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# Gold of the Pharaohs – 6000 years of gold mining in Egypt and Nubia

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## Abstract

The legendary wealth in gold of ancient Egypt seems to correspond with an unexpected high number of gold production sites in the Eastern Desert of Egypt and Nubia. This contribution introduces briefly the general geology of these vast regions and discusses the geology of the different varieties of the primary gold occurrences (always related to auriferous quartz mineralization in veins or shear zones) as well as the variable physico-chemical genesis of the gold concentrations. The development of gold mining over time, from Predynastic (ca. 3000 BC) until the end of Arab gold production times (about 1350 AD), including the spectacular Pharaonic periods is outlined, with examples of its remaining artefacts, settlements and mining sites in remote regions of the Eastern Desert of Egypt and Nubia. Finally, some estimates on the scale of gold production are presented. © 2002 Published by Elsevier Science Ltd.

*Keywords:* Auriferous quartz vein and shear zone mineralisation; Mining; Pharaonic dynastic periods; Gold production

## 1. Introduction

The natural southern border of Ancient Egypt was the region around Aswan with settlements on the Nile island of Elephantine. The desert region east of this location was more or less under Pharaonic control, at least during the Old Kingdom (2700–2160 BC) and Middle Kingdom (2119–1794 BC) but also during New Kingdom (1550–1070 BC) times, whereas during the different intermediate periods less Egyptian control of the Eastern Desert is documented. Large parts of this Eastern Desert belong geologically to the Precambrian basement of the Arabian–Nubian shield and host around 250 gold production sites, which were mined during different periods of ancient Egyptian history. Most of these sites were visited by the authors during four field campaigns between 1989 and 1993, and three additional campaigns during 1996–1999 in the Sudanese Nubian Desert (see Figs. 9 and 10, discussed later).

In the 1960s and 1970s expert teams of the Egyptian Geological Research Authority (EGSMA), the Geological Research Authority of the Sudan (GRAS) and the Soviet Techno Export group carried out extensive gold prospection programs in Egypt and NE Sudan. At the locations of all economically significant gold anomalies they discovered traces of extant mining such as stone mills, remains of settlements and mine-shafts, indicating a long history of ancient extraction.

Unfortunately these expert groups never co-operated with archaeological specialists in order to classify the many remaining ancient mining traces and tools and this interesting aspect of historical prospecting efforts was thus left uninvestigated. It was the goal of the studies described here to fill this gap; thanks to generous funding from the German Volkswagen Foundation, we were able to visit, in co-operation with EGSMA and GRAS, most of the known gold production sites and even to rediscover quite a number of hitherto unknown ancient mining locations.

The most important aim of our expeditions was a systematic survey, encompassing archaeological inspection and classification of the remaining, mostly previously undescribed archaeological surface inventory and material, and a preliminary investigation of the geological setting of the mining sites. Additionally, information was sought on the prospecting, exploitation and ore processing methods of the ancient miners.

In modern times mineral exploration is assisted by complex computer aided processing of satellite spectral imagery, highly sophisticated geochemical, petrographical and geophysical investigations, together with detailed geological field work. Nothing of that kind was available

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to the ancient prospectors, who most effectively executed their profession in search of scarce gold finds during the Predynastic to Middle Kingdom times, in the vast regions of the Egyptian and even more difficult Nubian Desert, during the relatively short span of 140 years between Thutmosis III and Amenophis IV (roughly 1480–1340 BC). During this period almost all important gold mining sites in the Eastern Desert of Egypt and in the Nubian Desert were discovered and exploited.

We visited almost 250 gold production sites. At most places only surface inventory, the examination of remaining open cast workings, accessible underground diggings and a preliminary mapping and sampling of the geology could be performed, due to lack of permission and/or time for detailed excavations and geological fieldwork.

## 2. Geological setting of the gold deposits of the Egyptian and Nubian deserts

The gold occurrences described in this study are located in the Precambrian basement of Egypt and Sudan, also called the Arabian–Nubian shield (ANS), which extends from the river Nile eastwards towards the Arabian Peninsula. To the south, the continuation of the ANS is the Mozambique Belt (Vail, 1988). It is generally accepted that the ANS formed in the Neoproterozoic (Kröner, 1979) by a complex accretion of terranes onto a pre-existing pre-Panafrican Basement called the Nile craton or East Sahara craton (Bertrand and Caby, 1978; Stern, 1994). Contacts between that craton and the Panafrican belt are exposed in northern Sudan (e.g. Stern et al., 1988), whereas the existence of pre-Panafrican basement in the Eastern Desert of Egypt is doubtful (Kröner et al., 1994).

The first stage in the evolution of the ANS was the accretion of several terranes or volcanic arcs (Kröner et al., 1992), consisting mainly of complex intercalations of mafic (basaltic–andesitic) to acid (rhyolitic–dacitic) volcanics, such as ignimbrites and tuffs as well as sedimentary rocks, such as greywackes, siltstones, conglomerates and marbles. Between these different terranes, ophiolitic sequences (partly composed of mafic to ultramafic units, and including serpentinitic xenoliths from the upper mantle) occur as prominent suture zones. An example of a complete ophiolitic sequence can be observed in the region of Bir Umm el–Fawakhir (El Gaby et al., 1988; Langwieder, 1994), in the Eastern Desert. At least five terranes or microplates, separated by suture zones have been identified (Stoeser and Stacey, 1988) within the ANS (Fig. 1). Age determinations (Jackson and Ramsay, 1980; Stern, 1994) indicate that collision and terrane assembly began earlier in the Arabian shield than in the Nubian shield.

Island arc volcanic rocks and ophiolitic sequences formed between 700 and 800 Ma (Stern and Hedge, 1985). These rocks are overlain by calc-alkaline volcanic rocks (Dokhan Volcanic Suite) and clastic sedimentary rocks (Hammamat Group; conglomerates, greywackes, siltstones). The Hammamat Group is interpreted as molasse-type sediments, indicating an extensional stage with the formation of intra-arc graben basins. The volcanic rocks of the Dokhan Group, which extruded approximately synchronously with deposition of the molasse sediments, are regarded as representing further volcanic arc magmatism. Fold structures in the Hammamat and Dokhan Groups indicate a late compressional phase, which might be the result of a collision of the accreted terranes with the East-Sahara craton (Abdelsalam, 1993; Abdelsalam and Stern, 1996). During that late stage of the evolution of the ANS, post-orogenic granites, dated between 620 and 570 Ma (Hassan and Hashad, 1990) intruded. However, shear zones and fold-structures within the post-orogenic intrusive rocks support further tectonic activity. Prominent shear zones became active, like the Najd fault system (Fleck et al., 1980; Fritz et al., 1996) or the Oko-shear zone in the

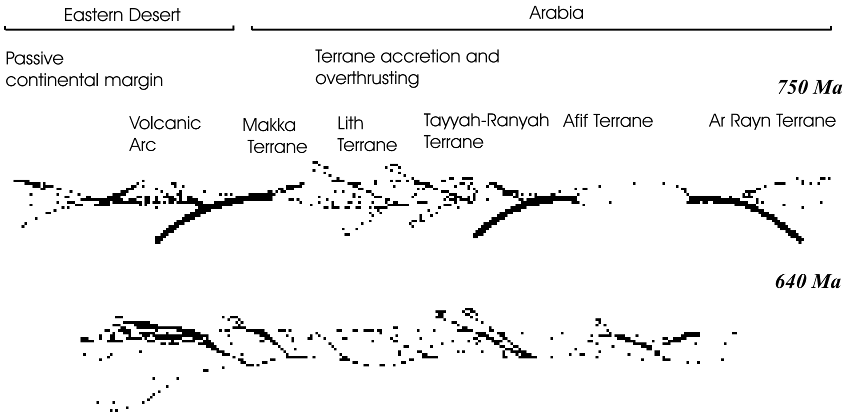

Fig. 1. NW–SE profiles giving an idea on the accretion of the various terranes onto the Arabian–Nubian shield, at about 750 and 640 Ma (modified after Kröner, 1985).

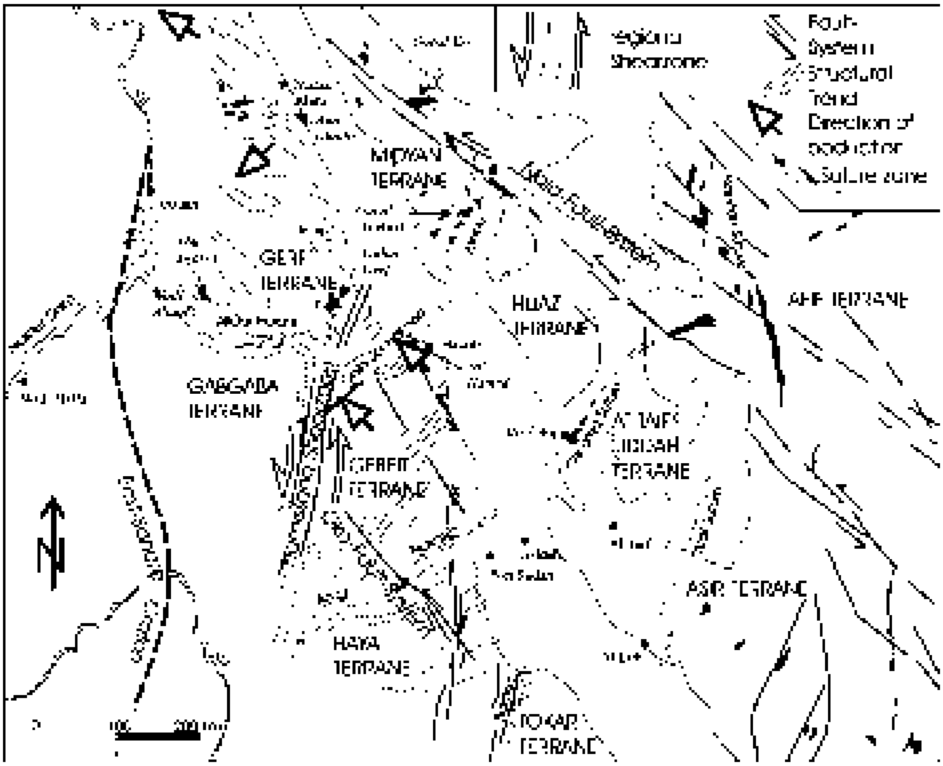

Fig. 2. Simplified structural map of the Arabian–Nubian shield of southern Egypt and NE Sudan (modified after Kröner et al., 1992).

Sudan (Abdelsalam, 1993, 1994) (Fig. 2). In the final stage of the orogenic evolution of the ANS, crustal extension can be assumed due to the occurrence of mafic and A-type felsic dike swarms (Stern et al., 1988).

After a prolonged period of erosion these basement sequences were largely covered by sand during the Cretaceous period (at about 90 Ma), forming the Nubian Sandstone. This sandstone was eroded during the relatively young continental uplift of the flanks of the Red Sea rift system. During this denudational period, the Precambrian basement with its gold-bearing quartz veins and quartz-filled shear zones became exposed at the surface and was thus open to exploitation.

### 2.1. New investigations on gold mineralization

Gold occurrences in the ANS are mainly confined to quartz-mineralized shear zones, which occur in the ophiolitic sequences, the island arc assemblages, the Hammamat and Dokhan Groups and in the post-orogenic granitoids. The latter seem to have had an important influence on gold mineralization, as productive shear zones and quartz veins often occur in the granitoids themselves or in their direct vicinity. Analytical investigations of different rocks in the ANS (e.g. serpentinites, basalts, clastic sedimentary rocks) indicate exposed gold concentrations of 20–50 ppb in mafic rocks and clastic sediments, and concentrations close to 200 ppb in the serpentinites (Langwieder, 1994). However, unaltered granitic rocks did not show positive gold anomalies (Murr, 1999). Structural investigations of the shear zones showed that they were formed during the previously mentioned compressional or transpressional late stage events of the orogeny. Post-orogenic intrusions, predating the quartz veins or shear zones, provided heat sources. The latter resulted in the formation of hydrothermal convection cells, and interstitial waters dissolved available mineral species; where such cells were present, low concentrations of gold were derived from the strained rocks, due to elevated temperature and pressure.

Where the aquifers provided open spaces, such as in the shear zones, the hydrothermal fluids precipitated their dissolved mineral content. The main constituent of such fluids was silica, and consequently quartz is by far the dominant mineral in the shear zones or veins. Other minerals like calcite, barite and chlorite are only present in small amounts (less than 5 vol%).

Microscopic ore analysis of quartz veins and host rocks of the important gold occurrences at Hangaliya (west of Mersa Alam; Fig. 9), Fatira, Gidami and Atalla (all in the area west of Safaga and Qusir; Fig. 9), in the Eastern Desert of Egypt (Murr, 1999), yielded three different stages of mineralization. During the first stage the main ore minerals were pyrite or arsenopyrite, minor pyrrhotite and chalcopyrite. This stage is preserved both in the rims of the quartz vein itself and in the host rock. A significant alteration can be observed in the host rock: primary minerals are completely transformed into a

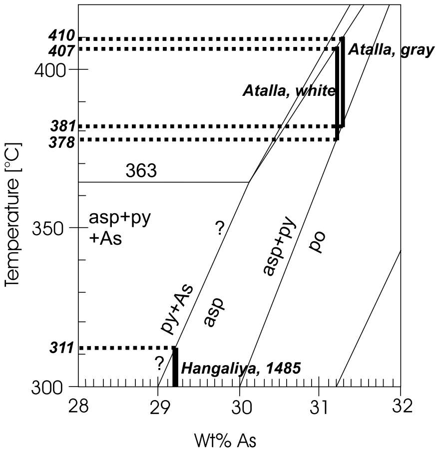

Fig. 3. Diagram of Kretschmar and Scott (1976) for estimation of formation temperature of arsenopyrite from the gold vein occurrences at Atalla and Hangaliya, Eastern Desert, Egypt (asp = arsenopyrite, py = pyrite, po = phyrrotite).

sericite–quartz–pyrite assemblage. A chemical comparison between unaltered host rocks (e.g. granites) and their alteration products shows no significant change in the composition for major elements. In particular, the Fe-content remains the same although the pyrite/arsenopyrite mineralization is evident. A chemical reaction of a fluid (pH between 3.5 and 5) with the host rock can be assumed, resulting in the formation of sericite and quartz. If gold was transported as a sulphide complex in the reactive fluid, primary iron from the host rock and sulphide from the fluid could have formed pyrite while the gold was being precipitated. Gold was confined within this first stage of mineralization mainly to pyrite or arsenopyrite.

The second stage of mineralization can be observed within the quartz veins. The main minerals are pyrite, sphalerite, galena and chalcopyrite, with minor amounts of digenite, hessite, calaverite, scheelite, hematite and tetraedrite. Gold occurs within quartz, sphalerite, galena, pyrite and chalcopyrite. The third stage of mineralization comprises mainly quartz; pyrite was rare and gold was not found. Therefore this generation can be regarded as barren.

Supergene alteration of the primary paragenesis resulted in the formation of lepidocrocite, jarosite, argentite, stromeyerite, anglesite, cerrusite, smithsonite, mimetesite and rare tellurates and arsenates. Gold was locally remobilised, re-precipitated and concentrated. Temperature estimations of the ore-formation can be done by arsenopyrite thermometry. In the first mineralization stage, temperatures of 300 °C (at Hangaliya) and about 400 °C (at Atalla) can be estimated (Fig. 3). The occurrence of calaverite and hessite in the quartz vein at Gidami (second mineralization stage) gives a maximum temperature of about 250 °C (Fig. 4).

Two main fluid phases were observed in primary fluid inclusions. In the first mineralization stage the fluids contain $CO_2$ and $H_2O$ in different ratios. Estimated $CO_2$-contents are between 25 and 95 vol%. The salinity is low (maximum of 6 wt%). From isochores (Fig. 5) a pressure of 1–2 kb can be estimated, assuming a temperature of 300–400 °C from the arsenopyrite thermometry. In the second mineralization stage the ratio of $CO_2$ and $H_2O$ changes. Pure $CO_2$-inclusions can be observed, indicating an unmixing of a primary mixed $CO_2$–$H_2O$-fluid due to the pressure release. The absence of water-rich fluids can be explained by a selective trapping of $CO_2$, whereas water is transported to higher levels within the hydrothermal system. Indeed, primary inclusions in identical quartz veins become more and more $H_2O$-rich, with increasing topographic levels, whereas the total density of the fluid decreases dramatically (Fig. 5). The above mentioned third stage of mineralization probably formed from this low-density $H_2O$-rich fluid phase.

A well-constrained model for the gold mineralization can be presented. Post-orogenic granitoid intrusions produced heat anomalies, leading to hydrothermal convection cells. Interstitial water was able to dissolve gold from slightly enriched rocks (e.g. serpentinites, ophiolites etc.). Joints and shear zones served as chan-

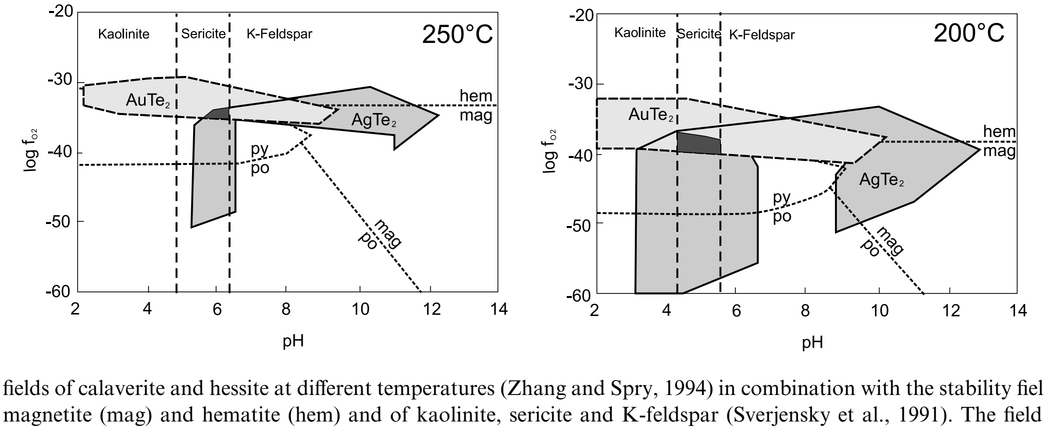

Fig. 4. Stability fields of calaverite and hessite at different temperatures (Zhang and Spry, 1994) in combination with the stability fields of pyrite (py), pyrrhotite (po), magnetite (mag) and hematite (hem) and of kaolinite, sericite and K-feldspar (Sverjensky et al., 1991). The field of the observed paragenesis of the second stage of the gold generations at Gidami is marked in black.

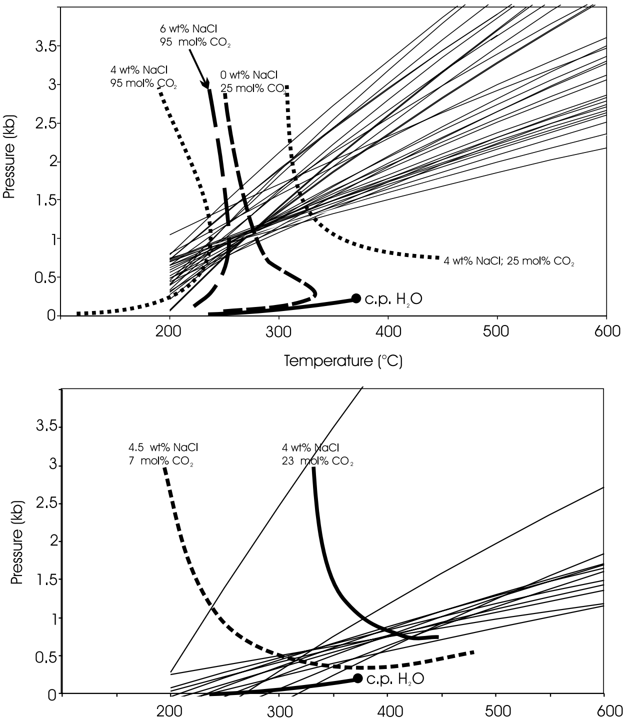

Fig. 5. Isochores of the quartz mineralization of the first stage (top) and the third stage (below) of Gidami mining site quartz generations. The decrease of density is obvious. Solvi for isochors are calculated after Bowers and Helgeson (1983) (c.p.: critical point of water).

nels for the circulating hydrothermal cells. Chemical reactions of the sulphide-enriched fluids with the host rocks resulted in host rock alteration, with liberation of iron and the formation of pyrite and/or arsenopyrite and, due to the breakdown of the gold-sulphur complexes, in the precipitation of gold. Estimated pressure and temperature ranges are 300–400 °C and 1–2 kb. If a rapid opening of the shear zone occurred, pressure release caused unmixing of the fluid. Also, changes in pressure, temperature, pH-value and degassing of volatiles induced precipitation of gold and sulphides from the fluids. $CO_2$ was trapped preferentially due to the higher wetting angle under these circumstances, whereas water was transported to higher levels where a further quartz mineralization occurred. As gold was precipitated at the lower levels, these upper parts normally are barren. Supergene alteration caused locally visible concentrations of gold, when, due to oxidation of pyrite and/or arsenopyrite, submicroscopic gold inclusions within them became liberated.

We are able to define three general geological environments of gold mineralization, exploited by the ancient miners:

(1) Gold mineralization associated with mafic to ultramafic units of ophiolitic affinity, such as basalts–andesites (amphibolites) and serpentinites with remains of pyroxenites and/or with their clastic erosion products such as greywackes and conglomerates. If these sequences were intruded by late Proterozoic granitoids, quartz vein mineralization with locally developed low gold contents could form within the whole rock unit but preferably along the granitoid assimilation rims, related to dilated shear zones or joint systems.

(2) Towards the southern part of the Egyptian Eastern Desert, but located mainly in NE Sudan, the gold environment changes to more rhyolitic–andesitic volcanic rocks with less common intercalations of clastic sedimentary rocks and marbles. This environment was penetrated by late granitoids producing the perfect tectonic setting to allow for gold-quartz vein-mineralization. The only present-day gold producer in NE Sudan is the Sudanese-French (GRAS–BRGM) joint venture operation of Ariab (Bakhiet and Matheis, 1993; Wipfler et al., 1999). At this locality high quality gold ore is mined in an extreme intensively leached SEDEX-deposit, occurring in a sequence of highly folded acid volcanics of mainly rhyolitic character. Due to superficial leaching, only a sponge type whitish silica residue remains from the former SEDEX-deposit, enriched up to 50 ppm in Au. According to drill core results, this leached zone changes gradually into a pyrite dominated massive sulphide ore body, which is stratabound and folded, with only an average of 0.5 ppm Au. It appears quite likely that sulphidic SEDEX occurrences or their oxidized remains might have been the primary gold source of this second type, hydrothermally leached and redeposited, forming the gold-bearing quartz mineralization investigated during our studies.

(3) In the western part of NE Sudan close to the Nile, a number of ancient mined gold-quartz mineralizations occur within the older gneissic pre-Panafrican basement. Some of these sites are remarkably rich with an average of one ounce (about 30 g/mt) Au per metric ton, such as Sarras, Duweishat and Abu Sari (Fig. 10). All along the eastern bank of the Nile between Ager and Ginnis, the extended hilly plain is covered by heaped remains of ancient alluvial workings of generally scattered quartz vein detritus. The remains of these operations indicate an intensive gold production. The concentration of New Kingdom (NK) temples, built during the reigns of Amenhotep III and IV (about 1380–1340 BC) opposite the eastern bank of the Nile might not be an accident and supports the importance of this region to the Egyptian NK occupants in Nubia. Due to the mentioned lack of detailed geological knowledge on this region, a convincing source for the rich gold mineralization in Nubian basement rocks unfortunately cannot be offered.

## 3. Gold production periods in Egypt and Nubia

In the Eastern Desert of Egypt, remains of gold production sites were dated to the time of “Earliest

Hunters" of Winkler (1938), who classified this nomadic population as part of the Amratiens, in the middle of the fourth millennium BC. During this time, obviously only small nuggets were picked from the wadi grounds. Yet, as accumulation of gold nuggets in the recent wadis free of continually flowing river systems is not pertinent, the occurrence of visible nuggets must have been restricted to the few remaining wadi grounds from Pleistocene times. Such a system is preserved in the area around Umm Eleiga (Klemm, 1995) in the southern part of the central Eastern Desert of Egypt, where stone fields bearing decorations of the "Earliest Hunters" could be detected.

### 3.1. Gold production in pre- and early dynastic times

Discoveries of gold artefacts, dating back as far as the Predynastic time (about 3500 BC) demonstrate that gold production must have taken place in Ancient Egypt (Kroeper and Wildung, 1994) as well. Statistical analysis of the geological environments around Pre- and Early dynastic mining sites indicate unambiguously that the earliest prospectors concentrated their mining activities on well-selected geological targets of gold enriched quartz veins, mainly in granodioritic rims of Neoproterozoic granitic intrusions, belonging to the so called older and younger granites of the Eastern Desert.

Furthermore, discoveries of the oldest mining tools are connected to mining sites associated with superficially altered quartz vein systems, which originally contained a variable copper-sulphide mineralization, that is almost completely leached out and which has been re-deposited as typical green malachite (and some other green secondary copper minerals) within the host rock's joint system. Obviously this green staining guided early prospectors to the auriferous quartz veins. Apart from gold, those malachite enriched sites also were mined for copper, as recently shown by Castel and Mathieu (1992).

Gold mining sensu strictu in Ancient Egypt started in Predynastic time with open pits and moderate underground activities (Fig. 6). During this early period, the gold-bearing quartz veins were crushed in situ to a fine powder fraction by huge calabash-shaped stone hammers of 6–10 kg weight, which must have been held with both hands (Fig. 7). In this way the gold slivers within the quartz were liberated for later processing. This mining method formed conspicuous smooth surfaces, both at the walls and the stopes of the underground operations. However, until now no convincing field evidence for a gold concentration procedure could be discovered. Taking into account the hydro-metallurgical concentration processes applied during later periods of gold production, comparable methods can possibly be assumed for this epoch as well. Apart from the large two-handed stone hammers, different types of discus-shaped hammers have also been found within Predynastic sites. This hammer type obviously was used only to gain lumpy quartz ore from the brittle vein systems, which was powdered later by the large hammers.

### 3.2. Gold production in old and middle kingdom times

During the Old (2700–2160 BC) and Middle Kingdom (2119–1794 BC) the previously described prospecting method of searching for malachite staining in the host rocks continued in general, but in addition hematite enriched quartz veins (in places with barite) became important for exploration and, in case of gold discovery, for subsequent mining targets.

Old Kingdom gold mining techniques continued with in situ crushing of the gold-bearing quartz vein systems, but two new basic types of stone hammer were developed: an oval stone axe of 2–5 kg weight with a chiseled notch for a forked wooden stick ("Rillenschlägel") and

Fig. 6. Trench of an Early Dynastic gold mining site at Abu Mureiwat, Eastern Desert, Egypt. Both sides of the formerly protruding quartz vein are filled up by waste, including broken stone hammers and ceramic fragments.

Fig. 7. Abandoned fine-grained granodioritic two-handed stone hammers from Pre- to Early Dynastic Higalig gold mine, southern Eastern Desert, Egypt. Modern hammer: 30 cm.

Fig. 8. Ergonomically formed one-handed andesitic stone hammers used in Old and Middle Kingdom times. Abu Mureiwat gold mining site, Eastern Desert, Egypt.

a more or less cylindrical one-handed stone hammer with a chiseled, ergonomically formed handle (Fig. 8). With the advantage of these new mining implements a more effective exploitation of the auriferous quartz veins could be established.

During the Middle Kingdom this tool inventory in general continued, but additional stone mortars were introduced, allowing for the lumpy quartz ore to be crushed first to about pea-sized grains and then for grinding it to a powder fraction. Again, no archaeological evidence for further gold recovery treatments during this period could be discovered, but the remark of the nomarch (provincial ruler) Ameni, who is quoted in his Beni Hassan tomb as having said "I forced their (Nubian) chiefs to wash the gold" (Newberry, 1893) gives a clear hint that hydro-metallurgical concentration processes were well established during these periods.

The majority of miners in these times were most probably members of desert tribes and not Egyptians of the Nile valley. This is suggested by the ergonomically formed handle of the one-hand stone hammers, fitting best in a hand of 18–20 cm in size, rather than one of 11–13 cm, which was the average for the Nile valley population at that time. Furthermore, this could be verified by sporadic finds of typical Nubian pottery. On the other hand, it has to be emphasized that typical Egyptian pottery of that time, such as red polished Meidum bowls (Ballet, 1987) were also frequently discovered in the surveyed surface remains, which can be seen as a hint for stronger Egyptian control of the mining operations, in contrast to the previous Egyptian restriction on gold trading.

In Fig. 9, only a few gold mining sites for both Pre- and Early dynastic times and Old and Middle Kingdom periods are shown. This corresponds with the low number of known gold artefacts from those early periods, compared to the later periods. However, quite a few of the early mining sites might have been so intensively overprinted by later operations that today no older surface remains are still visible. Systematic archaeological excavations certainly will modify the number of known sites shown in Fig. 9.

The first military campaign in the 18th year of Sesostris I (1956–1911 BC), at the beginning of the Middle Kingdom, was most probably organised to gain access to the Nubian gold. It is recorded by the Sestoris I nomarch Ameni, in his tomb at Beni Hassan, that he undertook expeditions to Nubia from where he returned with gold and gold ore for his king (Newberry, 1893). However, almost all ancient gold mines of these early times are more or less collapsed, and any estimation of the maximum depth without archaeological excavations is debatable; nevertheless, depths in open trenches of up to about 25 m seem realistic.

### *3.3. Gold production in New Kingdom times*

From the New Kingdom (1550–1070 BC) period onwards, gold mining operations concentrated more in the central Eastern Desert, predominantly south of the Qena-Safaga road, and were also spread over the eastern portion of the Red Sea hills. Due to the conquest of Nubia, exploitation of the Wadi Allaqi area and deep into the NE Sudan (Figs. 9 and 10) also became possible. Moreover, the gold prospecting targets were significantly enlarged: in the vicinity of the older mining sites quartz vein systems free of hematite and green copper aureoles were also successfully prospected.

More detailed studies of the quartz vein systems exploited during New Kingdom periods indicate the profound knowledge of the ancient prospectors. They obviously were aware of the general structural control of gold-bearing veins, which despite showing different strike-patterns in different parts of the Eastern Desert, have a general tendency of north–south or east–west strike directions. The prospectors followed only veins of these known productive orientations and ignored the many others running divergently within the same prospecting area. Whether this knowledge was based on systematic geological investigations or on trial-and-error based experience is not known. However, it is striking, that in regions where the normal N–S direction of the gold productive veins has locally changed, the ancient miners unerringly prospected the new productive vein strike directions, which might be regarded as a hint for a basic geological-structural knowledge.

In addition, unexplored new areas with an enlarged geological framework were prospected during New Kingdom times. Particular emphasis was placed on geological environments characterized by basaltic–(amphibolitic) and serpentinitic lithologies with or without black shales, in the vicinity of granitoid batholiths. Furthermore, due to the systematic exploration of remote desert regions during New Kingdom times,

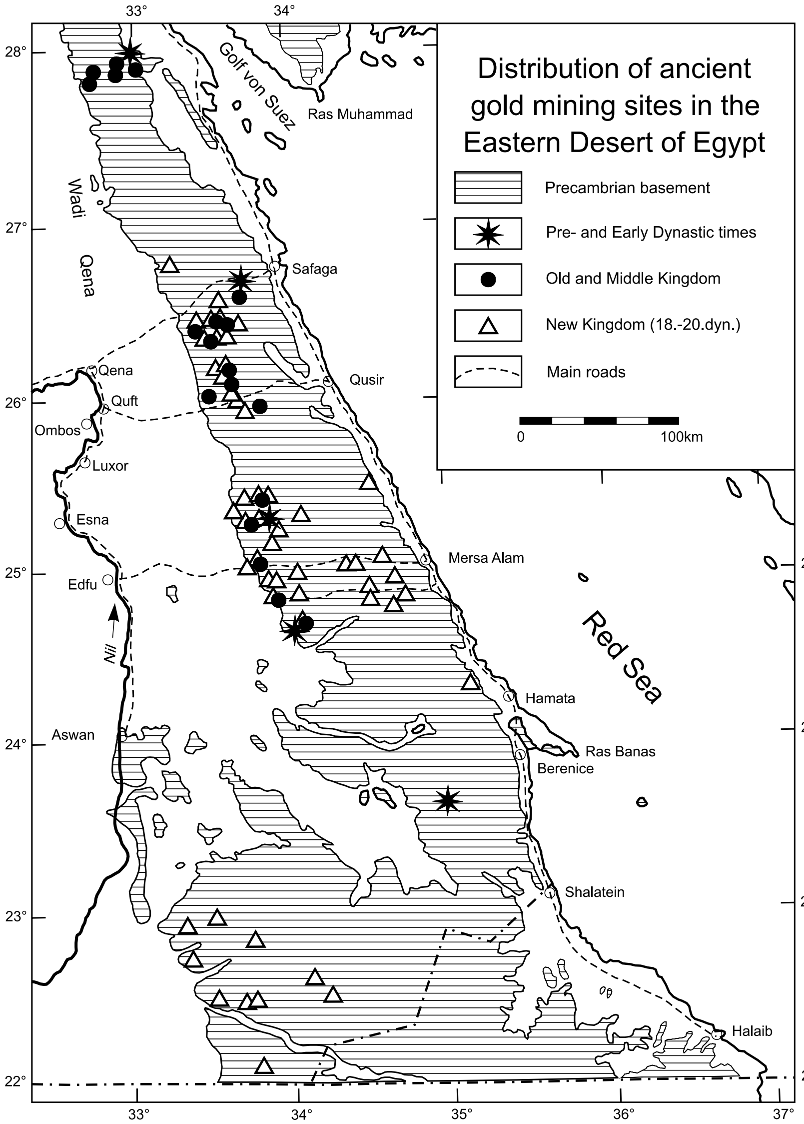

Fig. 9. Distribution of the Pre- and Early dynastic, Old and Middle Kingdom and New Kingdom gold production sites in the Eastern Desert of Egypt. Note the wide activities all over the Desert regions even into the very southernmost parts.

granitic–granodioritic areas in the southern and eastern parts of the Eastern Desert became new and important prospecting and mining targets. These were extended to the Wadi Allaqi and even to the North-Eastern Sudan.

As an important innovation, intensive gold prospecting and processing were extended to include wadi-working operations, where gold-bearing quartz samples were systematically picked from the coarse-grained fractions of the wadi sediments. At these sites, the simultaneous employment of hundreds of workers was possible, in contrast to the severely limited number of miners in underground workings. Archaeologically these wadi works are preserved in extended settlements along the exploited wadis (Klemm and Klemm, 1994). Normally house ruins remain only at the wadi boundaries, parallel to the hillsides as the remainder of the settlements was mostly washed away by sporadic floods, but in a few cases ruins still cover entire wadi sites. Consequently these sites led to an enormous increase in gold production, documented by an increase of known gold artefacts from those times.

In addition to the greatly expanded mining activities, a radically new milling technique had a strong impact on gold production at the onset of the New Kingdom: mill stones up to 80 cm long and 30–50 cm wide, with a flat and oval-shaped grinding plane, and differently sized sets of mill stones used with one or both hands (Fig. 11) were introduced. These stone mills are similar to the flour mills commonly used in the Nile valley since very early times (Roubet, 1989). The introduction of these flour milling techniques into the gold ore processing industry can be regarded as an indication that only from

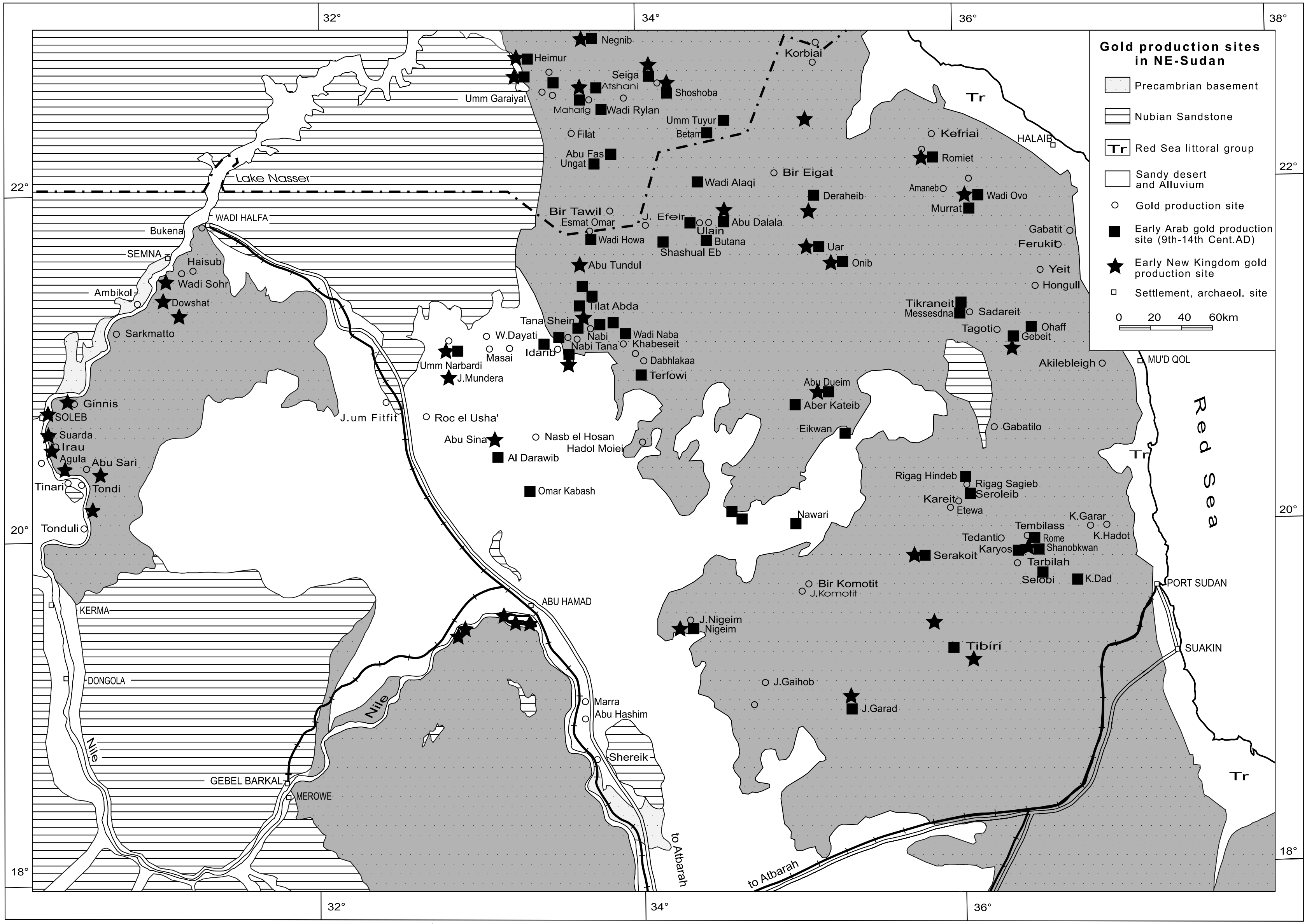

Fig. 10. Distribution of the New Kingdom and Early Arab gold production sites in NE Sudan. Note the concentration of the sites along the river Nile, but also the widely scattered localities all over the vast distances of the Nubian Desert. Note further that the Arab gold production sites never passed westwards the line situated at approximately Wadi Halfa – Abu Hamed.

Fig. 11. New Kingdom oval shaped andesitic stone mill with a selection of grinding stones from Hairiri gold mining site, Wadi Allaqi, southern Eastern Desert, Egypt (scale is 10 cm).

New Kingdom times onwards were the majority of miners Egyptians from the Nile valley. This assumption is also confirmed by the predominant occurrence of typical New Kingdom pottery remains within mining sites in the Egyptian Eastern Desert, but partly also in Nubia.

Before milling, the initial lumpy ore was crushed down to about bean-sized particles with a double-sided stone anvil of about 30 × 30 cm and a rounded stone pestle of 0.5–2 kg weight. Demonstrably, the separation of barren and gold-bearing quartz fragments exclusively by eye was perfected by the workers, as small and uncommon remaining mine dump heaps in the wadi grounds today contain only milky white and translucent barren quartz gravels (Fig. 12).

Separation of gold from the fine-milled quartz powder fraction was managed by washing as attested by preserved tailing dumps. At first view these tailings appear as mostly pink to reddish heaps of quartz sand, analogous to normal desert sand. Investigation with a simple hand lens, however, reveals both sharp edged quartz grains which are artificial products as well as remaining gold concentrations of about 3–5 g/t. This rather high residual gold content unfortunately caused the destruction of many ancient gold production sites at the beginning of the 20th century, when modern gold production started with cyanide leaching of the old tailings, thus destroying most of the preserved and untouched original archaeological sites (Schweinfurth, 1904).

At quite a few of the New Kingdom gold production sites, inclined gold washing tables constructed of stone fragments, consolidated by primitive clay/sand mortar and with a surface covered by a layer of the same material, can be observed. The lengths of these washing tables varies between 2.2 and 4 m, and they are 40–60 cm wide and 80–100 cm high, corresponding with an inclination angle of 15–20° (Fig. 13). At the end of this slope the washing water was recovered in a box about 60 cm deep and wide, walled by stone slabs and sealed again with the described mortar. Here also the detritus of the quartz tailings was deposited, from were it was dumped close by, at the tailing heaps, still partly preserved in many cases today. A mortar-sealed and stone slab protected gutter conducted the water back to a large, 80 × 60 cm basin, from where the water was recycled for further gold washing processes, most probably with primitive shadoufs (a scooping bucket conveyor, still in use in Egypt and Nubia today).

The question remains, however, as to how the planar surface of the inclined table was prepared, to separate the fine-grained gold particles liberated by the grinding process from the quartz ore. No direct archaeological evidence exists for this important step in ancient gold

Fig. 12. Remaining New Kingdom waste dam heaps from wadi workings at Umm Garaiyat, Wadi Allaqi, southern Eastern Desert, Egypt. Note that parts of the wadi ground became flooded later, destroying most of the ancient situation.

Fig. 13. Inclined Arab period washing table. This type of washing table could be archaeologically assigned in use from New Kingdom times on, but might have been in use already since earlier periods. Due to the intensive obliteration of these very old usages, they can no longer be recognized.

recovery. Due to the lack of any archaeological relicts in this respect it might be assumed that the covers of these inclined tables were of organic materials. Here in general two possibilities are likely, either a wooden grid or simply sheepskins, as both were commonly used in the more recent past for separation of gold slivers and quartz sand fractions. The sheepskin hypothesis is supported by the supposition that sheep were available at the mining sites as food, and further, both the lanolin-grease and the washed fibers of the sheepskins would have trapped the sharp-edged gold particles whereas the barren quartz particles were carried off with the water suspension. The legend of the Golden Fleece, therefore, may have been of Egyptian origin and of far greater antiquity than the voyage of the Argonauts. Finally, burning the pelts containing the gold particles yields a raw gold product, but obviously no witness to this last possible step of the gold recovery procedure would remain.

In early New Kingdom times, approximately between the reigns of Thutmosis I (1504–1492 BC) and Amenophis IV (1351–1334 BC), Nubia was conquered and incorporated into the Egyptian NK empire. Most probably the name Nubia is alliterated from "nub", the ancient Egyptian word for gold. Along the river Nile in Nubia, panning techniques most probably increased the gold production in New Kingdom times. As already mentioned above, the MK-nomarch Ameni forced the chiefs of the Nubians to perform gold washing. As alluvial river gold is still panned today in parts of Nubia, especially in the area around Shamkhiya, some 30 km west of Abu Hamed, this or a similar technique may already have been known during Pharaonic times. Inscriptions on dedication lists at NK Egyptian temples like Medinet Habu, where "gold of the water" is registered (Hölscher, 1957), support gold extraction from alluvial (wadi and river sediments) sources (Fig. 14). Nevertheless, no convincing archaeological evidence

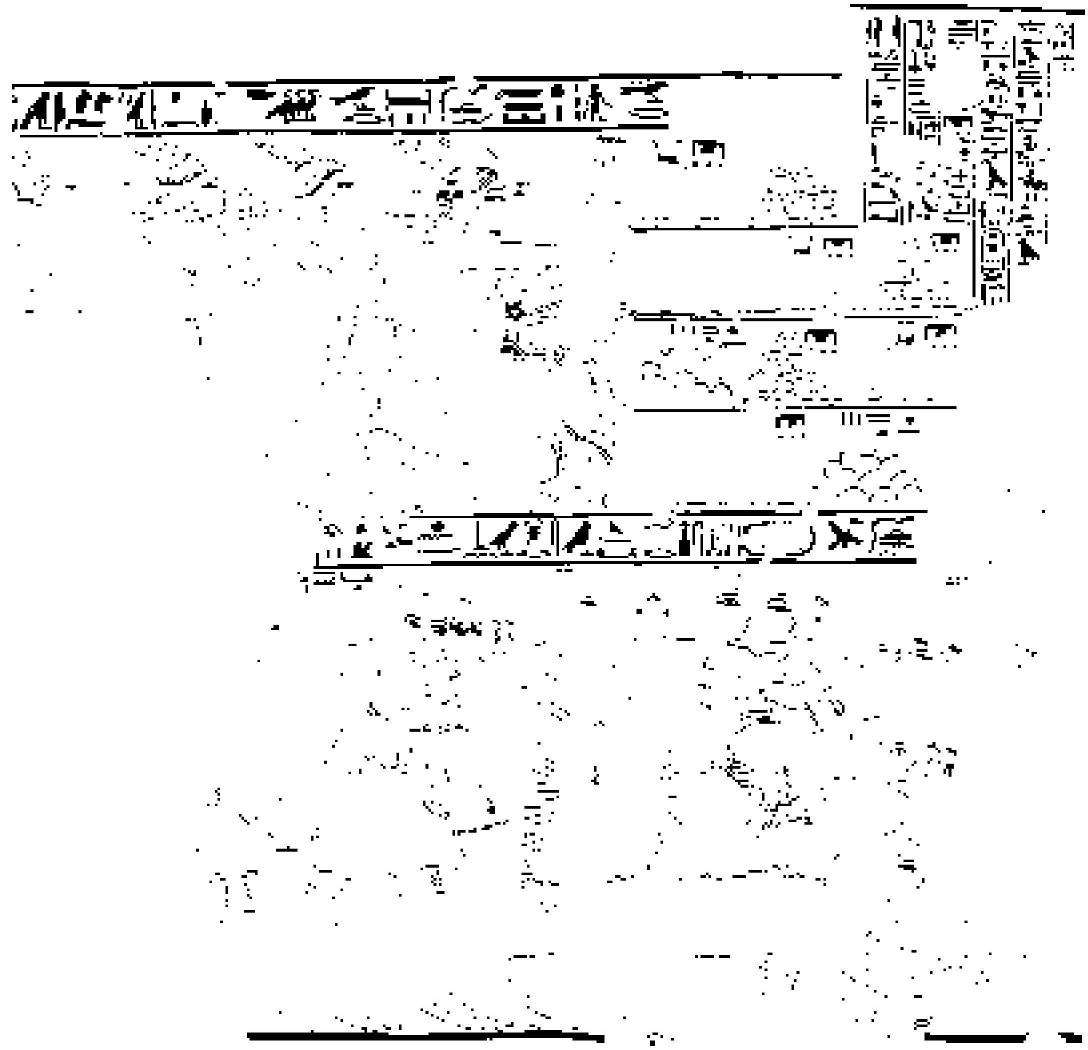

Fig. 14. Nubians (upper part) bringing gold in pochettes and ring ingots. Copy of wall painting remains in the tomb of Huy, viceroy of Kush (Nubia) under Tutankhamun, end of 18th dynasty, New Kingdom.

exists for panning or equivalent techniques having been applied during Pharaonic periods. The unique, probable gold washing plant reported by Vercoutter (1959) from the vicinity of Faras (now under the water of Lake Sudan), is doubtful, as the author himself was puzzled whether this could not possibly have been an installation for wine production.

The well-organized housing areas of the various gold working sites of New Kingdom times are constructed mainly of 3–4 roomed houses, with dry stone walls about 30 cm wide and up to 1.5 m high and, in many cases, with a front terrace (Fig. 15). The lack of any protective enclosing walls indicates that during this period the Eastern Desert of Egypt was peaceful and under the direct control of Pharaonic Egypt. In Nubia, starting from Wadi Allaqi, this peaceful situation became changed at places. At Umm Garaiyat the NK settlement is protected by a large enclosure wall and at other sites the NK settlements are hidden in side wadis, such as at Duweishat and Abu Sari. Other NK gold production sites further to the south, like Sai Island, Shamkhiya, Tanta and Mograt Island seem to have been operated only within strongly fortified settlements.

This latter assumption is based on the observation that almost all of the more southerly NK gold production sites today are only indirectly recognizable, as the typical NK stone mills and crusher stones are mainly incorporated into the walls of far later medieval fortifications of the Christian kingdom of Makuria. The most probable interpretation is that these fortifications are nothing less than rebuilt earlier defensive installations from NK times. This assumption is supported by a site called Ras el-Gazira at the easternmost part of Mograt Island (near Abu Hamed in Sudan), where a relatively untouched NK gold production site is directly protected by an impressive stone fortification with an extended field of rock palisades towards the open eastern plain of the island. Here, as at the other sites, mostly only scanty ceramic remains are detectable as surface inventory, but a detailed archaeological excavation is urgently required.

Fig. 15. Remains of a five roomed stone house from the New Kingdom settlement of Tilat Gadalla, Eastern Desert, Egypt.

Mining technique improved significantly in NK times, mainly of the introduction of bronze chisels, which allowed a much more selective separation of the gold-bearing quartz generations of a multiphase quartz vein from the barren parts of the host rocks. The miners followed selectively the most promising ore shoots, which resulted locally in a somewhat chaotic pattern of the underground operations. Fortunately, in most mines supporting pillars at sufficiently safe spacings ensured the safety of the ancient miners as well as our recent samplers. During NK time no sophisticated ventilation of the underground operations was developed, limiting the maximum depth of operation to about 30 m, the maximum depth for maintaining a sufficient oxygen level by normal circulation for men and burning oil lamps.

In Figs. 10 and 11 the distribution of the many NK gold production sites in Egypt and NE Sudan provides an impression of the very extensive gold production operations carried out during New Kingdom times. However, it should be emphasised that in Nubia these activities were restricted only to the rather limited period between about the reign of Thutmosis III and Amenophis III. From the weak Egyptian government of Amenophis IV onwards, throughout the Ramesside (about 1300–1100 BC) period, no archaeological evidence for Pharaonic gold mining within the Nubian Desert, south of Wadi Allaqi could be detected. In the Egyptian Eastern Desert, primary NK gold production started already early in the 18th dynasty and collapsed completely by the end of the Ramesside period, and seems to have been suspended throughout the entire Late Period, until early Ptolemaic times.

### 3.4. Gold production in Ptolemaic (Greek) times

It is very likely that in Ptolemaic and also in Roman times essentially no new prospecting strategies were developed and that only the ancient NK Pharaonic mining sites were reorganized and mined out. The mining was again limited by underground shaft termination at a final ventilation depth, approximately 30 m below surface (below which oil lamps are no longer able to function). Only those mines which were located close to the desert roads (Murray, 1925) were further exploited or re-established in Ptolemaic and Roman times (Fig. 16).

Based on Agatharchides, reported by Diodor III, 12, gold mining took place in the southern part of Egypt, close to the "border of Ethiopia". In spite of justified doubts about the authenticity of Agatharchides' description (Woelk, 1966) it is generally accepted that gold mining took place in the Wadi Allaqi district during Ptolemaic times, although the exact area is not mentioned literally. Our own investigations within the Wadi

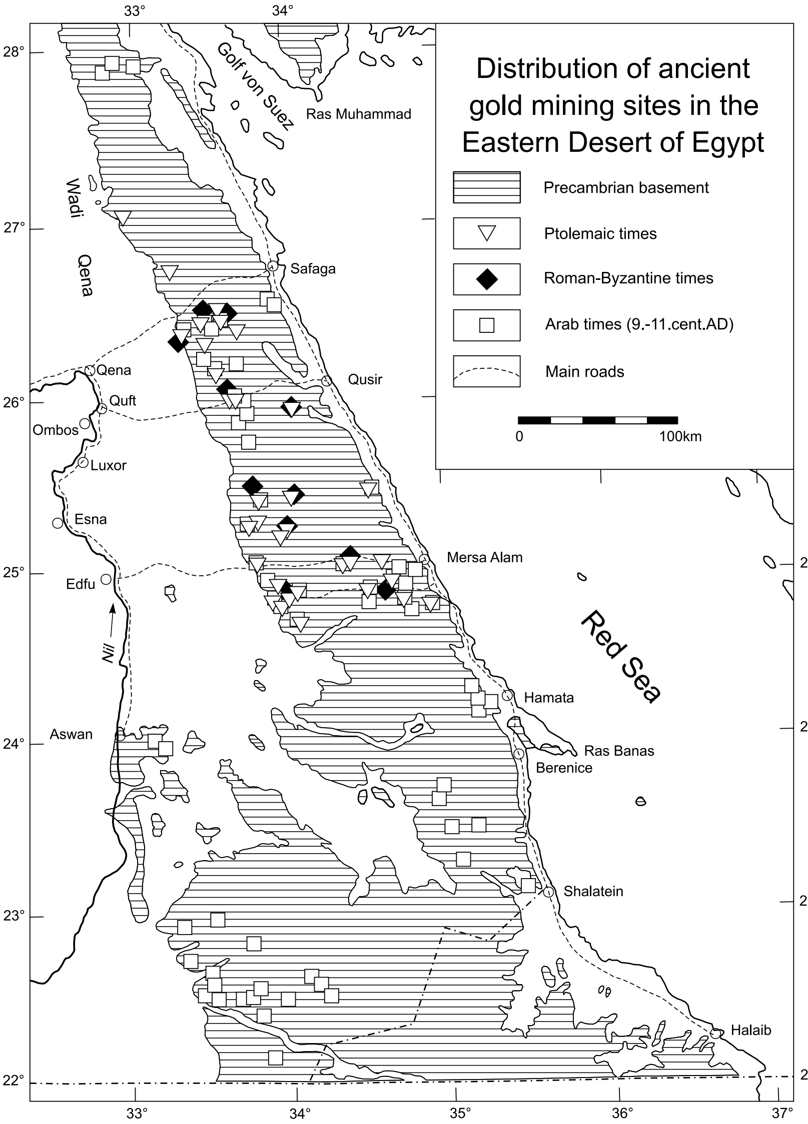

Fig. 16. Distribution of Ptolemaic, Roman–Byzantine and Arab gold production sites in the Eastern Desert of Egypt. Note that only in the central parts of the Eastern Desert during Ptolemaic times gold production activities took place; note further, the sparse Roman–Byzantine sites and widespread distribution of the many Arab sites.

Allaqi area, in contrast to Castiglioni and Vercoutter (1995) did not confirm any Ptolemaic mining site and it is most doubtful whether during that period any gold mining activity was feasible in this area, due to the aggressive desert tribes dominating the entire southern Eastern Desert and reaching deep into what is now NE Sudan (Updegraff, 1982). Most probably the common placing of Agatharchides' "border of Ethiopia" by Egyptologists at the Wadi Allaqi is misleading and the relevant locality must be sought much further towards the north. In fact, the known Ptolemaic gold mining sites cluster mainly within the central Eastern Desert around the more or less west-east running Qena-Safaga, Quft-Qoseir, Edfu-Berenice and Laqeita-Berenice roads, where fortifications guaranteed at least some safety (see Fig. 16).

A dramatic improvement in milling technique and ore processing was introduced by the Ptolemees. They used concave shaped mill stones of 70–80 cm length and 30–40 cm width, with parallel incised, 2 mm deep grooves on the milling plane. Semi-circular two-lugged mill stones of 5–10 kg weight were moved by hand over the grinding plane, milling the pea-sized crushed quartz into a powder fraction and setting free the fine gold slivers (Fig. 17). With this swinging milling method the whole process was about five times more effective than earlier methods. For crushing, the old anvil and pestle system remained, but with an enlarged size of the crusher stone.

Most probably this new design of a concave shaped milling stone is not an original Greek invention but derived from the Minoan island of Crete, where we have discovered this mill type within the ruins of the Minoan

Fig. 17. Concave shaped Ptolemaic gold mill with a two handled mill stone, with a two handled grinding stone, together producing a swinging milling technique and thereby increasing the fineness of the quartz ore powder fraction. Gidami gold mining site, Eastern Desert, Egypt.

Fig. 18. Remains of a circular heavy mineral concentrator from Daghbag gold mine, Eastern Desert, Egypt, introduced during Ptolemaic times into Egyptian gold ore processing, but originally designed in the Laurion district, Attica, Greece.

cities of Gournia and Festos. Obviously, based on the Greek mining experience, Ptolemaic underground mining in Egyptian gold mines became significantly improved. Thus, in gently dipping gold quartz vein workings, dome shaped mine ceilings allowed for the reduction of supporting pillars, to separation distances of 4–6 m, which increased the minable output.

Another important improvement was the adaptation of circular concentration washing plants from the Laurion mining district in Attica, as described in detail by Conophagos (1980, 259 ff). Due to this development it became possible to process also primary gold-bearing sulphidic ores with pyrite, chalcopyrite, galena, sphalerite and arsenopyrite, hitherto not extractable. Remains of such concentration plants (Fig. 18) are well preserved at Daghbag, Bokari and, in spite of recent destruction, also at Barramiya.

The reasons for the reduced Ptolemaic gold mining activities in the Central Eastern Desert of Egypt are not reported in historical documents, but we know from Roman sources that large parts of the Eastern Desert and Nubia were not to be subdued due to the aggressive attitudes of the local nomadic tribes (Sidebotham, 1991), which the Romans called Blemmyes. The Bisharin tribes inhabiting this region today are regarded as their descendants, and still habitually carry swords and daggers.

### *3.5. Gold production during Kushitic times in Nubia*

In Nubia quite a few NK gold mining sites became reworked later, reusing the older tools, especially the stone mills. At these sites one can observe that the typical, rather flat NK oval, trough-shaped stone mills bear a distinct deeper secondary concavity, indicating a different and later type of handling of the milling technique. The most probable age for renewed mining of these sites was during the strong Kushitic Kingdom (about 800–400 BC). Unfortunately, at these sites only local Nubian ceramics, hard to assign to a distinct period, have been found and more detailed excavations are needed to yield a better chronology. The relatively few sites where this reworked mill stone variety, dating to the Kushitic period, was identified, might not have been the only gold source of this time, because according to Ameni's report, washing of gold took place in Nubia at least since Middle Kingdom times.

### *3.6. Gold production in Roman and Byzantine times*

During Roman and Byzantine times, gold production decreased dramatically due to continuous attacks by the desert tribes of the Blemmyes. The Roman presence in the Eastern Desert was restricted exclusively to well-protected desert roads, with fortifications spaced at about a day's walk. It became economically ineffective to protect the many gold mining sites scattered all over the desert. Only a few highly productive sites close to the protected roads remained operable during Roman times. In spite of the highly evolved Roman prospecting experience, the gold mining activities in the Eastern Desert dropped nearly to zero in contrast to other regions of the Roman empire.

The final improvement in the effectiveness of gold processing was the import of the Roman quern technology (Childe, 1943), originally a Celtic invention

Fig. 19. Cylindrical granitic rotation stone mill (quern) with well-preserved upper rotation stones for central and peripheral handle sticks, introduced by the Romans but predominantly used in Arab times. Gabatilo Arab mining camp, Nubian Desert, NE Sudan.

(Cauuet, 1991). This type of a round mill, of 30–45 cm in diameter, consists of a basal stone with a disc-shaped hollow in which a round convex upper turning stone was fitted that had a central axial hole and a lateral one for the handle stick (Fig. 19). The quern produced an even finer powder fraction with an improved gold recovery in about a third of the time required by the earlier method. The crushing stones are of characteristic small size (about 15 × 15 cm) and were used as both hammers and anvils. The same tools remained in use until Arab times and querns are still used today within rural areas as flour mills.

For Byzantine times, only very poor archaeological evidence for gold mining exists. Even for the settlement at Bir Umm el–Fawakhir which was inhabited during Byzantine times, and despite the assumption of Meyer and Heidorn (1998), no unequivocal proof for gold ore dressing could be found by us during an extended survey. The Bedouin tribes, dominating the entire Eastern Desert of Egypt and the Nubian Desert, traditionally were not interested in mining and so they still are today (Fadl Hasan, 1967), refusing any digging in the ground, including even simple agriculture in sufficiently watered wadi grounds.

### *3.7. Gold production in Arab times*

For the early Arab times no field evidence for primary underground gold prospection could be detected and only existing ancient mining sites became reactivated all over the entire Eastern Desert. In contrast, in NE Sudan away from areas close to the River Nile, extensive wadi working operations in secondary gold deposits were started in the Eastern Desert regions at many new sites.

In general, it seems that the mining activities during this period became more concentrated in the southern parts of the Egyptian Eastern Desert including the Wadi Allaqi and especially in the NE Sudan. Within these areas gold mineralization is found predominantly in metasedimentary and acid volcanogenic host rocks intruded by granitoids. The abundant wadi works in secondary gold deposits formed part of huge fortified settlements, and inclined washing tables surrounded by tailings are found. According to Floyer (1893, 157 ff), the peak of the early Arab mining activities took place from the 10th to 11th centuries AD, beginning under A. Ibn Tulun (about 990 AD) until the Fatimitic time in Egypt, and until about 1350 AD in NE Sudan (Fig. 16). The rich and highly specialized ceramic finds at these sites indicate different ethnic populations. But more detailed assignations of them to well-defined historic epochs need further serious investigation.

It is unknown why the Arab gold operations became paralyzed around 1350 AD. Most probably, the productive wadi grounds were worked out and the few underground mines reached their lowermost ventilation levels. Around this time also, the Christian Kingdoms in Nubia collapsed and their population converted to Islam. Whether this religio-political step has any connection to the cessation of gold production in the Nubian Desert must be left for further investigations. Nevertheless, it might be taken into consideration that the conversion to Islam opened to the Arabs the possibility of immigration by systematic intermarriage with the local Nubian population. Their concomitant access to the fertile lands around the Nile valley offered a much better livelihood than the increasingly exhausted gold production sites of the unfavourable Nubian Desert.

## 4. Estimation of the amount of gold produced in Pharaonic Egypt

The wealth of gold in Pharaonic Egypt is legendary, as illustrated when in about 1340 BC a Mesopotamian Mitanni ruler asked Pharaoh Amenhotep III, in an urgent letter, for a larger gold consignment, arguing that “gold occurs in Egypt like sand on the roads”. After our inspections of nearly all of the many known Pharaonic gold production sites in Egypt and NE Sudan all these imaginative expectations must be rejected. During the entire Egyptian history of roughly 6000 years tradition in gold production, less than the monthly gold output of present South Africa was achieved.

The total tonnage of the entire ancient mined trenches and underground operations is of the order of 400 000–600 000 t of quartz ore. Assuming a recovery of 10 g/t, which is about two thirds of the maximum concentration mined, a maximum of 6000 kg Au would have been produced. The production of the wadi works is far more problematic to estimate, but might have been of the same order, or maximally double. This results in a maximum total gold production of 18 t. Roughly 40% of this gold was gained during Pharaonic times, yielding around 7 t Au. The rest is equally distributed between both Ptolemaic and Arab times, neglecting the very low production rates of Predynastic and Roman–Byzantine times.

This estimation, of course, does not correspond with the expectations of archaeologists when projecting the gold inventory of untouched tombs, like the one of Tutankhamun, and inferred from royal dedication lists in temples from the entire Pharaonic history. The only solution to this discrepancy might be seen in intensive recycling of gold more or less constantly throughout the Pharaonic history, but with an increasing tendency from about the 12th century BC on. The famous tomb robbery papyrus (Caminos, 1977) gives an impression of the destitution of justice and of implicit governmental agreement to these robberies, presumably also necessary for the supply of the public gold demand.

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## References

Abdelsalam, M.G., 1993. Structural evolution of the Oko Shear Zone, Sudan. In: Thorweihe, U., Schandelmeier, H. (Eds.), Geoscientific Research in Northeast Africa. A.A. Balkema, Rotterdam/Brookfield, pp. 121–125.

Abdelsalam, M.G., 1994. The Oko Shear Zone: post-accretionary deformations in the Arabian–Nubian shield. J. African Earth Sci. 151, 767–776.

Abdelsalam, M.G., Stern, R.J., 1996. Sutures and shear zones in the Arabian–Nubian shield. J. African Earth Sci. 23/3, 289–310.

Bakhiet, A.K., Matheis, G., 1993. Gold productive volcanogenic sulphide mineralization in the Ariab Belt, Red Sea Hills/Sudan: evidences for late proterozoic seafloor hydrothermal systems. In: Thorweihe, U., Schandelmeier, H. (Eds.), Geoscientific Research in Northeast Africa. A.A. Balkema, Rotterdam/Brookfield, pp. 533–540.

Ballet, P., 1987. Essai de classification de coupes Type Maidum-Bowl. Cahiers de la ceramique Egyptienne, tome 1, Le Caire, 1–16.

Bertrand, J.M.L., Caby, R., 1978. Geodynamic evolution of the Pan-African orogenic belt; a new interpretation of the Hoggar shield (Algerian Sahara). Geol. Rundsch. 67 (2), 357–388.

Bowers, T.S., Helgeson, H.C., 1983. Calculation of the thermodynamic and geochemical consequences of non ideal mixing in the system $H_2O$–$CO_2$–NaCl on phase relations in geologic systems: equation of state for $H_2O$–$CO_2$–NaCl fluids at high pressures and temperatures. Geochim. Cosmochim. Acta 47 (7), 1247–1275.

Caminos, R.A., 1977. Grabräuberprozess, Lex. Ägyptol., Bd. 2, 862–866.

Castel, G., Mathieu, B., 1992. Les mines de cuivre du Wadi Dara. In: BIFAO, vol. 92, pp. 51–65.

Castiglioni, A., Vercoutter, J., 1995. Das Goldland der Pharaonen. Mainz.

Cauuet, B., 1991. L'exploitation de l'or en Limousin des Gaulois aux Gallo-Romains. In: Annales du Midi, Toulouse, t. 103(194), pp. 149–181.

Childe, V.G., 1943. Rotary querns on the Continent and the Mediterranian basin. Antiquity 17, 19–26, London.

Conophagos, C., 1980. Le Laurium Antique et la technique Greque de la production de l'argent. Athens.

El Gaby, S., List, F.K., Tehrani, R., 1988. Geology, evolution and metallogenesis of the Pan African Belt in Egypt. In: El-Gaby, S., Greiling, R.O. (Eds.), The Pan African Belt of Northeast Africa and Adjacent Areas. Vieweg, Braunschweig, pp. 17–63.

Fadl Hasan, Y., 1967. In: The Arabs and the Sudan. University Press, Edinburgh, 298 pp.

Fleck, R.J., Greenwood, W.R., Hadley, D.G., Anderson, R.E., Schmidt, D.L., 1980. Rubidium–strontium geochronology and plate-tectonic evolution of the southern part of the Arabian shield. US Geol. Surv. Prof. Paper 1131, 38 pp.

Floyer, E.A., 1893. Étude sur le Nord-Etbai entre le Nil et le Mer Rouge, Le Caire.

Fritz, H., Wallbrecher, E., Khudeir, A.A., Abu El Ela, F., Dallmeyer, D.R., 1996. Formation of neoproterozoic metamorphic core complexes during oblique convergence (Eastern Desert Egypt). J. African Earth Sci. 23/3, 311–329.

Hassan, M.A., Hashad, A.H., 1990. Precambrian of Egypt. In: Said, R. (Ed.), The Geology of Egypt. A.A. Balkema, Rotterdam/Brookfield, pp. 201–245.

Hölscher, U., 1957. University of Chicago Orient. Inst. Publ., vol. 83: Medinet Habu, vol. 5, The Temple proper Part I: pl. 328. Chicago.

Jackson, N.J., Ramsay, C.R., 1980. Time-space relationships of upper Precambrian volcanic and sedimentary units in the central Arabian shield. J. Geol. Soc., London 137 (5), 617–628.

Klemm, R., 1995. Umm Eleiga Ein prädynastischer Goldfundplatz in der Ostwüste Ägyptens. Münchener Ägyptol. Unters. 4, 247–260, Peter Lang Verlag, Frankfurt.

Klemm, R., Klemm, D., 1994. Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens. Mitt. Deutsch. Archäolog. Inst. Kairo Band 50, 189–222.

Kretschmar, U., Scott, S.D., 1976. Phase relations involving arsenopyrite in the system Fe–As–S and their application. Can. Mineral. 14 (3), 364–368.

Kröner, A., 1979. Pan-African plate tectonics and its repercussions on the crust of north-east Africa. Geol. Rundsch. 68, 565–583.

Kröner, A., 1985. Ophiolites and the evolution of tectonic boundaries in the late Proterozoic Arabian–Nubian shield of Northeast Africa and Arabia. Precamb. Res. 27 (1-3), 277–300.

Kröner, A., Todt, W., Hussein, I.M., Mansour, M., Rashwan, A.A., 1992. Dating of late proterozoic ophiolithes in Egypt and Sudan using the single grain zircon evaporation technique. Precamb. Res. 59 (1–2), 15–32.

Kröner, A., Krüger, J., Rashwan, A.A.A., 1994. Age and tectonic setting of granitoid gneisses in the eastern desert of Egypt and south-west Sinai. Geol. Rundsch. 83 (3), 502–513.

Kroeper, K., Wildung D., 1994. Minshat Abu Omar I, Mainz, p. 162 with pl. 44.

Langwieder, G., 1994. Die Geologie des Gebietes Wadi El-Sid/Um el Fawakhir und Geochemische Untersuchungen an Quarzgängen des Goldlagerstättenbezirkes El Sid/Fawakhir. Unpublished M.Sc. Thesis, Ludwig-Maximilians-Universität München, 122 p.

Meyer, C., Heidorn, L., 1998. Three seasons at Bir Umm Fawakhir in the Central Eastern Desert. In: Kaper, O.E. (Ed.), Life on the Fringe. Research School CNWS, Leiden, pp. 197–209.

Murr, A., 1999. Die Genese der Goldlagerstättenbezirke Fatira, Gidami Atalla und Hangaliya in der Ägyptischen Ostwüste. Münchner Geol. Hefte A 27, 202.

Murray, G.W., 1925. The Roman roads and stations in the Eastern Desert of Egypt. JEA 11, 138–150.

Newberry, P.E., 1893. Beni Hassan I. Arch. Surv. Egypt (ASE) 1, pl. 8. London.

Roubet, C., 1989. The grinding stones of site E-78-3 Wadi Kubbaniye. In: Wendorf, F. (Ed.), The Prehistory of Wadi Kubbaniye, vol. III. Southern Methodist University Press, Dallas, pp. 473–489.

Schweinfurth, G., 1904. Die Wiederaufnahme des alten Goldminen-Betriebs in Ägypten und Nubien. Ann. Service Antiquit. Egypt 4, 268–280.

Sidebotham, S.E., 1991. Römische Straßen in der Ägyptischen Wüste. In: Antike Welt 22.Jg, 3, pp. 177–189.

Stern, R.J., 1994. Arc assembly and continental collision in the Neoproterozoic east African Orogen: implication for the consolidation of Gondwanaland. Ann. Rev. Earth Planet. Sci. 22, 319–351.

Stern, R.J., Hedge, C.E., 1985. Geochronologic and isotopic constraints on late Precambrian crustal evolution in the Eastern Desert of Egypt. Am. J. Sci. 285 (2), 97–127.

Stern, R.J., Sellers, G., Gottfried, D., 1988. Bimodal dike swarms in the North Eastern Desert of Egypt: significance for the origin of late Precambrian A-type granites in Northern Afro-Arabia. In: El-Gaby, S., Greiling, R.O. (Eds.), The Pan African Belt of Northeast Africa and Adjacent Areas. Vieweg, Braunschweig, pp. 147–179.

Stoeser, D.B., Stacey, J.S., 1988. Evolution, U-Pb geochronology and isotope geology of the Pan-African Nabitah orogenic belt of the Saudi Arabian shield. In: El-Gaby, S., Greiling, R.O. (Eds.), The Pan African Belt of Northeast Africa and Adjacent Areas. Vieweg, Braunschweig, pp. 17–63.

Sverjensky, D.A., Hemley, J.J., D'Angelo, W.M., 1991. Thermodynamic assessment of hydrothermal alkali feldspar–mica–alumosilicate equilibria. Geochim. Cosmochim. Acta 55 (4), 989–1004.

Updegraff, R.T., 1982. A Study of the Blemmyes. Ann Arbor, MI (Diss. 1978).

Vail, J.R., 1988. Tectonics and evolution of the Proterozoic basement of northeastern Africa. In: El-Gaby, S., Greiling, R.O. (Eds.), The Pan African Belt of Northeast Africa and Adjacent Areas. Vieweg, Braunschweig, pp. 195–226.

Vercoutter, J., 1959. The gold of Kush. Kush 7, 120–153.

Winkler, H.A., 1938. Rock drawings of Southern Upper Egypt II, London, pl. LVII.

Wipfler, E., Abdel Rahman, E.M., Schandelmeier, H., Matheis, G., 1999. Regionalgeologische Aspekte und geotektonische Kontrolle ophiolith-assozierter Lagerstätten im nordost-sudanesischen Teilbereich des Arabisch–Nubischen Schildes. In: Klitzsch, E., Thorweihe, U. (Eds.), DFG Nordost-Afrika: Strukturen und Ressourcen. Wiley, New York, pp. 306–365.

Woelk, D., 1966. Agatharchides von Knidos. Über das Rote Meer. Übers. u. Kommentar Bamberg.

Zhang, X., Spry, P.G., 1994. Calculated stability of aqueous tellurium species, calaverit and hessite at elevated temperatures. Econ. Geol. 89 (5), 1152–1166.