8 . LEAKAGE PATH OF KOKA RESERVOIR IN ETHIOPIA RIFT VALLEY AND ITS ESTIMATION USING HYDROGEOLOGICAL TECHNIQUES

エチオピア, Koka 貯水池の漏水と水理地質面からの漏水ルートの解明

Ethiopian Institute of Geological Surveys, Ethiopia,○ Sileshi Mamo

Department of Geoscience, Shimane University, Japan, Shuichiro Yokota

要旨：Ehiopia Rift Valley の Koka 貯水池は火山岩地帯に作られた浅いダム湖であるが，1960 年代の完成当初から多量の漏水が指摘されてきた．地形・地質調査の結果，貯水池の地形的凹地は断層運動による河川下流部の隆起によって形成されたものと推定された．筆者らはダム周辺の地表水・地下水の水質を中心に漏水ルートの解明につとめてきた．その結果，右岸の旧河道と思われる地形的鞍部に沿って流下していることが推定されるにいたった．

1 INTRODUCTION

The Koka Dam was built on the Awash River, Ethiopia, in 1960 for hydropower and irrigation purposes. The dam is a concrete gravity type with a height of 25m, crest length of 458m and a reservoir capacity of 1840Mm^3. The dam and reservoir is located in the axial zone of the northern Main Ethiopian Rift, *i.e.* the active Wonji fault belt (Fig. 1).

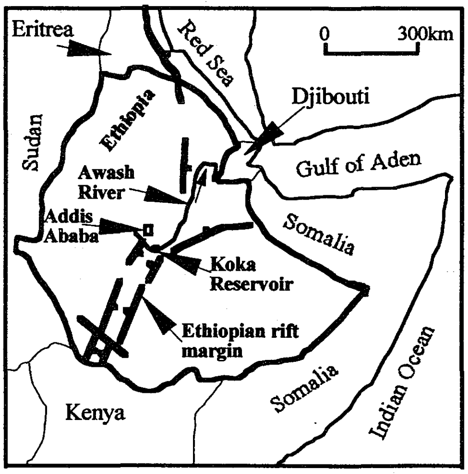

Figure 1. Location map of the Koka Reservoir.

Ignimbrites, pyroclastic pumice and tuff deposits, basalt and rhyolites with different age (Miocene – Holocene) constitute the Koka Reservoir banks and its surrounding area in addition to younger fluvial and lacustrine sediments. Slightly consolidated lacustrine sediments of fine to medium sand cover the reservoir area. Moreover, thin river sediments of silt cover the lacustrine deposit at the reservoir floor. NNE-SSW and NE-SW striking fault swarms and transverse faults cut these rocks into strips and form horst and graben structures. Permeability of rocks in the reservoir vicinity is grouped into four based on nature of rock masses/hydraulic properties and available permeability data as shown in Figure 2.

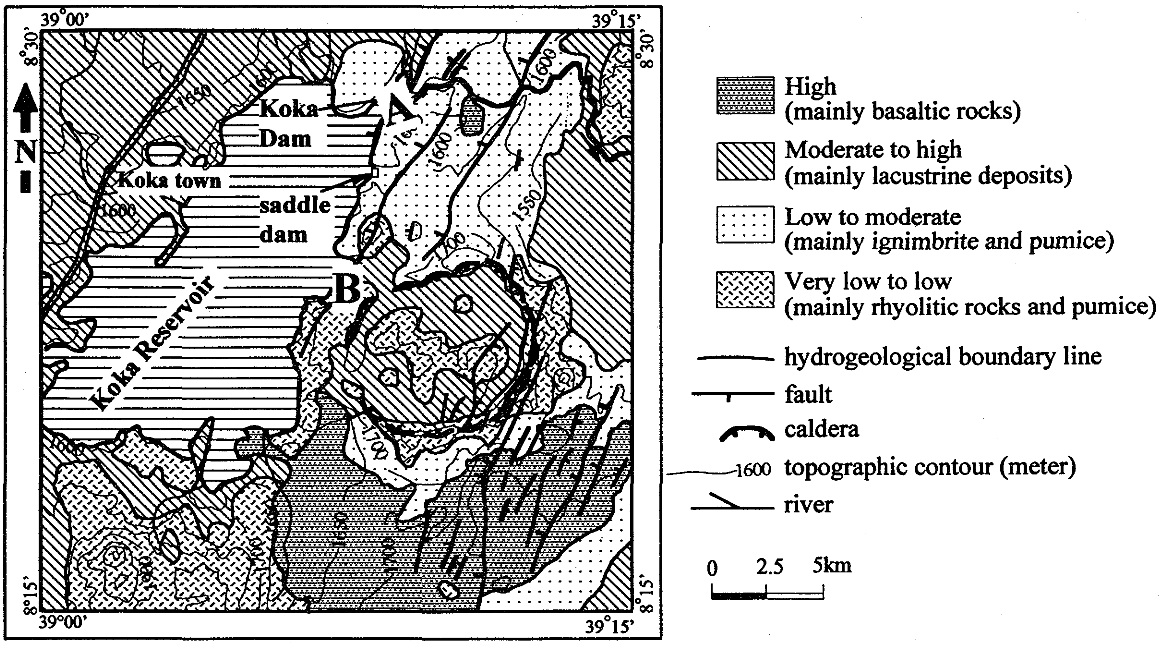

Figure 2. Topographic and permeability outline around the Koka Reservoir. The tones are permeability grades (very low to high).

The foundation rock mass of the main dam was initially treated by curtain grouting on a single line, and no serious problem on leakage was reported beneath the dam. However, the reservoir leakage has been reported since the construction of the dam. Previous studies on water balance have indicated leakage loss rates to be 90-435 Mm^3/yr, as given below.

Sogreah (1965) - 400 Mm^3/yr
Ital Consult (1970) – 435 Mm^3/yr
Meachem (1972) – 90 Mm^3/yr
Halcrow (1989) – 173 Mm^3/yr

These studies concluded leakage through the whole reservoir floor. However, according to the present study, reservoir leakage is found to be through the downstream right shore, A – B in Figure 2.

2 LEAKAGE PATH TRACING

Geological, hydrogeological and environmental isotope studies and evaluation helps to identify the Koka Reservoir leakage path.

2.1 *Topographic, geological and hydrogeological approach*

2.1.1 *Reservoir floor*

The reservoir floor consists of slightly consolidated lacustrine deposit, which is covered by thin silt sediment. This deposit of fine to medium sand has moderate to high permeability in the surrounding area. The reservoir area seems discharge area for local descending ground water, and the deep hot/regional ascending ground water head seems is/stabilized at the level of reservoir floor. Ground water discharge occurs at the left and upstream margin. Mixing of local descending cold and uprising very hot ground waters is observed at the retreated reservoir floor. The reservoir area was a permanent marsh before impoundment and this suggests ground water discharge. Previous water balance/budget data for the reservoir show high negative leakage value, which evidences high ground water inflow into the reservoir, more than ground water discharge at the peripheries/shore areas. These entail that no leakage could occur beneath the whole reservoir floor.

2.1.2 *Left and upstream reservoir margin*

Slightly consolidated lacustrine sediments (fine to medium sand) of moderate to high permeability cover the left, upstream west and southwest reservoir margins, which also forms the reservoir floor. Topography gently (to flat) grades to the reservoir except stream cut and isolated hill at the downstream left side, which is composed of pumice and rhyolite. Very hot (>40°C) uprising springs, and very hot and cold (<30°C) descending topographic springs discharge at the shore and also seen on the retreated reservoir floor. The descending cold ground water is seen mixing with upflowing very hot ground water at the reservoir floor.

The upstream southern margin and the surrounding hill is formed by low permeable slightly indurated pumice deposit with ash matrix and the overlying slightly jointed rhyolite. Pyroclastic deposit is highly weathered on top. Very hot springs (>40°C) and seepages flow into the reservoir at this shore. During low reservoir water level, springs also appear at lower level to the present discharge area.

No favorable conditions for inter sub-basins ground water underflow/outflow exist in these parts of the reservoir margins.

2.1.3 *Right reservoir margin*

Slightly indurated pumice with ash matrix covered by rhyolite patches and minor hills, and younger scoria flow constitute the right reservoir margin in the upstream extreme southeast. Paleodrainage was to the reservoir and basalt scoria flow direction is toward the reservoir. Topography gently grades to the reservoir. The high permeable scoria flow is thin and the underlying low permeable pumice is above the reservoir water level. Ground water flow is thought to be toward the reservoir although no discharge points occur, and reservoir head seems could not induce inter sub-basins ground water flow reversal with the adjacent southeast area.

Downstream of this shore, up to site B in Figure 2, is flanked by highly indurated pumice with ash cement and rhyolite of very low permeability. These form the west outer rim of Gedemsa caldera with steep slope. Ground water with deep/low head with respect to the reservoir level and ground water flowing northeast in the surrounding north area is reported within Gedemsa caldera. It seems that it has no interconnection with reservoir water as the permeability of rocks at the shore is very low, and since ground water in the upstream southeast seems to flow to Awash River and discharge into the reservoir together with that of south area.

The downstream right margin (A – B in Figure 2) is constituted by recent alluvium, pyroclastic deposits with pumice and tuff beds frequently highly weathered and some beds slightly to highly indurated, slightly to moderately and highly jointed rhyolite and ignimbrite form this reservoir margin. More than three joint sets exist in volcanic rocks and especially at the contact with the reservoir water, they are open and interconnected and the dominant ones have southeast dip direction. Northeast dipping ones are also important. They have shallow to sub-vertical dip (20-80°). Recent normal faults also cross this reservoir bank, and the reservoir margin downstream of the saddle dam, which may be old river course, is a fault scarp. These jointed volcanic rock masses (moderately high permeable), pyroclastic deposits of low to moderate permeabity, and faults as well as saddle prevail reservoir water leakage to the aquifer in the northeast adjacent area, although minor topographic divide exist between the two sub-basins.

Hydraulic head difference between reservoir level and ground water table, ground water flow direction, relatively steep ground water table gradient close to shore flattening out ward and moderate high permeability of formations (Figs. 3 and 4) indicate leakage/underflow in this area. The reservoir water contributes to this ground water discharge/hot springs at the right bank of Awash River, downstream of the Koka Dam.

Ground water table increment map made using ground water table data of the lowest ground water table/during maximum recession (13 August, 1969), and maximum reservoir water level (14 September, 1969) also shows ground water source from the reservoir in the west/saddle dam area and another regional ascending water source in the northeast/around B13 (see Fig. 3). Average reservoir leakage velocity in the order of 10^{-5} cm/s is estimated on the basis of the reservoir and ground water levels relationship.

Ground water temperature variation from cold (<30°C) to very hot (>40°C) away from the reservoir along flow direction, and hydrochemistry data also support dissipation of leakage water into the ground water through the mentioned part of the reservoir margin.

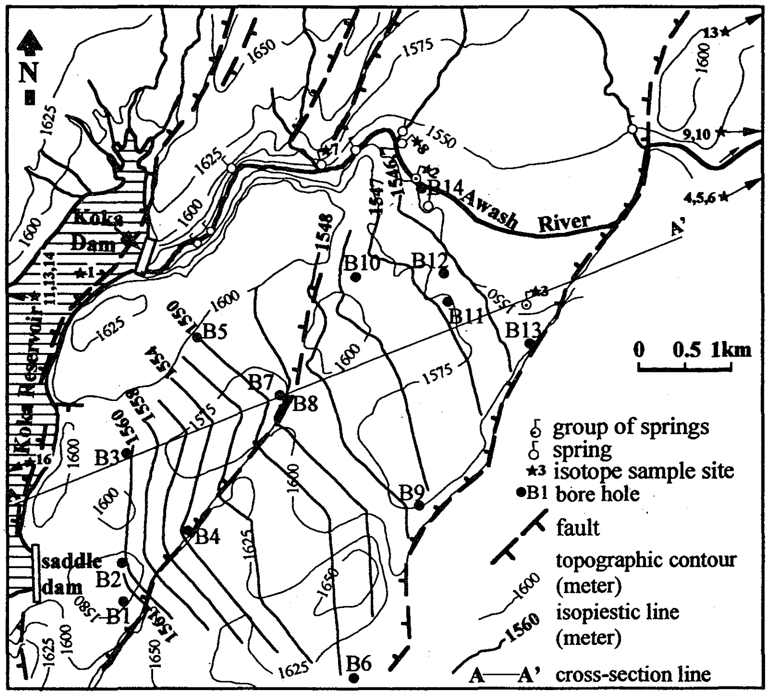

Figure 3. Ground water table map (for 14 September 1969).

2.2 *Environmental isotope approach*

Available isotope data evidence reservoir water mixing along ground water flow direction in the northeast reservoir vicinity (Fig.5), which indicates leakage through the mentioned reservoir margin. Reservoir water contribution of 45%, 29%, 27%, and 55%, 46% and 31% is estimated on the basis of ^{18}O and ^{2}H data respectively, for ground waters 2, 3 and 4 taking in to account ground water 11 as end member of pure ground water. Reservoir water contribution decreases away from the reservoir. Location of ground water points is given in Figure 3.

Two ground water sources seem to exist in the area: local enriched meteoric water (upper part) and depleted upland rain water for ground waters at the lower left in Figure 5. This group seems old water/paleo-ground water (?) at places mixed with local/modern ground water. Hydrothermal oxygen exchange processes with aquifer seem to have given oxygen shift for ground waters 4 and 11.

Recharge water sources, evaporation and hydrothermal oxygen exchange processes and Koka Reservoir water mixing, and also mixing between depleted and enriched local ground waters have contributed to stable isotope variation of these ground waters. 30-40 years ground water age or mixing of pre atomic bomb ground water and modern water can be expected from Tritium data except ground water 3 that shows modern water.

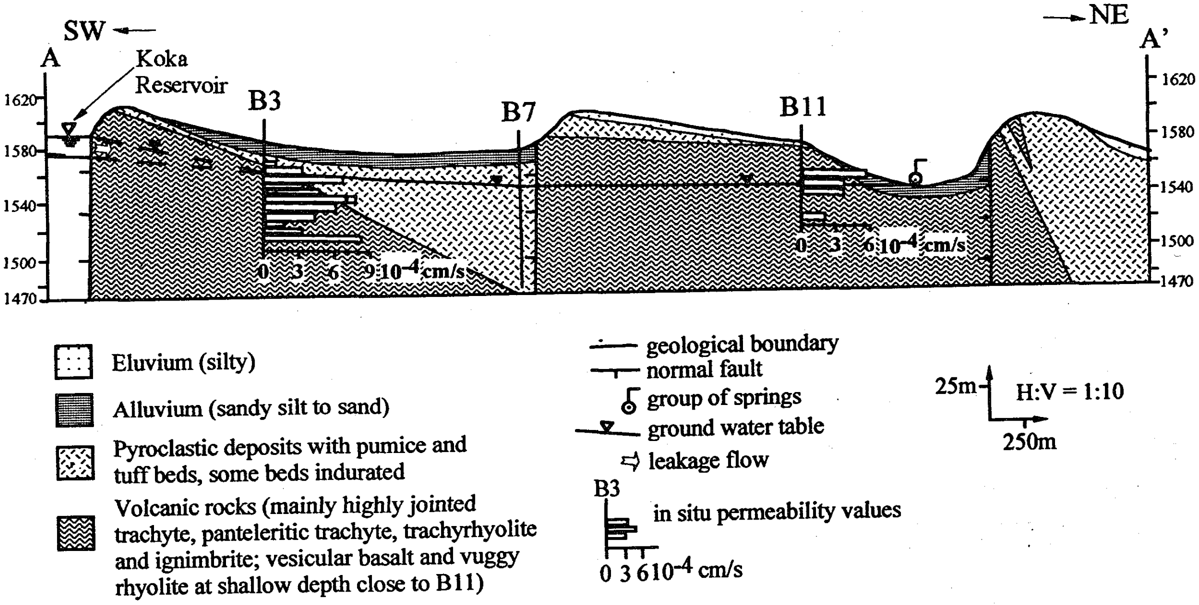

Figure 4. Cross-section map along line A-A' in Figure 3. Permeability data are based on Ital Consult (1970).

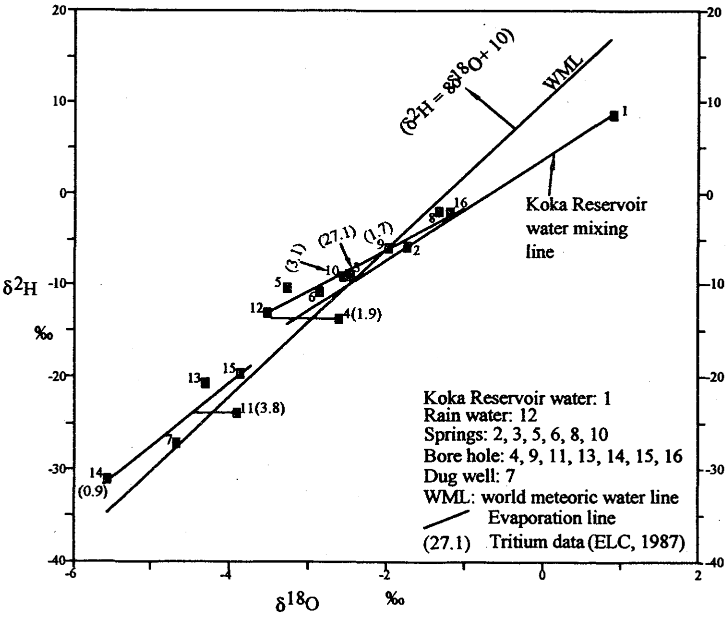

Figure 5. δ^2H versus δ^{18}O graph.

3 CONCLUSIONS

Koka Reservoir leakage path is identified to be in the right margin (A-B in Figure 6). Leakage occurs through pyroclastic deposits, jointed volcanic rock masses, fractured and brecciated zone of faults and beneath the saddle dam although its foundation has been made consolidated/rimmed. Reservoir leakage water joins/spreads into low-lying ground water in the adjacent northeast area. This ground water feeds the Awash River in close downstream area.

Leakage does not occur through the whole reservoir floor area as proposed by previous studies, and no leakage is anticipated through other parts of reservoir margin.

Although the left abutment of the Koka dam, which is the upthrown side of a fault consists of highly jointed ignimbrite that extends to the downstream left bank of Awash River, no evidence for leakage through this rock mass is encountered except its favoring permeability.

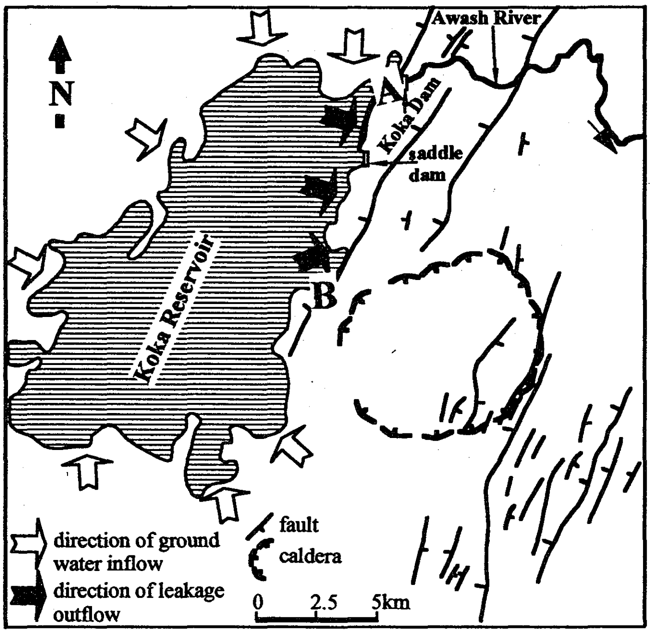

Figure 6. Conceptual reservoir leakage model.

REFERENCES

ELC Electro Consult, 1987. Geothermal reconnaissance study of selected sites of the Ethiopian rift system, fluid geochemical report, *Ethiopian Institute of Geological Srveys.*

Halcrow, 1989. Master plan for the development of surface water resources in the Awash basin, vol.4, climate and hydrology.

Ital Consult, 1970. Mekey river diversion scheme, vol.3, geology and hydrogeology, Rome.

Sileshi Mamo, 1995. Research study on the Koka Dam Reservoir leakage paths (Main Report), Addis Ababa, Ethiopia.

Sileshi Mamo and Shuichiro YOKOTA, 1998. Estimation of Koka Reservoir leakage paths by integrated hydrogeological and environmental stable isotope techniques. *Proceedings of 8th Congress of Engineering Geology.*

Sogreah, 1965. Survey of the Awash River basin, vol. I-IV.