Advanced Materials Research Vols. 955-959 (2014) pp 3198-3201 *Online: 2014-06-18*
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doi:10.4028/www.scientific.net/AMR.955-959.3198

Study of thermal water resources in Sri Lanka using time domain electromagnetics (TDEM)

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Keywords: Electromagnetics; geothermal water; Sri Lanka.

Abstract. Thermal springs can be utilized as an environmental friendly source of renewable energy, as well as for other purposes. Time domain electromagnetic (TDEM) method is used as an accessory tool in geothermal exploration to investigate the local heterogeneities in geology. The study consists of two of the thermal springs in Sri Lanka, Wahawa and Mahaoya, both in the same crustal unit. Major structural discontinuities of the area vary between two peculiar fracture sets striking ENE and NW. Close relationships between these individual springs have been witnessed by their approximate major cation chemistries, which provoke the idea of geochemical provinces. Survey reveals the pathways of the heated water to the surface, at Wahawa, although the path is not clear at Mahaoya. Near surface resistivity diagrams can be used only to interpret the immediate depths of the springs. The expected structural relationships may be identified with a grid of TDEM soundings encompassing both the spring systems.

Introduction

Hot water springs are indication of the geothermal energy. Other than exploiting them for electricity generation, thermal springs provide many other uses such as energy for product drying, air conditioning, recreational activities and agriculture needs. In Sri Lanka, a line of thermal springs scattered along the eastern periphery of the island [1]. As the pioneering work on geothermal exploration in Sri Lanka, a geophysical survey was carried out circumscribing all the major thermal springs [2].

Sri Lankan basement is composed of three main crustal complexes (Fig. 1a). Highland Complex (HC) being the central, Wanni Complex (WC) to the west and the Vijayan Complex (VC) to the east [3, 4]. The thermal springs are closely associated with the Highland-Vijayan boundary (HC-VC), while the ones in Mahaoya and Wahawa are both located within the Vijayan complex. The area is underlain by amphibolite grade metamorphic rocks and granitoid gneisses. Mahaoya spring is found in a synformal structure where the main rock type in the area is augen gneiss. Wahawa is underlain by garnetiferous biotite hornblende gneiss. Two shear zones, both running along north-western direction, could be found alongside of the Mahaoya thermal spring. Most of the surface hydrogeology in the area is controlled by the conjugate fractures consisting of one prominent north-eastern (Fig. 1b) and a minor north-western system [5].

One of the controversial heat sources that has been proposed[5] for the origin of the thermal springs is the dolerite dyke formations found in the Vijayan Complex (Fig. 1b). The Wahawa spring is closely associated with a dolerite dyke which extends up to 32 km towards NW. Another one is found far from Mahaoya and more towards Kapurella thermal spring (the one with the highest recorded temperature, 73.5 °C) which runs towards NW up to nearly 65 km.

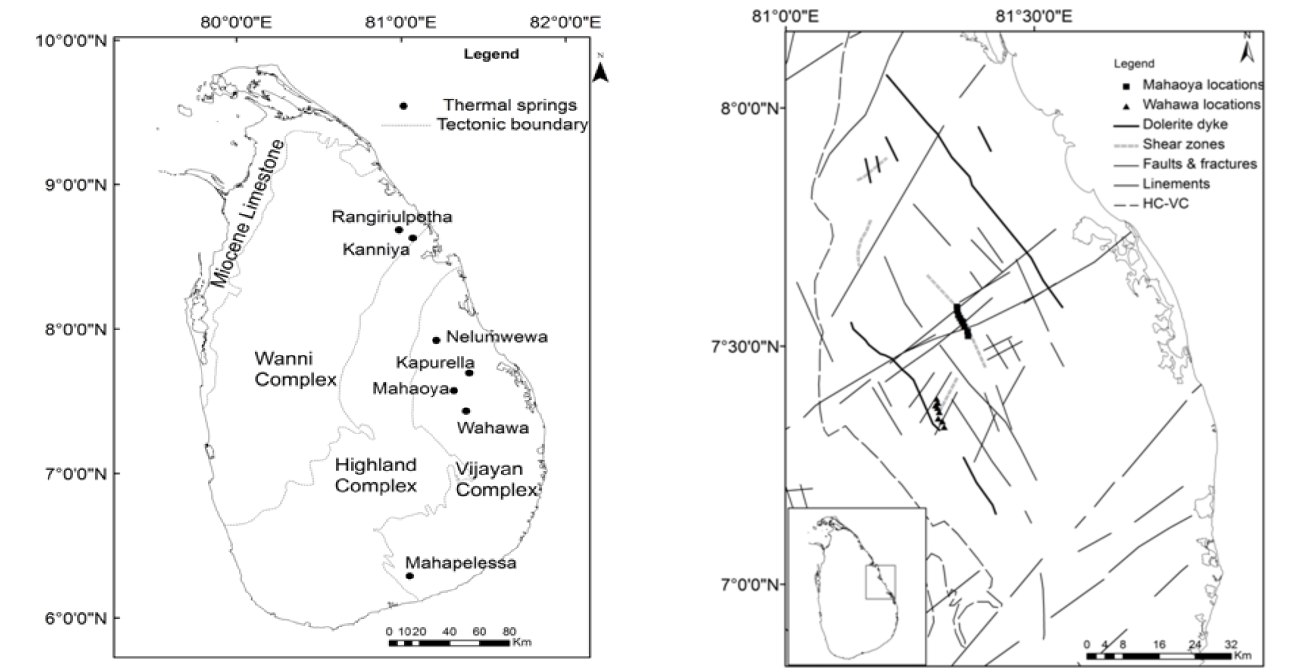

Fig. 1 a) Thermal springs in Sri Lanka. The dotted lines represent the boundaries between the crustal complexes. b)Structural features around the study area. Mahaoya locations are marked as boxes and Wahawa locations as triangles. HC-VC is the tectonic boundary between Highland and Vijayan complexes.

Mahaoya spring is composed of a few wells scattered in a small area where their temperatures vary in a range between 39°C and 56.5 °C. recorded in the Wahawa thermal spring system has the maximum temperature of 48.0 °C and it comprises of more than 15 small wells scattered in a fairly wide area. Aerially, Mahaoya lies 31km away from the HC-VC boundary, whereas the Wahawa is 16 km away. The distance between the two springs is nearly 20 kilometres. The altitude of the Mahaoya basin ranges between 40-80 metres, whereas in Wahawa it is 80-120 metres.

Geochemical provinces

Chemical analysis of the thermal springs provides important information about the geothermal reservoirs. Fig. 2 shows major cation chemistries of thermal spring which are obtained by the geochemical survey carried out by the same group in 2012. Results of Chandrajith *et al.* [6] complement these findings. Looking at their plots it can easily be seen that the thermal springs are not isolated occurrences but sharing similar characteristics of broad geochemical provinces (Fig.2). Accordingly, we can classify that both Mahaoya and Wahawa springs into the Mahaoya geochemical province. Likewise, Kapurella and Nelumwewa are components of Kapurella province and Kinniya and Rangiriulpotha are of Kinniya province.

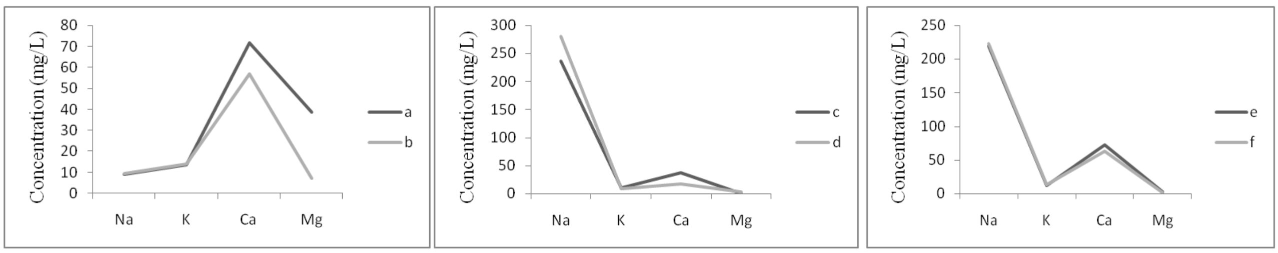

Fig. 2 Major elemental composition of six thermal springs categorized according into their geochemical provinces. a-Maha Oya, b-Whawa, c-Kapuralla, d-Nelum Wewa, e-Kinniya, f-Rangiri Ulpotha

Time domain electromagnetics-TDEM

Regardless of the amount of current injected to the transmitter loop and the conductivity of the ground which decide how deep we can measure, the TDEM method is not a deep exploring method [7]. Its advantage over conventional DC resistivity is that no contact is needed with the ground of the subject area [8].

The Geonics PROTEM system was used in acquisition of TDEM data. The TEM-47 transmitter uses a 2.0 ampere current to be transferred to the source loop with a side length of a square of 50 meters. Four transmitter current frequencies, 237.5 Hz, 62.5 Hz, 25.0 Hz, 6.25 Hz, were used with a turn off time of 3 micro-seconds. The receiver antenna consists of a three orthogonal component sensors with an effective area of 31.4 square metres.

The Geonics PROTEM-58 was the portable electronic data receiver used to record the data in-site. The higher accuracy of synchronization needed for a shallow sounding was secured by the reference cable between the transmitter and the receiver. Mahaoya and Wahawa springs were explored using 8 soundings each.

TEMX, TEMTD and TEMCROSS are Linux based software developed by the Iceland Geo-Survey and which were used in TDEM data analysis. The TEMX is used to filter out the noise in order to obtain a smooth data curve. The TEMTD was then used for model fitting followed by the TEMCROSS using which the profiles were developed.

Results and Discussion

The altitude of the area is assumed to be at the mean sea level in both the cases for the ease of interpretation. The N-S section in Fig. 3 represents the first 150 meters of the Wahawa thermal spring area. Most of the springs of the Wahawa system are located between the sites 01 and 06 where an artesian hot spring well is few meters away from site 01. The low resistivity zone just below the site 02 may be the shallowest accumulation of thermal water before it reaches the surface.

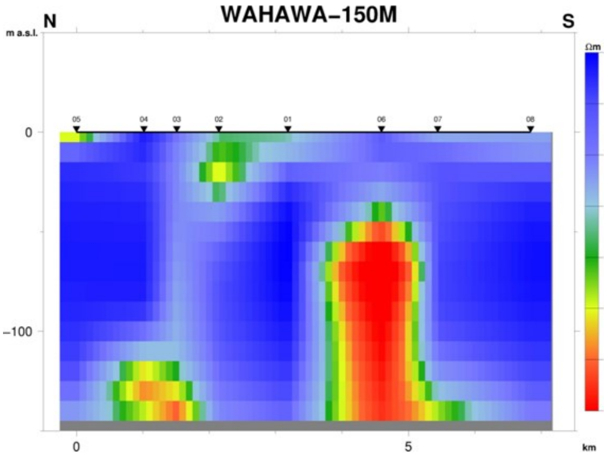

Fig. 3 Resistivity structure of Wahwa thermal spring up to 150m.

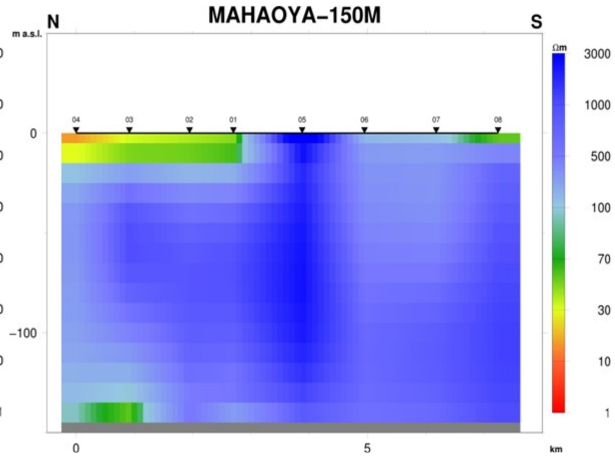

Fig. 4 Resistivity structure of Mahaoya thermal spring up to 150m.

Towards site 05 the shallow subsurface low resistivity is due to the proximity of a stream. It is seen that there are two vertical low resistivity regions starting right below the site 06 and between the sites 02 and 03 which may be the deep fractures circulating the thermal water to the surface, in fact these areas are not known to be bearing any conducting mineralization like graphite.

Comparison with the structural map confirms that the former is one of the major faults which extend towards NE, though the latter is not aerially visible. The rest of the ground shows higher resistivity owing to the unaltered crystalline rocks.

The Fig. 4 shows how the subsurface resistivity around Mahaoya spring is varying in the first 150 metres. The profile nearly runs along the N-S direction. Here, the thermal springs are not scattered as in the Wahawa ones but gathered in a small area between the sites 01 and 06. A shallow low resistive zone is found to the north of the section starting from site 01 to site 04. Here the thermal springs cannot be distinguished with a characteristic low resistive zone as was observed in the Wahawa location, and probably masked by the influence of the small lakes and the paddy cultivation in the area. Further, the fluid path in this section is not clearly visible except for the inverse 'L' shaped low resistive region to the north.

The nearly vertical low resistive zone is attributed to the composite result by the three structural discontinuities (north-eastward lineament, north-eastward fault and the eastwards fault) confluence near site 04. The one between the sites 06 and 07 is caused by a lineament which river Mahaoya runs through the town in a nearly E-W direction. And the most visible feature is the vertical high resistive zone below the site 05 which extends towards site 03 through site 01 starting at a depth of 50 m, which represents the unaltered rock.

It is sometimes arguable to get resistivity values as low as 1 Ωm or even low in crystalline rock fractures, but the higher ion content in geothermal fluids can improve the conductivity to compensate such low values.

Summary

The similarities in chemical data of the thermal springs invoke the idea of geochemical provinces. Though, Kapurella and Nelumwewa are considered here as different geochemical provinces, they could probably be sub-provinces of Mahaoya or vice-versa. In order to understand what we observe in the geochemical provinces it would be necessary to carry out a TEM survey in a grid covering the area between Mahaoya and Wahawa thermal springs. A non-linear survey that composed of only six sites running from Wahawa area to Mahaoya was extremely noisy and is inadequate in confirming the physical connectivity between the thermal springs. The identification of thermal systems as provinces is important in utilizing the resource in commercial scale.

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Advances in Environmental Technologies III
10.4028/www.scientific.net/AMR.955-959

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