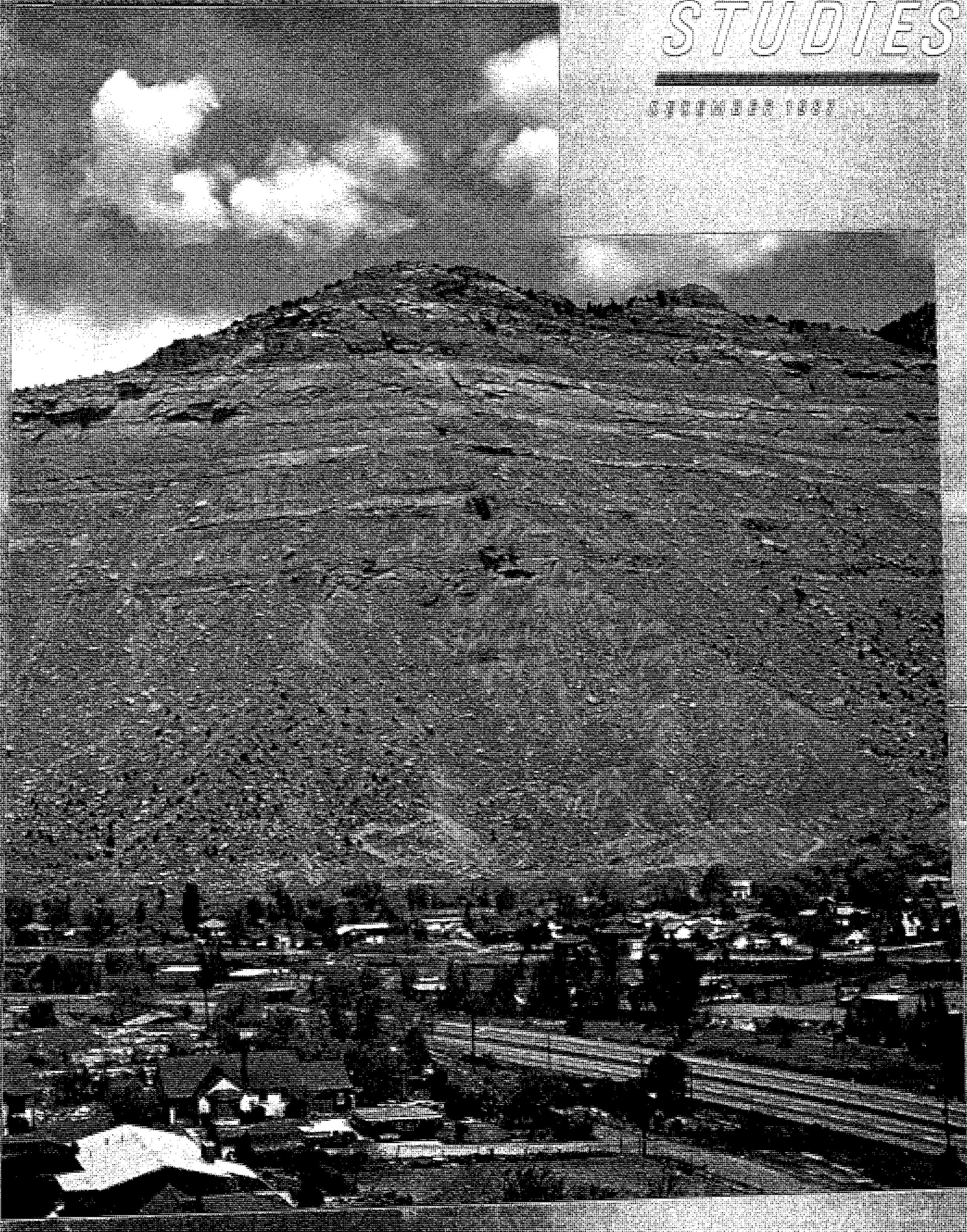
YOUNG UNIVERSITY

GEOLOGY STUDIES

DECEMBER 1987



VOLUME 34, PART 1

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

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A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted by BYU faculty and outside contributors is externally reviewed by at least two qualified persons.

Cover: Cretaceous coal-bearing rocks near Price, Utah

ISSN 0068-1016
12-87 600 31944

Stratigraphy and Depositional Environments of the Gebel el-Rus Area, Eastern Faiyum, Egypt

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ABSTRACT

One of the best-exposed sequences of Tertiary strata in the western desert of Egypt occurs along the Nile-Faiyum divide, east of the Faiyum depression. Eocene and Pliocene rocks are well preserved there and form many of the prominent ridges and peaks on Gebel el-Rus.

Middle and upper Eocene units, including the Gehannam Formation and Birket Qarun Formation in this area, form a sequence 120 m thick. Nearly 65% of this series is composed of slope-forming, largely noncalcareous mudstone, marly mudstone, and unlithified siltstone. The remaining 35% (of Eocene strata) forms resistant, ledge-forming units, which are mostly composed of calcareous sandstones and sandy limestones. They contain abundant foraminifera and sedimentary structures that are indicative of shallow marine environments, which were often affected by tidal currents.

More than 72 m of Pliocene rocks of the (here named) Seila Formation unconformably overlie Eocene strata with subtle, but observable angular discordance. Eocene units generally dip 1 to 7 degrees northward below horizontal Pliocene beds. Debris-flow deposits of Pliocene age cut into Eocene strata and fill paleochannels up to 120 m wide and 30 m deep that are traceable nearly 1 km. Elsewhere these deposits form broad sheetlike breccias that are often continuous with channel breccia deposits. This lower or breccia member of the Seila Formation occurs virtually everywhere along the Eocene-Pliocene contact on Gebel el-Rus, and is composed of subangular blocks up to 3 m in diameter that were derived from local sources.

Well-sorted sandstones and mudstones from the middle member of the Seila Formation were deposited in a gulf that resulted from a marine transgression, which invaded the area during the early Pliocene. These sands and muds drape over the breccia member with initial dips of 5° to 20° southeast and delineate the early Pliocene paleoslope.

Braided stream–alluvial fan deposits, largely composed of gravels and pebbly sands in lenticular masses, mark the regression of the Pliocene gulf from the Gebel el-Rus area. Sedimentary structures in this upper member show that the clasts were from an ancient highland source area immediately to the west.

During the Pleistocene the topography of the eastern Faiyum was reversed, forming part of the present-day Faiyum depression. Nile River waters invaded the depression in late Pleistocene times, forming the Paleolithic Lake Moeris. Lacustrine sediments from this lake onlap middle Eocene Gehannam Formation strata up to 40 m above present sea level on the lower slopes of Gebel el-Rus.

INTRODUCTION

SIGNIFICANCE OF THIS STUDY

Some of the best exposures of Tertiary rocks in the Western Desert of Egypt are found on Gebel el-Rus along the divide between the Nile Valley and the eastern Faiyum (figs. 1 and 2). The western face of this divide is a relatively steep escarpment that rises from 20 m above sea level to approximately 125 m on the peak north of the Seila Pyramid. Eocene and Pliocene strata, barren of all vegetation, are exposed on the ridge and overlook the lush cultivated fields of the Faiyum depression.

Bedrock is well hidden under a thick alluvial cover on the eastern side of Gebel el-Rus, which slopes gently to

A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, April 1985.

the Nile Valley 10 km to the east. The green Nile River Valley and steep-walled Meidum Pyramid, 10 km east of the Seila Pyramid, are on lower slopes and valley fill.

Gebel el-Rus, a rather small mountain, covering only about 8 square kilometers, contains many interesting geologic features. An angular unconformity between Eocene and Pliocene beds, Pliocene paleochannels filled with debris-flow deposits, a variety of sedimentary structures, trace fossils, and distinctive faunas are some of the important aspects of the area that require local detailed studies.

There has been a lack of even moderately detailed geological studies in the eastern Faiyum with respect to stratigraphy, paleoecology, and sedimentary petrology of the Eocene rocks. Environments of deposition for rocks exposed in escarpments and hills around the Faiyum depression and in surrounding regions have been discussed in a regional way by early workers, including studies by Beadnell (1905), Sandford, and Arkell (1929), and Tamer, El-Shazly, and Shata (1975). However, these and other studies have differed in their interpretation of the geologic section and its depositional history. The present study concerns a relatively small area with good exposures that was examined intensively in order to document evidences of environments and geologic history of these Tertiary rocks and to compare these data with those obtained by earlier regional studies.

Geological procedures included measurement and description of eight stratigraphic sections, correlation of the various lithologic units and subunits between sections (fig. 3), preparation of a geologic map on a scale of approximately 1:22,000 (figs. 4 and 5), lithologic descriptions, and evaluation of paleontological data.

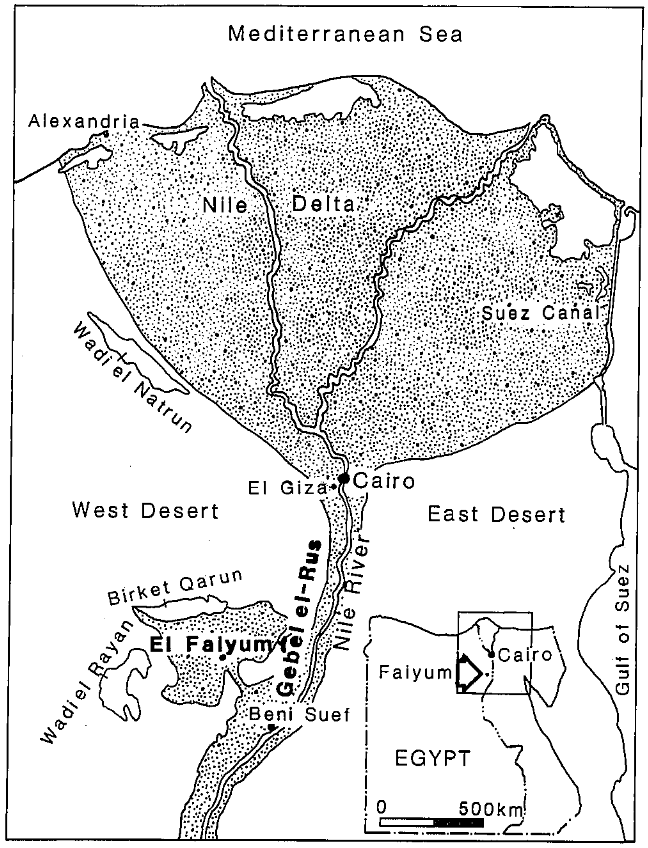


FIGURE 1.—*Index map of northern Egypt, the Nile Valley, and the Faiyum region.*

RELATIONSHIP TO THE ARCHAEOLOGICAL EXPEDITION

The area under consideration is part of a 40-square-mile archaeological site in the eastern Faiyum. Brigham Young University has recently received permission from the Egyptian government to study and excavate in this area.

The Departments of Ancient Studies and of Geology at Brigham Young University proposed this geological study to support this archaeological excavation. This geologic study will provide detailed stratigraphic and lithologic information on the area. Additional archaeological and geological investigations in this historic area are planned.

LOCATION

This study involves strata exposed on the western face and crest of Gebel el-Rus, which forms part of the eastern edge of the Faiyum depression and the western edge of the Nile Valley-Faiyum divide, approximately 8 km northwest of Seila and 20 km northeast of the city of Faiyum.

The area of interest is centered at approximately 29 degrees 22 minutes north latitude and 31 degrees 04 minutes east longitude (figs. 1 and 2).

PREVIOUS WORK

The earliest geological studies of the Faiyum were conducted in the 1890s by Blackenhorn (1901, 1902). He briefly described the rocks exposed in the area and discussed possible origins of the Faiyum depression. He (1901) concluded that the triangular depression was produced by faulting, although he lacked substantial evidence. The intensive controversy generated by his paper caused him to retract (1902); many of the faults he had proposed were later proven to be nonexistent. Displacements on minor faults that did exist are too small and too restricted in area to explain the origin of the depression.

Beadnell, of the Geological Survey of Egypt, conducted fieldwork in the area in 1898 and 1901 and completed some of the most comprehensive and informative studies yet done on the geology of the Faiyum area. In a

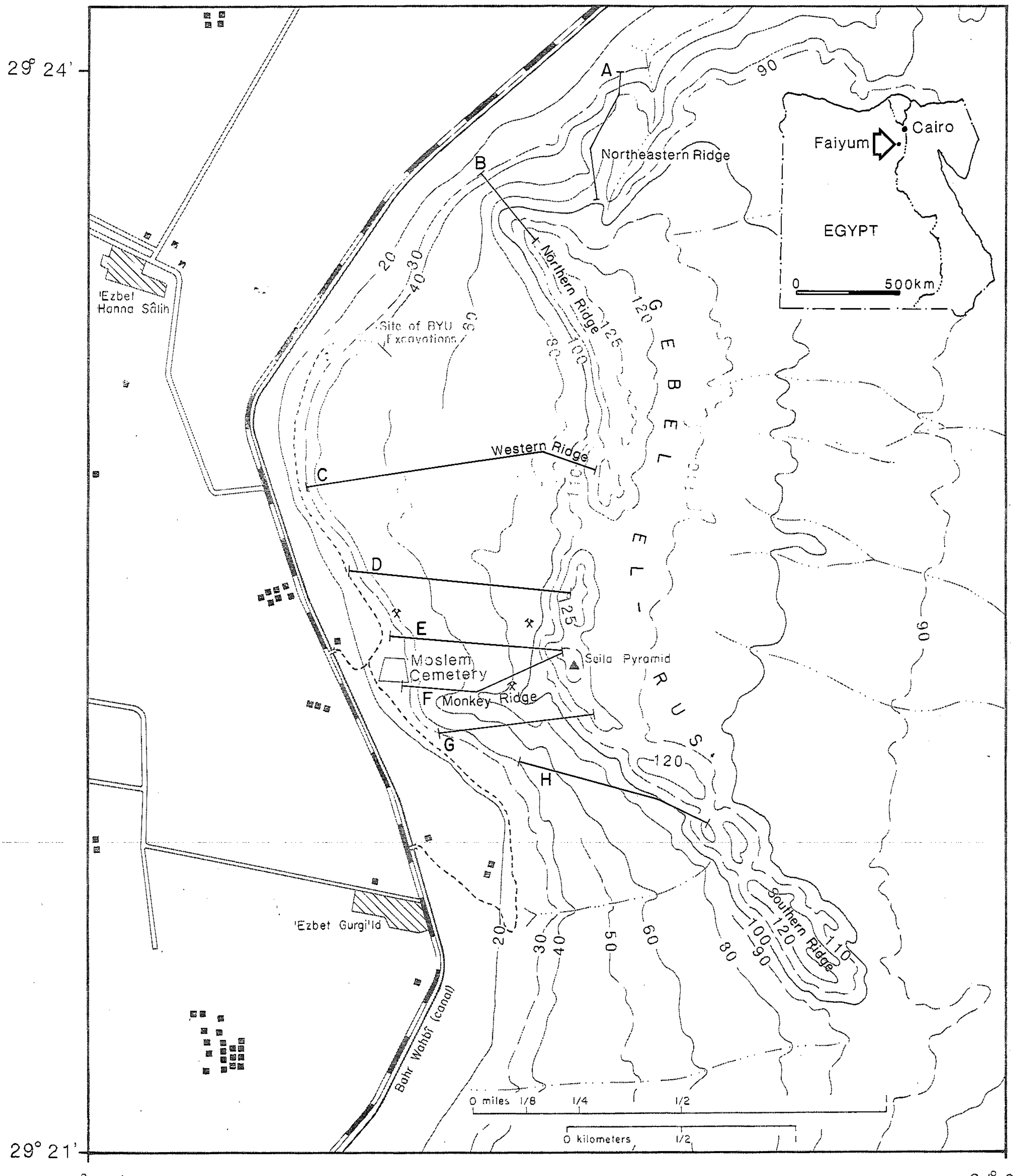


FIGURE 2.—*Index map of the Gebel el-Rus area in the eastern Faiyum, showing locations of stratigraphic sections A–H. Note symbols that indicate building stone quarries.*

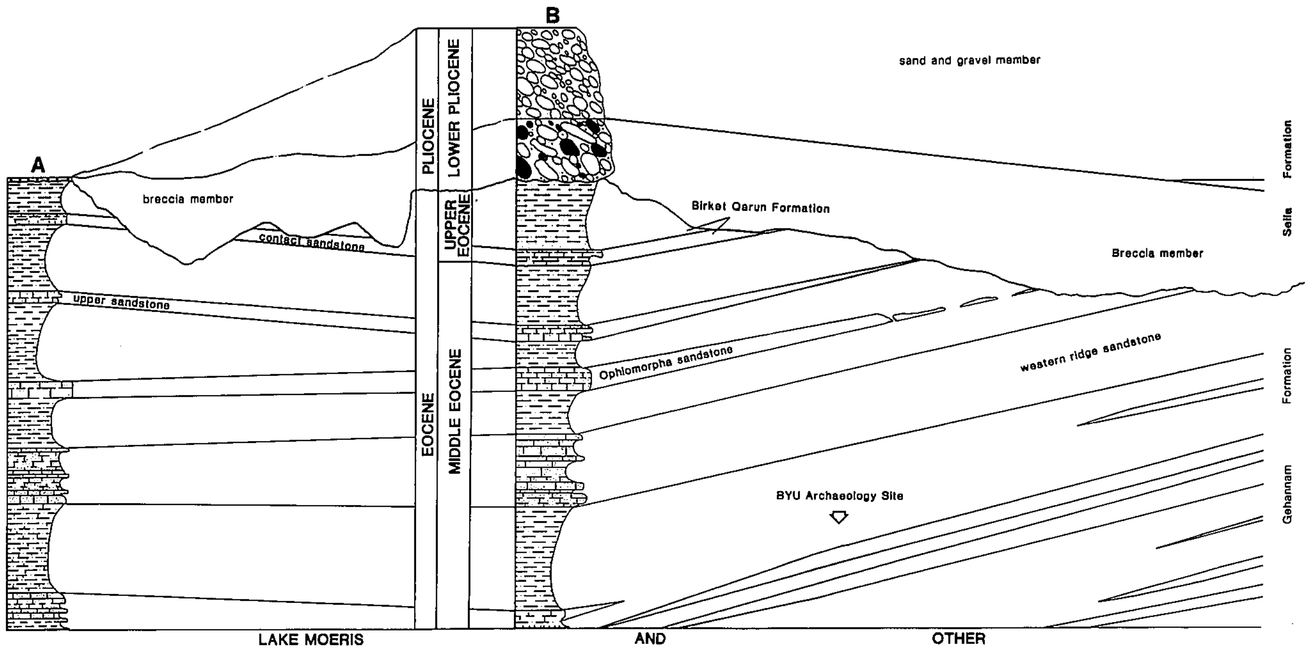


FIGURE 3.—*Measured stratigraphic sections A–H with correlation of various units exposed in the study area.*

preliminary paper (1901), he delineated the stratigraphy of the Faiyum and surrounding exposures, gave his ideas on the origin of the depression, and described unusual vertebrate fossils in units exposed around the basin. He also documented the general lithologic and invertebrate succession.

Beadnell (1905) later published more details concerning the geology of the Faiyum and surrounding areas on a region-by-region, epoch-by-epoch basis. His stratigraphic descriptions were accompanied by measured sections and cross-section illustrations. Also considered were the tectonic history and depositional environments of Eocene through Recent strata of the Faiyum.

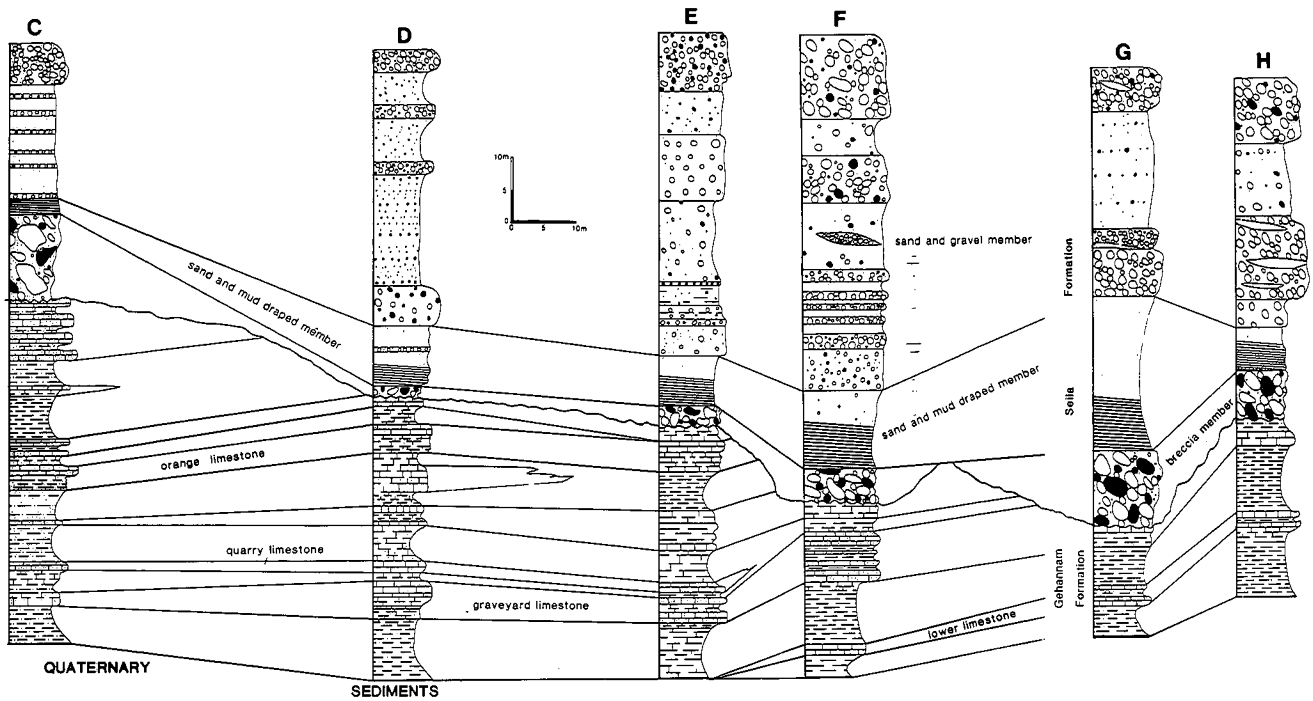
Gardner (1927, 1929, and 1934) further considered the origin of the Faiyum depression and described the Pleistocene and Recent geology of the northern Faiyum Desert. She (1927, 1934) described deposits of Pleistocene and Recent lacustrine environments and gave evidences of Paleolithic and historic man in the Faiyum depression. Her 1929 paper mainly emphasized the differing views on the origin of the Faiyum depression. She defended Beadnell's proposal that it was scoured out by wind erosion, which began during the Pliocene, and rejected Sandford and Arkell's (1929) hypotheses of post-Pleistocene fluvial erosion as the main agent of excavation.

Sandford and Arkell (1929) presented detailed descriptions of the Pleistocene-Recent Nile River Valley and lake terraces of the Faiyum depression and summarized the geologic history and regional paleodepositional setting of the Faiyum area. They briefly described and interpreted the Eocene through Pliocene sedimentary section and included a regional geologic map of the Faiyum-Nile Divide with cross sections of different units and geomorphic features.

Little (1936), then director of the Geological Survey of Egypt, wrote about the Faiyum and Hauwara Channel. His studies, like most of his predecessors', principally concerned the sediments and lake levels of Pleistocene-Holocene Lake Moeris. Beach deposits and terraces were dated from the pottery and stone tools of the early Egyptians. Brief descriptions of Pliocene and Eocene strata were included in this work.

Said (1962, p. 99–106) summarized the geology of the Faiyum depression as part of an extensive volume on the geology of Egypt. He based his report largely on the earlier works of Beadnell (1905). Conclusions on regional depositional environments of Eocene through Recent sediments were based largely on general lithologic and paleontological data given by Beadnell.

Tamer, El-Shazly, and Shata (1975a, 1975b) largely republished data based on Beadnell (1905), Gardner and



Thompson (1934). Their work is the most recent publication on the geology of the Faiyum area and is divided into two parts: one emphasizes the geomorphology and the other the stratigraphy of the Faiyum-Beni Suef region. They published one detailed stratigraphic section on the sedimentary sequences in the northeastern end of the Faiyum depression. Several cross sections and a simplified geological map were also published. They summarized depositional environments of exposed units and compared previous studies. They noted that little regarding the stratigraphy of the Faiyum has been published since Beadnell's (1905) work. They mapped folds and faults and briefly discussed them in a section on geomorphology of the Faiyum-Beni Suef region. They also discussed possible mechanisms of excavation for the Faiyum depression and summarized the views of others who have studied in the area. They concluded that the Faiyum depression probably resulted from a complex interaction of tectonic activity, chemical weathering of calcareous rocks, water erosion during wet climates, and wind abrasion when an arid environment prevailed.

ACKNOWLEDGMENTS

Studying in a foreign land can often be difficult and challenging because of differences in customs, language, and culture. Several Egyptians provided essential help to the Brigham Young University archaeology project and this geological study. I express my appreciation to the following: Dr. Ahmed Kadry, Director of Egyptian Antiquities Organization; Ali Khouly, Director of Antiquities for Middle Egypt and former Director of Antiquities for Middle and Lower Egypt; and members of the Permanent Committee of the Egyptian Antiquities Organization for granting Brigham Young University permission to excavate and work at the Seila site. Appreciation is also expressed to the following for support and assistance to the research team during the 1984 season: Mr. Moustafa el-Zairy, Chief Inspector at Beni Suef; Mr. Ali Bazidi, Chief Inspector at Faiyum; Mrs. Sami, Inspector at Faiyum; Mr. Akram Eshak, Inspector at Faiyum and Inspector working with the excavation team on site; and Mr. Sabri Gabbour, Director of the museum at Kom Aushim. I also thank Ramaddan Abused Mohammed and Abdel Setar Ahmed who assisted and accompanied me in the field during my geological excursions at the site. Support for the study was provided by Brigham Young University and the Mormon Archaeology and Research Foundation, and Mr. Wallace Tanner, its president and founder.

Dr. J. Keith Rigby was chairman of the thesis advisory committee, and Drs. Jess Bushman and Revell Phillips were committee members. Thanks is also given to Dr.

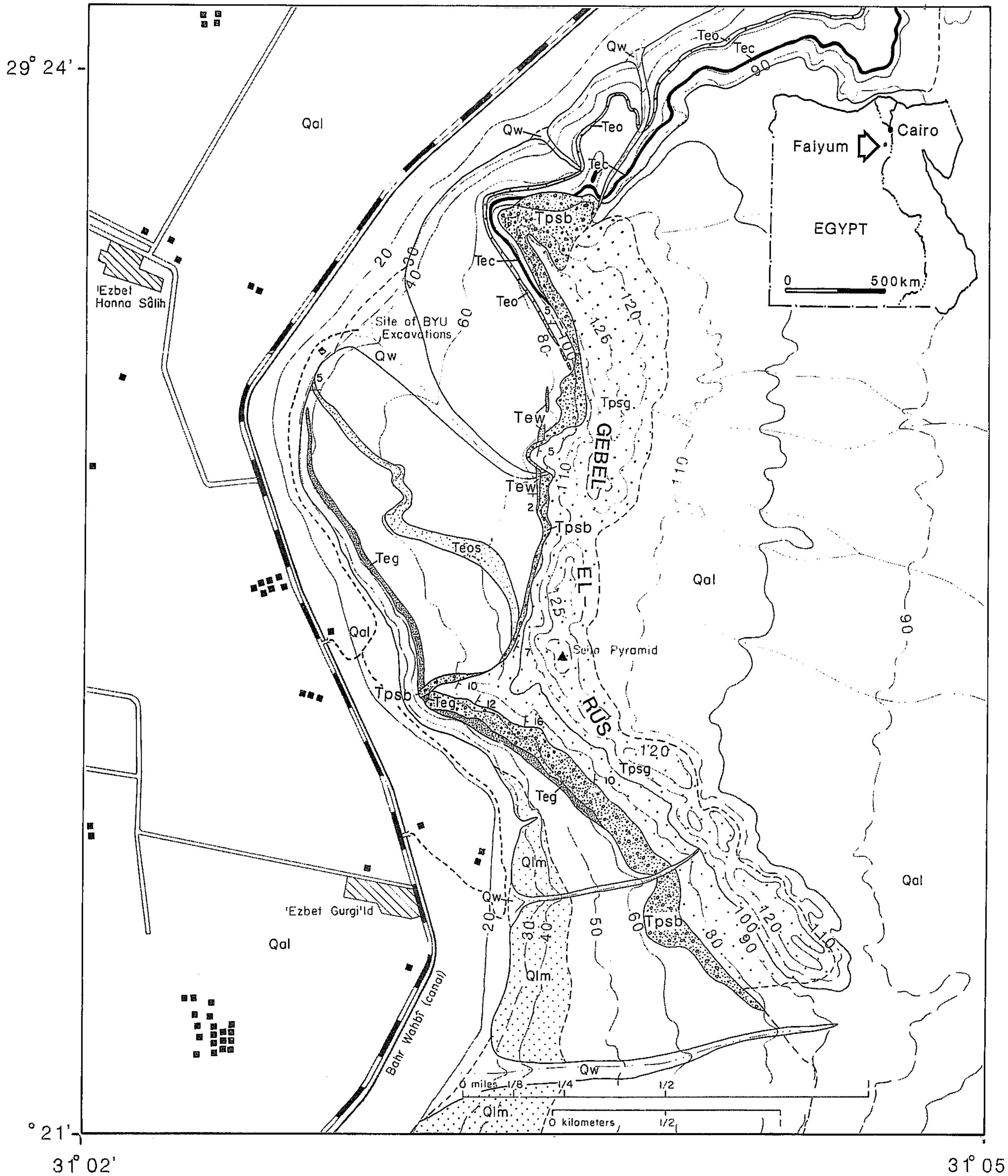


FIGURE 4.—*Geologic map of Gebel el-Rus area. Unit symbols are defined in figure 5.*

Wilfred Griggs, Director of Ancient Studies at Brigham Young University and the director of the Seila archaeological expedition in Egypt. He and Dr. Phillips encouraged the study and invited me to participate in the expedition. Phillips Petroleum Company and Marathon International Oil Company provided financial support for fieldwork and thesis preparation. Staff at Phillips Petroleum Company prepared several thin sections of lithologic and paleontological samples collected from the study area. Microfaunal identification and interpretations were provided by Dr. Stanley H. Frost.

REGIONAL STRUCTURAL RELATIONSHIPS

Said (1961) described the tectonic framework of Egypt, concluding that Egypt is composed of three structural units: (1) the Arabo-Nubian massif, (2) the stable shelf, and (3) the unstable shelf. The Arabo-Nubian massif is the basement core, and these rocks are well exposed east of the Faiyum depression in major ranges of the southern Sinai and along the Red Sea in the Eastern Desert of Egypt.

The Arabo-Nubian massif is overlapped and surrounded by the stable shelf, an area of thin continental and epicontinental Cretaceous and Cenozoic units. The Upper Cretaceous–Lower Tertiary Nubian Sandstone is overlain by Eocene rocks, part of which were investigated in this study. Eocene shale, limestone, and sandstone represent a major marine transgression that overlapped the stable shelf. The transgression began during the Late Cretaceous–Early Tertiary transition and ended with a regression that took place from the middle Eocene to near the close of the Oligocene.

The stable shelf, according to Said (1961, p. 200–6), is characterized by the thinness of the sedimentary section, minor normal faulting, and basin-producing rift zones of the Red Sea–Suez region. Although major anticlinal features are lacking in the stable shelf, there are several broad and gentle domes. Minor movement of these structures has produced local paraconformities rather than major unconformities.

Most of northern Egypt is considered part of the unstable shelf or mobile belt, according to Henson (1951, p. 118) and Said (1961, p. 199). Compressional stresses responsible for SW–NE-, NW–SE-, and E–W-trending folds and faults mainly began in the Middle and Late Cretaceous. Because of the incompetent nature of rocks of the unstable shelf, internal stresses were relieved through tensional movements, and normal faulting resulted when compressive stresses were released.

The Faiyum area lies within Said's stable shelf. Areas west of Gebel el-Rus and the Nile-Faiyum Divide, in the Western Egyptian Desert, have been extensively faulted and folded. The Nile Valley to the east is also fault-con-

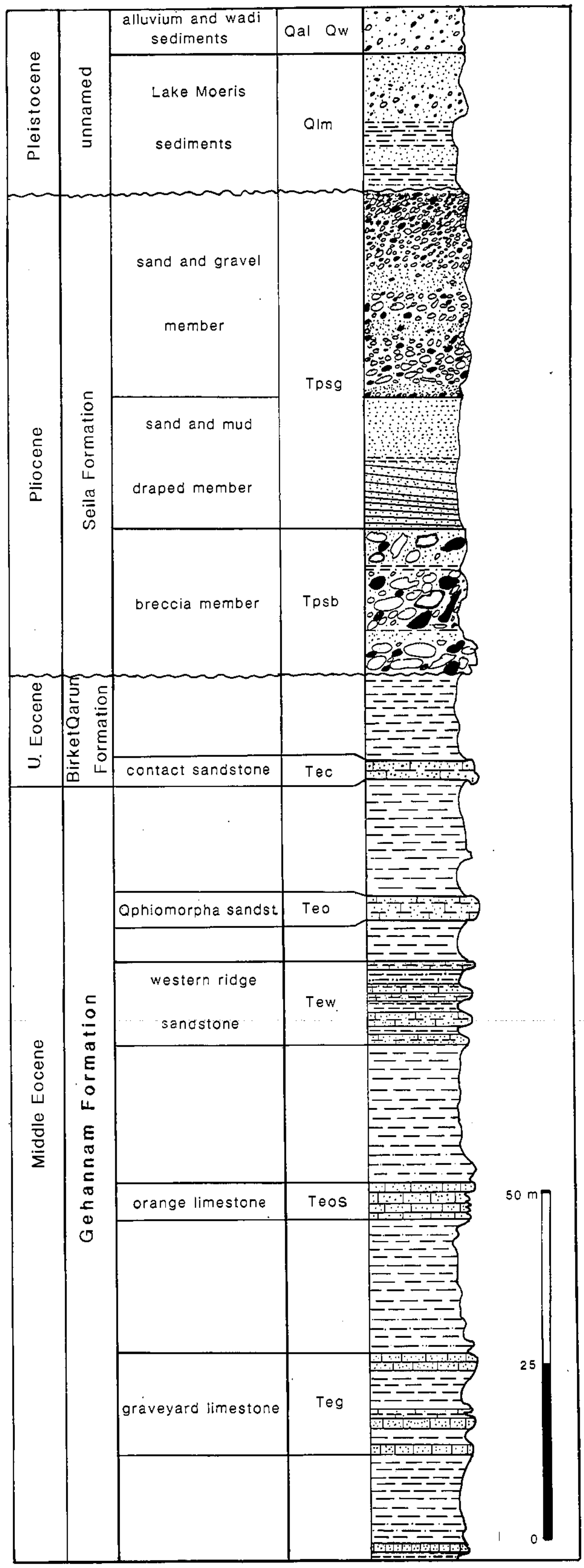


FIGURE 5.—*Generalized stratigraphic section of Tertiary units exposed in the Gebel el-Rus area.*

trolled. The Faiyum depression and its surrounding escarpments, however, have escaped the effects of major faulting and folding. The Gebel el-Rus area lacks any significant faults, and only minor tilting of Eocene strata is apparent. A gentle northward dip of 3 to 8 degrees of middle and upper Eocene rocks produced a subtle but observable angular unconformity between these rocks and overlying essentially horizontal Pliocene deposits (fig. 6).

According to Tamer and others (1975a, p. 21), the Faiyum depression overlies the axis of a major anticline and is affected by normal faulting. They described a great monoclinal edge that bounds the depression on the northern and eastern sides.

According to Said (1981, p. 20), the path of the Nile River, east of the Faiyum depression, is fault controlled. Along its fault-established course, the Nile cut a deep canyon in late Miocene times in response to an extremely low local base level. Downcutting was instantaneous with the desiccation of the Mediterranean Sea during the Messinian. The resulting Nile Canyon, according to Said (1981, p. 100) was 10–20 km wide, 1300 km long, and 2500 m deep. Although it is similar in width to the Grand Canyon in Arizona, the "grand canyon" of the Nile was 400 m deeper and was from 3–4 times as long. This Nile Canyon, possibly the deepest of any known in geologic history, was occupied by marine waters during the Pliocene and has since been filled in by estuarine and fluvial deposits. The peaks on Gebel el-Rus in part are composed of some of the earliest canyon-fill deposits of Pliocene age.

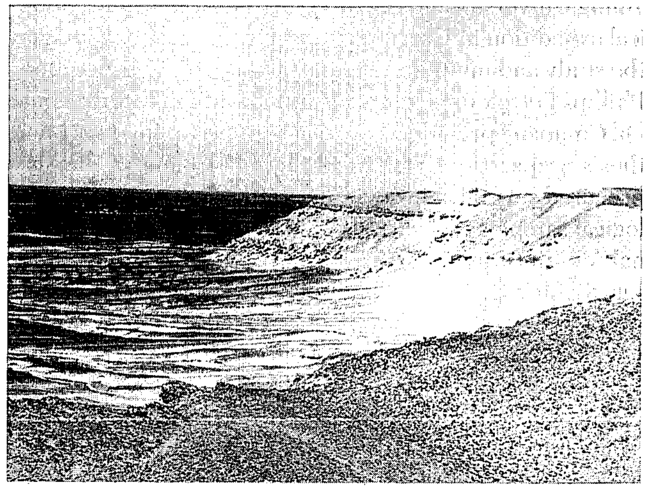


FIGURE 6.—*Northern Ridge on Gebel el-Rus. The basal ledge of thick debris-flow deposits of Pliocene age, near the peak, marks the Eocene-Pliocene contact. Eocene units rise stratigraphically along the ridge, from left to right (north to south). The Faiyum depression is in the background.*

EOCENE DEPOSITS

REGIONAL SETTING

Middle Eocene Gehannam Formation and upper Eocene Birket Qarun are exposed on the western flanks of Gebel el-Rus (fig. 6). The Gehannam Formation conformably overlies the Wadi el-Rayan Formation to the south and southwest of the Faiyum depression. Middle Eocene Wadi el-Rayan rocks are composed of interbedded nummulitic limestones, reefal limestones, and shaly sandstones, according to Beadnell (1905, p. 35–37). A marly limestone containing *Nummulites gizehensis*, a rather large foraminifer, marks the top of Wadi el-Rayan strata and the base of the overlying Gehannam Formation. The Wadi el-Rayan Formation, although of different lithology, is correlative with the lower Makattam limestone exposed in major quarries to the north near Cairo. Lithologic and paleontologic evidence suggests a shallow water, warm climate during deposition of Wadi el-Rayan Formation and Gehannam Formation sediments.

The Birket Qarun Formation, which overlies the Gehannam Formation on Gebel el-Rus and northward, is overlain by the Qasr el-Sagha Formation north of the Faiyum depression. Qasr el-Sagha units are correlative with the upper Makattam or Maddi Formation. Best exposures of these units are north of Birket el-Qarun (Lake of Qarun). Qasr el-Sagha strata are characterized by argillaceous sandstones, mudstones, and limestones. Many important terrestrial vertebrates and *Carolia placunoides*, *Ostrea fraai*, and other marine fossils are present in these Bartonian age rocks.

Faunal associations of terrestrial vertebrates together with marine mollusks in the upper Eocene Qasr el-Sagha Formation suggest that ancient environments were dominated by nearshore, shallow seas with adjacent fluvial systems. According to Brown and others (1982, p. 628), varieties of flora and a large and diverse vertebrate fauna in the overlying Oligocene Jebel Qatrani Formation suggest that northern Egypt was a forested, subtropical to tropical lowland coastal plain.

The fluvial-estuarine Jebel Qatrani Formation and nearshore deposits from the Qasr el-Sagha Formation are evidence for marine regression or shoreline progradation. According to Issawi (1972, p. 1448) several other sedimentary sequences deposited in northern Egypt indicate that the Tethys Sea regressed to the north during late Eocene and Oligocene time.

STRATIGRAPHIC NOMENCLATURE

Beadnell's stratigraphic nomenclature (1901 and 1905) included lower Eocene beds in the Wadi el-Rayan series, middle Eocene beds in the Ravine beds, and upper Eocene beds in the Birket Qarun Series and Qasr el-Sagha series. Said (1962, p. 101), however, used more formal stratigraphic nomenclature for the same units: lower Eocene Wadi el-Rayan Formation, middle Eocene Gehannam Formation (or Ravine beds), and upper Eocene Birket Qarun Formation and Qasr el-Sagha Formation. The present study emphasizes details of the Gehannam Formation (used here instead of Ravine beds) and the overlying Birket Qarun Formation of the Eocene series.

The Gehannam Formation forms the uppermost part of the middle Eocene in the Faiyum region and is generally conformably overlain by upper Eocene strata in the area. The Birket Qarun Formation was named from the large lake, Birket el-Qarun, that occupies the northern edge of the Faiyum depression. According to Beadnell (1905, p. 42) some 60 m of strata forms the major section of the cliff that rises above the northern shore of the lake. Only the basal 15 m of the Birket Qarun Formation is preserved on the northern flanks of Gebel el-Rus, in the research area. However, northwest of the Faiyum depression, on Gebel Gehannam, the Birket Qarun Formation is over 50 m thick and is overlain by the Qasr el-Sagha Formation.

Several resistant middle and upper Eocene ledge-forming units are well exposed in the study area. Key units are easily differentiated and correlated on the western flanks of Gebel el-Rus and have been given the following informal field names: from the bottom up, the lower limestone, graveyard limestone, quarry limestone, orange limestone, Western Ridge sandstone, *Ophiomorpha* sandstone, upper sandstone, and contact sandstone. Each of these units is discussed in the description of Eocene deposits.

GENERAL LITHOLOGIC DESCRIPTION

Eocene strata exposed in the Gebel el-Rus area are characterized by a variety of calcareous-clastic sediments that range from slightly calcareous mudstones to calcareous sandstones or sandy packstones. Rocks with low amounts of calcium carbonate compose 60% to 70% of the entire Eocene section, and the remaining 30% to 40% are rocks with moderate to high amounts.

Topographic expression of middle and upper Eocene units is largely controlled by the amount of calcium carbonate. Lithologic units with little calcium carbonate cement form slopes and recesses; they remain poorly lithified and are easily eroded. However, calcareous units are well lithified and form minor cliffs where thick bedded, or resistant ledges where thin bedded. Although calcium carbonate is a major determining factor, gypsum content is also important. Frequently, the slopes formed by units composed of low to moderate calcium carbonate cement steepen when considerable gypsum occurs as lenses or veins. Gypsum commonly has filled fractures as veins in massive rocks and as concave-up, lenselike structures in thin cross-bed sets. Gypsum is usually not very resistant to erosion, but in this desert area forms weakly resistant ledges and ridges.

The most abundant rock types of the Eocene section in the study area are mudstone and argillaceous siltstone. These fine-grained clastic deposits form wide, gentle slopes and broad, flat areas where thick. They erode to recessive units or undercuts that separate more resistant beds where thin. These deposits, poor in calcium carbonate, are generally brownish and olive gray and are covered by a thin veneer of loose debris or gypsum-cemented lag. Where mudstone units are exposed below surficial debris they are commonly very thinly laminated, resembling pages of a book.

Eocene strata made up of units with moderate to large amounts of calcium carbonate cement are marls, silty marls, calcareous sandstones, and sandy limestones or packstones. These units form steep slopes when composed of moderate amounts of calcium carbonate, and ledges and minor cliffs when rich in calcium carbonate content.

Limestones that lack abundant terrigenous material are generally thick bedded and massive. However, where terrigenous clastic materials increase, so do trace fossils and sedimentary structures, such as bidirectional short-wavelength ripple marks, cross-laminations that generally trend N. 125Y E., and load casts from 10 cm to 1 m in diameter. Sediments rich in calcium carbonate generally range from yellowish orange to grayish orange. Rocks that lack abundant clastic constituents such as chalky and pure limestones tend to be very pale orange or very light gray to nearly white.

Well-lithified, thick-bedded limestones, packstones, and wackestones of the study area have been used as building stones for centuries, as evidenced by several structures and many worked quarries. One of these quarries is shown in figure 7. Building stones for the Third Dynasty Seila Pyramid were apparently quarried from these sites. Recent tool markings and dynamite scars are evidences that these quarries have been used for modern building materials as well as for ancient structures.

Grain sizes range from coarse silt to fine and medium sand, and frameworks generally range from sorted to fairly well sorted. Sand grains are mostly angular and subangular. Only a few grains have rounded edges or corners, but most approach equant shapes. All terrigenous units are dominated by quartz, although the framework of many contain an array of accessory minerals. The latter include plagioclase, microcline, hornblende, biotite, muscovite, and zircon. These accessory minerals indicate a granitic source. Angular calcite and rounded glauconite grains are also present, and hematite and limonite clays form the matrix in most units. Cement compositions rarely vary from mirosparrite and micrite.

FIGURE 7.—*A quarry in the orange limestone unit from the middle Eocene Gehannam Formation near sections D and E.*

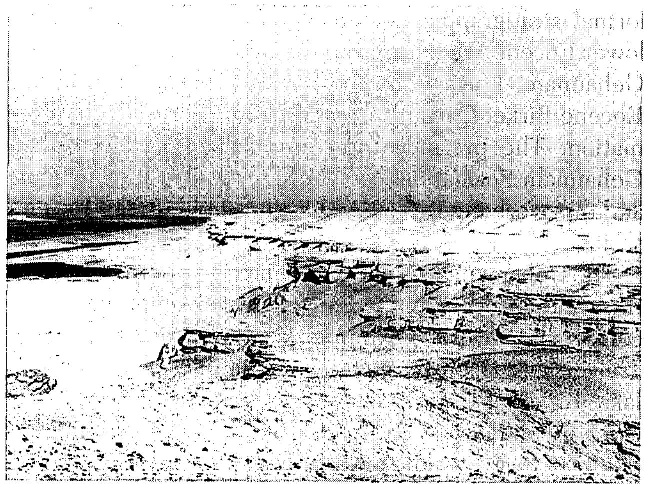


FIGURE 8.—*A modern Moslem cemetery, left, on flats below ledge-forming middle Eocene graveyard limestone. Center, the basal part of section F crosses outcrops to the right of the cemetery. Eastern edge of the Faiyum depression in the background.*

UNIT DESCRIPTIONS

Subdivision of Eocene strata in the study area was based on alternation of ledge-forming and slope-forming units. Major resistant limestone units range from 1 to 3 m thick and minor limestone subunits form ledges 0.5 to 1.0 m thick. Some key units may be a series of two to four ledges. Ledges are separated by thin, recessive beds, usually mudstones.

Gehannam Formation

Lower limestone. The lowermost resistant unit in the study area, here termed lower limestone, is exposed mostly to the south of Monkey Ridge and is correlated in sections F, G, and H (for location of informally named ridges on Gebel el-Rus, see fig. 2). This grayish orange unit ranges from 1 to 2 m thick, from north to south on Gebel el-Rus. It overlies 3 to 10 m of slope-forming noncalcareous mudstone, is truncated by Pliocene debris-flow deposits to the south, and dips into the subsurface when traced north of section F.

Graveyard limestone. The graveyard limestone overlies a 5–15-m-thick slope-forming silty mudstone and is named for rocks exposed in cliffs east of the present Moslem cemetery (fig. 8). A 14-m cliff there is capped by three resistant sandy limestone units separated and underlain by recessive units. The graveyard limestone is also well exposed in bluffs east of the dirt road leading to the Brigham Young University archaeological sites and is easily correlated between sections C and H. Weathered surfaces of the sandy limestone beds are yellowish orange.

Quarry limestone. A very light orange to nearly white chalky, micritic limestone, here named the quarry limestone, overlies the graveyard limestone and is composed of 1 to 5 m of marly mudstone. Where well lithified it has been extensively quarried in ancient and modern times and is easily seen from Barh Wahbi. The quarry limestone changes in lithology laterally. In sections B and C the unit is a well-lithified, silty, micritic limestone and was quarried there, anciently, as building stone for part of the Seila Pyramid. However, the unit grades into a chalky marl to the south and in sections E and F is poorly exposed, weakly lithified, and forms a nearly white lag on a broad slope.

Five to fifteen meters of mudstone overlies the quarry limestone and is interbedded with weakly lithified marly units. These interbeds generally form a broad, gentle slope that is largely covered by alluvial pavements, gypsum tufalike plateaus, and clayey soils. Small partings of marly interbeds frequently form steeper slopes and minor ledges between the quarry limestone and the overlying orange limestone.

Orange limestone. Five to ten sandy limestones interbedded and separated by thin beds of recessive sandy marls form the orange limestone. This unit is 2 to 3 m thick and is one of the best-exposed sequences in the entire Eocene section on Gebel el-Rus. It is easily traced laterally because of its thickness, lateral persistence, and consistent distinct orange color. In sections C, D, and E the orange limestone is well exposed and is capped by a 1.0–1.5 m sandy limestone that contains abundant nummulitid foraminifera. This relatively thick, resistant unit also has been quarried in several areas (fig. 7). Because it is well cemented, yet jointed, blocks from this unit were used with blocks from other units in the Seila Pyramid (fig. 9). Some 20 m of slope- and depression-forming strata separate the orange limestone from the overlying ledge-forming Western Ridge sandstone. Olive gray and grayish brown mudstones and grayish orange marls dominate in the unit that forms a broad, low area.

Western Ridge sandstone. The Western Ridge sandstone appears in sections A, B, and C and consists of four resistant calcareous sandstone beds that are interbedded with recessive marls and silty mudstones. Best exposure of this unit occurs on a low promontory, here informally termed Western Ridge, and is partially truncated there by Pliocene breccia deposits. Each resistant bed consists of a grayish orange calcareous sandstone that ranges from 0.5 to 1.5 m thick, and are interbedded with grayish brown mudstone units, 0.5 to 1.0 m thick. Thicknesses of resistant sandy beds decrease from south to north, and thicknesses of nonresistant shaly interbeds increase in the same direction. Amounts of foraminifera and bioturbation increase from the lower ledge-forming unit to the upper one of the series.

Ophiomorpha *sandstone.* Some 5 m of poorly lithified shaly siltstone and mudstone separates the Western Ridge sandstone from the overlying *Ophiomorpha* sandstone, which is the thickest single resistant unit exposed in the area. It is grayish orange and forms a cliff 3 m high on Northern and Northeastern Ridges. The sandstone is distinguished by abundant trace fossils, particularly *Ophiomorpha.* Minor amounts of *Thalassinoides*, other unidentified trace fossils, and sporadic oyster and clam fragments are also present. The unit is also characterized by well-preserved ripple drift cross-laminations.

The *Ophiomorpha* sandstone is easily correlated between sections A and B, and extends far beyond the research area to the northeast. However, it is truncated by erosion and buried by Pliocene strata on Northern Ridge near Western Ridge and is missing to the south. Large blocks of this jointed sandstone litter the slopes of Northern and Northeastern Ridges. Holocene talus deposits from this unit and the contact sandstone are shown in figure 6. These accumulations resulted from collapse after easily eroded underlying strata had been removed.

Upper sandstone. The *Ophiomorpha* sandstone is overlain by 3 to 7 m of poorly lithified, obscured mudstone and a thin bed of calcareous sandstone, here termed the upper sandstone. This sandstone bed forms a ledge 1 m thick and is the uppermost resistant ledge-forming unit of the middle Eocene section. Although a rather thin unit, it is a key bed because it allows for easy correlation of sections A and B. It contains short-wavelength cross-bedding that is only partially preserved, for bioturbation has destroyed most stratification in the bed.

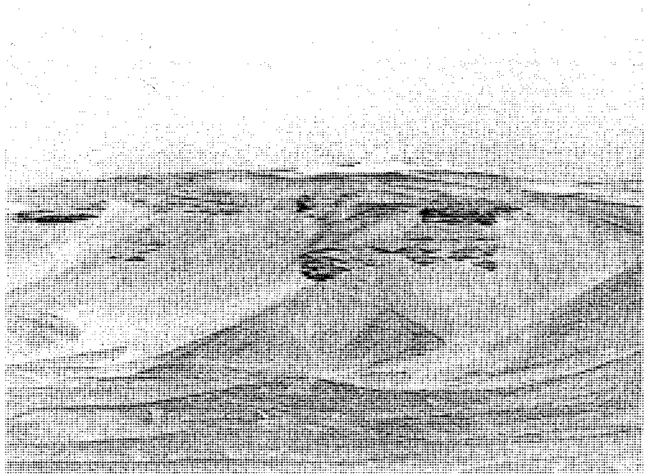


FIGURE 9.—*Third Dynasty Seila Pyramid built largely of blocks quarried from local, well-lithified, and jointed limestone units on Gebel el-Rus. Ledges in bluff are in the sand and gravel member of the Seila Formation in the type section, near section F.*

Birket Qarun Formation

Contact sandstone. The contact sandstone is the only ledge-forming unit from the upper Eocene preserved in the Gebel el-Rus area. The base of this unit marks the boundary between middle and upper Eocene rocks on Gebel el-Rus, and the sandstone overlies 10 to 15 m of silty mudstone. The contact unit is a pale yellowish orange calcareous sandstone and, like the upper sandstone, is easily correlated between sections A and B from Northeastern Ridge to Northern Ridge. The northward dip of this unit results in its being preserved north of its truncation by Pliocene debris-flow deposits on the western face of Gebel el-Rus on Northern Ridge.

The contact sandstone is characterized by large, bulbous loadcasts, up to 1 m in diameter, by tangential and hummocky cross-bedding that trends N. 145° E., numerous poorly preserved trace fossils, and bioturbated laminae. Upper Eocene silty mudstone deposits, 5 to 15 m thick, form a slope overlying the contact sandstone and are partially truncated by Pliocene debris-flow deposits on Northern Ridge.

FACIES INTERPRETATION

During the early and middle Eocene, most of Egypt was covered by a warm, shallow sea that resulted from a major marine transgression from the Tethys Sea. Sediments were deposited on deformed Cretaceous rocks in northern Egypt. According to Salem (1976, p. 34), well data show that thin Paleocene and thick Eocene sequences occur in subsurface structural basins and that Eocene deposits are thin and Paleocene deposits are missing over subsurface anticlinal highs. Salem's data also show that subsurface anticlinal highs that separate the basins are elongate ridges, generally trending NE–SW.

During the late Eocene and early Oligocene, fluvial and interdeltaic facies were dominant north of the Faiyum depression. These environments resulted from shoreward progradation coupled with a northward regression of the sea. Due to late Oligocene and early Miocene crustal upwarping, the Faiyum region became an area of topographic prominence. Thus, the study area was subaerially exposed beginning in the Oligocene and remained so until it was invaded by an arm of the Mediterranean Sea during the Pliocene.

Sequences from the middle Eocene Gehannam Formation and upper Eocene Birket Qarun Formation exposed in the study area were deposited in middle and late Eocene transgressive-regressive shallow seas. Sandy carbonate units and interbedded mudstones represent different energy levels. Ledge-forming calcareous sandstone beds, such as the *Ophiomorpha* and contact sandstones, were deposited in higher flow regimes than the silty mudstones that occur below and above them. Finer sediments were winnowed away in strong currents, and the thick accumulations of coarse sand provided suitable substrata for organisms such as clams and oysters.

Faunal assemblages from Gehannam and Birket Qarun Formations in the study area suggest subtropical, shallow seas during the middle and late Eocene. Nummulitid foraminifera, sessile benthonic organisms in sublittoral neuritic zones, are often abundant in many exposed sandy carbonate beds. Modern large foraminifera similar to Eocene nummulites live in shallow seas of the tropics.

The orange limestone contains common clusters of nummulites that were either used by other organisms to fill or line burrows or that crawled into the burrows themselves to escape dessication in very shallow water. This and many other units contain scattered microscopic echinoid spines and plates, oyster and clam shell fragments, and bioturbated beds. Although some sedimentary structures are present in many sandy carbonate beds on Gebel el-Rus, most bedding is massive, having largely been destroyed by bioturbation, possibly by the burrowing of clams. These findings indicate that abundant life processes and moderate currents were factors of the environment during deposition.

Many of the preserved sedimentary structures give evidence of nearshore shallow seas. Short-wavelength, cross-laminated sediments are present in a few of the ledge-forming units. The *Ophiomorpha* sandstone contains the best example of cross-bedding. Well-preserved ripple drift cross-laminated sets in this unit indicate rapid subaqueous deposition by currents with moderate flow regimes. The bidirectional pattern of the cross-laminations in many sandstone units is evidence that tidal currents contributed as a factor of the environment during sedimentation. Hummocky cross-bedding present in the contact sandstone enhances the possibility that deposition of many of these calcareous sands resulted from storms.

Undulating contacts between shaly units and overlying sandstones and loadcast structures into mudstones are abundant in the higher subunits of the study area. The Western Ridge sandstone and *Ophiomorpha* sandstone contain these structures. However, the best examples of loadcasts characterize the basal part of the contact sandstone. Large, bulbous loadcasts, up to 1 m in diameter, protrude into an underlying mudstone bed. Contact irregularities and loadcasts resulted from rapid accumulation of either regressive calcareous-clastic sands on a muddy sea floor or storm-driven sand deposited over a mud platform in a transgressive-like pattern.

Petrographic analysis of samples from many sandy carbonate units reveals that they are generally submature. Moderate amounts of plagioclase, microcline, hornblende, and other chemically unstable minerals indicate that the sediments are mineralogically submature. Although grains are generally sorted, they range from angular to subrounded and are thus classified as texturally submature.

Occurrence of feldspar, mica, and hornblende in these Eocene rocks suggests granitic sources were not far from depocenters and reworking of the sands after initial deposition was minimal.

PLIOCENE DEPOSITS

REGIONAL SETTING

Most high-level ledges and cliffs on Gebel el-Rus are composed of generally horizontal Pliocene deposits. Ridge-forming breccia deposits, composed of large subangular blocks detached from numerous Eocene units, are the earliest Pliocene deposits in the section. Laminated sands and sandstones that drape over these beds form steep slopes and are overlain by ledge- and cliff-forming gravelly sandstones and sandy, gravelly conglomerates.

Aigner (1983) described Pliocene deposits, near Cairo on the Giza Pyramids Plateau, that appear superficially similar to the breccia deposits on Gebel el-Rus. According to Aigner (1983, p. 319), large blocks from Eocene bedrock were detached by marine wave erosion that accompanied a partial transgression of the Mediterranean Sea. This marine ingression produced a gulf that occupied the Nile River Valley during the early Pliocene.

According to Said (1981, p. 20), marine waters from this Pliocene Gulf greatly affected the Nile River Valley from the delta area up to Aswan, Egypt. Into this estuary, 12 km wide and more than 1300 km long, were deposited over 460 m of sandstone and sandy mudstone and more than 1500 m of shale, as represented in the Abu Madi Formation and Kafr el-Sheikh Formation, respectively. Several other Pliocene gulf deposits are discussed by Said (1981, p. 100, 101).

STRATIGRAPHIC NOMENCLATURE

Pliocene deposits on Gebel el-Rus are here formally named the Seila Formation. The formation is named from Seila, a small town near the eastern edge of the Faiyum depression, approximately 8 km northwest of the study area. The Third Dynasty Seila Pyramid lies atop Gebel el-Rus in the central part of the study area and on the Seila Formation in the type locality (fig. 9).

Type Section of Seila Formation (New)

Unit	*Description*	*Thickness*	*Meters*
Sand and gravel member			
17	Conglomerate, sandy, poorly sorted and partially lithified; forms a steep slope and caps the ridge, top of preserved section.	10.0	73.7
16	Sandstone, dark grayish orange, gravelly, poorly sorted and poorly lithified; forms a steep slope.	6.0	63.7
15	Conglomerate, gravelly, poorly sorted and poorly lithified; forms a cliff. Clasts include: fragments of Eocene rocks 27%, chert 39%, quartzite 13%, discrete shell fragments 2%.	7.5	57.7
14	Sandstone, dark grayish orange, poorly sorted, poorly lithified with gravelly lenses; forms a steep grayish orange slope.	10.5	50.2
13	Conglomerate, pebbly and gravelly, poorly sorted and poorly lithified; forms a ledge. Clasts include: fragments of Eocene rocks 44%, chert 40%, quartzite 88%, and discrete shell fragments 1%.	1.4	37.7
12	Sandstone, dark grayish orange, poorly sorted, poorly lithified; forms a slope.	1.9	38.3
11	Conglomerate, gravelly, poorly sorted and poorly lithified; forms a ledge.	1.0	36.4
10	Sandstone, dark grayish orange, poorly sorted, poorly lithified, with lenses of pebbly sand; forms a steep slope.	1.5	35.4
9	Conglomerate, gravelly, poorly sorted, poorly lithified; forms a minor ledge.	0.4	33.9
8	Sandstone, dark grayish orange, poorly lithified, poorly sorted; forms a steep slope.	1.8	33.5
7	Conglomerate, gravelly, with coarse sandy and pebbly lenses; forms a ledge.	1.2	31.7
6	Sandstone lens, dark grayish orange, argillaceous matrix, poorly sorted, fine to medium grained; forms a steep slope.	1.4	30.5
5	Conglomerate, gravelly with sandy lenses and horizontal bedding; forms a ledge. Clasts are subrounded and subangular, ranging in size from cobble to pebble. Clasts include: fragments of Eocene rocks 60%, chert 7%, quartzite 6%, discrete shell fragments 5%.	2.1	29.1
4	Sandstone, dark yellowish orange to grayish orange, pebbly and cobbly, fairly well lithified; forms a very steep slope.	7.3	27.0
Draped sand and mud member			
3	Sandstone, ranges from pale yellowish orange to grayish orange, well lithified, interbedded with unlithified sand, fine to medium grained. Deposited with a stratigraphic dip of 110° SE. Near the top of the unit the sandstone is horizontally laminated and becomes argillaceous and forms a steep slope.	12.0	19.7
Breccia member			
2	Breccia beds, channeled, debris-flow deposits, composed of subangular upper Eocene calcareous sandstone blocks (up to 3 m in diameter). The contact between the Eocene and Pliocene here and all along Gebel el-Rus is very irregular.	5.7	.7
Middle Eocene Gehannam Formation			
1	Marl, very pale orange and pale yellowish orange, silty, partially lithified and poorly exposed; forms a steep slope.		2.0

No formal lithostratigraphic names have previously been applied to Pliocene deposits of the Faiyum region. Lithologies and depositional environments were utilized by early workers when describing these Pliocene rocks. Beadnell (1905, p. 73), for instance, noted the strata exposed on Gebel el-Rus and called them Pliocene gravel terraces. Said (1962, p. 105) simply called the same deposits Pliocene estuarine and fluviatile gravels. Little (1936, p. 228) described the coarse breccia deposits in the Faiyum region and called them Pliocene slipped masses.

Pliocene deposits in the Gebel el-Rus area were subdivided into informal lithologic units or members in this study. The oldest and lower member of the Pliocene in the area is here termed the breccia member. This unit occurs above the Eocene-Pliocene contact, and is composed of channeled and nonchanneled or sheetlike debris-flow deposits.

The middle member is here termed the draped sand and mud member. These draped sandstones and mudstones overlie the breccia member and have a general southeastward sedimentary dip. The member is named for the unusual way in which these beds drape over irregular debris-flow surfaces.

The upper member of the Pliocene Seila Formation is here termed the sand and gravel member. Coarse clastics from this informal unit occur at the highest levels in the Pliocene section and form prominent ledges and cliffs on the peaks of Gebel el-Rus.

DESCRIPTION OF LITHOLOGIC UNITS

Seila Formation (New)

Relatively dark-toned Pliocene deposits of the Seila Formation overlie and cut into light-toned Eocene rocks with angular discordance. These Neogene rocks hold up prominent cliffs and ledges on the western face of the north–south-trending Gebel el-Rus but blanket the gentle eastern slope that sweeps down to the Nile Valley. The highest altitude that Pliocene sediments occur in the study area is the cap on Northern Ridge (125 m above sea level), but they also range as low as only 30 m above sea level on the east–west-trending Monkey Ridge.

Breccia member. Oldest Pliocene deposits on Gebel el-Rus, here termed breccia member, are composed of subangular blocks of middle and upper Eocene calcareous sandstone in a muddy sandy matrix. These blocks range from 0.5 m to 3.0 m in diameter and occur in lenses and irregular sheets that overlie and partially truncate middle and upper Eocene strata. Many of these grayish-orange Eocene-derived blocks contain middle and upper Eocene nummulites, turritellid gastropods, and bivalves (clams and oysters). Some blocks are essentially oyster coquinas, and other less fossiliferous blocks contain faintly preserved *Ophiomorpha* and *Thalassinoides* trace fossils, small-scale ripple marks, and cross-laminations. Some of the nonfossiliferous sandy limestone blocks are concretionary, ranging from 0.5 to 2 m in diameter. Practically all blocks of the breccia member are either deposited in a poorly lithified sandy-silty matrix or partially lithified, argillaceous matrix.

Lenticular breccias are interpreted as channeled debris-flow deposits. Lenses of debris hold up prominent ridges on Gebel el-Rus such as Northern Ridge, Western Ridge, and Monkey Ridge. These filled channels range from 10 to 30 m deep, from a few meters to more than 120 m wide, and from tens of meters to nearly a kilometer in length. Blocks of these deposits are commonly densely packed in a fairly well lithified argillaceous matrix.

Sheetlike breccia deposits that are continuous with the debris-filled lenses and conjoin the ridges that they form are here termed nonchanneled debris-flow deposits. These sheetlike accumulations form moderately steep slopes and are made of block diffusely suspended in a poorly lithified matrix of fine-grained sand and silt that lacks a significant amount of mud and clay. Breccia channel fills and sheetlike deposits apparently accumulated contemporaneously.

Channeled debris-flow deposits are well exposed on Gebel el-Rus. The north and northeast sides of Northern Ridge exposed three well-preserved Pliocene channel fills that cut into upper Eocene strata. The lower channel segment, 100 m long, 50 m wide, and 20 m deep, trends N. 100° E. and truncates the contact sandstone along most of the northeast side of Northern Ridge. The middle and upper channels trend N. 140° E. and hold up the northwest nose of Northern Ridge. They both are 100 m wide, 15 m deep, and traceable for 600 m, beyond which they are buried by younger beds of the Seila Formation.

Perhaps the most spectacular paleochannels preserved are those which are well exposed and easily accessible on Monkey Ridge, 15 to 20 m above the Baḥr Wahbi and the canal road (figs. 10 and 11). Monkey Ridge trends roughly east–west and is held up by breccia fillings of two channels. Each channel cuts into the middle Eocene graveyard limestone. The lower channel, exposed on the south side, trends N. 130° E. and is mappable for over 700 m eastward from the ridge nose to where the breccia is buried in the escarpment. The channel ranges from 30 m wide on the side of Monkey Ridge to 120 m wide before it is buried at its easternmost end. It cuts 30 m deep into Gehannam Formation strata. These channeled lense deposits grade laterally into sheetlike accumulations farther to the southeast. This channel and its deposits apparently resulted from at least five events, each differentiated by an irregular layer or lens of coarse subangular blocks overlain by a layer of sandy mudstone. The thickest deposits of one of these events occurs at the channel's base, and deposits of each succeeding event are thinner. Two basal events are recorded in the section illustrated in figure 12.

The channel fill on the north side of Monkey Ridge is composed of deposits of one major event that overlies and partially truncates the southern debris channel at the nose of Monkey Ridge. The northern lenticular breccia fill is 50 m wide, 30 m deep, and is mappable for 400 m before the channel is buried by younger Pliocene deposits at its easternmost end.

Western Ridge is held up by breccias of a debris flow that fills a channel 50 m long, 70 m wide, and 10 m deep through the Western Ridge sandstone. It is traceable for only 50 m before it trends into the escarpment and is buried. Channeled debris-flow deposits also occur below

FIGURE 10.—*The nose of Monkey Ridge as seen from the south is composed of two breccia-filled paleochannels: (1) trends N. 75° E., forms the left half of the ridge; (2) trends N. 105° E. and forms the right half of the ridge. Both paleochannels cut into Eocene strata. The eastern edge of the Faiyum depression is in the foreground.*

the saddle between Western Ridge and Northern Ridge. These lenses are 50 m wide and over 30 m deep, but are seen only in cross section.

Dimensions and trends of these debris-filled channels are important for paleogeographic reconstruction of the Gebel el-Rus area during the Pliocene. Nearby Eocene rocks, perhaps as exposed ledges and cliffs, around an ancient topographic high must have been present toward the west during the Pliocene.

The sheetlike breccia deposits are composed of blocks as large as 3 m in diameter of Eocene sandstone and limestone. Such layers, 1 to 10 m thick, are mappable between Western Ridge and Monkey Ridge. Channeled breccia deposits grade into sheetlike breccias south of Monkey Ridge. These thin deposits finally pinch out near the southernmost edge of the study area.

Draped sand and mud member. Breccia deposits in the study area, except those on Northern Ridge (fig. 6), are overlain by poorly lithified sandstones that appear to grade continuously upward from the sandy matrix of the sheetlike accumulations and are here termed the draped sand and mud member. Sandstones from this middle member (fig. 13) are unfossiliferous, pale yellowish orange and grayish orange, fine grained, and are fairly well sorted. Grains range from angular to subrounded. They drape over the breccia member with dips ranging from 5° to 20° toward the southeast, at the base, to essentially horizontal near the top of the member. Well-lithified sandstone ledges, 1 to 8 cm thick, often occur where the sediments are cemented by calcium carbonate. Worm-tube-like trace fossils and parting lineations and small groove casts that trend N. 145° E. are preserved on bottoms of many thin, ledge-forming interbeds (fig. 14).

Sources of these Pliocene sandstones were probably local Eocene sandy carbonate beds. Petrographic studies of the Pliocene sand document mineralogic and textural similarities to many middle and upper Eocene units. Northeastward, southeastward, and east–west deposi-

FIGURE 11.—*Monkey Ridge, from the south. Debris-filled channels of Pliocene age of the breccia member of the Seila Formation produce the ragged ledges. The slope above is of the draped sand and mud member, and upper ledges are of the sand and gravel member of the Seila Formation. Channels are cut into light-toned Eocene beds.*

tional dips, cross-bedding that trends N. 135° E., angular grains, and the presence of feldspar, mica, and hornblende, indicate that there was a local source from the west and northwest.

Grayish brown mudstone locally overlies the breccia member instead of sand. Mudstone is especially common at this stratigraphic level between sections C and F. These unusual deposits are rich in bentonitic clays, rarely exceed 3 m in thickness, and usually lens or grade out both to the north and south on the western flanks of Gebel el-Rus. One mudstone lens in section D is overlain by horizontal, thinly laminated, and poorly lithified fine-grained sand.

Sand and gravel member. Poorly lithified, lenticular gravelly sandstones and sandy-pebbly conglomerates overlie the middle member on Gebel el-Rus (fig. 15). This upper member, here termed the sand and gravel member, contains numerous sandy, pebbly, and gravelly lenticular masses. Imbricated clasts, trending N. 135° E. (fig. 16), and trough cross-bedding in sandy lenses, trending N. 125° E., are characteristic of the ledge-forming conglomerates. No indigenous plant or animal fossils were found in these Pliocene beds on Gebel el-Rus. However, reworked upper Eocene clams, oysters, and snails occur in clasts or locally as discrete transported second-cycle shells and shell fragments. Many of the clasts of Eocene-derived sandstone and limestone contain middle and upper Eocene faunal assemblages of foraminifera, gastropods, clams, and oysters.

Silicified wood fragments, ranging from 10 cm to 0.5 m in length, occur as clasts in these gravelly conglomerates. Silicified burrows, usually less than 10 cm in length, are also common as clasts. Discrete shell fragments plus silicified wood and burrows represent 1% of clasts of these gravels. Fairly well rounded fragments of Eocene rocks, chert, and quartzite make up the remaining clasts and are 50%, 40%, and 9%, respectively.

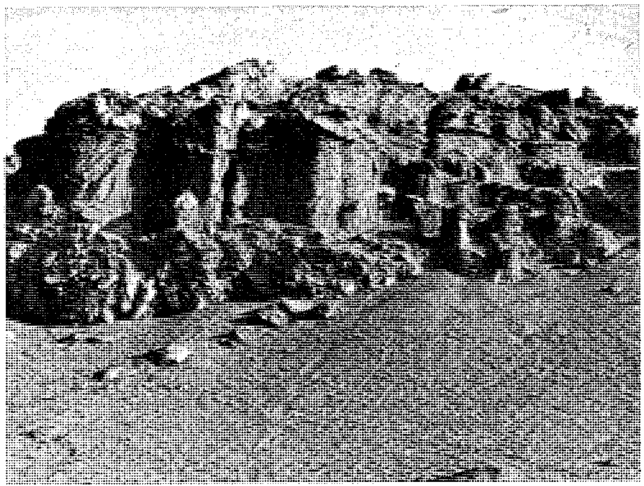


FIGURE 12.—*Debris-filled channel of Pliocene age, lower Seila breccia deposits on the south side of Monkey Ridge near section H. This deposit resulted from two separate events: the basal breccia deposit, overlain by a bed of sandy mudstone, makes up one event; the overlying breccia deposit resulted from a later event.*

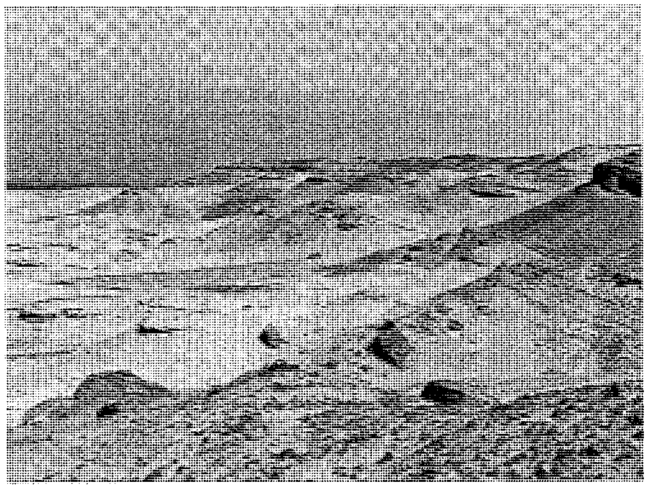


FIGURE 13.—*The Eocene-Pliocene contact, center, is evident where darker-toned Pliocene Seila Formation overlies lighter-toned Eocene units. The lower member of the Seila Formation is accentuated as rubbly debris-flow breccia deposits. The middle member of sandstone and mudstone dips 15° southeast and is overlain by sands and gravels of the upper conglomeratic ledgy member of the Seila Formation exposed here near section G.*

FACIES INTERPRETATION

Breccia lenses are the earliest Pliocene deposits in the area of study. They are interpreted as debris flows, which fill the channels cut into Eocene strata, and represent several events of subaerial mass wasting. Angularity, large sizes, and distribution of the clasts indicate that their sources were from nearby steep Eocene exposures that existed during the Pliocene where the present-day Faiyum depression lies.

Areas along both the west and east banks of the Nile Valley were dissected by the close of the Miocene and beginning of the Pliocene. Messinian lowering of the Mediterranean Sea initiated entrenchment of the Nile, which cut a deep gorge, and intense erosion also affected the northern Egyptian Eocene platform, including the Faiyum region.

Breccias, similar in appearance to those of the breccia member in the study area, are also common in many locations along the Nile River Valley. According to Sanford and Arkell (1933, p. 1–92), many such accumulations occur to the south in the Thebaids on the Nile's west bank above Armant. Little (1936, p. 228) mapped many of these deposits along an ancient northern shoreline of the Pliocene Gulf. Data from this current study rarely concur with Little's observation that blocks are often found dipping 5° to 15° toward the west and northwest. Only some blocks of the channeled debris-flow deposits are oriented with uniform western dips of 30° to 50° or more. Most blocks in Gebel el-Rus breccia lenses are irregularly oriented.

According to Said (1981, p. 20), orientation and position of the Nile River are a result of tectonics. According to Gorshkov (1963, p. 101–5), the valley has been the site of numerous major historic earthquakes. Said (1981, p. 21) suggested that movements of the "slipped masses," which have accumulated at the foot slopes of the cliffs of the proto-Nile Valley, were induced by earthquakes. However, modern slumped middle and upper Eocene units on the flanks of Northern and Northeastern Ridges on Gebel el-Rus have apparently become detached and accumulated by normal subaerial erosion. Blocks that comprise ancient deposits too were most likely initially detached by undercutting of easily eroded units below.

Little (1936, p. 228) described horizons from which the slumped masses were derived and said they have since been eroded back from 10 to 20 km northward. These sources formed a strike valley during the Pliocene that was subparallel to the modern Nile Valley in Egypt. Catastrophic debris flows, which likely resulted from flash floods, had potential to transport many large blocks and erode deep channels.

Aigner (1983, p. 118) suggested that similar beds near Cairo resulted from wave erosion that accompanied the transgressing Pliocene sea. He further proposed that detached blocks were directly deposited into the estuary. Little (1936, p. 228) hypothesized that many slumped block deposits scattered along the Nile River Valley mark the ancient shoreline of the Pliocene sea. However, breccia deposits from the Seila Formation in the study area most likely resulted from subaerial mass wasting and flash

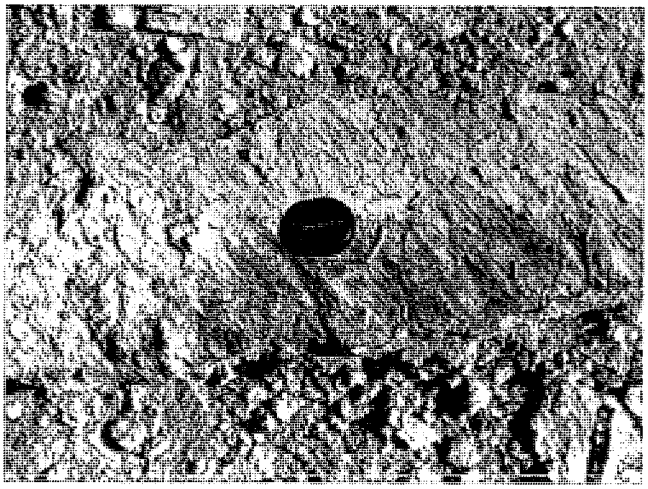


FIGURE 14.—*Trace fossils and sedimentary structures on an under surface of a sandstone from the middle member of the Seila Formation exposed in section G. Worm burrows from linear cylindrical structures on the surface with parting lineations, groove casts, and flute casts that trend N. 35° E.*

FIGURE 15.—*Lenticular sandy gravel of the upper member of the Seila Formation in Section F. Pebble imbrication and cross-bedding suggest paleocurrent trends of N. 125° E. and N. 145° E.*

floods that produced mud and debris flows beginning early in Pliocene times. Furthermore, many of the paleochannels trend from west to east, following the paleoslope into the gulf rather than paralleling its shoreline, as proposed by Aigner (1983) and Little (1936). The nonchanneled, sheetlike slumped masses were most likely detached similar to modern debris accumulations on Gebel el-Rus and deposited on slopes then facing the ancient Nile River Valley.

According to Said (1981, p. 101), shelly marine beds are found 125 m above the present sea level in the Pliocene Kom el-Shelul Formation south of the Giza Pyramids. From this and many similar examples it can be assumed that Pliocene marine waters invaded a significant area bordering the Nile River Valley, including the Gebel el-Rus area. The Pliocene sand of the Seila Formation that overlies the breccia member represents a fining-upward sequence that accumulated in the Pliocene Gulf.

Depositional attitudes of these sandstones result from an initial southeastward paleoslope and differential compaction of the water-saturated sediments deposited over the irregular upper surface of the breccia deposits. These sand accumulations are too well sorted for alluvial deposition, and grains are too angular and too muddy to have been deposited by eolian processes. The occurrence of occasional clayey mudstone deposits above the debris flows, instead of a sand, supports the idea that these sediments may be marginal marine or estuarine and that they accumulated during the early Pliocene where the sea transgressed over at least part of the eastern Faiyum.

Just as a fining-upward sequence indicates transgression of the Pliocene Gulf over the study area, a subsequent coarsening-upward sequence marks its regression. The moderately steeply dipping sand deposits grade upward into a horizontally laminated sandstone. Thus, as deposition continued, inclination of the paleoslope decreased. Eventually, Pliocene deposits became dominantly pebbly and gravelly sandstones, sandy pebble conglomerates, and ultimately coarse pebble conglomerates as marine waters regressed from the eastern Faiyum.

Cliffs and steep slopes retreated northward in later Pliocene times as a result of headward erosion, and fluvial systems emptied into the retreating sea from the west and northwest. Sediments deposited from this environment are preserved near the summits and high ridges of Gebel el-Rus. Partially lithified sandstones with numerous pebble and gravel lenses are characteristic of a braided stream–alluvial fan complex. The source of the Pliocene sandstones was mostly Eocene calcareous sandstones and sandstones from ancient surrounding cliffs. The later appearances of chert-dominated gravel lenses in the sandstones indicate that fluvial systems were developed well enough to transport coarse sediments from sources like the Oligocene rocks now preserved 30 km to the northwest, but not developed well enough to sort the sediments very effectively.

Chert and quartzite clasts in the conglomerates on Gebel el-Rus are likely reworked Oligocene interdeltaic and fluvial gravels. Said (1962, p. 103, 104) described proto-Nile River fluvial, estuarine, and marine gravels deposited north of the Faiyum depression. However, the original source for the cherty gravels is not known at the present. Quartzite clasts indicate that part of the source for the gravels was from metamorphic terranes.

FIGURE 16.—*Gravel of the upper member of the Seila Formation in section B on Northern Ridge. Imbricated pebbles and cobbles and planar cross-bedding indicate a paleocurrent trend of N. 135° E.*

Upper Seila Formation deposits are very lenticular internally and probably accumulated in braided streams of alluvial fans. Multiple scour-and-fill structures, planar cross-bedding, multiple bidirectional low cross-bed sets, and imbricated clasts are other evidences that support this type of depositional environment. The poor to moderate sorting of most Pliocene conglomeratic deposits on Gebel el-Rus are characteristic of sediment-choked braided stream systems. The numerous sedimentary structures in the gravels of the Seila Formation, such as cross-bedding and clast imbrication, give consistent paleocurrent trends ranging from N. 100° E. to N. 145° E.

EOCENE-PLIOCENE CONTACT

The Pliocene Seila Formation unconformably overlies middle and upper Eocene deposits in the study area. The angular Eocene-Pliocene contact is well exposed on the west flank of Gebel el-Rus (fig. 6). The unconformity is accentuated by a distinct undulating erosional surface, especially along Northern Ridge. Lighter-colored Eocene rocks abutt against darker Pliocene rocks and further delineate the boundary between Western Ridge and Monkey Ridge (fig. 13).

Unconformable relationships between Pliocene and Eocene strata in the study area range locally from a disconformity to a minor angular unconformity. Angular discordance is apparent north of Monkey Ridge, on the west flank of Northern Ridge. On the south side of Northern Ridge, Eocene strata dip 5° northwestward and are overlain by horizontal, ledge-forming Pliocene units. The angular relationship is readily apparent as the *Ophiomorpha* sandstone and the contact sandstone are traced southward along Northern Ridge. These units dip into the subsurface north of the study area but are truncated southeastward by Pliocene breccia beds between Northern Ridge and Western Ridge. Angular discordance is illustrated by southward truncation of the Western Ridge sandstone, graveyard limestone, and orange limestone in the escarpment in the center of the map, the area northwest of Seila Pyramid. These lower units also dip into the subsurface when traced northward.

Near Western Ridge the Western Ridge sandstone is essentially horizontal, and where overlain there by Pliocene rocks the surface between them is a local disconformity. However, the contact of these units along the escarpment southward between Western Ridge and Monkey Ridge is increasingly angular. The angularity becomes less pronounced south of Monkey Ridge, and the relationship between Eocene and Pliocene rocks there is disconformable. Such variation is largely dependent upon attitudes of the gently folded Eocene rocks.

GEOLOGIC HISTORY AND SUMMARY

Most of Egypt was covered by a portion of the Tethys Sea during the Early Tertiary as a result of a Cenomanian transgression (fig. 17A). Paleocene and lower Eocene sediments were deposited over an undulating surface of folded Cretaceous strata. Thick deposits are recorded in structural basins and linear anticlinal highs are overlain by only thin lower Eocene sediments.

Minor gentle transgressive and regressive middle Eocene events are recorded by gradual shifts of broad facies patterns in northern Egypt. Eocene strata of the study area correlate well with Eocene rocks throughout northern and central Egypt and are a part of a sheet of sediments that was uniformly deposited over a large region. Eocene sediments of the Faiyum and surrounding region accumulated in open, shallow subtropical seas. Tidal currents were also a contributing factor to the environment in the Faiyum area, especially near the close of the middle Eocene and beginning of late Eocene times.

Seas regressed from northern Egypt during the late Eocene and throughout the Oligocene. Upper Eocene littoral and tidal environments graded into Oligocene estuarine and fluvial conditions north of the Faiyum depression. Progradation of terrestrial deposits also influenced withdrawal of the seas. Absence of most of the upper Eocene and all of the Oligocene and Miocene deposits from the eastern Faiyum area suggests either Mio-Pliocene erosion of these systems from the area or that they were never deposited. If the latter is the case, then the region was already subjected to subaerial erosion at the beginning of the Oligocene.

Gentle regional folding and faulting of older strata in northern Egypt was contemporaneous with the late Eocene–early Oligocene regression. This diastrophic event was also responsible for the uplift of northern Egypt forming an Eocene platform. Basalt flows, which originally covered a large area between Cairo and the Faiyum, were extruded during the late Oligocene and early Miocene and apparently occurred concurrent with uplift of pre-Miocene rocks north of the study area (fig. 17B).

FIGURE 17.—*Generalized block diagrams A–F showing the paleogeography of the eastern Faiyum region during various times throughout the Tertiary.*

A—*During this time the Faiyum region was covered by a warm shallow sea.*

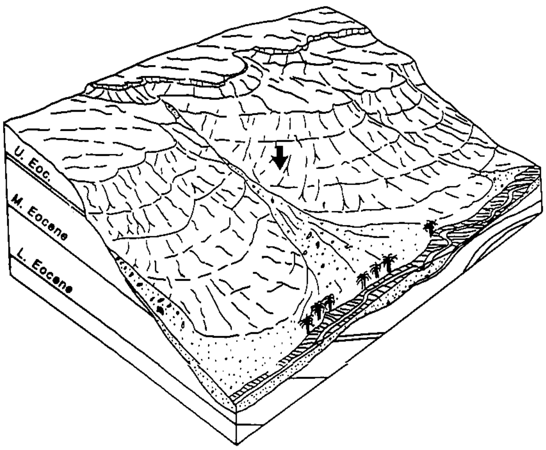
B—*During this time Eocene rocks were uplifted and gently folded. Gebel el-Rus area is identified by an arrow.*

C—*During this time Messinian desiccation of the Mediterranean Sea initiated extensive erosion of the easternmost part of the area. The ancient Nile Canyon was as deep as 2500 m (8200 ft) near the present-day delta area. With an estimated gradient of 1:400, the canyon near the Gebel el-Rus area was approximately 2250 m (7400 ft) deep. Gebel el-Rus area is identified by an arrow.*

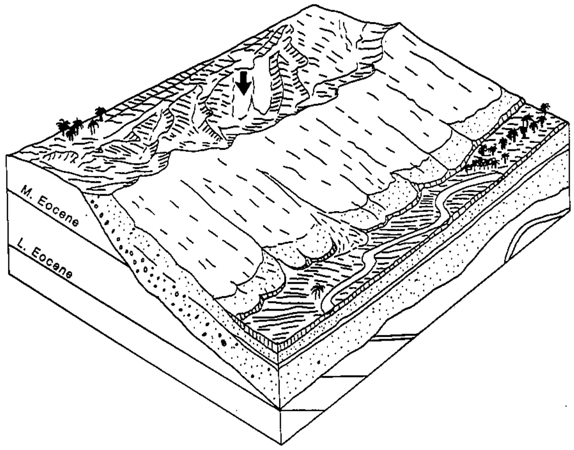
D—*During this time waters of the transgressing Pliocene sea invaded the area, depositing sediments that form the draped sand and mud member of the Seila Formation. Gravel deposits of the sand and gravel member define the regression of the sea from the area. Gebel el-Rus area is identified by an arrow.*

E—*During this time debris-flow deposits filled paleochannels, eventually producing the breccia member of the Seila Formation as an arm of the sea began to occupy the Nile Canyon. Gebel el-Rus area is identified by an arrow.*

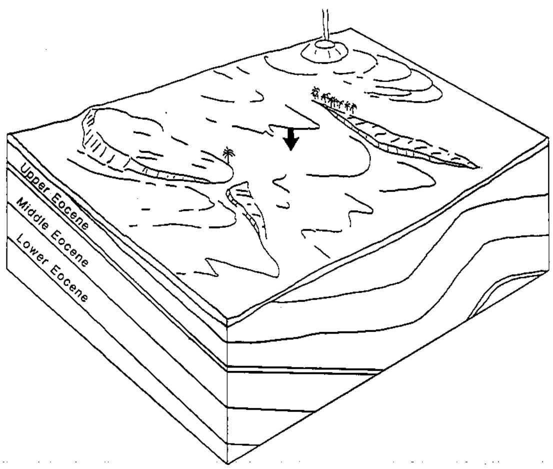
F—*During this time the topography of the area was reversed; the source area for the Pliocene sediments is now the Faiyum depression, and the deposits presently form areas of high relief. Gebel el-Rus area is identified by an arrow.*



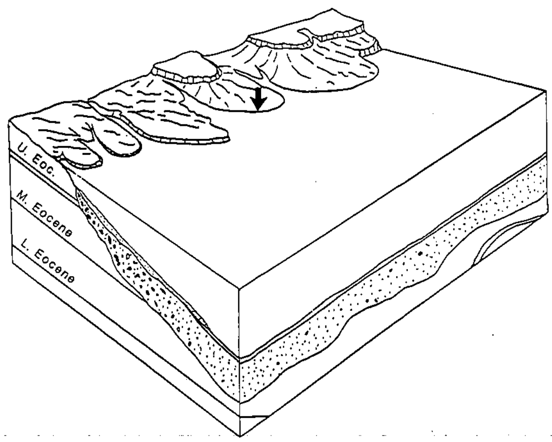
C. Late Miocene



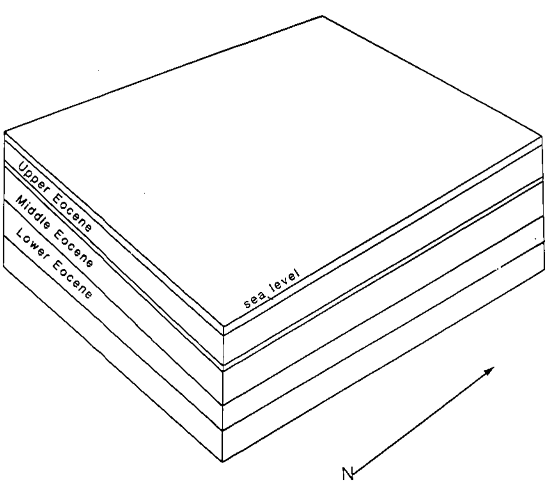
F. Late Pleistocene and Holocene



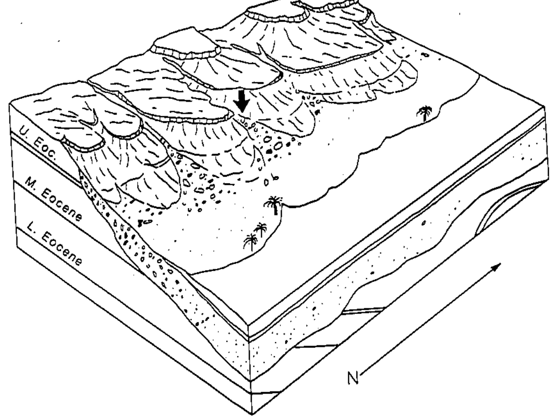
B. Late Oligocene and Early Miocene



E. Early and Middle Pliocene



A. Eocene



D. Early Pliocene

The Eocene platform was extensively dissected during the late Miocene. Erosion was influenced by steepened gradients produced by the lowering of local base level thousands of feet when the Mediterranean Sea dried up during the Messinian. The proto-Nile River reacted by eroding a deep, narrow gorge over 1300 km long. Pre-Pliocene rocks adjacent to this canyon and the Northern Egyptian platform were also deeply dissected (fig. 17C).

The early Pliocene record begins in the Faiyum area with debris flows, often confined in ancient channels (fig. 17D). Where preserved, these beds delineate surface relief at the beginning of the Pliocene and also the paleoshoreline of a transgressing estuary. This estuary is documented by a fining-upward sequence of sands and clayey muds overlying coarse debris-flow deposits (fig. 17E). The paleoslope is documented by layering in the sands, which dip from 5° to 20° toward the southeast. A coarsening-upward sequence of gravelly conglomerates occurs over the sands and muds and represents coarse marginal debris that accumulated during and after the sea regressed from the study area. These Pliocene braided stream–alluvial fan deposits are transported and reworked older deltaic gravels from the northwest.

Steep slopes and cliffs, facing east, are at least as young as late Pliocene and stood where the eastern part of the depression now lies and since must have been eroded back 20 to 30 miles to the north. Paleochannels filled with debris-flow deposits and braided-stream channels both show sediment transport from northwest to southeast out of a source area now lowered to the Faiyum depression.

The absence of Pliocene rocks in the Faiyum oasis and the presence of Pliocene deposits, derived from local sources to the west, that rim the Nile-Faiyum escarpment requires that the Faiyum depression, as we know it today, did not exist during the Pliocene. The sea that occupied the Nile Valley during the Pliocene would most likely have filled a nearby topographic low like the Faiyum depression, and at least some sedimentary record of it would have been preserved. The Pliocene sea rose to at least 80 m above present sea level as indicated by clay deposits of Pliocene age on Gebel el-Rus. Paleocurrents, documented by many sedimentary structures in the Pliocene deposits, give strong evidence that sediments were transported eastward from western and northwestern sources. Large sizes and angularity of many blocks derived from Eocene calcareous sandstone units deposited into paleochannels support the idea that sources were from nearby highlands that existed in the area where the Faiyum depression presently lies. Pliocene rocks on Gebel el-Rus were derived from sources that no longer exist and were originally deposited in areas of low relief, on slopes facing the ancient Nile Valley.

Development of the Faiyum depression took place subsequent to the deposition of all Pliocene rocks on Gebel el-Rus, probably beginning in late Pliocene–early Pleistocene times. The origin of the depression is presently unexplained; however, it was possibly the result of interaction of several processes, including (1) regional subsidence due to faulting, (2) erosion of minor structural features, (3) intense mechanical erosion of thick unlithified mudstone units not overlain by resistant Pliocene breccia bed deposits, (4) chemical erosion of limestone units when humid climatic conditions prevailed, and (5) later wind erosion for final modification during arid Holocene times. Periods of Pleistocene glaciation lowered global sea level hundreds of feet. Normal subareal erosion of Eocene rocks from the Faiyum depression was coincident with these periods of low base levels and associated humid climate.

Another possible explanation for development of the Faiyum depression is faulting on a regional scale. According to Said (1981, p. 20), the origin, orientation, and long-established position of the Nile River Valley is the result of tectonics. According to Gorshkov (1963, p. 101–5), the Nile Valley and the Faiyum region have been the sites of numerous earthquakes in ancient and historic times.

There are, however, no faults presently known in the Faiyum area with enough displacement to produce such a depression (which is as deep as 45 m below present sea level at the northernmost edge). Nevertheless, the only proof available for large-scale faulting in the Faiyum may lie in the subsurface. The triangular-shaped depression is about 10 km west of the Nile River, so close to the fault-controlled valley that the idea of it too being fault-controlled cannot be dismissed until subsurface data can disprove it.

Regional faulting followed by subsidence in order to produce the Faiyum depression should be further considered for the following reasons: (1) the depression's close proximity to the fault-controlled Nile River Valley, (2) its relatively straight northern and eastern sides, and (3) the fact that erosion alone, as a mechanism, has failed to completely explain its development. The straight eastern margin of the depression is generally parallel to the Nile Valley, which trends roughly north–south, and may be oriented by part of the same fault system responsible for orientation of the Nile River. The linear northern margin of the depression, however, is generally parallel to the predominant northeast–southwest fault trends of northern Egypt, which were active during the Neogene, as described by Said (1961, p. 199). Apparently, much is to be learned from further geological studies in the Faiyum depression concerning its origin.

The Pleistocene was nonetheless a significant epoch for the geomorphology of the Faiyum region because it was during this time that a major topographic reversal occurred. Gebel el-Rus and other high areas along the eastern margin of the Faiyum were in low relief, compared to the Faiyum region during the Pliocene. Pliocene valleys that sloped toward the ancient, deeply eroded Nile gorge were filled with resistant debris flow and gravel deposits and became areas of high relief during the Pleistocene. Conversely, the source areas that stood as a high Pliocene platform with prominent eastward-facing cliffs were lowered to negative relief during the Pleistocene (fig. 17F).

Excavation of the Faiyum depression was essentially completed by Paleolithic time, for lacustrine deposits dating from that time are preserved around the margins of the depression. Birket el-Qarun (Lake of Qarun) occupies the northern part of the depression and is a remnant of the ancient Lake Moeris that periodically covered large areas of the depression. Lake Moeris deposits are preserved on the lower western and southern slopes of Gebel el-Rus.

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