

A GEOSTRUCTURAL MODEL FOR THE NELUMWEWA THERMAL SPRING: NORTH CENTRAL PROVINCE, SRI LANKA

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ABSTRACT

The thermal spring (61 °C) at Nelumwewa of the North Central Province, Sri Lanka, was investigated for proposing a hydrogeological model to explain its operating mechanism. Combined geological, geophysical and remote sensing observations suggest that deep percolated groundwater absorbing heat from a possible Hot Dry Rock emerges at the surface through a NE-SW running fault plane, forming the thermal spring.

Keywords: Geothermal energy, Thermal springs, Hot dry rock, Fault zone, Dolerite

INTRODUCTION

Thermal springs are surface manifestations of subsurface geothermal energy which are utilized for direct and non-direct applications in many parts of the world. Thermal energy is conducted to the surface continuously through rocks and groundwater. At most places, this energy comes to the surface at specified places such as hot spots, plate boundaries, fault zone, volcanoes or as thermal water (Hochstein, 1990). All natural geothermal systems in the world are controlled by special geo-structural features such as faults, graben structures, volcanic domes, crater lakes, volcanic associated features and fracture systems (Faulds et al., 2010). Hence, the geo structural framework of an area is important in exploration and exploitation of geothermal energy.

Although Sri Lanka is located away from volcanic or tectonically active regions of the world, there are ten thermal springs with temperature between 40 and 61 °C present along a narrow and approximately N-S running belt (Figure 1). A combined geological, geophysical and remote sensing investigation was carried out in the area of the Nelumwewa thermal spring (61 °C) in the North Central Province of Sri Lanka, to establish the structural setting and governing mechanism of the geothermal system.

PREVIOUS WORK

Sri Lanka's thermal springs have been studied by several workers. The first scientific study on thermal springs of Sri Lanka was carried out by Seneviratna and Balendarn (1968) who presented a general account on the locations, geological settings, physical and chemical characters of water of the individual springs.

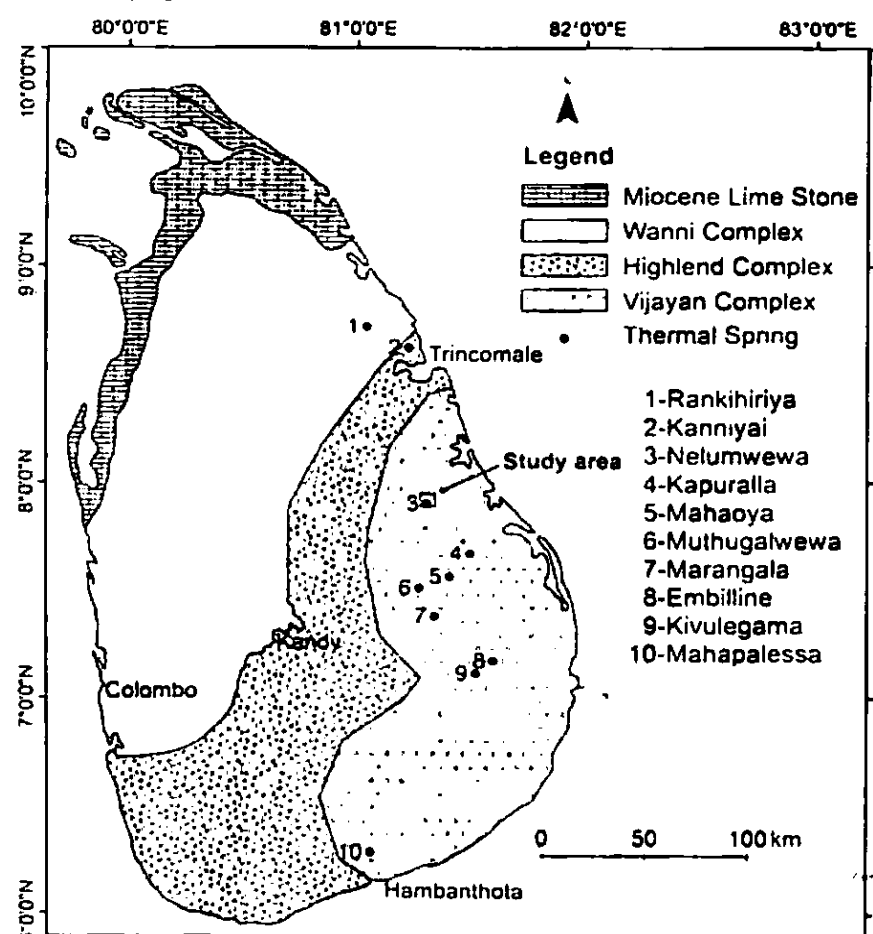


Fig. 1 Map showing the location of the study area in relation to main geological units and the thermal springs of Sri Lanka.

Arumugam and Ratnathunga (1974) compiled same data in Sri Lanka, in its publication of "Springs of Sri Lanka" during a survey of the island's water resources by Water Resources Board. Based on an isotope study, Dharmasiri and Basnayake (1986) reported that the thermal spring waters of Sri Lanka are of meteoric origin where deep percolation of infiltrated rain water returns to the surface after acquiring heat under the influence of the average geothermal gradient (30 °C/km). A model for the origin of thermal springs of Sri Lanka was proposed by Dissanayake and Jayasena (1988) and estimated the meteorically sourced water come in contact with subsurface temperature around 140 °C. Tectonic activity, radioactivity and exothermic igneous and metamorphic reactions have been suggested as the probable heat generators. Deeply extending fracture or fault zones have been proposed as the hydraulically convective zones which transmit heat via ascending groundwater to the surface. Based on a self-potential geophysical survey carried out near Mahapelessa thermal spring (currently named as Madunagala) in the Hambantthota District of southern province, Sri Lanka, Fonseka (1992) suggested the presence of deep extending fracture zone through which the groundwater flows up after absorbing heat of sub-surface. A gravity survey interpretation by Fonseka (1994) reported a negative gravity anomaly along the belt of thermal springs of Sri Lanka. Ilangasinghe et al., (2006) based on resistivity investigations indicated that there is a steady energy output of 33.3 kW (thermal) through a possible fault zone at Rankihiriya thermal spring, North East Sri Lanka. Adikaram and Dharmagunawardhane (2008) reported that there is a steady cumulative energy output of 0.52 MW (thermal) at Marangala thermal spring cluster. These steady power outputs, however, may not be cost effective in view of power generation. Senaratne and Chandima (2011) described the geology, hydrogeology and surface temperature of Wahawa thermal springs in the Eastern Province. Chandrajith et al., (2013) proposed that thermal springs in Sri Lanka are due to percolation of water

downwards through faults and fractures and heated by a steeper geothermal gradient.

Although there are no firm conclusions on the heat sources of the thermal springs, the common belief, is more towards meteoric water deep percolation and acquiring heat under average geothermal gradient. It is important to note that almost all thermal springs of Sri Lanka are situated on or close to regional fault/fracture zones. Therefore, deep percolation of meteoric water and acquiring heat under natural average geothermal gradient is possible.

However, the ten thermal springs of Sri Lanka are concentrated along an approximately NS running belt in the Eastern side of the country (Figure 2). Although regional fault/fracture zones (mega lineaments) are found in other parts as well in the country (Figure 2), there is no thermal springs present in association with any of those. This infers that the concept of mere

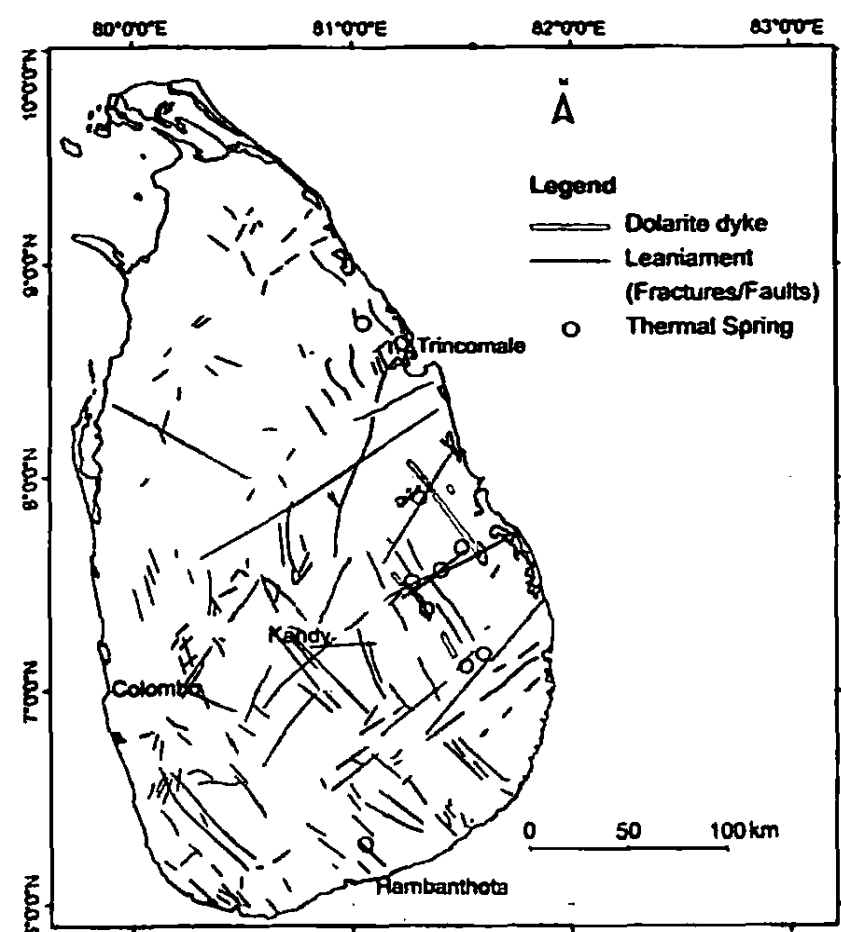


Fig. 2 Regional lineaments (Fractures and Faults) and distribution of dolerite dikes in the country and location of thermal springs (Modified after National Atlas of Sri Lanka, (2006)).

deep percolation and acquiring heat under average geothermal gradient does not satisfactorily explain the possible heat source of the thermal springs.

A noteworthy fact is that, seven out of the ten thermal springs of Sri Lanka are situated close to dolerite dikes (Figure 2) which are igneous bodies intruded from 140 to 170 Ma ago (Yoshida et al., 1988; Takigami et al., 1999). There are no dolerite dikes observed so far close to three thermal springs out of the ten (northernmost and southernmost) most probably due to the thick weathered overburden in the flat terrain of those areas masking the dolerite outcrops.

All above evidences infer that deep percolating groundwater through regional fractures, acquire heat from still hot dolerite bodies at depth and emerge at surface forming at least the majority of the thermal springs of Sri Lanka. Although economic significance and related geological structures of thermal spring associated geothermal systems in Sri Lanka have not yet been fully understood, Sri Lanka's thermal spring systems can be described as low enthalpy geothermal sources.

METHODOLOGY

Available structural and tectonic data of the area were used for preliminary interpretations. Surface displacements that appear on the aerial photographs of 1:50,000 scale were used for studying the geological structures and fracture lineaments. Geological field mapping was carried out covering an area of about 100 km² around the thermal spring and, data were compiled on to a geological and geo tectonic map of the area (Figure 3). Vertical Electrical Resistivity Sounding (VES) was carried out in the area to assess subsurface distribution of the fracture and fault traces which were observed on aerial photographs and satellite imageries.

RESULTS AND DISCUSSION

GEOLOGY AND GEOMORPHOLOGY

The Nelumwewa thermal spring is situated close to the boundary between two main geological units of the country; the Highland Complex and the Vijayan Complex (Figure 1). The area falls within the dry zone lowlands and has an average

elevation of about 30 m above mean sea level. The landscape of the study area has an undulating topography, probably controlled by the underlying geology and the geological structure (Dahanayake and Jayasena, 1983). Most of the area is covered by a few meters thick mantle of residual weathering products of the bedrock. Mahaweli River flows along the western part of the area and there are no other natural perennial water sources. Some man-made irrigation reservoirs and a network of irrigation canals are also distributed over the area.

The study area consists mainly of microcline granites and leucocratic gneisses (Figure 3). These rocks are surrounded, laterally, by migmatite and hornblende biotite gneisses. The dominant rock type of the area is hornblende biotite gneiss. Locally, very tight, small-scale folding is observed in the gneisses. The gneisses are cut by pegmatitic dikes, quartz veins and veins of granitic composition. These pegmatitic bands are comparatively thinner and are of centimetre scale. Doleritic intrusions of several tens of meters thick and many kilometres long occur as cross-cutting dikes, or as discontinuous layers parallel to local foliation (Figure 3). Some previous workers have also reported those igneous intrusions and tectonic deformations in this area (Dahanayake and Jayasena, 1983; Kröner, 1986; Kehelpannala, 2003). The strike trend of the rocks of the area is NW while dipping towards East and EW. Some rocks show evidence for syn-tectonic or post-tectonic deformations. The noteworthy feature in the area is that the Dimbulagala mountain which rises more than 250 m above the surrounding flat terrain, about 6 km SW of the thermal spring. During the present study, it was revealed that the mountain is bounded by three faults (Figure 3: fault 1, 2 and 3), and has uplifted along these faults. The rocks in the area also show jointing parallel to the trends of the faults. Fault 1 and 2 are about 1-2 km long NW-SE oriented vertical faults, whereas the fault 3 is a NE-SW running regional fault which has also a lateral shift. The thermal spring is situated on this fault. These types of faults are reported as common brittle

structures present in the Sri Lankan basement (Kehelpannala et al., 2006). The dip slope of the rocks in Dimbulagala mountain is greater than the angle of dip of the rocks in the surrounding flat terrain (Figure 3). The South Eastern side of the mountain shows the maximum uplift along the faults.

Presence of dolerite dikes in the area provide evidence for igneous activity while up thrusting of the Dimbulagala mountain as an isolated block along faults, suggests that an igneous

pluton at depth beneath the Dimbulagala Rock must have forced in to push up.

GEOPHYSICAL OBSERVATIONS

Forty three (43) resistivity soundings were carried out in the area using *Schlumberger* electrode configuration with a maximum (half) electrode separation of 85 m. Apparent resistivity distribution in the sub surface at 6, 27, 58 and 85 m depths at sounding locations were contoured using inverse distance weighted method (Majumdar et al., 2000). For each level,

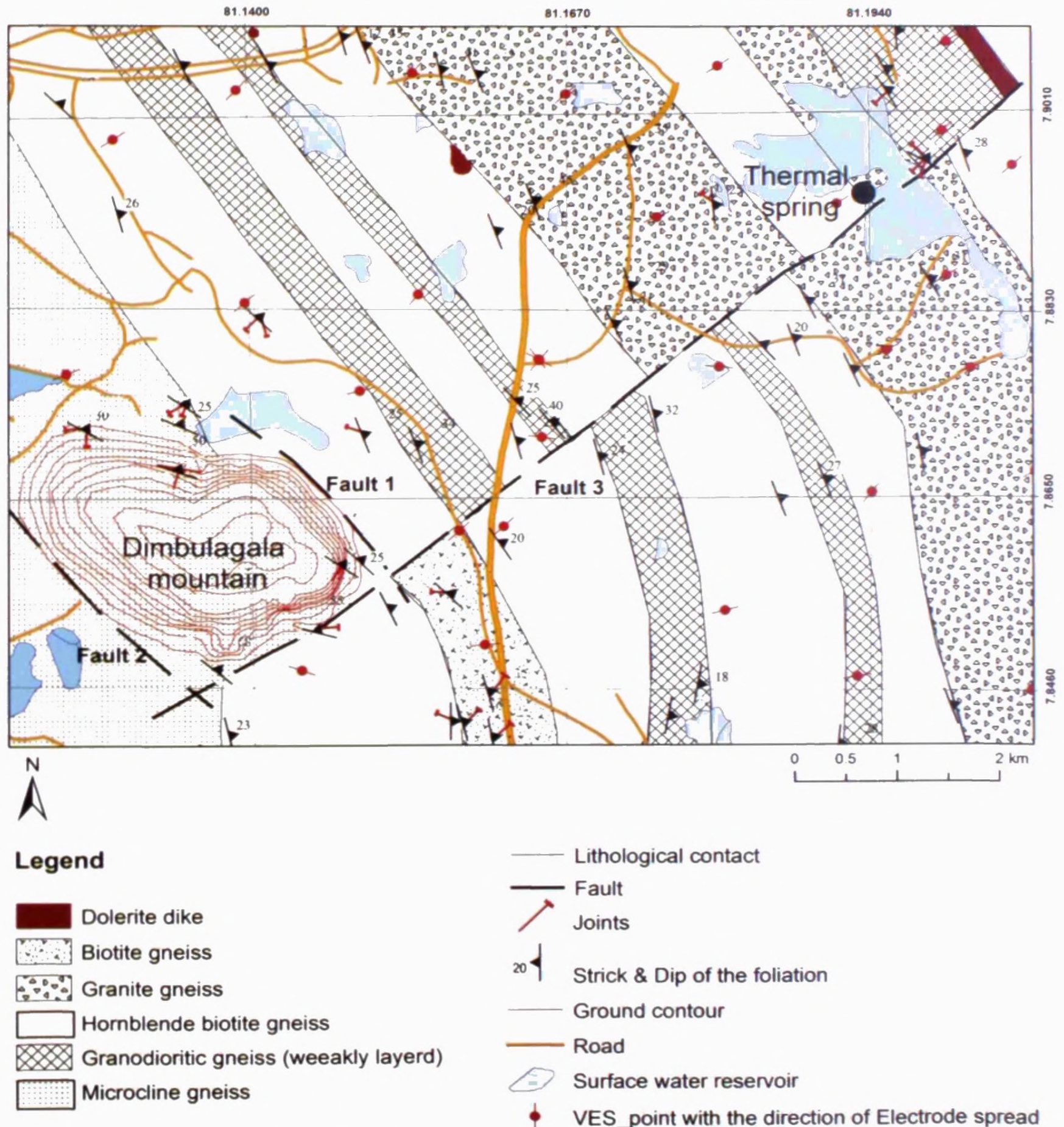


Fig. 3 Geology and geotectonic map of the area around Nelumwewa thermal spring.

a contour map was prepared (Figure 4), depicting the subsurface apparent electrical resistivity variation on a horizontal plane. The selected contour intervals for all the maps are not the same due to large variations of resistivity at the different depth levels. No soundings were carried out in the area on the Dimbulagala mountain.

Figure 4 shows that resistivity contours at all four depth levels are aligned generally in NE-SW direction. A linear low resistivity zone exists in the same direction along the middle part of the area coinciding with the trace of the fault 3 (Figure 3). The resistivity distribution at 6 m depth level shows mostly low values (< 200

Ω m) representing the weathered overburden all over the area (Figure 4a). The Influence of the underlying bedrock is not significant in the resistivity distribution at this level. However, NE-SW oriented lowest resistivity zone along the central part of the area probably indicate a deep extending weathering along the regional fault. At 27 m depth, the apparent resistivity clearly demonstrates a narrow NE-SW running low resistivity zone which also coincides with the trace of the fault (Figure 4b). Comparatively higher resistivity values at this depth level on either side of the low resistivity zone, indicates the presence of solid bedrock either side of the fault.

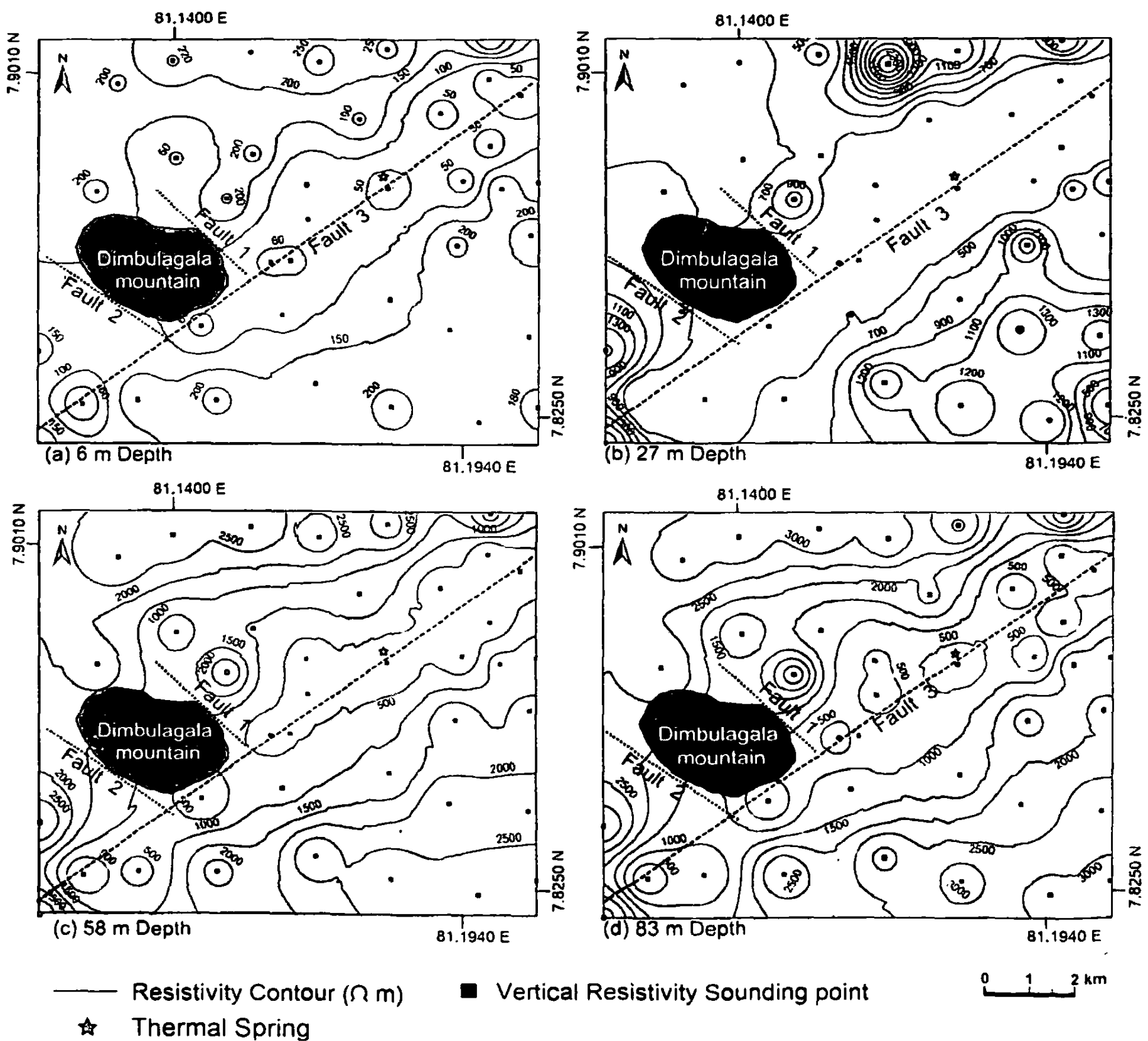


Fig.4 Spatial variation of apparent resistivity at different depths showing low (light) and high (shaded) resistivity zones.

At the 58m depth level, the low resistivity zone can be identified in the same direction as the fault similar to 27 m depth level. Widespread high resistivity values show the increasing effect of fresh and high resistive country rock (Figure 4c). Gradual narrowing down of low resistivity zone with depth indicates that either the fault zone is also progressively narrows forwards or reduction of degree of weathering of the wall rock with depth. The low resistivity zones at 83 m depth level are concentrated into few spots that are distributed in the direction of NE-SW (Figure 4d). These low resistivity spots probably represent separate flow tubes of ascending thermal water rising from below. Effect of weathering along the fault as a linear continuous zone is not significant at this depth. No observations were made below 83 m depth during the present study.

Resistivity sounding (Figure 5) indicates presence of three distinct subsurface layers in the area.

(a) The upper (completely) weathered

overburden layer with formation resistivity of less than 150 Ω m

(b) The middle slightly to moderately weathered rock layer with formation resistivity between 150 and 500 Ω m and

(c) Lower country rock layer with formation resistivity greater than 500 Ω

The resistivity soundings along the trace of the fault indicate low resistivity (<150 Ω m) to great depths and hence high weathering conditions (Figure 5). At the same time, presence of solid bedrock at shallow depths is indicated by the soundings when moving away from the fault zone.

THE GEOLOGICAL MODEL

The Nelumwewa thermal spring is situated close to a major lithotectonic boundary of the country (Figure 1). Dissanayake and Munasinghe (1982) have proposed this boundary as a collision zone between two mini plates, where

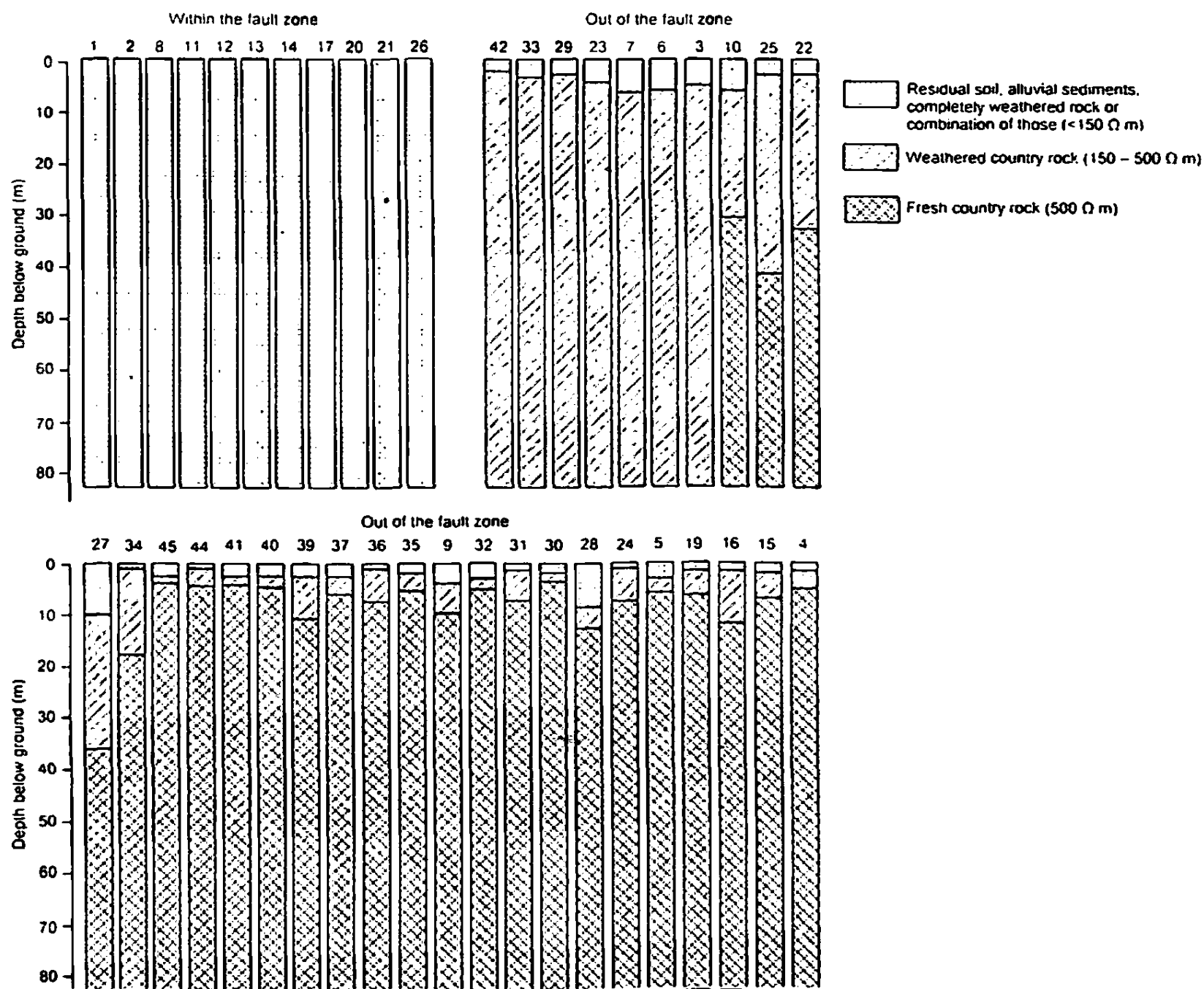


Fig. 5 Subsurface formation resistivity at sounding locations (Soundings out of the fault zone are arranged in the order of increasing distance from the fault plane).

igneous intrusions have also taken place. Several workers have proposed that this region also as a thrust zone contact (Vitanage, 1985; Kröner, 1986; Milisenda et al., 1988; Kleinschrod et al., 1991; Buchel, 1994; Kriegsman, 1993; 1995). Dolerite dikes present in the area are young and considered as intruded around 140-170 Ma ago (Yoshida et al., 1988; Takigami et al., 1999).

The present study has revealed that the Dimbulagala Mountain is an uplifted block of rock bounded by three fault planes. The vertical uplift is highest along the south-eastern boundary which also coincides with a regional (NE-SW oriented) fault on which the thermal spring is situated (Figure 3). The force necessary to push up the block of rock could have resulted from a large sub-surface doleritic intrusion rising beneath the mountain. The dolerite dikes present in the area could be the surface extensions of this pluton (Figure 6). If surrounding country rocks provide adequate thermal insulation, the solid pluton can still be sufficiently hot while connected with the deep extending regional fault which is generally good groundwater pathways. Thus, a deep seated dolerite pluton beneath the Dimbulagala mountain can be suggested as the Hot Dry Rock

(heat source) which transfers heat to deep infiltrated/percolated groundwater through the regional fault structure that also provides a pathway for ascending thermal water to emerge at the surface as a thermal spring (Figure 6).

CONCLUSIONS

Based on the findings of the present study, it is proposed that the Nelumwewa thermal spring, Sri Lanka, is a result of deep percolation of groundwater through a regional fault zones, heated up by Hot Dry Rock beneath the Dimbulaga Mountain and then returning to the surface along a NE-SW trending regional vertical fault plane in the area. Thus, deep groundwater percolation through a fault zone and associated Hot Dry Rock is proposed as the hydrogeological model for the Nelumwewa thermal spring in the North Central Province, Sri Lanka.

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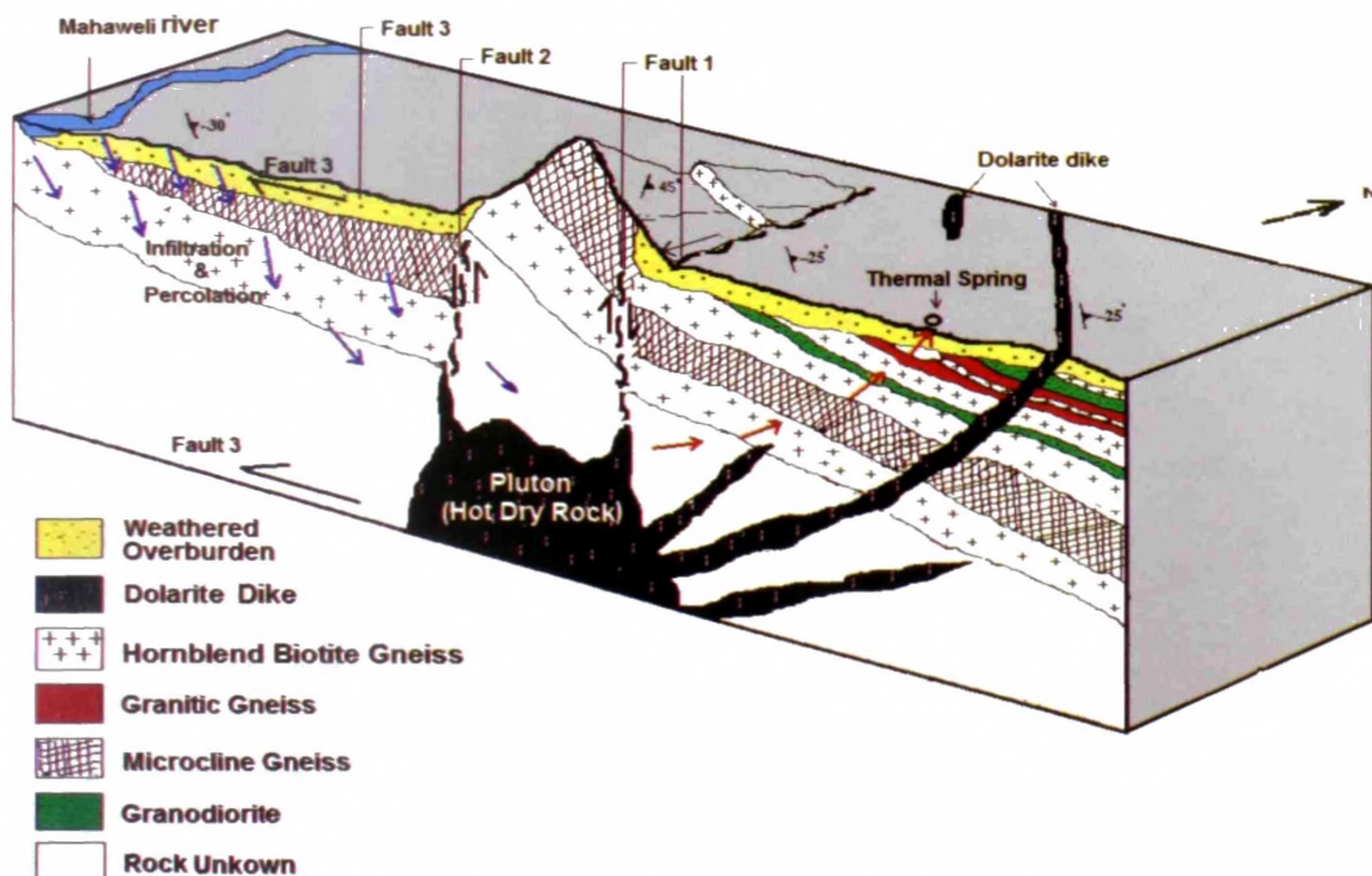


Fig. 6 Geological model of the subsurface in the Nelumwewa thermal spring area.

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