History of the Geological Research in Egypt

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Abstract

This chapter documented the history of the geological research in Egypt. It exhibits the ancient literature written and complied on the geology of Egypt including Hume's book and Geology of Egypt books of Rushdi Said that were issued in 1962 and 1990. In addition to literature, the chapter covers the history of geological mapping in Egypt and also a review on geological remote sensing publications including statistics on satellite sensors and techniques. Monitoring spatiotemporal variability in Egypt's Ground water resources using Grace data and the history of geochronological measurements are also considered.

1.1 Stages Before the Geological Survey and Stages After

Mohamed El-Sharkawi

It is fortunate that Geologist Samih Afia, the son of the famous Surveyor El Sayed Afia, to whom most of the survey triangulation points on top of the wild Eastern Desert mountains were planted, gave me old manuscript for reviewing. This manuscript mostly written by a typewriter and partly elegantly hand written with ink pen. The title is the Geological activities since 1609 till 1900. The last is actually the starting date of the newly established Geological Survey of Egypt in 1897, staffed with foreign geologists and engineers.

It is interesting to note that Egypt was visited by well known geologists, such as D.S. Dolomieu, who discovered the mineral dolomite during the French occupation of Egypt (1789–1802) and Napleon ordered him to leave the mission and return home, since he was a trouble maker. The other one is mineralogist Lord Hutchinson who was sent by King George of Great Britain to bring back to Britain the famous Rosetta Stone. He successfully managed to get it from the withdrawing French Army after failing trials to hide it away from the eyes of this specialized British mineralogist. Both Dolmuei and Hutchinson added nothing to our knowledge about the Egyptian geology. Contrary to these names foreign geologists such as W.F. Hume and O. Little inspired the activity of the following generations till present. Many recent discoveries relied on reading important accounts of the pioneer foreign geologists.

The reviewed Samih Afia-hold manuscript turned to be written by W.F. Hume and not O. Little as thought first. In parts in the manuscript Hume asked Little for revising or rewriting paragraphs. Due to the importance of this document and after being reviewed by myself, the Egyptian Geological Survey and the Geological Society of Egypt copied the worn yellow papers and loaded on CDs available at cost in the Geological Society of Egypt.

The British Museum announced in 1998 about a meeting to discuss the achievement of Joseph Hekekyan (1807–1875) the world first geomorphologist. The talk "Joseph Hekekyan at Heliopolis" was delivered by DG Jefferys in London in 1999. I attended the meeting and to my surprise to know that Hekekyan is an Armenian born in Turkey and lived in Egypt in the mid 1800s during the reign of Mohamed Ali who sent him to Great Britain to study Civil engineering for the purpose to construct a barrage in the Nile Delta named Alkanater Alkhayria. He was the chief Engineer for this ambitious project and was assigned by the ruler as the minister of Public Work.

After changing the ruler, Abbas I was not happy with Hekekyan and ordered him to resign from his post. He then contacted the president of the British Geological Survey seeking his advice for his future contributions to the science. His advice to Hekekyan is to explore the surface geology of Egypt. He roved the northern part of the country around Cairo and digged shallow hand wells in Heliopolis, describing in details the well log, with excellent colored illustrations. It is reputed that he discovered the famous statue of Ramses II in Memphis. His fancy drawings and his account on the geomorphological aspects of the studied parts in northern Egypt, hosted now in the British Museum, deserve ranking him as the pioneer geologist in the field of geomorphology. Egypt was visited by travelers, especially Sinai for the search for turquoise and visiting holy places, and the Eastern Desert for the search for gold in the ancient mines exploited by the Pharos. Wadi El Gimal in the southern part of the Eastern Desert is traversed by many pilgrims who stay at Zabara and Sikait on their way to Mecca digging for good emerald "Zomorod" to reimburse their expenditure for their pligrimage. Their adventures reached the hearing of interested audience in Cairo. The news about the treasures are normally kept secret by the successive rulers of Egypt. Adventures kept pace by foreign and local travelers. They follow the Roman and Arab routes in the wild Eastern Desert. The geology of the crossed lands was naively explained. The Western Desert, featureless land covered by loose sand dunes, was crossed by travelers especially in upper Egypt to reach the border of the present day Libya to see the imaginary Zarzora Oasis. The northern part of the Western Desert is not risky to travel. Alexander the Great reached Siwa with minimum losses. Contrary to the Persian Cambyses who lost his army at El Fawakhir Hill in the Western Desert following severe sandy wind storms.

During the phase prior to the establishment of the Geological Survey of Egypt in 1897, talks concentrated on the Egyptian treasures were with Geological tarnish. Egyptian geology was left to the Germans, British, French and Italians. Foreigners living Egypt were planning adventures to extract gold and was much easier to dig the Pharos ruins to gain the ready made gold treasures. Non-Specialists, such as Professor E. Sicken Berger, of the Medical School wrote three lectures bearing the title the Geology of Egypt and published by the National Printing House in 1891 with fancy views unrelated to modern geology. These views were read before the students of the school of Ulema (Dar El Uloum). This is the first published book on the Geology of Egypt. Reports coming from Fayium Oasis during the 1880s about the presence among the fossil field of skeleton of unicorn-look alike Arsinoitherium, inspired a rush from the British counselor and French Counselor to compete to acquire the best to ship it back to their museums. The account written by Walter Granger published in 1907, is worth reading. The Fayium fossil bone field still alive in the mind of the vertebrate paleontologists heralded with the discovery of the walking whales in the nearby Wadi El Hitan during 1970s by D. Gingerich.

Early in the last Century, most of the mining companies were operated and staffed by foreign geologists and engineers. A call from the director of the phosphate company in Quseir to encourage young Egyptian graduate to work under desert conditions, was received with dismay. The Manganese Company at Um Bogma was directed by the British. The young geologist S.O. Ford, obtained his Ph.D. On the geology of Um Bogma as external student to the geology department of Durham University in 1956.

Hassan Sadek Pacha is the pioneer Egyptian Geologist, basically was an engineer but studied also geology and cooperated with the foreign geologists. He participated in joint reports published by the Egyptian Geological Survey.

The first geology graduate from present day Cairo University was in 1929. The number increased in the following years. The graduates were mostly employed by the Geological Survey of Egypt and encouraged to work in the Egyptian deserts.

During the 1950s geology departments in the Egyptian universities were headed by Egyptian staff. They cooperated with the Geological Survey geologists who surveyed most of the Egyptian deserts.

Geological projects were run jointly with foreign geologists. The outcome of these projects inspired further researches to understand the geology of Egypt. The Geological Society of Egypt was established in the 1950s and still active till now.

Geologic thoughts were regularly re-evaluated to cope with the new concepts in this science. The Egyptian geologists are well experienced and participated in fostering the geologic activities in other countries.

1.1.1 Hume's Book

William Fraser Hume (1867–1949) at the age of 30 joined the Geological Survey of Egypt. His book "Geology of Egypt" is the greatest contribution to understand the geology of the country based on his travels and keen observations. He published volume I in 1925 (Fig. 1.1a), which deals with the surface features of Egypt, their determining causes, and their relation to Geological structures, published by Cairo Government Press (408 pp). Volume II consists of three parts published during 1934–1937.

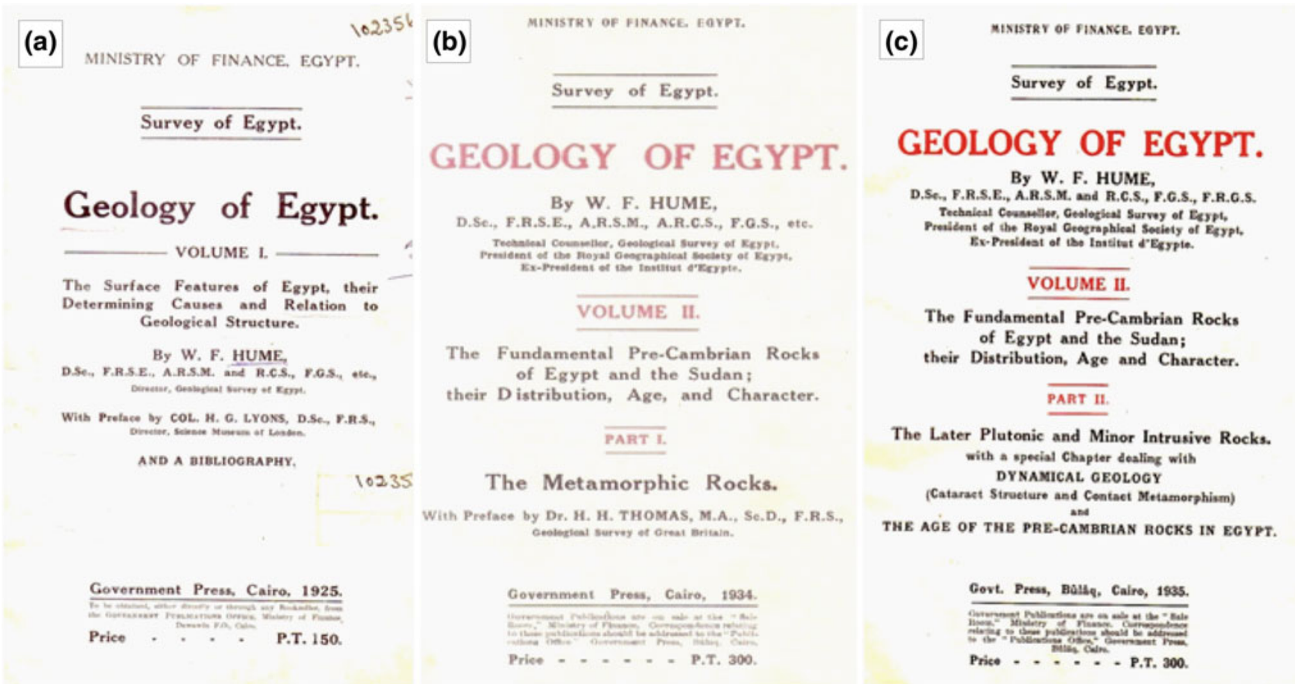
While walking along AlAzbakia Wall in Cairo, I spotted three books for sale, these were Hume parts of volume II on the Geology of Egypt, published by Cairo Government press.

The three parts of volume II bear the same title "the fundamental Precambrian rocks of Egypt and the Sudan, their distribution, age and character".

The first part of volume II is on the metamorphic rocks (pp. 1–300) published by Cairo Government Press in 1934 (Fig. 1.1b).

The second part of volume II deals with the late plutonic and minor intrusive rocks with a special chapter dealing with dynamic geology and the age of the Precambrian rocks in Egypt, (pp. 301–688) published by Government Press of Bulaq in 1935 (Fig. 1.1c).

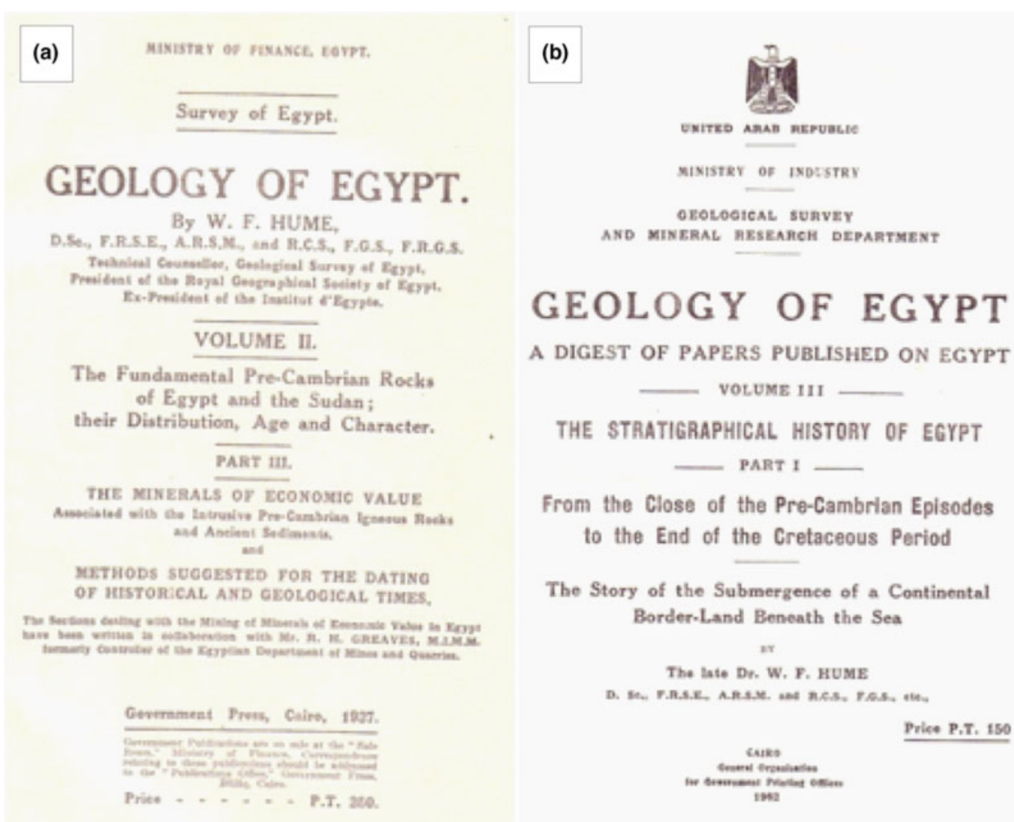
The third part deals with the minerals of economic value associated with the intrusive Precambrian igneous rocks and ancient sediments (in collaboration with R.H. Greaves) and methods suggested for the dating of historical and geological times (pp. 689–990), published by Cairo Government Press in 1937 (Fig. 1.2a).


(a)
MINISTRY OF FINANCE, EGYPT.
Survey of Egypt.
Geology of Egypt.
VOLUME I.
The Surface Features of Egypt, their Determining Causes and Relation to Geological Structure.
By W. F. HUME,
D.Sc., F.R.S.E., A.R.S.M. and R.C.S., F.G.S., etc.,
Director, Geological Survey of Egypt.
With Preface by COL. H. G. LYONS, D.Sc., F.R.S.,
Director, Science Museum of London.
AND A BIBLIOGRAPHY.
Government Press, Cairo, 1925.
Price . . . . . P.T. 150.

(b)
MINISTRY OF FINANCE, EGYPT.
Survey of Egypt.
GEOLOGY OF EGYPT.
By W. F. HUME,
D.Sc., F.R.S.E., A.R.S.M., A.R.C.S., F.G.S., etc.
Technical Counsellor, Geological Survey of Egypt.
President of the Royal Geographical Society of Egypt.
Ex-President of the Institut d'Egypte.
VOLUME II.
The Fundamental Pre-Cambrian Rocks of Egypt and the Sudan; their D istribution, Age, and Character.
PART I.
The Metamorphic Rocks.
With Preface by Dr. H. H. THOMAS, M.A., Sc.D., F.R.S.,
Geological Survey of Great Britain.
Government Press, Cairo, 1934.
Price . . . . . . P.T. 300.

(c)
MINISTRY OF FINANCE, EGYPT.
Survey of Egypt.
GEOLOGY OF EGYPT.
By W. F. HUME,
D.Sc., F.R.S.E., A.R.S.M. and R.C.S., F.G.S., F.R.G.S.
Technical Counsellor, Geological Survey of Egypt,
President of the Royal Geographical Society of Egypt,
Ex-President of the Institut d'Egypte.
VOLUME II.
The Fundamental Pre-Cambrian Rocks of Egypt and the Sudan; their Distribution, Age and Character.
PART II.
The Later Plutonic and Minor Intrusive Rocks.
with a special Chapter dealing with
DYNAMICAL GEOLOGY
(Cataract Structure and Contact Metamorphism)
and
THE AGE OF THE PRE-CAMBRIAN ROCKS IN EGYPT.
Govt. Press, Bûlâq, Cairo, 1935.
Price . . . . . . P.T. 300.

Fig. 1.1 Front page of volume I (**a**), volume II, part I (**b**) and volume II, part II (**c**)


(a)
MINISTRY OF FINANCE, EGYPT.
Survey of Egypt.
GEOLOGY OF EGYPT.
By W. F. HUME,
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VOLUME II.
The Fundamental Pre-Cambrian Rocks of Egypt and the Sudan; their Distribution, Age and Character.
PART III.
THE MINERALS OF ECONOMIC VALUE
Associated with the Intrusive Pre-Cambrian Igneous Rocks and Ancient Sediments.
and
METHODS SUGGESTED FOR THE DATING OF HISTORICAL AND GEOLOGICAL TIMES.
The Sections dealing with the Mining of Minerals of Economic Value in Egypt have been written in collaboration with Mr. R. H. GREAVES, M.I.M.M. formerly Controller of the Egyptian Department of Mines and Quarries.
Government Press, Cairo, 1937.
Price . . . . . . P.T. 250.

(b)
UNITED ARAB REPUBLIC
MINISTRY OF INDUSTRY
GEOLOGICAL SURVEY AND MINERAL RESEARCH DEPARTMENT
GEOLOGY OF EGYPT
A DIGEST OF PAPERS PUBLISHED ON EGYPT
VOLUME III
THE STRATIGRAPHICAL HISTORY OF EGYPT
PART I
From the Close of the Pre-Cambrian Episodes to the End of the Cretaceous Period
The Story of the Submergence of a Continental Border-Land Beneath the Sea
BY
The late Dr. W. F. HUME
D. Sc., F.R.S.E., A.R.S.M. and R.C.S., F.G.S., etc.,
Price P.T. 150
CAIRO
General Organisation for Government Printing Offices
1962

Fig. 1.2 Front page of volume II, part III (**a**) and volume III, part I (**b**)

The main theme of the three parts of Volume II is the Precambrian basement rocks, with field and lab photos in addition to folders housing coloured Geological maps.

It was a real treasure to acquire a copy of these publications who normally find their way to the libraries and not personal copies.

These books were written by an imminent geologist who travelled in the Egyptian desert riding camels in most cases. He wrote other books, but some were published later following his death on 1949.

The Geological Survey of Egypt published in 1962 part I (712 pp) of Volume III Geology of Egypt (Fig. 1.2b) with addition of the following phrase—"digest of papers published on Egypt" by the Editor Dr. Galal H. Awad. Volume III deals with the stratigraphical history of Egypt, and part I covers this history from a the close of the Precambrian episodes to the end of the Cretaceous Period. In other words the story of the submergence of a continental border-land beneath the sea. The Editor of part II of Volume III which was incomplete due to the death of W.F. Hume in 1949 is Dr. Rushdi Said.

1.1.2 Said's '62 & '90 Books

Rushdi Said was a graduate of Cairo University in 1941. He was granted a Ph.D. scholarship from the Egyptian Government to study abroad. Harvard University was his stop for a post graduate research in micro-paleontology. This degree granted in 1950 qualified him to teach at Cairo University, conducting research in the same field to be promoted to Associate professor during his service at Cairo University (1950–1968). Geology Department of Cairo University followed the British University system with only two Chair Professors. This means that Rushdi Said never to be promoted till the retirement or death of the relevant Chair Professors. He was an excellent university teacher. During 1959 I attended a course on the Geology of Egypt, with data gained from the oil business. These data were used only by Rushdi Said and printed and each student acquired these maps and illustrations. I graduated in 1960 and was a post-graduate student at the University of Newcastle Upon Tyne. One day in 1962, Professor Thomas Stanley Westoll the Chairman of the department, entered my room with a voluminous elegant hard bound and with colourful cover with attractive title "Geology of Egypt" by Rushdi Said, published by El Sevier, Amesterdam. He commented that it is a good production but we have to read to justify the scientific merit and admitted that it cost too much to buy it but he will order it to the department library. This was a good chance for the poor student "me" to go through the book in details. To my surprise, the book included all data we taught by Rushdi Said at Cairo University. The book

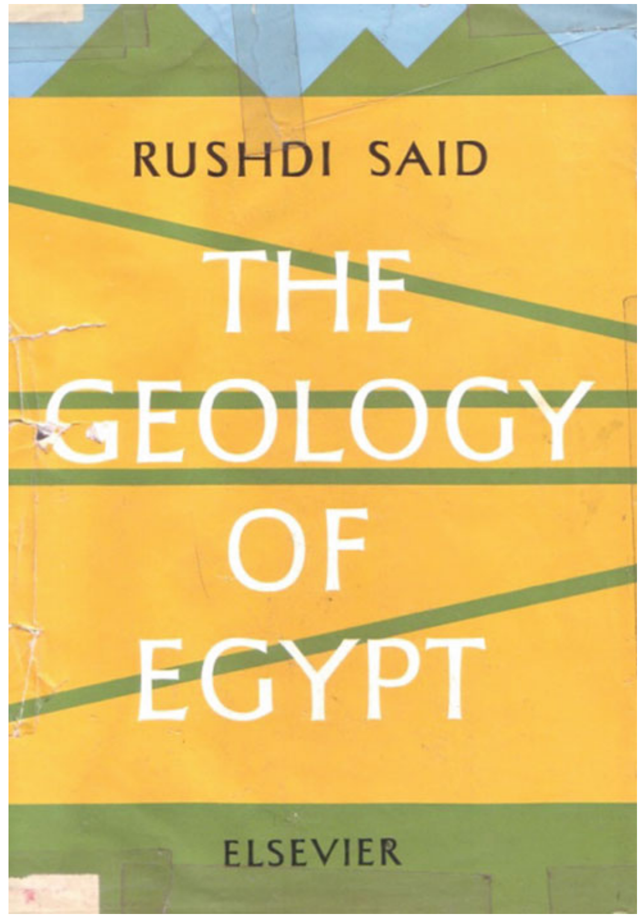


Fig. 1.3 Cover and front page of 1962 book

paper was heavy glossy and well prepared illustrations which characterized El Sevier as a leading publishing house. On my return to Egypt in 1965, I was informed that the Chair Professor Nasri Metri Shukri, who inspired Said to write a book on the Geology of Egypt (Fig. 1.3), did not write the chapter on the Precambrian of Egypt, on which Rushdi Said was expecting his support. That is why the weakest part of 1962 edition of Rushdi Said's Geology of Egypt is that dealing with the Precambrian rocks. No doubt this book written by an Egyptian was a beacon to Egyptian geologists and in general earth scientists. It was consulted by many oil companies and his author became a high rank consultant in the oil business. The Egyptian scientists refer to many geological aspects to Rushdi Said as he is the author of them, which are away from his speciality. Mineral resources in basement rocks were referred to be after Rushdi Said who was embarrassed to say no.

From 1962 till 1990, twenty eight years of feverish geological activities in all fields of geology, the Geological Survey was vibrant and Rushdi Said chaired the survey from 1968 till 1977, who directed the geological missions of the survey to solve certain problems. The Quaternary of Egypt was his piece of cake. The junior staff gained much from his experience and he gained also much from the outcome of these studies. Our knowledge about the geology of Egypt was modified and polished by the research activities of the university staff in all aspects of geology. The joint projects with foreign universities contributed much and changed much taboos in our geologic thoughts. New theories entered in the geologic arena, challenged by some, acknowledged by others. Heated meetings were active. Within this pregnant situation, Rushdi Said with his piercing thoughts decided to update his 1962 book though grant offered from a leading oil company and to be published in another publishing house. He will act as editor to avoid the criticisms he received on his 1962 book. He carefully invited leading Egyptian and foreign geologists to write or share with others in chapters.. Unfortunately Rushdi Said in the early sixties got involved in politics, where he was assigned as a member of the Egyptian Parliament. I remember meeting him in London in 1965 as a member of delegates to the U.K. representing the Egyptian Parliament. This definitely affected his scientific career.

During 1988 he was preparing the pits and pieces of his new book and showed me a chapter on the geology of Cairo-Suez stretch he wrote while living in USA. This chapter could have been accepted if reviewed during the 1960s and I advised him not to include it in the new book and call a scientist aware of the new additions to our knowledge about this important stretch. He listened carefully with a hard feeling that he lost much when he was involved in politics and migrating to USA. He is really a person who listen carefully to others views, one of the characters of a real scientist.

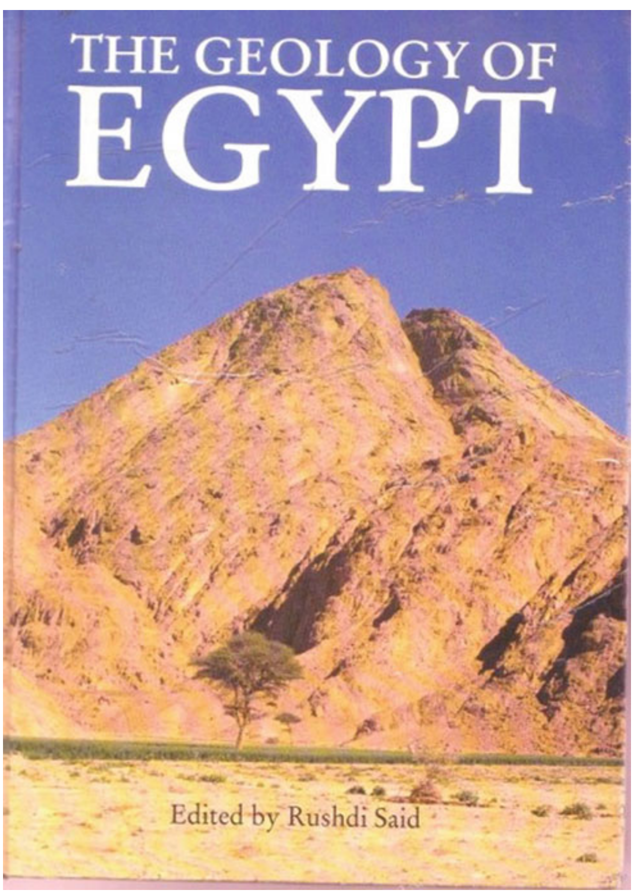


Fig. 1.4 Cover and front page of 1990 book

The 1990 book of Geology of Egypt (Fig. 1.4) is voluminous with many contributors, each in his speciality and responsible for what is included in his chapter. Reference should bear his name and not the editor. What was new in the science is included in this edition, published by Balkema, also in Amesterdam. The paper quality is not the heavy glossy of 1962 edition.

So, the plan to prepare a new book bearing the same title with the same policy followed by Rushdi Said in the 1990 book is welcome by all earth scientists.

It is not a coincidence that 28 years appears to be the reasonable lapse of time between publishing new data concerning the geology of Egypt. This new Geology of Egypt book published by Springer in 2020 followed (Said 1990a, b, 1962) and Hume main book Geology of Egypt Volume II published in 1934.

1.2 History of Geological Mapping in Egypt

Nagy Shawky Botros

1.2.1 Introduction

Egypt has an area of 1000 000 km^2. It is divided into four major physical regions: Nile Valley and Nile Delta, Western Desert, Eastern Desert and Sinai Peninsula.

In Pharaonic times, Egyptian roved the Eastern Desert looking for gold, copper and precious stones, and introduced the first geological map in history (the Turin papyrus map). The Papyrus (Fig. 1.5) was drawn during the reign of Ramses IV (1156–1150 BC) and reveals the bekhen stone quarries and the Fawakhir gold mines in the Wadi Hammamat (Harrell and Brown 1992). The papyrus map is now preserved in the Egizio Museum of Turin (Italy).

The Modern history of mapping in Egypt can be divided into three episodes. The first episode is extending from the French Expedition (1798–1801) to the establishment of the Egyptian Geological Survey, at 1896. The second episode extends from the establishment of geological survey until the revolution of 1952. The third episodes extends from 1952 to the present.

Fig. 1.5 Turin mining map showing Fawakhir gold mine and its surroundings

1.2.2 First Episode of Mapping

The first episode extending from the French Expedition (1798–1801) to the establishment of the Geological survey of Egypt was characterized by sporadic research carried out by individual naturalists and travellers and commissioned scientists. In this episode Napoleon Bonaparte's expedition and Rolf's Expedition (1874–1875) are of special importance (Said 1990a, b). In this episode, Egypt came to direct contact with Western scientific thinking and methodology.

Napoleon Bonaparte's expedition to Egypt in 1798 carried out the first multidisciplinary exploration mission and formed the Institute of Egypt, the first scientific organization in Egypt (Tawadros 2012). Napoleon's expedition was responsible for bringing Egypt to the attention of the scientists of Europe by the publication of the memorable "Description de l´ Egypte". This work included in many of its volumes, and specially the second volume (published in 1813) several chapters that are of interest to geologists and mineralogists and contain the first reliable map of the Eastern Desert of Egypt (Said 1990a, b). Several of the French scientists who accompanied the expedition, traversed the Egyptian Deserts and left their maps and scientific observations.

Rolf's Expedition (1874–1875) published the first reliable geological map of the extensive deserts of Egypt to the south of latitude of Fayum (scale 1:300 000). This map remained the standard geological map of the country up to the publication of the Survey map of 1910 (Said 1990a, b). Schweinfurth (1836–1925) visited Egypt and worked in Gabal Elba region in1864, and published detailed account on the Central Eastern Desert with a map which was published in ten sheets between 1899 and 1910 (Said 1990a, b). Fraas crossed the Eastern Desert at 1867 between Qift and Qusseir, and published a map and a geognostic profile of this area (Said 1990a, b).

The oldest scientific geological map of Africa originated from Egypt and was compiled by R. Russeger in 1842 (Fig. 1.6). The term Nubian Sandstone, which is sometimes still in use today, is mentioned for the first time in this map (Schluter 2008).

1.2.3 Second Episode of Mapping

The Egyptian Geological Survey was founded in the year 1896 as a result of a memorandum written by Captain H.G. Lyons (engineer, meteorologist, geomorphologist and museologist) to the ministry of Public Works in Cairo. The survey started as a small section in the ministry of Public Works with a humble annual budget of 730 Egyptian pounds a year and less than 2500 lb for field operations (Issawi 1979). By 1898, it was passed through various departments such as Topographic Survey, Mines and Quarries until 1945 when it was merged with the Ministry of Commerce and Industry (Issawi 1979).

Irrespective of the different titles and affiliations, the Egyptian Geological Survey has had from the beginning a specific role to play in exploring and mapping the Egyptian Deserts and in discovering and evaluating the country's mineral potential.

Shortly, after the turn of the nineteenth century, several eminent geologists collaborated to produce a geologic map. The scale was 1:1 000 000 in six sheets and 1:2 000 000 in one sheet. The map was accompanied by explanatory note by Hume. However, one third of the area of Egypt was not explored, so no information for this part was given in that map. In 1922, regional map by Gilbert Clayton (1875–1929) was carried out. This map was in one sheet, scale 1:2 000 000, and accompanied Hume's "Geology of Egypt: published in 1925. In 1928, map of Egypt was produced in Atlas of Egypt. The map was in four sheets, scale 1:1 000 000. A copy of this map appeared in the 14th International Geological Congress held in Madrid in 1926. The 1928 map included the results of mapping of Sinai and Gulf of Suez, and also included gneisses and granites recorded in the most south-west corner of Egypt.

In fact, much of the pioneering work in Egypt was undertaken between 1900 and 1940 when several eminent British geologists (Fig. 1.7) carried out field surveying on a systematic basis in both the Western and Eastern Deserts (O'Connor 1996). Important maps and explanatory memoirs of several classical areas of Egyptian geology were compiled in this time interval. For example, Ball and Beadnell worked

Fig. 1.6 Geological map of Egypt compiled by R. Russeger in 1842

Fig. 1.7 Photograph of members of the Geological Survey of Egypt in 1925. H.L. Beadnell (1), W.F. Hume (2), John Ball (3), George Murray (4), Patrick Clayton (5), O.H. Little (6), Hassan Sadek pasha, the first Egyptian geologist in the Egyptian Survey (7)

predominantly in the Western Desert of Egypt and produced descriptive accounts of the geology of Oasis districts including Kharga, Fayum, Kurkur, Farafra, Baharia and Dakhla Oasis (Ball 1900, 1939; Ball and Beadnell 1903). Beadnell was a specialist in Phanerozoic stratigraphy and contributed valuable scientific knowledge on the Cretaceous and Tertiary sequences around the Oases and also the Nile Valley around Aswan and part of the Red Sea Coast. His last published work in Egypt was a geographic and geological overview of the Sinai Peninsula (Beadnell 1927). Barron concentrated his work on the then little known topography and geology of the Sinai Peninsula and Cairo-Suez district (Barron 1907) and together with W. Hume compiled a report on the topography and geology of the Central Eastern Desert (Barron and Hume 1902). Hume was one of the most productive geological investigators in Egypt and his work includes the famous three –part treatise on “The Geology of Egypt”, V.2 which was the first major scientific compilation on the metamorphic and igneous geology of the Eastern Desert and the minerals of economic value (Hume 1934, 1935, 1937).

During the late thirties and early forties, an extensive program for oil exploration in the northern part of the country led to the publication of a regional geological map (1:500 000) for the area north of latitude 27°30′N (Issawi 1979).

1.2.4 Third Episode of Mapping

From 1928 to the early 1940s geological activity was very limited, and geological mapping did not receive any attention from the state. After the discovery of some ore deposits like chromite in Barramiya district, Tin in Um Bissila and cassiterite in Igla (all in the Central Eastern Desert), in the late 1940s and early 1950s, the geological mapping of the basement rocks in the Central Eastern Desert on a scale of 1:100 000 became the main activity of the Egyptian Survey.

In 1956 the survey under the name “Geological and Mineral Research Department” appeared as part of the new Ministry of Industry. This situation remained until 1965 when the Survey was amalgamated with the General Egyptian Organisation for Mining and Geological Researchers founded largely to supervise the national mining industry. By 1970 the Egyptian Geological Survey became a separated body under the name of Egyptian Geological Survey and Mining Authority (EGSMA).

During the interval (1944–1957), 22 quadrangles constituting an area covering 10 275 km^2 between latitudes 24°30′ and 25°40′N were mapped in the Central Eastern Desert (CED) of Egypt (Akaad 1996). The compilation and fitting of the 22 quadrangles maps into a single map for the Central Eastern Desert was undertaken by El Ramly and Akaad during three field seasons (1957–1960). Adjacent quadrangles mapped by different field parties had to be reconciled with discrepancies judged, decided upon and amended (Akaad 1996). Crucial areas were remapped and alterations and amendments were undertaken by El Ramly and Akaad and the compiled map was then reduced to scale 1:250 000 to permit publication (El-Ramly and Akaad 1960). This map was the first reliable map for any part of the Egyptian Basement and was accompanied by the first realistic and applicable succession of rock units, derived from the systematic mapping of a virgin terrain of a representative part of the CED (Akaad 1996).

The mapping of the South Eastern Desert (SED) and North Eastern Desert (NED), S and N of the CED 1960 map was carried out in three phases. The first phase was undertaken by Assiut University team under the supervision of Akaad in both Qift-Qusseir and Qina-Safaga districts. Noweir (1965, 1968) mapped the Um Hombos area (85 km^2) and the Hammamat- Um Selimat district (1145 km^2), later extended to 5500 km^2 (Akaad and Noweir 1980). Shazly (1966, 1971) supervised by Akaad mapped 1200 km^2 around G. Meatiq and Wadi Abu Ziran, and

Habib (1968, 1970) mapped 1400 km^2 around G. Abu Furad, south of Qina- Safaga road.

The second phase of mapping the SED was carried out by EGSMA team (1955–1972) and Hunting Ltd. (1967). Hunting Geology and geophysics Ltd. (1967), financed by UNDP and assisted by six geologists from the Aswan Regional Planning Project, prepared a photo-geological map of a region 75 000 km^2 between latitudes 22° and 25°N using aerial photographs 1:40 000, and work was ended in the 1:500 000 map (Hunting Geology and geophysics 1967).

The third phase of mapping concentrated in the NED, started in 1968. This work included mapping of nine quadrangles, in addition to the works of Sabet (1961), El-Akkad and Dardir (1965), Ghobrial and Lotfi (1967).

In 1971, a new geological map, scale 1:2 000 000, black and white in one sheet was produced. The map was accompanied with an explanatory note. This was followed by the publication of the basement complex (scale 1:100 000) of the Eastern and Western Deserts (El Ramly 1972).

In 1979, EGSMA published the coloured geological map of Aswan sheet, scale 1:1 000 000, and in the same year EGSMA published the first mineral map of Egypt, scale 1:2 000 000 (Afia and Imam 1979). The mineral map recorded at that time all available knowledge of mineral deposits and occurrences. The map is divided into two sheets; one sheet gives the distribution of metallic mineral deposits and occurrences, the other gives the distribution of the non-metallic mineral deposits and occurrences. The two sheets were prepared in both Arabic and English and the map was printed in black and white. The number of mineral locations plotted on this map amounts to 268 locations for metallic mineral and 376 locations for non metallic minerals, a total of 644 locations. Once, the map was out of print, and due to its obligation towards geology students and those interested in the basic information concerning the natural resources of Egypt, EGSMA decided to reprint the same map as second edition in 1994.

In 1981, an improved, updated and coloured version of the 1971 geological map was published in one sheet, scale 1:2 000 000, and in 1982 EGSMA published the coloured Dakhla Sheet, scale 1:1 000 000.

In 1984 the Overseas Development Administration (ODA) of London sanctioned a new geological project in EGSMA. The emphasis of this pilot project was placed on training to EGSMA field staff of field mapping techniques assisted by high resolution aerial photography with the objective of producing a revised geological and mineral occurrence map at scale of 1:50 000. The course of training covered a variety of geological and related remote sensing topics which included development in Earth Observation satellites and their applications for resource mapping and management (O'Connor 1996).

Following the success of the pilot training exercise, the project moved forwards towards mapping training on a regional basis supported by enhanced imagery derived from both the Landsat TM sensor and the traditional aerial photography which used, in part, as topographic maps. The enhanced imagery highlighted several sites of alteration zones which carried mineral potential (O'Connor 1996). EGSMA field-mapping geologists soon adapted to the TM imagery technique and it became the standard planning tool of the strategic remapping projects in the CED and SED. During the interval 1986–1992 five quadrangle sheets had been remapped

In 1983, EGSMA published the metallogenic map of the Aswan Quadrangle, scale 1:500 000. The number of locations plotted on this map is 192 locations and the geological information of this metallogenic map was based on the geological map of Aswan Quadrangle, scale 1:500 000 published by EGSMA in 1978. In 1984, EGSMA published another metallogenic map for the Qena Quadrangle, scale 1:500 000. The number of locations plotted on Qena metallogenic map is 79 locations and the geological information of this metallogenic map was based on the geological map of Qena Quadrangle published by EGSMA in 1978.

In 1998 EGSMA, in cooperation with the Egyptian Academy for Scientific Research and Technology, published the Metallogenic Map of Egypt on the scale of 1:1 000 000 in 4 sheets covering 1 million km^2. Latitude 27°00′ and Longitude 30°00′E were the border lines separating these sheets. The sheets were given the numbers I, II, III and IV (Fig. 1.8). Owing to density of data, the map was published as two parts: part one for Metallic and Non-metallic ores, and part two for Building, Construction Materials and Ornamental Stones.

For a long time, the South Western Desert suffered from lacking enough information for the development programs, except for sporadic works carried out in Kharga, Dakhla and Farafra Oases which are accessible through roads from the Nile Valley. Consequently a join project between the Egyptian Government and the United Nations Development Program (UNDP) and UNESCO was launched in 1998 under the title "Capacity building of the Egyptian Geological Survey and Mining Authority (EGSMA) and the National Authority of Remote Sensing and Space Sciences (NARSS) for the sustainable development of the South Valley and Sinai".

One of the main achievements of this project was the Geological Map of the Western Desert. The map of the southern Western Desert was prepared in digital formats and produced in its original form in thirty sheets distributed according to the International map grid of scale 1:250 000 and updated according to the latest available geological information. The symbols and colours of the International

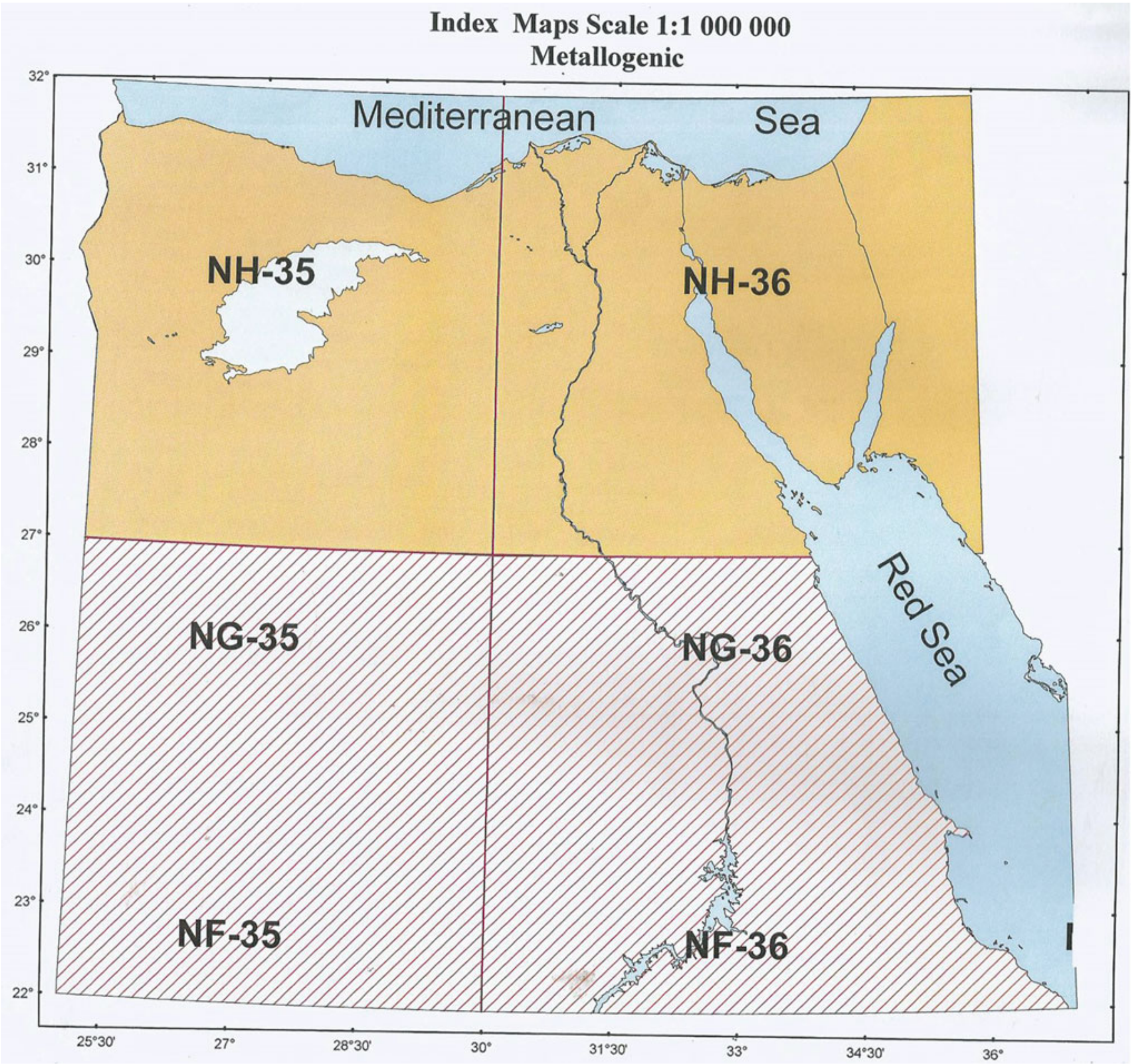


Fig. 1.8 The four sheets of the metallogenic map of Egypt, scale 1:1 000 000

Stratigraphic Chart issue in 2004 by the International Commission on Stratigraphy (ICS) of the International Union of Geological Sciences (IUGS) and the UNESCO for the World Map were applied in the Geological Map of the South Western Desert. Besides, digital geological mosaics for the South Western Desert on both the scale 1:1 000 000 and 1:2 000 000 were also produced during this project.

For the northern part of the Western Desert, 25 image maps covering the area north of Latitude 27°00′N as 1 × 1.5 degree quadrants were produced. These image maps were originally prepared at a scale of 1:250 000, matching the official map system of the country, but here printed at a scale 1:500 000. These image maps are useful in the identification of the different land use/land cover features, the selection of the suitable areas for development projects and enhancing the exploration activities for natural resources utilization and management. Moreover, image maps represent the base maps required for researchers, planners and decision makers to prepare their planes for investigating such vast area in the Western Desert.

Concerning Sinai, the geological map was also prepared in digital formats and produced in twelve sheets distributed according to the international map grid of scale 1:250 000 updated according to the latest available geological information.

Also besides, digital geological mosaics for Sinai Peninsula of scale 1:250 000 and 1:500 000 were produced during this project.

In both the Western Desert, (south and north) and Sinai Peninsula, the produced maps and the accompanying sheets are incorporated in three geological atlases of reasonable scale. The three atlases are entitled as follows: "Geological Atlas of the South Western Desert (2005)", "Atlas of Space images of North Western Desert, Egypt (2005)" and "Geological Atlas of Sinai (2004).

Generally speaking, and according to Naim (1996), the available geological maps covering the surface area of the country are as follows: 1:2 million scale (100%), 1:1 million scale(100%), 1:500 000 scale (100%), 1:250 000 scale (40%) and 1:100 000 scale (20%). In addition, many local areas are covered by detailed maps of 1:50 000, 1:20 000, 1:10 000 and 1:5 000 specially around mineral deposits and areas mapped for geotechnical purposes.

1.3 Geological Remote Sensing Publications in Egypt: Some Statistics on Satellite Sensors and Techniques

Ahmed A. Madani

1.3.1 Introduction

The years 2007 and 2018 witnessed two significant events for Egyptian remote sensing and space sciences community. EgyptSat-1 is Egypt's first Earth observation remote sensing satellite launched on board a Dnepr rocket on 17 April 2007 from the Cosmodrome in Baikonur, Kazakhstan. It consists of two devices. Infrared imager has one band covers (1.55–1.7 µm) wavelength region with 39 m spatial resolution at nadir. And, multispectral imager has three visible bands and one panchromatic covers (0.50–0.89 µm) with spatial resolution of about 7.8 m at nadir. Unfortunately, only few published papers were utilized Egyptsat-1 in soil applications. Afify et al. (2010) produced physiographic soil map for the Nile alluvium in the middle Egypt using Egyptsat-1 data. Zaghloul et al. (2013) utilized Egyptsat-1 data for detection of ancient irrigation canals of Deir El-Hagar playa, Dakhla Oasis, Egypt. The year 2018 marked the establishment of the Egyptian Space Agency based on the Presidential Decree No. 3, for 2018. Establishment of the Egyptian Space Agency was the first recommendation of the road map prepared by the space and remote sensing council and accepted by Academy of Scientific Research and Technology (ASRT) in 1998. The dream of establishing Egyptian space agency was realized twenty years later.

Satellite remote sensing activities in Egypt started in 1971 as a joint research project based at the counterpart of (ASRT) with the American side and then developed to a Remote Sensing Center in 1972. Since the entrance of satellite remote sensing techniques Egypt and so far, there is no any statistical information about the types of satellites sensors and/or techniques used for geological applications. In the present article, we reviewed satellite data types and techniques used for geological applications especially mineral exploration and geological mapping by looking into more than 100 peer-reviewed papers published in Egyptian Journal of Remote Sensing and Space Sciences (EJRS) during the last two decades.

Remote sensing is an essential technique used for geological, hydrological and environmental applications. It can be defined as a technique of obtaining information about an object without touching it by means of capturing images either from the air using aircrafts or from space using satellites. Before launching earth observation satellites, aerial photographs are considered the most important source for image data used for geological applications. Several authors were utilized analog aerial photos "scale 1:40 000" and/or photo-mosaic "scale 1:50 000" for geological mapping (El-Etr 1976; El-Etr and Abdel-Rahman 1976; Mostafa 1977; Madani 1995; Youssif and El-Assy 1999 and others). After Launching Landsat satellite series in 1972, multispectral satellite imageries (MSS) become the most useful and they have more advantages in lithologic discrimination compared with aerial photographs. Several authors were utilized ERTS-1 data for geological applications. El-Shazly et al. (1974) and El-Shazly et al. (1979) were utilized ERTS-1 "Landsat-1" satellite data for geological interpretation and mapping of west Aswan area and Sinai Peninsula.

Utilization of satellite data for geological applications in Egypt was increased significantly after the establishment of National Authority for Remote Sensing and Space Sciences (NARSS) in 1991 (re-organized in 1994) and increased the interest of the Egyptian universities to teach undergraduate and post-graduate remote sensing courses. In 1998, The Egyptian Journal of Remote Sensing and Space Sciences (EJRS) published its first issue. The present review represents the first attempt that tried to present some statistics on satellite data types and techniques used for geological applications in Egypt, especially their applications in minerals exploration and geological mapping.

1.3.2 A Review on Geological Remote Sensing Publications in Egypt (from 1998 till 2017): Statistical Approach

This review is based on a comprehensive survey of about more than 100 peer-reviewed papers (Table 1.1) published during the period between 1998 and 2017 in EJRS. Some papers published in ISI journals are added to this review. In the present review, we included all papers that utilized remote sensing techniques for lithological discrimination, mineral exploration, surface hydrology, geomorphology in addition to some environmental application (e.g. change detection). And, we excluded: (a) all papers that utilized remote sensing techniques in the fields of agriculture and soil mapping, urban planning, air pollution and space sciences; (b) all papers applied in regions outside Egypt; and (c) all M. Sc. and Ph.D. theses that utilized remote sensing techniques in geological applications. Figure 1.9a shows numbers and years of geologic remote sensing papers published mainly in Egyptian Journal of Remote Sensing and Space Sciences. Figure 1.9b shows the percentages of satellite sensors used for geological applications. Landsat series recorded highest score of about 76% of the total published papers whereas ASTER, Radar and SPOT data scored 12%, 7% and 5% respectively.

Table 1.1 shows sensor resolutions and suitability of common satellites used for geological mapping and mineral exploration. For regional geological mapping (scale 1:1 000 000 up to 1:100 000) Landsat satellite series and ASTER data are the most suitable data due to their moderate spectral and spatial resolutions. For detailed geological mapping (1:10 000 or finer) both are not suitable because they lack detailed spatial data. SPOT data are suitable to some extent.

1.3.2.1 Publications on Utilization of Remote Sensing Techniques for Geological Mapping

Geological mapping is the process of preparing a 2D map for an area of interest that shows the spatial distribution of rock units in addition to the distribution of the structural elements. List et al. (1990) reviewed the activities for geological map production in Egypt. They presented the methodology for production of what is called “new geological map of Egypt”, scale 1:500 000. Several geological maps of Egypt were produced by CONOCO and EMRA using the processed Landsat MSS & TM with aid of field data. About 20 geological maps (scale 1:500 000) covered entire Egypt produced by CONOCO in 1987 using the processed Landsat MSS data under the supervision of Egyptian General Petroleum Corporation. List et al. (1990) presented the digital image procedures for maps production.

The present review showed that, the most common used satellite sensors for geological applications are Landsat and ASTER data. Landsat sensors (MSS, TM, ETM+ & OLI) and ASTER data were utilized by many authors for lithologic discrimination and geological mapping. Sultan et al. (1986) utilized the processes Landsat TM data for mapping of serpentinites in the Eastern Desert of Egypt. Sultan et al. (1987) presented new Landsat band ratios imageries used for lithologic discrimination and mapping of Meatiq Dome area, Egypt. El Baz (1998) and Robinson (1998) studied the potential applications of Radar and Landsat data for mapping the buried radar rivers in the Western Desert, Egypt. Kusky and El-Baz (1999) revealed the presence of three main structural provinces characterized by different styles of deformation in the Sinai Peninsula using the processed Landsat imageries. Madani (2001) utilized Landsat data for mapping Wadi Natash volcanic field, SED, Egypt. Sadek and Khyamy (2003) applied band ratios 5/7, 5/1 & 4 of Landsat TM images to delineate the borders, lithologic units and structural features of low relief basement outcrops exposed in south Western Desert of Egypt between Long. 29°E and the River Nile. Sadek (2005) revealed that Landsat TM false color composite band ratio imagery (5/1, 5/7, 5/4 * 3/4) is the best discriminator for the different basement rocks and detected the mineralized alteration zones hosted within Wadi Beida sheared metavolcanics, Shalateen area, SED. Sadek (2006) revealed that the ETM+ image bands 7, 4 & 2 and FCC ratio image 5/7, 5/1 & 4 in RGB improved the lithological discrimination of basement rocks at Gabal Gerf area, SED as well as distinguishes the linear features (dyke swarms & faults). Gad and Kusky (2007) applied successfully new ASTER band ratio image 4/7, 4/6 & 4/10 for lithologic mapping in the Wadi Kid area, Sinai, Egypt. Aita and Bishta (2009) interpreted lithologic units, structural framework and high zones of radioactive anomalies of Gabal El-Minsherah-ElHasanah district, north Sinai using Landsat 7-ETM+ data and digital image processing techniques. Bishta and Aita (2009) applied the processed Landsat-7 data to discriminate structure and lithology for defining the horizons of radioactive anomalies at Gabal Halal, north Sinai, Egypt. Hassan et al. (2008) discriminated the Oligocene sands and gravels, Wadi Ghoweiba area, northwest Gulf of Suez, Egypt using FCC principal component color image PC2, PC6 and PC9 in RGB. Youssef et al. (2009) proposed and tested a new Landsat ETM+ band ratio 5/3, 3/1 & 7/5 in RGB for lithologic discrimination of basement rock units around Gabal Al Hadid, CED, Egypt. Wasfi et al. (2009) discriminated younger granitic masses at Gabal Qattar area NED, Egypt using DN values of Landsat ETM + band-5 imagery. Amer et al. (2010) presented a new method for using ASTER data for lithological mapping in

Table 1.1 Satellites suitability for geological applications and related references in Egypt

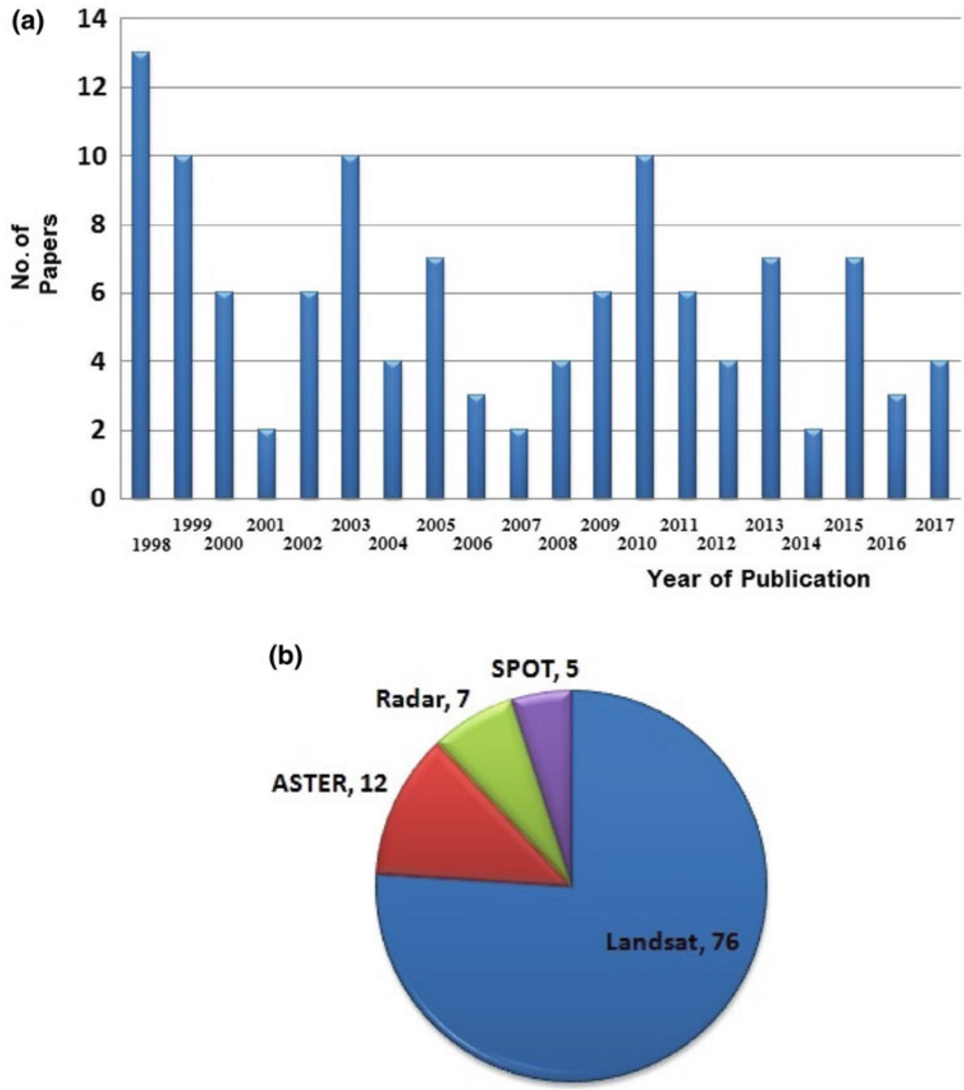
Applications	Common satellites used for geological applications					
	Landsat		ASTER		SPOT	
	Revisit 16 days		Revisit 16 days		Revisit 26 days	
	Spatial resolution 30–15 m	Spectral resolution Landsat-8 (11 bands)	Spatial resolution 30–15 m	Spectral resolution 14 bands	Spatial resolution 1.5 m	Spectral resolution 5 bands
(1) Geological mapping: (a) Regional mapping (1:1 000 000; 1:500 000; 1:250 000 & 1:100 000)	Suitable		Suitable		Suitable	Slightly suitable
(b) Detailed mapping 1:10 000 or fine scale	Not suitable		Not suitable		Suitable	Slightly suitable
Landsat references Kusky and El-Baz (1999), Hamdan and El-Etr (1998), Youssif and Aly (1998)*, Youssif and El-Assy (1998)*, Abdel-Motaal and Ramadan (1998), Yousif and Shedid (1999), Hegazy et al. (1999), El Baz et al. (2001),, Ramadan (2002)*[1], Wahbi et al. (2002), Abdeen et al. (2002), Bishta and El-Tarras (2002), Abdeen (2002), Sadek and Khayamy (2003), Ramadan (2003), Madani (2004)*[1], Sadek (2005), Madani et al. (2005), Assran et al. (2005) Wasfi (2007), Abdeen and AbdelGaffar (2008), Hassan et al. (2008), Sadek (2006), Youssef et al. (2009), Wasif et al. (2009), Aita and Bishta (2009), Bishta and Aita (2009), Abdeen et al. (2009), Salem et al. (2012), Kamel et al. (2016), Hassan and Sadek (2017), Hassan et al. (2017), Khamies and El-Tarras (2010), Masoud and Koike (2017)*[2] *ASTER references* Gad and Kusky (2007), Amer et al. (2010), Madani and Emam (2011), Madani (2012), Jakob et al. (2015), Madani (2015), Hassan and Sadek (2017), Hassan et al. (2017), Abdeen et al. (2003, 2009) *SPOT references* Wahbi et al. (2002), Abdeen et al. (2009)						
(a) Gold	Suitable		Suitable		Slightly suitable	
	Landsat references Ramadan (2002), Madani et al. (2003), El-Fouly and Salem (2003), Sdaek (2004), Salem (2007), Ramadan and Kontny (2004), Ramadan et al. (2005), Gabr et al. (2015), Amer et al. (2016) *ASTER references* Gabr et al. (2010), Amer et al. (2012)*[3], Gabr et al. (2015), Salem and Soliman (2015), Salem et al. (2016) *SPOT reference* Gabr et al. (2015)					
(b) Radioactive (Uranium) (Black sand), Heavy metals	Suitable		No reference		No reference	
	Landsat references Yehia et al. (1998), Ramadan et al. (1999), Ramadan and El-Lithy (2005), (El-Sadek and Mousa 2010a, b), Ramadan et al. (2013) and Shokr et al. (2016)*[2]					
(c) Iron Ore and BIF	Suitable				No reference	
	Landsat references Salem et al. (2013), Salem and El-Gammal (2015) *ASTER reference* El-Nagdy and Abdel Salam (2006)					

(continued)

Table 1.1 (continued)

Applications	Common satellites used for geological applications					
	Landsat		ASTER		SPOT	
	Revisit 16 days		Revisit 16 days		Revisit 26 days	
	Spatial resolution 30–15 m	Spectral resolution Landsat-8 (11 bands)	Spatial resolution 30–15 m	Spectral resolution 14 bands	Spatial resolution 1.5 m	Spectral resolution 5 bands
(d) Barite and Titanite	Suitable				No reference	
	Landsat reference Khalil et al. (2017) *ASTER reference* Madani and Emam (2011)					
(3) Environmental applications	References					
	Abdel Rahman et al. (1998), Nasr and Darwish (1998), El-Baz (1998)*[1], Robinson (1998)*[1], Ashmawy and Nassim (1998), El Gammal et al. (1998), Yehia et al. (1999a, b), c), Ahmed (1999), Hamdan (1999), El Gammal (1999a, b), Elewa et al. (2000), Ahmed (2000), El-Askary et al. (2000)*[4], Hassan (2000), Yehia et al. (2000), Hegazy (2001), El-Gamily (2001) Yehia et al. (2003), El Nahry (2003), Elewa (2003), Faid et al. (2003), El Gammal (2002), El Gammal (2003), El Gammal et al. (2003), Nasr et al. (2003), Hamdan et al. (2004), Hassan and El-Leithy (2004), Hassan et al. (2005a, b)*[5], El-Gammal (2005), El-Rakaiby and Ammar (2005), Eid et al. (2006), Elewa (2006), Abdou Azaz (2008), Youssef and Baroudy (2008), Azab (2009), Hegazy and Effet (2010), Abou El-Magd et al. (2010), El-Gammal et al. (2010), Rasmy et al. (2010), El-Gammal and El-Gammal (2010), Shokr (2011), El-beih et al. (2011), Belal and Moghanm (2011), Kato et al. (2012), El Asmar et al. (2013), Moawad (2013), Zaghloul et al. (2013), El-Gammal et al. (2013), Abou El-Magd and El-Zeiny (2014), Embabi and Moawad (2014), El-Hattab (2015), Gabr and El Baswawesy (2015), El-Hattab (2016)					

Fig. 1.9 **a** Numbers and years of publications of geological remote sensing papers. The publications included in the graph are cited in Table 1.1. **b** Satellite sensors percentages used for geological applications



arid environment. ASTER FCC band ratio image (2 + 4)/3, (5 + 7)/6, (7 + 9)/8 in RGB identified ophiolitic rocks much better than previously published ASTER ratios. PCA (5, 4 & 2) in RGB enabled the discrimination between ophiolitic rocks and grey and pink granites. Madani (2012) discriminated the Jurassic volcanicity at Jabal Al Maqtal area, SED, Egypt using ASTER PCA false color composite image. He delineated NW-SE strike-slip basin recorded at the study area using PC9 image. Salem et al. (2012) integrated remote sensing, geology and geochemistry data for lithologic discrimination of serpentinites and other rock units exposed at Um Salim-Um Salatit area CED, Egypt. Madani (2015) evaluated band ratios and fusion techniques for mapping Wadi Natash volcanic field, SED, Egypt. Also, he revealed the spectral properties of olivine basalts using ASD Field-Spec measurements. Jakob et al. (2015) improved the existing geological maps of Neoproterozoic Ras Gharib area, north ED, Egypt by including texture features in a classification scheme of ASTER and Landsat8 data. Kamel et al. (2016) stated that the products of Landsat ETM+ image processing procedures (FCC7, 4, 2, & FCC7, 5, 1 & PCA 1, 2, 4 & band ratios 5/1, 3/2, 7/2 & 5/3, 4/2, 3/1 & 3/1, 4/2, 5/7) are improved the lithologic discrimination between serpentinites, talc carbonates, and other rock units exposed at Wadi Ghadir—Gabal Zabara area, CED, Egypt. Hassan et al. (2017) proposed three Landsat-8 band ratio images (6/2, 6/7, 6/4 * 4/3; 6/7, 6/4, 4/2 & 7/5, 7/6, 5/3) for detailed mapping and lithologic discrimination of the rock units exposed in Meatiq dome area, CED, Egypt. They proposed fourteen spectral bands of ASTER data for the distribution of some rock forming minerals. These are; ASTER muscovite index (B7/B6), quartz index (B14/B12), ferrous iron index (B5/B3) ferrous silicate index (B5/B4), mafic index (B12/B13), hydroxyl-bearing minerals index (B7/B6 * B4/B6). Hassan and Sadek (2017) stated that the enhanced Landsat 8 band ratio (6/2, 6/7 & 6/5 * 4/5) and ASTER principal component image (PC2, PC6 & PC5) were successfully discriminate most of the rock units and produced a detailed geologic map for Korbiai-Gerf nappe complex SED, Egypt.

1.3.2.2 Publications on Utilization of Remote Sensing Techniques for Mineral Exploration

Remote sensing is an effective technique for mineral exploration through many ways such as mapping geological structure and locating the hydrothermal alteration zones hosting mineralization in the Eastern Desert. Results of the present preview revealed that the processed Landsat ETM + and ASTER satellite imageries are the most suitable data for gold exploration in which they successfully identify and delineate gold-bearing hydrothermally alteration zones recorded at (Haimur gold mine area, Um Khasila district, Shalatein district, Um El Touyur El Fuqani area, Al Faw-Eqat belt, Um Rus area, El-Hoteib area, Abu Marawat, Fawakhir area, Dungash district and Wadi Allaqi) areas. Madani et al. (2003) utilized Landsat ETM$^+$ imageries and scanned aerial photograph for mapping hydrothermal alteration zones at Haimur gold mine area, SED, Egypt. They utilized PCA, band ratios and fusion techniques to delineate the hydrothermal alteration zones as well as listwaenite ridges exposed at the study area and produced 1:20 000 geologic image map. Ramadan (2003) applied TM–ratioing enhancement and supervised classification methods for gold bearing listwaenites exploration at Um Khasila district, CED, Egypt. He indicated that the listwaenites and associated veins are promising for gold and silver mineralizations. Ramadan and Kontny (2004) combined the processed Landsat data and fieldwork with mineralogical and geochemical investigations in order to detect and characterize the alteration zones exposed at Shalatein district, ED, Egypt. The processed Landsat ratio imagery (5/7, 4/5 & 3/1 in RGB) successfully discriminated two different types of alteration products. Ramadan et al. (2005) utilized processed Landsat ETM+ imageries to recognize the mineralized alteration zones at Um El Touyur El Fuqani area, SED, Egypt. Their study indicated that the alteration zones in the metavolcanics and listwaenites are promising and need detailed exploration for AU and Ag mineralizations. Salem (2008) utilized the processed Landsat ETM$^+$ ratio imageries to trace gold bearing alteration zones exposed at Al Faw-Eqat area, SED, Egypt. Gaber et al. (2010) detected areas around Abu Marawat of high potential gold mineralization using ASTER data. Amer et al. (2012) utilized the processed ASTER data (PCA & band ratios) for detection of gold related alteration zones in Um Rus area, CED, Egypt. Gabr et al. (2015) utilized band ratios ASTER imagery for prospecting new gold bearing alteration zones at El-Hoteib area, SED, Egypt. In addition, they produced the lineament map for the study area using SPOT data. Abu El-Magd et al. (2015) mapped the alteration zones of Fawakhir area using reference spectra of ASTER data based on two supervised classification techniques including the spectral angle mapper (SAM) and spectral information divergence (SID). Salem and Soliman (2015) utilized ASTER images of band ratios supported by field geology, mineralogical, and geochemical analyses enabled detection of two alteration zones as targets for gold exploration at Al Faw-Eqat belt (a case study in the eastern end of Wadi Allaqi). Salem et al. (2016) explored the new gold occurrences in the alteration zones at Dungash district using the processed ASTER band ratio technique.

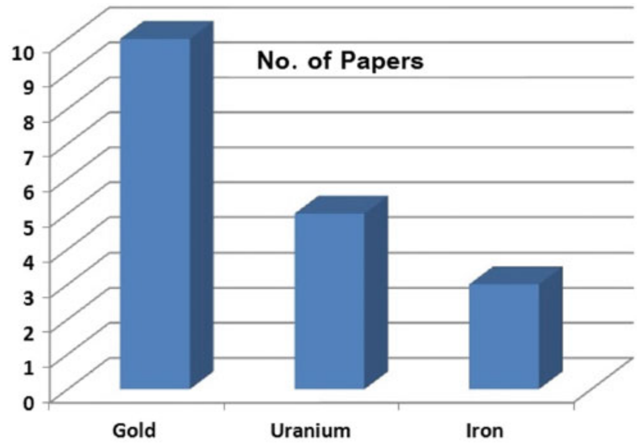


Fig. 1.10 **left** Numbers of published papers for each deposit in Egypt

Several studies (Yehia et al. 1998; Ramadan et al. 1999; Ramadan and El-Lithy 2005; Sadek and Mousa 2010 and Ramadan et al. 2013) proved the suitability of the processed Landsat images and airborne radiometric data for exploration of radioactive bearing minerals in several localities at the Eastern Desert (e.g. Gabal El Sela area, Wadi Araba area, El Qasia and Um Maggat granites, Um Greifat, Abu Gherban, Um Gheig, Essel, Kadabora granites, Gabal Um Naggat).

Salem et al. (2013); Salem and El-Gammal (2015) integrated remote sensing, geological and geochemical studies to locate the promising iron ore deposits around Aswan area and west of Lake Nasser, Egypt. El-Nagdy and Abdel Salam (2006) utilized hyperspectral analyses of ASTER data to discriminate Um Nar banded iron formation (BIF). They concluded that the interpretation driven from the hyperspectral analyses enhance the delineation of ductile and brittle geological structures as well as the lithologic discrimination. Figure 1.10 shows the number of published papers for each ore in Egypt. The percentage of the papers treated with gold is about 55.5% followed by 28% for uranium and ended by 16.5% for iron ore deposits. These percentages reflect the importance of gold as strategic mineral followed by uranium exploration and iron.

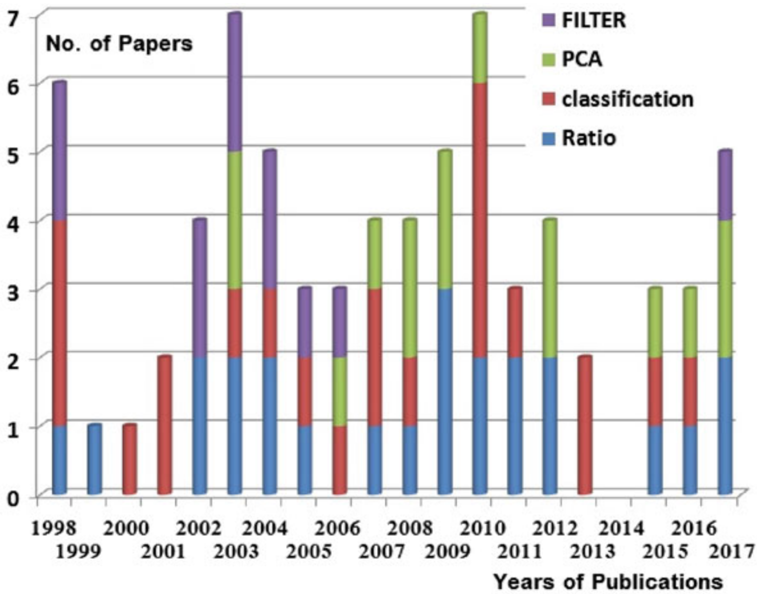


Fig. 1.11 The main remote sensing techniques used for geological and environmental applications

1.3.2.3 Remote Sensing Techniques

Analyses of satellite remote sensing data were performed either by visual and/or digital image processing. Digital image processing are grouped into three categories: pre-processing, main-processing and post-processing procedures. Figure 1.11 demonstrated the most frequently main image processing procedures used for geological applications. The present review revealed that: (1) band ratios and PCA are the most common techniques used for lithologic discrimination and geological mapping. To enhance lineament features in satellite images, filtering techniques are used. Band ratio can be simply generated by dividing the reflectance value of each pixel in one band by the reflectance value of the same pixel in another band (Drury 1993). It successfully delineated gold- bearing hydrothermally alteration zones which are mainly clay minerals, Fe-minerals and carbonate minerals exposed along major structure at several localities in the Eastern Desert. (2) classification and change detection are the most common techniques used for land-use mapping and other environmental applications.

1.3.3 Concluding Remarks

The present review is the first attempt that exhibits some statistics on satellite sensors and techniques and it recorded the most common ore deposits explored using remote sensing techniques in Egypt. Results of this short review revealed that: (1) Moderate spatial and spectral resolutions Landsat series are found to be the most common data used for geological applications followed by ASTER data. Little publications utilized high spatial resolution SPOT data for detailed structural mapping. (2) About 55% of published papers demonstrated methodologies successfully identified and delineated gold- bearing hydrothermally alteration zones whereas 28% of are treated with radioactive minerals especially uranium. (3) The most common techniques used for lithologic discrimination and hydrothermal alteration zones mapping are band ratios and PCA. For land-use mapping and change detection applications classification techniques are used. (4) Unfortunately, no record for papers utilized Egyptian satellite "Egyptsat-1" for geological applications.

1.4 Monitoring Spatiotemporal Variabilities in Egypt's Groundwater Resources Using GRACE Data

Mohamed Ahmed, Bassam Abdellatif

Temporal Gravity Recovery and Climate Experiment (GRACE) derived Terrestrial Water Storage (GRACE-TWS) data along with reservoirs, rainfall, and soil moisture datasets were used to monitor and quantify modern recharge and depletion rates of the Nubian aquifer in Egypt during the period from April 2002 through January 2017. Results indicate: (1) the Nubian aquifer in Egypt is receiving a total recharge of 18.46 $\pm$ 1.95 km^3 during 4/2002 − 2/2006 and 4/2008 − 1/2017 periods; recharge events occur only under excessive precipitation conditions over the Nubian recharge domains and/or under a significant rise in Lake Nasser levels, (2) the Nubian aquifer in Egypt is witnessing a groundwater depletion of −13.90 $\pm$ 0.82 km^3 during 3/2006 − 3/2008 period; the groundwater depletion is largely related to exceptional drought conditions and/or normal baseflow recession, and (3) a conjunctive surface water and groundwater management plan needs to be adapted for sustainable management of water resources of the Nubian aquifer in Egypt.

1.4.1 Introduction

To pursue and sustain plans for modernization and development, Egypt needs to secure its freshwater resources. In Egypt, the sources of freshwater include the surface water of the Nile River and groundwater in addition to a minor contribution (<2%) from rainfall and sea water desalination. Both climatic (e.g., changes in rainfall patterns, duration, and magnitude) and anthropogenic (e.g., population growth, overexploitation, and pollution) factors affect these sources. For example, according to climate change studies there is a tendency toward higher extremes, where the arid or semiarid areas are becoming increasingly dry and the wetter areas will witness intensified precipitation and flooding (e.g., Hulme et al. 2001). In addition, Egypt's total population is on rise; it increased from 22 million in 1950 to 100 million in 2017 and is expected to continue increasing for decades to come.

Given these challenges, understanding of the geologic and hydrologic settings of, and the controlling factors affecting, freshwater resources in Egypt are gaining increasing importance. The Nile River has been a dynamic surface freshwater resource for Egypt's population. However, Egypt is currently using its total annual allocation of Nile River water, estimated at 55×10^9 m^3/yr. Given the scarcity of surface freshwater resources in Egypt, limited rainfall, and the difficulties and expenses entailed in sea water desalination, groundwater remains a viable alternative that could address Egypt's growing demands for freshwater resources.

Currently, Egypt is required to utilize more of its groundwater resources, at the expense of limited Nile River water, to support national reclamation projects. For example, a minimum of 1.5×10^6 acres (feddan) will be reclaimed during the coming five years in Egyptian deserts. These reclamation projects depend solely on groundwater resources. In Egypt, groundwater resources are found in one of five major aquifer systems namely, Nile, Moghra, coastal, fractured basement, and Nubian aquifers (RIGW/IWACO 1988). Most of the current and future Egyptian reclamation projects depend mainly on Nubian aquifer groundwater resources.

The Nubian aquifer (area: 2×10^6 km^2) is a transboundary aquifer system shared by four countries: Egypt (38%), Libya (34%), Sudan (17%), and Chad (11%). The aquifer contains three major tectonically-defined sub-basins: the Dakhla sub-basin in Egypt; the Kufra sub-basin in Libya, northeastern Chad, and northwestern Sudan; and the northern Sudan sub-basin in northern Sudan (Thorweihe and Heinl 2002). In Egypt, the health of the Nubian aquifer affects the success of the Egyptian reclamation and development projects as well as the livelihood of many people. Hence, the ability to routinely observe the water resources of that aquifer and make those observations publicly available to the decision makers is highly recommended. In situ observations of the Nubian aquifer in Egypt are difficult to obtain; the historically available observations, if any, usually suffer from gaps, discontinuities, inconsistency, and poor quality. In addition, the historical observations are local, sparse, and do not adequately represent the entire aquifer averaged estimates. In this regard, satellite remote sensing observations offer an alternative and/or complement to local in situ measurements and could be used to monitor the Nubian aquifer health and longevity. Most of these observations are globally distributed, publicly available, and temporally and spatially homogeneous. The Gravity Recovery and Climate Experiment (GRACE) provides significant practical strategies to routinely observe and monitor the water resources of the Nubian aquifer in Egypt.

GRACE is a joint satellite mission that is sponsored by the National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR). GRACE is designed to map the temporal variations in Earth's global gravity field on a monthly basis as well as the Earth's static gravity field (Tapley et al. 2004a, b). The GRACE-derived variabilities in Earth's gravity field can be used to make global estimates of the spatiotemporal variations in the total vertically integrated components (e.g., surface water, groundwater, soil moisture and permafrost, snow and ice, wet biomass) of terrestrial water storage (TWS) (Wahr et al. 1998). GRACE-derived TWS (GRACE-TWS) data have been extensively used to quantify aquifers' recharge and depletion rates (Ahmed et al. 2011, 2014, 2016; Wouters et al. 2014; Ebead et al. 2017; Fallatah et al. 2017). In this study, temporal GRACE-TWS data that span the period from April 2002 through January 2017 along with the outputs of land surface models (LSMs) and other relevant remote sensing data were used to monitor the water resources of the Nubian aquifer in Egypt and provide improved estimates of recharge and depletion rates.

1.4.2 Data and Methods

GRACE-TWS data from the global mass concentration (mascons) solutions of the University of Texas Center for Space Research (UT-CSR; Release 05; version 1; $0.5° \times 0.5°$ grid; available at: http://www.csr.utexas.edu/grace/RL05_mascons.html) was used in this study. The UT-CSR mascon approach utilizes the geodesic grid technique to model the surface of the Earth using equal area gridded representation of the Earth via 40,962 cells (40,950

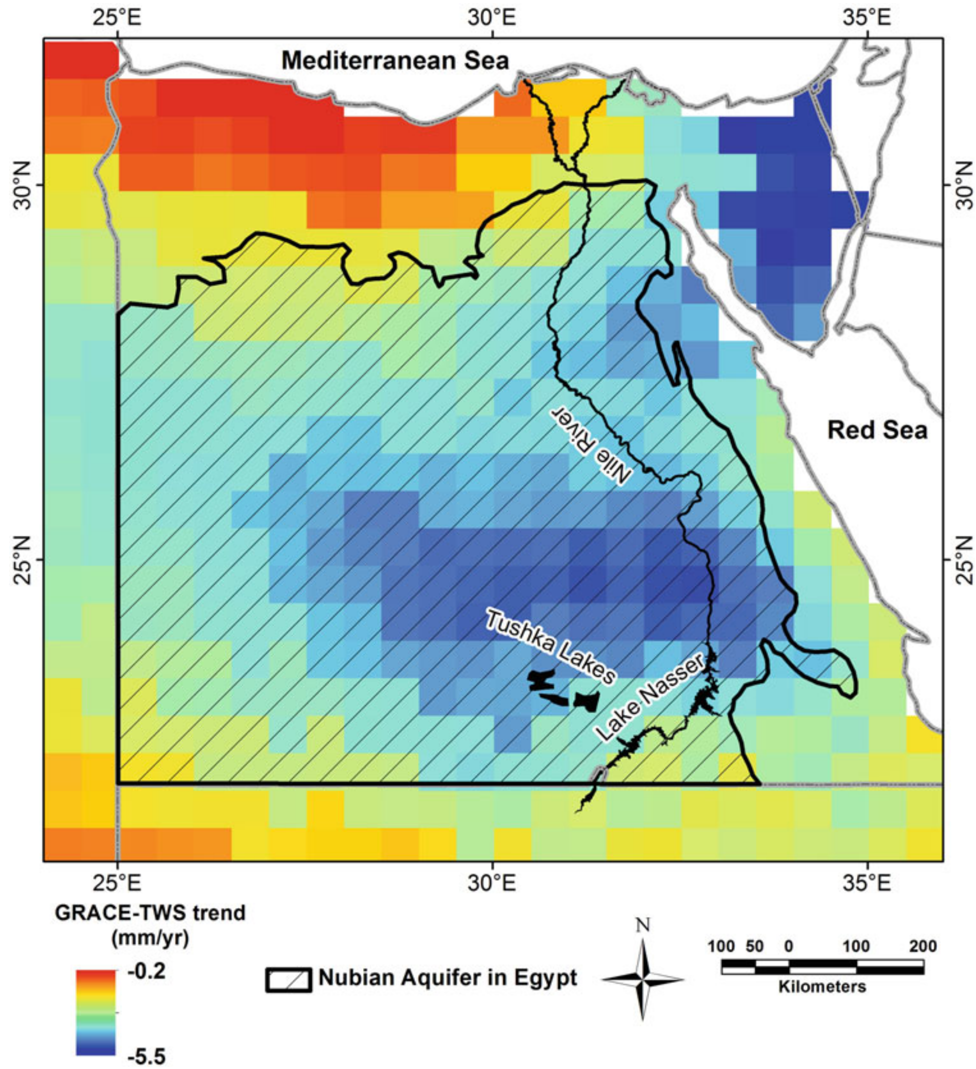


Fig. 1.12 Secular trend in monthly (April 2002–January 2017) GRACE-TWS estimates generated over the Nubian aquifer in Egypt (hatched area) and surroundings

hexagons + 12 pentagons) (Save et al. 2012, 2016). The secular trend in GRACE-TWS data was extracted by simultaneously fitting a trend and annual and semiannual terms to each GRACE-TWS time series (Fig. 1.12). GRACE-TWS time series over the Nubian aquifer in Egypt was generated by summing results for all grid points lying within the spatial domain of the Nubian aquifer in Egypt (black polygon; Fig. 1.12). Errors associated with monthly GRACE-TWS and trend values were then estimated using the approach advanced in Ahmed and Abdelmohsen (2018).

GRACE data cannot distinguish between anomalies resulting from different compartments of TWS (e.g., surface water [SW], soil moisture [SM], and groundwater [GW]). Therefore, the combined contributions of SW and SM need to be quantified and subtracted from GRACE-TWS time series to calculate GW time series over the Nubian aquifer in Egypt.

Two main SW reservoirs within the Nubian aquifer in Egypt were examined: Lake Nasser and the Tushka Lakes (Fig. 1.12). The Lake Nasser surface levels time series was extracted from the U.S. Department of Agriculture's Foreign Agricultural Service (USDA-FAS) global reservoir and lake monitoring database (GRLM; available at: https://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/). The Lake Nasser monthly level anomalies, with respect to the temporal mean (April 2002–January 2017), were then generated, over the entire Nubian aquifer in Egypt. On the other hand, the temporal variability in the volume, area, and water height in the Tushka Lakes were quantified, in a geographic information system (GIS) environment, using Landsat images along with a digital elevation model that was acquired prior to the formation of the Tushka Lakes. The SM data over the Nubian aquifer in Egypt was extracted from the Global Land Data Assimilation System (GLDAS) model (version 1; available at: ftp://hydro1.sci.gsfc.nasa.gov). The

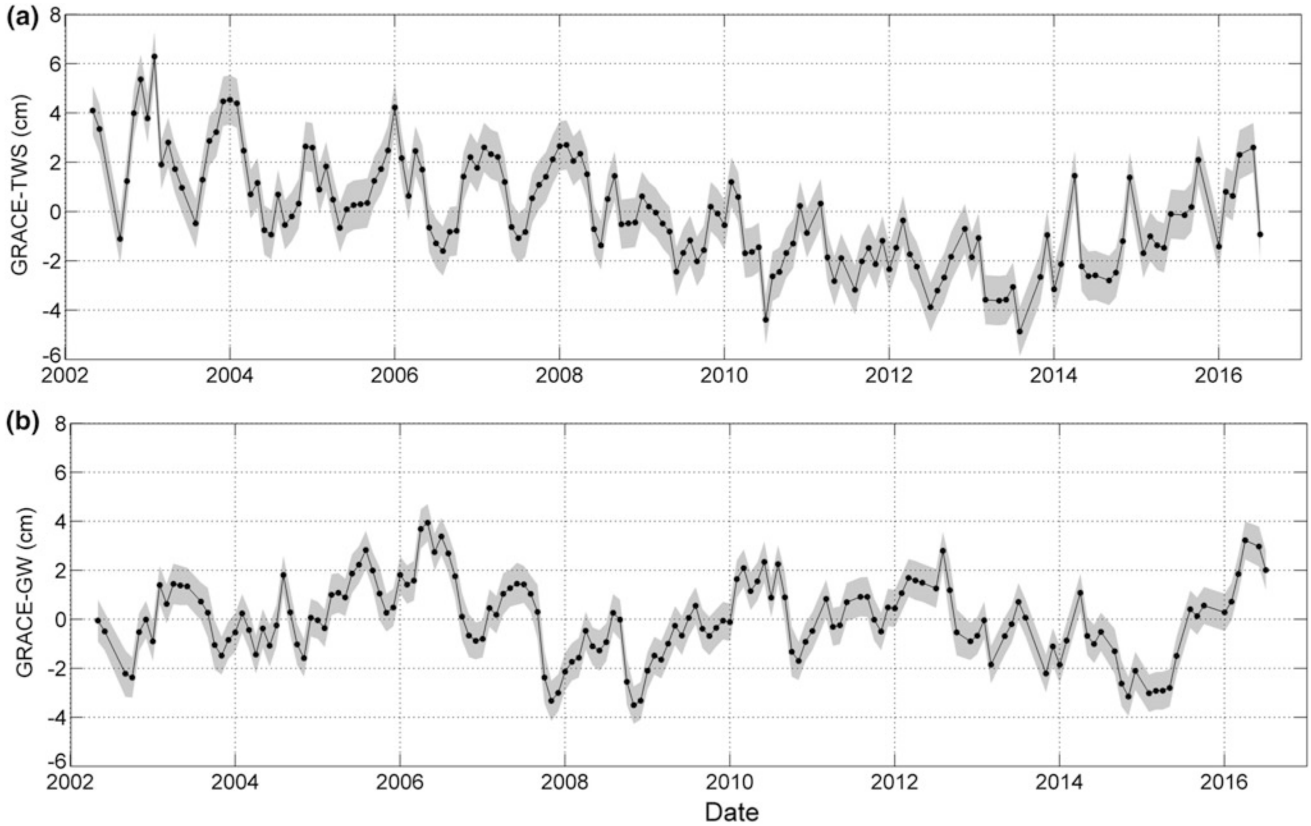


Fig. 1.13 Temporal variations in **a** GRACE-TWS and **b** GRACE-GW estimates, along with the associated uncertainties, extracted over the Nubian aquifer in Egypt

soil moisture time series was calculated by averaging the soil moisture estimates from four GLDAS model versions (Rodell et al. 2004). Trends in the SM and SW and associated trend errors were estimated using the procedures described in Ahmed and Abdelmohsen (2018).

1.4.3 Results and Discussion

Figure 1.12 shows the secular trend in GRACE-TWS generated over Egypt, northern parts of Sudan, and eastern parts of Libya. The outline of the Nubian aquifer in Egypt (black polygon) is also shown. Inspection of Fig. 1.12 indicates that the Nubian aquifer in Egypt is experiencing an overall negative GRACE-TWS trends during the investigated period (4/2002 − 1/2017). Higher GRACE-TWS depletion rates (< −5 mm/yr) are observed over the central parts of Nubian aquifer and the northeastern parts of Egypt. The northern coastal areas as well as the southern parts of the Nubian aquifer in Egypt, close to recharge areas in Sudan, are witnessing lower GRACE-TWS depletion rates (>−2 mm/yr). Figure 1.13a shows the temporal variations in GRACE-TWS time series averaged over the Nubian aquifer in Egypt. Examination of Fig. 1.13a shows an overall GRACE-TWS depletion of -3.26 ± 0.15 mm/yr that is equivalent to -2.15 ± 0.09 km^3/yr. The temporal variability in GRACE-TWS is related to temporal variations in one or more of the GRACE-TWS compartments (e.g., SW, SM, and GW).

Examination of temporal variations in Lake Nasser level anomalies over the Nubian Aquifer in Egypt shows that Lake Nasser is witnessing an overall height increase of 0.41 ± 0.05 mm/yr. However, piecewise trend analysis of Lake Nasser level anomalies indicates that Lake Nasser level anomalies are witnessing both decreasing and increasing trends during investigated period (4/2002 – 1/2017). Temporal fluctuations in Lake Nasser levels are mainly attributed to the seasonality in the Nile River. On the other hand, analysis of the temporal variations in the Tushka Lakes level anomalies indicates that they cumulatively lost 56, 80, and 98% of their volumes in 2006, 2010, and 2016, respectively, compared to their volume in 2002 that is estimated at 27.11 km^3. The loss in the Tushka Lakes' volumes, levels, and areas is believed to be an evaporation loss (e.g., Sultan et al. 2013). Trends in Tushka Lakes level anomalies over the Nubian Aquifer in Egypt indicate an overall systematic decrease in water levels of -2.29 ± 0.28 mm/yr. Finally, the temporal variations in GLDAS-derived SM time series averaged over the Nubian Aquifer in Egypt indicates that, during investigated period (4/2002 – 1/2017), the SM is witnessing an overall depletion of −1.05 ± 0.05 mm/yr.

The GW time series extracted by subtracting the combined SM and SW from GRACE-TWS is shown in Fig. 1.13b. Inspection of Fig. 1.13b shows that the Nubian aquifer in Egypt is witnessing an overall GW decline of −0.42 ± 0.03 mm/yr that is equivalent to −0.27 ± 0.01 km^3/yr during investigated period (4/2002 – 1/2017). Close examination of Fig. 1.13b indicates that the GW time series exhibits temporal variability over four distinctive periods: April 2002–February 2006 (Period I), March 2006–March 2008 (Period II), April 2008–December 2012 (Period III), and January 2013–January 2017 (Period IV). Piecewise trend analysis results of GW time series shows that the Nubian aquifer in Egypt is experiencing a GW increase (5.00 ± 1.24 mm/yr; 3.30 ± 0.81 km^3/yr) during Period I followed by a sharp GW decrease (−21.07 ± 1.25 mm/yr; −13.90 ± 0.82 km^3/yr) during Period II, then a GW increase during periods III and IV (Period III: 6.52 ± 0.85 mm/yr, 4.30 ± 0.56 km^3/yr; Period IV: 3.50 ± 2.11 mm/yr, 2.31 ± 1.39 km^3/yr). Analysis of GW time series reveals that the Nubian aquifer in Egypt is receiving groundwater recharge during Periods I, III, and IV and witnessing groundwater depletion during Period II.

The sharp GW decline rate during Period II (−21.07 ± 1.25 mm/yr) is largely related to exceptional drought conditions in Period I compared to the previous periods. Examination of the average annual rainfall (AAR) and Lake Nasser levels indicates a decline during Period I (AAR: 120 mm; Lake Nasser level: 174.6 m) compared to the average of preceding years (1998 to 2002; AAR: 133 mm; Lake Nasser level: 178.2 m). Other common contributing factor, for the observed GW depletion, could be the baseflow recession. Normal baseflow recession occurs naturally during periods of extended drought and could cause extensive water level declines over time periods of weeks to months that result in volumetrically significant storage depletion (e.g., Alley and Konikow 2015).

To quantify the recharge rates of the Nubian aquifer in Egypt during Periods I, III, and IV, the discharge rates (natural discharge + anthropogenic groundwater extraction) was added to the GW trends. The sum of the average annual groundwater extraction and natural discharge for Nubian aquifer in Egypt was estimated at 2.85 km^3/yr (Mohamed et al. 2016). The total recharge for the Nubian aquifer in Egypt are estimated at 6.15 ± 0.81 km^3, 7.15 ± 0.56 km^3, and 5.16 ± 1.39 km^3 during Periods I, III, and IV, respectively. The total recharge during Periods I, III, and IV is estimated at 18.46 ± 1.95 km^3, however, approximate average annual recharge rate of 1.51 ± 0.15 km^3/yr is estimated during the three periods. The increase in average annual recharge of the Nubian aquifer in Egypt during Periods I, III, and IV is partially attributed to increasing the AAR during the investigated periods compared to the preceding periods as well as the increase in Lake Nasser levels.

Given the current overall GW depletion rate (−0.27 ± 0.01 km^3/yr) during the entire investigated period (April 2002–January 2017), the longevity of the Nubian aquifer in Egypt can be estimated. Based on modeled recoverable groundwater volumes (5180 km^3) (Bakhbakhi 2006) the Nubian aquifer in Egypt could last for more than 10,000 years assuming a constant GW depletion and recharge rates. Increasing depletion rates and/or decreasing the recharge rate would reduce the aquifer's longevity. For example, if the GW depletion is doubled, the groundwater resources of the Nubian aquifer in Egypt could last for 9,000 years, assuming constant recharge rate. Moreover, if the GW depletion are doubled every 50 years, the groundwater resources of the Nubian aquifer in Egypt could last for 400 years, assuming constant recharge rate.

1.4.4 Summary and Conclusions

Egypt is currently planning to use more of its groundwater resources, at the expenses of the limited Nile River surface water to support national development and reclamation projects. In this study, temporal (April 2002–January 2017) GRACE-TWS data along with reservoirs, rainfall, and soil moisture data were used to provide improved estimates of recharge and depletion rates of the Nubian aquifer in Egypt. Results indicate that during April 2002–February 2006 (Periods I) and April 2008–January 2017 (Periods III and IV) the Nubian aquifer in Egypt is receiving a total recharge of 18.46 ± 1.95 km^3. Recharge events of the Nubian aquifer in Egypt occur only under excessive precipitation conditions over the Nubian recharge domains and/or under a significant rise in Lake Nasser levels. The sharp groundwater depletion (−13.90 ± 0.82 km^3) during March 2006–March 2008 (Period II) is largely related to exceptional drought conditions in Period I compared to the previous periods as well as the normal baseflow recession.

Findings indicate that Egyptian decision makers are facing a real challenge to provide and maintain sustainable freshwater resource management for Egyptian population. However, they are highly recommended to use a conjunctive surface water and groundwater management plan. The results of this study demonstrate that global monthly GRACE-TWS solutions can provide a practical, informative, and cost-effective approach for monitoring aquifer systems located in any geologic or hydrologic setting across the globe.

Acknowledgments

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1.5 Geochronological Measurements

Yasser M. Abd El-Rahman

The term “geochronology” was coined to distinguish between the geologic timescale, which is applicable to Earth processes from timescales related to humans (Williams 1893). After 1913, isotope geochronology emerged as a branch of science that uses the radioactive decay of isotopes in minerals to define the absolute age of most Earth materials and to quantify the geologic timescale (Condon and Schmitz 2013). Our understanding of evolution of the Egyptian basement is highly affected by the isotope geochronology as explained by Stern and Ali (This book) and El Bialy (This book).

The Egyptian basement is a complex of igneous and metamorphic rocks exposed in the Eastern Desert, Sinai, and limited areas in the southern part of the Western Desert. The earliest book of Hume (1934, 1935) on the geology of Egypt does not include radioactive measurements. Based on the petrographicaly and structural similarities between the basement rocks of Egypt and those rocks that are overlain by the Cambrian sandstone in Jordan, he assigned Precambrian age for the entire Egyptian basement complex. Moreover, Hume (1934, 1935) divided the basement complex into 9 groups that belong to Protarchaean, Metarchaean, Eparchean and Late Precambrian or Gattarian age. The details of the Hume’s classification are given by El-Bialy (This book).

In 1962, Rushdi Said published his book “The Geology of Egypt”. Until 1962, significant geochronological measurements on the Egyptian basement complex were absent. Using K-Ar technique, Gheith (1959) concluded that some crystalline basement rocks from the Eastern Desert of Egypt were formed during the upper Cambrian and lower Ordovician Periods (430–450 Ma). Applying the same K-Ar technique, Higazy and Ramly (1960) concluded also that the ages of the basement complex of the Eastern Desert range from Eo-Cambrian to Devonian. Said (1962) noted that these measurements were conducted on granites and other rock assemblages that belong to Hume’s Gattarian episode. Although Said (1962) acknowledged the series argon loss caused by hydrothermal and later alteration, he considered that the only available radiogenic ages determined by Gheith (1959) and Higazy and Ramly (1960) substantial. Thus, Said (1962) concluded that the age of the Egyptian complex is Precambrian but the Hume’s Gattarian episode could be as late as lower Paleozoic.

In early seventies, isotopic age determination of the basement rocks was accumulating using mainly the Rb-Sr technique (e.g. Hashad et al. 1972; El Shazly, et al. 1973). At the end of seventies, geochronology of the basement rocks in the Eastern Desert of Egypt was enriched by the Ph.D. work of Stern (1979a) and Dixon (1979), while geochronology of the basement rocks of Sinai was benefited from the Ph.D. work of Bielski (1982). Hashad (1980) compiled geochronological data in 1970s, but without robust analytical details. Another updated compilation for the geochronological data was considered during a trial to understand the evolution of the Arabo-Nubian massif by Bentor (1985). At the end of seventies and in eighties, the zircon U-Pb dating technique was applied to the Egyptian basement rocks (e.g. Abdel-Monem and Hurley 1979, 1980; Dixon 1981). The analytical procedure was based on the method of Krogh (1973), who used the technique of zircon hydrothermal-dissolution and Pb extraction taking the advantage of teflon™ availability (Mattinson 2013). One of the comprehensive geochronological studies on the Egyptian basement rocks in eighties was conducted by Stern and Hedge (1985). They provided the ages for twenty-four rock units from the Eastern Desert of Egypt using combined Rb-Sr and U-Ph zircon techniques. In addition to the Rb-Sr technique, whole-rock Sm/Nd modal ages were defined for the basement inliers in the Western Desert of Egypt by Schandelmeier et al. (1987).

Rushdi Said was the editor of the updated version of the Geology of Egypt book that was published in 1990. The book included two chapters on the basement rocks in the Eastern Desert and Sinai that were written by El-Gaby et al. (1990), and Hassan and Hashad (1990). Moreover, there was a chapter on the basement inliers in the Western Desert of Egypt that was written by Richter and Schandelmeier (1990). The compiled geochronological data between 1962 and 1990 on the basement rocks from the Eastern Desert and Sinai supports the late Proterozoic age measured for these rocks and the occurrence of older aged for the basement inliers in the Western Desert. However, El-Gaby et al. (1990) and Hassan and Hashad (1990) suspected the reliability of some of these ages, which result in controversies over the origin of some of the rocks units in the Egyptian basement complex. El-Gaby et al. (1990) and Hassan and Hashad (1990) considered the gneiss domes in the Eastern Desert and Sinai as a structurally low reworked part of the older Sahara Craton exposed further to the west as inliers in the Western Desert of Egypt. Their conclusion was based mainly on the highly metamorphosed and deformed natured of these rocks and on their structurally lower position relative to the late Proterozoic ophiolitic and volcano-sedimentary assemblages without potent geochronological evidence. Another example to show how lithology surpassed the available geochronological data was given by El Gaby et al. (1990) who suggested by the total absence of island arc metavolcanic rocks (the Younger Metavolcanics) from the Sinai. Shimron (1980) and Bentor (1985) affiliated the Sa'al and Kid metavolcanic rocks to the Younger Metavolcanics, which is consistent with the age given by Rb-Sr ischron age of 734 Ma given by Bielski (1982). Based on high proportion of acidic volcanic rocks, El Gaby et al. (1990) affiliated the Sa'al and Kid volcanic rocks with Dokhan Volcanic Group, which is younger group of Cordilleran volcanics in Egypt that was formed between 639 and 581 Ma.

Modern geochronology has evolved by reducing sample size from whole-rock and multigrain fraction to single mineral grains (Nemchin et al. 2013). After 1990, such approach was adopted and geochronological studies on the Egyptian basement were based mainly on zircon U-Th–Pb measurements using ID-TIMS (isotope dilution-thermal ionization mass spectroscopy), SIMS (secondary ion mass spectrometry), SHRIMP (sensitive high mass resolution ion microprobe), and recently LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry). In early 1990s, Alfred Kröner commonly used single zircon evaporation techniques to date different rock units from the Egyptian basement complex, such as gneisses from Sinai (Kröner et al. 1990), ophiolitic rocks and their associated gabbro-diorite complexes (Kröner et al. 1992), and granitoid gneisses from the CED and SED (Kröner et al. 1994). Wilde and Youssef (2000, 2002) used SHRIMP II ion microprobe at Curtain University to date zircon yielded from the Ediacaran Dokhan Volcanic Series and Hammamat Group from the NED. El-Gaby et al. (1990), and Hassan and Hashad (1990) were highly convinced that the volcanic rocks from Sinai and NED are affiliated with this Ediacaran Dokhan Volcanic Series. Sa'al volcano-sedimentary complex, which was a matter of debate as mentioned earlier, was assigned late Mesoproterozoic age by Be'eri-Shlevin et al. (2012) CAMECA IMS 1270 facility hosted by the Swedish Museum of Natural History (NORDSIM). This instrument was commonly used to date various rocks units from Sinai (e.g. Be'eri-Shlevin et al. 2009b, 2011; Samuel et al. 2011; Abu El-Enen and Whitehouse 2013; Eyal et al. 2014). Using U-Pb zircon LA-ICP-MS data support the presence of Pre-Ediacaran volcano-sedimentary rocks in Sinai (e.g. Moghazi et al. 2012; Andresen et al. 2014). Recently, another CAMECA IMS-1280HR SIMS facility hosted by the Institute of Geology and Geophysics, Chinese Academy of Science was used to date the Ediacaran Hammamat Group in thier type locality at Wadi Hammamat area in the CED (Abd El-Rahman et al., 2019). The same facility used in combination of Neptune multicollector ICP-MS hosted by the same institute were used to detect the recycled Hf isotoe signature from Cryogenian zircon yiekded from a felsic vlcanic fragment from the juvenile crust of the Eastern Desert of Egypt (Li et al., 2018).

Similar to Sinai, the volcano-sedimentary units in the NED are considered part of the Ediacaran Dokhan Volcanic Series and associated Hammamt Group by El-Gaby et al. (1990), and Hassan and Hashad (1990). Based on LA-ICP-MS U-Pb zircon dating, Tonian-Cryogenian volcanic rocks and volcano-sedimentary successions were identified from the Ras Gharib Segment (Bühler et al. 2014; Abd El-Rahman et al. 2017). Adopting modern geochronological approach enabled Eliwa et al. (2014) to define the Tonian age (741 ± 3 Ma) of the muscovite trondhjemite using the SIMS zircon U-Pb zircon dating. The same pluton was assigned six-point Rb-Sr isochron age of 516 ± 7 Ma by Abdel-Rahman and Doig (1987).

Regarding the CED, the ID-TIMS laboratory at the University of Oslo for U-Pb dating were commonly used to determined the ages of various rocks units from this segment of the Egyptian basement complex (Andresen et al. 2009; Augland et al. 2012; Lundmark et al. 2012). The geochronology of the Eastern Desert was greatly benefited from the work of Kamel Ali. Ali et al. (2009) recorded the common presence of the pre-Neoproterozoic zircon xenocrysts during the U-Pb SHRIMP zircon dating of the Neoproterozoic volcanic rocks for the CED. Stern et al. (2010) compiled the data on the pre-Neoproterozoic zircons to exhibit their distribution and significant in the juvenile Neoproterozoic igneous rocks. Ali et al. (2010a, b) integrated his work on zircon yielded from the metasedimentary rocks in the CED with the earlier study of Dixon (1981) to assume ~750 Ma glaciation, not only in the CED, but also in the ANS. The work of Kamel Ali includes dating the granitoids and granitoids gneisses from the CED using both SHRIMP and LA-ICP-MS U-Pb zircon techniques.

After Kröner et al. (1992), who dated the ophiolitic rocks and associated intrusive gabbro-diorite complexes using single zircon evaporation method, Ali et al. (2010a, b) reported SHRIMP U-Pb zircon ages for the ophiolitic layered gabbro, overlaying arc-type dacite and younger intrusive gabbro and diorite bodies to understand the ophiolite emplacement history in the Allaqi suture zone. Following the track of Kröner et al. (1994), who dated the granitoid gneisses from Hafafit area, Ali et al. (2015) yielded SHRIMP U-Pb zircon emplacement ages for the Wadi Beitan granitoid gneisses further towards the south in SED. In addition to the ophiolitic rocks and the granitoid gneisses, the SED are characterized by the presence of the bimodal Shadli Metavolcanics, which are poorly dated. The mafic and felsic lava yielded a Rb-Sr isochron age of 712 ± 24 Ma, which is considered to represent the time of volcanic eruption by Stern et al. (1991). Unfortunately, there is no study conducted on this rock unit using high-spatial-resolution technique to yield U-Pb zircon age.

The basement inliers in exposed in the southern part of the Western Desert are known to be older than the basement complex in the Eastern Desert and Sinai (Richter and Schandelmeier 1990). Based on zircon fraction dissolution method of Krogh (1973), Sultan et al. (1994) confirmed the Archean and Paleoproterozoic emplacement age from Gebel Kamil and Gebel El Asr. Using a modern geochronological approach, Bea et al. (2011b) confirmed the Archean age of the Uweinat-Kamil inlier based on SHRIMP U-Pb zircon dating. However, Bea et al. (2011a) integrated both SHRIMP and Pb–Pb stepwise evaporation and obtained an Ediacaran age for one of the Bir Safsaf inlier, which is one of the four basement inliers located midway between the Neoproterozoic Eastern Desert and the Archean terranes of the Gebel Kamil.

Accessory minerals other than zircon were rarely used in geochronological studies on the Egyptian basement complex. Few studies used monazite were analyzed by electron microprobe (EMP) Th-U-Pb dating method. For examples, Finger and Helmy (1998) and Karmakar and Schenk (2015) used this in situ monazite EMP dating method to obtain the age of metamorphic events in high-grade rocks from the Egyptian complex and Abu Sharib et al. (2019) dated the metamorphism based on the monazite of the metasedimentary rocks of CED. It worth mention that Zoheir et al. (2015) considered for the first time Re–Os isotope systematic arsenopyrite to determine the timing of epigenetic gold mineralization in CED.

1.6 Airborne Geophysical Mapping

Sultan Awad Sultan Araffa

The airborne surveys in Egypt are acquired out at different times of different scales for a lot of purposes as mineral resources exploration, petroleum exploration, groundwater aquifer definition, and natural radiation mapping. The most airborne survey data is principally magnetic, electromagnetic and in several surveys, total count (TC) radiation for Thorium, Uranium and Potassium elements data were recorded (Fig. 1.14). The airborne surveys are carried out for different agencies such as: Geological Survey of Egyptian and Mining Authority (EGSMA), the Nuclear Materials Corporation (NMC), the Desert Research Institute (DRI), and the Egyptian General Petroleum Corporation (EGPC). According to the independent interests of the different agencies, some information of surveys that are including flight line spacing, flight direction, and flight elevation has been flown. The following is a brief description of the several airborne surveys.

1.6.1 Period from 1962–1978

Airborne magnetic surveys are an important geophysical tool for many junior mining and mineral exploration companies, and for many oil companies for detecting structures and depth of top surface of basement rocks to estimate the thickness of sedimentary succession. These surveys make it possible to gather detailed information about the presence of various magnetic and non-magnetic bodies in the Earth's crust over a large scale geographical area. This type of survey is cost-effective, safe and time efficient because of the large areas of land that can be surveyed. Magnetometers have been attached to a small machine of airplane or helicopter, which can be flied pre-planned survey lines over the survey area and take readings that show differences in earth magnetic fields. The improvement of technology in magnetometers and other magnetic sensors have made it possible to accurately acquire data relative to these magnetic fields from the height of the aircraft. The regional airborne surveys are acquired at different higher altitudes and at wider line spacing intervals. These airborne surveys give more general information about the magnetic fields over a larger survey area but provide clues about which areas may be of more interest. Detailed airborne surveys have been acquired at lower altitudes and narrower line spacing intervals in order to give higher resolution data for better processing of the area.

a. **Aswan Region**

This survey is acquired on Aswan Region by Lockwood of Canada, Ltd. (1968) for the United Nations Development Project (UNDP), this is one of the earlier airborne surveys, was done in 1968 over two large areas in the Aswan area of Eastern Desert, Egypt (Fig. 1.14). This survey aims to apply geophysical investigations for the assessment of mineral ore deposits. The main elements of the survey are shown in Table 1.2. The magnetic data were measured as total intensity magnetic anomaly maps at different scales: n such as 1:50 000, 1:100 000, and 1:1 000 000 (10 nT C.I). The processing and interpretation of magnetic data have been applied on map of scale 1:500 000. The constructed maps of total intensity magnetic maps have not been removed for IGRF from the data. The measured aeromagnetic data were adjusted to a datum of 34, 500 nT, which represents the mean values of total intensity of the earth's field in the area under consideration. The most magnetic anomalies over the parts of Nubian Shield, like those observed on the Red Sea region in the Arabian Shield, to delineate these features such as ring structure, plutons, dyke systems. The quantitative processing and interpretation of data in the northeastern part of study area, Huntec (1969) found two magnetic sources: (1) large and regional sources of deep depths at average depths of 1 km below observation level; and (2) shallow features at average depths of 300 m below observation level. Much remarks were given to the study of the systems of magnetic lineation caused by dykes, some of which were reversely polarized. The result of interpretation indicated that, none of the dyke systems are related to the development of the Red Sea rift zone.

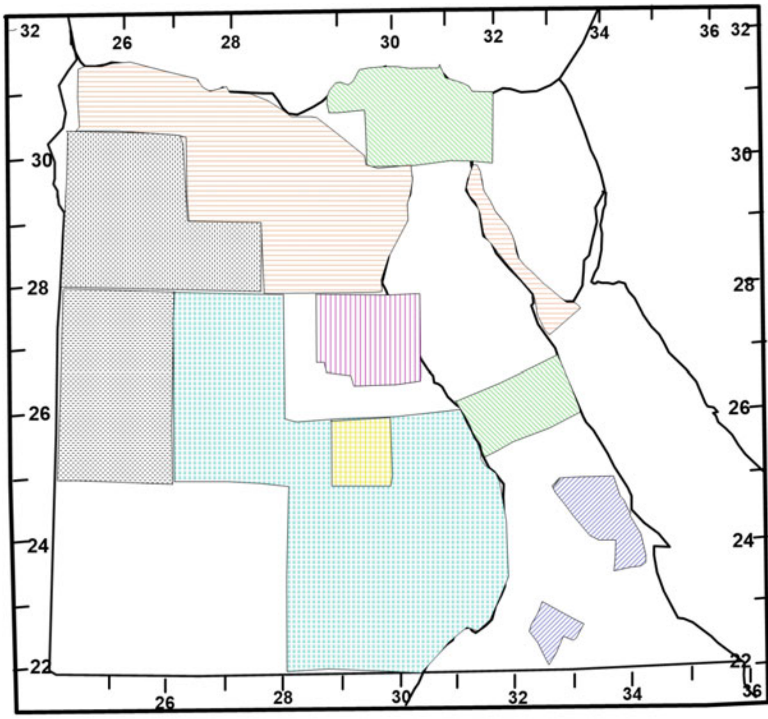

Fig. 1.14 Index map showing locations of airborne geophysical survey areas

b. **Delta Area**

The Delta Area was surveyed for Geological Survey of Egypt (EGSMA) during the period from 1962 to 1963, the EGSMA flew more than 20,000 line kilometers in Nile Delta area along N-S flight lines of line spacing of 1 km and 200 m above land surface (Fig. 1.14). Using a Russian AN2 (single engine) aircraft and an AM13 fluxgate magnetometer. The resulting data contoured for 10 nT interval for a map of scale 1:100 000. The main results of interpretation of the aeromagnetic data has been prepared by El Diasty (1969), where the result indicated that the southern part of the surveyed area is occupying by E-W trending, high frequency, short wave length anomalies which indicating shallow depths producing magnetic bodies. These high frequency anomalies lie adjacent to the low amplitude, long, wave length anomalies that occupying the northern part of the area. The Western Desert of Egypt was surveyed by Aero Service company where this survey was flown in 1961 under AID contract ICA c1775 for the Desert Research Institute (DRI) by in the Aero Service company (1961). The purpose of the survey to assist the definition of possible aquifer thickness by estimating depth to basement surface from magnetic interpretation. Most of this survey was regional, where the flight lines along which data were measured are too far apart to be contoured. The spaced flight lines were flown in the Kharga Oasis area to give greater magnetic detail. The main elements of the reconnaissance survey and the Kharga Oasis survey are given in Table 1.3. Flight line locations were represented on 1:500 000 scale topographic

Table 1.2 Main elements of UNDP airborne survey, Aswan Region, Egypt

	SW zone	NE zone
Survey area in sq. km.	5,000	15,000
Line -kilometers flow	10,000	15,000
Flight line direction	N 25°E	N 60°E
Flight line spacing (km)	0.5	1.12
Flight elevation (m)	130	150
Instrumentation: Magnetic Radiation (TC) Electromagnetic	Fluxgate (18) Yes None	Fluxgate (18) None (400 and 2300 Hz)

Table 1.3 Main elements of UNDP aeromagnetic survey of Western Desert, Egypt

	Reconnaissance survey	Kharga Oasis detail
Survey area in sq. km.	N.A.	12,000
Line -kilometers flow	11,500	5,000
Flight line direction	N–S	N–S
Flight line spacing	50 Pairs	3.3 km
Flight elevation	2000 Bars	2000 Bars
Instrumentation: Map scales	Gulf Mark III Fluxgate Mag. 1:10 000	Gulf Mark III Fluxgate Mag. 1:100 000 1:500 000

maps. The magnetic data were compiled at 1:100 000 (six sheets). 1:500 000 aeromagnetic compilation was also prepared. The datum for the magnetic data was chosen to be 3,700 nT. The main results of interpretation for airborne survey indicated that the magnetic tool could be give a depth to basement rocks, and, thus, aid in the estimation of thickness of the overlying sedimentary successions specially that contain ground water aquifers. (Table 1.3).

c. **Qena-Safaga sector**

Qena-Safaga sector was flown for magnetics from Safaga and Quseir, on the Red Sea, southwest to the Nile River (Fig. 1.14). This project was flown with the same aircraft and Instrumentation as the Delta Area (described above). The area of the par is about 20,000 square km. Flight line direction was normal to the axis of the Red Sea (about N. 60°E.), the spacing 2 km, and the altitude above ground, 150 m. The data for the northern half of this sector were processed and interpreted by El Hakim (1978). The magnetic data for the southern half of the sector were constructed at a scale of 1:100 000 and contoured at 10 nT intervals.

d. **Western Desert (Aeromagnetic surveys for oil exploration)**

Part of Aeromagnetic survey was acquired at different areas for oil companies (Fig. 1.14) a part of the contour map was available for the large area in northwestern part of Egypt (bounded, by the, River Nile on the East, the Libyan Desert on the West, the Mediterranean Sea on the north, and latitude 28° on the south). The direction of flight line was N-S and the line spacing of 2 km apart.

e. **Airborne radiometry surveys**

A major mineral resources survey of natural gamma radiations was made by the EGSMA (through UNDP) in 1968, as a part of the Lockwood aeromagnetic survey in the Aswan Region (see above). The data were acquired a flight altitude of 130 m, for cosmic radiation, and for instrument drift. The collected data were compiled as profiles and as contour maps (1:50 000 and 1:100 000 scales). The total count γ radiation data yielded much information useful in prospecting for most ore mineral elements. The data are represented as contour maps (same scale as the magnetic maps) that have been interpreted qualitatively, the maps have been especially useful in ground follow up geophysical and geochemical investigations. The total count of radiation was applied for both Qena-Safaga sector and for the Delta area. Some more additional information for radiation surveys was obtained from Nuclear Materials Corporation (NMC). The location map which indicates the areas which were applied by airborne radiometric surveys was prepared by NMC. This map indicate that it is not possible to determine which areas were flown by NMC, but certainly the areas in the Eastern Desert (Aswan Region), south of Idfu, were flown by Lockwood. According to the NMC plans a country wide aeromagnetic and gamma ray spectrometry survey, to be done with a twin engine Islander, equipped with Geometrics magnetometer and an Exploranium gamma ray Spectrometer. Surprisingly, no Doppler navigation is planned. And although on board recording equipment is both analog and digital, data reduction will be by manual methods.

f. **Airborne Electromagnetic Survey**

The main objective of Airborne Electromagnetic (AEM) surveys is to acquire a rapid and relatively low-cost technique for metallic ore bodies, such as massive sulphides which located in bed rock. This method can be applied for most geological environments except where the country rock is highly conductive. Also, this technique can be applied to general geologic mapping, geotechnical applications and groundwater exploration. This technique can be applied in some regions such as semi-arid areas, particularly with internal drainage patterns, can be usually poor AEM environments. The Weathered products of mafic flows can give more conductive backgrounds, specially flows of Tertiary or Quaternary age. Some geological materials exhibit high range of conductivity over seven orders of magnitude, bodies of massive sulphides is the strongest electromagnetic responses, followed in decreasing order of intensity by graphite, unconsolidated sediments (clay, gravel and sand), and basement rocks. The consolidated sedimentary have range in conductivity from the level of graphite down to less than the most resistive igneous materials. The aquifers which contain fresh water is highly resistive than that contain salt water. The following examples can be suggested possible target types and they can be indicated the grade of the AEM response that can be expected from these targets. The alternating magnetic field is defined by passing a current

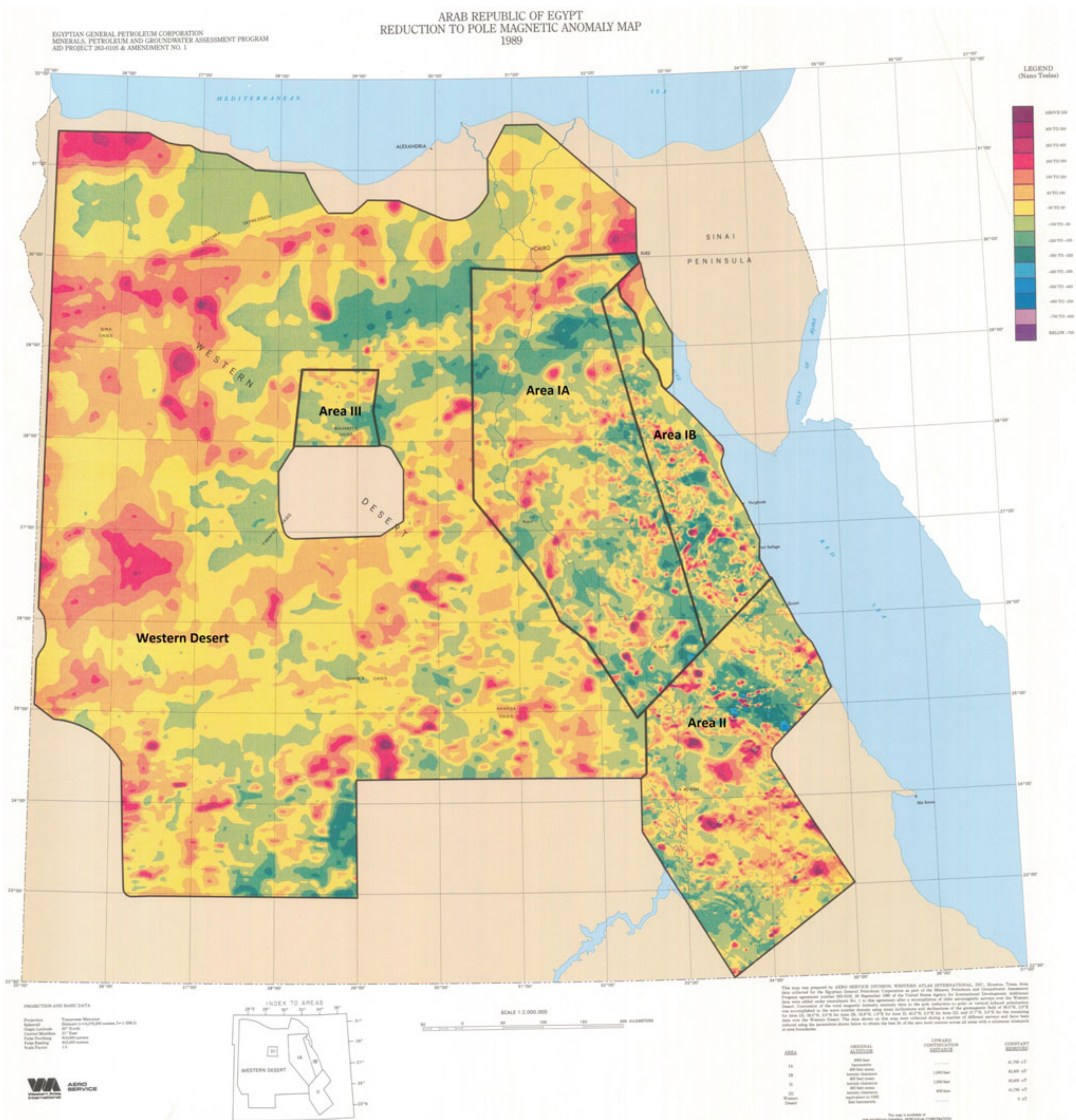

Fig. 1.15 Index map for Aero service survey for Egypt

through a coil. The resultant magnetic field is measured through the receiver of the instrument which is consisting of a sensitive amplifier and meter or potentiometer bridge.

By this way the airborne electromagnetic (AEM) technique was carried out at some areas in Egypt. The airborne electromagnetic (AEM) data were measured only in the southwest part of the Aswan Region in 1968 by Lockwood Survey. The direction of axis of the transmitting coil was vertical and the direction of axis of the receiving coil was horizontal, trailing 50 m below and 139 m aft of the DC 3 aircraft.

1.6.2 Period from 1980–1984

The Airborne survey for this period was carried out by Aero-service Western Atlas International, INC, Houston, Airborne data were collected for Egyptian General Petroleum Cooperation and Egyptian Geological Survey as apart of mineral, petroleum and groundwater assessment program through the agreement number 263–0105 November 1980 of the United State Agency for international development additional data were added under amendment No.1 to this agreement after recompilation of order aeromagnetic surveys over the Western Desert. Conversion of total magnetic intensity anomaly data to the pole (reduction to the pole) or vertical induced polarization was accomplished in wave number domain using mean inclination and declination of geomagnetic field of 39.5°N, and 2.0°E for area IA; 39.5°N, and 2.0°E for area IB: 32.8°N, and 1.9°E for area II; 40.5°N, and 2.0°E for area III; and 37.7°N, and 2.0°E for the remining data over the Western Desert. The maps of airborne survey which carried out by Aero service company are represented by different scales such as 1:50 000 for Eastern Desert and Bahariya Oasis; 1:100 000 for some parts of Eastern Desert; 1:500 000 for most areas of Egypt and 1:2 000 000 for all Egypt in one sheet. Also, different maps of aeromagnetic are constructed such reduced to pole, Interpreted maps for depths of magnetic sources. The airborne surveys include different geophysical data such as aeromagnetic, airborne radiation for total cont., Thorium, Potassium and Uranium elements in PPM and maps for ratios for U/K, K/Th (Fig. 1.15). The geologists of geological survey of Egypt used ratio maps of radioactive elements (U, Th and K) as results of interpretation for airborne data which acquired by aero service to detect the contacts between geologic units and then used for regional and detailed geologic mapping. In some areas in Eastern Desert the interpreted maps are used to detect and define the source of magnetic bodies which can be at shallow depths (near surface) or can be extended to deep depths. The aeromagnetic maps used by geophysicists of geological survey to planning for ground geophysical investigations specially for mineral exploration on some areas in Eastern Desert which are rich for metallic and none metallic ore minerals.

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