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Geological Structures and Tectonics around the Koka Reservoir, Northern Main Ethiopian Rift

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Abstract

The Koka dam and its reservoir, located in the northern Main Ethiopian Rift, are the main facilities for irrigation and hydroelectric power in Ethiopia. However, a considerable water leakage from the reservoir has observed since the completion of the Koka dam in 1960. Topographical and geological conditions around the reservoir have been studied to obtain fundamental information on paths of leakage. The reservoir area is located in the Wonji Fault Belt of the northern Main Ethiopian Rift, and is characterized by small horst and graben structures with distinct fault scarplets. The structures are elongated NNE–SSW in the northeastern hills of the reservoir, which is the probable leakage zone, and they obliquely intersect the course of the Awash River flowing out from the reservoir. The northeastern hills consist of rhyolitic ignimbrites and various volcanic rocks intercalated with post–Pliocene pumiceous and lacustrine deposits. They dip gently, but are partially displaced by faults.

Considering that uplift and tilting of fault blocks continued during the Quaternary, such movements may have shifted the course of the river. A low elevation zone elongated northeastward from a point 3.5 km south of the Koka dam was inferred to be an old river course. Although this zone is partially divided by an uplifted horst mound, it is elongated northeastward from the reservoir bank. In contrast, the current river course where the Koka dam was constructed is deep, and may be a newer one. While the former is characterized by remarkably weathered rock mass, the latter is fresh due to rapid dissection. Based on these topographical and geological characteristics, the low elevation zone corresponding to a paleo–channel might have become a leakage path as water level rose after inundation.

Key words: Ethiopia, Koka dam, Leakage path, Reservoir, Rift, Ignimbrite

Introduction

The Koka dam and its reservoir, located in the northern Main Ethiopian Rift (MER, Fig.1) are the main facilities for irrigation and hydroelectric power in Ethiopia. The Koka reservoir covers an area of 236 km^2 with the capacity of $1{,}850 \times 10^6 m^3$. However, a considerable water leakage from the reservoir has observed since the completion of the Koka dam at 1960, and this is economically serious problem for the region. Some attempts have been made to estimate the leakage loss rate of reservoir water (Sogreah, 1965; Ital Consult, 1970; Halcrow, 1989). According to these reports, the rate ranges from 90 to $435 \times 10^6 m^3$/year (Mamo, 1995; Mamo and Yokota, 1998).

This area is topographically characterized by low relief hills, which have been formed as horst and graben structures in the northern MER. The hills around the reservoir consist of ignimbrites and various volcanic rocks intercalated with post – Pliocene pumiceous and lacustrine deposits. In generally, leakage path is closely related to topographic and geologic conditions including physical properties of rock masses around the reservoir. However, the leakage paths are still presently unknown because rocks distributed there are varied and geological structures are complicated.

One of the authors, Sileshi Mamo has attempted to determine the leakage paths from the viewpoints of hydrogeology using isotope techniques. Geological conditions around the reservoir are not clear as to the leakage paths concern. Here, we attempted to compile a geological map around the reservoir to understand geological structures and tectonic movements in addition to interpretations of permeability of rock masses.

Topographic and geologic characteristics around the Wonji Fault Belt

1. Northern Main Ethiopian Rift and Wonji Fault Belt

The Koka dam and its reservoir are located on the Wonji Fault Belt (Mohr, 1962, 1967), which is one portion of the northern MER (Fig.1). The MER is a part of East African Rift System, and comprises a series of rift zones, extending over a distance of about 1,000 km from the Afar Triple Junction at the Red Sea–Gulf of Aden intersection to the Kenya Rift in the south (Fig.1). In the Ethiopian Rift zones, the MER and the Southwestern Ethiopian Rift (SWER) are the two major rift sectors. The MER forms the northeastern sector, and is subdivided into northern, central, and southern segments (Chrowicz *et al*., 1994). Younger volcanic rocks of the Pliocene to Pleistocene age predominate in the MER. In contrast, the SWER forms the southwestern sector and links to the north–south trending Kenya Rift in south. The

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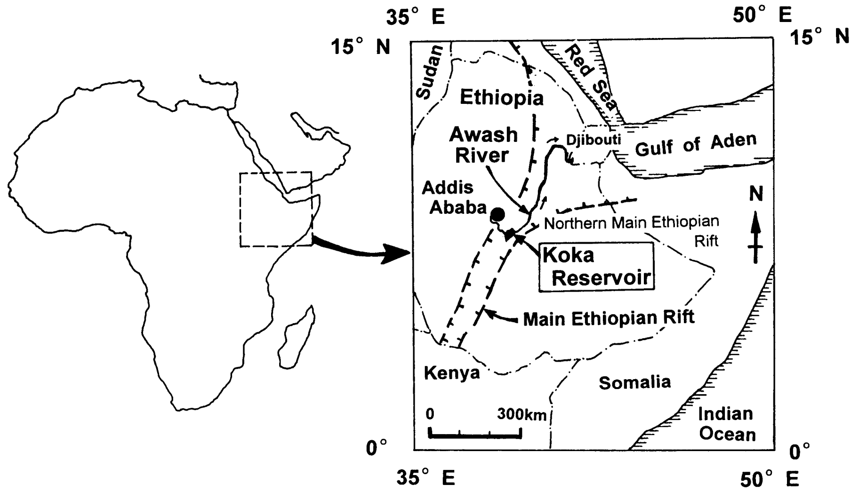

Fig. 1. Index map of the Koka reservoir located in the northern Main Ethiopian Rift.

SWER is characterized by predominantly older volcanics ranging from the Eocene to Miocene (*e.g*., WoldeGabriel *et al*., 1990; Stewart and Rogers, 1996; Kabeto and Sawada, 1997, 1999; Boccaletti *et al*., 1999; Kabeto *et al*., 2000).

Two stages of rifting: late Oligocene to early Miocene, and late Miocene to early Pliocene were proposed for the MER and SWER (Davidson, 1983; WoldeGabriel *et al*., 1990; Ebinger *et al*.,1993). The northern, central and southern segments of the MER, and their major rift-bounding faults are oriented to N 45°E, N 30°E and N 5–10°E, respectively (Kabeto and Sawada,1999). The NE–SW gross structural trend of the MER is segmented by NW–SE trending mostly dextral transverse faults (*e.g*., Mohr,1967; WoldeGabriel *et al*., 1990; Chrowicz *et al*.,1994; Hayward and Enginger, 1996; Kabeto and Sawada, 1999). The latest stage of development of the MER in late Miocene to early Pliocene is also followed by a narrow well-developed Quaternary faulting that is mostly related to the Wonji Fault Belt (Mohr, 1962, 1967). Therefore, the distribution and structures of the Quaternary strata are commonly affected by faulting in this Belt.

The age and geochemical characteristics of the volcanism changes along and across the MER, and its complicated history and nature reflects the tectonic evolution of the rift (*e.g*., Hart *et al.*, 1989; WoldeGabriel *et al.*, 1990; Wolde, 1996; Boccaletti *et al*., 1999; Kabeto *et al*., 2000). Ebinger and Sleep (1998) have also concluded that uplifting, magmatism and extension in Ethiopia and east Africa is attributed to simple plume activities beneath the Ethiopian Plateau (Afar plume). However, George *et al*. (1998) and Rogers *et al*.(2000) suggested that the presence of two mantle plumes, Afar and East African.

2. Topographic features in and around the Koka reservoir

Fig.2 shows the topography around the Koka reservoir and the Awash River. The Awash River on which the Koka dam was built is one of the major rivers flowing in the MER. It flows northeastward from the western margin of the MER, forming steep gorges up to 25 km upstream of the Koka reservoir. It meanders east up to the reservoir with low gradient, and it finally attains to the Lake Abe in the Afar depression zone. The location of the Koka reservoir in the midstream of the Awash River is regarded as a local depression zone elongating in NE-SW trend, and the reservoir shapes an ellipsoid elongating NE–SW trend in plan. The zone also might have been formed as a result of tectonic movements in the Wonji Fault Belt. Water level of the reservoir is around EL.1590.7 m. Although the bottom topography of the reservoir is not clear, the water depth may be mostly shallower than 10 m.

As shown in Fig.2, the Koka dam is located in the northeastern side of the reservoir, outlet of the Awash River. The eastern bank (right bank) of the reservoir is characterized by low relief hills ranging from 1,600 to 1,800 m, and their hilly slopes directly face to the reservoir. However, there exist shallow zones where elevation is below the water level of the reservoir. On the contrary, wide plain spreads over around the western bank (left bank), and scattering distribution of small isolated mounds is seen, where villages are located. Awash River and its large tributary, the Mojo River joins each other near the western bank of the reservoir. Along the upstream course of the Awash River in the western bank, small marsh and ponds are found separated from the main reservoir. As a result, while the eastern bank of the reservoir is nearly straight line, the western bank is irregular. These topographical contrasts may be attributable to faulting and tilting in the area.

A slightly dissected Gedemsa Caldera is recognized in southeast of the reservoir. Its diameter is 8 km long, and its western slope faces the reservoir directly. A large fluvial plain, of which elevation is around 1,500 m, spreads over the northeastern side of the caldera, and this has been utilized for a large sugarcane farm, the Wonji Sugar Plantation.

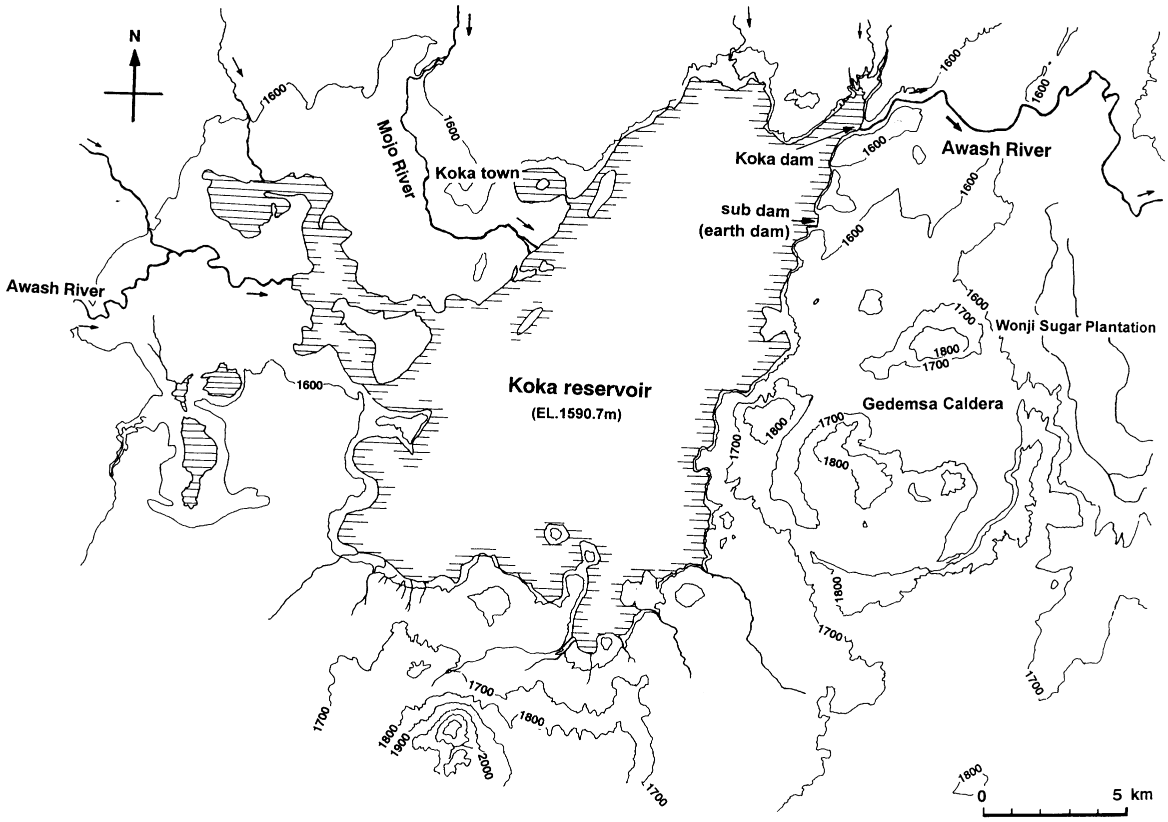

Fig. 2. Topographic outline around the Koka reservoir. Koka dam is located at northeastern side of the reservoir.

3. Geological setup around the Koka reservoir

Fig.3 shows a regional geologic map compiled by the authors based on previous investigations (Ethiopian Institute of Geological Surveys, 1981; Damte *et al*.,1992) and additional field survey. The volcanic rocks in this area are mainly of rhyolitic ignimbrite (pyroclastic rocks) and rhyolitic to basaltic lava flows intercalated with lacustrine or pumiceous deposits. Recent fluvial and lacustrine deposits cover these partially. Basaltic rocks are distributed mainly along the downstream of the Awash River, and in the Belale Forest, southeastern bank of the reservoir. These basaltic lava are named as Bofa Basalt (Ethiopian Institute of Geological Surveys, 1981). They are porphyritic with plagioclase, and are vesicular. This was dated between 0.44 and 0.61 Ma by whole rock K–Ar method (Morton *et al*., 1979). Basaltic rocks are also appears as numerous volcanic cones. Damte *et al*. (1992) divided basaltic rocks distributed here into two members; Bofa Basalt and others. However, it is not easy to discriminate them based on their characteristics.

According to Meyer *et al*.(1975), the faulting in the Wonji Fault Belt (WFB) started at the beginning of Pleistocene (1.6 Ma *ca*), causing the unconformity between the overlying "Wonji Series" (Pleistocene to Holocene) and underlying " Nazareth Series " whose recent rift floor products are about 1.8 Ma (Bigazzi *et al*.,1993; Boccaletti *et al*.,1999).

According to the compilation of Damte *et al*.(1992) and Boccaletti *et al*.(1999), the Gedemsa area is located in geologically well studied Nazareth – Dera area, where several tectonomagmatic units are identified; Melaksa (<0.2 Ma), Boseti (0.21 Ma), Gedemsa (0.21–0.85 Ma), Dera–Sodere (<0.44 Ma), Bofa (0.44–0.61 Ma), Boku–Tede (0.51 –0.83 Ma), Keleta (1.5 Ma), Nazareth (1.41–1.71 Ma), and Eastern Margin (1.8 Ma) units, respectively. Ignimbrites and various volcanic rocks of both the Nazareth and Wonji Groups are widely exposed in this area. The former constitute many flow units interbedded with paleosol layers and aphyric flood basalts (*e.g*. Meyer *et al*.,1975; Boccaletti *et al*.,1999). They also sometimes intercalated with ash fall layers and lacustrine deposits. Some NNE–SSW trending faults and minor traverse faults cause displacements in these strata, resulting in horst and graben structures.

The Gedemsa unit is related to the products of Gedemsa Caldera collapse (Peccerillo *et al*., 1995; Baccoletti *et al*.,1999). The pre–caldera activity gave rise to pantelleritic rhyolite ignimbrites associated with ash flows, pumice falls, and surge deposits. Pantelleritic rhyolitic lava domes are also present in the pre–caldera sequences. The post caldera products are composed of resurgent pantelleritic lava domes and basaltic spatter cones scattered within the Caldera. Basaltic dikes, though to be from these scoria cones are aligned in the NNE–SSW trend, which is almost similar to the Wonji Fault Belt trend.

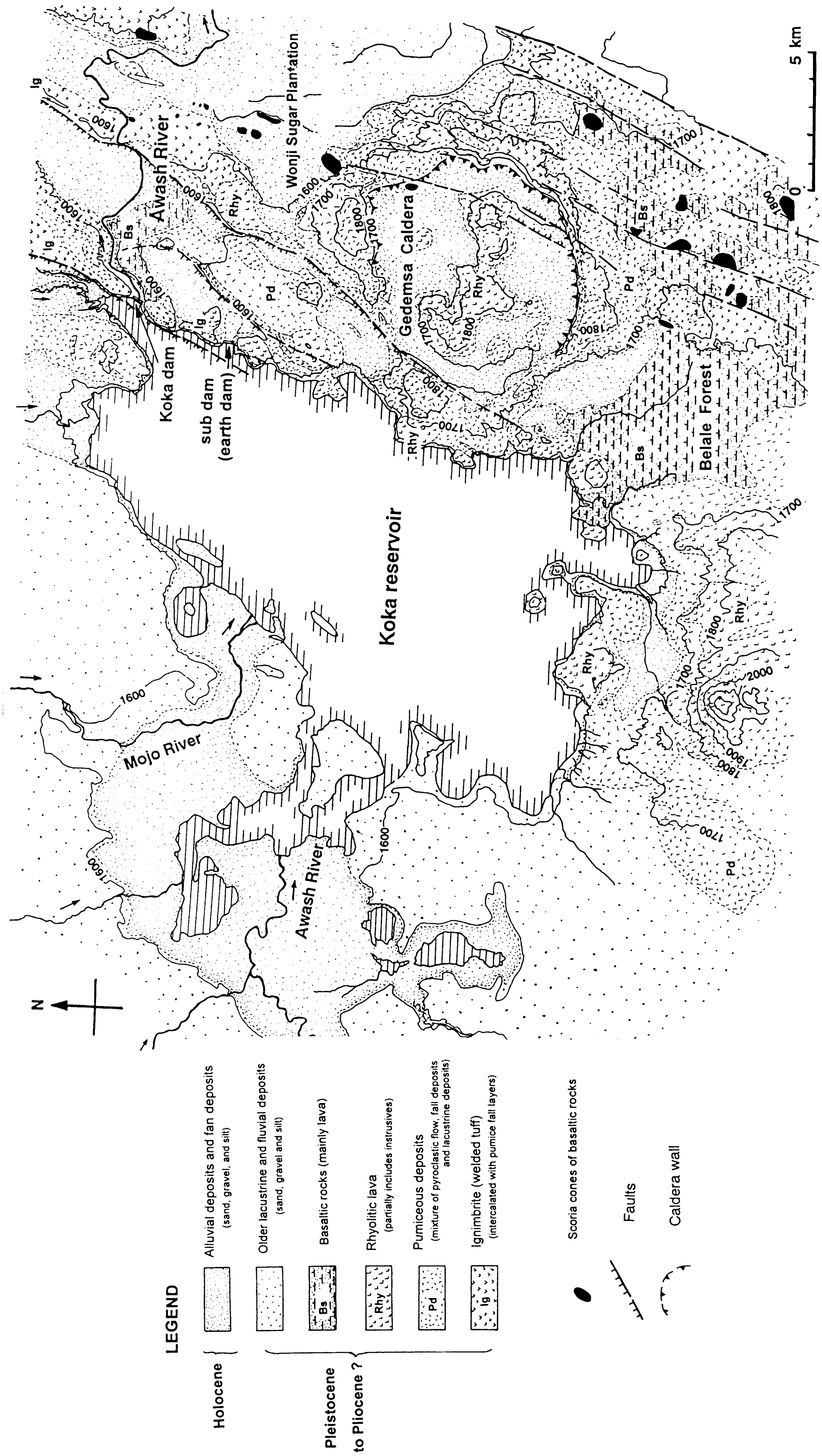

Fig. 3. Geological map around the Koka reservoir.

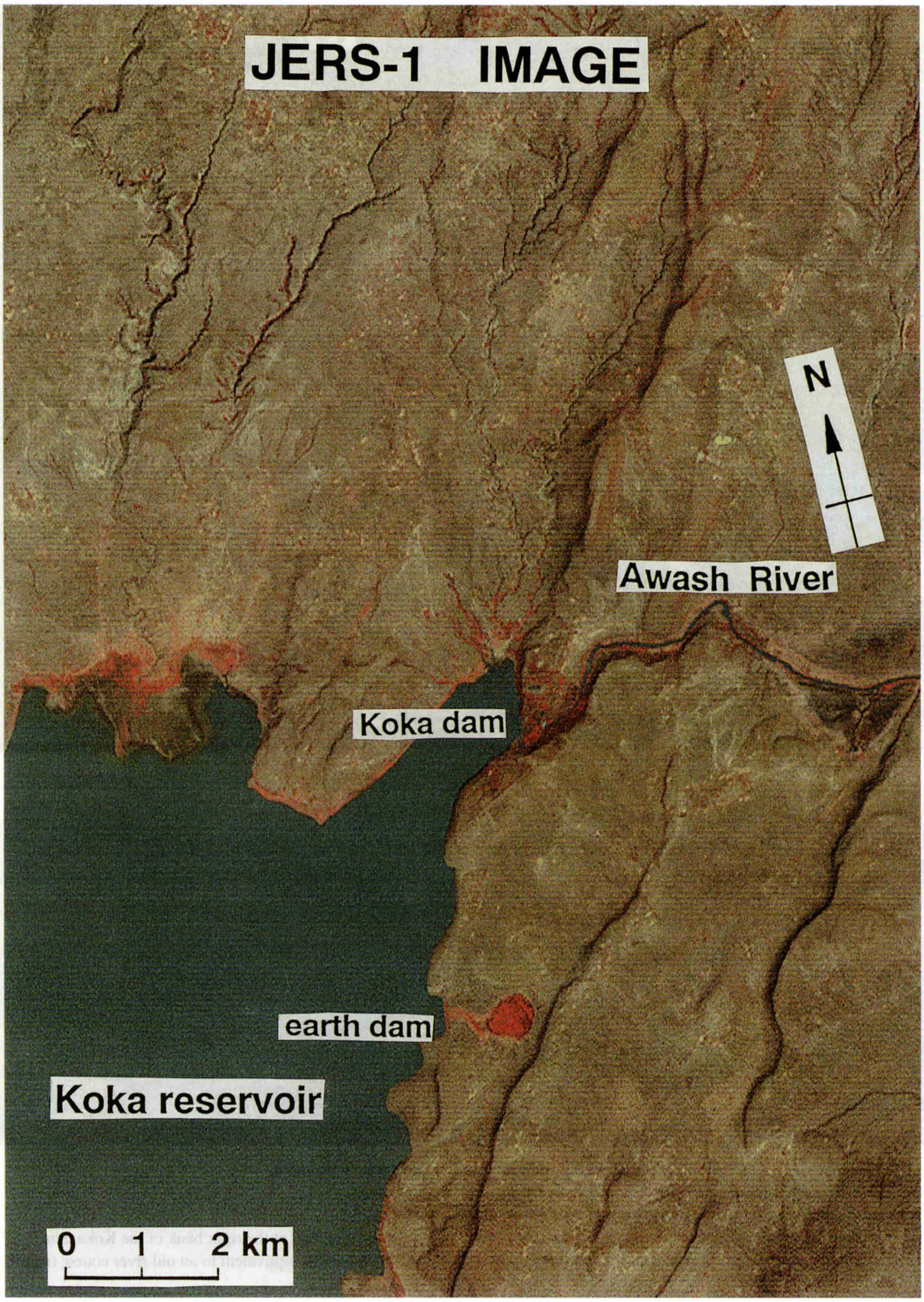

Fig. 4. Satellite JERS−1 image around the northeastern bank of the Koka reservoir.

Recent lacustrine and fluvial deposits cover the rocks in the area, especially along the main river courses. They are composed of fine to medium sand, and sometimes with coarse sand, pumice, silt and tuff. These deposits may be thinner than 20 m.

Fig.4 shows an image obtained by a satellite JERS−1, and this shows the topographical contrast well in this area. Scarplets of NE−SW trending faults are recognized clearly. Reddish portions in Fig.4 show relatively wet condition because the image is captures the spectral response to infrared wavelength. For example, reddish portion appearing in eastern part of the sub dam (earth dam)

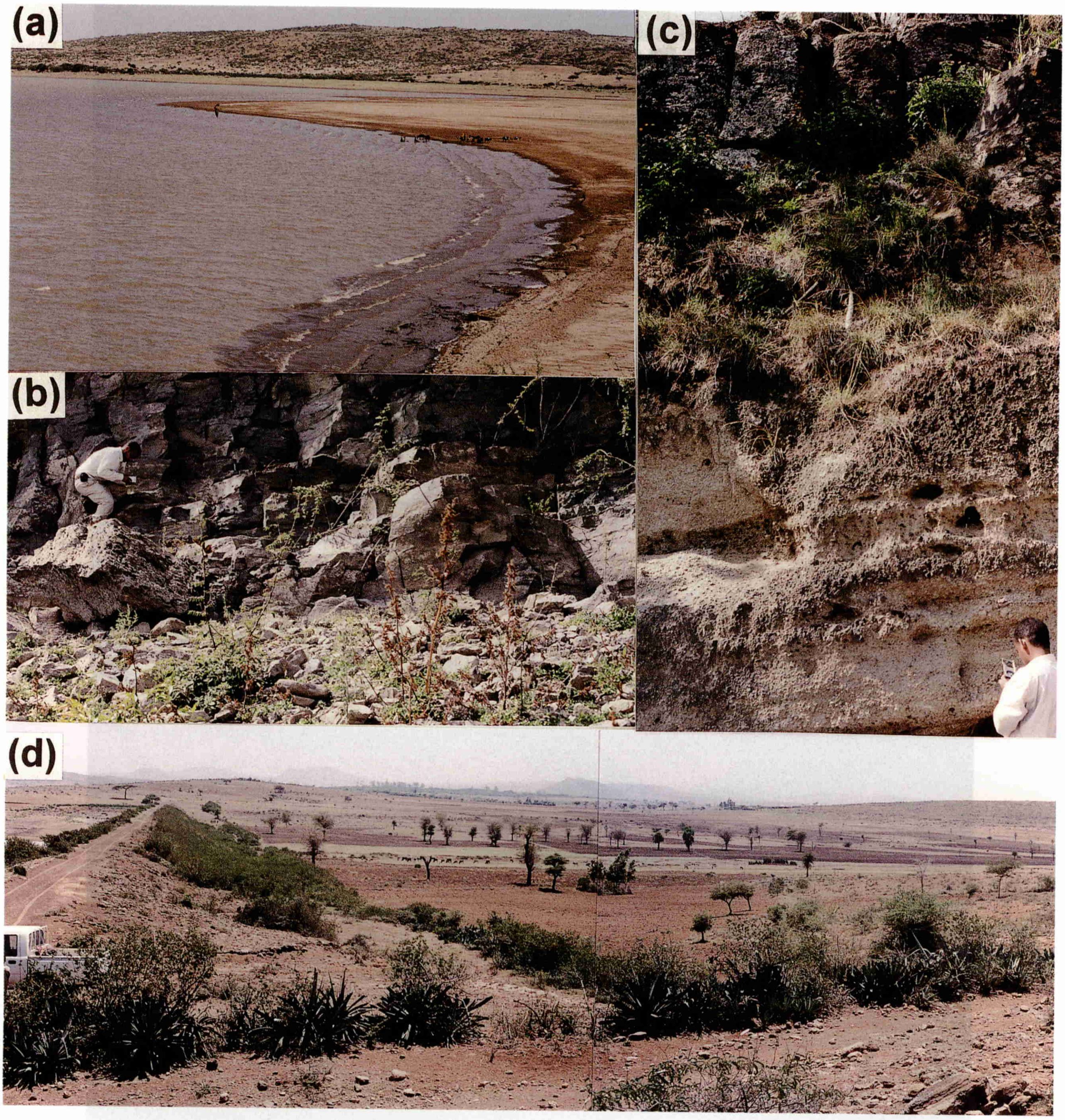

Fig. 5. Koka reservoir and some exposures around it.
(a) Northern shoreline of the Koka reservoir viewed from Koka dam site.
(b) Jointed ignimbrite exposed along the shoreline of the Koka reservoir.
(c) Highly weathered ignimbrite (upper) and pumice fall deposits (lower) exposed at the right bank of the Koka dam.
(d) Sub dam (left) and a low elevation zone elongating outerward, which may be equivalent to an old river course (right).

indicates that this area is relatively wet due to a large quantity of water seeping from the sub dam (earth dam).

Fig.5 (a) shows topography around the shoreline of the reservoir, and Figs.5(b) and (c) show exposures of ignimbrite with intercalated pumiceous sediments. Fig.5 (d) shows the topographical features of a low elevation zone elongated northeastward from the sub dam.

Detail topography around the northeastern bank of the reservoir

Considering that reservoir water leaks toward the downstream of the Awash River, northeastern bank of the reservoir and its surroundings may be the most probable zone on leakage, and therefore the area needs to be studied in detail. Fig.6 shows a more detail topographic map of this

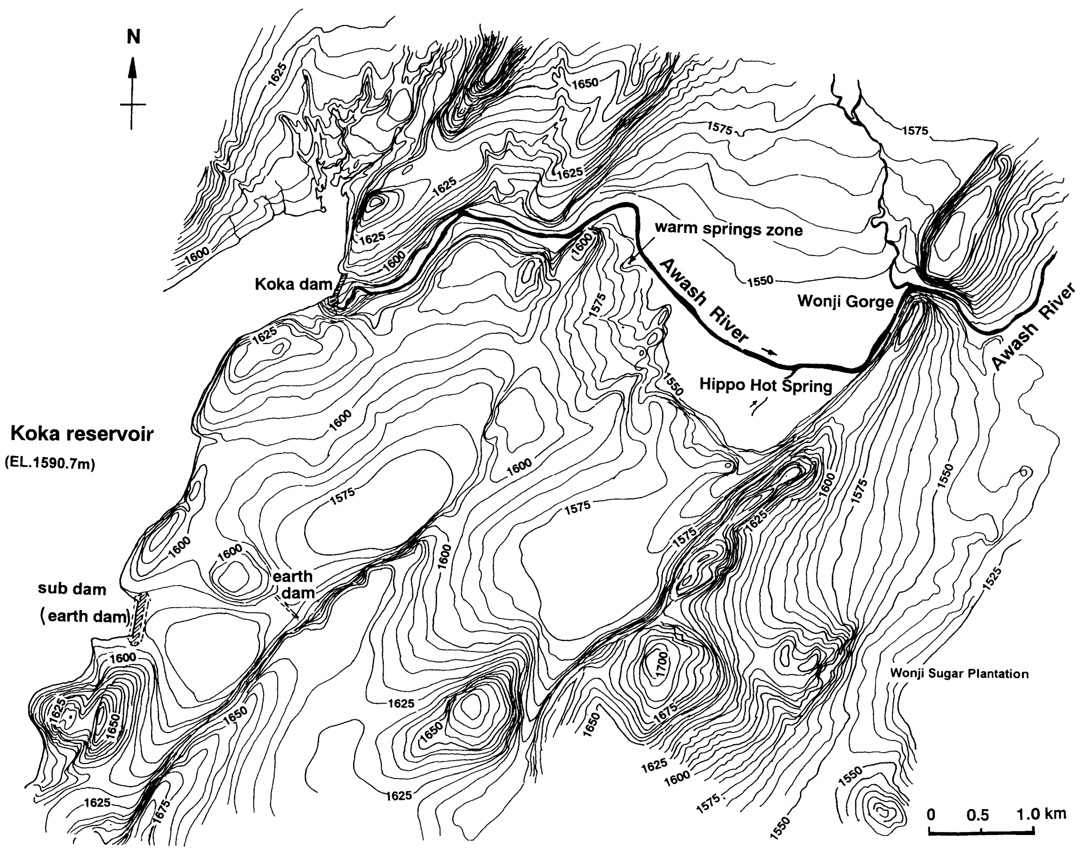

Fig. 6. Topography in the northeastern bank area.

area, which includes the main Koka dam and two sub dams. While one of sub dams is located at the bank, 3.5 km south of the main Koka dam, the other one in the hollow zone mentioned above. Both are small earth dam of 5 meters high, and were constructed just after the completion of the main dam.

As already stated, the alignment of the NNE – SSW trending horst and graben structure are predominant in this area, and these are attributable to faulting of NNE–SSW trend. One of the horst blocks face to the reservoir, and the other is of 5–8 km east from the reservoir bank. The summit of such uplifted horsts shows a relatively low relief.

The Awash River flowing out from the Koka dam intersects these two uplifted horsts in this area, forming distinct gorges. One is the gorge just downstream of the Koka dam site, and the other is the Wonji Gorge, downstream of the Hippo hot spring as shown in Fig. 6. There exist two small shallow grabens between these horst blocks. One is the zone elongating northeastward from reservoir bank at 2 km south of the Koka dam, and the other is the zone elongating NNE–SSW trend around the Hippo hot spring. Extension of the former is, however, not so evident.

Gentle slopes that have been formed as composite fan deposits are recognized in some places. One is the left bank of the Awash River in the Hippo hot spring area, and the other is at western slopes of the Wonji Sugar Plantation (Fig.6).

Geological conditions in the northeastern bank area of the reservoir

Fig.7 shows a detail geologic map of the northeastern bank area, which the authors compiled based on their surveyed data and log data of boreholes investigated by Ital Consult (1970). The hills are mostly composed of rhyolitic ignimbrite and rhyolitic lava. Intercalations with some pumiceous sediment were confirmed in log data also. Distribution of basaltic lava (Bofa Basalt) was confirmed downstream of the Koka dam, and small scoria cones of basalt were also confirmed in the eastern hills near the Wonji Sugar Plantation. Although the lower and upper strata of the Bofar Basalt have been defined as the Nazareth and Wonji Groups, respectively, lithofacies however resemble each other, and construction of stratigraphy is therefore not easy in this area. Then, we describe here only the characteristics of individual lithofacies and their distribution as follows.

1. Ignimbrites (welded tuff)

Ignimbrites distributed here are welded tuff formed as pyroclastic flow deposits, and characterized by lenticularly elongated pumices. They are intercalated with some thin ash

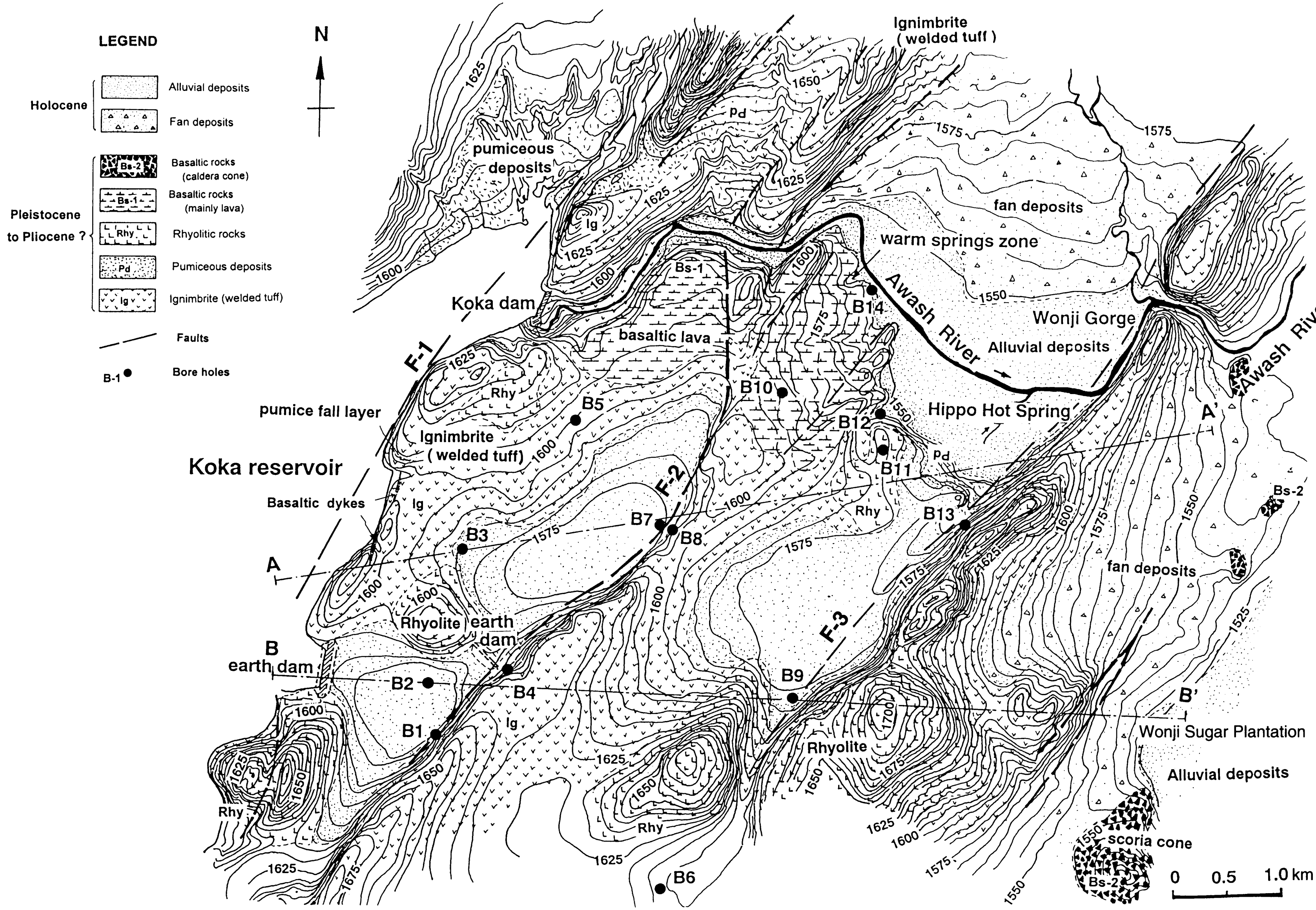

Fig. 7. Geological map of the northeastern bank area.

layers with pumiceous and lacustrine deposits. Based on mapped data, at least 4 to 5 flow units are distinguished in this area, and they may belong to the Nazareth or Wonji Groups. While they are relatively hard in fresh exposures (Fig.5(b)), soft in weathered portions (upper portion of Fig.5 (c)). Especially, ignimbrites exposed around the sub dam are highly weathered. The ultimate product of their weathering comprise of soft and loose sand with brownish color.

Systematic joints are developed in exposures of ignimbrite. Joint planes are generally tightly closed, but some of them are open. Based on the distribution of ignimbrites exposed just to the downstream of the main Koka dam, its foundation too may be composed of these ignimbrites. Therefore, rock mass condition on permeable properties is considered to be relatively good.

2. Rhyolitic to dacitic lava (trachyte) and lava dome

The lavas distributed here are mainly rhyolite to trachyte. They form small lava domes, and they show a monadnocks topography. These rocks are highly vesicular, and rich in plagioclase and quartz phenocrysts. Various kind of volcanic rocks are also exposed along the caldera wall of the Gedemsa Caldera. They are mostly rhyolitic to dacitic lava, and some portions are surge deposits. The greenish welded tuff associated with Gedemsa Caldera was dated on whole rock K–Ar method gave about 0.85 Ma (Morton *et al*.,1979). However, a fission track age on glass of a pre–caldera unit gave a more reasonable age of 0.21 Ma for the Gedemsa unit (Bigazzi *et al*.,1993).

3. Basaltic rocks

Basaltic rocks are mainly exposed as lava (Bofa Basalt) along the Awash River, especially downstream of the Koka dam and around the Hippo hot spring. It was dated to 0.44–0.61 Ma (Morton *et al*., 1979). They include plagioclase phenocryst, and show dark gray and dark greenish gray. They may overly the ignimbrites mentioned above. Basaltic lava is vesicular, and slightly to moderately jointed. Top of the lava is highly weathered in there.

Basaltic scoria cones are recognized at eastern hills. On the wall of a new well at the Wonji Sugar Plantation, it was reddish scoria layer below the unconsolidated lacustrine deposits (alluvial deposits). Basaltic dikes are also observed along the area of shoreline. They intrude ignimbrite, and elongate in N 40°to 50°E with 3 meters width at 1 km south of the main Koka dam. Several dykes with 0.5 m width and N 20°–30°E are also observed near the sub dam. Chilled margin were recognized in these exposures. There may be recent dikes from basaltic flows of Melkasa unit (Damte *et al*.,1992), whose age is younger than 0.2 Ma (Morton *et al*.,1979).

4. Pumiceous deposits and lacustrine deposits of tuffaceous sandstones and mudstones

Pumiceous and tuffaceous deposits are widely distributed here. Some of them are ash fall layers with pumices, but others are tuffaceous sandstones or mudstones formed as lacustrine deposits, and are relatively consolidated. The latter are exposed around the Hippo Hot Springs and others. They appear to be stratigraphically below the ignimbrite in some exposures. Probably, they may be same age as the pyroclastic and volcanic rocks mentioned above.

5. Surficial sediments

Surficial deposits distributed along rivers and low land. They are divided into alluvial deposits and fan deposits. Especially, fan deposits may develop around the northern side of the Hippo Hot Spring and western slope of the Wonji Sugar Plantation. They are mainly composed of loose sand, silt, and gravels. Around the shallow valley, gravelly deposits are observed in well walls. Some breccias covering gentle slopes are recognized around the sub dam.

Geological structure in the northeastern bank area of the reservoir

1. Horst and graben structures and faults

As shown in Figs. 6 and 7, this northeastern bank area is characterized by alignment of NNE–SSW trending faults. At least, three major faults are topographically recognized here, and they form horst and graben structures. However, we could not confirm their fault planes in exposures. Based on topography, major faults show sense of easterly uplift. They are numbered F–1, F–2 and F–3 from west to east. One of them (F–1), having an easterly sense of uplift elongates in NNE–SSW trend intersecting just upstream of the Koka dam. The other two faults, F–2 and F–3 extend 1.5 to 2 km east and 4 km east of the shoreline, respectively (Fig.7). Each blocks bounded by faults slightly tilts eastward. Most of strata also dip eastward almost concordant with the topography. These faults and blocks elongate in NNE–SSW trends intersecting the course of the Awash River.

Fig.8 shows geologic sections in A–A' and B–B' lines as shown in Fig.7. Rocks in this area are mainly composed of ignimbrite, and small rhyolitic lava caps the former partially. Probably, they dip eastward at low angles. Based on topography and distribution of lithofacies shown in Fig.8, vertical displacements are estimated to be 50–60 m in F–1 and F–2, and 70 to 100 m in F–3, respectively. In some places, we confirmed that strata dip steeply along these faults. In addition to these major faults, NW–SE trending transverse faults are also estimated in individual blocks.

2.Tectonic movements and river course changes

Considering that the shoreline of the right bank almost correspond to the scarplets of the NNE–SSW faults (F–1), this depression domain of the reservoir might have been formed by uplifting and tilting of fault blocks. Fig.9 shows

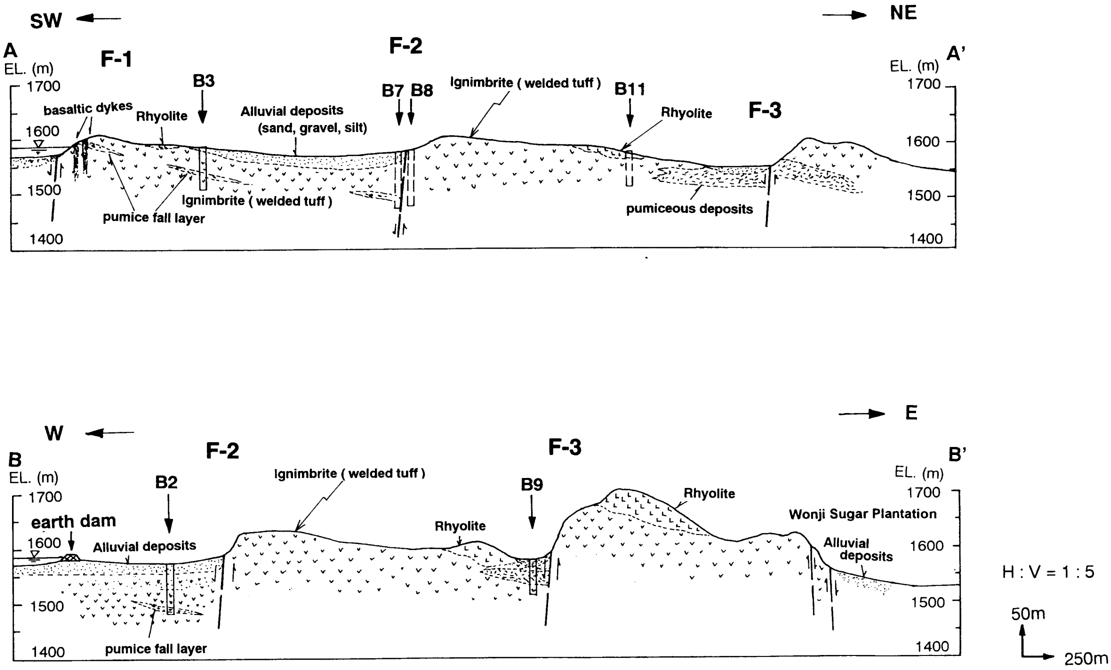

Fig. 8. Geologic sections of the northeastern bank area.
Locations of sections A–A' and B–B' are shown in Fig.7.

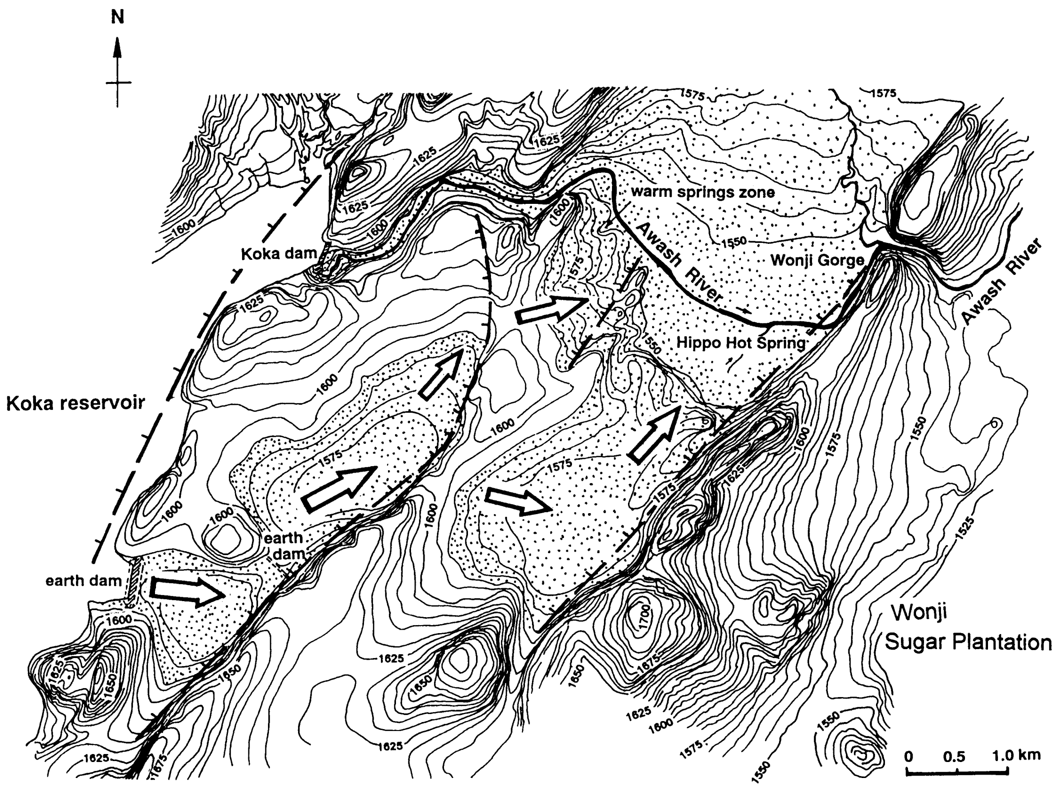

Fig. 9. Lowland elongating from the sub dam (earth dam).
Dotted portion shows the area below EL.1590 m (water level of the reservoir). Arrows show the probable old river course before uplifting of fault blocks.

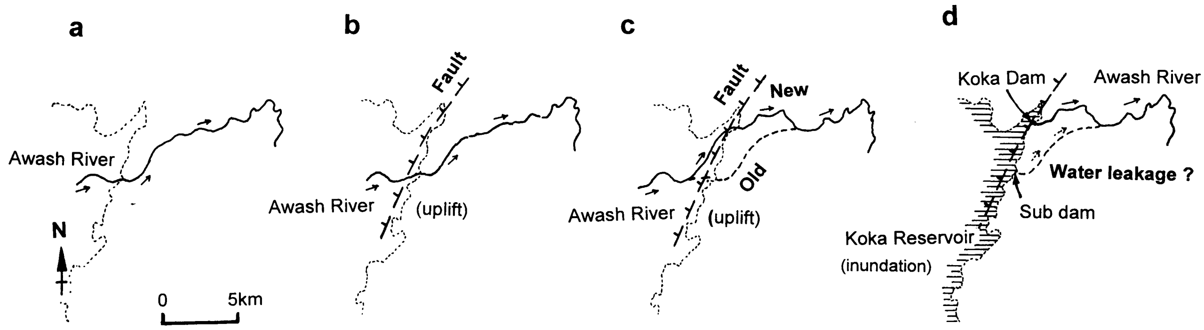

Fig. 10. Schematic image showing river course change of the Awash River.
a: Before faulting, the old Awash River flows from west to east.
b: NNE–SSW faulting and uplifting of blocks begin. The old river course (paleo–channel) was partially divided by uplifting of the horst.
c: Formation of the current river course.
d: The Koka dam was constructed along the new river course. After inundation, water level increased and water leakage occurred along the old river course(paleo–channel).

the distribution of the area below the water level of the reservoir (EL. 1590 m). Although, a low elevation zone elongates northeastward from the vicinity of the sub dam (Fig.5(d)), this zone is not same as the graben, and it is rather obliquely intersected by the NNE–SSW trending horst and graben structures. Considering that uplifting and tilting of blocks have continued up during the Quaternary Period, such movements might have disturbed and shifted the river course. Based on topographic features, a shallow hollow zone elongating northeastward from the vicinity of the sub dam is estimated to be an old course of the Awash River. It elongates northeastward, but it is partially divided by an uplifted horst mound.

On the contrary, the current river course where the Koka dam was constructed represents the newer one. While the former course is shallow and characterized by remarkably weathered rock mass, the latter deep and fresh by rapid dissecting. Based on these topographical and geological characteristics, a hollow zone corresponding to a paleo–channel also have become as one of leakage paths as water level rose after inundation. A model of the river course shifts is schematically shown in Fig.10.

The course of the old Awash River was divided by uplifting of a horst from the downstream, which was accompanying NNE–SSW faulting along the present Koka reservoir. However, vertical displacement is not uniform along the fault generally. As a result, a new river course appears in northern side corresponding to the current main dam site. Fresh rock masses exposed along the newer river mouse may be suitable for construction of concrete dam.

After inundation, a paleo–channel might have become a leakage path as water level rose, because the shallow zone is remarkably weathered with high permeable rock mass and alluvial loose deposits distributed along it. Consequently, the shallow zone corresponding to an old river course might have also become as one of leakage paths. However, detail paths are unknown at the present step. Another methods and efforts are necessary to determine the paths more precisely.

Conclusions

To obtain fundamental information on paths of leakage water from the Koka reservoir, topographical and geological conditions around it have been studied. Results are highlighted as follows:

(1) The reservoir is located along the Wonji Fault Belt of the northern Main Ethiopian Rift, and is topographically characterized by NNE–SSW trending horst and graben structures with distinct fault scarplets.
(2) Rhyolitic ignimbrites and various volcanic rocks intercalated with pumiceous and lacustrine deposits since the Pliocene constitute the hills around the reservoir.
(3) These structures mentioned above intersect the course of the Awash River flowing out from the reservoir.
(4) A low elevation zone elongating northeastward from the point 3.5 km south of the Koka dam was inferred to be an old river course (paleo–channel) on the basis of topographical features.
(5) In contrast, the current river course where the Koka dam was constructed is newer.
(6) While the paleo–channel is low elevation and composed of highly weathered rocks, the latter deep with fresh by rapid dissecting.
(7) Based on these features, the low elevation zone corresponding to a paleo–channel might have become one of leakage paths as water level rose after inundation.

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References

Bigazzi,B.,Bonadonna,F.P.,Di Paola, G.M. and Giuliami,A.,1993, K-Ar and fission track ages of the last volcano tectonic phase in the Ethiopian Rift Valley (Tullu Moye area). *In*: Geology and mineral resources of Somalia and surrounding regions, 1st. Aegon. Oltremare, Firenze, Relaz., E Monogr., No.113, 311-322.

Boccaletti,M., Mazzuoli,R., Bonini,M., Tura,T. and Abebe,B.,1999, Plio-Quaternary volcano tectonic activity in the northern sector of the Main Ethiopian Rift: relationship with oblique rifting, *JAES*, **29**, 679-698.

Chrowicz,J.,Collet,B.,Bonavia,F.F.and Korme,T.,1994, Northwest to north northwest extension direction in the Ethiopian rift deduced from the orientation of extension structures and fault-slip analysis, *Geol. Soc. Am. Bull*., **105**, 1560-1570.

Damte,A., Boccaletti,M., Mazzuoli, R. and Tortrici, L.,1992,Geological map of the Nazareth -Dera Region (main Ethiopian rift), Consiglio Nazionale delle Ricerche, Firenze.

Davidson,A.,1983, The Omo river project, Ministry of Mines and Energy, *Ethiopian Inst. Geol. Surv.Bull*., **2**, 1-89.

Ebinger,C.J. and Sleep,N.H.,1998, Cenozoic magmatism through east Africa resulting from impact of a single plume, *Nature*, **395**, 789-791.

Ebinger,C.J.,Yemane,T.,WoldeGabreil,G.,Aronson,J.L.and Walter,R. C.,1993, Late Eocene- recent volcanism and faulting in southern main Ethiopian rift, *Jour. Geol. Soc. London*, **150**, 99-108.

Ethiopian Institute of Geological Surveys, 1981,Geological map of the Ethiopian Rift valley, controlled by Kazmin,V. and Berehe,S.

George,R,M.M., Rogers,N. and Kelley,S., 1998, Earliest magmatism in Ethiopia: Evidence for two mantle plumes in one flood province, *Geology*, **26**, 923-926.

Halcrow, 1989, Master plan for the development of surface water resources in the Awash basin, Vol.4, Climate and hydrology (unpublished).

Hart,W.K., WoldeGabriel,G., Walter,R.C. and Mertzman, S.A., 1989, Basaltic volcanism in Ethiopia, Constrains on continental rifting and mantle interactions, *Jour. Geophys. Res*., **94**, 7731-7748.

Hayward,N.J. and Ebinger,C.J., 1996, Variations in the along-axis segmentation of the Afar Rift system, *Tectonics*, **15**, 244-257.

Ital Consult,1970, Meky river diversion scheme, Vol.3, Geology and Hydrogeology (unpublished), Rome.

Kabeto,K. and Sawada,Y.,1997, NE-SW and NW-SE Precambrian shear zones in West Ethiopia: Possible implications for the evolution of the main Ethiopian rift structures, *Proc. of the 8th International Conference of Ethiopian Studies, Kyoto, Japan*, No.3, 603-604.

Kabeto,K. and Sawada,Y.,1999, Precambrian basement structures: Implications for the Cenozoic Ethiopian Rift Structures, *Proc. of International Conference on Geodynamics of Continental Rifting, IGCP* 400, No.1, 80-86.

Kabeto,K., Sawada,Y., Roser,B.O., Abebe,T., Chernet,T., Masunaga,T. and Wakatsuki,T., 2000, Compositional differences between evolved volcanics at rift margin and rift center from northern Main Ethiopian Rift: Implications for parental magma differences and processes of evolutions, *Chemical Geology* (submitted).

Mamo,S., 1995, Research study on Koka dam reservoir leakage path, Ethiopian Geological Surveys (unpublished).

Mamo,S. and Yokota, S.,1998, Estimation of Koka reservoir leakage paths by hydro geological and isotope techniques, *Proc. 8th International Congress of International Association of Engineering Geology and Environment*, 2409-2416.

Meyer,W., Pilger,A., Rosler,A. and Sets, J.,1975, Tectonic evolution of northern part of the main Ethiopian rift in southern Ethiopia. *In*: Pilger, A. and Rosler, A.(*eds*.), Afar S Ethiopia. Schweizerbart, Stuttgart, 355-362.

Morton,W.H.,Rex,D.C.,Mithell,,J.G. and Mohr,P.,1979, Rift-ward younging of volcanic units in the Addis Ababa region, Ethiopian rift valley, *Nature*, **280**, 284-288.

Mohr,P.A.,1962, The Ethiopian rift system, *Bull. Geophysical Observatory, Addis Ababa Univ*., **5**, 33-62.

Mohr,P.A.,1967, The Ethiopian rift system, *Bull. Geophysical Observatory, Addis Ababa University*, **11**, 1-65.

Peccerillo,A.,Yirgu,G.and Ayalew,D.,1995, Genesis of acid volcanics along the Main Ethiopian Rift: Case history of the Gedemsa Volcano, SINET, *Ethiop. J. Sci*., **18**, 23-50.

Rogers,N., Macdonald,R., Fitton,J.G., George,R., Smith,M. and Berreiro, B.,2000, Two mantle plumes beneath the East African rift system: Sr, Nd, Pb isotope evidence from Kenya Rift basalts, *Earth and Planet.Sci. letters*, No.1769, 387-400.

Sogreah,1965, Survey of the Awash river basin, Vol.1-4 (unpublished).

Stewart, K. and Rogers,N.W.,1996, Mantle plume and lithosphere contributions to basalts from southern Ethiopia, *Earth and Planet. Sci. Letters*, No.139, 195-211.

Wolde, B.,1996, Spatial and temporal variations in the compositions of Upper Miocene to Recent basic lavas in the northern main Ethiopian rift: implications for the causes of Cenozoic magmatism in Ethiopia, *Geol. Rundsch*, **85**, 380-389.

WoldeGabriel, G., Aronson, J. L. and Walter, R.C.,1990, Geology, geochronology, and rift development in the MER, *Geol .Soc. Am. Bull*., **102**, 439-458.

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（要　旨）

横田修一郎・Sileshi MAMO Fantaye, 2000，北部エチオピア主地溝帯，Koka 貯水池周辺における地質構造とテクトニクス，島根大学地球資源環境学研究報告，19, 113–125.

北部エチオピア主地溝帯に位置する Koka ダムとその広大な貯水池はエチオピアにおける灌漑と水力発電のための主要な施設である．しかしながら，Koka ダムが 1960 年に完成して以来，そこでは多量の漏水が指摘されてきた．貯水池からの漏水経路に関する基本的情報を得るため，貯水池周辺の地形・地質的状態について研究してきた．

この貯水池は北部エチオピア主地溝帯の Wonji 断層帯に位置しており，明瞭な断層崖をもった小規模な地累－地溝構造によって特徴づけられている．漏水の可能性が高い貯水池北東側の丘陵ではこの構造は NNE–SSW 方向に伸びており，貯水池から流出する Awash 川の河道を横断している．鮮新世以降の流紋岩質火砕流堆積物や多様な火山岩類が軽石質堆積物や湖成堆積物を挟んでこれらの丘陵の岩盤を構成している．それらの地層は緩やかに傾斜し，断層によって部分的に変位されている．

断層ブロックの隆起や傾動が第四紀を通じて継続してきたことを考えれば，そのような構造運動は河道を移動させてきたことも考えられる．Koka ダムから約 3.5 km 南の地点から北東方向に伸びる低標高のゾーンは地形的特徴から旧河道の 1 つと推定された．この浅い低標高ゾーンは隆起した地累ブロックによって分割されているが，貯水池の東岸から北東方向に伸びている．これに対して，Koka ダムが建設された現在の河道は深く，新しいものであろう．前者は著しく風化した岩盤によって特徴づけられているのに対して，後者は急速な下刻によって新鮮な状態である．このような地形・地質的特徴に基づけば，旧河道に相当するこの低標高ゾーンは貯水による水位上昇にとともに漏水経路の 1 つになってきたと考えられる．