

• *Northeast Africa – Geology – Groundwater – Paleoclimate*

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From Bardai to SFB 69: The Tibesti Research Station and Later Geoscientific Research in Northeast Africa

Von Bardai zum SFB 69: Die Forschungsstation im Tibesti und die nachfolgende geowissenschaftliche Forschung in Nordost-Afrika

With 2 Figures and 7 Photos

Joint geoscientific research in the central and eastern regions of the Sahara started in 1969, originating from research at the Bardai Research station (FU Berlin) as well as from fieldwork by DEA/Wintershall oil geologists operating in Libya, northern Chad and Niger. It ended at the close of the 1970s, on the one hand due to the fact that fieldwork in the Tibesti region became the victim of civil war in Chad, and on the other hand because DEA was bought up by Texaco. However, work was resumed and continued on a large scale from 1981 to 1995 as a special research project, or *Sonderforschungsbereich*, in Egypt and Sudan, which was sponsored by the German Research Foundation, DFG. One-and-a-half decades of comprehensive geoscientific research in Northeast Africa and parts of East Africa resulted in the reconstruction of the geological history, groundwater situation and climate changes during Holocene times. Aside from its general scientific value, this work is of prime importance in the search for solutions to fundamental problems of groundwater use in arid and semiarid areas, as well as for questions related to climate change.

1. Early Contacts in Tripoli

The research station in Bardai, set up in 1964, must be seen as an institution that influenced geoscientific research far beyond what was originally intended. The few years of its active existence produced a number of enthusiastic young scientists with adequate desert experience who later became active members or leaders of other projects in the Sahara and Sahel areas. Bardai therefore became an important contribution to German research in Africa. The purpose of this

article is neither to discuss the background, origin or initial results of the Bardai project in any detail, nor the reasons for its much-too-early end (for details on the Bardai project, see *Jükel* 1974, *Gabriel* 1990). Initiated by *Jürgen Hövermann*, the Bardai project was certainly influenced by *Wolfgang Meckelein's* earlier research (1959) in south-central Libya, with its encouraging and also partly provocative results. Both *Meckelein* and *Hövermann* were interested in questions such as the influence of climate on geomorphology. *Meckelein's* view was rather conservative: He coined the term

“core desert”, or “*Kernwüste*”, stable and almost unchanged during Quaternary times. *Hövermann* (1963, 1972) was convinced of Holocene climate changes, and he proved their influence on the Saharan relief. He chose the Tibesti Mountains because of their elevation, with their volcanoes reaching heights of more than 3000 m asl, as well as their climatic zonation surrounded by a cuesta-type landscape and large, open plains. This promised to be an ideal arrangement for studying the impact of climate and climate change on relief.

There was one critical problem, however: the time factor. It was *Hans-Joachim Pachur* who focused his work on this question. He was less interested in studies of relief and vegetation, and after adjusting to the difficulties of desert work, he concentrated on studying drainage systems leading out of the Tibesti Mountains, which transported eroded material and deposited it on the vast plains of southern and central Libya, including *Meckelein*'s “*Kernwüste*”. To reconstruct climatic history, *Pachur* had an important key in stratigraphic sections of river and especially lake deposits that allowed ^{14}C dating of different levels, including the palaeoclimatic characteristics of the sedimentation phases. This was the beginning of one line of scientific work with an important practical application: the history of groundwater recharge and its meaning for present and future generations. Other aspects were brought in by scientists who were originally unconnected with the Bardai project. One of these was *Christian Sonntag* from Heidelberg University who, several years later, was able to assess the age of the groundwater and the origin of rain frontiers in the past. The geological background, also important in questions related to groundwater, was investigated by geologists from a German oil group: Since the winter of 1958–59, *Manfred Fürst* and *Eberhard Klitzsch*, working for DEA/Wintershall, explored large areas in western and southern Libya, northern Chad and northern Niger in order to reconstruct the development of geological basins in the area,

which had been poorly researched previously. Scientific by-products of this research included the first modern publication on the geology of Libya (*Hecht et al.* 1963) and, some years later, a general interpretation of the geotectonic evolution of the central Sahara (*Klitzsch* 1970).

Interest in palaeoclimatic questions arose mainly from the fact that the availability of large amounts of groundwater, partly near the surface, and the presence of lakes stood in contrast to the full aridity of the area.

Our discovery of many earlier human dwelling sites in presently unpopulated areas, often in connection with rock carvings, also indicated that climate must have changed drastically during the Holocene. As early as 1962, we therefore introduced *Helmut Ziegert* (1967, 1969) to areas in Fezzan (Dor el Gussa and Djebel Ben Ghnema); he became a temporary member of the Bardai team in Tibesti in 1965–66. In 1962, we had our first contact with *Rudolph Kuper*, who is still very active and successful in the eastern Sahara with his research on the prehistory of the region (*Lenssen-Erz et al.* 2002).

During several years, supplies and crew changes for the Bardai research station were organised to and from Tripoli. The DEA/Wintershall office and guesthouse there helped with accommodation and other arrangements, and they were places where lasting scientific contacts began. In addition, the office acted as a kind of bank in order to guarantee payments for supplies and other obligations in Libya. To give an accurate impression of how honestly Libyan contractors conducted themselves, the following incident can be regarded as typical: One day in 1965 or 1966, a contractor from Sebha in Fezzan came to our office and presented a sample bag carrying a note signed by a member of the Bardai team that stated that the bearer of the bag was entitled to 500 Libyan pounds. We paid him, and he went back to Sebha. More than a month earlier, this man had been

guaranteed later payment when he was called by the team to pick up the load of a Unimog that had broken down some 100 km south of Sebha. He did so, took the load through open desert approximately 1000 km to Bardai, returned to the Unimog, put it on his truck, went almost 1000 km north to Tripoli to deliver the Unimog to a Mercedes garage and came to us to collect his payment, showing a handwritten bill on a piece of cotton! Apart from handling these types of duties and hosting returning or leaving teams, we supplied the first group approaching Bardai with a 10-page route description. It was based on five seasons of fieldwork in Fezzan and northern Chad and first visits to Bardai and Aozou in 1961 and 1962 (*Klitzsch* 1965). It dates from November 24, 1964. We thought it useful to have realistic information about irritating road signs (most of them from times of war), mined areas and difficult dune fields. Large parts of the open desert track were up to 30 km wide and marked by occasional car wrecks, most of them French vehicles from *Leclerc's* troops. *Leclerc* had gone all the way from Fort Lamy (Ndjamena) to Fezzan in 1942. In 1966, the Petroleum Exploration Society of Libya, an organisation formed by about 800 geoscientists working in Libya at the time, undertook a fieldtrip to eastern Fezzan, Uau en Namous and Tibesti with 60 geologists. The Bardai station hosted this large group, and its team took the guests to Trou au Natron on various days as well as to geological and prehistoric sites in the vicinity of Bardai. The guidebook produced for these excursions includes articles from members of the Bardai team as well as from geologists working from Tripoli (*Williams* and *Klitzsch* 1966). During crew changes in Tripoli, it became common for members of the Bardai team to give lectures at the monthly meetings of the Petroleum Exploration Society in Tripoli.

Thus Bardai became a well-known place of research within the very large international community of geoscientists in Libya. Its active research in areas even more remote than those to which

most field geologists in Tripoli or in camps in the desert had access to was highly appreciated and admired, especially since this research seemed to be purely academic. Many occasions to meet and discuss problems of scientific or practical interest became roots for cooperation. *Pachur* and several others were helped by American oil companies to overcome technical problems with their vehicles in the Libyan desert. Much later, in Egypt, the same companies gave practical assistance in several instances, officially sponsoring cartographic and remote sensing work that allowed us to topographically and geologically map all of Egypt.

In the late 1960s, the Bardai station was gradually affected by the civil war in Chad. At the same time, DEA was bought up by Texaco, and *Klitzsch* got a new position at TU Berlin. Experienced geoscientists from the Bardai project (FU Berlin) and from former DEA/Wintershall, who had already been in close contacts during Bardai station times, now met again in Berlin. It was only logical at this point to develop ideas for joint research in arid Africa.

2. First Attempts at Joint Research

As early as 1969, while funds for the Bardai project were still available, *Horst Hagedorn* (FU) and *Klitzsch* (now TU), together with *Heinrich Kallenbach* (TU), undertook fieldwork along the Djebel Messak in the western part of the inner escarpments of the Murzuk Basin. For *Hagedorn*, it was an ideal area in which to study geomorphological features and to look for interesting alternatives to research in Tibesti. *Kallenbach* and *Klitzsch* were interested in subdividing the continental upper part of the Murzuk Basin sediments. This was important for later hydrological studies, because these strata host groundwater reservoirs over large parts of Libya. During the following years, the Bardai funds allowed us to take groundwater samples from many locations in southern Libya, and we were able to get *Sonn-tag* to identify groundwater ages. Meanwhile,

Pachur (1974) continued to prove the existence of large palaeorivers across southern and central Libya. In 1970, *Hövermann* and *Hagedorn* invited *Klitzsch* to participate in a research mission from Algiers, through Hoggar and Air, to Zinder and Niamey in Niger, from there to Gao in Mali, and then back to the Algerien coast, passing Adrar des Iforas, Regane and the Atlas Mountains towards Oran. *Hövermann* and *Hagedorn* were interested in verifying (or falsifying) their ideas on climate change and its evidence in the relief of the western and southern Sahara. They were also looking for areas that would offer useful hints for future research. *Hagedorn* later formed a research group that successfully concentrated on areas in the southern Sahara (*Gabriel* 1990).

Klitzsch's major objectives were the study of the generally more marine character of strata in the western Sahara as well as questions related to groundwater. His observations later became the basis for an expedition by *Ulf Thorweihe* (TU Berlin) along the same route, during which water samples were systematically collected for *Sonntag*'s dating and stable isotope analyses. Again, the Bardai fund was able to help in an important situation, when a first step towards falsifying *R.P. Ambroggi*'s disastrous and misleading theory (1966) – published in the distinguished Scientific American – could be achieved. *Ambroggi* claimed the groundwater in Saharan basins to be in equilibrium and to be continuously recharged from areas of high rainfall to the south. This was a *carte blanche* for politicians and engineers in Libya and Egypt to exploit groundwater from the large sedimentary basins unrestricted. In contrast, as the Bardai research group, we were convinced that the Saharan groundwater had been recharged only during humid periods in Holocene times or earlier, and that it was fossil and nonrenewable. In this situation, the connection between geological knowledge from fieldwork and a close professional relationship to oil exploration and its results in terms of basin analysis became important for research on hydrogeological questions.

Paleoclimatic research, carried out by part of the Bardai team – namely *Pachur*, and also for some time *Peter Ergenzinger*, *Baldur Gabriel*, and *Ziegert*, as well as, until late 1995, *Sonntag* from Heidelberg – was of similar value.

In the early 70s, however, research in Libya became more and more difficult, and the funds of the Bardai project no longer allowed financing large new projects to continue research already under way. At this stage, only smaller projects could be undertaken. It had already become obvious during the second half of the 1960s that oil companies encouraged the Libyan government to exploit fossil groundwater on a very large scale in some areas. The American oil company Occidental offered and later financed groundwater development for agricultural use in the Kufra area. This project was followed by the so-called "Great Man-Made River" project, which today connects the northern Kufra Basin and the northern Murzuk Basin with the Mediterranean coast near Adjedabia and Tripoli using two large pipeline systems. *Ambroggi*'s publication of 1966 (mentioned earlier) certainly influenced this course of events. A similar situation arose in Egypt. In contrast to Libya, there was little geological knowledge about the size and sediment content of the basin already under hydrogeological exploitation. Groundwater was known to be at or near the surface along a chain of oases between Baris, Kharga, Dachla, Farafra and Baharia, more or less parallel to the Nile valley. This area was called New Valley, and it was here that drilling began. Asking how this groundwater would be recharged, we were answered by a hydrological engineer: through large fault systems from Mount Cameroon. Others thought that, as in Libya, the groundwater was fed from areas further south with higher rainfall, such as Tibesti, Ennedi and Ethiopia, or from the Nile. Only engineers and geologists from the national oil company were more professional and open to hearing doubts and having serious discussions. They later became our partners in Egypt.

3. Contacts between Deutsche Forschungsgemeinschaft and the Academy of Science in Cairo, and their results

A new phase set in when *Deutsche Forschungsgemeinschaft (DFG)* was invited to visit the Academy of Science in Cairo in 1976. Among other matters, the Egyptian side was concerned with asking for cooperation in studying the large sedimentary basin of western Egypt and its hydrogeological situation. *Klitzsch* was a member of the DFG delegation and immediately formed a group of scientists interested in the problem and determined to research it. After this very helpful Egyptian introduction, DFG could not possibly escape from sponsoring fieldwork in Egypt. From the very beginning, we included northern Sudan in our proposal for obvious hydrogeological reasons. DFG accepted, and by the end of 1976, a period of fieldwork in western Egypt and northern Sudan began with individual but well-coordinated projects.

Pachur carried his paleoclimatic investigations to Egypt and Sudan; *Franz K. List*, *Bernd Meissner*, and *Gerhard Pöhlmann* – all former members of the Bardai group – were in charge of remote sensing and cartography, including related fieldwork; and basin analysis including basement geology and hydrogeology were commissioned to *Karl-Werner Barthel*, *Kallenbach*, *Klitzsch* (all TU Berlin), and *Sonntag*. The teams were backed by young scientists paid from the DFG fund. In addition, scientists for remote sensing and cartography work were sponsored by CONOCO under *Coy H. Squyres*. They, for PR reasons, were interested in producing a geological map of Egypt. Our Egyptian partners were geologists connected to the Academy of Science. Our work was very successful, and so, in 1978, the DFG's "Geokommission" proposed a "Sonderforschungsbereich", or large research project, to continue work on these issues – the most formidable form of science funding in Germany. It was to include funds for internal infrastructure and an obligation for the universities to back projects with adequate laboratories and

equipment; it was to be conducted for a maximum duration of 15 years with prolongation – after assessments – every three years. After this important step forward, however, a dangerous incident delayed the proposal's progress.

4. The Djebel Kissu Incident

Early in 1980, nine members of two research teams were taken prisoner at Djebel Kissu in northwestern Sudan, 25 km east of the Libyan border, and brought to Libya by Libyan militia. They were accused of having crossed the Libyan border illegally. As a matter of fact, at that time Libya concentrated troops on its side of the border in order to invade Chad, which in fact took place only a short time later. In order to remain safe and unobserved, Libyan troops also controlled bordering areas in Egypt and Sudan. One group, comprised of geologists *Heinz Schandelmeier* (TU) and *Axel Richter* (FU) as well as two Egyptian truck drivers, had been working east of Djebel Kissu in Precambrian strata, while the other, including *Pachur*, *Meissner*, *Hans-Werner Linke* (FU) and *Thorweihe* (TU) as well as a geologist from our Sudanese partner (*El Shafie*), were returning from a paleoclimatic and hydrogeological mission to Wadi Howar in Sudan to pick up fuel and water. It took a great deal of time and energy to convince our government that our teams had not touched Libyan territory. After almost half a year of imprisonment and isolation near Tripoli, our teams were allowed to return to Germany along with their African members, as it was very important for us not to leave them behind due to the extremely bad relations that Egypt and Sudan had with Libya at the time.

5. SFB 69: The Special Research Project "Geoscientific Problems of Arid and Semiarid Areas"

Despite this unfortunate and irritating incident, DFG accepted our proposal for the large and ex-

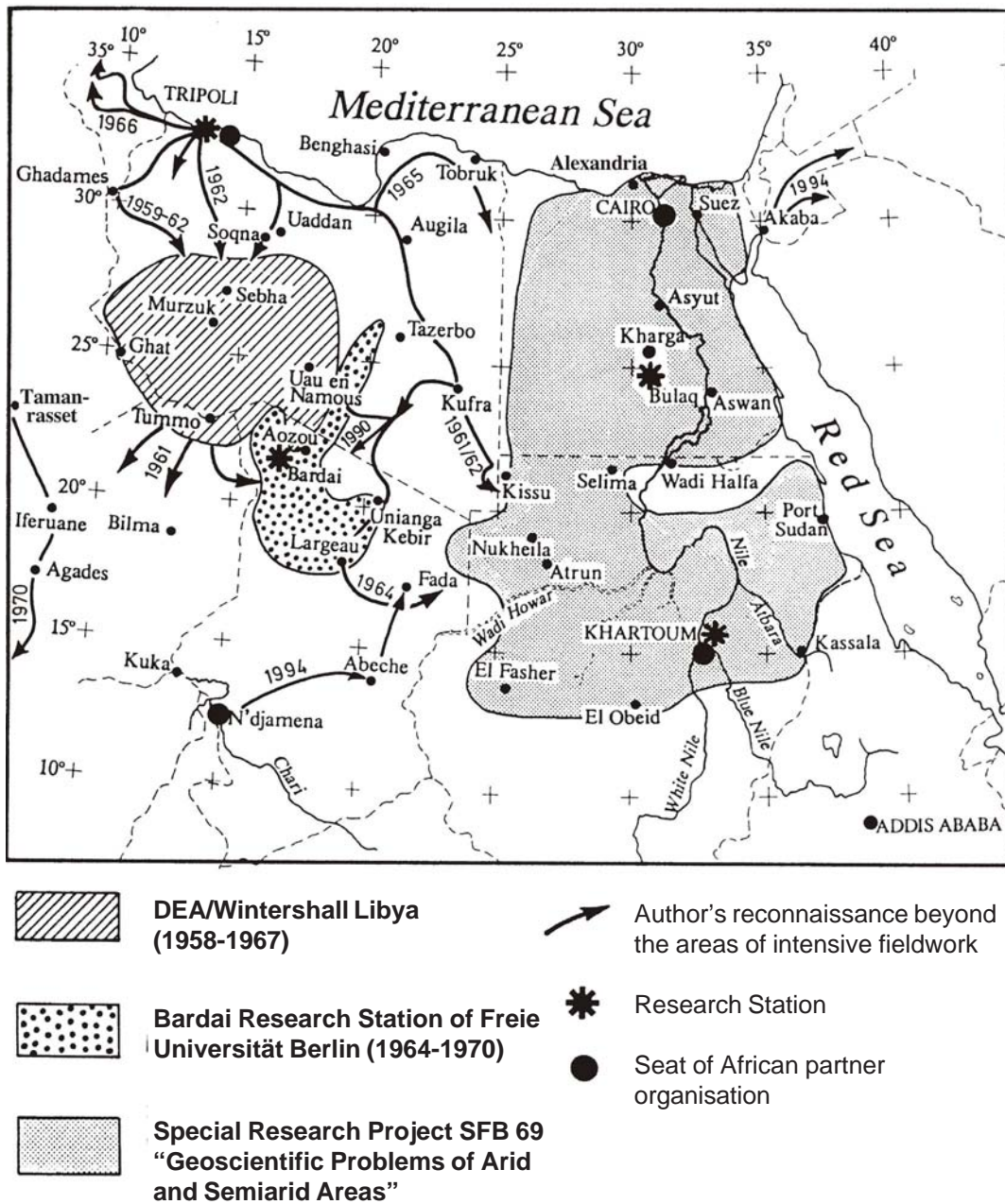


Fig. 1 Areas of intensive fieldwork in the eastern Sahara, 1958-95, from the bases at Tripoli, Bardai, Bulaq and Khartoum (after Klitzsch 1994, completed) / von Tripoli, Bardai, Bulaq und Khartoum aus in den Jahren 1958-1995 bearbeitete Gebiete der Ostsahara (nach Klitzsch 1994, vervollständigt)

pensive project mentioned earlier. SFB 69 started in 1981 and lasted the maximum time allowed until the end of 1995. Due to the Djebel Kissu incident, we were obliged to stay away from the Libyan border by at least 100 km; nevertheless, in 1984, 100 km from the border, one of our field vehicles hit an anti-personal mine from a minefield laid out by the Egyptian army in Wadi Wasa (Gilf Kebir) a short time before, despite the fact that we had an Egyptian permit to work in

the area. Fortunately, nobody was injured, and we just had to change a wheel.

The large number of Berlin geoscientists with experience in remote desert areas made possible a comprehensive reconstruction of the geological situation, climatic history and groundwater situation, including groundwater change as it corresponded to climate change as well as the interaction between all these different aspects. DFG al-



Photo 1 Darb el Arbain, "The Trek of 40 days": An old caravan trek connecting Darfur in Sudan with Kufra in Libya and Assiut in Egypt. The surface is covered by very hard rocks from Permo-Triassic age, representing a continental basin in northern Sudan and southern Libya formed after the collision of the African plate with northern continents towards the end of Carboniferous time. Most of the sediments from this basin have low permeability and thus restrict northward groundwater flow. / *Darb el Arbain, der „40-Tage-Trek“: ein alter Karawanenweg, der Darfur im Sudan mit Kufra in Libyen und Assiut in Ägypten verbindet. An der Oberfläche sehr hartes Gestein permo-triassischen Alters, entstanden in einem kontinentalen Becken in Nord-Sudan und Süd-Libyen, das nach der Kollision der Afrikanischen Platte mit nördlichen Kontinenten zum Ende des Karbons gebildet wurde. Die meisten Sedimente dieses Beckens haben geringe Wasserdurchlässigkeit und behindern deshalb den Grundwasserstrom nach Norden.*

lowed us to include specialists from research teams outside of Berlin as necessary.

The region chosen was the eastern Sahara, because hydrogeological problems were evident there, the geology was largely unexplored and the area seemed to be ideal for paleoclimatic studies due to its vicinity to the Nile and the Ethiopian highlands, the Ennedi Mountains and Tibesti (*Fig. 1*). In addition, we had done research in this area before and had been welcomed by local partners. In order to understand the influence of global structural events such as the opening of the Indian Ocean on the formation of the basins in the eastern Sahara, we included Somalia in the project for some time.

Primarily with the assistance of DAAD, we were able to integrate more than 30 young African scientists, which partly allowed us to pursue research in other countries: Kenya, Tanzania, Ethiopia and Chad. As partners in Egypt and Sudan, we chose institutions with both professional competence and administrative power. Our partner in Sudan was the former Geological Survey (now the Geological Research Authority of Sudan) and in Egypt the General Petroleum Company. This state company was not only active in oil exploration but was also responsible for groundwater exploration in Egypt's western desert at the time. The Egyptian Academy of Science, our partner in previous projects, turned out to be much too complicated for such a large project and had too little administrative influence to be of help in the large number of anticipated customs, transport and permit-related problems. Local universities were included by separate agreements, and they were helpful in supplying us with capable PhD candidates.

German participants and project leaders came from the groups that had already been involved in Bardai (since 1964), in Libya (since 1959) and in the preliminary projects in Egypt and Sudan (since 1976). Colleagues from the former Bardai

group (*List*, FU Berlin, *Meissner* and *Pöhlmann*, TFH Berlin) again shouldered a major portion of the remote sensing and cartography work as well as research in paleoclimatology and related fields (*Pachur*, *Gabriel*, FU Berlin). In addition, *Ergenzinger* (FU Berlin) was involved in near-surface hydrological problems. Basin analysis, which included structural and basement geology, palaeontology, hydrogeology, groundwater modelling, geophysics, pedology, mineral deposits and a number of integrating subjects, was essentially taken over by colleagues from Berlin's Technical University. The TU Berlin also acted as the leading institution responsible for organisation, logistics and contracts.

Each season – usually from September to April – 80 to 140 researchers were sent on fieldwork to the study area and had to be supplied with travel arrangements, visas, desert permits, food and spare parts for vehicles and other equipment. Moreover, good regular contact to the official partners was important, especially because of customs problems, as well as the scientific and logistic integration of local scientists.

The final publication of the project includes a chapter on the organisation of the project, the subprojects, their leaders, all scientists involved, the PhD theses born out of the project (approx. 110, 33 from African candidates), habilitations (12) and guest scientists (around 160 from 30 countries) as well as the international and local conferences (*Klitzsch* and *Thorweihe* 1999: 647-676).

At the end of the project, the feedback from our foreign partners and DFG was so positive that DFG organised and financed a large exhibition that was shown in six towns in Germany in 1995 and 1996. Afterward, English and French versions were produced and toured 22 towns in Africa, the Near East and India between 1997 and 2003, accompanied by lectures and high-ranking official events.

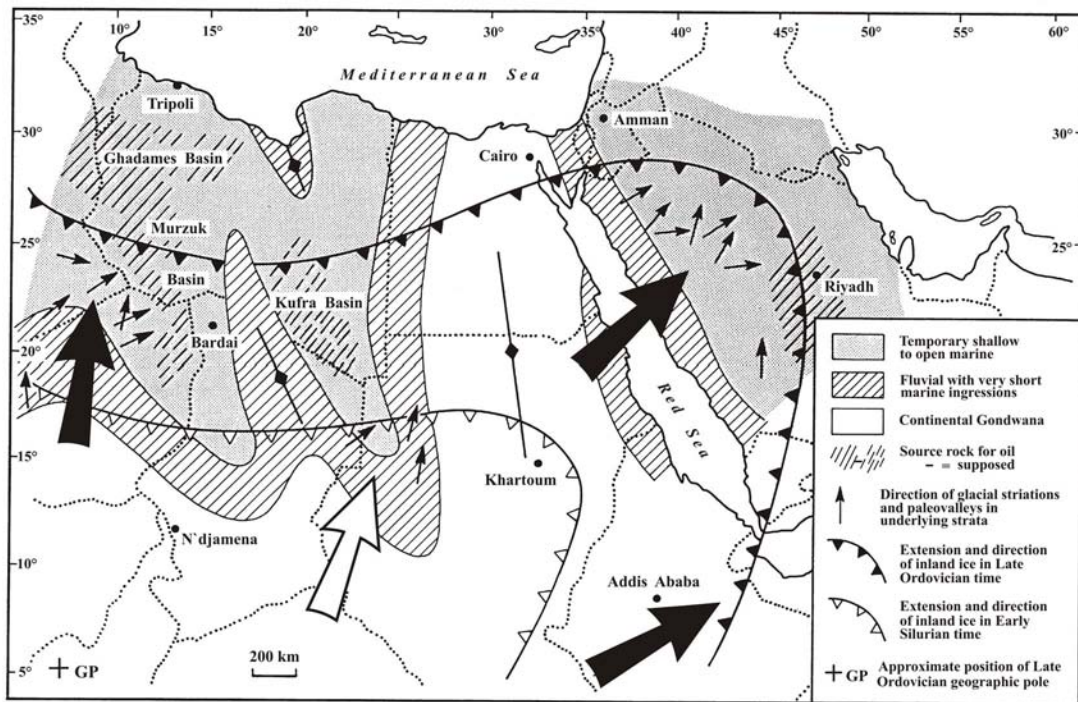


Fig. 2 Paleogeography of the eastern Sahara in late Ordovician and early Silurian time: extension of inland ice, transgressions and formation of source rock for hydrocarbons (after *Semtner and Klitzsch 1994*, modified) / *Paläogeographie der Ostsahara im späten Ordovizium und frühen Silur: Ausdehnung des Inlandeises, Transgressionen und Bildung von Muttergestein für Öl- und Gaslagerstätten (nach Semtner und Klitzsch 1994, verändert)*

6. Major Results of Research in Northeast Africa between 1969 and 1995

The geology of the eastern Sahara was reconstructed, including the history and the sedimentological character of Paleozoic to Neozoic basins and their Precambrian basement. Structural and paleogeographical changes were identified and related to global events. The results were presented in a great number of publications and PhD theses and illustrated in a paleogeographic-paleotectonic atlas of Northeast Africa and Arabia (*Schandelmeier and Reynolds 1997*). Periods of glaciation were identified as well as their sediments of the late Ordovician, early Silurian and late Carboniferous ages (*Fig. 2*). Reconstruction of the climatic develop-

ment in late Pleistocene and Holocene times was mainly based on paleolakes, paleodrainage, prehistoric settlements, and ^{14}C dating. Apart from its general scientific value, this project was of principal importance in the assessment of the general decline of groundwater in the groundwater model of the Nubian aquifer system during late Holocene times. It was also connected to research by *Kuper* (Cologne) and *Stefan Kröpelin* (Berlin/Cologne) on the history of man in the eastern Sahara (*Kröpelin 1997, Pachur 1999*). An interesting article on our knowledge of the Libyan desert in the younger Quaternary was published by *Gabriel* in 1986.

The first groundwater model of an interconnected basin system in Africa was constructed. It cov-



Photo 2 The lake of Nukheile (Merj) in northwestern Sudan, stopping point for caravans along Darb el Arbain. The lake represents fossil groundwater exposed to the surface and fed through highly permeable sandstone from the Silurian age. The groundwater is more than 5000 years old. The lake is very saline because of an extremely high rate of evaporation. Dug wells in its vicinity contain good fresh water with very low salinity. / *Der See von Nukheile (Merj) im nordwestlichen Sudan, Haltepunkt für Karawanen auf dem Darb el Arbain. Im See tritt fossiles Grundwasser aus stark durchlässigem silurischen Sandstein an die Oberfläche. Das Grundwasser ist über 5000 Jahre alt. Die Salinität des Sees ist wegen der starken Evaporation sehr hoch. Brunnen, die in der Umgebung gegraben worden sind, enthalten gutes Trinkwasser mit sehr geringem Salzgehalt.*

ers the so-called Nubian aquifer system of southeastern Libya, western Egypt, northwestern Sudan and northeastern Chad. The description of the Libyan part of this system was based on Klitzsch's fieldwork of 1961-1963 and on hydrological data from groundwater studies by German consultants in the years 1972-1975. All other data resulted from fieldwork as part of SFB 69 and from drilling tests for groundwater and the oil exploration of our Egyptian partner, who also drilled in northern Sudan with Sudanese permission. In addition, our geological and hydrogeological fieldwork was supplemented by geophysical investigations.

The results present the pattern of the groundwater table during the last 12,000 to 10,000 years, the directions and speed of groundwater flow and the approximate amount of groundwater reserves at present (Heinl and Brinkmann 1989, Thorweihle 1997). Sonntag (1982) identified the age of the groundwater and its local recharge at different times during the Holocene through rain frontiers originating from the Atlantic (northern Sahara) and from monsoonal frontiers (southern Sahara). Sub-projects of a more local character carried out investigations in the vicinity of the Nile in Sudan (under Wolfdietrich Skala, FU Berlin and Frithjof

Voss, TU Berlin, Köhnke et. al. 1999) and in Egypt (Uwe Tröger, TU) in order to assess the relationship between groundwater and the Nile, as well as the influences of droughts within the catchment area of the Nile system.

For all of Egypt, a first geological map 1:500 000 was produced in 20 sheets based on systematic fieldwork and remote sensing. A major achievement here was a new and stratigraphically detailed subdivision that included complicated strata such as the former Nubian Sandstone Formation, which consists of several different marine and continental formations from Cambrian to Paleocene ages.

Prior to our work, this formation was considered to be mainly or totally Early Cretaceous (Klitzsch et al. 1986–87 and Hermina et al. 1989). For most of Egypt, 78 topographical sheets were produced in 1:250 000 (Pöhlmann et al. 1981–84), and 44 sheets for northern Sudan (Meissner and List 1988–93). The subdivision of strata was extended to northern Sudan; this, too, was documented in a number of maps of different scales, and also printed and published by TFH Berlin. In addition, under Meissner and Ursula Ripke, remote sensing methods backed by fieldwork resulted in maps of land-use and other applied questions. Research to improve remote sensing methods was carried out



Photo 3 This slight depression visited by a team of geologists represents the middle part of Wadi Howar in northern Sudan. Until 3000–4000 years ago, Wadi Howar was part of a permanent river connecting northern Darfur with the Nile. Rainfall several months before allowed colloquintes to grow between older camel thorn and small acacia trees. / *Geologenteam in einer kleinen Mulde, die den mittleren Teil des Wadi Howar im nördlichen Sudan bildet. Bis vor 3000–4000 Jahren was das Wadi Howar Teil eines perennierenden Flusses, der das nördliche Darfur mit dem Nil verband. Regen, der einige Monate zuvor gefallen war, hat hier den Aufwuchs von Bittermelonen zwischen älterem Kameldorn und kleinen Akazienbäumen ermöglicht.*



Photo 4 Peter Wycisk (now Halle) inspects a fossil soil of the Cretaceous age in southwestern Egypt. The soil is the result of very long periods of weathering during which no erosion or deposition took place. The bed on top represents a later phase of deposition of a fluvial sandstone, also Cretaceous in age. In some areas in southern Egypt and northern Sudan Cretaceous and older strata consist mainly of such fossil soils. In some areas, weathering results in soils useful for the ceramic industry or in bauxite (Sudan, south of Wadi Howar). A negative role is played by such sediments: Because they have very low to almost no permeability, they hinder groundwater flow in certain basin areas. / Peter Wycisk (jetzt Halle) untersucht einen kreidezeitlichen Boden im südwestlichen Ägypten. Die Bodenbildung geht zurück auf sehr lange Phasen der Verwitterung, in denen keine Abtragung oder Sedimentation stattfand. Die oberste Schicht stammt aus einer späteren, ebenfalls kretazischen Phase der Ablagerung eines fluviolen Sandsteins. In einigen Gebieten des südlichen Ägypten und des nördlichen Sudan bestehen kreidezeitliche und ältere Schichten vielfach aus derartigen fossilen Böden. Gelegentlich schafft die Verwitterung Böden, die für Keramik genutzt werden können, oder auch Bauxit entsteht (Sudan, südlich des Wadi Howar). Die negative Rolle dieser Sedimente besteht darin, dass sie geringe bis keine Durchlässigkeit aufweisen und damit in bestimmten Beckengebieten den Grundwasserstrom behindern.

by Jörg Albertz (TU, Albertz et. al 1990). It was coordinated with remote sensing and fieldwork by List, Meissner and others.

The systematic exploration of mineral deposits, mainly depending on stratigraphical position, re-

sulted in the discovery of interesting horizons as well as in the localisation of useful resources. Under Klaus Germann (TU), deposits for the Sudanese ceramic industry and for other practical purposes were discovered, including potential bauxite deposits. This research also arrived at princi-



Photo 5 Landscape near Fada in the central Ennedi Mountains (northeastern Chad). Differentiating erosion has divided an escarpment formed by Ordovician and Silurian age sandstone. Steep parts of the escarpment represent thick-bedded fluvio-continental sandstone above thin-bedded marine sandstone, siltstone and shale. The landscape was formed by erosion, mainly during Pleistocene and early Holocene time, with southward drainage. / *Landschaft bei Fada im zentralen Ennedi-Gebirge (Nordost-Tschad). Die differenzierende Abtragung hat eine Schichtstufe aus ordovizischem und silurischem Sandstein geteilt. Die steilen Bereiche der Stufe bestehen aus einer mächtigen Schicht aus fluvial-kontinentalem Sandstein über einer geringmächtigen Lage aus marinem Sandstein, Silt- und Tonstein. Die Landschaft wurde durch die Abtragung geformt, im Wesentlichen im Pleistozän und frühen Holozän, mit einer Entwässerung nach Süden.*

pal results about mineral deposits developing from weathering processes (Germann et al. 1999). The total reconstruction of the stratigraphical, sedimentological and paleogeographical history of the basins in the eastern Sahara (Klitzsch and Wycisk 1999) was not only useful in connection with mineral deposits, but also as an important scientific base for future oil exploration as well as for the construction of a groundwater model.

The structural development of northeastern Africa, its dependence on major plate tectonical events,

such as the opening of the Atlantic and the Indian Ocean, and their drastic consequences for volcanism and the formation of large graben systems were other important topics of the project. It also included a definition of Precambrian structural developments and their relationships with the formation of gold and other mineral deposits. In this research, new results were achieved above all by Schandemeier (1999), Gerhard Franz (TU, Pudo and Franz 1999), and the young African scientists Elsheik Mohamed Abdel Rahman (Sudan, 1993) and Evelyne I. Mbede (Tanzania, 1993).



Photo 6 Well-bedded marine sandstone of Silurian age near Fada in front of massive fluvial sandstone. The later in general has high porosity values and is an excellent reservoir for groundwater in North African basins. A. Seilacher inspects tracts of Trilobites (*Cruziana*), which are used for the stratigraphic age dating important for the reconstruction of geological basins and for hydrocarbon and groundwater exploration. Trilobite tracts are also used to reconstruct Paleozoic seaways – in this case between Northeast Africa and Argentina. (Seilacher is the only German that has been awarded the Crafoord prize for Geosciences.) / Wohlgebankter mariner Sandstein aus dem Silur bei Fada vor massivem fluvialen Sandstein. Letzterer hat eine generell hohe Porosität und bildet einen hervorragenden Grundwasser-Aquifer in den Becken Nordafrikas. A. Seilacher untersucht Stücke von Trilobiten (*Cruziana*), die für die stratigraphische Datierung genutzt werden, die wiederum wichtig ist zur Rekonstruktion der geologischen Becken und zur Exploration auf Kohlenwasserstoffe und Grundwasser. Die Trilobiten werden außerdem herangezogen zur Rekonstruktion der paläozoischen Seewege – in diesem Fall zwischen Nordostafrika und Argentinien. (Seilacher ist der einzige Deutsche, der mit dem Crafoord-Preis für Geowissenschaften ausgezeichnet wurde.)

The hydrogeological outcome was of importance for more realistic developments in groundwater exploitation in Egypt. Moreover, it became an important argument in the general discussion about the role of fossil groundwater in African countries (*Thorweihe* and *Heinl* 1996). A major consequence was an international conference on non-renewable groundwater, which was held in Tripoli in 1999 under the protection of UNESCO. Its groundwater branch in Paris had successfully convinced the responsible partners in Libya to stage the conference, which was mainly organised in Paris between 1997 and 1998. At this conference, *Klitzsch*, *Pachur*, *Sonntag* and *Thorweihe* presented our view. It is, however, certainly not realistic to expect immediate results in countries such as Egypt and Libya; but the results of the conference support those in Africa and elsewhere who are convinced that *Ambroggi's* theories (1966) are misleading and obsolete. The decades ahead will be dominated by water problems, not only in North Africa and the Near East. As long as the exploitation of groundwater and the use of surface water from the river systems of the Nile, Euphrates and Tigris, or Jordan – and in North America, for example, from the Colorado – are controlled by shortsighted politicians, serious conflicts will appear in the near future. The scientific and practical cooperation of all geosciences and of related engineers is indispensable in reaching realistic solutions to these problems and in convincing politicians of their validity. Their decisions will influence the welfare of future generations.

Another important practical result of the project was to demonstrate the possibility of working, partly under extremely difficult circumstances, in fruitful cooperation with African partners for many years and, in addition, to successfully include more than 30 African PhD candidates in field and laboratory work. Moreover, many applied geologists and engineers from our partners accompanied our fieldwork, and many laboratory employees became familiar with modern equipment and related methods. Thanks to DFG,

DAAD and Carl Duisburg Foundation as well as to the positive attitude of most German colleagues, we represented German research in Africa to the best of our abilities, and we managed to set an example of a modern, scientific, and at the same time practical attitude. Most of our African PhDs now occupy important positions at universities; some are deans, presidents or heads of research institutions. Others work in the oil industry or in groundwater and mineral exploration. This positive influence holds true especially for those from the Sudan project, despite the fact that we had to overcome three drastic changes of government. It does not hold true for those from Somalia, where civil war in 1991 resulted in the loss of most of our equipment. Some of our Somali team members could not return to their country. A number of interesting and useful investigations in structural geology and stratigraphy as well as in hydrogeology and paleoclimatology had to be given up before they were fully concluded. For geological questions related to the opening of the Indian Ocean, we therefore continued fieldwork in western Madagascar, because this crustal fragment was positioned next to Somalia and Kenya until Jurassic times. This work, together with detailed stratigraphic investigations from formerly nearby areas in Kenya and Tanzania, resulted in a better understanding of structural events and their chronology. They improved the correlation between the processes leading to the opening of the Indian Ocean and their influence on the drastic rifting in East and Northeast Africa and Arabia. Moreover, these results are of fundamental interest for oil exploration: Stratigraphical position and timing of rifting are the geological reasons for large accumulations of hydrocarbon deposits in central Sudan and southern Chad, along the East African coast up to the western foreland of India and in the Red Sea including the Gulf of Suez area and Yemen.

This summarising account of results would not be complete without tributes to outside scientists and their research which contributed substantial-

ly to several of the highlights mentioned earlier. *Adolf Seilacher* (1991, Tübingen/Yale) was not only of great help regarding stratigraphy and paleoenvironment in early Paleozoic strata, but he also influenced our scientific conceptions. For the stratigraphic interpretation of late Paleozoic and Mesozoic strata, *Annie Lejal-Nicol's* advice (1990, Paris, paleobotany) was indispensable, as was the work of *Otfried Hankel* (1986) and *Eckart Schrank* (1999, both palynology), and *Christa Werner* (1999, vertebrates).

For the scientific supervision of endless analytical work in laboratories, including help for PhD candidates from many different projects and several different nations, *Günter Matheis* (TU) was the permanent partner and supervisor. Geophysical research under *Hans Burkhardt* (TU) was organised and carried out in Egypt and Sudan with large teams by *Rainer Fiedler-Volmer* (TU). The scientists responsible for organisational and administrative assistance to the speaker (*Klitzsch*) and co-speaker (*List*) were *Matheis* (1981–86), *Linke* (1987–91),



Photo 7 Glacially eroded gully in the eastern Ennedi Mountains, incised into lower Silurian sandstone and filled with clayey-sandy tillites, including large blocks of sandstone. The peneplain in the foreland has been formed by the more recent erosion of soft shale (lowest Silurian), the basis of which crops out in the background to the left. In the hinterland the glacial sediments are overlaid by fluvial and shallow-marine sandstone (Silurian), the latter carrying traces of trilobites. In the foreground: *Dr. Nabil Barazi* (Klitzsch et al. 1993) / *Glaziale Erosionsrinne im östlichen Ennedi-Gebirge, eingeschnitten in Sandstein des Unteren Silur und aufgefüllt mit tonig-sandigem Tillit sowie großen Sandsteinblöcken. Die Verebnung im Vorland wurde durch die Ausräumung des weichen Tonsteins des Untersten Silur gebildet, dessen Basis links im Hintergrund aufgeschlossen ist. Im Rückland werden die Glazialsedimente von fluviailem und flachmarinem Sandstein des Silur überlagert, letzterer führt Trilobitenspuren des Silurs. Im Vordergrund: Dr. Nabil Barazi (Klitzsch et al. 1993)*

and *Thorweihe* (1991–95). All three of them not only had to handle large amounts of important logistic and administrative obligations, but were also involved in their own subjects of research.

The successive documentation of results from the individual projects was published in English in volumes 50, 75 and 120 of *Berliner Geowissenschaftliche Abhandlungen* (*Klitzsch* et al. 1984, *Klitzsch* and *Schrank* 1987 and *Klitzsch* and *Schrank* 1990). Major final results were published in a special volume by *Deutsche Forschungsgemeinschaft* (*Klitzsch* and *Thorweihe* 1999). Apart from the international exhibition on Water in the Desert (see earlier), examples of the impact of the project through reputed scientists include the following: *Rushdi Said*, the most prominent Egyptian geoscientist, accompanied and supported our research over many years. His book, *The Geology of Egypt* (*Said* 1990), contains major contributions from members of our team. He and *Sandy Petters* from Nigeria were invited to conduct research at the Institute for Advanced Study in Berlin (*Wissenschaftskolleg*) in 1989-90. They were the first geoscientists and the first Africans to be invited by this institution. *Said* (1993) wrote a book on the Nile River during this time, and *Petters* (1991) completed his textbook on the Regional Geology of Africa in close cooperation with us.

7. Conclusions

To a large extent, the geoscientific results of research in the central and eastern parts of the Sahara, and in neighbouring areas in East Africa, have their roots in the Bardai project. This is one of *Hövermann's* lasting merits! Much of the burden of creating this project in remote Tibesti rested on *Hagedorn's* shoulders, and toward the end, it was *Dieter Jäkel* who kept it alive. Several Bardai team members became an important creative core for projects that were formed later, once the Bardai station had lost its function.

Those who continued to work in eastern North Africa were included in new, comprehensive geoscientific research projects, whose major aims were to understand the development and present situation of the geology, the climate history and its influence on groundwater recharge and discharge as well as the interaction between climate, groundwater and geological situation and the formation of useful deposits. Because of the very extensive size of the area, remote sensing to support fieldwork was indispensable, as was cartographic documentation. Apart from new sedimentological aspects, we produced an up-to-date reconstruction and documentation of the geoscientific situation of the areas concerned. Most of the results are of practical use for economic development, and they have encouraged a shift in thinking toward more realistic conceptions of groundwater exploitation in arid North Africa.

The Bardai project can be seen as a master example of how basic research in the geosciences can reach practical value in important issues of human societies through inter- and transdisciplinary work. Foreign aid for developing countries has many examples in which biased investigations and their realisation have had negative consequences, usually due to a lack of fundamental facts in geology or physical and human geography. The development of such sensitive environments as deserts or semi-deserts is especially something that should not be left to engineers, agriculturalists or politicians alone.

The ongoing discussion regarding education in Germany and the value of research at our universities calls for a critical comment: The Bardai project and later research are best-practice examples of highly efficient scientific contributions related to the future of mankind. Presently, however, geosciences no longer play much of a role in education, and the two universities responsible for the projects mentioned here have continuously lost positions during the last few years. There has been no geoscientific project of comparable size and

efficiency carried out in Africa by any other country. And no other German university has included so many Africans in its research. We were convinced that the best course of action was to contribute toward better and more independent development in Africa, and we believed in equal partnership in cooperation. Now, however, we have a situation that does not allow comprehensive research; the only place in Berlin where geoscientific research and cooperation of practical value for Africa is continued on a large scale is the Technical Fachhochschule (TFH), where *Meissner* continues projects in Ethiopia, Sudan and Chad. Individual research or projects in small groups will certainly continue, but the geosciences have a more important role to play. They should help, in this time of growing fundamental problems, to find solutions and to locate their position in society, just as the Bardai project and SFB 69 did.

8. Literature

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- Summary: From Bardai to SFB 69: The Tibesti Research Station and Later Geoscientific Research in Northeast Africa*
- Modern geoscientific research of the central and eastern Sahara, following in the footsteps of nineteenth-century German researchers in Africa, was pursued in several phases. Starting in the winter of 1958/59, geologists working in Tripoli for DEA/Wintershall began to reconstruct the sedimentary basins of Libya, northern Chad and northern Niger. In 1964, the Bardai research base was found

ded in Tibesti by Freie Universität Berlin. Operating from this base, research was undertaken in northern Chad and southern Libya in the following years, primarily geomorphological and (paleo-)climatological investigations. After DEA was taken over by an American company and due to the escalating civil war in Chad at the end of the 1960s, both groups merged into a new team and started fieldwork predominantly in Libya, supported financially by the Bardai funds and focusing both on climatic changes and assessing the age of the groundwater. Based on this work, the special research project "Geoscientific Problems of Arid and Semiarid Areas" was set up in 1981. Led by Berlin's Technical University and Freie Universität, and with substantial financial support from *Deutsche Forschungsgemeinschaft DFG*, the project ran until the end of 1995. Its major objective was the geoscientific investigation of the eastern Sahara in close cooperation with scientific and applied institutions in Egypt and Sudan. During each fieldwork season, up to 140 scientists toured the desert in successive organised teams. As a result, the ages of sediment strata in the sedimentary basins of the eastern Sahara were determined to range from Cambrian to older Tertiary – information hitherto unknown. This laid the foundation for the detection of tectonic movements, which, together with a facies investigation and reconstruction of climatic changes in the Late Pleistocene and Holocene, was the precondition for setting up a model of the groundwater situation. This groundwater model was also to serve as a tool in regional planning. The model represents the whole aquiferous system of western Egypt, northwest Sudan, northeast Chad and southeast Libya. Supplementary work in Somalia and Madagascar helped to further understand the tectonic evolution of the eastern Sahara as influenced by the opening of the Indian Ocean. A large number of PhD students and graduates from the countries investigated were involved in the research, financed by DAAD. Today, they occupy major positions in their home countries. The results of this special research project were presented at a number of conferences and have been published in several volumes. They were also shown to a wide audience in an exhibition that toured approximately twenty countries.

Zusammenfassung: Von Bardai zum SFB 69: Die Forschungsstation im Tibesti und die nachfolgende geowissenschaftliche Forschung in Nordost-Afrika

Die moderne geowissenschaftliche Erforschung der Zentral- und Ostsahara auf den Spuren deutscher Afrikaforscher des 19. Jahrhunderts erfolgte in mehreren Phasen: Beginnend im Winter 1958/59 rekonstruierten Geologen der DEA/Wintershall von Tripoli aus die Sedimentbecken von Libyen, Nord-Tschad und Nord-Niger. 1964 wurde die Forschungsstation Bardai von der FU Berlin gegründet. Von dort aus wurden im Tibesti und seiner Umgebung in den folgenden Jahren im Nord-Tschad und in Süd-Libyen vor allem geomorphologische sowie paläo- und rezentklimatologische Untersuchungen durchgeführt. Nach Übernahme der DEA durch eine amerikanische Firma und wegen des Ende des sechziger Jahre aufkommenden Bürgerkrieges im Tschad verschmolzen Teile beider Gruppen zu einem neuen Team, das mit Mitteln des Bardai-Fonds vor allem in Libyen Feldforschungen durchführte, bei denen die Klimaentwicklung und das Alter des Grundwassers im Mittelpunkt standen. Aus diesen Arbeiten erwuchs 1981 der Sonderforschungsbereich „Geowissenschaftliche Probleme arider und semiarider Gebiete“. Er wurde von der TU Berlin und der FU Berlin aus mit erheblicher finanzieller Unterstützung der Deutschen Forschungsgemeinschaft bis Ende 1995 durchgeführt. Aufgabe war die geowissenschaftliche Erforschung der Ostsahara. Das geschah in enger Zusammenarbeit mit wissenschaftlichen und praxisorientierten Institutionen in Ägypten und dem Sudan. In den jeweiligen Geländezeiten waren bis zu 140 Wissenschaftler in aufeinander abgestimmten Gruppen in der Wüste unterwegs. Als Ergebnis wurden die vorher weitgehend ungegliederten Schichtfolgen der Sedimentbecken der Ostsahara datiert und dem Kambrium bis Alttertiär zugeordnet. Erst damit wurde die Grundlage für die Klärung der tektonischen Entwicklung geschaffen, die zusammen mit der faziellen Interpretation und der Rekonstruktion der Klimaentwicklung in Spätpleistozän und Holozän Voraussetzung für die Erstellung des Grundwassermodells wurde. Mit diesem Grundwassermodell wurde eine Grundlage für entsprechende Landesplanung geschaffen. Das Modell umfasst das gesamte Aquifersystem West-Ägyptens, des

Nordwest-Sudan, des Nordost-Tschad und Südost-Libyens. Ergänzende Arbeiten in Somalia und Madagaskar dienten vor allem dem Verständnis der tektonischen Entwicklung der Ostsahara in Abhängigkeit von der Öffnung des Indischen Ozeans. An den Arbeiten waren, in erster Linie mit Unterstützung durch den DAAD, zahlreiche einheimische Doktoranden und Diplomanden beteiligt. Sie sind heute überwiegend in wichtigen Positionen ihrer Heimatländer tätig. Die Ergebnisse des Sonderforschungsbereiches wurden auf mehreren Konferenzen vorgestellt, in zusammenfassenden Bänden veröffentlicht und in ca. 20 Ländern in Ausstellungen einer breiten Öffentlichkeit zugänglich gemacht.

Résumé: De Bardai au SFB 69: La base de recherche du Tibesti et la recherche géoscientifique subséquente en Afrique du Nord-Est

L'exploration géoscientifique moderne du Sahara central et oriental dans la lignée des chercheurs allemands du 19^{ème} siècle spécialistes de l'Afrique s'effectua en plusieurs phases: tout d'abord, au cours de l'hiver 1958/59, des géologues de la société DEA/Wintershall basés à Tripoli reconstruisirent les bassins sédimentaires de la Libye, du Tchad septentrional et du Niger septentrional. En 1964, l'Université Libre de Berlin créa la base de recherche de Bardai, qui permit d'effectuer, dans le courant des années suivantes, des études géomorphologiques ainsi que paléoclimatiques et de climatologie récente au Tchad septentrional et dans la Libye méridionale et plus précisément dans la région du Tibesti. Suite à la reprise de DEA par une société américaine et en raison de la guerre civile qui éclata au Tchad vers la fin des années soixante, des parties des deux groupes fusionnèrent en une nouvelle équipe laquelle mena, moyennant des aides provenant du fonds Bardai, des explorations surtout en Libye, plaçant au centre de ses intérêts les évolutions climatiques et la datation des nappes phréatiques. En 1981, ces travaux donnèrent naissance au domaine spécial de recherche « Problèmes géoscientifiques des espaces arides et semi-arides ». Sous la direction de l'Université Libre de Berlin et de l'Université Technique de Berlin, les études liées à ce projet se poursuivirent jusqu'à la fin de

l'année 1995, moyennant une contribution importante de la part du Centre Allemand de la Recherche Scientifique (DFG). L'objectif en fut l'étude géoscientifique du Sahara oriental. Une étroite collaboration avec des institutions scientifiques ou vouées à l'application des acquis scientifiques d'Egypte et du Soudan fut mise en oeuvre. Pendant les périodes de terrain, le nombre de chercheurs en activité dans le désert en équipes interdépendantes pouvait atteindre les 140. Les stratifications des bassins sédimentaires du Sahara oriental, jusqu'alors généralement peu différenciées, furent datées et catégorisées du cambrien au paléo-tertiaire. Ceci permit de donner une base solide à l'explication de l'évolution tectonique, laquelle constitua finalement, de pair avec l'interprétation des faciès et la reconstruction de l'évolution climatique lors de l'holocène et du pleistocène tardif, la condition préalable à l'élaboration d'un modèle des nappes phréatiques. Ce dernier jeta également les bases d'un aménagement du territoire adapté. Le modèle englobe l'ensemble du système aquifère de l'Egypte occidentale, du Soudan du Nord-Ouest, du Nord-Est du Tchad et de la Libye du Sud-Est. Des travaux complémentaires menés en Somalie et au Madagascar aidèrent en premier lieu à la compréhension de l'évolution tectonique du Sahara oriental, celui-ci s'effectuant en interdépendance avec l'extension de l'Océan Indien. De nombreux étudiants originaires des pays étudiés et préparant leurs mémoires ou thèses furent associés aux recherches et bénéficièrent en particulier d'un soutien financier de la part du DAAD (organisme allemand pour les échanges académiques). Aujourd'hui, ils occupent pour la plupart des postes importants dans leurs pays d'origine. Les résultats obtenus par le domaine spécial de recherche furent présentés lors de plusieurs conférences, publiés en volumes récapitulatifs et rendus accessibles, sous forme d'expositions, au grand public d'environ 20 états.

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