Origin of the Qattara Depression, Egypt

CLAUDE C. ALBRITTON, JR.* }
JAMES E. BROOKS } *Institute for the Study of Earth and Man at Southern Methodist University, Dallas, Texas 75275-0274*
BAHAY ISSAWI *16 Misaha Street, Dokki, Giza, Cairo, Egypt*
AHMED SWEDAN *Egyptian Geological Survey and Mining Authority, Salah Salem Street, Abbassiya, Cairo, Egypt*

ABSTRACT

As a working hypothesis, we propose that the Qattara Depression originated as a stream valley that was subsequently dismembered by karstic processes during the late Miocene epoch and afterward was deepened by deflation and otherwise modified by mass wasting and fluviatile processes.

The Depression is excavated in sedimentary rocks of Tertiary age that have a regional dip of a few degrees toward the Mediterranean Sea. The precipitous northern wall is the scarp slope of a cuesta capped by carbonate rocks of middle Miocene age. Its cliffy slopes descend to pediments graded southward to an axial valley. That valley, now extensively covered by saline crusts, sabakha deposits, and salt marshes, slopes westward into the deeper quadrangular part of the basin where elevations as much as 134 m below sea level have been measured. Nearby sinkholes and cavernous subsurficial limestone attest to past karstic activity. Presumably karstification reached a peak during the recession of the Mediterranean Sea late in the Miocene epoch when the north-dipping aquifers discharged into the then almost empty basin.

As the Mediterranean Sea receded, what is now the Western Desert of Egypt and its offshore continuations were subjected to extensive erosion by streams. A major stream issuing from the Gilf Kebir Highlands flowed northward to near the present site of Siwa Oasis, its alluvium now mostly covered by aeolian deposits of the Great Sand Sea. If it reached the Mediterranean Basin, then it may have done so through the Sahabi Channel System of Libya, or by a much shorter route through the Qattara area to an exit near the head of the Ras Alam er Rum submarine canyon offshore near Alexandria. In either case, the stream responsible for the Qattara cuesta, whether a tributary of the "Gilf River" or a part of that river's descending course into the Mediterranean Basin, apparently became inactive after its waters were diverted into underground courses through sinks and caverns. With the refilling of the Mediterranean and the accompanying diminution of subsurface aqueous activities and with the advent of more arid climatic regimes, surface processes associated with deserts have completed the shaping of the Depression to give it its present configuration and character.

INTRODUCTION

The Qattara is the largest and deepest of the undrained natural depressions in the Sahara Desert (Fig. 1). Cliffy slopes mark its northern and western boundaries. Near its south boundary, the floor rises and merges imperceptibly with the surface of the Libyan Plateau, often called the "Western Desert of Egypt." In most reports, the over-all boundary has been taken at the sea-level contour, and by that definition, estimates of the Depression's area have ranged between 18,100 and 19,500 km^2. For comparison, the larger of these figures is equal to almost half the area of Switzerland. Its maximum length is ~300 km, and its maximum breadth is 145 km. The lowest point, 134 m below sea level, is near the western end about 35 km southeast of Qara, the only permanently occupied oasis in the area.

According to El Ramly (1967), average annual precipitation ranges from 25 to 50 mm along the northern rim, decreasing to less than 25 mm in the deeper western part. Bassler (1968) reported that, despite these low averages, anomalous torrential rains during the winter months have impeded field operations, "transforming access roads into expanses of mud and lakes."

Geographically, the Depression is divisible into two parts by a line running west-northwest from along the southwestern escarpment of Cecily Hill (Fig. 1) across the floor to a point 35 km northeast of Qara. The segment west of this line shows no clearly defined axis and is approximately quadrangular in plan. By contrast, the segment to the east has an axial valley which follows a broadly arcuate course extending through Moghra Lake and thence curves west-southwestward along a line approximately parallel to the base of the bordering cliffs to the north.

The Qattara Depression is excavated in sedimentary rocks of Cenozoic age. Over much of the floor, this bedrock is variously concealed by younger deposits of wind-blown sand, saline crusts and salt marshes (*sabakha*), alluvium, or pediment gravel.

The Tertiary strata dip northward toward the Mediterranean Sea at angles of a few degrees. Superposed on this homoclinal structure are broad anticlinal and synclinal warps with general westerly trends.

Seven sets of fractures classified according to direction of strike have been identified by analysis of LANDSAT imagery (El Shazly and others, 1976, p. 15–17). The most widely publicized and at the same time most controversial of these has been called the "Qattara fault zone," a set of east-trending fractures alleged to run tangent to the extreme southern edge of the Depression. This has been called a "major crustal shear" by Moody (1966), who would extend it northward to connect with the Palmyra Fracture Zone of Syria. Neev (1975) identified the fault zone as transcurrent in nature and curved its trace to the northeast to connect with the Eratosthenes Fracture Zone off Cyprus. Most recently, Neev and others (1982) proposed that the Qattara-Eratosthenes megashear is one in a swarm of ancient left-lateral faults belonging to a system extending from Anatolia across Africa from the Nile Delta to the delta of the Niger and possibly across the Atlantic into the Amazon Basin. On the Egyptian Geological Survey's Geologic Map of Egypt (1981), faulting along the southern end of the Depression is not indicated.

Recent deep drilling and geophysical investigations in and near the Depression have revealed that the simple homoclinal structure

*Deceased November 1, 1988.

Geological Society of America Bulletin, v. 102, p. 952–960, 10 figs., July 1990.

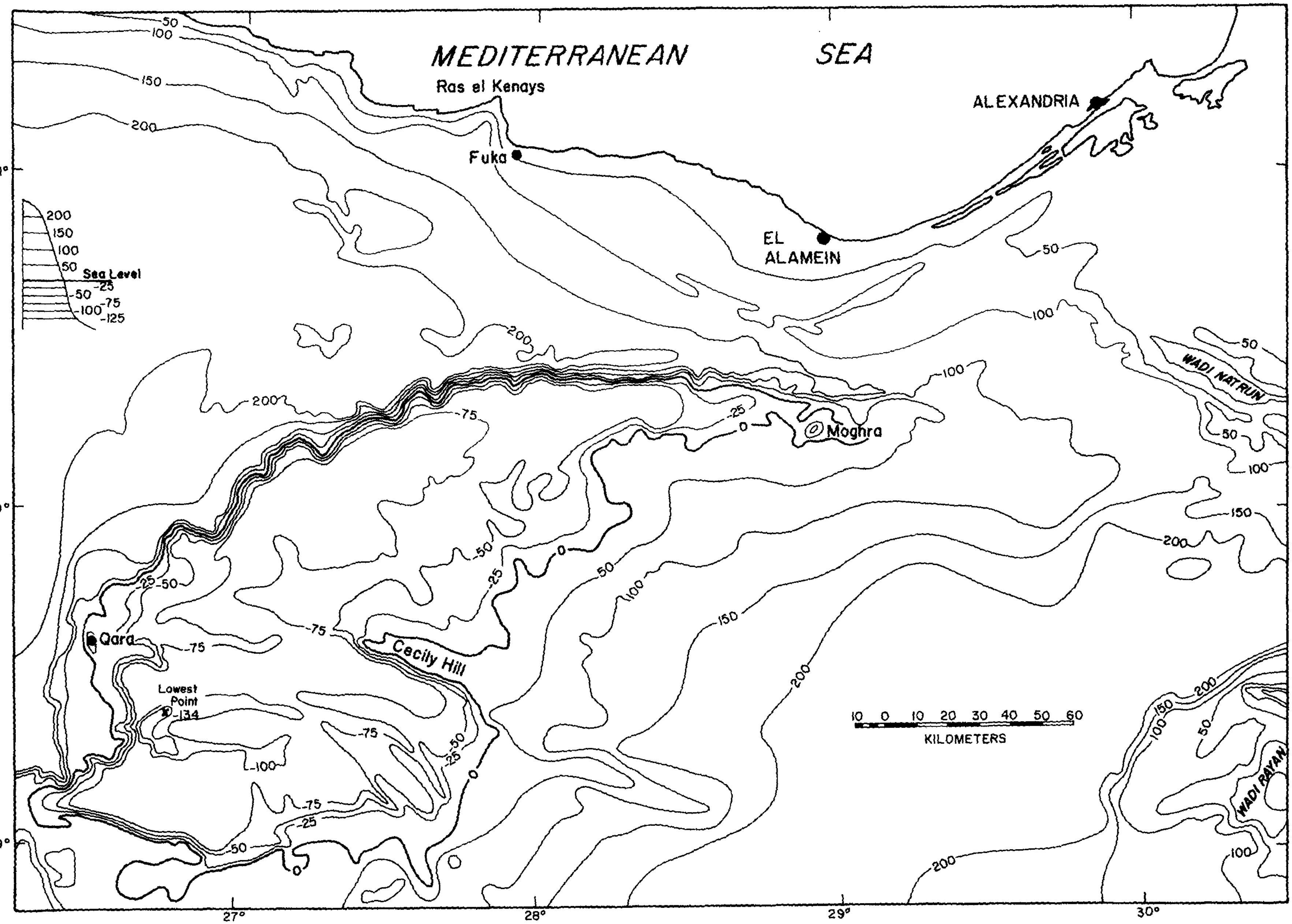

Figure 1. The Qattara Depression: location and topography.

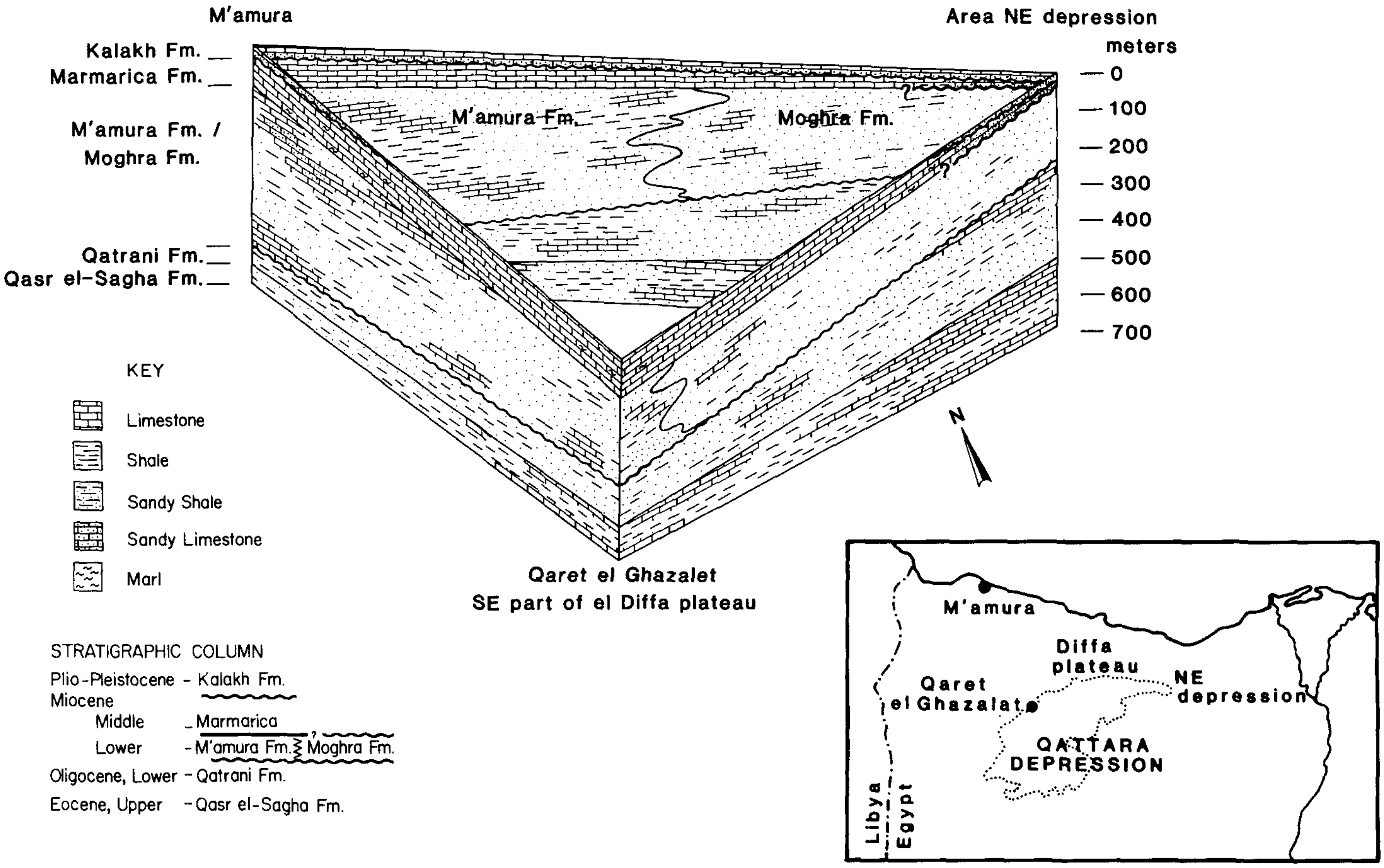

Figure 2. Cenozoic stratigraphic relationships, northwest Egypt (including the Qattara Depression).

apparent in the surficial strata of Tertiary age conceals a complex array of strongly deformed rocks ranging in age from Eocene to Precambrian (Said, 1962, p. 197–201; Salem, 1976). The Depression appears to overlie a horst trending east-northeast bordered by the Northern and Matruh basins to the north and by the Abu Gharadig Basin on the south. Estimated depths to crystalline rocks constituting the Precambrian basement vary between 3.3 and 4.5 km beneath the Depression, as compared with 5.1 to 6.2 km in the basins to the north (Meshref and others, 1980).

Of the several sets of surficial fractures recognized by El Shazly and associates, only three are represented on the tectonic map for the basement surface in the Meshref report. The most numerous trend north-northwest–south-southeast. Fractures trending east-northeast–west-southwest and northeast-southwest are also common to the surface and subsurface reconstructions. It is thus possible that surficial fractures of these three trends may be upward reflections of deep-seated fractures. Even so, the role that fractures may have played in the development of the Depression remains problematical.

STRATIGRAPHY

The Qattara Depression formed in sedimentary rocks, ranging in age from Eocene to Pliocene-Pleistocene. Stratigraphic relations among these units are complex, displaying both lateral and vertical changes (Fig. 2). Younger sedimentary deposits of Quaternary age mantle the eroded floor of the Depression in many places.

Tertiary

Eocene. *Qasr el-Sagha Formation.* The type section of this unit was established in the northern Fayum Depression, southeast of the eastern Qattara Depression, by Beadnell (1905). There it consists of 180 m of shale and limestone with sandstone in the upper part (Said, 1962). The unit contains both marine invertebrate fossils and the fossils of terrestrial vertebrates.

The strata correlated with the Qasr el-Sagha in the western Qattara Depression are predominantly clastic. They are about 36 m thick and are gypsiferous gray shale, which is interbedded with yellowish-brown calcareous sandstone and sandy limestone. The limestone contains marine invertebrate fossils of late Eocene age (Said, 1962). Fossil vertebrates collected by B. Slaughter and D. Gillette (1982, personal commun.) bear out this age. The formation overlies the middle Eocene "*Nummulites gizehensis* beds," believed to be correlative with the late Eocene Maadi Formation of the Cairo area.

Oligocene. *Qatrani Formation.* The Qatrani Formation at its type section at Gebel Qatrani north of the Fayum Depression was described by Beadnell (1905) as being 250 m thick and composed of variegated sandstone, shale, and marl. In the upper part, some beds contain a fluvio-marine fauna. Other layers contain fossil wood; still others contain abundant silicified bones of land vertebrates. From this evidence, Said (1962) concluded that the Qatrani was deposited in a near-shore marine to estuarine or bay to deltaic environment. Bown (1982), however, suggested that the ichnofossils and rhizoliths of the Oligocene Qatrani Formation in the Fayum area indicate that the environment of deposition was that of a coastal, tropical to subtropical, monsoonal rain forest with adjacent more open areas.

Although present in the subsurface in the eastern Qattara, the Qatrani Formation is exposed in the southwestern (and deeper) part of the Depression. There it consists of 41.6 m of variegated sandstone and shale with numerous marl interbeds. Fossil wood and vertebrate remains are common (B. Slaughter and D. Gillette, 1982, personal commun.). Here the Qatrani Formation rests conformably on the Eocene Qasr el-Sagha Formation and unconformably beneath the Miocene Moghra/Mamura Formation.

The Qatrani Formation is, however, truncated beneath a post-Oligocene erosion surface to the west and north of the Depression. At Qaret Hemeimat (just east of Siwa and ~100 km southwest of Qara, near the deepest point of the Qattara Depression), Shata (1953) reported a surface section with Miocene resting on middle Eocene. In a well near Mersa Matruh (~200 km almost due north of Qara), Miocene sediments are reported to rest directly on Turonian dolomites (Said, 1962, p. 202). Geologists who have worked in the area commonly regard this as a regional surface, and Said (1962, p. 104, 320) referred to the widespread presence of terrestrial basalt above the Qatrani (where present) and beneath the Miocene strata.

Early Miocene. The basal Miocene strata, below the carbonates of the Marmarica Formation, were described by Said (1962) and were named by him the "Moghra Formation." He recognized that within the area of the Depression two facies exist within the Moghra, a predominantly fluviatile to transitional facies to the east and a marine facies to the west. Said and subsequent workers ascribed the fluviatile facies to a large, northward-flowing river system in northeast Africa. Said stated, relative to this ancient drainage system, that "all the succeeding phases of Egyptian geology are inseparably tied to the history of this river" (1962, p. 208). Subsequent to Said's published description of the Moghra Formation, the Stratigraphic Subcommittee of the National Committee of Geological Sciences, reported by El Gezeery and others (1974), in recognition of the differing lithologic character and geographic distribution of the two facies of the Moghra of Said, identified the marine (western) facies of Said as a separate formation to which the Subcommittee applied the name " Mamura Formation." By this action, the definition of the Moghra Formation was restricted to the "fluviatile and fluvio-marine facies" of Said, largely east of longitude 27°30′E. The Subcommittee's revisions are followed here, recognizing, of course, that the Moghra and the Mamura are almost synchronous, and that the lateral boundary between the two is gradational and thus inevitably arbitrary. Both lie conformably beneath the strata of the Marmarica Formation except at the eastern Depression, where the relationship is unconformable. Said (1962) reported that the Moghra Formation rests conformably on Oligocene rocks, but recent workers and the writers believe that the contact is, in fact, unconformable, with both the Moghra and the Mamura resting on the eroded surfaces of Oligocene and Eocene strata.

Moghra Formation. This formation is a predominantly clastic unit consisting of fine- to medium-grained, reddish-brown, usually friable sandstone and siltstone. Many of the units are cross-bedded, and some contain numerous small- to medium-sized, well-rounded quartz and chert pebbles. Large accumulations of petrified logs, 20–75 cm in diameter and as much as 10 m in length (Fig. 3), are present in several stratigraphic horizons. The trunks lie nearly parallel to each other, with a general east-northeast orientation. Fossil vertebrates are present in the Moghra Formation, especially in the upper part. Large animals, such as hippopotamus, are present together with micro-vertebrate remains, including rodents (B. Slaughter, 1982, personal commun.). Some layers of carbonate rocks within the upper Moghra Formation (fluviatile and fluvio-marine facies) contain marine and fluvio-marine fossils.

According to Said (1962), the Moghra Formation is 202.5 m thick at the type locality, the escarpment adjacent to Moghra Oasis. The minimum thickness reported by Said is 50 m. The formation thickens northward and westward to a maximum of 410 m.

Mamura Formation. This formation, or the marine facies of the Moghra of Said, lies west of 27°30′E longitude. Like the Moghra, the Mamura Formation varies widely in thickness. Said (1962, p. 206) reported thicknesses in the subsurface, ranging from 192 to 442 m, and in the reefal phases, from 34 to 95 m. The section is dominated by carbonate, at many horizons interbedded with clay shale. Sufficient fossils are present to clearly demonstrate the marine to marine-transitional origin of these strata. They rest on truncated Oligocene to Eocene beds, the Oligocene being beveled to the west.

Middle Miocene. *Marmarica Formation.* As described by Said (1962), this formation ranges in thickness within the area of the Depression from 78 to 95 m. It is a calcareous unit, varying from pure limestone and calcarenite to shaly limestone and marl. The formation is fossiliferous throughout, with many oyster banks, various "reefal" assemblages of marine invertebrates, and widely distributed foraminifera. The basal 1–2 m, where it rests on the underlying Mamura Formation (west) or Moghra Formation (east), is fossiliferous sandy limestone to quartzose sandstone (Fig. 4) commonly containing pebbles and in places being almost conglomeratic. This basal unit is massive and well-indurated and forms the caprock for the rim of the Depression throughout much of the northern and western escarpment. The top 2–18 m of the Marmarica is a uniformly massive-bedded, white limestone and is fossiliferous throughout the region. The middle interval of the formation is richer in chalk and marl and has thin crystalline limestone with shale partings, and thus it forms slopes. Its contact with the underlying units is conformable throughout the western and central Depression but becomes unconformable in the last 60–70 km of exposure at the eastern tip of the Depression (Fig. 5).

Pliocene-Pleistocene. *Kalakh Formation.* The uppermost unit of the Cenozoic sequence in

Figure 3. Fossil logs in Miocene Moghra Formation, base of northern escarpment, Qattara Depression.

Figure 4. Line shows contact (probably disconformable) between Miocene Marmarica Formation (indurated calcareous sandstone) and underlying Moghra Formation (friable sandstone), eastern escarpment. Small breastwork marks position of Italian machine-gun emplacement remaining from El Alamein campaign of World War II.

which the Qattara Depression has formed is the Kalakh Formation. The thickness averages 14 m, and the unit commences with a basal conglomerate that is 1–2 m thick and consists of cobbles and pebbles of Marmarica Limestone in an oolitic calcareous matrix. The overlying strata are of white to pinkish-white limestone and are calcarenitic to oolitic in texture, containing scattered quartz pebbles. Some oyster banks are present. The Kalakh Formation rests unconformably on the underlying Marmarica Formation, in many sections with some angularity.

Quaternary

The Quaternary sediments associated with the Qattara Depression consist mainly of wind-blown sand and sabakha deposits. The sands, which cover much of the Depression, are in seif and barchan dunes with intervening sheet sands (Fig. 6). There are two principal areas of dunes. Those in the eastern part of the Depression are parallel and longitudinal. Their axes trend north-northwest–south-southeast, parallel to the presently prevailing wind direction. The group in the western part of the Depression forms a large, complex dune field which covers ~3,000 km^2. Dunes in this field have two predominant orientations approximately at right angles to each other. The dominant group trends north-northwest–south-southeast. The subordinate group has axes that trend east-northeast–west-southwest. The sands that compose these dunes and sheets are predominantly fine grained and well rounded. The sand is about 95% quartz; the remaining 5% consists of clay, carbonate, and some shell fragments.

The sabakha deposits cover large areas of the floor and lower slopes of the Depression, generally occurring at or below the elevation of −50 m. In the northern parts of the Depression, the sabakha is commonly moist and, in addition to the fine sand, contains saline deposits together with reddish-brown very fine silt and clay. The sabakha deposits in the southwestern part of the Depression are indurated in many places and have a rough, granular crust of salt. In some areas, the surface is of gypsiferous silt.

SALT DEPOSITS OF UNCERTAIN AGE

In 1933, Ball described a thick bed of massive, translucent rock salt capping a mesa that rises about 30 m above the floor of the deep western part of the Depression. The mesa extends for about 35 km east and west and averages about 6 km across. Ball reported that the salt rests on soft clay but gave no further stratigraphic details, and he was uncertain about the age of the salt. In his words: "Whether we have there the remains of a lenticular salt deposit which was originally intercalated in the Miocene strata, or of a similar deposit laid down on the bed of a lake which may have existed within the depression at some intermediate stage of its development, is not certain" (Ball, 1933, p. 292).

Recent investigations by the Egyptian Geological Survey have cast doubt on Ball's report. According to these reports, the mesa is formed of some 40 m of clastic deposits belonging to the Moghara Formation. It is capped by about 3 m of friable silt and clay containing thin bands of white halite and is cut by numerous veins of gypsum measuring 15 to 20 cm wide. The lithology of the caprock suggests that it may be an erosional remnant of a sabakha deposit formed at a time when the floor of the surrounding Depression stood 30–40 m higher than at present.

PREVIOUS VIEWS ON ORIGIN

Over the years, the majority opinion has held that wind erosion has been mainly responsible for excavating the Depression (Walther, 1912; Ball, 1927, 1933; Murray, 1951; Squyres and Bradley, 1964; Bloom, 1978). The sand sheets and dune fields within the Depression and the longitudinal dunes crossing the southern border and extending far southward assuredly indicate that the wind is now and long has been an effective agent of erosion. Granting that, the question arises as to how the limestone cap of the Marmarica Formation was breached in order to give the wind access to the clastic deposits of the Moghra Formation.

Said (1960, 1962) appealed to the solvent

Figure 5. Line shows angular unconformity between limestones of Miocene Marmarica Formation and fine-grained sandstone of underlying Miocene Moghra Formation, eastern Depression.

Figure 6. Floor of central Depression. Covered by sheet sands (rippled) and with occasional barchan dunes (distance).

Figure 7. Northern escarpment, eastern Depression, showing scarp retreat by mass-wasting.

action of rain water to account for the breaching of the cap. Minor depressions on the gentle-dip slopes of the Marmarica Formation would have been the sites of ephemeral lakes. Some of the lake water would migrate downward along joints carrying carbonates in solution. Upon evaporation of the playas, the surficial insoluble residue and precipitated carbonates would remain as dust to be blown away by the wind. With deepening and coalescence of these basins, the wind would at last gain access to the readily deflatable strata of the Moghra Formation.

Several large basins of internal drainage indent the plateau north of the Qattara. Characteristically these are rimmed by cliffy slopes upheld by limestone and showing clear evidence of recession by mass wasting (Fig. 7). Climbing dunes, entrained in steep gullies, emerge along the southern sides (Fig. 8). The mechanisms proposed by Said to account for these "little Qattaras" seem quite reasonable. On the other hand, the cuesta on the north side of the "big Qattara" lacks the irregular re-entrants one might expect to have formed by coalescence of solution pits while, at the same time, being characterized by extensive mass wasting (Fig. 9).

The presence of a cuesta along the northern side of the Qattara is the basis for a hypothesis which proposes that the Depression began as a stream valley incised nearly along the regional strike of the Tertiary strata. The question then arises as to how a segment of a valley with external drainage became an undrained basin. Two possibilities have been suggested. During an interval of arid climate, water ceased to flow down the valley, and the wind excavated a segment of it to form the present depression (Collet, 1926; Al Izz, 1971; Said, 1981). Alternatively, during the time when the stream was active, infiltration of ground water through carbonate rocks initiated karstic processes (Blanckenhorn, 1921; Stringfield and others, 1974). According to this view, the deeper western part of the Depression represents a segment of a former stream valley interrupted and lowered by development and coalescence of sinks.

The idea that the depressions of the Western Desert owe their origin to deformation rather than to erosion has been more often denied than affirmed. The possibility that the Qattara originated as an asymmetric graben by downward displacement of strata north of the Qattara fault zone, however, has been suggested by Said (1979). With the recession of sea level in the Mediterranean Basin during the late Miocene epoch, sea water entrapped in the fault trough evaporated to dryness. By that interpretation, Ball's halite deposits in the western reaches of the Depression represent a remnant of a formerly thicker and more extensive sequence of evaporites, most of which have been redissolved resulting in a lowering of the Depression's floor. At least the southwestern part may thus be a relic of the Mediterranean sea floor of Messinian time.

AN ECLECTIC AND SPECULATIVE CHRONOLOGY OF EVENTS

We propose that the Qattara Depression originated as the valley of a through-flowing stream draining into the ancestral Mediterranean. The stream incised its bed into the Moghra Formation. A cuesta upheld by the Marmarica Formation formed along the northern side of the valley. During this early stage in geomorphic history, the cuesta front must have retreated northward as a result of stream erosion and mass wasting. Concurrently, its relief must have increased as the axial stream incised its valley.

With the lowering of the Mediterranean Sea during the late Miocene epoch, ground water impounded in northward-dipping aquifers discharged into the Mediterranean Basin. That discharge activated karstic processes which interrupted the external drainage by the production and coalescence of sinks in what is now the deeper western part of the Depression. The axial stream then drained westward into these sinks.

In the eastern part, the axial stream continued to incise its valley deeper into the Moghra Formation until the Mediterranean region again became a sea. Southward-flowing tributaries to the axial stream, heading along the cuesta, cut fan-shaped pediments into the weakly resistant Moghra Formation

LATE TERTIARY DRAINAGE IN EGYPT AND LIBYA

Field studies combined with interpretations of LANDSAT and radar imagery have fairly well established that at some time during the late Tertiary period streams issuing from the Gilf Kebir Highlands (southwestern Egypt) flowed northward through the strip presently occupied by the Great Sand Sea (McCauley and others, 1982a, 1982b). The thickness of the sand increases northward. A well drilled 160 km south of Siwa Oasis penetrated at least 120 m of sand; related seismic surveys north of the well indicate

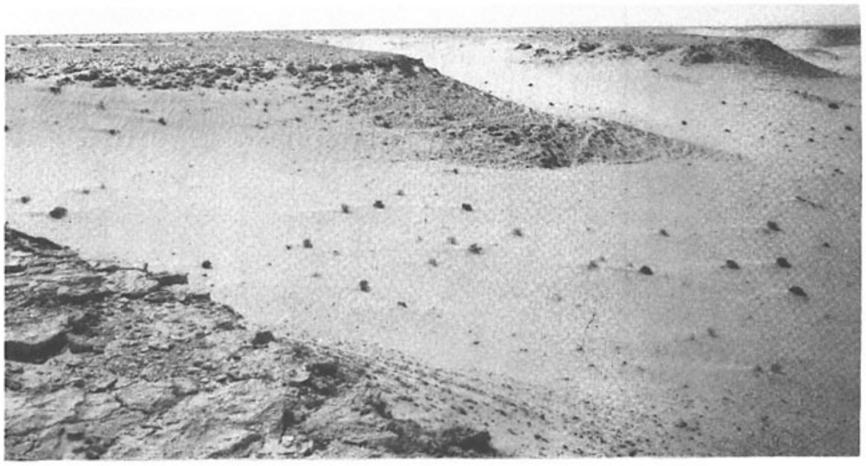

Figure 8. Small depression, Marmarica Plateau, north of Qattara. Rim is basal Marmarica limestone. Depression is in friable sandstones of Moghra Formation. Prevailing northwest wind blows weathered Moghra sand up small south-heading wadis and produces small longitudinal and "elephant-head" dunes immediately downwind on the Plateau.

that the sand reaches 200–300 m in thickness (Haynes, 1982). According to Said (1983), beneath the surficial layers of wind-blow sand, accumulations of indurated coarse sand and gravel must be alluvial in origin.

Similar evidence for old drainage systems in presently arid parts of Libya has been forthcoming in recent years. Pachur (1980) reported discovery of a major "fossil" drainage system emanating from the northern flanks of the Tibesti Mountains and traceable for more than 1,000 km toward the Gulf of Sirte. Geophysical crews prospecting for oil along the northeastern flank of the Sirte Basin have found deposits of alluvium filling channels cut in middle Miocene carbonate rocks of the Al Jaghbub Formation, the equivalent of the Marmarica Formation of Egypt (Barr and Walker, 1973). This Sahabi Channel System is between latitudes 29°N to 30°N and longitudes 20°45′E to 23°E. The main channel runs northwest for more than 100 km, then west or southwest for more than 50 km. It has a maximum depth of 1,300 ft (~400 m) and ranges in width from less than a kilometer to 5 km. Walls are steepsided, and there are no signs of meandering. The channel fill consists of unconsolidated sand, silt, and clay.

Barr and Walker (1973) speculated that the Sahabi Channel probably extends to near the apex of the Gulf of Sirte where a channel with an apparent depth of 1,800–2,000 ft (555–615 m) has been detected. They proposed that the Sahabi Channel was cut during the late Miocene epoch when the Mediterranean Sea had virtually disappeared by evaporation.

According to Said (1983), Egypt was subjected to vigorous erosion by streams attending the lowering of base level during the late Miocene epoch. Drainage lines in the Eastern Desert have been preserved, but those in the Western Desert have mostly been obliterated by later erosion or else covered by younger sediments such as dunes or sheets of wind-blown sand. Linear ridges of alluvium resting on wind-scoured limestone of Eocene age have been observed in the area ~300 km south of the Qattara Depression (R. Said, 1989, personal commun.). A striking example of such an "inverted wadi" is shown on an aerial photograph reproduced by Whitney (1984).

Granted that a stream flowed northward from the Gilf Kebir to near the present site of Siwa Oasis, and assuming that this "Gilf River" debouched into the Mediterranean Basin, then the question arises as to what course it may have taken from the Siwa area. Said (1983, Fig. 2) suggested that it pursued a course northwest, exiting Egypt near the 28th parallel. In that case, the Sahabi Channel System may represent its western continuation leading toward the Gulf of Sirte. An alternative possibility is suggested by Figure 10, showing the river turning eastward and following a much shorter course across the Qattara area to enter the Mediterranean Basin near the present site of Alexandria.

With shrinkage of the Mediterranean Sea during the late Miocene epoch, the "Eonile" excavated a canyon about 1,300 km long with a maximum depth of about 2,500 m (Said, 1981, p. 100). Concurrently, the continental margin to the west was subjected to extensive erosion by streams. Seismic reflection profiles reveal a rough and gullied topography produced by Messinian rivers whose northern extremities lie as much as 2.5 km below present sea level. The Ras Alam er Rum Canyon trends north-northeast and by projection would cross the present shoreline at about 31°30′N and 29°E, heading toward the eastern end of the Qattara (Ryan, 1978; Barber, 1981).

As noted above, the surface of unconformity beneath the Pliocene-Pleistocene strata directly north of the Qattara Depression has a local relief of as much as 95 m. The drainage pattern of streams responsible for the erosion manifest in this unconformity remains to be discovered, but it seems clear that the landward area north of the Qattara and the contiguous continental margin now offshore was subjected to stream erosion during the Messinian salinity crisis.

KARSTIC FEATURES IN EGYPT AND LIBYA

The Western Desert of Egypt has been characterized as a karstland by Stringfield and others (1974). These authors proposed that solution of carbonate rocks has been largely responsible for development of the depressions in which the

Figure 9. Mass-wasting, northern escarpment, central Depression. Two prominent cliffs are in Marmarica Formation. Strata below lower cliff are Moghra Formation.

oases occur. Specific lines of evidence to support this generalization were not given, although its plausibility is increased by reports of karstic features at localities scattered over the Western Desert and its continuation into Libya.

For example, at localities southeast of the Qattara, surficial limestone of Eocene age preserves patches of *terra rosa* soils which extend downward as pipe-like fillings of cavities in the bedrock. Haynes (1982) has interpreted these cavities as karstic features developed when a subtropical climate prevailed there later in Tertiary time.

Sinkholes have been reported in the western part of the Qattara (El Ramly, 1967). The Gib Afia water well, drilled northwest of Qara Oasis, lost circulation between depths of 228 and 246 m, where the drill passed through a cavern in limestone of Eocene age (El Ramly, 1967). According to R. Said (1981, personal commun.), this well is located in an enclosed depression 37 m deep. He suggested that this depression is either a sinkhole or a crater formed by impact and explosion of a meteorite. The first hypothesis seems the more likely in the absence of any reports of geologic features normally associated with impact structures.

According to El Ramly (1967), the early and middle Miocene formations, as well as those of the late Eocene, are important hydrostratigraphic units in the Western Desert. Such appears to be also the case in Libya. Guerre (1980) has described the karstic features of the Benghazi Plain in eastern Libya. These include sinkholes and a network of caverns hollowed in limestone formations of Eocene and Miocene age. The known depth of karstification extends to more than 130–150 m below sea level.

DISCUSSION

The origin of the Qattara Depression is still a geological puzzle and is likely to remain so until details of areal geology and stratigraphy can be coordinated with information from seismic surveys and well logs. The following are some of the issues that should be addressed.

Conflicting reports concerning the mineralogy

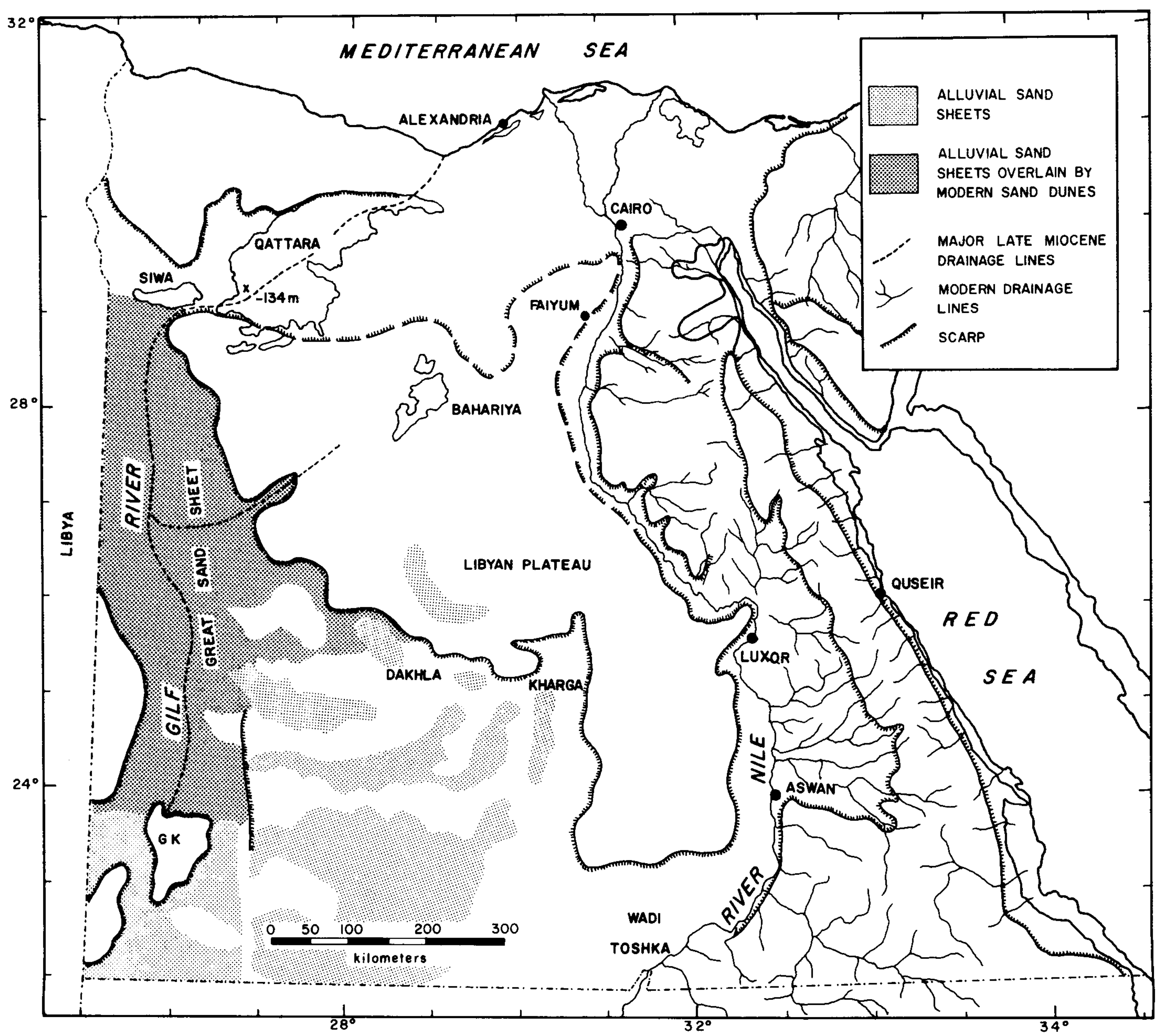

Figure 10. Possible course of the "Gilf River," flowing northeastward through the Qattara to enter the Mediterranean Sea just west of Alexandria.

and age of the salt deposits in the western part of the Depression need to be resolved. Do they fit into the Tertiary sequence exposed in nearby walls of the Depression? Or are they erosional remnants of formerly more extensive sabakhas; or are they precipitates from a saline lake that evaporated to dryness?

Is there a Qattara fault zone? If so, has it displaced rocks younger than Eocene, and in that case, what role has it played in the geomorphic history of the area?

Is there alluvium beneath the sand sheets and sabakhas along the course of the axial valley? Where are the sinks in the western reaches of the Depression located with respect to the terminus of that valley?

What is the configuration of the irregular surface of unconformity beneath the Pliocene-Pleistocene deposits north of the Depression? Is there evidence that the streams which sculpted that surface drained into the Mediterranean Basin? Conversely, is there any evidence that, during the Messinian desiccation event, isostatic upwarping of the Mediterranean floor produced shoreline bulges that caused northward-flowing streams to reverse their courses and drain inland (see Norman and Chase, 1986)?

These questions and others that bear upon the problem at hand are not unanswerable, but are not likely to be resolved in the near future. The Qattara Depression is difficult to access physically and because of political and military considerations, as well. Information from petroleum exploration companies is privileged, and when given, is not usually allowed to be cited as a source.

ACKNOWLEDGMENTS AND HISTORY OF PROJECT

In 1967, Brooks was asked by Dr. Rushdi Said (then President of the Egyptian Geological Survey and Mining Authority) to make a reconnaissance trip to the Qattara. He was accompanied by Professors Bob Slaughter and William Gealy, both then of Southern Methodist University, and by a geological field party of the Egyptian Survey headed by Dr. M. Tag. The expedition was also assisted in the field by Mr. Dub Martindale of the Pan-American Petroleum Company (now AMOCO). The purpose of the expedition was to examine the Depression with regard to its origin, to study the sabakha deposits, and to prospect for vertebrate fossils. Brooks revisited the Depression in 1976 with Said and Dr. M. Kassas of the University of Cairo.

In 1977, Albritton, Brooks, and Said began a series of conversations with the National Science Foundation with regard to the possibility of funding a joint expedition with the Egyptian Geological Survey for the purpose of studying the nature, bounding relationships, and the genesis of a layer of rock salt reported by Ball (1933) in the early Tertiary succession of the southwestern depression. The intent was to use this as a clue to answer the larger question of the origin of the Qattara. These conversations eventuated in a travel grant from the Foundation to Albritton and Brooks to enable them to visit Cairo and the offices of the Egyptian Survey in 1978. Studies of geologic and topographic maps and aerial photographs of the Depression, as well as conversations with Dr. Bahay Issawi and his staff, made it possible to plan an expedition in 1981. This expedition was supported by the AMOCO Petroleum Company, and extensive logistical support in the field was provided by the Geological Survey of Egypt.

Specifically to be acknowledged for support of the project are the following: The Egyptian Geological Survey and Mining Authority for extensive logistical support, The National Science Foundation (United States) and the AMOCO Petroleum Company for financial support, and the Institute for the Study of Earth and Man at Southern Methodist University. Especially useful discussions have been held with Dr. Rushdi Said, Professor Bob Slaughter, Dr. David Gillette, Professor Fekri Hassan, Dr. Geoffrey Franks, Professor C. V. Haynes, and Dr. John Harms.

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MANUSCRIPT RECEIVED BY THE SOCIETY JUNE 3, 1988
REVISED MANUSCRIPT RECEIVED SEPTEMBER 29, 1989
MANUSCRIPT ACCEPTED OCTOBER 11, 1989