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A GEOLOGICAL EXCURSION TO THE MESOZOIC SEDIMENTS OF THE ABAY BASIN (BLUE NILE), RECENT VOLCANICS OF THE ETHIOPIAN MAIN RIFT AND BASEMENT ROCKS OF THE ADOLA REA, ETHIOPIA

by

A. Mogessie, K. Krenn, J. Schaflechner, U. Koch, T. Egger, B. Goritchnig, B. Kosednar, H. Pichler, L. Ofner, D. Bauernfeind, S. Tadesse[1], K. Hailu[2] & M. Demessie[2]

Institute of Mineralogy and Petrology
University of Graz, Austria
[1]Department of Geology and Geophysics
Addis Ababa University, Ethiopia
[2]Ethiopian Institute of Geological Surveys
Ethiopia

1. GENERAL INTRODUCTION

The field excursion to Ethiopia took place from April 5 to 22, 2001. Ethiopia has a varied geology and spectacular topography with the major East African Rift cutting its plateau into two halves. The areas visited are i) the Blue Nile Gorge (the river Abay Gorge as locally known) containing a complete stratigraphy of the Ethiopian geology starting with a Precambrian rock unit at the base overlain by a thick sequence of Mesozoic sediments capped by the Tertiary trap basalts making up the Ethiopian plateau; ii) the Main Ethiopia Rift containing a number of lakes and geothermal fields and iii) the Adola gold belt including the Kenticha tantalum-bearing pegmatites (Fig. 1). Nine earth science students (7 from the University of Graz and 2 from the Mining University of Leoben) took part in this excursion. The nine students were divided into three groups. The first group (K. Krenn, B. Kosednar and T. Egger) was responsible for the report on the Blue Nile gorge and the road geology from Addis Ababa towards the Ethiopian Rift; the second group (U. Koch, B. Goritschnig and L. Ofner) wrote the report on the Ethiopian rift and the third group (J. Schaflechner, H. Pichler and D. Bauernfeind) was responsible for the report on the Adola belt and the Kenticha pegmatites. A geological excursion guide was compiled by Dr. Solomon Taddesse of the Addis Ababa University which was used during the excursion. The present report is compiled and edited by A. Mogessie using the student reports, the excursion guide and literature data.

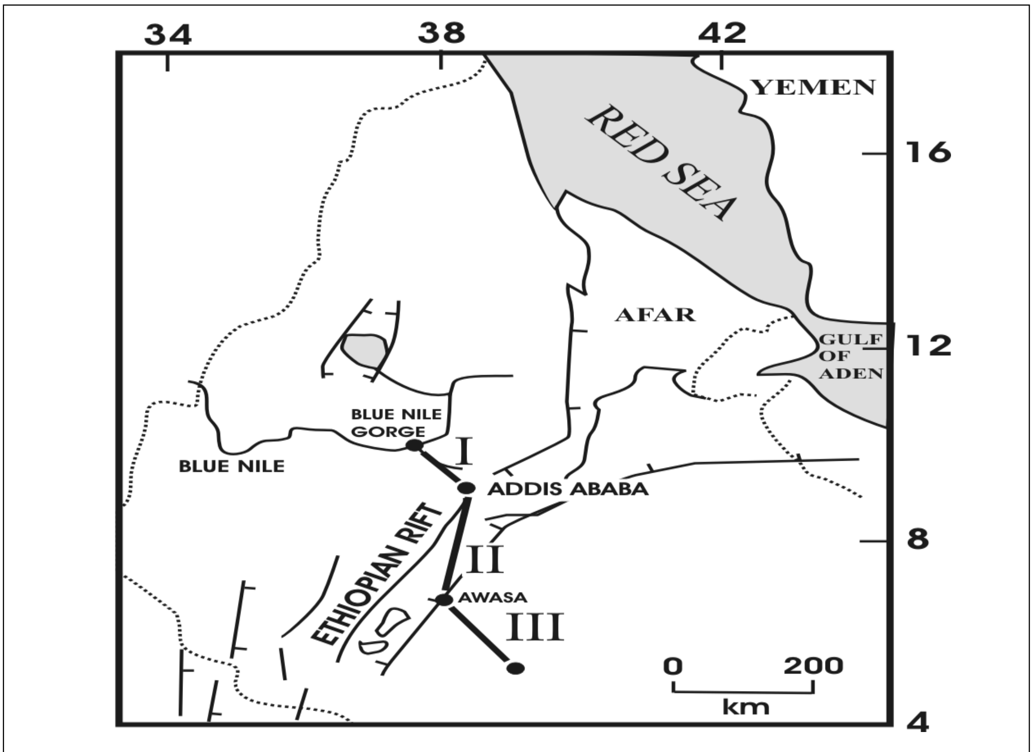

Figure 1
Location of the excursion routes (I. Blue Nile Gorge – Addis Ababa, II. Addis Ababa – Awasa, Rift Valley, III. Adola Belt). See Fig. 17 for details.

2. INTRODUCTION TO THE GEOLOGY OF ETHIOPIA

The basement upon which all the younger formations were deposited contains the oldest rocks in the country, the Precambrian, with ages of over 600 million years. They are exposed in areas where the younger cover rocks have been eroded away. The Precambrian contains a wide variety of sedimentary, volcanic and intrusive rocks which have been metamorphosed to varying degrees. The basement in the south and west, where granitic rocks and gneisses predominate, has been higher metamorphosed than the Precambrian sequences in the north which is metamorphosed to greenshist facies.

The Basement rocks contain most of the presently known metallic deposits of Ethiopia. In particular, the gold deposits of the northern, western and southern provinces all occur in the same rock units, where they are associated with fracturing, quartz reefs or sulphides. Under favorable conditions these deposits have given rise to major placer deposits along river beds, as in the Kibre Mengist-Adola area. Similarly occurrences of potentially exploitable talc and nickel deposits are associated with ultrabasic bodies, and in a layered body of this type platinum mineralisation occurs at Yubdo in Welega Province.

At the end of the Precambrian time uplift occurred, which was followed by a long period of erosion. Sediments which were deposited during the Palaeozoic time interval, which lasted some 375 million years, have been largely removed by erosion, except for shales and deposits partly of glacial origin laid down in northern Ethiopia towards the end of this period. Subsidence occurred in the Mesozoic, which began some 225 million years ago, and a shallow sea spread initially over the south-eastern part of Ethiopia and then extended farther north and west as the land continued to subside. As a consequence sandstone was deposited. Deposition of mudstone and limestone followed as the depth of water increased. In western Ethiopia sedimentation ended with the deposition of clay, silt, sand and conglomerate brought in from the land as the sea receded due to uplift of the landmass. In the southeast gypsum and anhydrite were precipitated on inter-tidal flats. Again there was a fresh invasion of the sea in the south-east in Late Mesozoic times during which the sequence of sedimentation was repeated, ending with the precipitation of gypsum and anhydrite. The same cycle of sedimentation was repeated in the south east in the Ogaden during the Tertiary period. It ended with the deposition of conglomerates. sandstones and mudstones with some interbedded marls, and finally erosion as the area was uplifted.

Extensive fracturing occurred early in the Cenozoic, the earliest rocks of which are dated at 65 million years, although major displacement along the fault systems which approximates to the alignment of the Red Sea, Gulf of Aden and East African rift systems did not occur until later in the Tertiary. Faulting was accompanied by widespread volcanic activity and the two processes, which are partly related, have largely determined the form of the landscape in the western half of Ethiopia and in the Afar Depression. The outpouring of vast quantities of basaltic lava over the western half of the country was accompanied by, and alternated with, the eruption of large amounts of ash and coarser fragmental material, forming the Trap Series. More recent volcanism is associated with the development of the Rift Valley, activity being concentrated within this structure and along the edge of the adjoining plateau.

Volcanism has persisted into the present time in the Afar region within small eruptive centers. The composition of the lavas produced ranges from basalt to rhyolites. The youngest sediments are of Quaternary age. These include conglomerate, sand clay and reef limestone which accumulated in the Afar Depression and the northern end of the main Rift Valley (KAZMIN, 1975).

3. THE BLUE NILE GORGE

3. 1 The geology of the Blue Nile Gorge and the surrounding areas

The Northwestern and Southeastern plateaus of Ethiopia are separated by the Rift Valley. Along the western margin of the Northwestern Plateau in the Blue Nile Gorge, a 2000 m section of Mesozoic strata capped by massive Tertiary volcanics is exposed. It includes ca. 600 m of Late Jurassic-Early Cretaceous sediments. The altitude of the plateau ranges from 3000 to 4000 m in the northeast and around 1500 m in the southwest, with an average height between 1800 to 2500 m. The basement of Ethiopia consists of metamorphic and igneous rocks of Precambrian and Lower Paleozoic age. Between the Ordovician and Early Mesozoic a system of northeasterly as well as northwesterly trending troughs were filled with continental sediments. Early Jurassic marine sediments filled this troughs and at Late Jurassic time, the transgressive sea was widespread over a part of Ethiopia. Regression happened at the end of the Jurassic.

3. 2 Mesozoic Sediments of the Blue Nile Gorge (Abay River Basin)

Mesozoic sediments are widely deposited in Ethiopia during a continuous subsiding period of the land and migration of the sea from east, in the Ogaden towards the west and north covering the central part and northern areas of the country. Today a large part of these Mesozoic sediments are exposed on the Eastern Ogaden, central dissected plateau areas in the Blue Nile river basin and in northern Tigray around Mekele.
The Abay River section (Fig. 2) is exposed along a road cut at the Addis Ababa-Debre Marcos highway, between kilometer marks 198 and 215. As part of the Northwestern Plateau, the Blue Nile Basin covers 204 000 square kilometres.

Figure 2
View of the Mesozoic stratigraphy, Blue Nile Basin. The upper part is Tertiary volcanics, the lower part is a metamorphic basement and the middle section is Mesozoic sediment (see Figure 3).

The typical Mesozoic succession of the basin is about 1200 m thick and includes from bottom to top five formations (Fig. 3): i) Lower Sandstone or Adigrat Sandstone (Triassic), ii) Gohatsion Formation or Abay Beds, iii) Antalo Limestone (Jurassic), iv) Muddy Sandstone (Mugher Sandstone) and v) Upper Sandstone (Cretaceous).

The Paleozoic and the Mesozoic sediments are the base for discordant layers of thick massive flood lavas, mainly basalt, which are generally Post-Oligocene in age and reach a maximum thickness of 5500 meters.

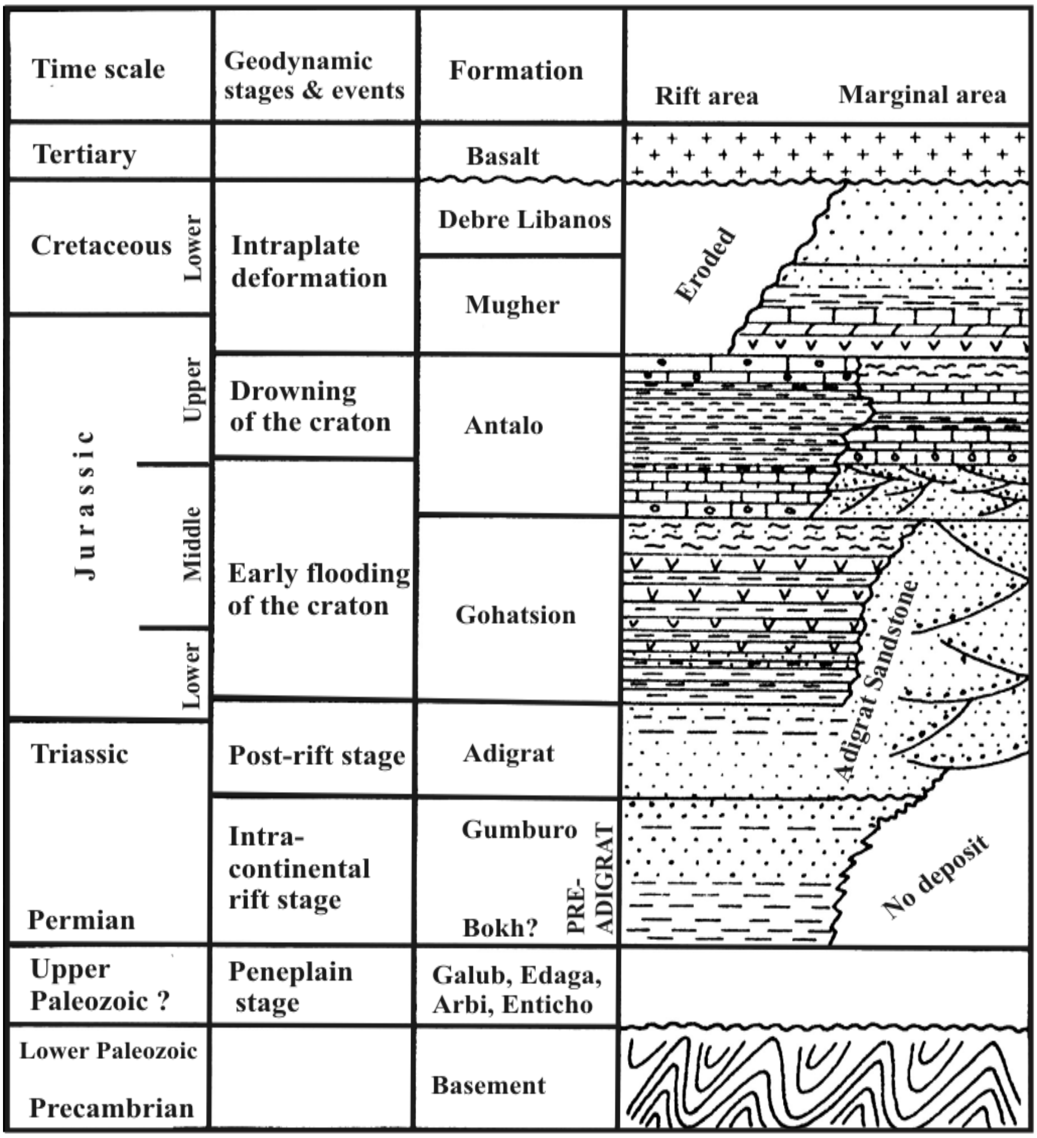

Figure 3

Chronostratigraphy, major geodynamic events and lithostratigraphy of the Abay (Blue Nile) Basin.

3. 3 Summary of the main sedimentary sequences of the Abay River Basin

i) Lower Sandstone unit (Pre-Adrigat and Adrigat Sandstone): The Lower Sandstone unit unconformably overlies the basement and in some places Paleozoic continental sediments. The thickness ranges from about 100 m to 700 m; in the Abay River Basin. In the excursion area they are about 300 m thick and outcrops on both sides of the river, forming nearly vertical cliffs. This unit is formed by several layers with the thickness of the layers varying from 30 cm at the bottom to 1m near the top. They appear as fine-grained sandstones intercalated with reddish shales and siltstones, mudstones and beds of conglomerates. Medium- to coarse–grained sandstone including planar crossbedding structures are characterisitic. The upper part, which is about 40 meters thick, is also formed by a number of fining-upward sequences with reddish coarse sand at the base and siltstone (10–20 cm thick) at the top. The boundary with the overlying shale-gypsum-shale unit is transitional, and consists of interbedded sandstone, siltstone, mudstone, and shales at its lower part. The upper part is characterised by alternations of gypsum, dolomite, limestone and shales.

ii) Gohatsion Formation: at its lower part, this formation is represented by greenish, grey or brown coloured dolostones of about 50–80 cm thick and shales. The dolostones are characterized by flute casts at the base of beds, ripples and flaser bedding at the lower part and parallel lamination at the top. Probably they represent deposits in shallow ponds and lagoons. At the top occur mudstones with thin layers of angular quartz including fossils like bivalves and gastropods, further fine siltstone with small bivalves and gastropods, fine-grained sandstones with cross-lamination at the base and parallel lamination at the top. This sequence is cyclically repeated. The middle part is formed by several cycles: non fossiliferous shale, dolostone with bivalves, fine-grained sandstone and thick beds of gypsum. In the lower part of this zone the layers are thinner than in the upper part. The upper part is characterised by fossil free, green, red and brown clays and siltstone covered by dolostone.

iii) Antalo Limestone: the bottom of this unit is characterized by fossiliferous and burrowed mudstone and oolitic limestone with corals, stromatoporoids, bivalves, gastropods, echinoids, foraminifers and ostracods. Silty limstone with very thin marl layers follow. The upper part is formed by 5 m thick massive limestone. Total thickness reaches about 180 m. The middle and the upper part of the Antalo Limestone are characterized by marly limestones, silty limestones and hard limestones at the top and a planar laminated oolitic and reef limestone, followed by bedded mudstones at the base. The maximum thickness of the oolitic unit is 170 m. This hard limestone unit was formed in shallow water, which is documented by the occurrenec of oolitic bars, coral offshore patches and more protected inshore facies. Boundaries on both sides of this unit are transitional.

iv) Muddy Sandstone Formation: this unit is not found in the Abay section, but is exposed in the canyons of Mugher, Ega, Wodem, Dersena, Beresssa, Adabai, Zhema, Wenchit and Chennli rivers. Alternating gypsum, dolomite and shale make up the lower part of this unit which has a. thickness of about 15 m. Gypsum occurs as vug- and vein-filling in the dolomite and shales, and also as lenses and beds. Dolomites are grey, yellow and brown and show a dolomitic content ranging from 56 to 97 percent (average 84 %) with calcite, clay and quartz making up the rest. The shale is green, yellow or dark grey and is often calcareous or dolomitic.

It is laminated and contains a few thin laminae (4 mm to 1.5 m) and veinlets of bluish grey to white gypsum. Fossils are extremely rare. The upper part of the unit is composed of a 240 m thick vari-coloured mudstone, including yellow, green, red, tan, white, purple, brownish red and various shades of grey. It also shows massive bedding, thin laminae and ripple lamination. Locally thin beds of lignite and carbonaceous siltstones occur, which contain cross-lamination and convolute bedding with grey-green colour. Clay minerals like kaolinite, illite, chlorite, montmorillonite and mixed-layer minerals, as well as quartz, K-feldspars and muscovite have been found as detrital components.

A sandstone facies follows with fine- to medium grained standstone, subdivided into fining upward sandstones and thick massive sandstones. The grain size of the first type decreases upward, from medium-grained at the base to fine-grained sandstone at the top. In addition it contains planar cross-bedding at the base and rippled cross-laminations at the top.

The second type is composed of fine to medium-grained sandstones with no visible sedimentary structures. The sandstones and siltstones consist of quartz, K-feldspars, muscovite, plagioclase, kaolinite and illite, and minor amounts of calcite, dolomite hematite tourmaline, zircon and rutile. Thin, very fine-grained sandstone and siltstone beds with a relatively high degree of sorting occur sporadically within the Muddy Sandstone Formation and may represent deposition by wind energy.

v) Upper Sandstone: this unit consists of mainly grey, brown and red sandstone with intercalated lenses of conglomerate and claystone. It is mainly exposed in the valley of Zega Wodem river. The thickness of the formation varies between 0 and 280 m. Main sedimentary structures seen in the sandstones are large and small scale planar-tabular and asymmetrical trough cross-beds, convolute beds, flat-beds, scored and channel surface, and massive beds.

Quartz, K- feldspar and cherts are the major components. Muscovite, clay and iron oxides are minor detrital components. Interstitial minerals are calcite, dolomite, hematite and kaolinite. Heavy minerals such as zircon, tourmaline, rutile, and opaque minerals make up less than one percent of the sandstone. Pebble conglomerates occur throughout the formation. The conglomerate horizons are massive, cross- bedded or horizontally stratified and are ungraded, inversely graded or normally graded. They contain clay-clasts and siliceous pebbles which are well rounded. Brown claystone occurs as thin beds at the top of some fining-upward sequences and makes up less than 10 percent of the formation. Claystone is composed mainly of kaolinite and hematite with subordinate amounts of illite and quartz. The formation is devoid of fossils except silicified fossil woods and is unconformably overlain by Tertiary basalts.

3. 4 Industrial minerals in the mesozoic sediments

The Mesozoic sediments are important for their associated industrial minerals and building materials including limestone, sand, sandstones, gypsum and clays. Favourable conditions for oil and gas are also present. Very large deposits of gypsum and anhydrite are known to occur in the sedimentary formations of Danakil depression, Ogaden, Shoa, Gojjam, Tigray and Harraghe. Total reserves are enormous because the thickness of the gypsum deposits is many hundreds of meters and the formations are known to extend laterally for hundreds of km (GETANEH, 1985). Reserves of dolomite deposit at Hula-Kuni has been estimated to be over 1.434.000 tons.

3. 5 Geodynamic stages and events

For a better unterstanding of the sedimentary evolution of the Abay River Basin (Blue Nile Basin) a summary is presented below:

1. Peneplain stage: represents the situation before any tensional effect and before the break-up of Gondwanaland. It corresponds to the Pan-African metamorphic peneplain. This peneplained basement is covered by soil sediments and glacial deposits.

2. Intracontinental rift stage: the breaking up of Gondwanaland produced continental rifts along the borders of Africa as a result of NW-SE tensional stresses with a corresponding thinning of the continental crust. Aulacogen-like basins were formed and filled up with Karroo sediments.

3. Post-rift stage: this stage corresponds to the deposition of basal clastic sediments (Lower Sandstone) over the entire East African craton.

4. Early flooding of craton: corresponds to the rifting stage and subsidence of future African continental margin, and to the eustatic sea level rise. The flooding of the rift basins occurred in Early Liassic time. The internal arms of these basins were later covered by the marine transgression as a backward effect of this event. The Gohatsion Formation represents the beginning of this marine transgression over the Ethiopian craton. Also the Antalo Limestone could be related to a sea level highstand.

5. Drowning of the craton: This stage is related to a major Callovian – Early Oxfordian transgression caused by the Gondwana break up and by the formation of the African continental margin. The deposition of the Muddy Sandstone and the Upper Sandstone units is a result of this event.

3. 6 Tertiary Volcanic Rocks

The rocks of the Trap series are the earliest group of volcanic rocks, which were erupted from fissures during early Tertiary. They consist of piles of flood basalts and ignimbrites which are overlain by shield volcanoes and mainly consist of porphyritic olivine basalt. The basalts are transitional from alkaline to tholeiitic. Within the early Tertiary volcanics, lignite, opal, oil shale, aluminium ores (bauxite), lateritic iron ores, bentonites, industrial clay minerals, perlite and pumice are found.

4. THE RIFT VALLEY

The Ethiopian Rift (Fig. 4) lies in the north of the East African Rift as a part of the Afro-Arabian Rift system. The East African Rift extends from north-eastern Ethiopia to Mozambique in southern Africa, with a length of more than 4000 km. More than one-quarter of the rift system lies in Ethiopia. The whole Rift appears as a system of down-faulted troughs starting from the Jordan-Dead Sea Rift, the Red Sea and the Gulf of Aden and continues southwards through East African Rifts up to Mozambique. From the Lake Turkana basin (in the south) up to the main watershed of Lake Ziway, the floor of the Ethiopian Rift rises in an irregular profile and it descends northwards into Afar. There the floor lies below sea level (max. 150 m) in places like Dallol. The extension rates for the Ethiopian Rift Valley lies between 1 and 3 mm/year. The Ethiopian Rift system can be subdivided into the Main Ethiopian Rift (MER), the Lake Chemo Rift and the Lake Turkana Rift.

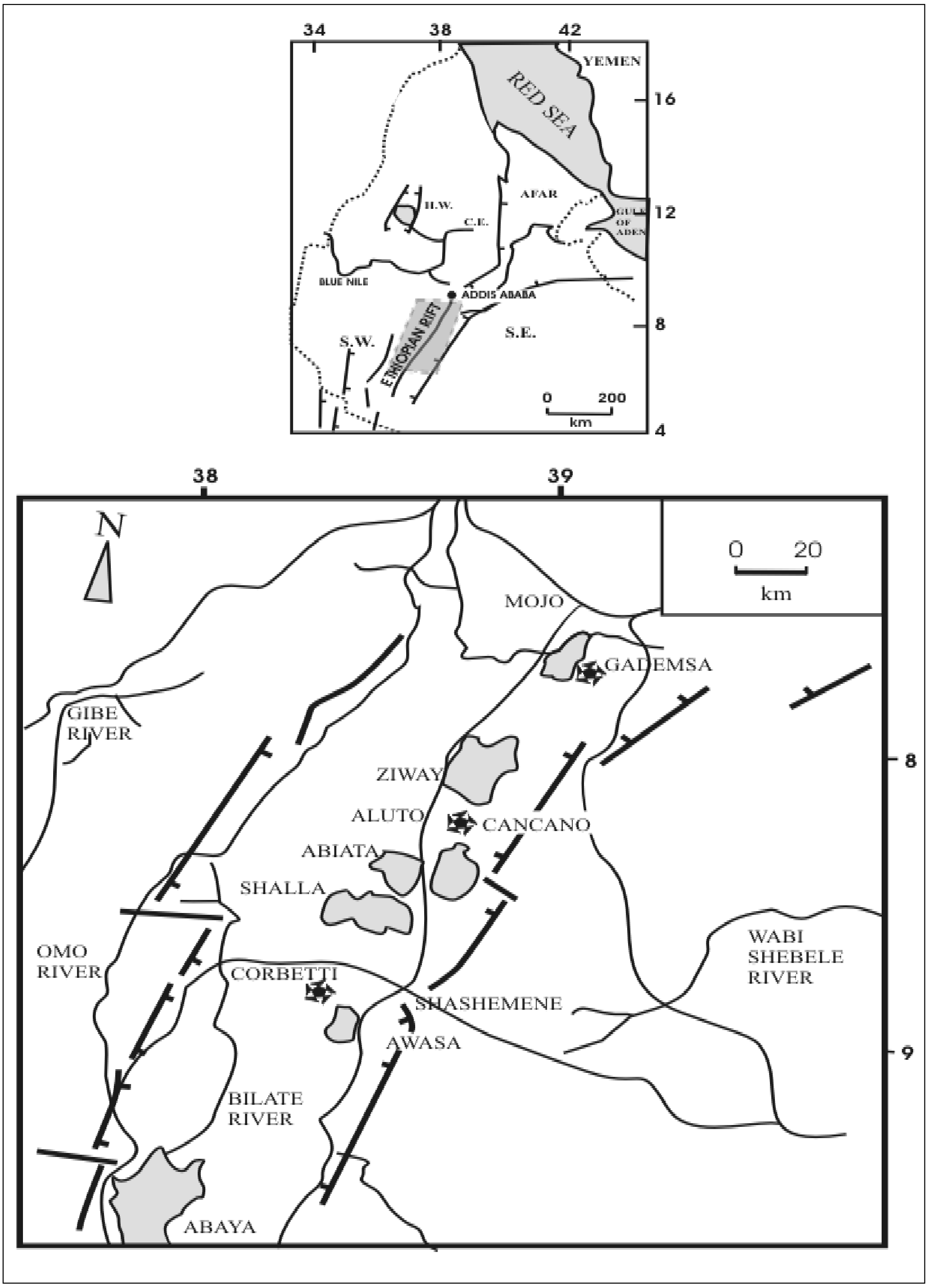

Figure 4
Sketch map of the Ethiopian Rift showing the locations of the different Rift lakes and volcanoes.

The margins of the central MER have an average width of about 70–80 km and are formed by stepped fault zones. The Rift has a length of 700 km stretching from the Ethio-Kenyan border in the south to the Afar Depression in the north and cut across old Tertiary plateau lavas. The highlands of the country are dissected by the Rift into the eastern and western plateaus. The Rift is further bounded on two sides by a series of large normal faults. The eastern escarpment of the MER is characterised by step faults with significant throws in its northeastern sector exceeding 1500 m between the top of the plateau and the rift floor. The western margin is gradational and less marked thus accounting for the asymmetry of the MER. Continuous tectonic movements are confirmed by numerous young faults, affecting Holocene rock units and by the intense seismicity of the whole region (DI PAOLA, 1972). A clear regional and temporal progression of the rifting from north to south is documented. Basaltic volcanic rocks become progressively younger northwards to Afar, although young basaltic volcanism of minor volume is also common along the axial zone of the Ethiopian Rift. 65–40 million years ago, the first cycle of volcanic activity on the Ethiopian Plateau occurred. Especially in the southwestern plateaus, basalts as old as 54 million years have been found. During the period of 28–15 million years rifting occurred with a volcanism that spread over the whole of the northwestern Ethiopian plateau and covered large areas in southwestern Ethiopia and northern Kenya. The important centres of volcanic activity and the thermal high happened in the west. Volcanic events in the last 15 million years were restricted at first to Afar and MER and then to their axial zones. During the period of 10–15 million years the rifting in southern Afar and MER continued.
Basin-fill volcanoclasic sediments and Plio-Quaternary volcanic products cover the rift floor. The plateaus bordering the rift consist of a thick succession of flood basalts and subordinate amounts of rhyolites emplaced during the oligocene. An important petrological feature of the MER is the abundance of silicic peralkaline volcanics related to both the fissural activity from 1.6–1.5 million years ago to recent, and to the several volcanoes rising from the rift floor. The recent type of volcanism occurred mainly in the axial zone (the Wonji Fault Belt, WFB) in the MER and the axial ranges in Afar. The axial zone of the MER contains the youngest volcanoes, and subdivides the rift floor into several small horsts and grabens till to the edge of the eastern escarpment. Some of these faults form minor rift-in-rift structures. with NNE-SSW direction representing a typical tectonic feature of the Rift Valley.
Rift volcanics and sediments are important for geothermal energy (e.g. Aluto Volcano), soda ash, epithermal gold, diatomites, bentonites, salt, sulphur, pumice and others.

4. 1 Gademsa Caldera

Gademsa is a recent (0.8 to 0.1 Ma) volcano in the central sector of the MER. The lowest exposed volcanic products are acidic lavas covered by thick plinian pumice deposits, which are overlain by an ignimbrite sheet. In the northern part of the volcano basic surge deposits are found. Products of post-caldera activities are acidic lava and pyroclastics. The volcanic products are peralkaline trachytes and rhyolites, mafic rocks occur only as inclusions within some of the post-caldera products (PECCERILLO et al., 1995).
The composite structure of the caldera was formed by repeated large plinian pyroclastic eruptions and the geometry of the caldera is almost circular, measuring about 10 kilometres (Figs. 4, 5). The whole caldera structure is strongly affected by many large closely-spaced NNE-SSW trending faults, especially at its eastern part. These faults belong to the Wonji Fault Belt and manifest active tectonics within the rift.

Figure 5
View of Gademsa Caldera.

Evidence of past hydrothermal activity is observed in the north-west caldera wall and on a small dome inside. Gademsa caldera is the northernmost studied area in the MER where epithermal mineralization occurs. Rhyolite lavas, ignimbrite and pumice deposits represent the host rocks. The alteration belongs to the low sulphidation type. and covers a roughly NW elongated area some 5 km long and several hundred metres wide. Propylitic alteration, which is largely affected by later intermediate argillic alteration, surround the zone of potassic alteration. Several thin quartz adularia veinlets cut the zone of potassic alteration. The occurrences are formed of crust-form quartz and granular quartz. Carbonates and clay minerals are also present. The ore mineral assemblage includes pyrite, chalcopyrite, enargite, iron oxide minerals, epidote, chlorite and gold. In the western part of the caldera, pyrite occurs in fractured propylitized rhyolite, with narrow zones of potassic alteration and development of intermediate argillic alteration. In the fractures, thin veins of cavernous quartz with abundant copper sulphide dissemination occur. Gold content ranges from 100 to 440 ppb and is related to quartz veins. Precipitation of quartz veins is related to WNW-ESE transtensional rift tectonics (Figs. 6a, b).

4. 2 Aluto Volcano

Aluto (Fig. 4) is a Quaternary volcanic centre located along the Wonji Fault Belt in the central sector of the MER. The geology of this complex is relatively well-known from surface mapping supplemented by data on the deep stratigraphy and structure from eight deep exploratory wells that were placed to depths ranging from 1300 to 2500 m.

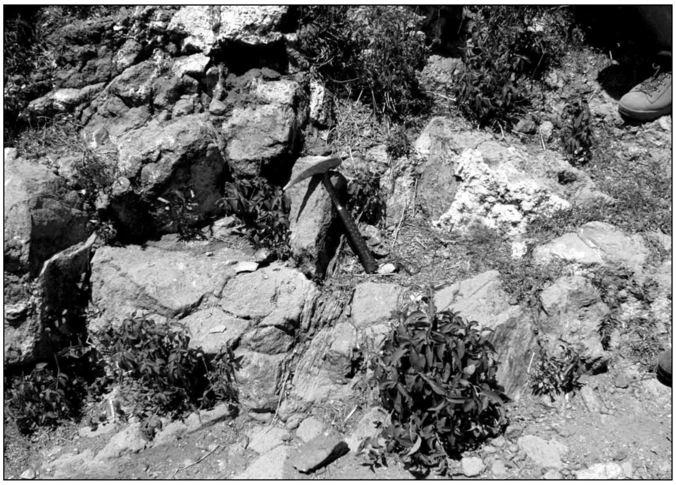

Figure 6a
A shear zone within a gold mineralized quartz vein.

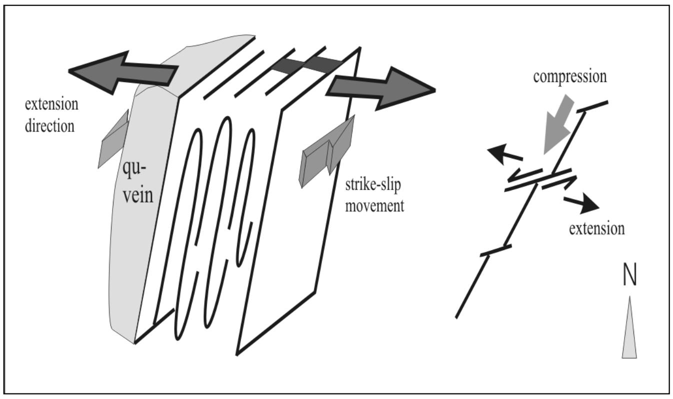

Figure 6b
A schematic structural view of figure 6a.

According to GIOVANNI & MSERET (1993) the oldest outcropping rocks in the area are found at the adjacent eastern rift escarpment and consist mainly of silicic volcanics commonly known as the Tertiary ignimbrite unit. This unit is overlain by a fissural basaltic unit known as Bofa basalt, which in turn is covered by sediments of lacustrine origin that extends over large areas of the rift floor. The volcanic products of the Aluto volcanic centre itself consist of a succession of ash-flow tuffs, silicic tuff breccias, silicic domes and pumice flows. These volcanic products are very young and are associated with surface thermal manifestations that consist of hot springs and fumaroles with temperatures of up to 95°C, steaming grounds, silica sinter and travertine deposits. The hydrothermal deposit temperatures measured in the deep exploratory wells range from 88 to 335°C. The alteration observed in the studied samples from Aluto include an upper facies characterized by intermediate and propylitic assemblages. Intermediate argillic facies are typically represented by smectite group clay minerals; alteration intensity is variable, from incipient groundmass argillification to almost pervasive metasomatism. Propylitic alteration includes the characteristic minerals, calcite, chlorite, adularia, quartz and epidote. The metallic minerals found in the studied samples mostly include oxides and sulphides. The oxides consist of magnetite, ilmenite, hematite and Ti-oxide. Sulphide minerals are pyrite, chalcopyrite, sulphosalts possibly galena. Pyrite is most abundant. Gold value ranges from a few ppb to 100 ppb.

4. 3 Geothermal Resources

Ethiopia is considered to be one of the favoured countries with respect to high geothermal energy potential. The country´s high enthalpy geothermal energy is mainly concentrated in the MER and Afar rift. Detailed exploration studies within the Ethiopian rift show that the areas of Aluto-Langano, Tendaho graben, Corbetti caldera, Gademsa caldera, lake Abaya and Dallol are the most promising for tapping a tremendous amount of geothermal power.

In the Aluto-Langano, the capacity of the existing deep wells is close to 30 Mega Watt; the energy potential of the field is estimated between 10–20 MW/km^3 for over 30 years. Similarly, the capacity of the existing producing wells in Tendaho is about 5 MW (AQUATER, 1996). Other prospect areas are Tullu-Moye, Bossetti, Kone, Fantale, Doffan, Meteka, Teo, Lake Abe and Danab.

4. 4 Industrial Minerals within the Ethiopian Rift and on the road to Adola

4.4.1 Abiata Soda ash (sodium carbonate)

The Ethiopian Rift valley lakes, particularly Lake Abiata, Lake Shalla and Lake Chitu, contain hundreds of millions tons of brines of soda ash. Abiata has revealed the presence of 400,000,000 tons of brines of soda ash (EIGS, 1989). At this locality, 25,000 tons of brines of soda ash are produced annually by a small scale pilot plant. The water of the 8 meters deep lake is high alkaline with a pH of 10 to 11. Dissolved components in the water are: Na_2CO_3 0.5 wt.%, $NaHCO_3$ 0.4 wt.%, NaCl 0.3 wt.% and traces of Na_2SO_4, $NaSiO_3$ and NaF.

The principle of the extraction is to evaporate the alkaline water of the lake to get the soda ash. Production starts with pumping the water with PVC- pipes to the place of evaporation. First the brine gets into a preconcentration pond where the dissolved components are enriched in the brine. This concentrated product ("Trona", $Na_2CO_3HCO_3$) is then pumped into 24 evaporation ponds, which have a total length of 12 km and the form of a "U". After the evaporation process the soda ash is run through a "cascade assorting". First it is dried and then crushed and sieved. If the grains are too big, the crushing and sieving process will be repeated. The final assorting is made by hydrocyclones which work with the principle of centrifugation. The product is used for ceramic, glass, soap and textile industry. Soda ash from this plant is mainly exported to Eastern Africa. The plant has 300 employees working in 8 hour shifts. Unfortunately such a company is facing some environmental problems like seapage and a seaweed problem which goes hand in hand with the increase of temperature.

4.4.2 Diatomite at Bulbula

Ethiopian diatomite deposits are located in Kora Anenu, Lake Abiata and Chorora within the Ethiopian Rift Valley. Diatomite reserves in these localities are estimated at 40,000 tons. The Lake Abiata deposit at Bulbula (Fig. 7) was sedimentated in the Pleistocene and is interbedded with ignimbrite, tuff and pumice. The diatomite contains 82 % silica, the rest is kaolinite. In order to extract the diatomite, first the material is dehydrated then it is micronized in a cyclone to 75 micrometers. Because of its high porosity the micronized diatomite is able to absorb molecules. It is used as a collector for pesticides against cockroaches. The diatomite powder is 50 % WDP (water dispersible).

Figure 7
View of the diatomite outcrop at Bulbula, Lake Abiata.

4.4.3 The Corbetti caldera

Corbetti (Fig. 4, 8a, 8b) is a Holocene volcanic complex found in the central sector of the MER and located 230 km south of Addis Ababa. Most abundant volcanic rocks are peralkaline pyroclastics (ignimbrite and pumice) (DI PAOLA, 1972). The caldera is elliptical with its long axis measuring about 12 km. The wall of the caldera has a variable height between about 50 m and 200 m. Post-caldera activity is represented by the emplacement of two very recent volcanic centres (Urji and Chabbi) within the caldera situated on active faults that parallel the major structural zone of the rift system. The Urji and Chabbi centres have extended pumice flows and falls with minor obsidian flows. Both centers are at fumarolic stage. Several NNE trending minor normal faults cut all the volcanic rocks within the caldera except the youngest products of the Urji and Chabbi centers. Eight shallow bore holes have been sunk at different locations in and outside the caldera ranging in depth from 50–200 m. The bore holes were irregularly located but have enabled constructing shallow subsurface volcanic stratigraphy. Altered rock forms a roughly north-south elongated area some two kilometres long and several hundred meters wide. Steam activity is apparent only along the extremities of this zone, but it is possible that thick soil cover may have masked the rest of the area. Low sulphidation (Adularia-sericite type) alteration processes are indicated by propylitic and advanced argillic assemblages in ignimbrite, pumice and rhyolite. The propylitic alteration, which is largely overprinted by later intermediate argillic alteration, surrounds an elongated and discontinuous core of potassic alteration. Advanced argillic alteration is limited to areas in proximity to the vents. Crusts of salts and silica occur around the vents; some of these salts are greenish in color and appear to be rich in ferrous iron and copper. Surface alteration zones locally occur, with Fe- and Ti-oxide. Gold content, although irregular or erratic, commonly exceeds 150 ppb both in compact rocks and in pumice fragments. The Corbetti caldera appears to be one of the most economically promising among the newly discovered occurrences in the MER.

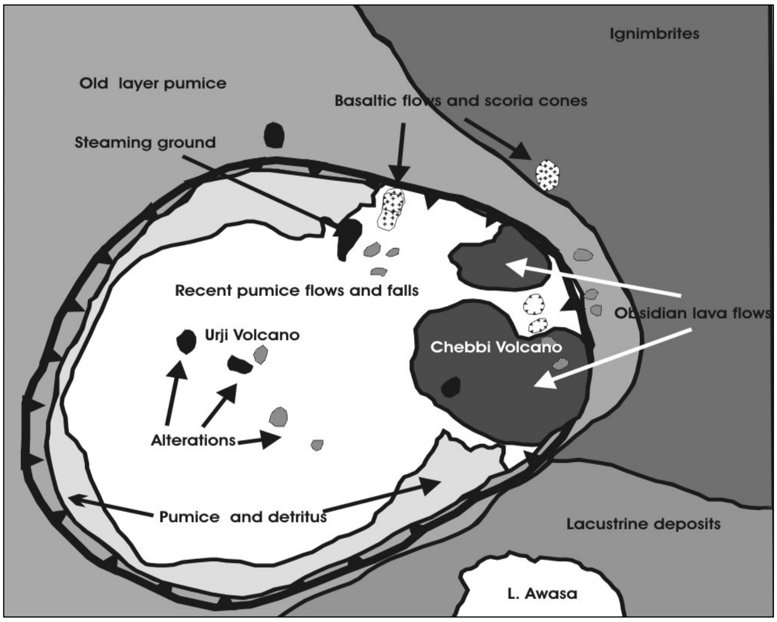

Figure 8a
A sketch map of the Corbetti Caldera.

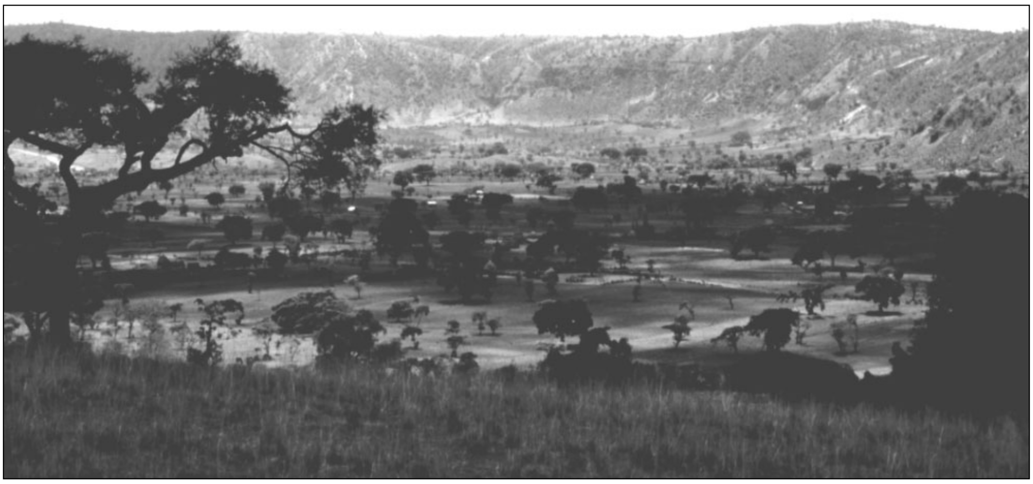

Figure 8b
A panorama view of the Corbetti Caldera.

4.4.5 Buambwa Wuha Kaolin plant

During this excursion we had a chance to see the types of mineralization and the extraction methods of kaolin. The reserves of kaolin at Buambwa Wuha (Fig. 9a) are estimated to be over 500,000 tons. The mining is arranged in tiers (starting at the top level at an altitude of 2205m) with each level having a height of about 20 metres. Each layer has a height of about 5 metres. One of the products is Al_2O_3 which is used for the ceramics industry in Awasa. Further products are kaolin, feldspar and quartz. The quartz is used for the glass industry. At the moment there are 45 workers employed at the plant and the reserve of kaolin is estimated to be enough at least for the next 17 years.

Figure 9a
View of the kaolinite outcrop at Buamba Wuha.

4.4.5.1 Processing and manufacturing of kaolin:

A good example of the extensive processing of kaolin is found in those products intended for the paper industry where there is a great demand for kaolin-based pigments. There are many ways to produce these pigments. One of the methods used is called the "water-washed process". Generally, in the processing of water clays, water is used as a transport and process medium involving the following:

i) Blunging: The kaolin is mixed with water and chemical dispersants to create milk-shake-like slurry. Slurry is simply the water and dispersed clay mixture, which puts the clay particles in suspension (Fig. 9b).

ii) Degritting: The slurried kaolin is usually transported through pipelines to degritting facilities, where sand, mica and other impurities are extracted with the help of gravity.

iii) Centrifuging: The centrifuge seperates the fine kaolin particles from coarse particles. Fine particles, still in the form of slurry, move on for further processing to enhance brightness.

iv) Brightness enhancement: With both the fine and coarse kaolin particle fractions, brightness is enhanced through one or more processes including bleaching, magnetic separation, flocculation, ozonation, which will remove iron, titanium, organic, and other undesirable materials.

v) Delamination: For customers who want a delaminated clay product suited for light weight coating applications, coarse particles are used. Delamination occurs as the coarse particles of kaolin, which when magnified appear as "booklets", are broken into thin platelets. After delamination, the brightness of the coarse particles may be enhanced through one or more of the same processes used in the fine particle fraction.

vi) Filtering and drying: Large rotary vacuum filters remove water from the slurried kaolin. Large gas-fired spray dryers remove and evaporate the remaining moisture.

vii) Additional processing: Additional processing (for example, calcining), further increases its brightness, whiteness, and opacity, electrical insulating properties, hardness and durability, which enhance the value of higher-grade kaolin.

Figure 9b
View of the plant for the Kaolin production at Buamba Wuha.

5. GEOLOGY OF THE ADOLA AREA

The Adola area (Fig. 10) is located about 500 km south of Addis Ababa where the neoproterozoic basement of southern Ethiopia is well exposed. It is a basement representing a part of the East African Orogen and one of the earth´s greatest collision zone which marks the disappearance of a major ocean basin (Mozambique Ocean), a formation of a vast tract of juvenile Neoproterozoic continental crust, and where East and West Gondwana were joined.
The Adola area is actually the northern extension of the Mozambique orogenic belt. It forms a portion of the late Proterozoic intracratonic trough initiated on the ancient consolidated basement within the Mozambique. The area consists of a wide variety of volcano-sedimentary units that underwent intensive tectonic activity and various degrees of metamorphism. KAZMIN (1975) classified the Ethiopian Basement into three groups: i) Lower, ii) Middle and iii) Upper Basement Complexes. Among these two major Precambrian tectono-stratigraphic units are recognized in the Adola area (TADESSE, 1999): i) Middle high-grade gneiss complex and ii) the Upper low-grade volcano sedimentary complex. The first phase is represented by rocks of the Arwata Group and the second by rocks of the Mormora Group. Detailed structural studies regarding the tectonic relationship between the volcano-sedmentary and gneiss rocks (BERAKI et al., 1989; WORKU & YIFA, 1992; GEBREAB, 1992; WORKU, 1996; WORKU & SCHANDELMEIER, 1996) indicated that the contacts are of regional shear zone and are joined by ductile to brittle-ductile shear zone in a north-south direction.

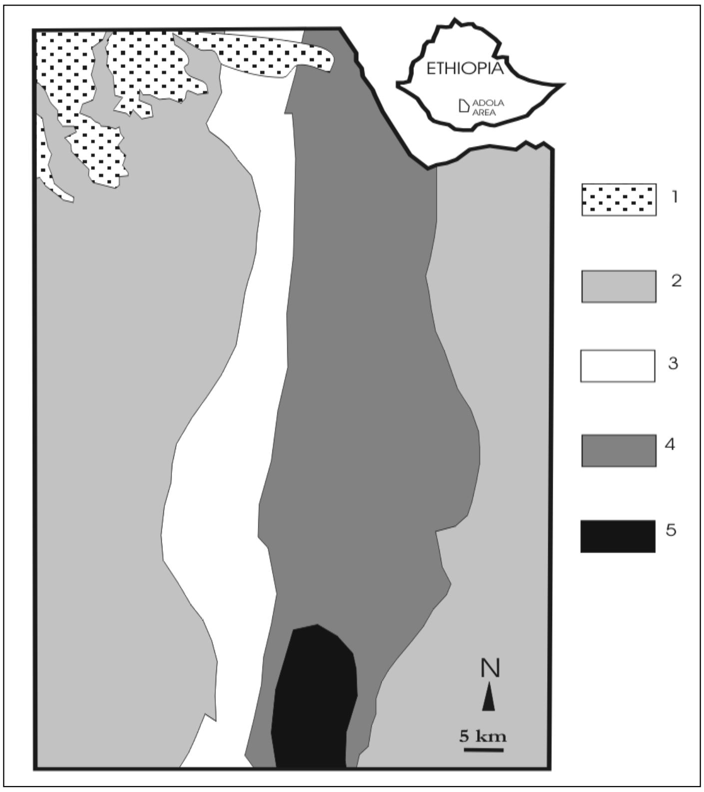

Figure 10
A geological sketch map of the Adola area.
1: Cenozoic basalts, rhyolites and tuffs
2: Kenticha formation: mica schists, gneisses and amphibolites
3: Chakata formation: phyllites, quartzites and amphibolites
4: Aflata formation: biotite-hornblende gneisses, mica schists and amphibolites
5: granitic gneisses

5. 1 The Middle Complex

EMRDC (1985) subdivided the rocks of the Middle Complex into two Formations: Aflata and Kenticha. The rocks of the Aflata Formation are the oldest and consist of continuous outcrops along the western and eastern margins of the area. This formation is mainly composed of migmatized biotite gneiss in the western part and of amphibolites in the eastern part. The rocks of Kenticha Formation consisting of rocks dominated by biotite-muscovite gneiss border the Megado belt in the east and west.

5. 2 Upper complex

The Upper Complex is represented by low-grade (greenshist facies) metamorphic volcano sedimentary units of the Adola Group and Kajimaiti Beds. The rocks of the Adola Group consist of the volcano-terrigenous sequences comprising amphibolites, carbonaceous quartz-mica, chlorite-actinolite and biotite-shists. The rocks mainly occur on the western and eastern limbs of the Megado Belt. The Megado Belt, the major structure in the area, is a narrow N-S trending structure of 120 km long and 5–12 km wide bounded to the east and west by shear zones containing chains of intrusions of basic and ultrabasic compositon and amphibolite bodies. These intrusive rocks are grouped into three different ages: i) the meatmorphic granites of the Gariboro Ultra-Metamorphic Complex with a Rb-Sr age of 680 Ma ± 30 Ma (GILBOY, 1970); ii) post-tectonic intrusive rocks with a Rb-Sr age of 505 ± 10 Ma (GILBOY, 1970; CHATER, 1971) and iii) post-tectonic intrusions characterized by the absence of any definite evidence of metamorphism (EMRDC, 1985).

The youngest rocks are basalts and subordinate rhyolite lavas which lie in the north western part of the area. These volcanic rocks are usually thought to belong to the trap series formed in a period between the beginning of Paleocene and Miocene (KAZMIN, 1972).

5. 3 Mineralisation

Gold deposits and placers are located within the Megado Belt and practically within the Kenticha Belt. The Megado Belt is essentially an Upper Proterozoic greenstone belt which suffered several periods of deformation and magmatism and has undergone metamorphism of greenshist to lower amphibolite facies. Most of the primary gold prospects like Lega Dembi deposit are found in this Belt. Within the Kenticha belt, rare-metal pegmatites containing tantalum occur.

5. 4 Kenticha Tantalum Mine

The Kenticha Tantalum mine is situated 52 km south of Shakisso and 500 km south of Addis Ababa. Two main lithologies can be observed: A N-S striking serpentinite and a 2 km N-S striking 200–300 m wide pegmatite showing zonal structure. This pegmatite is host to the Ta-deposit, which is mined here. The Main Kenticha pegmatite (Figs. 11, 12a,b) is the most evolved pegmatite so far known in the area and shows a variety of internal zoning and replacement phenomena. The outer border zone (foot wall) of the pegmatite is formed by alaskite granite that grades inwards to aplite.The alaskite granite is composed of muscovite, K-feldspar, quartz and albite. Spessartine, tourmaline, ilmenite and magnetite can also be found as minor phases of the assemblage. Columbite-tantalite and the Mn-columbite complete this association and form the ore of Kenticha mine.

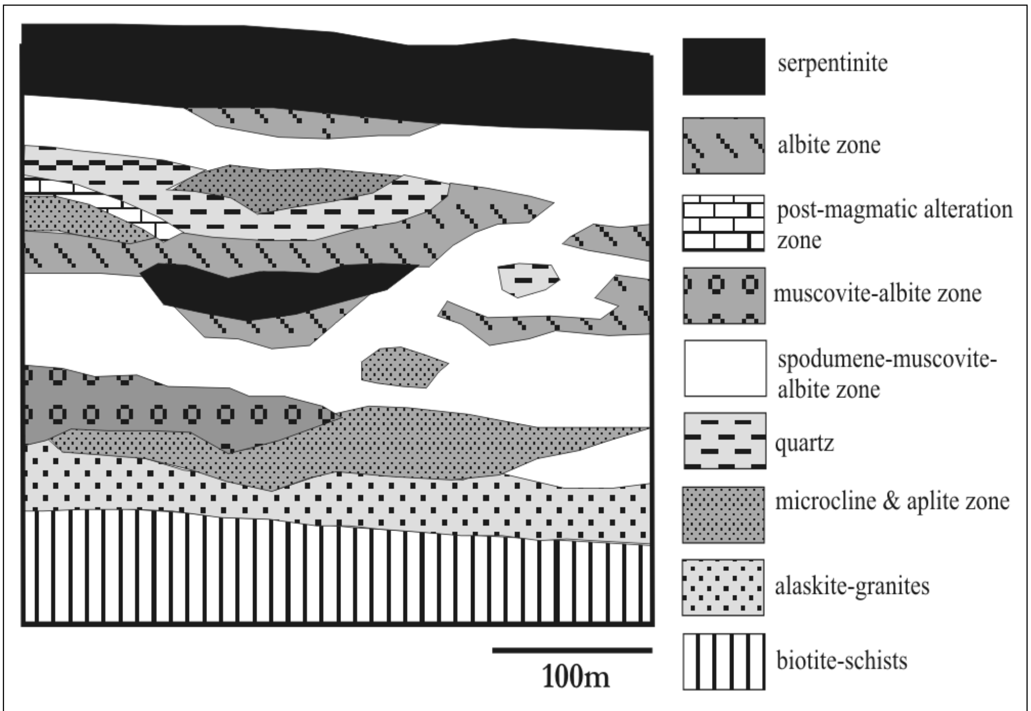

Figure 11
A geological cross section of the Kenticha tantalum mine.

Figures 12a and 12b
Outcrops of Kenticha pegmatite (Photo F. Koller).

The first intermediate zone is made up of muscovite-quartz-albite-microcline pegmatite. This zone is characterized by a medium grained texture, sometimes giant microcline crystals are found. The second intermediate zone is composed of albite, cleavelandite, quartz, spodumene, microcline and sericite. As characteristic accessory and rare minerals apatite, lepidolite, (Mn-) tantalite, (Mn-) columbite, amblygonite, beryl and ixiolyte appear in the assamblage. The third intermediate zone continues upwards with a major mineral association of albite, spodumene, amazonit, microcline and sericite. The accessory and ore minerals include apatite, Li-mica, tantalite, topaz, beryl, pollucite and ixiolite. The central zone is entirely formed by elongated, discontinuous, lenticular quartz and replacement bodies. These replacement bodies consist of fine-grained Li-micas, which replace the microcline-perthite and quartz bodies. An alteration seam is observed in the contact between serpentinite and pegmatite and has a local thickness of up to 15 m. It contains chlorite, talc and tremolite-actinolite which result from the interaction of pegmatite forming aqueous fluids and the intruded country rocks (serpentinite).

5.4.1 Mineralogy

The metamorphic rocks within the Kenticha rare metal field contain a series of minerals such as columbo-tantalite group minerals ($(Fe,Mn)(Nb,Ta)_2O_6$)), ixiolite ($(Ta,Nb,Sn,Fe,Mn)_4O_8$)), beryl ($Be_3Al_2Si_6O_{18}$), staurolite (($Fe_2Al_9Si_4O_{22}(OH)_2$)), phosphate (apatite, amblygonite, lithiophyllite), tourmaline (schorl and elbaite), spodumene ($LiAlSi_2O_6$), garnet (spessartine and manganian almandine), rutile (TiO_2), ilmenite ($FeTiO_3$), and magnetite (Fe_3O_4).

5.4.2 Geochemistry

All granites and pegmatites within the rare metal field are peraluminous and this is shown in their mineral assemblages, which are characterized by the presence of biotite, muscovite, garnet, cordierite and topaz. The granites and the pegmatites vary in mineralogy and major elements as well as trace element geochemistry. They also differ in mineral association, alteration and replacement texture. TADESSE (2000) suggests the compositional variation to be due to a result of magmatic fractionation and an evidence of cogenetic relationships between various granite and pegmatite bodies.

The relatively less fractionated bodies of biotite and two mica granite are assumed to be generated earlier than the rare metal enriched alaskitic granite and pegmatite bodies. Based on the geochemical and mineralogical characteristics of the pegmatites, two major distinct groups can be recognized: i) primitive (barren) pegmatites with very low grade of fractionation of elements, and ii) mineralized pegmatites with a different grade of rare metal mineralization (rich pegmatites). The pegmatites of the second group show high Ta, Nb, Rb, Cs, Li, Rb/Sr and low K/Rb, Ba, REE contents as compared to the pegmatites of the first group. They also display a complex zoning structure.

5.4.3 Mining and preparation

The pegmatite shows deep weathering and oxidation. Mining is conducted with bulldozers in an open pit mine. To separate metal rich minerals and clay minerals the product is rinsed and washed with water. With different steps of gravity and density separation, spiral cleaner, Ferraris table, a final magnetic separation of tantal (not magnetic) and magnetic by-products such as magnetite, hematite and sphene is made. Quartz and microclinic feldspar are the other by-products.

5. 5 The Lega Dembi gold deposit

The Lega Dembi gold deposit (Fig. 13) is Ethiopia´s largest primary gold producer. It is situated in the Megado Belt, which forms part of the late-Proterozoic Adola granite-greenstone terrane in southern Ethiopia. Lega Dembi was privatised in 1980 and awarded to a local company Midroc Ethiopia for $175 million. A mining license has been awarded and a new company – Midroc Legadembi Gold Mine Share Company (Midroc Gold) – started production in August 1998. The mine plans to produce 5 t gold per year. The nearby 300 kg/year Adola gold project is also being privatised by the Ethiopian government.

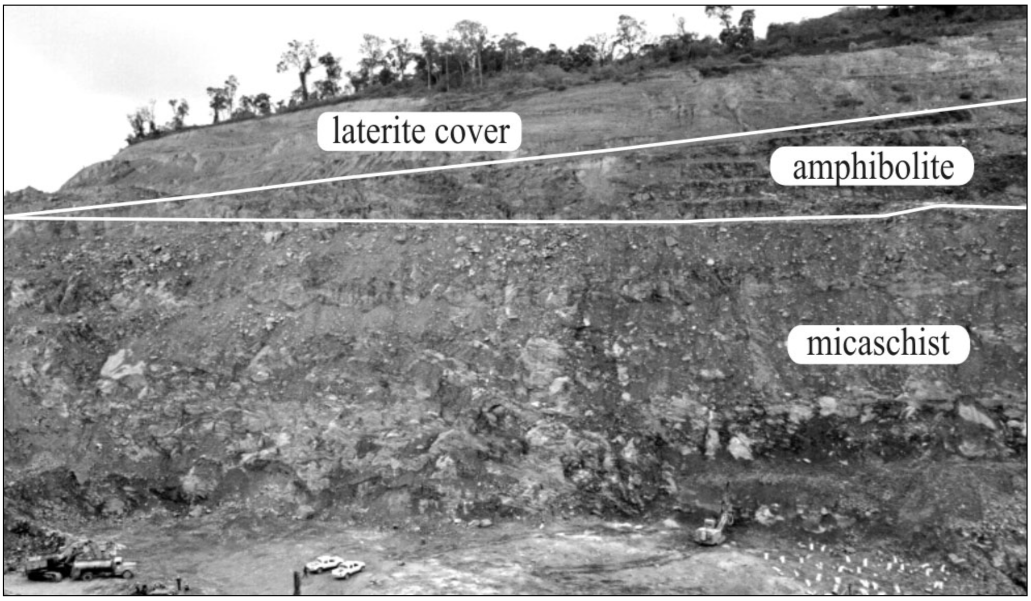

Figure 13
A view of the vertical rock section at the open pit mine, Lega Dembi.

The gold mineralization in Lega Dembi occurs in a N-S trending, steep westerly dipping quartz-vein system that follows the structural contact between underlying feldspathic gneisses and the volcanosedimentary sequence of the Megado Belt. This contact also marks the northern extension of the regional-scale, sinistral strike-slip Lega Dembi-Aflata shear zone. Mineralization and intense quartz-veining is best developed in graphite-rich sediments within an area not more than 80 m away from this tectonic contact. Hydrothermal wall-rock alteration includes actinolite/tremolite-biotite-calcite-sericite and chlorite-calcite-epidote assemblages. Gold occurs preferentially in the sericite alteration zone, where it is closely associated and crystallized together with galena. The different deformation of the gold-quartz veins suggests a syn-kinematic timing for the gold mineralization during transcurrent shearing in a dilational segment of the shear zone. In addition to the structural control, lithological control on gold deposition is indicated by the almost exclusive occurrence of the gold mineralization in graphite-rich metasediments. This close relationship suggests that gold precipitation was the result of chemical reduction of regional ore-bearing fluids. Temperature conditions of mineralization are fixed by the actinolite-biotite alteration assemblage and by arsenopyrite chemistry, which indicate that ore deposition occurred at or close to high metamorphic conditions at upper-greenschist to lower-amphibolite metamorphic grades. The age of the gold mineralization is about 545 Ma.

5.5.1 Grain size distribution of gold in quartz-sulphide ores

Galena-chalcopyrite-pyrite ores contain Au-minerals in several habits and associations, different from ore types previously reported. Most importantly, gold occurs as electrum disseminated within quartz, accounting for about 60 % of total visible gold in the studied samples. Most electrum grains are rounded and typical grain diameters are in the range 10–75 mm. The maxium measured size of a single grain was a diameter of 315 mm. Gold is also observed at the grain margins of galena and chalcopyrite and locked in these minerals. Grain size is directly comparable with free gold in quartz (typically 10–100 mm). Grain shapes are more varied and range from rounded to elongate. Au is enclosed within pyrite, and in this association it is typically much finer (with varying composition). Au is also present in petzite, Ag_3AuTe_2 and hessite, Ag_2Te (Fig. 14). These are relatively common accessory minerals in the pyrite zone, characteristically associated with the Pb-As sulphosalt phases as small inclusions. Microscopic investigation revealed that the ore mineralogy is more complex than previously recognised.

There are differences in mineralogy between the main ore types and those in the hanging wall. Pentlandite grains contain 6–8 wt.% Co, and alter to violarite, $FeNi_2S_4$. The accessory mineral within this association is sphalerite.

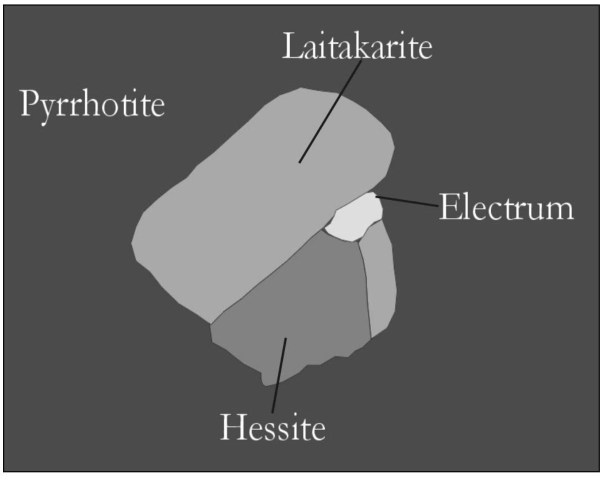

Figure 14
A back-scattered electron picture showing the phases associated with electrum, sample from Lega Dembi gold mine (taken from COOK & CIOBANU, 2001).

The following characteristics of the Lega Dembi gold deposit have been suggested by COOK & CIOBANU (2001):

(1) Ore mineralogy at Lega Dembi is very complex.

(2) Fine-grained gold (native gold, electrum, tellurides) locked within pyrite would appear to be the main reason for lower-than-typical gold recoveries in quartz-sulphide ore. Invisible gold within arsenopyrite may possibly play a role.

(3) Fine-grained gold is intimately associated with a characteristic suite of minerals. This As-dominated association is previously unreported from Lega Dembi and contrasts with the Pb-Sb character of higher levels. This may reflect deposit zonation or evolution of the hydrothermal system during shear-zone development and fluid pumping.

(4) Hanging wall ores carry significant amounts of Ag, primarily as argentopentlandite but also hessite.

(5) Observed assemblages and textures can be effectively explained by sequential processes of syn-deformational ore remobilisation (Fig. 15).

Figure 15
View of an ultramafic rock completely altered to talc (white center) bounded by the gold-bearing graphite mica schist (Lega Dembi open pit gold mine).

5.5.2 Gold extraction – the cyanide process

This is a method of extracting gold from ores by dissolving them in a dilute solution of sodium cyanide or potassium cyanide. The method includes three steps.

i) contacting the finely ground ore with the cyanide solution

ii) separating the solids from the clear solution

iii) recovering the precious metals from the solution by precipitation with zinc dust.

More gold is recovered by cyanidation (Fig. 16) than by any other process. In cyanidation, metallic gold is oxidized and dissolved in an alkaline cyanide solution. The oxidant used is atmospheric oxygen, which, in the presence of an aqueous solution of sodium cyanide, causes the dissolution of gold and the formation of sodium cyanoaurite and sodium hydroxide. When gold dissolution is complete, the gold-bearing solution is separated from the solids. For extracting gold from low-grade ores, heap leaching is practiced. The huge heaps are sprayed with a solution of sodium cyanide, and this percolates down through the piled ore, dissolving the gold. Immense amounts of solution and solids are associated with a vast percolating circuit, because of the very low concentrations of gold in the ores.

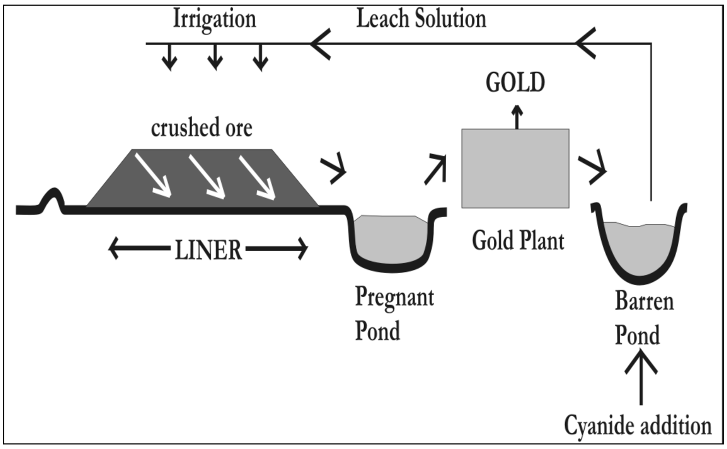

Figure 16
A schematic diagram showing the cyanide process for the production of gold.

In order to eliminate the huge costs associated with the purchase and installation of solid/liquid separation equipment, techniques have been developed that do not require the entire separation process. One of these is the addition of granular activated carbon to the ore slurry during or after having a complete gold solution. The dissolved gold is readily adsorbed onto the carbon, by removing it from solution, and the granular carbon is separated from the ore by running the slurry through a sieve. Gold is then percolated from the carbon particles by a strong solution of sodium cyanide and sodium hydroxide, and it is recovered from solution directly onto steel wool or by the Merrill-Crowe process. There the gold-bearing solution is de-oxygenated and passed through a filterpress, where the gold is displaced from solution by reduction with zinc metal powder.

6. EXCURSION

The excursion to the Blue Nile Gorge, the Rift Valley and the Adola Gold Belt (Fig. 17) took place from April 5 to 22, 2001.

1. Excursion day

We made geological traverses along the Abay Gorge (Blue Nile Gorge), which has a complete stratigraphic section ranging from the Precambrian to theTertiary. Along the western margin of the Northwestern Plateau in the Blue Nile Gorge, a 2000 m section of Mesozoic strata capped by massive Tertiary volcanics is exposed. It includes ca. 600 m of Late Jurassic-Early Cretaceous sediments. The altitude of the plateau ranges from 3000 to 4000 m in the northeast and around 1500 m in the southwest, with an average height between 1800 to 2500 m. The basement of Ethiopia consists of metamorphic and igneous rocks of Precambrian and Lower Paleozoic age. Between the Ordovician and Early Mesozoic a system of northeasterly as well as northwesterly trending troughs were filled with continental sediments. Early Jurassic marine sediments filled this troughs and at Late Jurassic time, the transgressive sea was widespread over a part of Ethiopia. Regression happened at the end of the Jurassic. The Paleozoic and the Mesozoic sediments are the base for discordant layers of thick massive flood lavas, mainly basalt, which are generally Post-Oligocene in age and reach a maximum thickness of 5500 meters.

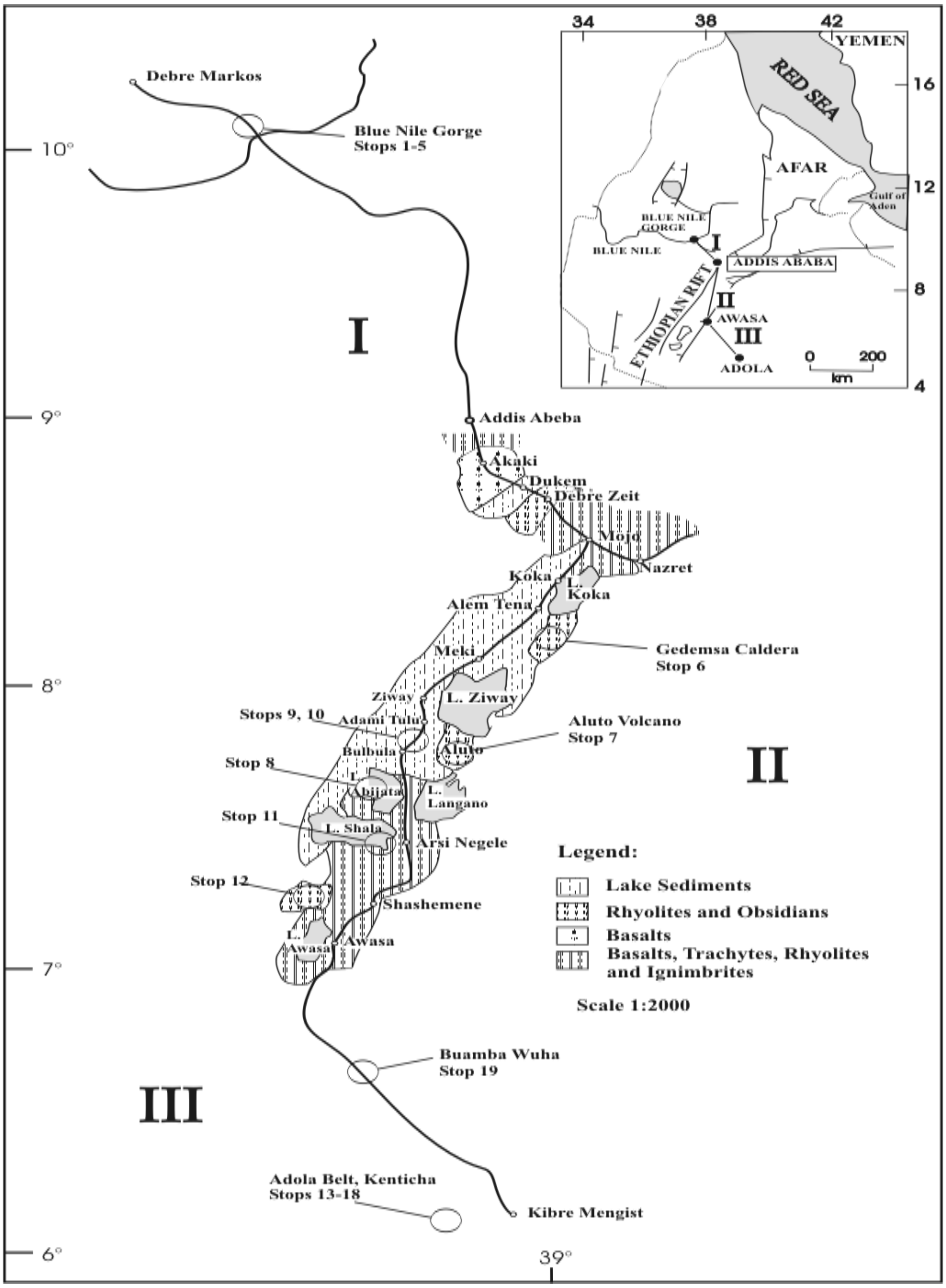

Figure 17

Schematic geological map of the excursion areas with excursion stops I, II and III as in Fig.1.

Stop 1: GPS: N10°03.890´, E38°11.945´; Lower Adigrat Sandstone. Mixed layering of massive and foliated lithologies, influenced by conjugated brittle faults.
Stop 2: GPS: N10°03.919´, E38°12.462´; Shales interbedded by gypsum.
Stop 3: GPS: N10°02.739´, E38°13.893´; Fossil-rich sandstone of the Limestone Formation.
Stop 4: GPS: N10°01.659´, E38°14.508´; Fossil-rich unit of the Upper Marl (Limestone Formation).
Stop 5: GPS: N10°01.935´, E38°14.49´. Tertiary basalts and trachytes, forming the upper level of the Mesozoic profile.

2. Excursion day
Preparation for the trip to the Rift Valley and visit the Natural History Museum in Addis Ababa (where one of the oldest human skeletons "Lucy" is on show).

3. Excursion day
Road geology – From Addis Ababa to Nazret.

Addis Ababa (2400 m high): The central part of the city is basalt which is covered in many places by a layer of ignimbrite or welded tuff. The welded tuff is more common in the southern and western part of the city. Addis Ababa is situated in the northwestern margin of the MER and has a very complex fault system. Filwoha hot springs, just 400 meters southwest of the Hilton Hotel are situated along a fault zone. From Addis Ababa to Mojo, except a few quite minor faults of Quaternary age, there is a gentle gradient all the way from the plateau down to the rift floor.

Mount Wachacha: this is a volcano which is 4.5 million years old and 3400 m high. It is largely made up of trachytes with large phenocrystals of feldspar found near the top. This volcano and Yerer mountain are situated along the outer margins of the Ethiopian Rift escarpments.

Kaliti: A flour mill site some 15 km south of Addis Ababa on the Debre Zeit road. It is situated on a southerly oriented ridge between north-south flowing perennnial rivers, both named Akaki. The town lies on a horizontally bedded welded tuff and some subordinate lava flows.

Akaki: The town is set in an industrial area, where textil mills and metalworks factories are found. In 1940 the first hydroelectric power generation was started from a dam (Aba Samuel) built on the river. The dam has a storage capacity of 65 million m^3 and an annual output of 23000 megawatt hours. Basalts are the main outcrops and the hill in the center of the town is a basaltic cinder cone. Similar eroded cinder cones (scoria) are common to the southeast of the town near Debre Zeit road, where they are quarried for road making.

Mount Yerer: is a 3.5 million years old volcano exposed in the southeastern part of Addis Ababa. It mainly consists of agglomerates and is much more eroded than Mt. Wachacha.

Dukem: the village lies on a flat plain, underlain by recent fluvial or lacustrine sediments. Also basaltic cinder cones are seen in the area. Dukem is known for its wine. Delicious grapes are cultivated along the intermittent river of Dukem which starts from Yerer mountain and eventually flows into Lake Koka to the south.On the road from Dukem to Debre Zeit rhyolites and obsidians occur as main outcrops.

Debre Zeit: recent basalt lavas and ashes are common. At Debre Zeit the road crosses craters aligned roughly NNE-SSW, and formed by explosive eruption in recent times (about 100.000 years ago). There are thirteen volcanic lakes in the vicinity out of which five are permanent. From Debre Zeit to Mojo, basalts, trachytes, rhyolites and ignimbrites are found.

Mojo: the town lies on alluvial and lake deposits, interbedded with volcanic tuff and agglomerates. In the river section water-lain tuffs are exposed. The tuffs continue from the road junction of Langano and Nazret up to Lake Shala and form the main part of the rift floor in this region. From Mojo to Nazret basalts, trachytes, ryholites and ignimbrites occur.

Stop 6
Gademsa is one of the volcanoes representing recent volcanics of the Ethiopian Main Rift. We had an excellent view of the Gademsa Caldera with its gold mineralization and alteration features represented by synkinematic deformed and mineralized quartz veins associated with gold. The lowest exposed volcanic products of the Gademsa volcano are acidic lavas covered by thick plinian pumice deposits, which are overlain by an ignimbrite sheet. Products of post-caldera activities are acidic lava and pyroclastics. The composite structure of the caldera was formed by repeated large Plinian pyroclastic eruptions and the geometry of the caldera is almost circular, measuring about 10 kilometres.

4. Excursion day
Stop 7
We visited the Aluto Langano geothermal fields with their alteration features. From the top of the Aluto volcano one observes the different lakes within the Rift. The Aluto volcano is a complex alkaline rhyolite massif located between Lake Langano in the south and Lake Ziway in the north. Geothermal activity is manifested as hot springs, fumaroles and hot ground within and outside the volcano. The thermal manifestations are mainly controlled by fault structures. Deep exploratory drilling for geothermal resources commenced in this area in 1981 and at present there are eight deep-drilled holes out of which five are productive and expected to generate approximately 2–2.5 MW of electricity per well.

5.Excursion day
Stop 8
GPS: N7°40.643´, E38°35.858´, altitude: 1580 m. We visited the soda ash plant at Abiyata lake and made geological traverses at Lake Shala and Abiyata Lakes. Lake Abiata (1575 m) is a closed alkaline lake (8.4 g dissolved salts/liter; chiefly sodium carbonate) which shows evidence of drastic shrinkage in very recent times. Lake Shala (1570 m) is unique amongst the lakes of the MER for its steep shores and great depth. It is also closed and alkaline (16.8 g of dissolved salts/liter) with hot alkaline springs containing high chloride and gas bubbles, which rise intermittently from the source vents, discharging 0.12 liters/s of clear water at temperatures of 62°C. The source of the various elements present in these waters is not clear. Lake Shala may overlie evaporite deposits. The mildly alkaline hot waters could also leach chemicals from volcanic rocks and sediments in the region.

Stop 9
GPS: N7°43.309´, E38°38.862´ Diatomite outcrop at Bulbula.
Diatomite reserves in these localities are estimated at 40,000 tons. The Lake Abiata diatomite at Bulbula was deposited in the Pleistocene and is interbedded with ignimbrite, tuff and pumice. It contains 82 % silica and the rest is kaolinite.

Stop 10
GPS: N7°52.661´, E38°41.925´, altitude: 1700 m.
We visited the diatomite treatment plant which employs 124 people and has been in operation since 1997. In order to extract the diatomite, first the material is dehydrated then it is micronized in a cyclone to 75 micrometers. Because of its high porosity the micronized diatomite is able to absorb molecules. The diatomite powder is 50 % WDP (water dispersible).

6. Excursion day
Stop 11
GPS: N7°29.887´, E 38°38.294´, altitude: 1700 m Shala-Abiata National Park viewpoint.
We drove to a high point at the boundary between Lake Shala and Lake Abiata to have a good view of this part of the MER. We used this time to summarize and discuss the geological features and the type of rocks we have encountered during the first 5 days of our excursion.

7. Excursion day
Stop 12
GPS: N7°13.277´, E38°24.265´, altitude: 1950 m: the Corbetti caldera:
We made geological traverses at Corebetti Caldera with its gold mineralization and alteration features. Corbetti is a Holocene volcanic complex found in the central sector of the MER. The most abundant volcanic rocks are peralkaline pyroclastics (ignimbrite and pumice). After Corbetti we drove to see the volcanic and hot spring activity of the Wendo Genet area.

8. Excursion day
We drove to the basement towards Shakisso, Adola area.
This route shows a dramatic change in topography and geology. One drives through the main Ethiopian rift for about 250 kms (from Addis Ababa to Awasa) and then turns to the south west crossing the rift floor, over the baslatic plateaus and then to the precambrian basement.

9. Excursion day
National holiday in Ethiopia. Introduction about the geology of the Adola area (see section 5 in this report) and discussion about the geothermal fields we visited earlier in the Rift Valley.

10. Excursion day
We made geological traverses of the Kenticha ultramafic body and the disseminated chromite mineralizations in the morning and geological traverses and mine operation of the tantalum deposit related to the pegmatite veins in the afternoon.The Kenticha Tantalum mine is situated 52 km south of Shakisso and 500 km south of Addis Ababa. Two main lithologies can be observed: An N-S striking serpentinite and a 2 km N-S striking 200–300 m wide pegmatite showing zonal structure. This pegmatite is host to the Ta-Nb deposit, which is mined here.

Stop 13
Locality: Road geology 3 km north of Kenticha Mine, GPS: N05°28.839´, E039°02.066´.
Site description: serpentinite with massive chromite layers as well as hematite and magnetite crystals, with heavily weathered surface

Stop 14
Locality: A road profile toward the Mine, GPS: N05°28.685´, E039°02.017´.
Site description: Shear zone within serpentinite with vertically oriented talc deposit. A mylonitization can be observed along the shear zone. The talc- ayer strikes SW-NE (S150/90).

Stop 15
Locality: Embankment along the road, GPS: N05°27.705´, E039°01.465´.
Site description: growth of tourmaline at the contact along fluid trails, apparently indicating the involvement of a B-enriched fluid can be observed. Adular $K(AlSi_3O_6)$ crystals are found within the joints.

Stop 16
Locality: Ta-Pegmatite in the mine, GPS: N05°27.714´, E039°01.465´.
Site description: The outcrop shows the typical mineral zonation for metal-rich granitic pegmatites. The core is formed by quartz, followed by columbo-tantalite. The outer shell from the core to the rim contains green amazonite, white K-feldspar, followed by a shell of white mica, a possible reaction product of the ultrabasic wall rock and the intruding pegmatite. The age of the pegmatite is estimated to be 550 Ma.

Stop 17
Locality: Contact between ultramafic and basement rocks, GPS: N05°17.095´, E039°00.433´.
Site description: The site is a 20 m long road profile a few kms north of stop 13. The lithology of the contact zone between the serpentinite and the basement shows a talc-chlorite-shist. A NW-SE trending shear zone can be observed.

11. Excursion day
Stop 18
We visited the Legadembi Midroc gold mine and the gold processing plant. Finally we made geological traverses at the mine area and the surrounding basement rocks.
The Lega Dembi gold deposit is located in late-Precambrian metamorphosed sediments of the N-S trending volcano-sedimentary Megado belt, which forms part of the late-Proterozoic Adola granite-greenstone terrane in southern Ethiopia. The gold mineralization occurs in an N-S trending, steep westerly dipping quartz-vein system that follows the structural contact between underlying feldspathic gneisses and the volcano-sedimentary sequence of the Megado belt.

12. Excursion day
Stop 19
GPS: N6°5.087´, E38°46.046´, altitude: 2200 m Buambwa Wuha kaolin plant.
We made a stop at Buambwa Wuha Kaolin plant to visit the type of mineralization and its extraction methods. The reserves of kaolin at Buambwa Wuha are estimated to be over 500,000 tons.

One of the products is Al_2O_3 which is used for the ceramics industry in Awasa. Further products are kaolin, feldspar and quartz.

13. Excursion day
We drove back to Awasa from Shakisso and visited the Awasa Lake and surroundings.

14. Excursion day
We drove back to Addis Ababa from Awasa through the Ethiopian Rift with a short stop at Debre Zeit (45 km south of Addis Ababa) to visit the crater lakes of Bishoftu and Hora.

15. Excursion day
Summarized the geology, the rock types, industrial minerals and ore deposits we visited during our excursion.

16. Excursion day
Visited Addis Ababa and environs. Invitation at the Austrian Ambassadors´ residence, in Addis Ababa concluded our excursion.

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