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Short communication

RESISTIVITY SURVEY TO LOCATE HOT WATER RESERVES AT FILWOHA, ADDIS ABABA

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ABSTRACT: Hot springs and boreholes are the sources of the hot water for the public bath at Filwoha, in Addis Ababa. Most of the boreholes were drilled without ample information about the subsurface. The shortage of such information has limited the full utilisation of the hot water potential in Filwoha. To overcome this limitation a resistivity survey was conducted in the area, using a Schlumberger array with two different electrode separations. Two low resistivity zones were delineated, one around the Addis Ababa Stadium and the other near the Ministry of Foreign Affairs. Using geophysical, geological and geochemical information a preliminary conclusion has been drawn that the low resistivity zones are due to water that escape through the major Filwoha Fault. On the basis of these results, additional geophysical survey and two test-drilling sites are recommended and further suggestions are given to reserve the area for a recreation centre.

Key words/phrases: Filwoha, hot springs, resistivity survey

INTRODUCTION

Geophysical surveys in urban areas are complex, and need much care in comparison to surveys that are usually carried out in rural areas. Part of the complexities arises from the presence of electric cables, underground pipelines, densely constructed buildings, highly crowded motor traffic and different types of alien soil that are dumped during construction. In such a situation, it is not only the challenge faced during data gathering that has to be tackled, but also the data analysis to attain a meaningful interpretation.

The geophysical survey in the Filwoha area is a good example of such a challenge. Filwoha is an area that is located in the south eastern part of the city of Addis Ababa. This part of the city was selected for this survey in view of the possibility of developing the hot water potential that is manifested by the presence of hot springs. The area, known as Finfine locally, is believed to have been the original site where Addis Ababa started as a city. Even though there is no any concrete information about the location of these hot springs in the past, non-written information indicates that there were some additional hot springs in the area presently occupied by the stadium.

Except the terrain that is sloping steeply south west from the eastern part of Police Garage (see map, Fig. 1) up to the location where the hot springs are observed, the rest of the area is almost flat. Two rivers enter this locality at one corner with their confluence near Zewditu Memorial Hospital. In general, the area has a high density of roads, buildings and houses. Most of the roads are lined up with electric cables. The problem that has been faced due to the presence of these challenges was overcome by choosing the Imperfect Schlumberger array (Hochstein, 1982). This method stretches its capacity beyond its usual suitability for ground water exploration, to overcome the problem of getting open space for a straight profile.

Five fourth year students of the Addis Ababa University, Physics Department (including the author), participated in the survey.

GEOLOGY

The lithologic units that are mapped in the area are: (1) Welded tuff (2) Rhyolite (3) Aphanitic basalt and undifferentiated volcanics (4) Alluvial deposit. The surface exposure of these rock types, adopted from the Geological Map of Addis Ababa (Morton, 1974), is given in Figure 1. Even though no reliable data is available about the age of the rocks, the first three are believed to be of the Upper Tertiary, with their origin related to the Addis Ababa Entoto volcanics, while the alluvial deposit is of Quaternary to recent. As can be seen from Figure 1 there are two hot springs, at the junction where the major fault of Filwoha vanishes under the alluvial deposit. This fault trends south west and extends from the Finfine Hall to the north-eastern part of the mapped area.

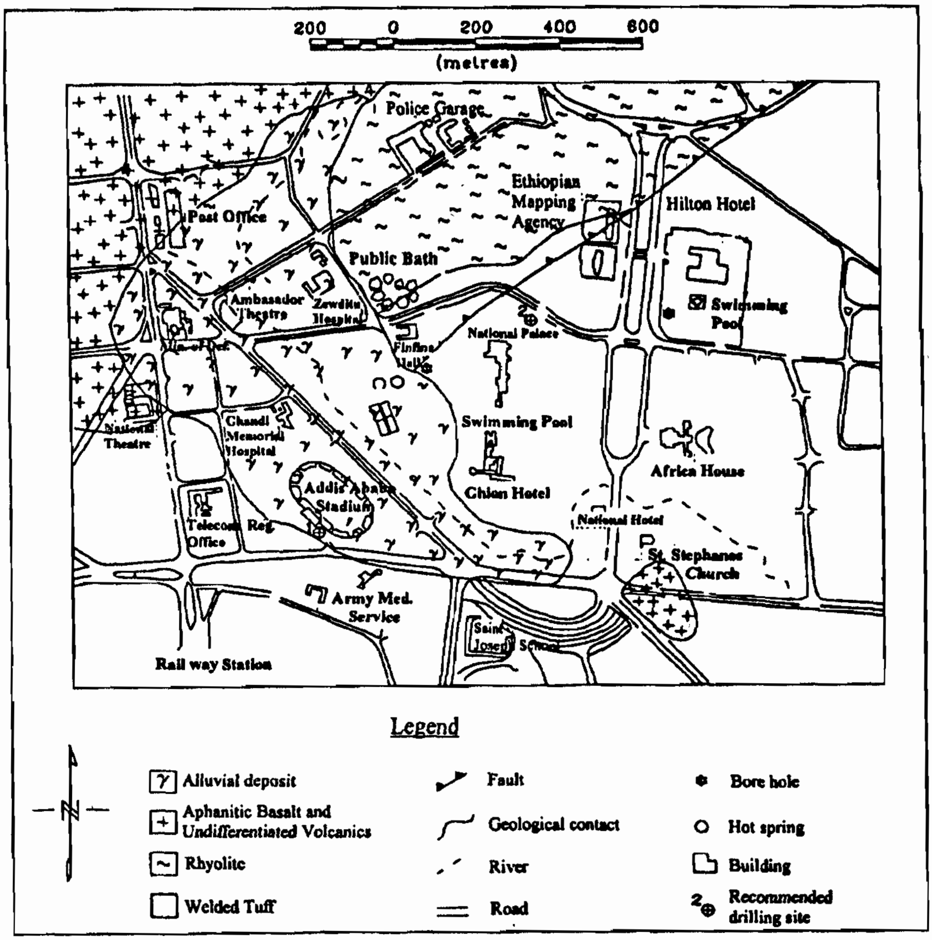

Fig. 1. Geological map of Filwoha area. Adopted from geological map of Addis Ababa (after Morton, 1974).

Due to the shortage of data, from a number of boreholes, it is hard to give a representative vertical sequence of lithologic units for the area. However, from the geological logging result of the borehole at Addis Ababa Hilton Hotel (WATENCO, 1967) it is possible to get some information about the vertical sequence of the lithologic units in the area. The result is summarised in Table 1. Besides this, the water temperature measurement carried out during the survey showed that the water from the borehole at Addis Ababa Hilton Hotel was 40° C hot and the one from the borehole near Finfine Hall was 72° C hot. Moreover, previously conducted geochemical survey (Beruke Alemayehu, personal communication) showed that the source of the hot water lies at higher depth.

Table 1. Lithologic log of Hilton Hotel well No. 1 (summarised from WATENCO well report, 1967).

From (meters)	To (meters)	Thickness (meters)	Lithologic description
0	21.3	21.3	Soil and Silt
21.3	54.2	32.9	Trachyte and Tuff
54.2	66.7	12.5	Trachyte and Basalt
66.7	193.8	127.1	Basalt
193.8	400	206.2	Trachyte, clay and Basalt

FIELD MEASUREMENT

The resistivity survey in the area was carried out using RAC-8 resistivity meter. This measuring instrument was selected due to the advantages of easy portability and wide resistance measuring range (10^{-4} Ω to 10^{4} Ω). The system consists of a transmitter and a receiver without any interconnecting cable. The transmitter has a power output of 80 watt, in the form of square wave, in low frequency range. By taking care that the output power does not exceed 80 watt one can take any combination of the current (10^{-4} A to 3.33×10^{-1} A) and the voltage (0V to 500V). The receiver operates as a highly sensitive AC voltmeter that provides a direct read-out of the V/I (voltage/current) ratio with a minimum voltage measuring capacity of 10^{-6} V.

Twelve hollow iron stakes, with holes (for connecting wire) at their side, were used as current electrodes. Non-polarizable porous pots filled with copper sulphate solution were used as potential electrodes. Most of the time saline water had to be used to improve the contact resistance between the ground and the electrodes. The type of cables used were 3 mm stranded copper wire (for connecting current electrodes) and steel wire (for connecting potential electrodes).

Since the area is crowded with houses and buildings, it is difficult to lay a base line and the presence of too many roads gives rise to heavy traffic that causes a frequent problem of cable breakage. Besides this, there are high tension power lines along most of the roads, which cause disturbance in readings either through leakage of current in the ground or by induction. In order to overcome these problems it was necessary to adapt some modification to the usual procedure of field measurement.

As a substitute to the grid work, scattered points in almost the same distance (whenever possible) were taken (Figs 2 and 3). To avoid cable breakage when it crosses roads, most of the time profiles were laid parallel to the road or on an open ground. Sometimes it was difficult to lay a straight line for a profile. In such a case the configuration indicated on Fig. 5 was used and the apparent resistivity was computed using equation (2), based on the measured V/I (Hochstein, 1982). On those places where there was a possibility to lay a straight profile the configuration given in Fig. 4 was used and the apparent resistivity was computed using equation (1).

Before conducting the lateral profiling survey, it was necessary to determine the optimum electrode separation that was related to the depth at which the investigation was to be conducted. To achieve this goal it was necessary to have a priori knowledge about the depth of investigation and about the current penetration power. Some records of a borehole at Addis Ababa Hilton Hotel together with some vertical electrical sounding measurements around the borehole were used to serve this purpose. On the basis of this data, the separation between the current electrodes was chosen as 400 and 800 meters. In relation to this, the separation between potential electrodes was taken as 50 and 100 meters respectively. The resulting apparent resistivity data from the two electrode separations were then plotted as contour maps (Figs 2 and 3).

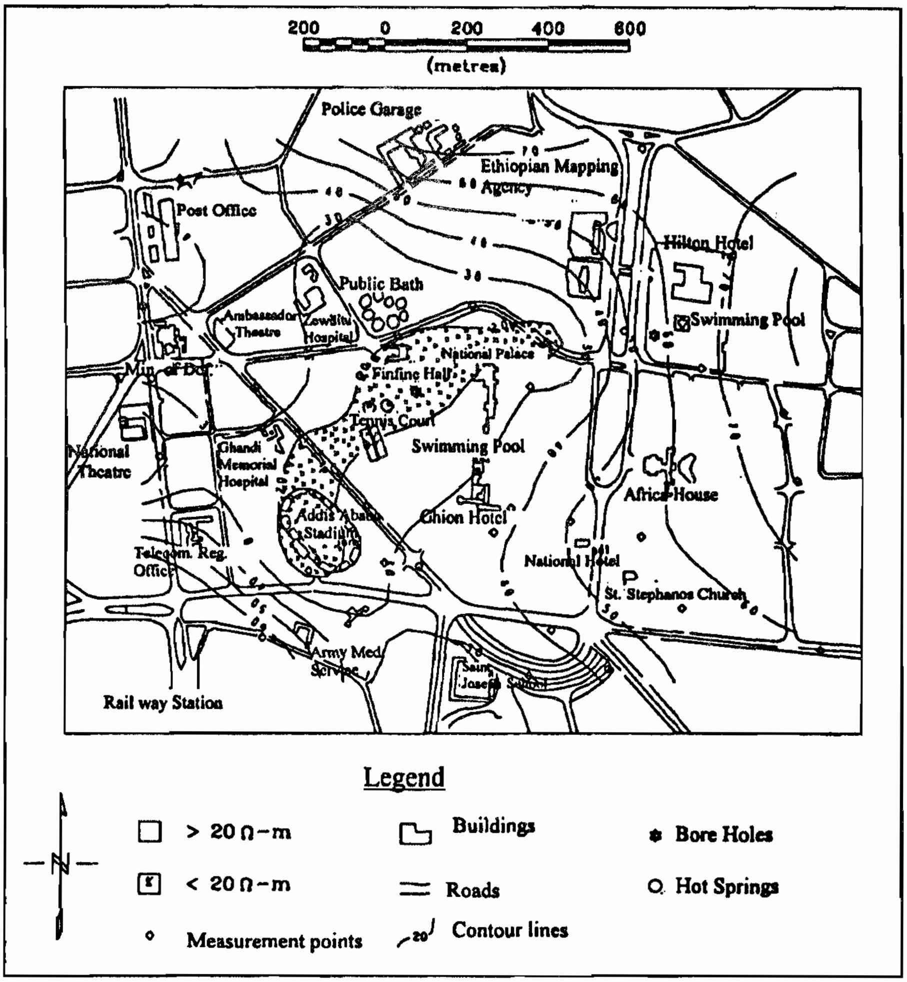

Fig. 2. Apparent Resistivity (ρ_a) Contour map of Filwoha area. Symmetric Schlumberger configuration, AB/2 = 200 m, and contour interval of 0 Ω-m.

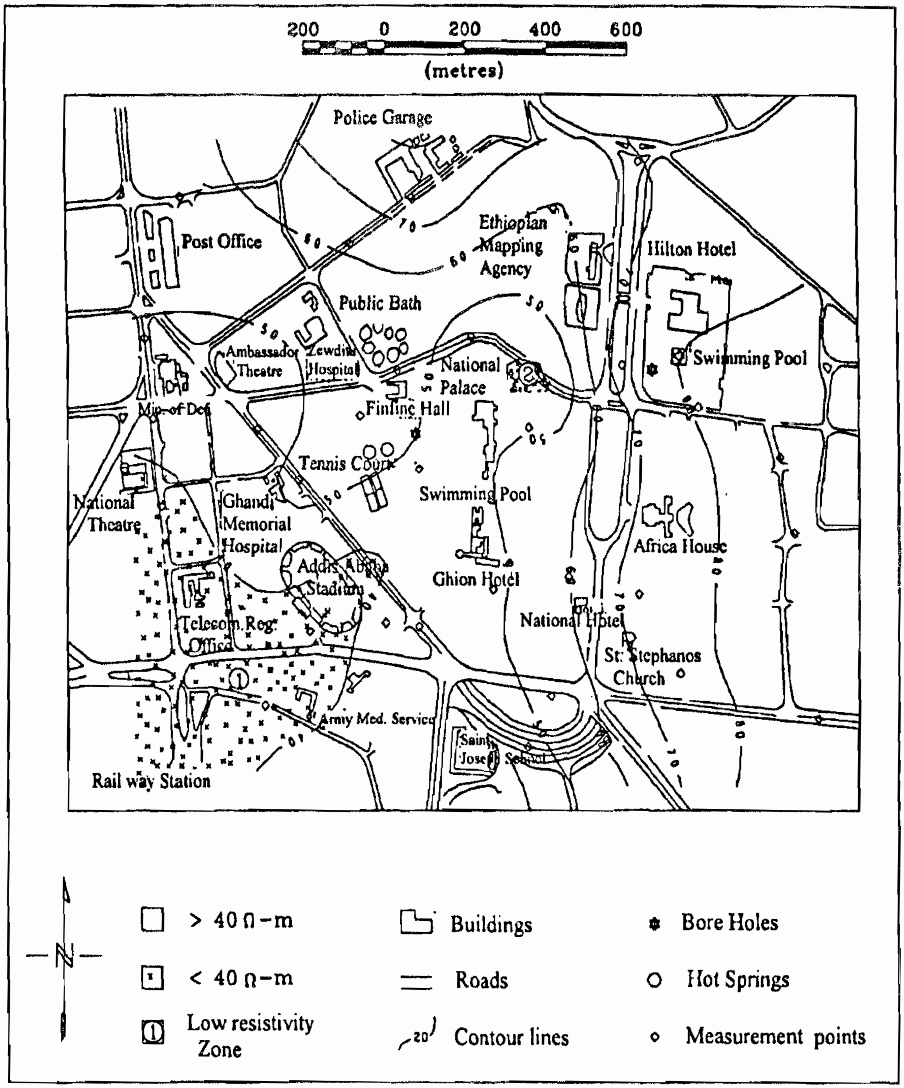

Fig. 3. Apparent Resistivity (ρ_a) Contour map of Filwoha area. Symmetric Schlumberger configuration, AB/2 = 400 m, and contour interval of 10 Ω-m.

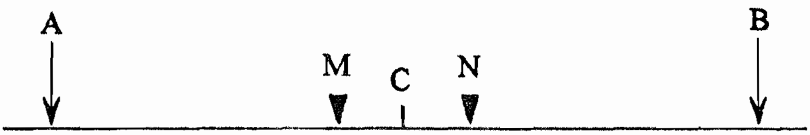

Fig. 4. **Schlumberger array.**

$$\rho_a = \pi\left[\frac{(AB/2)^2}{MN} - \frac{MN}{4}\right]\frac{\Delta V}{I} \tag{1}$$

Where: MN = the distance between the two potential electrodes
AB = the distance between the two current electrodes
C = the measurement point
I = the electric current
ΔV = the measured potential difference
ρ_a = the apparent resistivity

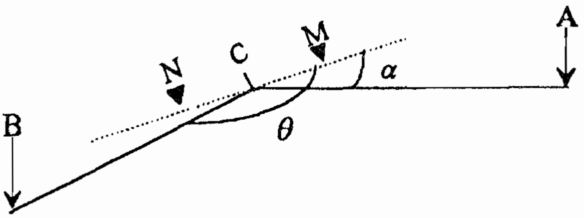

Fig. 5. **Imperfect Schlumberger array.**

$$\rho_a = \frac{2\pi}{MN}\left(\frac{\cos\alpha}{AC^2} - \frac{\cos\theta}{BC^2}\right)^{-1}\frac{\Delta V}{I} \quad \text{..... for } MN << AC \text{ and } MN << BC \tag{2}$$

Here AC and BC are the distances between the two current electrodes and the point that lie halfway between the two potential electrodes. The symbols α and θ are angles as shown on Fig. 5.

RESULTS AND DISCUSSION

The resistivity contour lines, shown both in Figs 2 and 3, mostly followed the topography in the northern, north-eastern and eastern part of the area. These contour lines show a resistivity decrease toward south-west, up to the stadium. There were two low resistivity zones in the area (zones 1 and 2), that were indistinguishable at shallow depth and emerged as two distinct zones at higher depth.

At shallow depth there was a low resistivity zone (marked by the symbol **x** in Fig. 2) that was elongated in the north-east direction. If one projects the major fault of Filwoha on the apparent resistivity map of Figure 2 one can see that the elongated low resistivity zone is highly correlated to the presence of the fault. The correlation is such that the fault lies halfway from the western flank of the low resistivity zone and the axis that passes through the centre of the low resistivity zone. Especially if one takes the fact that the fault dips toward north-west and the low resistivity zone represents the resistivity at depth, one can fully accept that the low resistivity zone lies in the south-eastern part of the fault, where welded tuff is prevailing. When one compares this rock unit to the rhyolite, the former is conducive to accommodate water. Moreover, the presence of the two hot springs at the place where the fault disappears under the alluvial deposit, might be a good indication that the hot water in the area is related to the major Filwoha Fault.

On the other hand, at depth this low resistivity zone is divided into two zones (marked by the symbol **x** in Fig. 3) that are aligned parallel to the orientation of the fault (see Fig. 3). One of this zones is in-between the National Palace and the Ethiopian Mapping Agency (zone 2). The other is near the Addis Ababa Stadium (zone 1). The zone around the Addis Ababa Stadium is wide, opens to the south-west and shows an elongation to the north-east direction, towards zone 2. On the other hand, the low resistivity zone near the National Palace has a closed form. Compared to zone 1, this zone is smaller. The surface projection of this zone lies south-east of the major Filwoha Fault.

The trend of the contour lines east of Ghion Hotel, in the north-south direction might indicate the presence of some structure. To verify this assumption it is necessary to carry out additional geophysical work in the area.

CONCLUSIONS

From the shape and location of the low resistivity zones, the location of the hot springs and the trend and location of the fault, the low resistivity zones are assumed to be caused by hot water that escapes through the fault. The assumption is especially justifiable when one considers the increase in the water temperature as one approaches the fault from the east. This statement is based on the water temperature data (obtained during the field survey), from the boreholes in the Addis Ababa Hilton Hotel and in the National Palace. Moreover geochemical analysis showed that the source of the hot water lies at higher depth.

To be certain about the assumption that the hot water escape through the fault, it is necessary to carry out high precision gravity survey, additional vertical electrical sounding and geochemical measurements in the area. The gravity survey will be specially used to study and model the subsurface structures.

By correlating the present geophysical result with the geology of the area and the information on geochemical work, possible test drilling sites are recommended (details are given in Table 2) at the locations marked as ¹⊕ and ²⊕ in Figure 1. Together with the information that can be drawn from the existing boreholes and the additional geophysical survey, the suggested boreholes can help in making a systematic geothermal study of the area.

The selection of the drilling sites at the specific locations is not only to see the cause of the low resistivity zones at the respective locations but also to make a geological analysis on the pseudo-profile that is parallel to the major Filwoha fault.

Using the information to be gained from the recommended geophysical survey and drilling, it is suggested that the area should be reserved for those organisations that are interested in the usage of hot water for recreation.

Table 2. **Details test drilling in Filwoha area.**

Zone	Borehole	Location Symbol	Inclination (degree)	Depth in meters	
				Min.	Max.
1	Fil 1	$^{1}\oplus$	90	300	450
2	Fil 1	$^{2}\oplus$	90	380	500

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