2 Relief, Climate, People, Languages, Toponymy and Exploration History

2.1 Topography of Surrounding Plateaus

From a geographic point of view, Afar is mostly located in Ethiopia, where it constitutes a Regional State on its own because it is a Federal Republic, but it also occupies the south-eastern part of Eritrea, most of Djibouti and part of Somalia to the east (Fig. 2.1). The Afar depression cover a surface of around 200,000 km^2 and ranges from 157 m below sea level (Asal salt lake to the east, the lowest point in Africa, in Djibouti Republic) and 120 m below sea level (salt plain to the north, in Ethiopia) up to 800 m above sea level to the south. That is an average elevation of 200 m with the exception of a few mountains, mostly active or recently extinct volcanoes such as Dubi, Nabro (2218 m) and Moussa Ali (2028 m) located along the Eritrean border.

Afar's western margin is characterised by the high Nubian plateau, a fertile highland area where most of the population of Ethiopia (nearly 80 million) live. It varies on average from 1500 to 3000 m above sea level, with several heights above 4000 m, the highest being 4550 m at Ras Dashan, with Tullu Demtu and Mount Batu above 4300 m. Generally, the elevation increases towards Afar and the Rift Valley, so that the drainage system is mostly oriented to the west, feeding the huge Blue Nile basin (and the Mediterranean sea). Lake Tana (2460 m) occupies the centre of the plateau. It was formed from a local Quaternary volcano-tectonic event (emission of alkali basalts closing a basin of the upper Blue Nile to the south of the lake). The Nubian plateau gradually slopes down to the Sudan lowlands to the west, whereas towards Afar the contrast is very sharp, with nearly vertical scarps determined by normal faults that have quickly downthrown the whole pre-rift geological sequence. The division between the Nubian plateau and Afar continues north in Eritrea and marks the limit with the Red Sea. The relief contrast tends to diminish further north. This limit clearly trends NNW, parallel to the Red Sea north of the Gulf of Zula and Bure peninsula that marks (at 15°N) the northern limit of the Afar depression.

It apparently trends N-S along the Afar margin, following the line of the 40°E meridian for 600 km, but more detailed mapping shows that this results from the succession of en-échelon faults in a NNW direction. At a level of 9°N, the limit of the Nubian plateau changes direction and trends NNE, parallel to the Ethiopian Rift valley that extends south to Kenya through Lake Turkana Rift (surface elevation 360 m, 110 m deep).

The Nubian plateau is characterised at its northern part by high mountains cut by steep valleys. Parallel with the eastern escarpment are the heights of Mount Biala (3810 m), Abuna Yosef (4190 m) and Kollo (4300 m). West of Lake Tana are Mounts Guna (4210 m), Uara Sahia (3960 m) and Choqa (also called Birhan) (4154 m). South of 10°N, the highlands are more tabular than the northern portion but equally broken.

Despite a few heights between 3000 and 4000 m, the majority do not exceed 2400 m, that is, less than on the eastern side of the rift valley (Somalian plateau border).

The southern margin of Afar is also marked by a sharp escarpment trending nearly 10°N, which correspond to the NE limit of the Somalian plateau. This plateau, generally less elevated than its Nubian equivalent, is gently inclined towards the SW (down to the Indian Ocean) and is mainly occupied—although with a rather dry climate—by the hydrographic basin of the Wabi Shebele and Jubba rivers. The mountain chain of Ahmar, with an average of 2900 m peaks at 2960 m at Mount Kundudo. The northern limit of the plateau, also marked towards Afar by steep normal faults, trends in a WNW direction and extends west through Somalia, similarly marking the southern limit of the Gulf of Aden.

As observed along the Red Sea western side, the altitude of the plateau gradually decreases away from Afar. Note,

J. Varet, *Geology of Afar (East Africa)*, Regional Geology Reviews,
https://doi.org/10.1007/978-3-319-60865-5_2

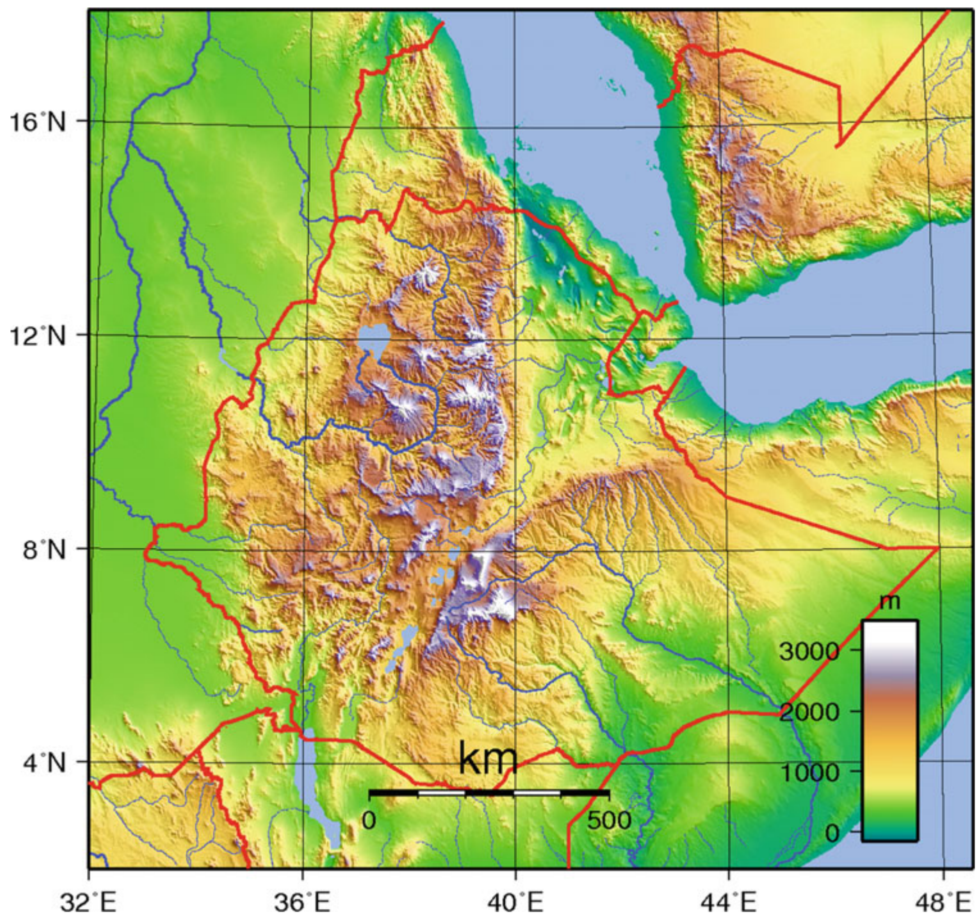

Fig. 2.1 The Afar depression surrounded by the Ethiopian, Yemen and Somalian plateaus, in the area of junction of the Gulf of Aden, the Red Sea and the Main East African Rift Valley, as seen on this relief map, also showing the political boundaries (in *red*) of concerned countries: Ethiopia, Eritrea, Djibouti Republic, Somalia and Yemen. Observe the mainly diverging flow pattern of the rivers (towards Mediterranean and Indian ocean basins)

however, that a small plateau is observed in the border area of Ethiopia, Somalia and Djibouti (Ali-Sabieh region), known as Aisha Horst.

Towards the west, the border of the Somalian plateau virgates to take a NW direction, parallel to the Ethiopian Rift valley, in symmetry with the Nubian plateau bordering the other side of the valley. That is where the Somalian plateau is the most elevated, forming the Bale Mountains. Tullu Demtu (4377 m) is the second highest mountain in Ethiopia, and this elevated range include Mounts Batu (4307 m), Chilalo (4036 m) and Kaka (3820 m).

The Great Ethiopian Rift Valley runs in a NNE direction from south (Kenya border) to north into Afar. It is a depressed area, on average 1000 m below the borders. The northern half is occupied by the Awash River, which flows northwards into central Afar where it ends in Lake Abhe at the Djibouti border, making a curve in this endoreic basin (Fig. 2.2). The southern part of the valley is occupied by several lakes, a characteristic that is found further south all along the two branches of the East African Rift.

In the southern part of the Ethiopian Rift valley, a parallel rift structure controls the Omo river basin which flows towards south and feeds Lake Turkana, which is larger than all the other Ethiopian Rift valley lakes put together. Omo is a 600 km long perennial river with many affluents and a total fall of about 2000 m, from 2500 m at its source to about 500 m at Lake Turkana level.

Both Awash and Omo river basins developed a strong sedimentation in the Eocene to the present period, with thick detrital sediments which are found intercalated with various lacustrine deposits resulting from the important past climatic variations. This allowed thick sedimentary filling to develop, notably in central Afar, where the floor would otherwise be several hundred metres below sea level.

This situation, together with the normal faulting along the rift margin and successive erosion, allowed for good conditions during Pleistocene both for the first human settlements and for conservation of the resulting fossils. The most ancient fossils of homo species have been extracted from sediments in both Omo and Awash river basins.

Fig. 2.2 The Awash river basin extending over 800 km from Entoto hills near Addis Abeba to Lake Abhe through central Afar. Note that it also receives the tributary of a few smaller rivers including the Mile to the north (*Source* Wikipedia)

2.2 Climate and Ecology

The Afar triangle is a rather dry region, with desert conditions probably among the hottest and the driest in the world. However, because of the high elevation of the surrounding plateaus in a nearly tropical environment, the upper highlands benefit from a temperate climate. The mountains catch the precipitation of the monsoon winds from the Indian Ocean, producing a rainy season from June to September. Heavy rains cause the Nile and the Awash to flood in the summer, differing from the usual North African conditions.

The Ethiopian Highlands have flora and fauna similar to those of other mountainous regions of Africa but habitats differs on either side of the Great Rift Valley because of the drier climate to the east. The tropical savannas and grasslands in the Rift Valley change to Sahelian Acacia savanna to the northwest.

The Ethiopian plateaus have good fertile soil and are heavily populated, mainly by fixed farming communities that have converted the region to agriculture. In contrast, the Afar depression is inhabited by scarce nomadic tribes living from cattle, sheep, goat and camel breeding. However, in the last few years, agriculture has tended to develop, albeit with a rather industrial character (sugar and cotton plantations) along the Awash River basin. It is interesting to note that the same ethnic group, speaking the same language, occupies the whole Afar, despite the countries official limits. The total population of Afar can be estimated to be up to two million, as a few areas are more densely populated (Awash valley, flood plains at the bottom of the Ethiopian scarp, and Danakil hills along the Red Sea) than the average desert. However, even in the most remote and desert places, one can find human settlements. As a whole, in the three countries concerned (Ethiopia, Eritrea and Djibouti) this is 1% of the total surrounding communities.

If the Afar depression appears as a simple geographic feature bounded to the west by the edge of the Ethiopian highlands, to the south by the Somali plateau and to the east by the Yemen plateau, its characteristics appear more complex in reality. This striking topography allowed the first plate tectonics reconstruction to consider the whole Afar triangle as part of the Red Sea—Gulf of Aden oceanic floors (Allan 1970). Two features, however, underline the complexity of this rather simple scheme: the Danakil Alps, which display a clear relief between northern Afar and the Red Sea and the Aisha—Ali-Sabieh horst which separates the southern Afar depression from the Gulf of Aden. These are even more significant when one sees that both consist of pre-Mesozoic formations covering an outcropping Precambrian basement (see Chap. 4). Note, however, that the Danakil Alps are limited to northern Afar. South of the Bidu-Nabro-Dubbi transverse structure, the nature of the area located along the Red Sea appears stable and is made exclusively of volcanic products with no pre-Tertiary formations.

A rather elevated area, peaking at an altitude of 1780 m at Mt Goda, is observed along the northern shoulder of the Ghoubbet Rift which is the last rift segment of the Gulf of Tadjourah, in fact a single rift with the emerged Asal Rift segment (Fig. 2.3). This feature, known for its relict forest ("Forêt du Day", Fig. 2.4), is frequently interpreted as the southern extremity of the Danakil Alps. It is, however, of quite a different nature and origin. It corresponds in fact to the uplifted shore of this recently formed oceanic rift (less than two million years ago). This Dalha plateau, which extends north and gently downslopes towards NW, is made of basalts, dating from 7 to 4 million years ago, overlying faulted rhyolites (Mabla rhyolites, 12–8 million years ago). However, despite its altitude and level of erosion, no pre-Tertiary formation is observed in the "North Ghoubbet" block.

The Afar depression is otherwise characterised by its rather dry and hot climate. The average waterfall does not exceed 100 mm/year, but rain is generally local, and in some areas there is no rain at all for several years. In this context, in the absence of soil, the geology directly determines the vegetation. The distensive tectonics allows for the development of open fissures and normal faults which may allow for the accumulation of eolian sediments, and eventually some grass and trees (generally acacias). The recent volcanic activity eventually favours spots where vegetation benefits from more favourable environments such as craters or lava channels (Figs. 2.5 and 2.6).

In this generally desert and rugged context, however, we note a few exceptions, found in the Awash River basin, and of a few galleys that descend from the plateaus and allow for flood plains, offering sites where water can be gathered by the nomadic population, allowing for larger settlements and eventually irrigated agricultural developments (Fig. 2.7).

For the local communities in many places in Afar, the only other source of water in the dry climate is the hot springs (and wetlands or irrigated areas around them when not too salty; see Figs. 2.8 and 2.9). The notable exception is the Awash River basin where the availability of water allows for richer cattle breeding (Fig. 2.10) as well as agro-industrial developments (sugar, cotton etc.). Elsewhere, water can only be obtained by condensation of the steam from fumaroles (sites generally called "Boina"; see Fig. 2.11). The Afar population nearby would dig, build and finally install more or less elaborated systems for water collection from steam (see Figs. 2.12 and 2.13).

In many places in Afar, although groundwater is eventually available, it happens that, because of the active geological context, and in particular the high heat-flow, the groundwater reaches rather high temperatures. At Baloo, Republic of Djibouti near the Ethiopian border, the well drilled near the village produces water at 60°C which requires cooling before it is distributed, and at Karapti San the temperature is so high that the well had to be closed because of the lack of proper high temperature drilling equipment in the Ministry of Agriculture in charge of the drilling (Figs. 2.14 and 2.15).

2.3 Ethnographic Context

From the ethnographic point of view, the region is characterised by its specific nomadic population, which had different names according to the observer. In northern Ethiopia they were long called "Taltal", a name used by emperor Johannes of the Tigray dynasty who married an Afar girl. In the southern Ethiopian highlands, inhabitants of the depression are still frequently called "Adal", a word which described the population of southern Afar. The Arabs of the Southern Red Sea called them "Danakils", a name also used by the Italians during the colonial period and which is still used in northern Afar (see the two-volume book, 1488 pp, by Luca Lupi, IGM, Firenze 2009, entitled "Dancalia[1]") whereas the Somali call them "Oda'Ali".

As shown by the CNR-CNRS Afar team (1973), the term "Danakil" was first used in the thirteenth century by Ibn Said, the Arab geographer, and this term, currently used by the Arabs, was reported by the first European geographers. The first geographic map printed in Venice in 1541 named the region "Regno de Dangali", probably from data of Portuguese origin.

However, the people known by outsiders by so many different names call themselves "Afars". It was therefore reasonable to name this geographic region "Afar". All Afars, whatever the political boundaries of Ethiopia, Eritrea and Djibouti Republic, belong to the same culture and have the same ethnic roots. Afar is hence a well-defined human and physical geographic entity.

[1]Luca Lupi 2009 « Dancalia, l'explorazione dell'Afar, una storia italiana » IGM, Firenze 1488 pp.

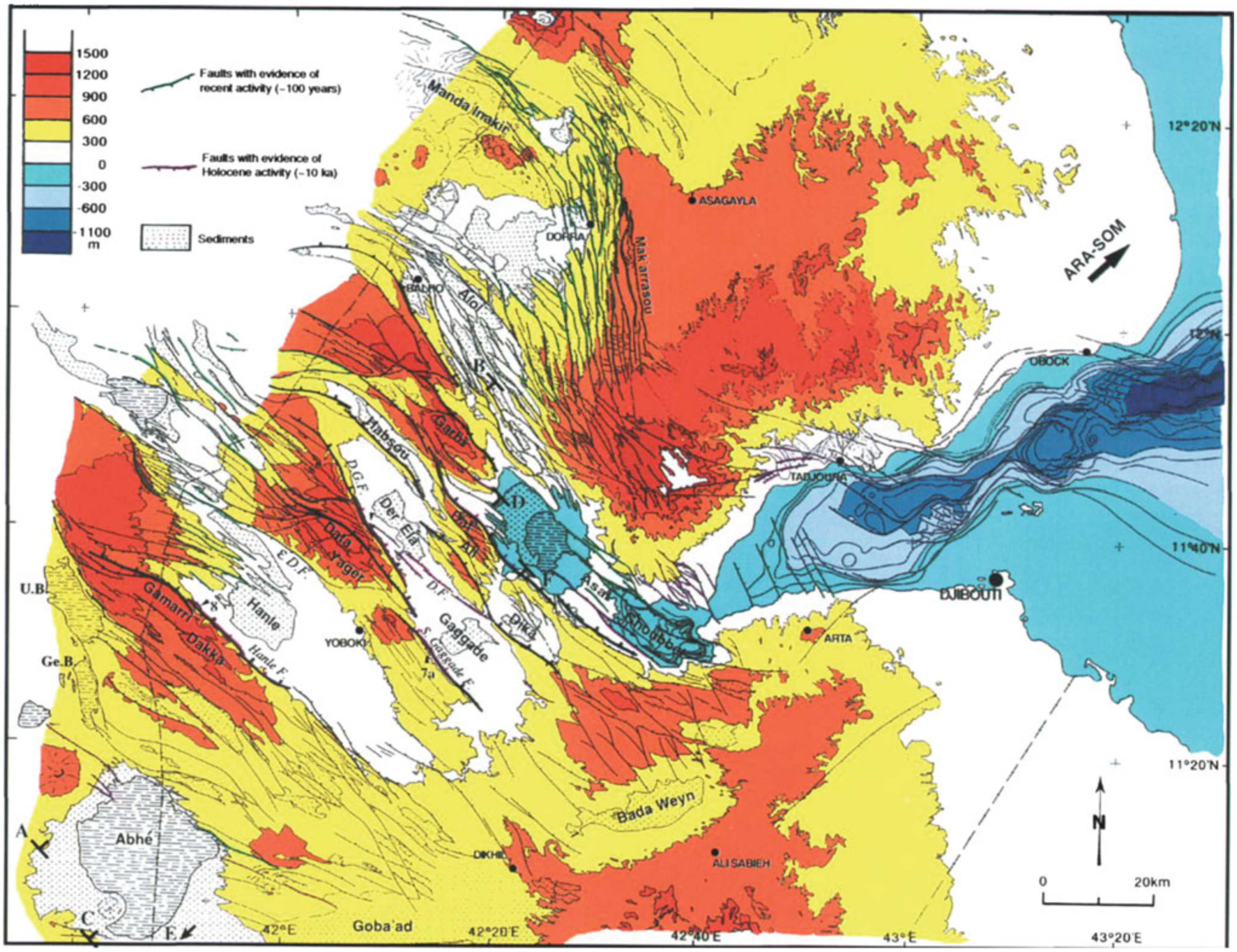

Fig. 2.3 Detailed relief map (redrawn from IGN) of the shoulders of the Ghoubbet-Asal rift and Gulf of Tadjourah (from Manighetti et al. 2001a, b). Observe the high altitude of the Goda massif (Day forest) culminating at 1780 m, and the plateaus gently dipping towards the NW. Observe also in the bathymetric map of the Gulf of Tadjourah the successive troughs corresponding to the Aden ridge extension towards Afar (with Asal-Ghoubbet as first partly emerged rift segment)

In Ethiopia, the Federal State established after the eviction of the DERG recognised Afar as a “Regional State” (Fig. 2.16), as it was previously divided into several provinces, including the nearby plateaus (Tigré, Wollo, etc.). The Afars number 1,276,867 people (or 1.73% of the total population) in Ethiopia according to the most recent census (2007). The Afars are estimated to make up over one-third of the population of Djibouti Republic, which is approximately 300,000 people, and are considered to be 5% of the population in Eritrea, that is, another 300,000. Therefore, altogether, the Afar population is probably at present (2014) over two million.

Afar people are predominantly Muslim. They have a long history of association with Islam through the various local Muslim politics, and are traditionally pastoralists, raising goats, sheep, camels and cattle in the desert. Being nomads, they move their houses according to the influence of climate on the pasture land (Fig. 2.17). A few of them practice fishing along the Red Sea coast (Tiho and Edd area, Eritrea). They live in houses made of curved light woods covered with palm fabrics (Figs. 2.18 and 2.19) which can be transported by camels when moving camp. The division of work between men and women is well established, men taking care of looking for pasture lands and protecting the group, women in charge of the households, water and energy supply and food preparation (Figs. 2.20, 2.21, 2.22). Afars are known for their martial prowess. Men traditionally sport the “jile”, their famous curved knife (Fig. 2.23) and are known to have an extensive repertoire of battle songs. All speak the same language that is part of the Cushitic branch

Fig. 2.4 The Day forest, one of the only forested areas in Afar. Observe the deeply eroded trap basalts of the Dalha formation along the Southern slopes of Mt Goda (1780 m)

Fig. 2.5 Typical view of northern Afar. The dry basaltic surfaces do not offer much life support. However, open fissures and normal faults will produce lowlands in which eolian sediments will be fixed, allowing for the presence of some vegetation. Similarly, blocky and Aa flows as well as lava channels may also favour low spots in which some acacia tree may survive (*Photo* Marinelli)

Fig. 2.6 Craters appear as favourable sites for wetlands or even lakes that allow for the development of vegetation of interest for Afar farmers. Three examples from Alayta, Erta Ale (Catherine volcano) and Manda Inakir (*Photos* Marinelli)

Fig. 2.7 The Teru plain, in central western Afar, where the wadies from the Ethiopian plateau hit the axial volcanic range of Alayta, offers a thick green surface where the grass, up to 2 m high, is difficult to penetrate. (F. Barberi and J.Varet, *Photo* Marinelli 1969)

Fig. 2.8 The deeply faulted central Afar is presently affected by a very arid climate. Hot springs offer some of the rare sources of water, which although quite enriched in minerals (which deposit by evaporation, in white), allow for scarce pasture land to be maintained. Alol-Sakalol graben (*Photo* Varet 2012)

Fig. 2.9 Hot-spring irrigated pasture land on the eastern shore of lake Abhe (*Photo* Varet 2014)

Fig. 2.10 The Awash river basin is the exception in Afar economy, with abundant water available for cattle breeding and irrigated agro-industrial developments (*Photo credit* Imail Ali Gardo)

Fig. 2.11 All over Afar, fumaroles are generally captured by the Afar men with installation of artisanal steam condensation devices allowing the production of the only drinkable water available in this desert environment (Garrabayiis, *Photo* Varet 2012)

of the Afro-Asiatic family of languages. Afar language is hence widely spoken by this population in the whole Afar region of Ethiopia, south-eastern Eritrea and north-western and central Djibouti Republic. They mainly rely upon their cattle for nutrition (mainly milk and also meat from goats, sheep and camels) but may also use some cereals bought in markets from other communities to cook bread in earth-dug and firewood heated ovens.

One should note, however, that in recent years, particularly after the Afar Regional State was established in Ethiopia, the Afar social system underwent important changes, with the development of schools which fixed part of the population in villages and the creation of water points, with cisterns and wells pumping groundwater with solar powered pumps or even extensions of the electric grid. The tendency is therefore for the development of agricultural activities in combination

Fig. 2.12 If the second man is handling the usual gun that Afar men carry on their shoulders, the first is carrying a hoe which is used to dig in the fumarole site to build a water collector condensing steam. The author in 1970. Boina at Ma'alalta. *Photo credit* Franco Barberi

Fig. 2.13 In central Afar, along an open fissure cutting through the Stratoid series, from which the steam surge, producing clay alteration products as well as carbonate and silica deposits, a set of water condensers is being built for drinking water collection and bathing developments (*Photo* J. Varet 2015)

with traditional pastoralism. Artisanal mining also tend to develop, such as salt mining and salt evaporation ponds (e.g. around Lake Afrera). An Afar Geothermal Development Company was even inaugurated in January 2015.

2.4 Afar Topographic Maps and Toponymy

When the geological exploration of Afar started in 1967, no topographic map was accessible, at a proper scale, except for the Djibouti Republic (then still French Territory of Afar

Fig. 2.14 Typical Afar habitat (*Photo* Varet 2012); observe the rocky and dry surrounding. Near this village called Karapti San, located in the northern extension of the Asal graben, a well drilled by the water department of the ministry of agriculture had to be closed due to its too high temperature (Haga et al. 2012)

and Issas, TFAI) where well-documented 1/100,000 maps were published and sold by IGN. In Ethiopia, one should rely on the 1/1,000,000 scale US aeronautical ONC map as well as the 1/250,000 Joint Operation U.S. Army map. Fortunately, a "topomorphic" map was published in Florence in 1968 from air photographs transcription for Mobil Oil exploration.

Colonel E. Chedeville dedicated his life (1906–1996) to the study of the Afar people and language, which he was teaching at the Paris-Sorbonne Oriental Language Institute (INALCO). Despite the fact that he was forbidden to enter Ethiopia,[2] he provided the CNR-CNRS Afar team with rather detailed toponymic maps of the whole Afar region, whether in Ethiopia, Eritrea or Djibouti, thanks to his own ability to travel through the country without motor vehicle or escort, benefiting from the Afar people's hospitality.

In the maps produced with his help, the "restricted" names referring to unusual items such as water point, oued, valley, hill or confluence were printed in small characters whereas "broader" names such as plateaus, grabens and plains were spread over the area to which they refer. The names given to geological entities or formations (volcanic, sedimentary or tectonic units) were from this last category.

[2]He took a stance against the settlement of the boundary with Ethiopia in 1954 and wrote numerous articles in the period 1948–1954 criticizing the cession of the Afambo area.

A few of the most useful Afar words used in topography are given in Tables 2.1 and 2.2.

2.5 History of Afar Exploration

The history of Afar exploration was recently developed in detail, with numerous illustrations, in a well-documented book edited by the Istituto Geografico Militare (L. Lupi, Firenze 1488p. 2009). Here we recall a few major steps.

The region has long been an area of difficult access for various reasons:

1. The rather hot climate and desert conditions
2. Access for vehicles is rather limited and hazardous
3. The people themselves are hostile towards foreign incursions
4. The political situation and the influence of various outside forces (Italian and French colonisation, Ethiopian imperial influence, Eritrea Liberation Front, etc.)

Even now, parts of Afar are difficult to access, notably around the Eritrean border, whether in Ethiopia or in Djibouti Republic.

For a long time the Afar warriors were considered to be very fierce as several exploring parties were slaughtered by the tribesmen. This was notably the case with the Italian army officer Giulietti who was killed together with all his party of

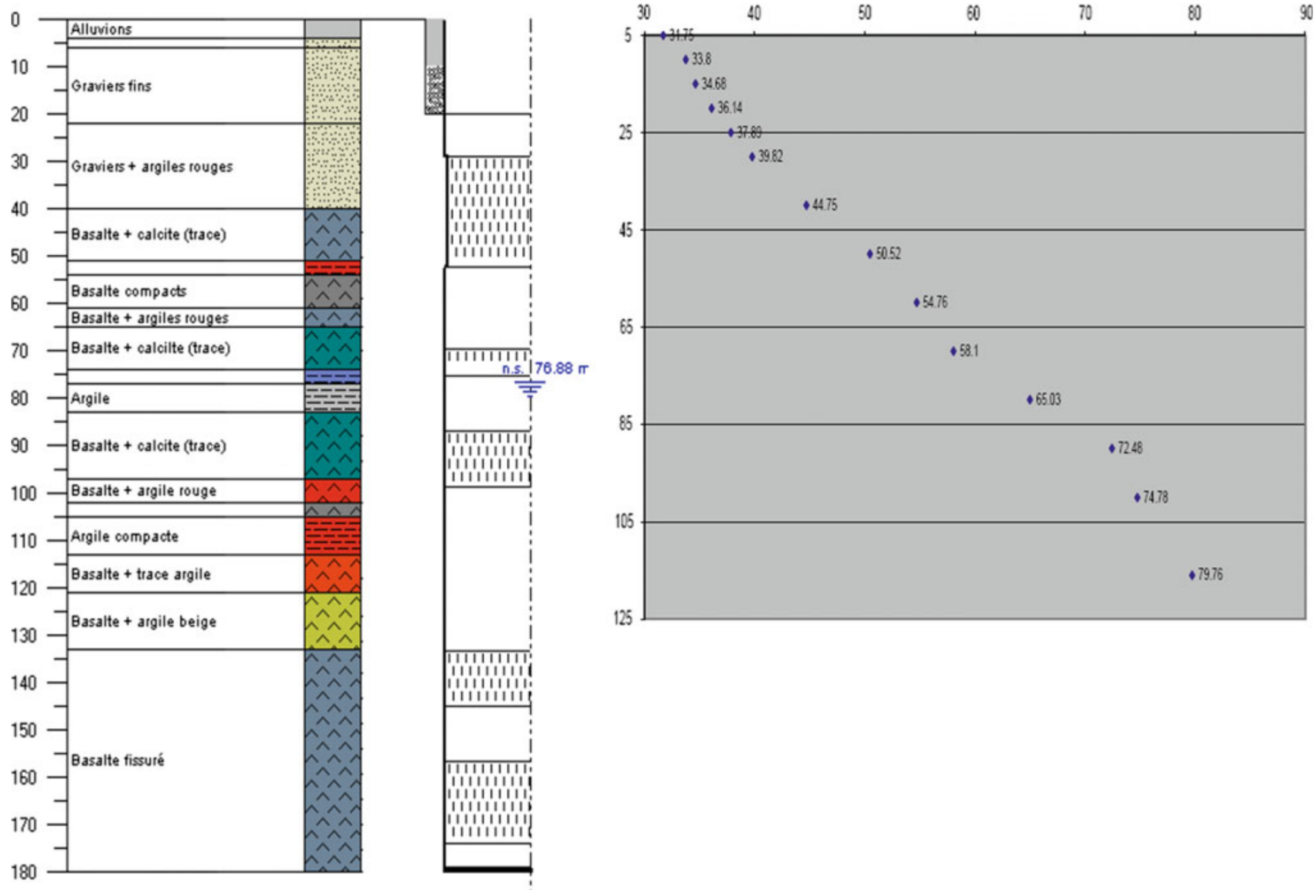

Fig. 2.15 Near the village of Karapti San, located in the northern extension of the Asal graben, a well drilled by the water department of the ministry of agriculture had to be closed due to its too high temperature (Haga et al. 2012)

14 soldiers at Lake Afrera, therefore called Giulietti in old Italian maps. The access to the Afar depression long being much easier from the coast than from the plateau, geological explorations started from the north (the Gulf of Zula accessible from Massawa) or from the ports located to the south-east (Assab, Tadjourah and Djibouti). The first geological report of the coastal region is that of Salt (1814), followed by Ruppel (1934), Johnston (1884), Issel (1869), Blanford (1870), Zichy (1880) and Aubry (1855) and Justin Visentin and Zanettin (1968). The presence of crystalline basement and Jurassic limestone is known from the Danakil Alps, as well as the recent volcanic rocks and the presence of salt and coralliferous limestone in the depression. This first description of inland Afar was by Munzinger (1869), who gave a detailed description of the salt plain and surrounding area, described as an ancient gulf of the Red Sea, desiccated after obstruction by volcanic events. The basic geological knowledge of Ethiopia was established by W.T. Blanford, who did not really penetrate Afar. He introduced the term "Aden Series" to describe the volcanic formations located on the Red Sea shore, shown as being distinct from (younger than) the traps of the Yemen and Ethiopian plateaus. The term was later used extensively in the geological literature and maps of Ethiopia for any volcanic rock postdating the trap series of the plateau. It was even used later by Mohr (1967) to describe all volcanoes of the Ethiopian Rift system, whatever their age, petrology or geological position.

Nesbitt (1934) provided the first description of a few recent volcanoes of northern Afar after visits he made to the region with T. Pastori, who provided useful oral information to H. Tazieff and G. Marinelli.

Gortani (1949, 1951) published geological descriptions of the journey he made with Bianchi from Asal to Gawani, and show the presence of heavily faulted trap series

Fig. 2.16 The Afar regional state of Ethiopia

Fig. 2.17 Moving the camp with camel transport of the house spare parts and households (*Photo credit* Ismail Ali Gardo)

Fig. 2.18 Building the wood framework for a house (*Photo credit* Ismail Ali Gardo)

Fig. 2.19 Weaving palm trees fibre for roofing (*Photo credit* Ismail Ali Gardo)

Fig. 2.20 The house seen from outside (Dodom plain, J.Varet 2013) and from inside (Awash basin, *Photo credit* Ismail Ali Gardo)

Fig. 2.21 The house seen from outside (Dodom plain, J.Varet 2013) and from inside (Awash basin, *Photo credit* Ismail Ali Gardo)

covered by recent volcanic action. Basalt samples collected during these expeditions were later studied by Heike Merlin (1950). Desio (1941) also described some volcanoes of central Afar.

Dainelli and Marinelli (1912) were the first to provide a collection of the knowledge of the region and the impressive books published by Dainelli (1943) remain the source of reference on the information available at the beginning of the twentieth century. Determined to deliver unique information, he concluded his synthesis with these words: "*taking into account the general conditions of the area, it is quite improbable that the geology will ever be systematically studied*".

Despite this prophetic view, scattered geological information was collected by Gortani (1949, 1951), Justin Visentin and Zanettin (1968), and a gravity traverse was undertaken by Gouin and Mohr (1964). Useful geological descriptions of the sedimentary formations and tectonic environment of the Dallol potash salt mine were published by Holwerda and Hutchinson (1968) and Hutchinson and Engels (1970), and a geological map was published by Bannert et al. (1970) after an important German geological expedition (Brinkmann and Kursten 1969; Bannert and Kedar 1971) (Figs. 2.24, 2.25, 2.26).

It is in this context that a Franco-Italian team was assembled by H. Tazieff and G. Marinelli (Figs. 2.27 and 2.28) with the support of CNR and CRNS to undertake a systematic geological exploration of Afar which started in December 1967 and was continued with yearly winter expeditions (December to January) until 1976. The result of this work was 1/500,000 scale maps of the whole Afar depression (two sheets) and several more detailed maps (1/100,000 scale) of a few relevant units such as the Erta Ale range. As a whole, it was this team that provided the first description and the geological definitions of the major volcanic units of the Afar depression, still of relevance today (Tazieff et al. 1969, 1972; Tazieff and Varet 1969; Barberi and Varet 1970; Barberi et al. 1970, 1972; Marinelli and Varet 1973).

In order to organise the field work, we could benefit from complete air photo coverage of the region both in Ethiopia and Djibouti. Thanks to the desert character of the region, the lack of soil or vegetation, and even frequency of erosion, allow us to differentiate the nature and map the contours of the geological units, notably volcanic units (flows, domes, ignimbrites, tufs, scoria cones, hyaloclatite rings etc.) as well as sedimentary formations (salt, gypsum, diatomite, coral reefs, clay plains or detrital talus etc.), tectonic features (faults, open fissures) or hydrothermal manifestations [hot springs, fumaroles, hot ground showing specific vegetation ("Fialé" herbs)]. The photo-interpretation was carried out in the field using stereoscopes, covering consecutive daily field visits, using four-wheel-drive cars and long marches to reach the targeted sites following itineraries planned the day before. The most inaccessible sites were selected for helicopter visits, frequently organised with two pre-established

Fig. 2.22 Afar family in front of their house, located on a recent basaltic flow (Erta Ale range, *Photo* Marinelli 1970)

landing sites in the morning and evening after a daily walking itinerary. Mirror signalling to the helicopter was frequently a very useful tool for final positioning.

Fresh rock samples, favouring aphyric lavas—representative of the magmatic liquid evolution—when there was a need for limited loading, were systematically collected and processed and examined as thin sections under a polarizing microscope, using a point counter when necessary for modal analysis. More than 5000 samples were collected over the whole Afar depression and carefully marked on air photographs and field maps, mainly by F. Barberi and J. Varet (Fig. 2.29). The most representative parts of them were crushed and powdered for chemical analysis, age determination, neutronic activation analysis, or selected for microprobe studies. Rocks, powders and thin sections are now stored at the Earth Science Department Afar store of the University of Pisa thanks to the initiative of Roberto Santacroce. Altogether more than 100 scientific papers were published in various specialised Earth Science Journals in the period 1968–1980).

More recently, renewed interest by Afar studies followed the Asal 1978 tectonic and volcanic event. The seismic crisis, with the earthquake reaching a magnitude of 5.3, and the opening along Asal-Ghoubbet axis reaching 2.4 m wide in the submarine part (Ghoubbet Rift), was well documented because of the seismic and geodetic networks established in 1973 across the rift. The Ardoukoba basaltic eruption (Fig. 2.30) was studied from volcanological, petrological, mineralogical and geochemical standpoints, and placed in the context of the volcano-tectonic and magmatic evolution of the Asal Rift (Demange and Tazieff 1978; Ruegg et al. 1979; Demange et al. 1980).

In February 1980, a scientific colloquium was organised jointly by CNRS (France) and ISERST (Djibouti), attended by 60 geoscientists from Djibouti, France, Italy, Iceland, UK and USA. A volume of the Bulletin de la Société Géologique

Fig. 2.23 Young Afar girl carrying water in goat skin water bag (*Photo credit* Ismail Ali Gardo)

de France was produced including 27 written contributions on all aspects of the event and its geodynamic context (Colloque Rift d'Asal. *Bul. Soc. Geol. Fr.* 1980, (7) XXII, pp. 797–1013).

The 1978 volcano-seismic and tectonic event was followed by a 10-year period of relatively fast opening (6 cm/year) and in 1988 the characteristics changed and the incursion of magma in the Fialé caldera could be documented with several pulses at shallow depth (3.5–2.5 km) which lasted until 2005. The whole event provided further detailed imaging of the magmatic and rifting process (Doubre et al. 2007a, b). Based on satellite imagery processing (including radar interferometry), ground field surveys (GPS, tectonics, palaeomagnetic measurements and age determinations), new bathymetric studies in the Gulf of Tadjourah, detailed seismicity data and seismic profiling, new quantitative models were proposed for the penetration of the Aden oceanic spreading axis within eastern Afar and the deformation of the lithosphere in the south-western part of the Afar floor. Block rotation was shown to occur together with bookshelf faulting affecting the 3.5–1 million years old stratoid series (Manighetti et al. 1997, 1998, 2001a, b), providing more precise information than the microplate deformation model proposed by Barberi and Varet (1977).

Similarly, the Dabbahu event which affected the northern part of the Manda Harraro range at Da'Ure in September 2005 (Fig. 2.31), followed by successive small basaltic emissions in 2007, 2009 and 2011, allowed for a new geo-scientific investigation into Afar geology and geophysics in the years 2005–2012. This volcanic range, already identified by Varet and Treuil (1973) and Barberi and Varet (1975) as the most active spreading segment in Afar, opened up to 8 m width along a 70-km axis. The event was preceded by an international conference held in Addis Ababa in June 2004 entitled "The East African Rift System: Geodynamics, Resources and Environment", which was summarised in a special publication (N°259) of the Geological Society of London entitled "The Afar Volcanic Province Within the East African Rift System" edited by Yirgu, Ebinger and Maguire in 2006. This important volume (336 pp) includes 17 articles: Plate kinematic and geodynamic framework of the Afar volcanic province (Part 1), Geochemical constraints on flood basalt and rift processes (Part 2), Rifting in the Afar volcanic province: modelling and kinematics (Part 3) and

Table 2.1 Translation of a few Afar words of use in toponymy

English	Afar
Nouns	
Mountain, massif	‘Ale
Mount, hill	Kôma
Rock, small rocky hill or plateau	Dâ
Large rocks	Deet
Plateau	Râsa
Ridge	Gêra
Summit	San
Cape, point	Damum
Col, pass	Dâba
Hole	Bôdu
Fire	Kira
Plain	Bahari
Powder	Bodo
Valley, oued	Da’ar
Small valley	Dabba
Water, water point	Lê
Well	Ela
Shallow well	Buyyi
Lake, sea	Bad
Adjectives	
Large	Kadda
Small	‘Unda
Black	Data
White	Ado
Red	‘Asa
Yellow	Hurud
Green	Ar’Dar

Rifting in the Afar volcanic province: geophysical studies of crustal structure and processes (Part 4). This initiative helped, following the 2005 event, to establish the “Afar Rift Consortium”, supported by NSF (USA) and NERC (UK). It included American, British, Ethiopian and French geophysical and geological teams who built a research program answering the invitation of the Ethiopian authorities, with heavy involvement of the University of Addis Ababa geology department and geophysical observatory. This allowed the development of a new research approach providing insights on the characteristics and behaviour of the lithosphere and asthenosphere in the central Afar triple rift junction and mantle plume.

Following the Manda-Hararo sequence of volcano-tectonic events, an international symposium entitled “Magmatic Rifting and Volcanic Activity” was organised in Addis Ababa, Ethiopia on the 11–13 January, 2012, attended by more than 200 geoscientists, including at least 50 Ethiopian research staff and students, and marked the end of the 5-year Afar Rift Consortium project. A total of 67 oral presentations and 66 poster contributions were presented, covering the themes of active magmatic rifting, mid-ocean

Table 2.2 Some useful geological terms

Geological terms	
Earth	Baloo
Basalts (black rocks)	Dâta Deet
Rhyolites (red rocks)	‘Asa Deet
Scoriaceous lava flow (“Aa”)	Manda
Smooth lava flow (Pa Hoe Hoe)	Rasa
Cooked earth	Alayta
Fault	Andidou
Earthquake	Baloo Anguaui
Open fissure	Adale Andidou
Necked clay plain	Bôda
Pasture land	Affara Dara
Evaporitic plain	Koubi Adoul
Diatomite (white powder)	Ado Bodo
Travertine	Diikiil
Hot spring	Ni’iI Lê
Fumarole	Boïna
Eruption	Badok Tawle
Smoke	‘Irta
Intermittent hot spring (coughing water)	Kahouh Ye
Salty water	Asbo lê
Water spring	Geda Lê
Cold water	Da’Him Lê
Putrefied lake	Abhe Bad
Mer (bad water)	Ad’He bad
Camel hill	Gali Koma
Coloured mountain	Bora’le Ale
Stomach mountain	Ale Bagu
Long mouth	Afdera

ridge processes, rifted continental margins, mantle-lithosphere interactions and the causes of breakup, natural hazards, rifting and climate, and resources from magmatic rifts. The session included: (1) Recent activity in Afar; (2) Structure and origins of Afar, both mainly centred on the Manda Harraro-Dabbahu event; (3) Magmatic rifting in Iceland, allowed for useful comparisons; (4) Resources from magmatic rifts (for which two sessions dealt with geothermal, epithermal gold and oil); (5) Geohazards from volcanic or tectonic origin, including effects on dams in the Awash valley; (6) MOR processes was based on examples from Aden and mid-Atlantic Ridges; (7) Kinematics, dynamics and structure in Afar and Asal concerned crustal deformation (block rotation) and the active Asal-Goubbet Rift; (8) Mantle-lithosphere interactions was based on seismic imaging, thermal regime and magmatic mantle processes in the East African Rift; (9) Rifting and climate was dedicated to undergoing climate change studies in the East African Rift; (10) Continental rifting and continental margins dealt with Afar margins and comparisons with the Atlantic and the Red Sea; (11) Active magmatic rifting was based on satellite imagery processing, seismic anisotropy, and petrological and geochemical modelling.

Fig. 2.24 Girl carrying the wood (for cooking needs) back home (*Photo credit* Ismail Ali Gardo)

Fig. 2.25 Young Afar man with the traditional "Jile" (*Photo credit* Ismail Ali Gardo)

Several other eruptive events affected the Afar area in recent years, including:

- The Jebel al Tair basaltic eruption in the Southern Red Sea in September 2007.
- The Alu-Dalla Fila eruption in the northern part of the Erta Ale range in November 2008.
- The Dallol phreatic eruption in January 2011 (non-volcanic).
- The major Nabro caldera pyroclastic and lava flow eruption in June 2011.
- The submarine hyaloclastite eruption of Zubair giving birth to a new island 180 m high, north of the archipelago in December 2011.
- Not to mention the Erta Ale continuous activity in both lakes, the central one still fluctuating, and the northern one exhibiting a hornito activity (Fig. 2.32). In 2014 an eruptive event occurred with a flow outside the caldera along the northern rim followed by the appearance of a new active pit crater in the northern lava lake (Fig. 2.33). In early 2017, while this book edited, a new fissure appeared along the axis of the wide elliptic caldera colapse located south of Erta Ale caldera followed by an important basaltic eruption, still flowing after 8 month, whereas several new active craters appeared along this NNE-SSW fissure. A new active lava lake appeared in the central part of this wide southern sink.

Fig. 2.26 Afar girls with dough prepared to bake bread in an oven dug in the soil and pre-heated with firewood (*Photo credit* Ismail Ali Gardo)

Fig. 2.27 Haroun Tazieff with H.H. Ras Mengesha Seyoum, Governor of the Tigray province, who supported the CNR-CNRS Afar expeditions (*Photo* Marinelli 1967)

Fig. 2.28 Professor Giorgio Marinelli in the field in Afar Universita di Pisa (Italy; *photo* F. Barberi, 1967)

Fig. 2.29 Franco Barberi and Jacques Varet at Lake Afrera (*Photo* Marinelli 1967). The author had burnt his legs on the fumarolized top of Gada Ale volcano (Erta Ale range)

Fig. 2.30 The eruption of Ardoukoba volcano in the Asal rift axis, November 7–14, 1978 (Demange and Tazieff 1978; Demange et al. 1980); in the background, one of the normal faults bordering the Asal Lake, on the NW side of the rift

Fig. 2.31 Manda Harraro range September 2005 rifting event. View from the north (with people for scale) of the Da'Ure 500 m-long fissure vent formed during Dabbahu's historical eruption. A small pumice dome was formed besides pumice falls. The central part of the Dabbahu volcano is seen on the first horizon line (Vye-Brown et al. 2013)

Fig. 2.32 The Erta Ale volcano, seen from the north, with its two lava lakes, active at least since 1967 when discovered by Tazieff (1968), one located north of and the other to the centre of the elliptic caldera elongated NNW-SSE (Red Sea direction). The southern lava lake is not active. A larger elliptic caldera collapse is observed to the south, where the Haili Gub rift volcano is also visible, marking the southern extremity of the Erta Ale range (*Photo* Varet 1972). It is along a fissure affecting the axis of this wide caldera that new basaltic activity is observed and continues for several months

Fig. 2.33 In January 2014, it was observed that the lava lake at the central pit had risen up near to the rim. This was followed by a rise of the lava in the northern crater with basaltic overflow in the northern caldera. This eruption was followed by the appearance of a new pit crater inside the northern lava lake where the major activity is now located. (*Photo* from the east, looking SW; Ale Bagu volcano in the back; Geoff Maclay, March 3, 2014)

References

Allan TD (1970) Magnetic and gravity fields over the Red Sea. *Phil Trans Roy Soc* A 267:153–180

Aubry A (1855) Observations géologiques sur le pays Danakil, Somalie, le Royaume du Choa et les pays Galla. *Bull. Soc. Geol. Fr*. Vol. XIV.

Bannert D, Kedar EY (1971) Plate tectonics in the Red Sea region as inferred from space photography. NASA, Washington

Bannert D, Brinckmann J, Kading K, Ch. et al. (1970) Zur Geologie der danakil-Senke (Nôrdliches Afar Gebiet, NE-Aethiopien. *Geol Rundsch* 59/2:409–443

Barberi F, Varet J (1970) The Erta `Ale volcanic range. Bull Volc 34:848–917

Barberi F, Varet J (1975) Volcanological research in Afar (L. R. Wager prize summary lecture). Bull Volc 39(2):166–174

Barberi F, Varet J (1977) Volcanism in Afar: small-scale plate tectonic implications. Bull Geol Soc Amer 88:1251–1266

Barberi F, Borsi S, Ferrara G, Marinelli G, Varet J (1970) Relations betweentectonics and magmatology in the northern Danakil Depression (Ethiopia). Philosophical Trans Royal Soc London A267:293–311

Barberi F, Tazieff H, Varet J (1972) Volcanism in the Afar depression: its tectonic and magmatic significance. Tectonophysics 15:19–29

Blanford WT (1870) Observations on the geology and zoology of Abyssinia, made during the progress of the British Expedition to that country in 1867-68. McMillan, London

Brinkmann J, Kursten M (1969) Geological sketchmap of the Danakil Depression (1:250.000). Budesantalt jur Bodenfoschung. Hannover. 4p.

CNR—CNRS Afar team (1973) Geology of northern Afar (Ethiopia). *Rev Geogr Phys Geol Dyn* 15:443–490

Dainelli G (1943) Geologia dell' Africa Orientale. *Rend. Acc. It. Roma*

Dainelli G, Marinelli O (1912) Risultati scientifici di un viaggio nella colonia Etitrea. *Publ. R. Istit. St. Sup. E ref. di Firenze*, p 601

Demange J, Tazieff H (1978) L'éruption tectonique de l'Ardoukoba (Djibouti). *C.R.* Acad Sc Paris 287:1269–1272

Demange J, Stieltjes L, Varet J (1980) L'éruption d'*Asal* de novembre 1978. Bull Soc Géol France 12 (6):837–843

Desio A (1941) Apunti Geomorfologici sulla Dancalia occidentale. *Bol R Soc Geogr Ital* Vol. VI

Doubre C, Manighetti I, Dorbath C, Dorbath L, Jacques E, Delmond J-C (2007a) Crustal structure and magmato-tectonic processes in an active rift (Asal-Ghoubbet, Afar, East Africa): 1. Insights from a 5-month seismological experiment. *J Geophys Res* 112

Doubre C, Manighetti I, Dorbath L, Dorbath C, Bertil D, Delmond J-C (2007b) Crustal structure and magmato-tectonic processes in an active rift (Asal-Ghoubbet, Afar, East Africa): 2. Insights from a the 23 year recording of seismicity since the last rifting event. *J Geophys Res* 112

Gortani M (1949) Il problema delle fosse tettoniche africane e le ricerche italiane in Dancalia. *Ann Hébert et Aug* 7:201–222

Gortani M (1951) Risultati di une spedizione geologica nella Dancalia meridionale. *Proc XVIIIth sess Intern Geol Congr London, 1948*, XIV:193–198

Gouin P, Mohr PA (1964) Gravity traverses in Ethiopia. *Bull. Geoph. Obs. Addis Abeba* 3(3):185–240

Haga AO, Youssouf SK, Varet J (2012) The Manda-Inakir geothermal prospect area, Djibouti Republic. Proceedings of the 4th African Rift Geothermal Conference. Nairobi, Kenya, 21-23 November 2012, 7p

Heike Merlin O (1950) I basalti dell' Africa Orientale. *Mem Ist Geol Min Univ Padova*, 17

Holwerda JG, Hutchinson RW (1968) Potash bearing deposits in the Danakil area, Ethiopia. *Econ. Geol*. 63:124–150

Hutchinson RW, Engels GC (1970) Tectonic significance of regional geology evaporate lithofacies in Northern Ethiopia. *Phil. Trans. Roy. Soc. London A*. 267(1181):313–329

Issel A (1869) Malacologia del Mar Rosso. Ricerche zoologiche e paleontologiche. Pisa

Johnston (1884) Travel in southern Ethiopia through the country of Adal and the kingdom of Shoa. London.

Justin Visentin E, Zanettin B (1968). Prime osservazioni geologico-petrografiche Dancalia interna fra Sardo e Dallol. *St Trent Sc Nat* 45, N°1

Manighetti I, Tapponnier P, Courtillot V, Gruszow S, Gillot P-Y (1997) Propagation of rifting along the Arabia-Somalia plate boundary: The gulfs of Aden and Tadjourah. J Geophys Res 102:2681–2710

Manighetti I, Tapponnier P, Gillot P-Y, Jacques E, Courtillot V, Armijo R, Ruegg J-C, King G (1998) Propagation of rifting along the Arabia-Somalia plate boundary: Into Afar. J Geophys Res 103:4947–4974

Manighetti I, King GCP, Gaudemer Y, Scholtz CH, Doubre C (2001a) Slip accumulation and lateral propagation of active normal faults in Afar. J Geophys Res 106:13,667–13,696

Manighetti I, Tapponnier P, Courtillot V, Gallet Y, Jacques E, Gillot Y (2001b) Strain transfer between disconnected, propagating rifts inAfar. J Geophys Res 106:13,613–13,665

Marinelli G, Varet J, (1973) Structure et évolution du Sud du "horst Danakil" (TFAI et Ethiopie). *C.R. Acad Sci*, (D) 276:1119–1122

Mohr PA (1967) Major volcano-tectonic lineament in the Ethiopian Rift system. Nature 213:664–665

Munzinger W (1869) Narrative of a journey through the Afar country. J Royal Geogr Soc 39:188–232

Nesbitt LM (1934) Desert and Forest: the exploration of Abyssinian Danakil (London: Jonathan Cape) pp 450 (Also Published in 1935 by A. A. Knopf, New York, under the title 'Hell-hole of creation: the exploration of the Abyssinian Dankil')

Ruegg JC, Kasser M, Lépine JC, Tarantola A, (1979). Geodetic measurements of rifting associated with a seismo–volcanic crisis in Afar. Geophys. Res. Lett. 6:817–820

Ruppel E (1934). Skizze der geologischen formationen Abyssiniens. Mus. Senckenberg. 1.

Salt H (1814) A voyage to Abyssinia and travels into the interior of that country executed under the orders of the British Government in the years 1809 and 1810. Revington, London

Tazieff H (1968) Relations tectoniques entre l' Afar et al Mer Rouge. Bull. Soc. Geol. DFr., 7 (X):468–477.

Tazieff, H, Varet, J. (1969) Pétrographie et tectonique de l'Afarseptentrional (Ethiopie). Colloque Géol. Africaine Clermont-Ferrand (résumé). Ann Fac Sc Clermont (41):54

Tazieff H, Marinelli G, Barberi F, Varet J (1969) Géologie de l'Afar septentrional Symposium *Ass. Interna. Volcanologie; Canarie*s. *Bull. Volc*., t. XXXIII-4, pp 1039–1072

Tazieff H, Barberi F, Giglia G, Varet J (1972) Tectonic significance of the Afar (or Danakil) depression. Nature 235:144–147

Treuil M, Varet J (1973) Critères volcanologiques, pétrologiques et géochimiques de la genèse et de la différenciation des magmas basaltiques exemple de l'Afar. Bull Soc Géol France 7(15):506–540

Varet J (2013) The Afar system and carbonates. Cocarde workshop (abstract), Sicily, p 48–49

Vye-Brown C, Smith K, Wright, T (2013) Active rifting, magmatism and volcanism in the Afar depression, Ethiopia. Large Igneous Province Commission IAVCEI

Zichy W (1880) Die Danakil Küste. Petern Mittheil 26:292

http://www.springer.com/978-3-319-60863-1

Geology of Afar (East Africa)
Varet, J.
2018, XVIII, 336 p. 377 illus., 346 illus. in color.,
Hardcover
ISBN: 978-3-319-60863-1