The Ethiopian Rift Valley
(Between 7° 00′ and 8° 40′ lat. North)

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Abstract

The Ethiopian Rift Valley, which cuts the uplifted Ethio-Somalian Plateau, is one of the most important structures of East Africa, and nevertheless it is still largely unknown.

A preliminary 1/500,000 geological map as well as volcanological and petrological descriptions of an important part of this structure are presented.

This part of the Ethiopian Rift Valley is marked by a set of NNE-SSW normal faults. « En échelon » arrangements, rift-in-rift structures, asymmetry and open tensional fissures are its most important tectonic features. The region has been affected by volcanism since Eocene in the neighbouring Plateaux and since probably Pliocene within the Rift, with fissure eruptions and growth of individual volcanoes. Non-volcanic rocks consist exclusively of lacustrine sediments. Magmatic products on both Plateaux are represented mainly by huge piles of basaltic lava flows, whilst within the Rift most of the volcanics are widespread ignimbritic units.

The presence of such large amount of ignimbrites can easily explain some important volcano-tectonic collapses which produced large regional calderas. Although still insufficient, the available petrological data suggest that the Plateau basalts have more alkalic character than those within the Rift, which show a transitional nature between alkali basalts and tholeiites. Intermediate rocks seem to be scarce and most of the silicic products are monotonously represented by peralkaline rhyolites (mostly pantellerites).

The genesis of the peralkaline silicic rocks might be related to the presence, along the Rift axis, of a huge basic igneous body recently discovered by a geophysical investigation. This could explain the presence of large volume of these rocks within the Rift, although the apparent scarcity of intermediate rocks remains unexplained.

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Résumé

La Rift Valley d'Ethiopie qui recoupe le Plateau Ethio-Somalien est une des plus importantes structures de l'Afrique orientale, et néanmoins encore très peu connue.

Ce texte présente une carte géologique préliminaire au 1/500.000 ainsi qu'une description volcanologique et pétrologique d'un secteur important de cette structure.

La partie étudiée de la Rift Valley d'Ethiopie présente les caractéristiques suivantes: système le failles normales orientées NNE-SSW, style « en échelon », structures « rift in rift », asymétrie du graben et présence de nombreuses fissures de tension ouvertes. Toute la région a été affectée par le volcanisme depuis l'Eocène dans les Plateaux environnants et probablement depuis le Pliocène dans le Rift, avec éruptions fissurales et édification de volcans individuels. Les roches non volcaniques sont représentées uniquement par des dépôts lacustres. Les produits magmatiques des deux Plateaux sont, pour la plupart, représentés par des centaines de coulées de lave basaltique empilées, tandis que dans le Rift, la majeure partie des produits volcaniques est constituée par des ignimbrites. Les éruptions d'ignimbrites sont responsables de la formation de grandes caldéras régionales. Les données pétrologiques actuellement disponibles, bien qu'encore insuffisantes, suggèrent que les basaltes de Plateau ont un caractère plus alcalin que ceux du Rift qui montrent une nature transitionnelle entre les basaltes alcalins et les tholéiites. Les roches intermédiaires semblent être rares et la majorité des produits acides est représentée uniquement par des rhyolites peralcalines (pantellérites pour la plupart).

Récentes données géophysiques indiquent la présence, le long de l'axe du Rift, d'une importante intrusion de magma basique qui pourrait ainsi expliquer la grande quantité de roches peralcalines que l'on trouve dans le Rift, bien que l'apparente rareté des roches intermédiaires reste inexpliquée.

Introduction

During the last ten years, especially after the acceptation and the development of the plate tectonics theory, the interest of many geologists and geophysicists in continental drift problems has strongly increased, including the study of the world's rift zones.

One of the most interesting rift areas is the East African Rift System. The Ethiopian Rift Valley is an important part of this structure owing to its junction, in the Afar depression, with the Red Sea-Gulf of Aden oceanic megastructure, where sea-floor spreading is taking place.

Some accounts on the geology of the northern part of the Ethiopian Rift Valley have already been given by DAINELLI (1943) and, more recently, by Gibson (1967), Cole (1969) and Gibson and Tazieff (1970). Other accounts on the geology of the Ethiopian Rift Valley as a whole can be found in Mohr (1962, 1967) and in Baker *et al.* (1972). However, these studies are either too localized or too general and are based on little actual volcanological field work.

The aim of this paper is to describe in some detail the geology of the central Ethiopian Rift Valley, which was, up to now, almost unknown.

Since no appropriate topographic maps of the region investigated were available, the geological map attached to this paper is a preliminary 1/500,000 map, drawn from 1/50,000 approximate scale aerial photographs, with unavoidable topomorphic distortions. Petrological notes are based on the study of more than 500 rock samples collected during several field trips from January 1969 to July 1970, when the writer joined the Geological Survey of Ethiopia as a Technical Assistant of the Italian Government.

Physiographic Outlines

The region described in this paper is located in southern Ethiopia. It includes the central portion of the Ethiopian Rift Valley, a portion of the Ethiopian and of the so-called Somalian Plateaux, covering a surface of about 25,000 km^2.

The Ethiopian Rift Valley and the two Plateaux are accessible by some good main roads, *i.e.* Addis Ababa - Modjo - Nazareth - Dire Dawa; Nazareth - Asella - Bekoji; Modjo - Shashamanne - Neghelle Sidamo; Shashamanne - Wolamo Soddu - Arba Minch; Shashamanne - Dodola - Goba and Addis Ababa - Butajira - Hosanna. There are also several tracks which can be driven only by four wheel drive cars.

The average altitude of the Plateaux, on both sides of the Rift, is about 2500 m a.s.l., whilst the floor of the Rift Valley gently decreases from an altitude of 1600 m a.s.l. at Lake Awasa (southern limit of the geological map) to an altitude of 1350 m a.s.l. just north of the Boseti - Gudda volcano (northern limit of the geological map). Proceeding northeastward from the Boseti - Gudda volcano, the floor of the Rift Valley continues to decrease down to about 250 m a.s.l. at its end, *i.e.*, the southern shore of Lake Abbe (about 360 km NE from the northern limit of the geological map). Proceeding southwestward from lake Awasa, the altitude of the Rift floor suddenly reaches 1100 m a.s.l. at lake Abbaya (Margherita) (about 50 km south of lake Awasa) and it remains at that level up to the southern shore of lake Chamo near the Kenya border (about 160 km from the southern limit of the geological map).

As shown in the map, five lakes of tectonic or volcano-tectonic origin (Zwai, Langano, Abiata, Shalla and Awasa) occur in the region described in this paper.

Two other important tectonic lakes, namely lake Abbaya (Margherita) and lake Chamo are also located within the Ethiopian Rift Valley, south of lake Awasa, but are not considered in this paper. Another small lake, the artificial lake of Koka, formed after the recent barrage of the Awash River by the Koka Dam, near Nazareth (Adama) is located just north of lake Zwai.

The floor of the Rift Valley is not uniformly flat, but it is occupied by some reliefs, rising for about 500 m or more, such as it occurs on the Plateaux, especially along the escarpments limiting the Rift, where some reliefs, more than 1000 m high, occur.

Geological Outlines

Tectonics

The Ethiopian Rift Valley is a graben with an average width, in the portion examined, of about 70-80 km. It is limited, to the West, by the Ethiopian Plateau and, to the East, by the Somalian Plateau.

Tensional movements are responsible for the formation of this trench which affects the uplifted Ethio-Somalian Plateau. A great number of step faults produces a total difference of altitude of more than 1000 m between the top of the Plateaux and the floor of the Rift Valley. All these faults are normal faults which run for hundreds of km in a NNE-SSW direction or, in a few cases, in a NE-SW and, more rarely, in a N-S direction. Some NW-SE faults also occur, most of which are clearly the result of a local distortion of the main tectonic trend, as shown by their continuity with the NNE faults. Only in a few localities (East of lake Awasa and East of lake Langano) important clearly independent NW-SE faults have been observed, which cut, or are cut by, the main fault system. These faults show no traces of horizontal displacement across the Rift. Therefore, they must be assumed to be due to local collapse or readjustment of blocks related to the tensional movements which produced the present tectonic pattern of the Ethiopian Rift Valley, rather than to a transversal tectonics.

The downthrow of a single step fault can easily exceed 300 m.

One of the best examples of the step faults which originated the Somalian Plateau escarpment is found at the northeastern limit of the region climbing the escarpment from Dehra (Arussi Province) up

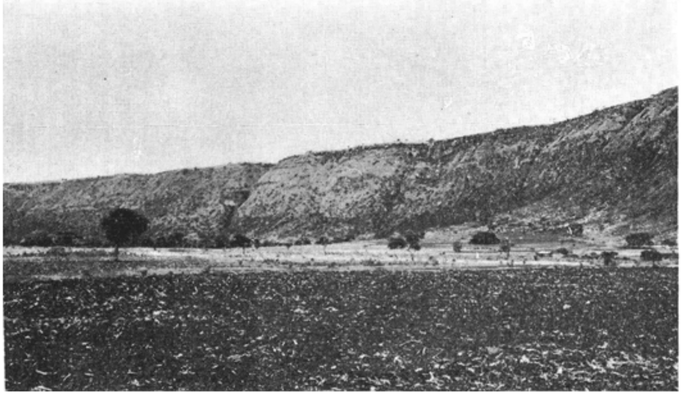

FIG. 1 - Eastern escarpment main fault at the Asella latitude.

to the top of the Plateau, via Sire. Between Sire and Asella, the main fault dies out SW from Sire to start again at the same latitude but displaced about 15 km to the West. No transversal faulting connecting these main faults exists, because the « en échelon » tectonic style is the only responsible for this important displacement of the Rift margin. This is confirmed by a gentle flexure of the Somalian Plateau which deeps NNE down to the Rift. Other less evident « en échelon » style arrangements are visible in some other places (Fig. 2).

Some differences in the tectonic lineaments between the eastern and the western escarpments, exist. The former is characterized for all its lenght by step faults with an important throw compared to the distance from one block to the other. The latter shows in its NE sector an abrupt displacement, sometimes exceeding 1500 m (M. Guraghe), between the top of the Plateau and the Rift floor, whilst in its SW sector the main faults have a small downthrow and progressively die out, so that, at its SW end the structural limit Plateau-Rift floor becomes only a physiographic feature. This could be interpreted as

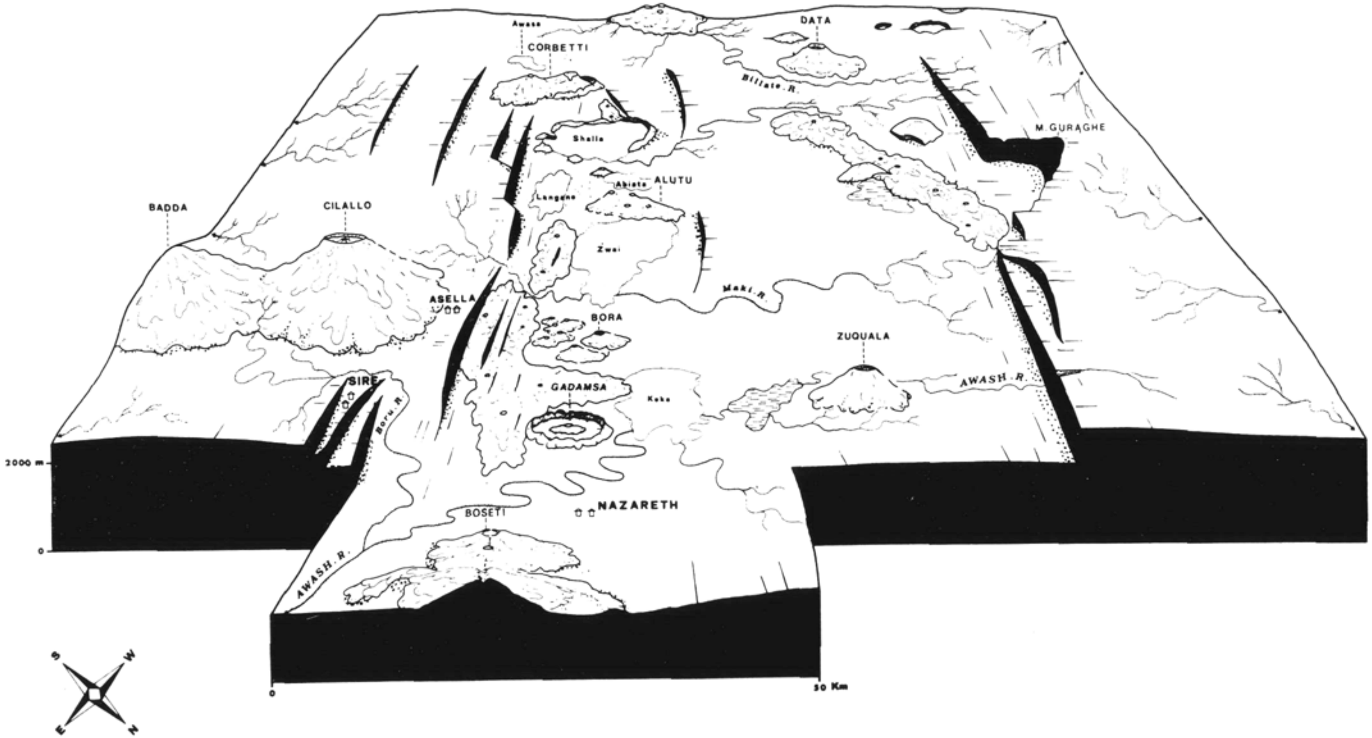

FIG. 2 - Block diagram showing the main structural features of the Ethiopian Rift Valley between 7° 00′ and 8° 40′ lat. N seen from NE (see, geological map) (*Drawn by M. Foddi*).

due to the fact that the main faults are either actually absent or hidden by a huge quantity of volcanic products filling a possible former depression existing in this area.

The different tectonic style of the two Rift margins makes this portion of the Ethiopian Rift Valley asymmetric. The asymmetry is also marked by a line of young faults, affecting the Rift floor, located very close to the eastern escarpment. These faults, the Wonji Fault Belt of MOHR (1962), shattered the Rift floor into several relatively small « horst » and « graben ». Some of these faults are antithetic, so as to determine a minor rift-in-rift structure.

This « en échelon » arrangement of groups of faults without transverse structures seem to be a typical tectonic feature of the Rift Valleys (see Hepworth: Discussion in GIBSON and TAZIEFF, 1970).

The more depressed areas are occupied by lakes or swamps. Four lakes of tectonic origin (Zwai, Langano, Abiata and Awasa) have an elongated shape parallel to the main tectonic trend of the Rift, and shallow waters (few metres or tens of metres). The genesis of lake Shalla is quite different. MOHR (1967) first recognised lake Shalla to be a caldera. This lake has an elliptical contour with its major axis (about 25 km long) perpendicular to the main tectonic trend of the Rift. It has vertical contour walls and it is very deep (more than 250 m). Therefore, lake Shalla has to be considered one of the most important volcano-tectonic sinkings on the floor of the Rift Valley. Other similar structures existing in this region will be described later.

The hundreds of faults forming the youngest tectonic line close to the eastern escarpment and running parallel to each other in a NNE-SSW direction, are also arranged in a « en echelon » fashion. MOHR (1967; 1968) interpreted this « en échelon » fault set as the result of a displacement of the Rift margins due to transcurrent faulting across the Rift. Actually, nothing suggests the existance of transverse structures in this part of the Ethiopian Rift Valley; the same fact has already been pointed out for the northern part of the Ethiopian Rift (GIBSON and TAZIEFF, 1970). Only some dextral movements with a displacement of a few metres (or tens of metres) have been observed (Agge - Gadamsa) for NNE-SSW trending faults.

As already observed by GIBSON (1967) in the Fantale volcano area, some of the youngest faults are open tensional fractures without any displacement. In the area under study, faults of this type are visible mostly east of the Bora - Bericcio volcanic complex. However, in this area, some fractures showing a sigmoidal shape also occur; this seems to denote that longitudinal shear stresses might be associated to the tensional ones.

Tectonic movements are still active in the Ethiopian Rift Valley, as confirmed by young faults often affecting very recent formations and by the high seismicity of the whole region.

Stratigraphic outlines

The part of the Ethiopian Rift Valley surveyed is exclusively made up of volcanics and volcano-sedimentary products, with neither marine sediments nor crystalline rocks. Sediments of lacustrine origin are well represented; they cover large areas of the Rift with sometimes great thickness.

The successive periods of volcanic activity in this part of the Rift Valley include the following main events:

— fissure eruptions with emplacement of explosive dominantly ignimbritic products followed by volcano-tectonic collapses;

— building of silicic central volcanoes on the ignimbrites;

— basaltic fissure eruptions;

— edification of recent mostly pantelleritic centres with associated « subhistorical » basaltic fissure eruptions.

The stratigraphic succession of products may be reconstructed as follows:

— alluvium and lacustrine sediments	Recent Pleistocene
— recent alkaline and peralkaline rhyolitic pumice, ashes and obsidian lava flows	Holocene
— alkali trachytic lava flows and domes	Recent Pliocene
— recent basaltic lava flows and spatter cones	Recent Pleistocene
— basaltic hyaloclastites	Recent Pleistocene
— old alkaline and peralkaline rhyolitic lava flows and domes associated to pumice and ashes	Early Pleistocene Late Pliocene
— alkaline and peralkaline ignimbrites associated to pumice, ashes and lahars (mud flows)	Pliocene
— tertiary basalts and ignimbrites of the Plateau Trap Series	Pliocene Early Eocene

Basalts and Ignimbrites of the Plateau Trap Series

This is the most ancient and massive volcanic formation of Ethiopia. The age of this formation was usually considered (DAINELLI, 1943; MOHR, 1967) as early Eocene-late Miocene. Only recently (REX *et al.*, 1971) new age determinations have proved that the Plateau volcanic activity continued at least up to Pliocene. Therefore during all Tertiary, the uplifting of the region was accompanied by the eruption of a large volume of magma. A Plateau was formed consisting of hundreds and hundreds of basaltic lava flows and ignimbritic units, which are known to cover, in other places of Ethiopia, Mesozoic marine sediments.

The trap series, in the region studied in the present paper, often shows an exposed thickness of about 1000 m. Elsewhere, for instance in Wollo Province, a thickness of 2000 and sometimes 3000 m is rather common. The trap series is mostly made up of basaltic lava flows with subordinately associated ignimbritic units intercalated between the basic lavas. Also silicic lava flows and lava domes are sometimes associated with the basalts of the trap series but their volume is always small compared to that of the ignimbrites. The rocks of the trap series almost always appear strongly weathered with a soil cover frequently as thick as some tens of metres. Only in a few places, it is possible to observe unweathered basaltic lava flows of the trap series (quarries or highway trenches). In the investigated area, basalts and ignimbrites of the trap series occur on the top of the Ethiopian and of the Somalian Plateaux, but the best examples are, of course, along the main faults which originated the two escarpments. The last cover on both scarps is almost always ignimbritic; owing to the unclear tectonic style of the southwestern part of the western escarpment, no trap series basalts are visible there. It also seems that in this area the ignimbritic activity has been more important than in the northeastern part of the same Plateau, and than in the eastern plateau. In fact, in the area between Hosanna and Wolamo Soddu, three ancient big calderas occur, few km far from each other. They are almost circular and cut in pyroclastics (mainly ignimbrites, but also pumice formations occur) with eroded rims. It has to be remarked that these structures have a transversal alignment relatively to the main tectonic trend of the Rift Valley. They are, from West to East, respectively 10-15 and 6 km in diameter. These three big volcano-tectonic sinkings are probably linked with highly explosive eruptions of a very great amount of silicic magma which could account for the wide ignimbritic cover found in this area.

Basalts of the trap series, when good outcrops exist such as at Sire, East Langano, East Awasa (Arussi Province), consist of subhorizontal flows, a few metre thick (3-5 m, rarely more) with rather well preserved scoriaceous levels between the flows. The alternance in time of different eruptive episodes is demonstrated by the presence of paleosoil layers. Strong variations are observed in textural features from strongly porphyritic to aphyric basalt types.

Ignimbrites of the trap series always show a well welded structure with evident « fiammae ». Foreign inclusions are quite noticeable, even macroscopically, in many places. Ignimbrites interbedded with basalts of the trap series are generally constituted by few units (3 or 5), each about 5 to 20 m thick. The last ignimbritic cover, especially on the eastern Plateau is formed by one or two ignimbritic layers 10 to 25 m thick. On top of the western Plateau (SW of M. Guraghe), the base of the last ignimbritic cover is not visible, therefore the thickness must be more than 50 m, which is the thickness of the exposed part. In this area, no sure distinctions can be made between Plateau and Rift ignimbrites using only field observations.

It is worth mentioning that carbonized and silicified wood occur as inclusions into an ignimbritic formation, in an area located on the Somalian Plateau, in Sidamo Province (southeastward from the southern limit of the geological map). A first outcrop is on the main road which climbs the Somalian escarpment from Wendo to Neghelle Sidamo, ten km from Wendo, in a weathered ignimbritic formation. A second outcrop is on the main road which runs along the Somalian escarpment from Wendo to Dilla, about 17 km from Wendo, in a quarry of ignimbrite. Especially in this second outcrop, many branches and truncks of carbonized and silicified wood are included in a well welded, compact and fresh ignimbritic formation. Unfortunately, since the structure of the wood is not sufficiently preserved, the samples collected have no stratigraphic utility (J. Beauchamp, 1971, personal communication).

The Rift Pyroclastic Formation

Under this name it is indicated a formation including three principal rock types: typical ignimbrite, « sillar » and layered pumice.

In the region investigated, this is the most ancient formation outcropping on the floor of the Rift Valley. Its age is Upper Pliocene, according to MOHR (1967) who assumed the same age for the Rift ignimbrites and the last ignimbritic cover of the Plateaux. As a matter of fact, age determinations are known only for the Plateau ignimbrites (MILLER and MOHR, 1966; MOHR and GOUIN, 1967; REX *et al.*, 1971); up to now, no Rift floor ignimbrites have been dated. This formation is found all over the Rift extending from the eastern to the western escarpment.

FIG. 3 - Rift floor ignimbrite at the latitude of Golja close to the eastern escarpment.

It is constituted by several layers with variable thickness, from 0,5-1 m up to 20 m or more in a single unit. In many cases, paleosoils are observed between ignimbritic sequences; in other cases (East of lake Zwai), two ignimbritic sequences are separated by lacustrine deposits and the upper unit shows a perlitic base.

Typical ignimbrite is a hard, well welded rock with nicely developed « fiammae » containing small inclusions of foreign rocks. This is the most common type outcropping in this region. A coarse and less welded ignimbritic-like formation of « sillar » type (ROSS and SMITH, 1961) is locally well represented (around lake Shalla, western shore of lake Langano, East of lake Zwai). It is generally formed of horizontal layers and its exposed thickness can easily reach 150 m (southern shore of lake Shalla). This poorly welded ignimbrite is extremely rich in big pumice fragments and the amount of xenoliths is impressive; sometimes (southern shore of lake Shalla, camp Langano), the inclusions have gigantic dimensions (up to 10 m in diameter). Another important pyroclastic product associated with typical ignimbrite is a layered pumice formation. It is generally constituted by unwelded pumice of small size (few cm) and each layer is generally thin (few tens of cm). The best outcrop is found just West of lake Awasa; here, along a curved wall more than 200 m high, which is the ancient lake contour of Awasa (see geological map), many

FIG. 4 - Thin layers of lacustrine sediments between two ignimbritic units, same locality as Fig. 3.

thin layers of such unwelded pumice outcrop interbedded with thin layers of lacustrine deposits and paleosoils. Other evidence of these pumice layers is found around the inside walls of Corbetti Caldera (DI PAOLA, 1972) and Gadamsa Caldera. The pumice layers contain some xenoliths small in size and amount. Ashes, consisting of fine and incoherent glass particles, are frequently interbedded both with ignimbrite and pumice layers. Sometimes, these ashes are aggregated to form pisolites; more rarely, the glass particles are slightly cemented and the ash deposit becomes a cohesive soil (ashtuff).

Since the ignimbrites are intensely faulted, it is possible to observe this formation almost everywhere even when it is covered by more recent volcanic or lacustrine products. The total thickness of this formation is not known but it exceeds 200 m on the West of Nazareth or on the West and East of lake Shalla. The emplacement of typical ignimbrites, « sillar » and unwelded layered pumice, represents the most important volcanic event of the Ethiopian Rift Valley. No clear stratigraphic relations can be seen among these three principal rock types; only in a few localities (southern shore of lake Shalla, western shore of lake Langano) the « sillar » type underlies the typical ignimbrite.

FIG. 5 - Fault line showing ignimbrites over « sillar », western shore of L. Langano.

Since no clear centres of eruption are visible, all these pyroclastics must have been erupted mostly from fissures, probably during a wide time interval in Pliocene, and since they are of the same nature, their exact stratigraphic relations are not determining factors.

West and East of Nazareth, there are « lahar » deposits associated with the ignimbritic activity. These lahars flowed from North to South and are formed by ill-sorted fragments of different rock types cemented by fine pyroclastic material. They cover an area of about 35-40 km^2 with a thickness up to about 50 m. Another limited occurrence of « lahar » is found near the southern shore of lake Shalla.

Old Rhyolitic Lava Flows and Domes

Ignimbrite and pumice are the result of eruptions of gas-rich silicic magma; most probably, the same magma, having lost its gases during the explosive activity, was erupted later on as viscous lava flows and domes. Most of these domes pushed their way through the ignimbrites, but it is not always possible to find clear relations between the two different types of volcanism. Sometimes, individual volcanoes of conspicuous dimensions (500 m high) made up of viscous lava flows, stand above the ignimbritic « basement » (Data, Damota, Wondo Guenet). These lavas often show a « vertical sheeting » or especially when covering the slopes of a volcano, a marked flowage folding. Domes often show a glassy carapace due to the quenching of the viscous lava. Sometimes, domes are affected by hydrothermal and fumarolic phenomena. In some places (Boku, South of Nazareth), some active fumaroles exist; they are utilised as turkish bath by local people. Probably the existence of these active fumaroles in a relatively old volcanic formation is due to the rejuvenation of the regional faults. These lavas presumably erupted during a period of time starting from late Pliocene until lower Quaternary.

Thin and subordinated layers of unwelded pumice and ash deposits are often found interbedded in these silicic lava flows and lava domes.

Basaltic Hyaloclastites

Limited occurrences of subaqueous basaltic volcanism are found in some places of the Ethiopian Rift Valley. According to TAZIEFF (1968), hyaloclastites are the result of explosive activity of a basaltic magma under shallow water. The occurrence of these volcanic rocks is not surprising here, since in this region the extension of lake basins in the past could have been greater than at present, as extensive lacustrine deposits show. In this region, hyaloclastites occur both as small monogenic rings and as horizontal layers of local extension. Hyaloclastitic rings always show a large top crater which sometimes is occupied by a small lake, such as lake Chitu (SW shore of lake Shalla). In some cases (SW shore of lake Shalla), the crater of the hyaloclastitic ring is occupied by small basaltic spatter cones which were formed when the active vent became isolated from water; dykes of basaltic lava often cut the hyaloclastitic layers. Hyaloclastites consist of a fine glassy material, generally yellowish to brown in colour, which contains small boulders of basaltic lava; sometimes, (southern shore of lake Zwai) the hyaloclastitic layers contain fossil lacustrine gasteropodes. In the region investigated, hyaloclastites are quantitatively strongly subordinated to the other volcanic products.

Recent Basalts

These basalts are, volumetrically, in the Ethiopian Rift Valley, the second volcanic formation, though they are quite subordinate to ignimbrites. Recent basalts outcrop in two distinct lava fields each about 80 km long and 10 km wide. These uninterrupted lava fields are elongated parallel to the main tectonic trend of the Rift (NNE-SSW) and were clearly produced by fissure eruptions. An impressive number of aligned spatter cones mark the feeding fissures. One lava field is located close to the western escarpment just along the main faults which limit the Rift in the Butajira-Silti area (base of M. Guraghe-Shoa Province). The second field is located close to the eastern escarpment, just East of lake Zwai. Another small lava field of recent basalt is located just South of lake Shalla on the axis of the Rift. The recent basalt of the Butajira-Silti area is formed by some horizontal or subhorizontal lava flows sometimes associated with layers of hyaloclastites, and since many faults affect this formation it is possible to observe that basalts lie directly on the ignimbrites of the Rift. The thickness of the basaltic formation, in this area, is only few ten metres. « Subhistorical » basaltic lava flows, erupted from some vents, have flown towards the lower parts of the Rift, jumping the faults when they encountered them.

At about 80 km NE from Butajira, in the Bishoftu area (outside the northern limit of the map) recent basaltic lava fields and numerous spatter cones, whose craters are sometimes filled by small lakes, occur. Mohr (1967) considered some of them as explosion craters; field observations have not confirmed this interpretation. All of them are simply typical basaltic spatter cones built around the eruptive vent. The recent basaltic lava field on the opposite side of the Rift (East of lake Zwai) shows the same features but its thickness is greater (up to about 100 m). There, the recent basalts also cover the ignimbrites and all the formation is intensely faulted; even the spatter cones are sometimes affected by recent faulting. Very recent to « sub-historical » basaltic flows which are not affected by any tectonics, are observed; they flowed jumping over the fault walls as it can be seen for a lava flow coming from one of the biggest spatter cones of this area, which reaches the southern limit of the Wonji Sugar Estate Farm. Another recent basaltic lava field lies near Malkassa, and it extends as far as the Fantale Volcano area (outside the northern limit of the geological map), where an historical basaltic eruption was recognized first by THEILHARD DE CHARDIN and LAMARE (1930). The characteristics of this lava field are quite the same of those mentioned above: extensive basaltic lava flows erupted from NNE-SSW fissures, numerous young faults originating several small « horsts » and « grabens », a great number of well preserved spatter cones aligned along the feeding fissures.

All these lavas look very fresh with abundant scoriaceous surfaces of the « aa » type. Sometimes, they are completely aphyric, other times small phenocrysts of plagioclase, olivine and pyroxene are visible. Recent porphyritic basalts rich in large (more than 2 cm) plagioclase phenocrysts as well as olivine and pyroxene have been observed in some limited outcrops of the Nazareth-Malkassa-Gadamsa area.

Owing to the above stated characteristics, the recent basalt formation including hyaloclastites must have been emplaced during a rather long period of time starting from Pleistocene until Recent.

Some phreatic explosion craters, though very rare, occur in the recent basalt formation. However, since MOHR (1967) called « explosion craters » a great number of common basaltic spatter cones or the hyaloclastite rings, it is to be pointed out that the phreatic explosion craters, observed by the writer, in the field, are quite different, as it is to be expected, from basaltic spatter cones or hyaloclastite rings. Two of such phreatic explosion craters are located at about 15 km NE of lake Zwai. The largest crater is almost perfectly circular having a diameter of about 200-250 m with a vertical pit about 20-30 m deep. The craters appear as holes in the flat basaltic lava field and all around them, in a radius of several ten metres, a great amount of big blocks, both of basalt and of the underlying ignimbrites, are found. Another phreatic explosion crater is located in the recent basaltic lava field of the Butajira-Silti area. More exactly, this crater is located just on the left of the main road Addis Ababa-Hosanna, between Butajira and Silti. It is a circular crater with a diameter of about 700 m, whose vertical walls cut an almost flat basaltic surface. Its bottom is occupied by a small lake, whose surface is more than 50 m lower than the rim of the crater. The inside walls are constituted by several recent basaltic lava flows, covered by thin layers of fine sand containing numerous inclusions of different dimensions and nature.

As far as 100 m from the rim of this crater, big scattered blocks of recent basalt and of the underlying ignimbrites are visible. The

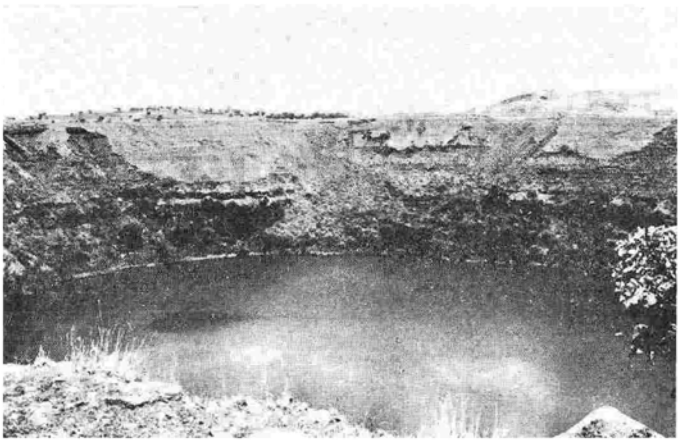

FIG. 6 - Phreatic explosion crater near Silti (western escarpment).

presence of these big blocks of buried rocks all around the craters, suggests that these craters are not related to a normal basaltic activity, but that they were produced by violent explosions of phreatic origin.

Trachytic Flows and Domes

These rocks are confined to some individual volcanoes such as Zuquala and Boseti-Gudda, both standing on the floor of the Rift Valley. Especially in the Boseti-Gudda volcano, trachytic lavas are associated with rhyolitic pyroclastics and lavas. Other occurrences of trachytic lava are found on the main road Nazareth - Asella between Dehra and Eteya, where two small domes outcrop. It is to be noted that the biggest individual volcano in the region investigated, Cilallo volcano, which rises on top of the Somalian Plateau, just along the eastern escarpment of the Rift, was formed mainly by trachytic lava flows.

Also trachytes are affected by faults. The age of the Rift trachytes is probably the same as that of the recent basalt formation, *i.e.* from Pleistocene up to Recent, while the trachytes of Cilallo are probably at least partly pliocenic.

Recent Rhyolitic Pyroclastics and Obsidian Lava Flows

These rocks are the latest volcanic products of this part of the Ethiopian Rift Valley. They are found mostly on the slopes of individual volcanoes such as, from North to South: Boseti, Ittisa (inside the caldera of Gadamsa), Bericcio, Bora, Alutu and finally the Urji and Chabbi volcanoes which grew inside the Corbetti Caldera (Di Paola, 1972). All these volcanoes lie on the same alignement parallel to the main tectonic trend of the Ethiopian Rift Valley. Presently all of them are at fumarolic stage.

Most of these latest rocks consist of pyroclastics such as unwelded pumice flows, pumice falls and ashes. Some obsidian lava flows, erupted from fissures located above the recent basaltic lava field on the South of Gadamsa caldera, are also present. Obsidians are generally the final products of this latest volcanic activity, but somewhere (southern slopes of Alutu) they are also interbedded with pumice and ashes. Obsidians appear as generally porphyritic viscous lavas, but aphyric varieties also exist on the southeastern and northern slopes of Alutu and on the eastern slope of Chabbi.

Judging from field evidence, these latest volcanic products of the Rift Valley must have been erupted very recently (Holocene).

Sometimes, even these very recent volcanic products are affected by regional faulting.

Lacustrine Sediments

Lacustrine sediments are the only non-volcanic formation in this portion of the Ethiopian Rift Valley. It is a quite important formation which covers an area of about 4000 km^2 and whose thickness is sometimes considerable, ranging from about 40 m in Bulbula River and 50 m in Boru and Maky Rivers up to more than 100 m between Modjo and Koka. These lacustrine deposits are the result of the drying up of a big lake which in the past occupied the floor of the Rift

Valley. Lakes Zwai, Langano and Abiata are, in fact, the remnants of that ancient large water basin. Also lake Awasa is the remnant of a larger lake, but there are no definite data which indicate whether the two old basins were connected or not. Lake sediments must have been deposited during a wide time interval, probably from the end of Pliocene until Recent. This is suggested by their considerable thick-

FIG. 7 - Faulted lacustrine sediments, W of L. Zwai.

ness and by the fact that, in many places, they underlie young volcanic products. Furthermore, lacustrine sediments are often rather deeply affected by regional faults (West of lake Zwai).

Lacustrine deposits consist of layers of cemented volcanic sands and ashes, transported pumice, silt, clay and diatomites.

Finally, the present-day alluvium is mostly represented by the Awash River floods (Koka - Wonji Sugar Estate Farm).

THE VOLCANIC CENTRES

In this portion of the Ethiopian Rift Valley, as mentioned above, there are several individual volcanoes and volcanic complexes. Some of the most important structures will briefly be described, starting from the North.

Zuquala Volcano

Zuquala is located about 20 km SW of Modjo. It is a typical cone-shaped volcano with a base diameter of about 12 km. It rises completely isolated for about 1100 m from the surrounding flat floor which is one of the western steps of the Rift Valley. Zuquala has steep flanks covered by thick vegetation. It is made up of several thick and viscous alkali-trachitic lava flows which seem to be by far the most important products of this volcano. No pyroclastics have been observed by the writer even in deep stream gullies. Zuquala has an almost perfectly circular top caldera, whose rim is at 2800 m a.s.l.; the diameter of the caldera is about 2 km; its depth is about 300 m and its bottom is partially filled by a small lake. No traces of post caldera manifestations have been observed.

Boseti-Gudda and Boseti-Bericcia Volcanic Range

This range is located about 15 km East of the town of Nazareth at the same latitude of Zuquala Volcano, close to the eastern escarpment, on the left side of the Awash River. It is formed by two distinct reliefs: Boseti-Gudda and Boseti-Bericcia, rising for about 1000 and 800 m respectively from the Rift floor. The base has an elliptical shape whose axes are 20 and 15 km long. These two volcanoes are strictly related to each other; in fact, they originated from the same NNE-SSW fissure.

Boseti-Gudda is a composite volcano, showing a remnant of a caldera rim on its western slope. The pre-caldera products of Boseti-Gudda consist mostly of viscous, thick (up to 50 m) trachytic lava flows, whilst the post-caldera activity is mostly represented by very recent pantelleritic obsidian lava flows associated with pumice and ashes. Several small craters are aligned along the feeding fissure; on the bottom of one of those craters, a « cake » of obsidian, similar to that of the Sakurajima volcano (Japan), occurs.

Boseti-Bericcia consists mostly of very recent pantelleritic obsidian lava flows with associated pyroclastics (pumice and ashes). The fissure connecting Boseti-Gudda to Boseti-Bericcia is a still open fracture through which « subhistorical » basaltic lava flows were erupted just at the junction of the two volcanoes slopes, flowing down on both sides of the fissure. Both volcanoes are, at present, at considerable fumarolic stage. Their open feeding fracture, although displaced about 15 km to the East, still belongs to the most tectonically active line of the Rift. This « en échelon » arrangement is the Rift floor equivalent of that already mentioned for the Somalian Plateau escarpment (see pag. 521 and Fig. 2).

Gadamsa Caldera

This caldera is adjacent to the Wonji Sugar Estate Farm SW boundary. It is almost perfectly circular with a diameter of about

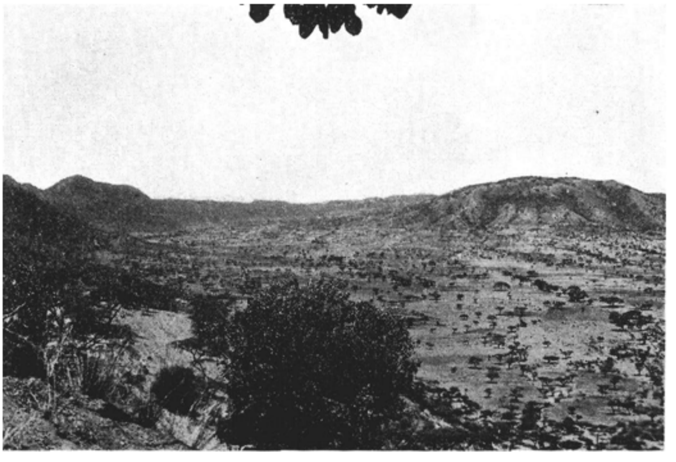

FIG. 8 - Gadamsa Caldera.

10 km. The rim of the caldera is well preserved with vertical inside walls 100-200 m high.

Only a small section of the NW rim has been eroded. The rocks which form the rim of the caldera are mostly rhyolitic lavas, even though pumice and ignimbrites are rather abundant.

The north-eastern rim of the caldera is formed by some very thick (20-30 m) rhyolitic lava flows, 2-5 km long, showing a clear flowage folding. In some places, coarse explosion breccias made up of heterogeneous volcanic material, lie at the base of the lava flows. The lava is covered and interbedded with finely bedded pyroclastic materials (small pumice, minute salic crystals, ashes) dipping, as the lava flows, towards the Wonji plain. The interior of the caldera shows several signs of post-caldera activity. Some small dome-like features occur mostly consisting of pumice falls with subordinate rhyolitic lavas. The most important feature is an irregular chain of hills rising for about 200-250 m from the floor of the caldera. It is made up of alternations of rhyolitic lavas and pumice deposits.

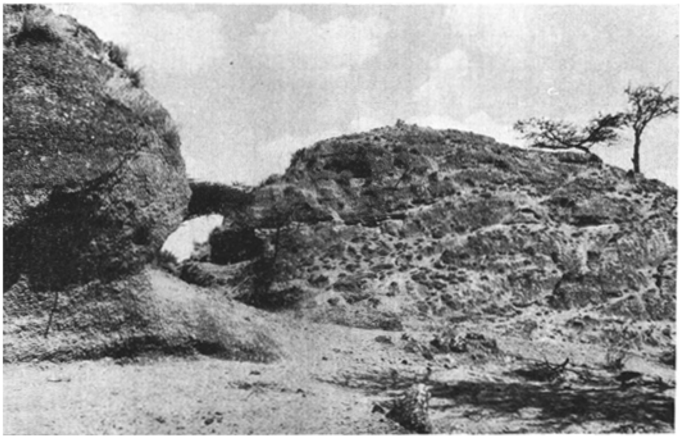

FIG. 9 - Layered pumice deposits on the NE inner rim of Gadamsa Caldera.

This chain is locally named Ittisa and, on its eastern part, there is a large crater with a diameter of about 1 km and a depth of about 100 m. A large amount of the underlying formations is found as blocks within the pumice deposits and as xenoliths in the lavas inside the Ittisa crater. The most abundant inclusions are represented by a strongly porphyritic basalt, which, as previously mentioned, outcrops in this area. The whole caldera is strongly affected by many large regional NNE-SSW faults, especially on its eastern part. Along one of these faults, close to the inside NE rim of the caldera, a small basaltic spatter cone was built; at present, this spatter cone shows vertical and dextral dislocations due to a later movement of the same fault.

Another small basaltic spatter cone is located close to the western inside rim of the caldera. Weak traces of fumarolic activity are visible at the base of the western rim of the caldera and on a small pumice dome on the West.

Bora and Bericcio Volcanic Complex (1)

In an area of about 500 km² located between the artificial lake of Koka and lake Zwai, close to the eastern escarpment, there is one of the most recent volcanic complexes of the Ethiopian Rift Valley. This area is cut by the so-called Wonji fault belt and it appears even more extensively affected by faulting than other areas affected by

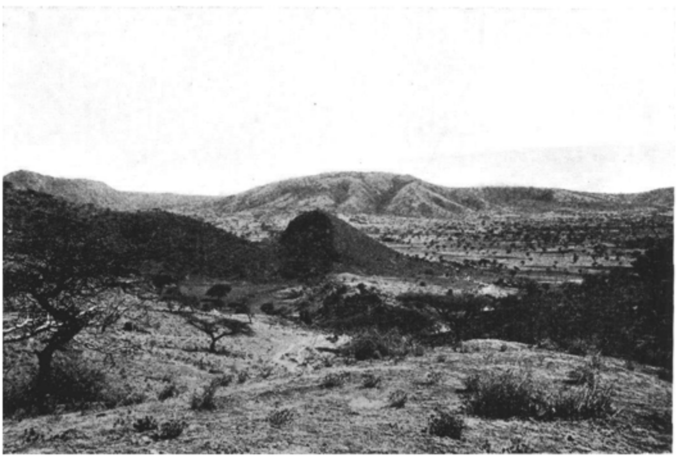

FIG. 10 - N-NE fault affecting a basaltic spatter cone inside Gadamsa Caldera. On the background, Ittisi volcano.

the same young tectonics. Especially in the eastern part of this area, the number of open tensional fissures and faults with extremely variable downthrow is impressive. Often faults and fractures cross each other at a small angle with a range of directions from N-S to NE-SW. Almost all the formations are shattered into many small « horst » and « graben » structures: This complex includes two rather large volcanic centres (Bora and Bericcio) associated with a great number of smaller volcanic foci and with subhistorical limited fissure eruptions. Most of the products found in this area are silicic pyroclastics. Bora volcano is located on the NE of lake Zwai and it consists of alternances of

(1) In some old Italian topographic maps, the name Bora (or Borra) is assigned to Bericcio (or Bariccia) and vice-versa. In the present geological map, these names have been inverted after information got from local people by Ethiopian geologists speaking fluent Gallinian idioma.

pumice and ash layers poorly welded or completely unwelded; inclusions of foreign rocks are scarce; subordinate rhyolitic lavas are sometimes associated with pyroclastics. Bora rises for about 350 m above the floor of the Rift and it has a large top crater (more than 1.5 km in diameter and more than 100 m deep). Its western slope is affected by a volcano-tectonic collapse (sector-graben). Bericcio volcano is located just NE of Bora; it rises for about 500 m from the

FIG. 11 - Bericcio Volcano seen from NW.

floor of the Rift and it has a more regular cone-shaped profile. A small circular crater is located on the top, just in the centre of the volcano. Another crater (about 1 km across) cuts its southern slope. Bericcio is made up of completely unwelded pumice flows and it seems that no lavas are associated with these pyroclastics.

Just East of the Bora and Bericcio volcanoes, a great number of smaller volcanic centres occur. They are exclusively made up of silicic pyroclastics, mostly pumice flows or pumice falls, the latter forming perfect domes. Lavas are once more subordinated. Craters, generally small, are abundant and irregularly scattered.

Further on the E, it rises for about 250 m another small volcanic centre, Tulu Moje, also made up mostly of pumice and ashes but with a base mostly made up of trachytic and rhyolitic lavas. It has a top crater about 700 m in diameter and it is more intensively faulted than Bora and Bericcio. Its northern base is covered by subhistorical thick obsidians lava flows erupted along a fissure which affects the volcano itself.

Two other obsidian flows clearly erupted from the same fissure are located about 5 km to the NE. These obsidian lava flows appear as almost circular bodies (1 to 4 km in diameter) which did not flow very far from their centre of emission because of the high viscosity of the lava. Obsidians cover their own feeding fissures and are not affected by any faulting. Associated with obsidians, there are some subhistorical basaltic lava flows which seem to have erupted from the same fissures. These eruptions of basalts are younger than obsidians or penecontemporaneous. The Bora, Bericcio (and Tulu Moje) volcanic centres, as well as the other numerous secondary loci of pyroclastics, stand above the ignimbrites of the Rift. These ignimbrites are frequently hidden by thick sequences of lacustrine sediments or by stream deposits. The considerable abundance of pyroclastics shows that this area has been a zone of highly explosive volcanic activity. In fact, lavas (mostly obsidians) are strongly subordinated representing the final eruptions of a magma which lost its gases during pyroclastic activity. Different faulting patterns in the pyroclastics do not necessarily indicate great differences in age. In fact, Tulu Moje volcano is more faulted than Bora and Bericcio volcanoes because it is located just in the middle of the most active tectonic line of the Rift floor. All the products of this area must have been erupted during a relatively short period of time in Holocene, as their high stratigraphic position and the present considerable fumarolic activity show. Erosion has affected rather deeply this area in a short time because of the completely incoherent nature of the pyroclastics.

Cilallo Volcano

This is the biggest individual volcano in the central Ethiopian Rift Valley, and one of the biggest of Ethiopia. Cilallo is located about 30 km East of lake Zwai in Arussi Province, just where the main faults which limit the eastern escarpment, SW from Sire, die out (Fig. 2). Cilallo has an elliptical base (about 30×20 km) whose major axis lies parallel to the main tectonic trend (NNE-SSW). It rises with gentle slopes for more than 1500 m from the top of the Plateau. At its top, there is a large, almost circular caldera about 6 km in diameter, whose southern rim represents the summit of the volcano (4000 m a.s.l.).

The northern rim of the caldera is cut by a deep stream gully and all the slopes of the volcano are deeply affected by erosion. In many places, forests and a thick soil cover make field observations quite difficult. The slopes of Cilallo are mostly constituted by thick alkali trachytic lava flows. No pyroclastics have been observed by the writer at least on the western and northeastern slopes. All around the inner rim of the Cilallo caldera, enormous dykes, radially disposed, are visible.

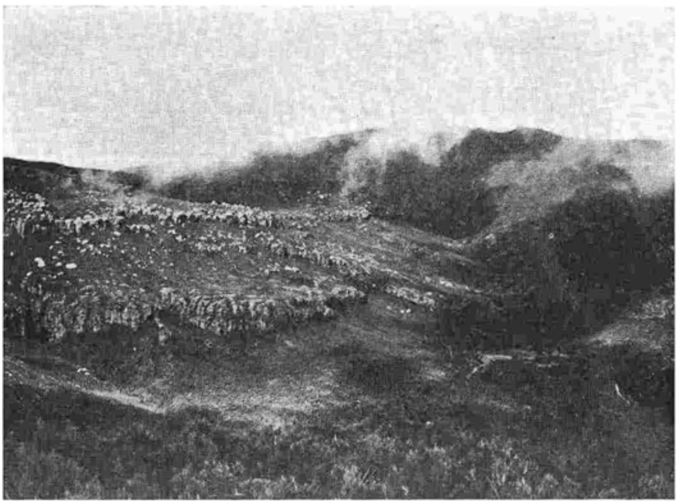

FIG. 12 - Cilallo volcano summit caldera seen from NE.

Post caldera activity is represented by some important alkali trachytic lava flows which occupy the bottom of the caldera. Another example of post-caldera activity is a small outcrop of fresh porphyritic plagioclase basalt, just on the NE rim of the caldera.

The birth of Cilallo is probably related to an early period of tectonic movements which opened the Rift Valley. In fact, at the western base of the volcano, the ignimbrites of the trap series constitute a moulding cover on the Cilallo lava flows (Gondi, Simba stream valleys).

However, it is to be noted that, in this region, no clear stratigraphic and petrographic differences have been observed between Plateau and Rift ignimbrites, therefore the problem of their distinction is at present far from being solved.

Badda Volcano

Badda is another big volcano located just East of Cilallo, so close that their products partly overlap each other. Badda rises for about 2000 m from the top of the Somalian Plateau, its summit being at about 4200 m a.s.l. Badda is relatively old, deeply affected by erosion and probably of the same age of Cilallo. It is elongated towards NNE-SSW much more than Cilallo. Some samples collected from thick lava

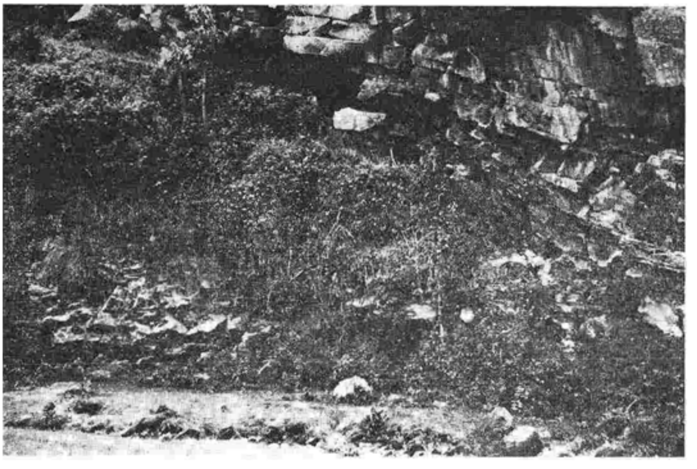

FIG. 13 - Ignimbrite overlying trachytic lava flow at the foot of Cilallo volcano near Gondi.

flows are alkali trachytes such as the Cilallo lava flows. The lava flows of this volcano stand on the basalts of the trap series and it seems that lavas are the majority of its products. In fact, no pyroclastics have been observed by the writer climbing the eastern slope of Badda from the village of Robi.

Large amount of alkali trachytic magma erupted by these two big volcanoes, could have been produced by differentiation of the basalts of the trap series.

At about 60 km SW from Cilallo two other big volcanoes (Cacca and Encuolo) rise from the top of the Somalian Plateau. These two volcanoes are not shown in the geological map because they have not yet been studied in detail by the author.

Alutu Volcano

Alutu is located between lake Zwai and lake Langano with an elongated NNE-SSW base axis about 15 km long. It probably occupies a narrow graben, now partially hidden by the lake waters, visible on a small peninsula near the northern shore of lake Langano (South of Alutu), and cutting Debre Tseyon island in lake Zwai (North of Alutu).

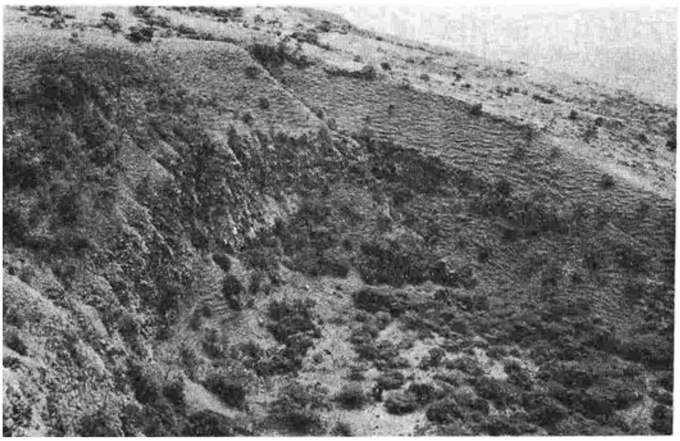

FIG. 14 - Crater on the northern slope of Alutu volcano.

Generally speaking, Alutu is set, as the other recent volcanic centres, along the line of young faults affecting the floor of the Rift Valley close to the eastern escarpment (the Wonji Fault Belt). Also Alutu is partially affected by NNE-SSW faults and fractures.

This volcano has several craters (never exceeding 1 km in diameter) located at different altitudes. The craters are commonly aligned along NNE-SSW fissures but also E-W alignments exist.

Alutu is constituted of silicic pyroclastics such as pumice flows, pumice falls and ashes, with subordinate rhyolitic lava flows, mostly obsidians. These lavas, especially the most recent ones, have been erupted from the same craters which previously had erupted pyroclastics; the lava flows descended the slopes of the volcano in every direction, frequently showing a flowage folding. Both old and very recent obsidians are porphyritic, sometimes very rich in crystals as it can be seen in one of the last eruptions descendig the southern slope of Alutu. In a few places, (southeastern slope) aphyric varieties also occur.

The age of Alutu must be considered very recent because its products (pyroclastics and lavas) cover recent basaltic lava flows to the West and a hyaloclastite ring to the North, and because the volcano is at present in a stage of considerable fumarolic activity. Alutu also is rather deeply affected by erosion, but this is the result, like for Bora and Bericcio, of the incoherent nature of most of its products.

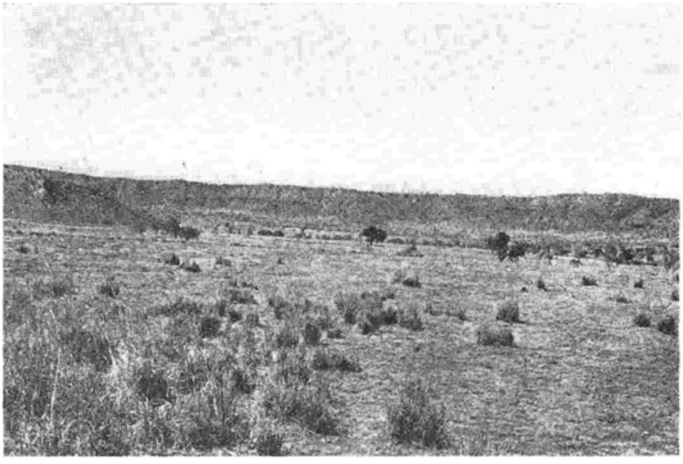

FIG. 15 - Corbetti Caldera, seen from E.

Lake Shalla Caldera

As already mentioned, lake Shalla is a very large caldera which probably represents the most important volcano-tectonic sinking of the whole Ethiopian Rift Valley. Lake Shalla is an elliptical basin with axes of 25 and 15 km. It has deep waters (about 250 m) and its surface is at 1500 m a.s.l.

This lake collects many important streams, among which a small river coming from the western escarpment but no output exist. Shalla caldera has vertical walls which, in some places, reach a height of 150-200 m. It is set along the axis of the Rift Valley and some NNE-SSW and N-S faults affect its rims. The caldera cuts mostly ignimbrites and pumice deposits of « sillar » type but also some rhyolitic lavas. The age of Shalla caldera is probably late Pliocene. In fact, the

Quaternary recent basaltic formations, represented in the SW shore of the lake by some hyaloclastite rings, spatter cones and lava flows, seem to be the only post-caldera activity. Present activity consists of hydrothermal manifestations which occur all around the lake.

Corbetti Caldera

This volcanic complex has already been described in some detail by Di Paola (1972). It is located between lake Shalla and lake Awasa, along the axis of the Rift. Post-caldera activity is here represented by two very recent volcanoes (Urji and Chabbi) mostly formed of pumice flows and pumice falls with subordinate obsidian lava flows. The age of the Urji and Chabbi volcanoes is probably the same (very recent to subhistorical) as that of the Alutu, Bora, Bericcio, Ittisa, Boseti-Gudda and Boseti-Bericcia volcanoes.

The occurrence, in this portion of the Ethiopian Rift Valley, of a huge widespread ignimbritic formation and other silicic pyroclastics easily accounts for the presence of those three regional volcano-tectonic sinkings described above, namely Gadamsa, Shalla and Corbetti calderas.

Petrological Notes

Mineralogy

The volcanic rocks of the above described formations range in composition from alkali olivine basalts to peralkali rhyolites. No significant petrological differences between the rocks of the trap series and those of the Rift floor have been detected in the area investigated but this could also depend on incomplete sampling owing to the large extension of this region.

Basalts

Among basic rocks, some rare picritic varieties occur, olivine basalt being the most representative ones. Basalts show different textures such as aphyric, porphyritic, doleritic or ophitic. They are, generally, well crystallized but some varieties with a partially glassy groundmass are also present. The mineralogical assemblage is the following: magnesian olivine, clinopyroxene of augite type; calcic plagioclase with An from 68 % to 85 %, magnetite and ilmenite, rare and small apatite crystals. Olivine is always stable as phenocrysts and it is always present in small grains in the groundmass. Pyroxene is often zoned and sometimes missing as phenocrysts. Neither orthopyroxene nor pigeonite have been detected. Plagioclase is only slightly zoned (generally two zones) with a bitownitic core and a labradoritic rim. Among recent basalts of the Rift floor, most of the subhistorical lava flows show a more alkaline character at least judging from the presence of titaniferous augite (clear pleocroism on lilac colours). It is here to be noted that titaniferous pyroxene appears, in the basalts of this region, only in those rocks with an ophitic or doleritic texture. Textural variations, with inverted order of crystallization plagioclase-pyroxene are rather common indicating variation of the P_{H_2O} conditions of crystallization (NESBITT and HAMILTON, 1970).

Hawaiites

These rocks represent lava flows always associated with basalts both on the Plateaux and on the Rift floor. Of course, they cannot be distinguished in the field; some differences from basalts can be detected petrographically but a more accurate distinction can be made only on a chemical basis. Mineralogically, they appear as sub-aphiric rocks, made up of small crystals of olivine, clinopyroxene, plagioclase, and iron ores with an appreciable amount of glass. In these rocks, olivine is less abundant than in basalts. Owing to the small size of crystals, no accurate measures have yet been made, however plagioclase phenocrysts when present have a labradoritic composition, and the pyroxene seems to be augitic.

Trachytes and Rhyolites

These rocks have a variable mineralogical composition. Some varieties seem to be dark trachytes such as those described by BARBERI *et al.* (1970) for the Danakil Depression. In fact, mineralogically, they are porphyritic rocks with phenocrysts of sodic plagioclase (oligoclase), associated with alkali feldspar (anorthoclase); mafic minerals are represented by calcic clinopyroxene with sometimes associated orthopyroxene; iron ores are always abundant. The groundmass is made up of alkali feldspar, clinopyroxene and a variable amount of glass.

Other varieties show the characteristics of more oversaturated rocks of up to alkali rhyolitic composition, *i.e.* with phenocrysts of anorthoclase, aegirinaugitic pyroxene, fayalite and magnetite. In the groundmass, the alkali feldspar predominates and mafic minerals are represented by aegirinaugite and by two alkali amphiboles (riebeckite and barkevickite). Again, the amount of glass is variable from sample to sample.

Peralkali Rhyolites

These rocks are represented by some lava flows, lava domes and pumice flows, but especially by ignimbrites which are by far the most common product. Petrographically, they appear to be always highly glassy, with variable contents of the following minerals: alkali feldspar, generally anorthoclase (more rarely sanidine), acmitic pyroxene, alkali amphiboles (riebeckite, barkevickite and more rarely Fe-hastingsite), rarely fayalite and quartz. In many samples, big elongated crystals of aenigmatite mark the peralkaline character of these rocks. Often, in rhyolitic lavas, the groundmass shows a spherulitic texture due to the recrystallization of the glass; quartz-feldspar intergrowths are also rather frequent. In ignimbrites, foreign inclusions of buried rocks are always present. These xenoliths are exclusively of volcanic origin (rhyolites and basalts); neither marine sediments nor crystalline rocks have been observed among xenoliths.

Chemistry

Thirty new chemical analyses and CIPW norms of volcanic rocks of the region investigated are quoted in Tables 1 and 2. The X-ray flluorescence method has been used (FRANZINI and LEONI, 1972) except for three of them, which have been analized with traditional methods.

Five additional chemical analyses of volcanics beloging to the same region, or close to it, are reported for comparison; for this portion of the Ethiopian Rift Valley, these analyses are the only ones found in the literature (MOHR, 1970).

The analyses are still too scanty to allow an accurate comparison between Plateaux and Rift volcanism. However, some preliminary observations can be made.

Four chemical analyses are available for the Somalian Plateau in the investigated area; one of them clearly indicates an alkali basaltic nature with normative nepheline, whilst two others correspond to intermediate rock types which apparently do not show any genetic

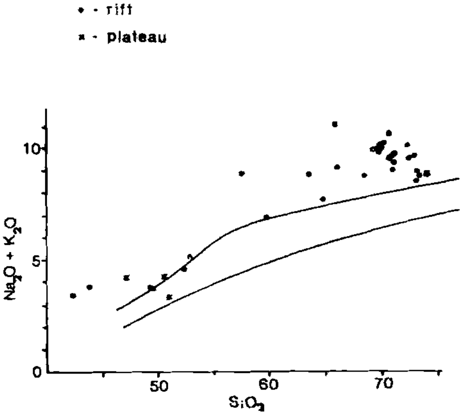

FIG. 16 - Alkalics-silica diagram of volcanic rocks from the central Ethiopian Rift Valley (KUNO, 1968).

affinity with alkali basaltic magmas. They are in fact oversaturated in silica, rather rich in iron and titanium and in spite of their evolved nature, as indicated by the rather low values of MgO, the alkali content is the same, or even lower, than that of the analysed basalts. This fact indicates that the two intermediate rocks are probably genetically related with a less alkalic, transitional or tholeiitic basaltic magma. The fourth sample is a pantellerite, identical to those of the Rift Valley floor.

A transitional nature between alkali basalts and tholeiites is also shown by two of the four available chemical analyses of the Rift basalts. On a purely normative basis, they should be called olivine-tholeiites (YODER and TILLEY, 1962), however in an alkali-silica diagram these basalts fall in the alkalic fields, with points very near to the boundary line (Fig. 16). The other two samples have an alkali basalt composition showing normative nepheline.

TABLE 1 - Chemical analyses and C.I.P.W. norms of basic, intermediate and non-peralkaline rocks from the central part of the Ethiopian Rift Valley.

		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
SiO_2		47.27	50.58	50.92	42.38	43.80	49.18	49.27	52.77
TiO_2		1.98	3.30	3.07	4.15	1.97	2.00	1.94	2.33
Al_2O_3		15.97	12.86	12.85	14.59	18.13	16.24	16.05	16.08
Fe_2O_3		2.94	4.02	4.33	5.76	3.70	0.88	2.44	1.93
FeO		7.41	9.39	8.44	9.62	7.68	9.01	7.57	8.35
MnO		0.19	0.25	0.22	0.21	0.05	0.17	0.18	0.19
MgO		6.42	3.98	5.66	6.24	5.48	6.54	6.85	3.16
CaO		11.04	8.96	10.78	10.65	12.12	10.92	10.92	8.75
Na_2O		3.11	3.24	2.63	2.88	3.00	3.13	3.04	3.95
K_2O		1.12	1.03	0.77	0.64	0.88	0.69	0.68	1.25
P_2O_5		0.51	0.47	0.43	0.44	0.34	0.45	0.44	0.44
H_2O^+		1.74	1.59	0.20	2.24	0.86	0.77	0.62	0.78
H_2O^-		0.30	0.33	0.18	0.29	0.68	0.02	—	0.02
		100.00	100.00	100.48	100.09	98.69	100.00	100.00	100.00
				C.I.P.W. Norms					
q		—	5.09	5.24	—	—	—	—	2.05
or		6.62	6.08	4.56	3.78	5.36	4.08	4.02	7.38
ab		23.56	27.40	22.27	20.42	13.86	26.47	25.71	33.40
an		26.31	17.51	20.93	24.99	34.34	28.23	28.14	22.46
ne		1.48	—	—	2.13	6.67	—	—	—
di	wo	10.49	9.96		10.42		9.60	9.66	7.54
	en	6.50	5.11	24.38	6.84	20.83	5.19	5.96	3.27
	fs	3.36	4.61		2.84		4.09	3.15	4.26
wo		—	—	—	—	—	—	—	—
hy	en	—	4.80	9.57	—	—	1.91	5.22	4.59
	fs	—	4.33		—		1.50	2.76	5.98
ol	fo	6.64	—	—	6.09	8.79	6.44	4.12	—
	fa	3.78	—		2.78		5.59	2.40	—
mt		4.26	5.83	6.29	8.35	5.53	1.28	3.54	2.79
il		3.76	6.27	5.82	7.88	3.85	3.80	3.68	4.42
ap		1.21	1.11	0.94	1.04	0.77	1.07	1.04	1.04
hm		—	—	—	—	—	—	—	—

Somalian Plateau (Trap series)

1) Alkali olivine basalt: porphyritic lava flow in an highway trench at Agere Salam (outside the southern limit of the geological map).
2) Hawaiite: aphyric lava flow in a stream gully at Sire.
3) Hawaiite: porphyritic lava flow from the Asella - Cilallo area (REPOSSI, 1932).

Rift Floor

4) Alkali olivine basalt: scoriaceous boulder in a hyaloclastite ring at Adamitullu (Analyst: R. ROMANO).
5) Alkali olivine basalt: porphyritic lava flow near Welenchiti (MERLIN, 1950).
6) and 7) Olivine basalt: porphyritic lava flows in a trench of the Addis Ababa - Dire Dawa highway, 30 km from Adama (Nazareth).
8) Hawaiite: subaphyric lava flow 1 km North of Abura.

Continued: TABLE 1 - Chemical analyses and C.I.P.W. norms of basic, intermediate and non-peralkaline rocks from the central part of the Ethiopian Rift Valley.

	9	*10*	*11*	*12*	*13*	*14*	*15*
SiO_2	52.47	57.54	59.80	63.29	64.74	69.56	69.57
TiO_2	1.84	1.06	2.37	0.89	1.43	0.46	0.66
Al_2O_3	17.11	14.40	11.39	13.73	14.09	14.88	14.64
Fe_2O_3	1.95	3.99	3.94	1.73	2.08	1.81	1.56
FeO	7.31	6.82	5.35	6.96	4.04	1.01	1.20
MnO	0.16	0.13	0.27	0.49	0.18	0.08	0.20
MgO	4.25	2.09	1.94	0.45	1.00	0.32	0.52
CaO	8.58	4.41	4.56	2.66	3.45	1.34	1.17
Na_2O	3.36	4.49	3.96	6.30	4.64	5.15	6.00
K_2O	1.22	4.38	2.99	2.51	3.10	4.79	3.95
P_2O_5	0.57	0.32	0.56	0.20	0.40	0.07	0.13
H_2O^+	1.06	0.08	2.75	0.79	0.65	0.53	0.34
H_2O^-	0.12	0.08	0.12	—	0.20	—	—
	100.00	99.79	100.00	100.00	100.00	100.00	99.94
			C.I.P.W. Norms				
q	3.37	2.21	15.95	8.53	17.78	18.76	17.52
or	7.20	26.04	17.66	14.83	18.31	28.30	22.79
ab	28.41	38.22	33.49	53.28	39.24	43.55	50.83
an	28.00	6.15	4.48	1.78	8.47	3.34	1.39
ne	—	—	—	—	—	—	—
di wo	4.52		6.04	4.22	2.51	0.92	1.51
di en	2.36	11.71	3.49	0.44	1.02	0.79	1.05
di fs	2.02		2.28	4.22	1.51	—	0.33
wo	—	—	—	—	—	0.26	—
hy en	8.21	7.13	1.34	0.68	1.46	—	0.15
hy fs	7.04		0.87	6.57	2.16	—	0.07
ol fo	—	—	—	—	—	—	—
ol fa	—	—	—	—	—	—	—
mt	2.82	5.82	5.71	2.51	3.01	2.18	2.09
il	3.49	2.02	4.50	1.69	2.71	0.87	1.22
ap	1.35	0.70	1.32	0.47	0.94	0.16	1.01
hm	—	—	—	—	—	0.30	—

Rift Floor

9) Hawaiite: doleritic lava flow (faulted), 15 km from Dehra to Sire.
10) Alkali trachyte: aphyric lava from Adama (Nazareth) area (REPOSSI, 1932).
11) Alkali trachyte: subaphyric glassy lava interbedded with pumice on the western ancient contour of lake Awasa.
12) Alkali trachyte: porphyritic lava flow (same as 6 and 7).
13) Rhyolitic trachyte: porphyritic fine-grained groundmass lava flow at the foot of the eastern scarp, 5 km East of Tulu Mojè.
14) Rhyolitic trachyte: porphyritic lava flow from Tulu Mojè crater.
15) Porphyritic lava (dome East of Nazareth) (Analyst: R. R. CIONI).

TABLE 2 - Chemical analyses and C.I.P.W. norms of silicic peralkaline rocks from the central part of the Ethiopian Rift Valley.

	16	*17*	*18*	*19*	*20*	*21*	*22*
SiO_2	65.79	69.27	70.83	74.03	70.54	73.14	70.20
TiO_2	0.53	0.50	0.44	0.40	0.45	0.38	0.38
Al_2O_3	14.56	11.88	10.95	10.58	11.12	9.83	11.12
Fe_2O_3	2.95	6.48	4.08	2.88	6.03	4.08	3.77
FeO	2.70	0.49	2.02	2.07	0.37	1.71	0.85
MnO	0.29	0.31	0.31	0.20	0.32	0.29	0.17
MgO	0.12	0.19	0.16	0.13	0.12	0.12	0.36
CaO	1.00	0.29	0.55	0.42	0.47	0.30	0.88
Na_2O	6.37	4.57	5.11	4.67	5.40	4.30	4.71
K_2O	4.65	5.37	3.93	4.17	4.06	4.61	5.58
P_2O_5	0.08	0.03	—	0.03	0.23	—	0.04
H_2O^+	0.79	0.48	1.33	0.82	0.70	0.91	0.88
H_2O^-	0.17	0.14	0.29	0.20	0.19	0.33	1.10
	100.00	100.00	100.00	100.00	100.00	100.00	100.04
			C.I.P.W. Norms				
q	9.40	23.31	26.18	30.36	25.79	31.74	23.40
or	27.47	31.72	23.21	25.02	23.98	27.24	33.72
ab	49.00	31.20	34.44	30.92	34.59	24.63	26.59
di wo	1.85	0.51	1.13	0.81	0.34	0.58	
di en	0.16	0.44	0.17	0.10	0.29	0.05	3.54
di fs	1.89	—	1.06	1.72	—	0.60	
wo	—	—	—	—	—	—	—
hy en	0.13	0.02	0.22	0.20	—	0.15	0.43
hy fs	1.52	—	1.33	2.77	—	1.92	
ac	4.29	6.55	7.73	7.39	9.76	10.16	11.16
ns	—	—	—	—	—	—	0.35
mt	2.12	1.14	2.04	0.46	0.93	0.93	—
il	1.01	0.95	0.83	0.76	0.85	0.76	0.74
ap	0.19	0.07	—	—	0.54	—	0.09
hm	—	3.43	—	—	2.01	—	—
tn	—	—	—	—	—	—	—
		Peralkalinity Index (P.A.I.)					
mol. $\frac{Na_2O+K_2O}{Al_2O_3}$	1.06	1.12	1.15	1.15	1.21	1.23	1.25

Somalian Plateau (*Trap Series*)

19) Pantellerite: ignimbrite, 10 km before Asella from Adama (Nazareth).

Rift Floor

16) Comenditic trachyte: porphyritic lava flow from the northern slope of Zuquala volcano at 2000 m a.s.l.
17) Comendite: ignimbrite at the Billate River bed, 3 km after Colito to Wolamo Soddu.
18) and 20) Pantellerites: subaphyric slightly glassy lava (dome, Abura).
21) Pantellerite: recristalized glassy lava (shear-faulted dome, Agge).
22) Pantellerite: aphyric lava in a quarry at 54 km from Addis Ababa to Modjo (outside the northern limit of the geological map) (MERLIN, 1953).

Continued: TABLE 2 - Chemical analyses and C.I.P.W. norms of silicic peralkaline rocks from the central part of the Ethiopian Rift Valley.

	23	24	25	26	27	28	29
SiO_2	72.88	73.47	70.93	72.27	72.88	65.92	70.51
TiO_2	—	0.42	0.44	0.40	0.42	0.35	0.41
Al_2O_3	10.12	9.40	9.54	9.28	9.51	8.92	9.19
Fe_2O_3	6.15	4.92	4.81	6.22	5.22	5.99	3.79
FeO	1.09	0.63	1.14	0.61	0.85	—	2.26
MnO	—	0.23	0.29	0.36	0.24	0.23	0.31
MgO	0.54	0.18	0.22	0.07	0.10	0.23	0.05
CaO	0.64	1.05	0.44	0.25	0.28	0.99	0.27
Na_2O	6.00	4.52	4.72	4.53	4.97	4.75	4.88
K_2O	2.54	4.23	4.60	4.96	4.67	4.38	4.74
P_2O_5	—	0.01	0.02	—	0.01	—	—
H_2O^+	0.42	0.83	2.60	1.05	0.73	8.24	3.12
H_2O^-	—	0.22	0.20	—	0.12	—	0.47
	100.38	100.11	100.00	100.00	100.00	100.00	100.00
			C.I.P.W. Norms				
q	29.50	32.52	28.25	30.84	30.18	24.43	29.20
or	15.06	25.02	27.17	28.91	27.80	25.88	28.00
ab	37.91	24.63	23.46	20.44	22.33	21.50	20.88
di wo		0.81	0.85	0.35	0.58	0.66	0.55
di en	2.51	0.50	0.20	—	0.10	0.57	0.01
di fs		0.26	0.70	0.40	0.53	—	0.61
wo	—	1.39	—	0.12	—	1.26	—
hy en	0.35	—	0.34	—	0.10	—	0.10
hy fs		—	1.20	—	0.79	—	3.43
ac	11.46	12.01	13.91	15.71	15.25	16.45	10.96
ns	—	—	0.15	—	0.61	—	1.85
mt	3.20	1.16	—	1.16	—	—	—
il	—	0.76	0.83	0.76	0.76	0.49	0.77
ap	—	—	0.04	—	—	—	—
hm	—	—	—	—	—	0.30	—
tn	—	—	—	—	—	0.22	—
		Peralkalinity Index (P.A.I.)					
mol. $\frac{Na_2O+K_2O}{Al_2O_3}$	1.25	1.28	1.34	1.38	1.40	1.42	1.43

Rift Floor

23) Pantellerite: ignimbrite near Koka (PAGLIANI, 1940).
24) Pantellerite: porphyritic lava (series of domes between Nazareth and Wonji); (Analyst: R. R. CIONI).
25) Pantellerite: coarse ignimbrite interbedded with pumice on the northern inner rim of Corbetti Caldera.
26) Pantellerite: subaphyric lava (dome on the southern rim of Corbetti Caldera).
27) Pantellerite: ignimbrite along a fault near a small lake about 8 km West of Colito.
28) Pantellerite: soft ignimbrite on top of faulted basalt about 5 km East of lake Zwai.
29) Pantellerite: ignimbrite (same as 27).

Continued: Table 2 - Chemical analyses and C.I.P.W. norms of silicic peralkaline rocks from the central part of the Ethiopian Rift Valley.

	30	31	32	33	34	35
SiO_2	71.16	68.30	69.64	69.83	70.45	72.23
TiO_2	0.41	0.53	0.44	0.38	0.44	0.34
Al_2O_3	9.32	8.26	9.44	8.86	9.32	8.51
Fe_2O_3	3.53	6.86	5.06	3.91	3.43	3.32
FeO	2.09	2.25	1.42	2.34	3.89	4.03
MnO	0.28	0.42	0.26	0.26	0.36	0.38
MgO	0.04	0.21	0.24	0.04	0.05	0.04
CaO	0.27	0.79	0.54	0.24	0.33	0.26
Na_2O	4.98	4.57	5.54	5.12	6.18	6.13
K_2O	4.72	4.09	4.33	4.96	4.48	3.94
P_2O_5	0.01	0.02	0.02	—	0.01	—
H_2O^+	2.87	3.40	2.41	3.74	0.91	0.75
H_2O^-	0.32	0.30	0.66	0.32	0.15	0.07
	100.00	100.00	100.00	100.00	100.00	100.00
C.I.P.W. Norms						
q	29.34	27.86	26.00	28.98	26.64	31.44
or	27.80	24.16	25.58	29.30	26.46	22.80
ab	21.48	19.71	24.44	17.95	22.99	22.01
di wo	0.58	1.58	1.06	0.49	0.65	0.58
di en	—	0.24	0.22	0.01	0.01	—
di fs	0.66	1.47	0.90	0.54	0.72	0.66
wo	—	—	—	—	—	—
hy en	—	0.27	0.36	0.08	0.11	—
hy fs	4.49	1.66	1.45	3.60	6.35	6.86
ac	10.16	16.68	14.63	11.31	9.92	9.70
ns	2.20	—	1.35	2.91	4.19	4.27
mt	—	1.58	—	—	—	—
il	0.76	1.00	0.83	0.72	0.83	0.61
ap	—	0.04	0.04	—	0.02	—
hm	—	—	—	—	—	—
tn	—	—	—	—	—	—
Peralkalinity Index (P.A.I.)						
mol. $\frac{Na_2O+K_2O}{Al_2O_3}$	1.44	1.45	1.46	1.55	1.62	1.68

Rift Floor

30) Pantellerite: ignimbrite from the SE shore of lake Awasa.
31) Pantellerite: ignimbrite from Boru River bed, 11 km from Dehra to Sire.
32) Pantellerite: ignimbrite along a fault South of Gadamsa Caldera.
33) Pantellerite: big pumice from the pyroclastic formation in 28.
34) Pantellerite: non-porphyritic obsidian lava flow on the SE slope of Alutu volcano.
35) Pantellerite: non-porphyritic obsidian lava flow at the northern base of Alutu volcano.

Intermediate rocks are relatively scanty and indicate an evolution towards alkaline and peralkaline silicic terms. The silicic volcanism of the Rift is largely peralkaline (P.A.I. ranging from 1,06 to 1,68), with predominance of pantellerites over comendites, as indicated by

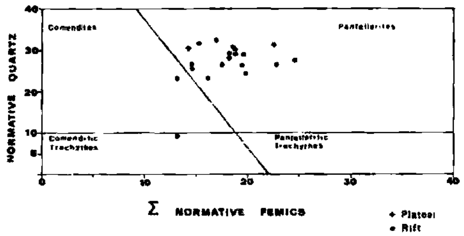

FIG. 17 - Normative quartz-femics diagram (MACDONALD and BAILEY, 1972, in press) of peralkaline silicic rocks from the central Ethiopian Rift Valley.

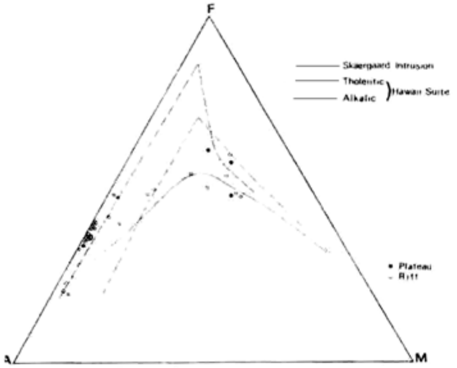

FIG. 18 - AFM diagram of volcanic rocks from the central Ethiopian Rift Valley (Total iron as FeO). Hawaii suite trends redrawn from MACDONALD and KATSURA (1964).

the normative quartz-femics classification diagram of Fig. 17 (MACDONALD and BAILEY, 1972). Among the peralkaline silicics, a change in the rock type (comenditic trachyte - comendite - pantellerite) with increasing P.A.I. values, is to be noted (see Table 2).

In the A.F.M. diagram (Fig. 18), the Rift volcanics are disposed along a curve which indicates an hypothetical iron enrichment trend, intermediate between the alkalic and tholeiitic trends. The position of the two intermediate rocks from the Somalian Plateau indicates a greater iron enrichment than the equivalent intermediate Rift volcanics.

Summary and Conclusions

On the basis of the present study, some general geological evidences emerge.

1. — The tectonic structure of this portion of Ethiopia is relatively simple. The graben which cuts the uplifted Ethio-Somalian Plateau is dominated by NNE-SSW tensional faults with some relevant examples of arrangements in an « en échelon » style. No trascurrent faults across the Rift exist. Another characteristic of this structure is its asymmetry which is marked by the different faulting styles of the Plateaux margins and by a strip of tensional faults and open fractures more active and younger in its eastern than in its western side. The most recent volcanism is mainly located along this belt. All the volcanism has been produced by fissures parallel to the main tectonic trend.

2. — Stratigraphically, this region is characterized by several sequences of different volcanic products, which have been erupted during some ten million years, probably since Eocene up to Recent. Both Plateaux are mostly made up of basaltic lava flows, whilst the Rift floor is predominantly occupied by silicic volcanics, mostly ignimbrites. The only non-volcanic rocks of this region are represented by widespread lacustrine sediments. Crystalline rocks or marine sediments are completely lacking, even as xenoliths in the most ancient explosive volcanic products of the Rift floor. So, these rocks, if they exist, must be very deeply buried.

3. — Volcanism, both on the Plateaux and within the Rift is dominantly characterized by fissure eruptions as shown by the Plateau trap series and by the majority of the volcanics of the Rift floor. Important volcano-tectonic collapses which produced regional calderas must be related to a huge quantity of pyroclastics (mostly ignimbrites) emplaced by fissure eruptions. However, fissure eruptions alternated, in many periods of the history of the Ethiopian Rift Valley, with the growth of individual volcanoes; some of them, standing on the Plateaux, are very large and relatively old. Others, rising from the floor of the Rift are small and very recent, showing at present a considerable fumarolic activity.

4. — The petrology of the Ethiopian Rift Valley and of the neighbouring Plateaux is far from being satisfactorily known, however some preliminary indications can be given:

— the basalts of the Plateaux trap series seem to be more alkalic than those of the Rift which show a transitional nature between alkali basalts and tholeiites. No generalization is however possible, since some contrasting indications are also found, as the presence of intermediate rocks with no alkalic affinity among the Somalian Plateau trap volcanics and the apparently strong alkalic character of the last basic products within the Rift. Furthermore in the Ethiopian Plateau, tholeiitic lavas have been already found in late Jurassic volcanism and within the trap series (ABBATE *et al.*, 1969; LES BAS and MOHR, 1970).

— The main petrologic feature of the Ethiopian Rift Valley is the abundance of silicic peralkaline volcanics (mainly pantellerites) related both to the fissure activity and to the several central volcanoes rising from the Rift floor. Volcanic rocks of intermediate composition (such as hawaiites and mugearites) seem to be relatively scarce.

It is interesting to note, however, the close association of peralkaline silicic rocks with basalts of transitional nature. Occurrences of this magmatic association are increasingly common, as it has been recently described for Aden and Afar volcanism (GASS and MALLICK, 1968; BARBERI *et al.*, 1970). Volcanism and geology are very similar to those of the whole East African Rift System, although there are important differences in magma association. Other sectors of this structure (KING and SUTHERLAND, 1960; KING, 1970) are characterized by the association of alkali olivine basalts with typical final alkalic products such as trachytes and phonolites. It seems that the genetic model of COOMBS (1963), which postulates association of peralkaline silicic rocks with transitional basalts (like in Ethiopia) and association of trachytic and phonolitic rocks with alkali olivine basalts (like, for instance, in Kenya), may be valid also for the East African Rift System. However, geochemical and isotopic studies are needed for further steps in this discussion.

5. — The petrological and volcanological picture of the Ethiopian Rift Valley is very similar to that of the continental Rifts. This part of the Ethiopian Rift looks like the central and southern parts of the Danakil depression, except for the different tectonic trend. It is, in fact, a depressed region affected by tensional tectonics. No evidences of crustal separation have been found, but this area lies probably on an attenuated continental crust.

6. — The main petrologic problem of the Ethiopian Rift Valley is the origin of peralkaline silicic rocks. A genesis by fractionation of basaltic magma, owing to the presence of magmatic reservoirs could be hypothesized for the pantellerites belonging to the individual

volcanoes of this region. At first it seems difficult to admit a simple fractionation origin for the large volume of fissural peralkaline volcanics within the Rift. However, recently BAKER and WOHLENBERG (1971) have interpreted the high Bouguer anomaly, located all along the axis of the Gregory Rift Valley, as an evidence of a shallow intrusion of a basic igneous body (density 3.05, 10 km wide and from 2.5 km to 30 km deep). This seems to be also supported by a seismic refraction survey (GRIFFITHS *et al.*, 1971 in BAKER *et al.*, 1972). According to BAKER *et al.* (1972), the same situation may occur in the Ethiopian Rift where crustal dilatation is supposed to have been even more intense than in the Kenya Rift. This could explain the large volume of the Rift peralkaline silicic rocks, as the result of fractionation of the basic magma trapped in such a gigantic reservoir. However, assuming as true the apparent scarcity of intermediate rocks in all the region, many doubts on the validity of such a genetic model remain, unless a not well understood selective mechanism acts for a preferential uprise of peralkaline liquids.

An origin due to partial melting of an alkali basalt magma at the base of the crust or in the upper mantle by relief of lithostatic load due to crustal warping (BAILEY, 1964), is a model which is in contrast with the striking evidence of tensional tectonics characteristic of the Ethiopian Rift Valley.

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