formation of the Hajar Mountains, but also important regional phenomena such as (1) the opening of the Red Sea, which split Arabia from Africa and raised up the whole of Arabia above sea level; and (2) the formation of the Zagros Mountains in Iran (along with their associated earthquakes), including, as a by-product, the formation of the shallow Arabian Gulf (discussed briefly below). More broadly, plate tectonics explains the continuing collision of Afro-Arabia with Eurasia, evident on land from the Levant to Iran, but also in progress across the whole of the Mediterranean region.

The ophiolite rocks of the Hajar Mountains in the UAE and Oman are the most extensive and most complete exposures of ophiolite in the world. They have been



**Fig. 2.56** Basic structure of the earth's interior and types of relative motion between plates

intensively studied and have helped geologists better understand many aspects of plate tectonic processes.

Of special interest to naturalists, the history of plate tectonic movements helps to explain the distribution of many plants and animals, both in the geological record and today. Two examples relevant to Arabia will help to illustrate the point.

First, the collision of Afro-Arabia with Asia in the Oligo-Miocene (beginning roughly 30 million years ago) introduced Asian freshwater fish groups to Arabia, first walking catfish (Clariidae) and bagrid catfish (Bagridae) and later, by the mid-Miocene (ca. 18 million years ago), Asian cyprinids (Cyprinidae) (Freyhof et al. 2020). The catfish species eventually succumbed to the arid and hyper-arid conditions that later beset Arabia, but the Asian cyprinids, particularly the genus *Garra* (sub-family Labeoninae), have prospered and diversified not only in the arid



**Fig. 2.57** Successful radiations between Asia and Africa, via Arabia: (a) *Garra barreimiae*: Fossils show that the Asian cyprinid ancestors of the UAE’s wadi fish, *Garra barreimiae*, reached Arabia by about 18 million years ago, not long after its collision with Eurasia. They have also successfully colonized Africa. (b) *Eusparassus laevatus*: The stone huntsman spider genus *Eusparassus* is considered most likely to have originated in Namibia, but it has radiated throughout Africa and today includes a number of species centered in the near East and Central Asia. *E. laevatus*, a denizen of UAE wadis, is found in East and South Arabia and in the Afar region of Northeast Africa (Moradmand 2013). Photo credits: Gary Feulner

mountains of Arabia but also in many environments on the African mainland (Levin et al. 2021) (see Chap. 21) (Fig. 2.57).

Second, and of greater significance, the collision turned Arabia into a literal crossroads for the exchange of terrestrial megafauna between Africa and Asia, with results that we take for granted today. In particular, it was during the Miocene that even-toed hoofed mammal like pigs, deer, antelope and giraffe first moved into Africa from Eurasia, while members of the elephant family and apes and Old World monkeys spread in the opposite direction (Stewart 2005).

Geological and oceanographic studies have shown that the Arabian Gulf is a relatively recent geographical feature, geologically speaking, and probably an ephemeral one (McKinnon 1990). It is not an ocean basin, but only a very shallow downwarping of the continental crust of the Arabian plate, incidental to the deformation and uplift of the Zagros Mountains at the plate boundary with Eurasia. The maximum depth of the Gulf is only 90 m—less than two-thirds the height of the tallest dunes in the interior of Abu Dhabi and only one-quarter the length of the largest oil tanker vessels currently in service. The average depth is only 30 m.

Moreover, the Gulf has been largely emptied on a number of occasions during at least the past half million years (McKinnon 1990; Glennie 1991, 1996, 2001; Sanlaville 1992, 1998; Goodall 1994; Parker 2009), as global sea levels have fallen by 100-plus meters in response to repeated cycles of glaciation (“Ice Ages”) in the northern hemisphere. At such times the area of today’s Gulf is thought to have been a marshy extension of the Tigris-Euphrates-Karun river system that flows from the

north and drains most of Iraq and Syria, and parts of Turkey and Iran, perhaps similar to the Shatt al-Arab where those three rivers meet today, with anastomosing channels and intermittent freshwater lakes (Parker et al. 2004; Cuttler et al. 2011). Thus the Gulf region is not considered to have been a very significant physical barrier to most terrestrial plants and animals.

Most recently, the Gulf was fully dry at the peak of the last glacial maximum at about 17,000 to 18,000 years ago (see Chap. 4). As global sea level rose thereafter, the Gulf began to fill at about 16,000 years ago, was still largely empty at 12,000 years ago, and reached its current level (and a meter or two more) by about 6000 years ago (Lambeck 1996; Uchupi et al. 1999). All of these historical geological and geographical changes must be taken into account, as well as the vicissitudes of paleoclimate (e.g., Parker 2009; Parker et al. 2004, 2016; Parton et al. 2015) (see also Chap. 3), in order to fully understand the mix of flora and fauna that we see in the UAE today.

## 2.6 Conclusions

The UAE packs a great deal of geographical and biological diversity into its modest physical area. The coastal areas are dotted with lagoons, mangrove forests and world famous sabkha. The sand deserts form a vast sea that grades from mega-dunes in the south, on the edge of the Empty Quarter, to the low, shrub-covered dunes of the coast and the *ghaf* covered dune hills of the northern emirates. The mountains are like a tropical reef at the margin of the sand sea, creating and concealing a wealth of microenvironments that can only really be discovered by investigation on foot. The potential biodiversity of the UAE is enhanced by its position at the junction of the three major biogeographical regions of the Old World, and it has demonstrably received contributions from each.

The most fundamental geological influences on the present day natural history of the UAE include three which are consequences of regional plate tectonic movements: (1) the opening of the Red Sea beginning ca. 35 million years ago, splitting Arabia from Africa and slowly raising up the whole of Arabia above sea level; (2) the plate tectonic collision of Afro-Arabia with Eurasia beginning ca. 30 million years ago, which facilitated the exchange of flora and fauna between the two; and (3) the formation of the Zagros Mountains in Iran, including, as a by-product, the formation of the shallow Arabian Gulf. A fourth fundamental influence is the regional response to repeated cycles of glaciation (“Ice Ages”) in the northern hemisphere over the past half million years or more: the alternation of cooler and hyper-arid climatic conditions in Eastern Arabia with warmer, humid ones, coupled with the repeated emptying and filling of the Arabian Gulf, as global sea levels fell and rebounded with the waxing and waning of the far-away glaciers.



## 2.7 Recommended Reading

Feulner (2005), now available online, is a well-received and often dramatically illustrated popular introduction to many of the diverse environments of the UAE and the processes that created and maintain them. Featured discussions include the early plate tectonic wanderings of Arabia, the genesis of the country's petroleum reserves, the growth of salt domes, the formation and erosion of the mountain regions, sand dune formation and desert oases, sabkha environments, and a simple guide to Hajar Mountain structural units and rock types.

Glennie (2001) is a wide-ranging but more technical account of the geological and geographical evolution of the country, written for the scientifically literate layman. It includes discussion of the early plate tectonic movements of Arabia, the UAE's petroleum deposits, salt domes, sand dune and sabkha formation, and the presence of riverine environments in the Miocene of western Abu Dhabi. An in-depth discussion of the plate-tectonic events leading to the emplacement of the ophiolite is informed in part by Glennie's professional acquaintance with neighboring areas of the Near East. Also discussed in detail are the climatic and sea level changes of the Pleistocene and Holocene.

Many of the extensive photos in Searle (2019) will be nostalgic for old-timers who recall the UAE and Oman from the 1970s and 1980s, but the text assumes a fair level of geological sophistication on the part of the reader.

Thomas and Ellison (2014) is an elegant and informative trophy volume produced by the British Geological Survey (BGS) team that undertook the geological mapping of the UAE in the 2000s. The BGS also produced a series of geological maps and corresponding explanatory booklets (e.g. Phillips et al. 2006). Not surprisingly, the BGS texts also assume that the reader will have an above average level of prior geological understanding. The BGS publications are available from the UAE Ministry of Energy, Department of Geology and Mineral Resources, in Abu Dhabi.

## References

- Anacker BL (2011) Phylogenetic patterns of endemism and diversity. In: Harrison S, Rajakaruna N (eds) *Serpentine: the evolution and ecology of a model system*. University of California Press, pp 49–70
- Borreguero M, Jeannin P-Y (1990) Emirates Arabes unis expedition 1990. *Cavernes* 2:1–80
- Bretzke K, Armitage SJ, Parker AG, Walkington H, Uerpmann H-P (2013) The environmental context of Paleolithic settlement at Jebel Faya, Emirate Sharjah, UAE. *Quat Int: The Middle Palaeolithic in the Desert* 300:83–93
- Cuttler R, Tetlow E, Al-Naimi F (2011) Assessing the value of palaeoenvironmental data and geomorphological processes for understanding Late Quaternary population dynamics in Qatar. *Proc Seminar Arab Stud* 41:47–60
- Emirates Wildlife Society–WWF (2006) Establishment of a mountain protected area in Wadi Wurayah, Fujairah Emirate, United Arab Emirates. EWS-WWF, Dubai, UAE, pp 1–83
- Feulner GR (1998) Wadi fish of the UAE. *Tribulus* 8(2):16–22

- Feulner GR (2005) Geological overview. In: Hellyer P, Aspinall S (eds) *The Emirates – a natural history*. Trident Press, London, pp 41–62
- Feulner GR (2006) Rainfall and climate records from Sharjah Airport: Historical data for the study of recent climatic periodicity in the UAE. *Tribulus* 16(1):3–9
- Feulner GR (2011) The flora of the Ru'us al-Jibal – the mountains of the Musandam Peninsula: an annotated checklist and selected observations. *Tribulus* 19:4–153
- Feulner GR, Green SA (2003) Terrestrial molluscs of the United Arab Emirates. *Mitteilungen der Deutschen Malakologischen Gesellschaft* 69/70:23–34
- Feulner GR, Roobas BR, Hitchings V, Otto HHH, Campbell O, Roberts HGB, Hornby RJ, Howarth B (2021) *Butterflies of the United Arab Emirates including northern Oman*. Motivate Publishing, Dubai
- Freyhof J, Els J, Feulner GR, Hamidan NA, Krupp F (2020) *Freshwater fishes of the Arabian Peninsula*. Motivate Publishing, Dubai
- Glennie KW (1991) Sand dunes in the Emirates. *Tribulus* 1(1):14–17
- Glennie KW (1992) Plate tectonics & the Oman mountains. *Tribulus* 2(2):11–21
- Glennie KW (1996) Geology of Abu Dhabi. In: Osborne PE (ed) *Desert ecology of Abu Dhabi*. Pisces Publications, Newbury, pp 16–35
- Glennie KW (2001) Evolution of the Emirates' land surface: an introduction. In: Ghareeb E, Al Abed I (eds) *Perspectives on the United Arab Emirates*. Trident Press, London. (1997). Reprinted in Al Abed I, Hellyer P (eds) *United Arab Emirates: a new perspective*. Trident Press, London, pp 9–27
- Glennie KW, Boeuf MGA, Hughes-Clarke MW, Moody-Stuart M, Pilaar WFH, Reinhardt BM (1974) Geology of the Oman Mountains. *Verhandelingen Koninklijke Nederland Geologisch Mijnboukundig Genootschap* 31:1–423 + figures (3 parts)
- Goodall TM (1994) The Sabkhat Matti – a forgotten wadi system? *Tribulus* 4(2):10–13
- Harrison SP, Kruckeberg AR (2008) Garden on the rocks. *Nat Hist* 117(4):40–44
- Hill A (2021) Climate change is making UAE hotter – a trend that will continue. In: *The National*. <https://www.thenationalnews.com/uae/environment/climate-change-is-making-uae-hotter-a-trend-that-will-continue-1.1249027>. Accessed 10 Jul 2022
- Judas J (2015) A checklist of the flora and fauna of Wadi Wurayah National Park (unpublished draft)
- Kwarteng AY, Dorvlo AS, Vijaya Kumar GT (2009) Analysis of a 27-year rainfall data (1977–2003) in the Sultanate of Oman. *Int J Climatol* 29:605–617. <https://doi.org/10.1002/joc.1727>
- Lambeck K (1996) Shoreline reconstructions for the Persian Gulf since the last glacial maximum. *Earth Planet Sci Lett* 142:43–57
- Larsen TB (1984) The zoogeographical composition and distribution of the Arabian butterflies (Lepidoptera; Rhopalocera). *Jour Biogeo* 11:119–158
- Levin B, Simonov E, Franchini P, Mugue N, Golubtsov A, Meyer A (2021) Adaptive radiation and burst speciation of hillstream fish *Garra* in an African river. *bioRxiv* <https://doi.org/10.1101/2021.05.04.442598>. Accessed 4 May 2021
- McKinnon M (1990) *Arabia: sand, sea, sky*. BBC Books, London, pp 1–224
- Moradmand M (2013) The stone huntsman spider genus *Eusparassus* (Araneae: Sparassidae): systematics and zoogeography with revision of African and Arabian species. *Zootaxa* 3675 (1):1–108. <https://doi.org/10.11646/zootaxa.3675.1.1>
- Parker AG (2009) Chapter 3: Pleistocene climate change in Arabia: developing a framework for hominin dispersal over the last 350 ka. In: Petraglia MD, Rose JI (eds) *The evolution of human populations in Arabia, vertebrate paleobiology and paleoanthropology*. Springer, Dordrecht. [https://doi.org/10.1007/978-90-481-2719-1\\_3](https://doi.org/10.1007/978-90-481-2719-1_3)
- Parker A, Eckersley L, Smith MM, Goudie AS, Stokes S, White K, Hodson MJ (2004) Holocene vegetation dynamics in the northeastern Rub' al-Khali desert, Arabian Peninsula: a pollen, phytolith and carbon isotope study. *J Quat Sci* 19:665–676

- Parker AG, Preston GW, Parton A, Walkington H, Jardine PE, Leng MJ, Hodson MJ (2016) Low-latitude Holocene hydroclimate derived from lake sediment flux and geochemistry. *J Quat Sci* 31(4):286–299
- Parton A, Farrant AR, Leng MJ, Telfer MW, Groucutt HS, Petraglia MD, Parker AG (2015) Alluvial fan records from southeast Arabia reveal multiple windows for human dispersal. *Geology* 43(4):95–98
- Phillips ER, Ellison RA, Farrant AR, Goodenough KM, Arkley SLB, Styles MT (2006) Geology of the Dibba 1:50,000 map sheet, 50-2, United Arab Emirates. British Geological Survey, Nottingham
- Sanlaville P (1992) Changements Climatiques dans la Péninsule Arabique durant le Pléistocène Supérieur et L'Holocène. *Paléorient* 18(1):5–25
- Sanlaville P (1998) Les changements dans l'environnement au Moyen-Orient de 2,000 BP a 6,000 BP. *Paléorient* 23(2):249–262
- Scott-Jackson J, Scott-Jackson W, Rose J, Jasim S (2008) Investigating Upper Pleistocene stone tools from Sharjah, UAE: Interim report. *Proc Seminar Arab Stud* 38:43–54
- Searle M (2019) Geology of the Oman Mountains, Eastern Arabia. Springer Nature, Dordrecht, pp 1–475
- Stewart JR (2005) Miocene geology and fossils of Abu Dhabi. In: Beech M, Hellyer P (eds) Abu Dhabi 8 million years ago: late Miocene fossils from the western region. Abu Dhabi Islands Archaeological Survey (ADIAS), Abu Dhabi, pp 1–68
- Thomas RJ, Ellison RA (2014) Geological evolution of the United Arab Emirates. Department of Geology and Mineral Resources, UAE Ministry of Energy, Abu Dhabi
- Tourenq C, Brook M, Knuteson S, Shuriqui MK, Sawaf M, Perry L (2011) Hydrogeology of Wadi Wurayah, United Arab Emirates, and its importance for biodiversity and local communities. *Hydrol Sci J* 56(8):1407–1422. <https://doi.org/10.1080/02626667.2011.631139>
- Uchupi E, Swift SA, Ross DA (1999) Late quaternary stratigraphy, palaeoclimate and neotectonism of the Persian (Arabian) Gulf region. *Mar Geol* 160:1–23
- United Arab Emirates University (1993) The national atlas of the United Arab Emirates. United Arab Emirates University, Al Ain
- Valett HM (1991) The role of the hyporheic zone in the structure and function of a desert stream ecosystem. Dissertation, Arizona State University
- van Harten A (ed) (2008) Arthropod fauna of the United Arab Emirates, vol 1. Dar Al Ummah, Abu Dhabi, pp 1–754
- van Harten A (ed) (2009) Arthropod fauna of the United Arab Emirates, vol 2. Dar Al Ummah, Abu Dhabi, pp 1–786
- van Harten A (ed) (2010) Arthropod fauna of the United Arab Emirates, vol 3. Dar Al Ummah, Abu Dhabi, pp 1–700
- van Harten A (ed) (2011) Arthropod fauna of the United Arab Emirates, vol 4. Dar Al Ummah, Abu Dhabi, pp 1–832
- van Harten A (ed) (2014) Arthropod fauna of the United Arab Emirates, vol 5. Department of the President's Affairs, Abu Dhabi, pp 1–744
- van Harten A (ed) (2017) Arthropod fauna of the United Arab Emirates, vol 6. Department of the President's Affairs, Abu Dhabi, pp 1–775
- Zander A, Bruckner H (2005) Chronology and evolution of submerged mangrove swamps buried in the subsoil of Dubai. *Tribulus* 15(2):10–16

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