GEOPHYSICAL SIGNATURES OF THE PHOSPHATE OCCURRENCE AT KAWISIGAMUWA, NORTH WESTERN SRI LANKA

S.A. SAMARANAYAKE [1], S.N. DE SILVA[2], W.K.D.G.D.R. CHARLES[1], T.B. NIMALSIRI[1], N.D. SUBASINGHE[1*]

National Institute of Fundamental Studies, Hanthana road, Kandy, Sri Lanka.[1]

Geological Survey and Mines Bureau, Pitakotte, Sri Lanka[2].

[*]*Corresponding Author email: deepal@ifs.ac.lk*

(Received 06th December, 2016; accepted 10th August, 2017)

ABSTRACT

The occurrence of phoscorite bodies in Sri Lanka provides important information on the post metamorphic structures and on the scarce magmatic intrusions of the country. Although much smaller compared to the carbonatite-based phosphate deposit at Eppawala, Kawisigamuwa phosphate deposit has significant importance. Present study focuses on the Kawisigamuwa phosphate body to interpret the mode of occurrences of them using geophysical techniques. The earth resistivity meter and magnetometer were used in acquiring geophysical data in an area of 2 km^2 encompassing the surface manifestations of the body. The magnetic signal depicted two broad magnetized bodies lying normal to the existing antiform and along the EW direction. The antiform trending along NS direction is proposed to have a plunge to create excess stress along EW direction. 2D resistivity profiles show extensive low resistive zones identified here as phoscorite intrusion and clay formations due to the intense weathering.

Keywords: *Phospate deposit, phoscorite, Sri Lanka, Magnetic Survey, Resistivity Survey*

INTRODUCTION

In Sri Lanka, there are few occurrences of phosphate rich mineral deposits, among which the largest and the well-known one is located at Eppawala, in the Anuradhapura District. The next noticeable occurrence is at Kawisigamuwa, near Ridigama, in the Kurunegala District (Fig.1) (Subasinghe, 1990). A significant number of studies on geological, geophysical and geochemical aspects as well as the economic and agricultural uses have been conducted on the Eppawala phosphate deposit, which is currently mined for rock phosphate (Dahanayake and Subasinghe, 1989 a,b, Dahanayake and Subasinghe, 1990, Manthilake *et al.* 2008, Pitawala and Lottermoser, 2012, Pitawala *et al.* 2003, Tazaki *et al.* 1987, Weerakoon *et al.* 2001). Subasinghe, 1990, Hewawasam and Dahanayake, 1995). Hewawasam, (2013) studied geological and mineralogical aspects of Kawisigamuwa

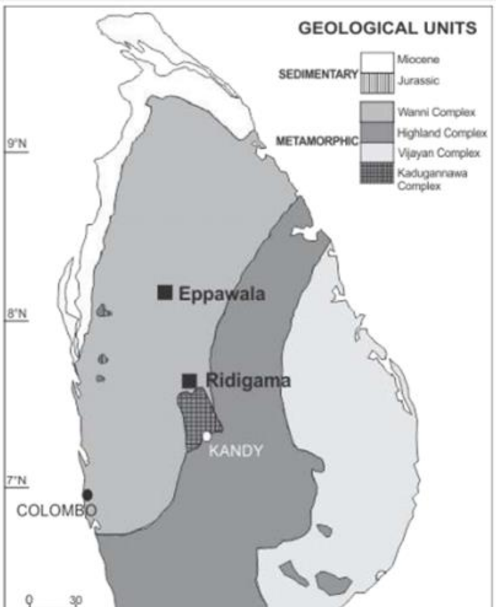

Fig. 1 *Geological map of Sri Lanka and the locations of Eppawala and Ridigama (Kawisigamuwa) phosphate deposits. (Hewawasam, 2013).*

phosphate deposit, although no systematic studies were found on its economic viability.
Kawisigamuwa deposit contains two types of residual phosphate occurrences: (a) The primary apatite crystals and (b) Secondary phosphate minerals formed due to weathering associated with aluminium, ferruginous and siliceous fractions. This is better described as *Phoscorite*.

The objective of this study is to understand the special distribution of phoscorite deposits in Kawisigamuwa area using geophysical techniques, principally, magnetic and electrical resistivity methods.

GEOLOGICAL SETTING OF THE STUDY AREA

Sri Lanka consisits mainly of Precambrian metamorphic rocks, except for the Miocene limestone belt in the Northwestern coast. In addition, there are few sedimentary deposits and igneous intrusions. Crystalline region is widely devided as Wanni Complex, Highland Complex Kadugannawa comples and Viayan Complex, as shown in Fig. 1 (Cooray, 1994).

Study area belongs to the transition zone between Highland and Wanni Complexes (Fig. 1) . To the East of the study area, a hillock composed of hornblende biotite gneiss is located. Major rock type in the area is granitic gneiss. Magnetite fragments can abundantly be found in the north end of the study site with less or no apatite, whereas towards the south, apatite crystals are coexisting with magnetite, which is in minor amounts. An antiform with axis trending nearly North-South direction is mapped in this area (Hewawasam and Dahanayake, 1995) and its southern end traces beyond the apatite rich area. According to the geological interpretation, the northern end of the antiform extends up to the river, just 500 m north from the area in question.

The phosphate deposit in Kawisigamuwa area extends in the N-S direction with sporadic exposures (Fig. 2). It is composed of both primary apatite crystals and secondary minerals including phosphate enrichments. Large primary apatite crystals are embedded in secondary phosphate enrichment, which is rich in aluminous-ferruginous, siliceous material and smaller primary apatite crystals. Among the several intrusions into the Precambrian granites and gneisses, the largest intrusion is observed along the fractured NS axis of a minor antiform. Along this axis, mineralization of apatite, hematite, magnetite and zircon is a common feature (Hewawasam, 2013).

METHODS OF STUDY

Prior to the geophysical survey, initial geological mapping was carried out to assess the study area and accessibility. Fig. 2 shows the general geology of the study area.
Magnetic survey lines in the E-W direction were designed perpendicular to the trend of the apatite rich ridge, which is the general strike direction of the study area. The sampling interval was 1s and the line separation was kept at about 200 m.

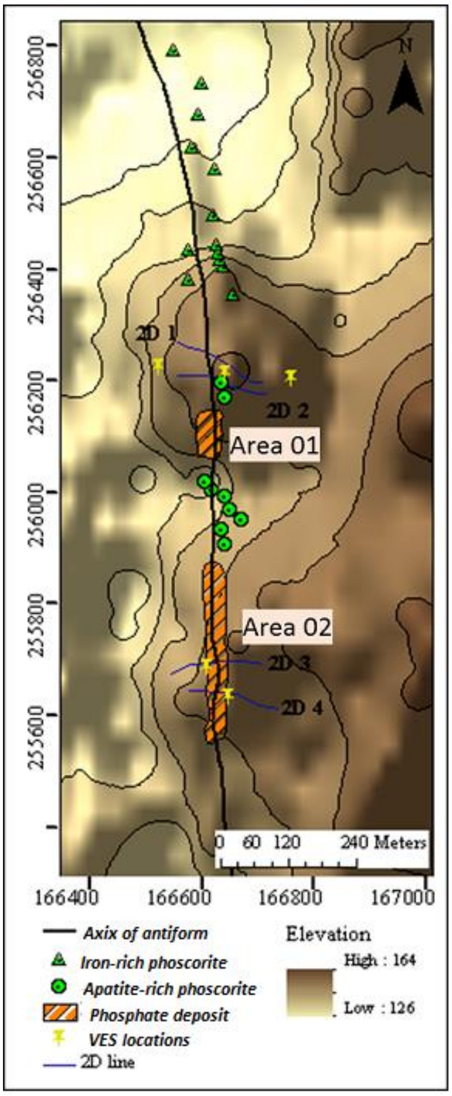

Fig. 2. *Location and morphological map of the study area. Phoscorite bodies were found in Area 1 and Area 2, along the axis of the antiform. The study was focussed on these areas.*

After the base correction, data processing was conducted using the *Oasis Montaj*® (Geosoft Inc., Canada) software.

The vertical electrical soundings (VES) and profile locations were selected based on the outcome of the initial field surveys. 2D resistivity surveys were arranged perpendicular to the ridges at the study location. The system used here comprised of 28 electrodes with maximum electrode separation of 6 m having the total spread of 164 m. This survey was conducted with the maximum spread with nominal depth penetration limits of 30-35m. 1D VES profiles were carried out to validate those data acquired from 2D resistivity method and to allocate fixed parameters for 2D data inversion process. Current electrode separation of 1D Vertical Electrical Sounding was extended to 50-70 m (AB = 2L = 70m) maximum in locations where the ground is relatively high than of the normal terrain level and the depth detection limit down to 15-20m.

One-dimension (1D) raw data were processed and interpreted in RESISTfreeware package setting appropriate resistivity values for different layers with true depth/thickness estimation. The threshold for the Root Mean Squire (RMS) was kept at 5% assuring the data reliability and model fitting. EarthImager-2D software package (Advanced Geosciences Inc., USA) was used for processing 2D raw data. The dynamic range for processing was set as 10 Ωm and 1500 Ωm minima and maxima respectively, to maintain a constant platform enabling to compare and contrast results. In fixing the limits for 2-D data inversion process the results obtained from 1-D interpretation has been considered as the control.

The GSM-19 v7.0 Overhauser high-sensitive magnetometers (GEM Systems, Canada) were used as the base as well as the walk magnetometers. They were integrated with GPS (Global Positioning System) receivers. ABEM Terrameter model 300 SAS (ABEM, Sweden) was used in the field for 1D data acquisition process. The dynamic range of the instrument is between 100KΩ and 1mΩ, which is quite adequate for the survey. AGI (Advanced Geosciences Inc., USA) Mini-sting system is capable of acquiring resistivity data along 160 m length with 30-35 m depth detection limit. This system is powered by both a built in power source and an external battery. Therefore, AGI mini-sting was used for the 2D data collection.

RESULTS AND DISCUSSION

Fig. 3 shows the total magnetic intensity map of the study area which reveals marked features running parallel to the E-W direction. There are two distinctive formations (enclosed in dashed boxes) that could be identified in here. The most prominent anomalous feature (A) is found at the upper middle area of the diagram. The anomaly here suggests a broad magnetic body with an approximate width of 250m and extending in the E-W direction. Another similar anomaly is seen to the lower middle of the diagram (B) but having a subtle expression.

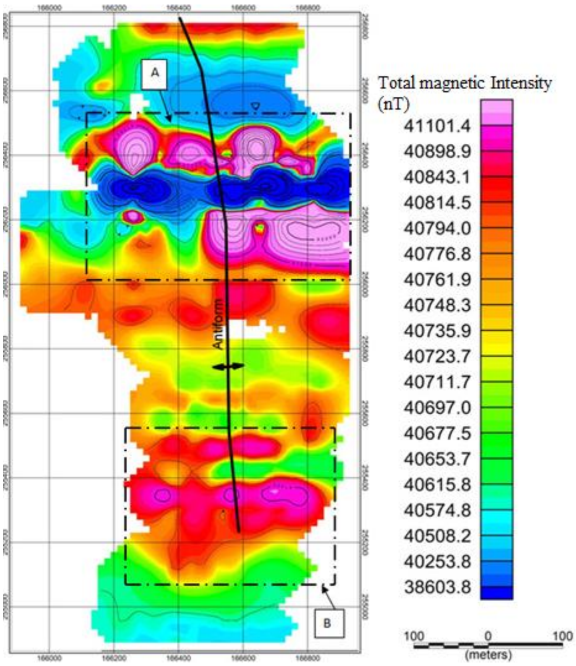

Fig. 1. *Magnetic intensity map of the study area. Dotted black rectangles indicate the anomalous features*

Figure 4 shows the 2D resistivity profiles from area 01 on Fig.1, which is rich in magnetite pebbles. The dark lines dipping towards East represent low resistivity areas probably indicating weak zones and areas rich in iron-minerals. The dark blue pocket towards the east end of the profile (Figure 4a) may be representing an aquifer confined by the upper layers. The red coloured high resistive zone could be related to the weathered magnetite rich rocks. A similar 2D result is seen in Figure 4b which was done in the area 01. Here again the red coloured high resistivity zone infers the bed rock with areas of intense weathering. To the west of the bed rock, another weak zone, which is marked using a dark line, can be seen.

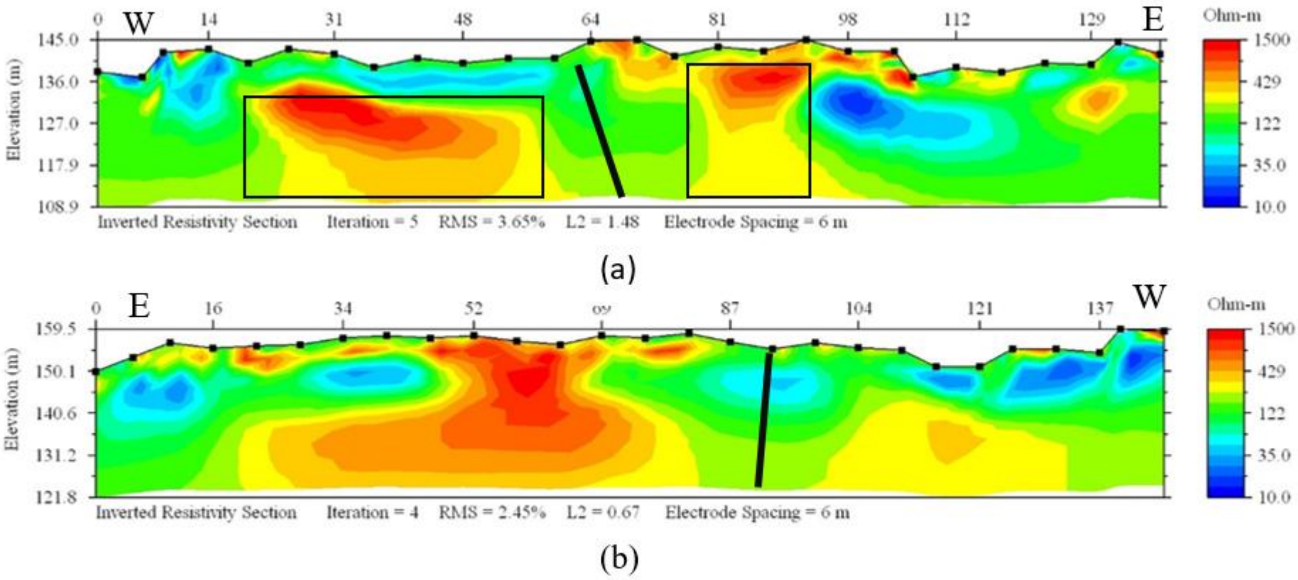

Fig. 4. *Resistivity profiles of area 1. The top figure is profile 2D1 and the one at the bottom is 2D2. The black rectangles show the magnetite containing weathered bed rock. The near vertical dark lines are the weak zones.*

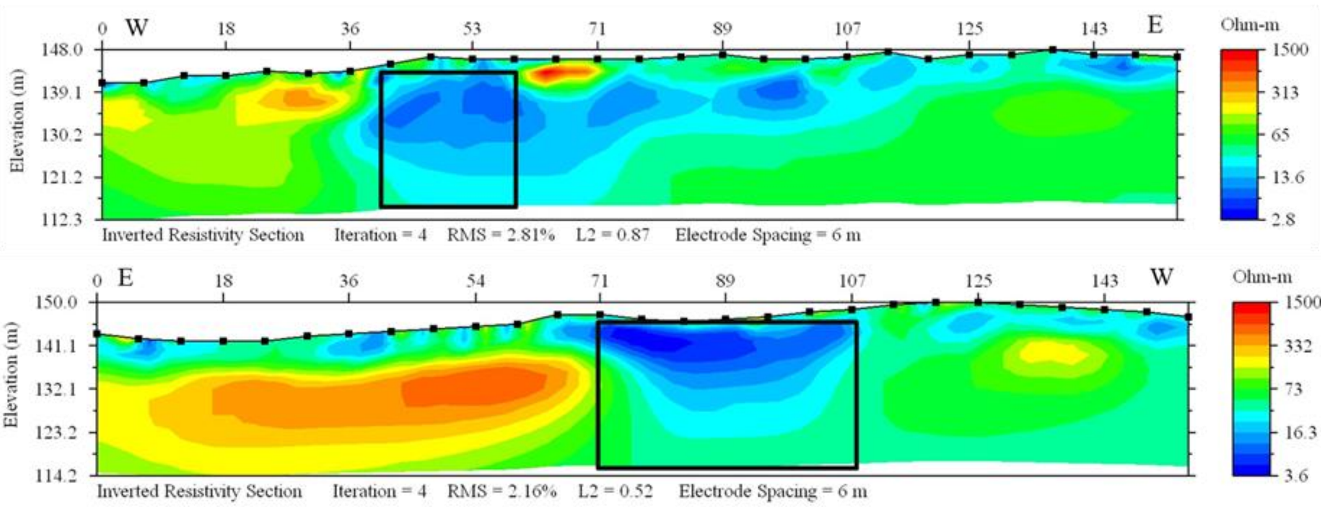

Fig.5*. 2D profiles of area 2. The top figure is 2D3 profile and the bottom one is 2D4. In these diagrams the dark rectangles show very low resistive areas at some locations extending to depths of about 20 m.*

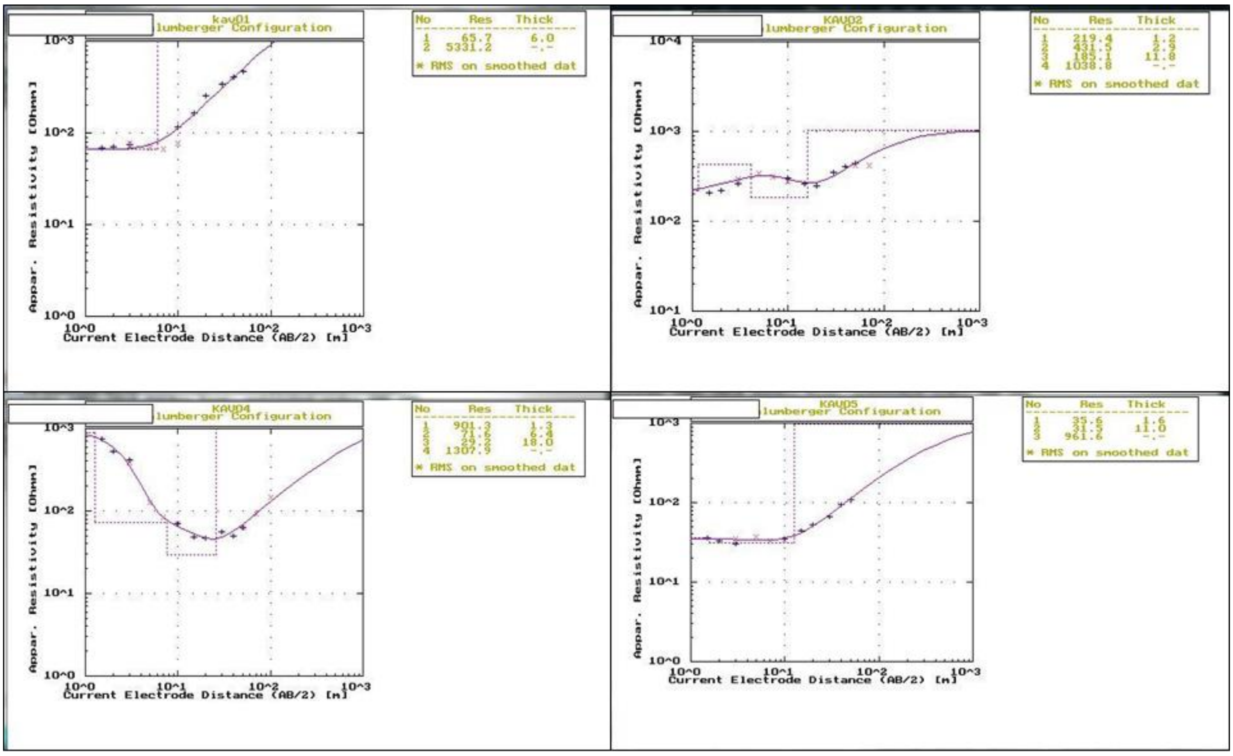

Fig. 6. *Vertical Electrical Sounding (VES) plots for the study site. Top left; VES01 (256205 N, 166759 E), top right; VES 02 (256212 N, 166641 E), lower left; VES03 (256224 N, 166524E), lower right; VES04 (256632 N, 166648 E).*

Fig. 5 shows the 2D resistivity profiles at location 2 where rocks rich in apatite are found. In the 2D3 diagram a connected low resistive zone is found from far East extending to a 2/3 of the profile. This could be a shallow saturation of groundwater. However, the formation marked with a black rectangle where resistivity values drop as low as 2 Ωm may resemble a clay formation. A similar occurrence is recorded in 2D4 (Fig. 5) which was carried out nearly parallel to the profile 2D3 and in area 2.

1D Vertical Electrical Sounding (VES) surveys were carried out in order to validate the 2D resistivity data and are shown in Figure 6. These results confirm the high and low resistive zones recorded in 2D profiles and described above.

The field observations described here and by Hewawasam and Dahanayake (1995) do not support a feature trending in the E-W direction as opposed to what is shown in the magnetic intensity map (Fig. 3). The latter does not

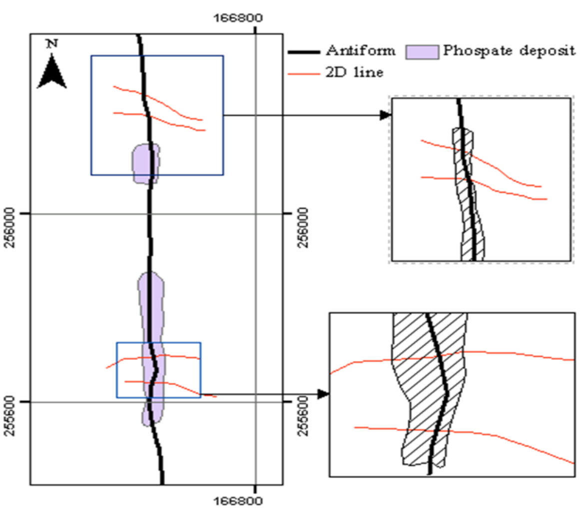

Fig. 07*. Location of phosphate deposit and antiform with weak zones identified in resistivity profiling. The first and the last electrode of the 2D lines have been extended (dashed lines) to demarcate the weak zone along the axis of the antiform.*

comply even with the recorded joint patterns and of a fracture system. Therefore, intensity pattern clearly suggests the existence of at least two magnetized bodies in locations identified in the map (Fig. 7). The northernmost anomaly should be dealt with in detail to distinguish it as a magnetized body or not. One plausible explanation is that the antiform to have a north and south plunging structure to provide room for magmatic intrusion and mineralizations.

The weak zones identified in 2D diagrams with relatively low resistive areas are associated with The weak zones identified in 2D diagrams with relatively low resistive areas are associated the axial plane of the antiform (Figure 7). Stresses developed after the ductile deformations might have created weak areas on the axial planes. The intense weathering conditions in Kawisigamuwa has effected significant clay profiles (Hewawasam, 2013) which are identified as thick zones of very low resistivities (Fig. 5). In addition, during the emplacement of phoscorite bodies, thermal fluids may have aided alteration of country rocks to form clayey minerals.

CONCLUSIONS

The phosphate deposits at Kawisigamuwa generally display a N-S trend in surface observations. The geological and earth-resistivity information suggests that the axial plane of the antiform with axis in N-S direction could be a possible facilitator for the phosphate occurrence. However, the magnetic intensity maps suggests that subsurface magnetized bodies may be extending in the E-W direction and further to each sides of the antiform, at depth.

ACKNOWLEDGEMENTS

Authors wish to thank the National Institute of Fundamental Studies and the Geological Survey and Mines Bureau for the equipment, transport and laboratory facilities. Part of this work was carried out to make a comparison with the magnetic signatures of the Eppawala Phosphate deposit. Grant RG/2012/NRB/03 from National Science Foundation, Sri Lanka is acknowledged for partial support.

REFERENCES

Bibby, H., Bennie, S., Stagpoole, V. and Caldwell, T. (1994). Resistivity structure of the Waimangu, Waiotapu, Waikite and Reporoa geothermal areas, New Zealand. *Geothermics,* **23,** 445-471.

Cooray, P.G. (1994). The precambrian of Sri Lanka: a historical review, Precambrian Research, **66(**1), 3-18.

Dahanayake, K. and Subasinghe, S.M.N.D. (1989a). A modern terrestrial phosphorite-an example from Sri Lanka. *Sedimentary geology,* **61,** 311-316.

Dahanayake, K. and Subasinghe, S.M.N.D. (1989b). Secondary phosphate mineralization in a karstic environment in central Sri Lanka. *Mineralium Deposita,* **24,** 169-175.

Dahanayake, K. and Subasinghe, S.M.N.D. (1990). Variable Mineralogy and solubility of a terrestrial phosphorite resulting from differential weathering phenomena—an example from Sri Lanka. *Chemical Geology,* **84,** 42-44.

Hewawasam, T. and Dahanayake, K. (1995). Some geological and geochemical attributes of the phosphate deposit at Ridigama, NW Sri Lanka.

Hewawasam, T. (2013). Tropical weathering of apatite-Bearing Rocks of Sri Lanka: major element behaviour and mineralogical changes. *Journal of the Geological Society of Sri Lanka,* **15,** 31-46.

Manthilake, M., Sawada, Y. and Sakai, S. (2008). Genesis and evolution of Eppawala carbonatites, Sri Lanka. *Journal of Asian Earth Sciences,* **32,** 66-75.

Meidav, T. and Furgerson, R. (1972). Resistivity studies of the Imperial Valley geothermal area, California. *Geothermics,* **1,** 47-62.

Pitawala, A. and Lottermoser, B. G. (2012). Petrogenesis of the Eppawala carbonatites, Sri Lanka: A cathodoluminescence and electron microprobe study. *Mineralogy and petrology,* **105,** 57-70.

Pitawala, A., Schidlowski, M., Dahanayake, K. and Hofmeister, W. (2003). Geochemical and petrological characteristics of Eppawala phosphate deposit, Sri Lanka. *Mineralium deposita,* **38,** 505-515.

Subasinghe, S.M.N.D. (1990) Mineralogical, Sedimentological and Solubility Studies of the Phosphate Deposits in Sri Lanka with Special Reference to the Eppawala Apatite Marble Formation. *M.Phil Thesis* (Unpblsh.) University of Peradeniya.

Tazaki, K., Fyfe, W. and Dissanayake, C. (1987). Weathering of apatite under extreme conditions of leaching. *Chemical geology,* **60,** 151-162.

Telford, W. M., Geldart, L. P., Sheriff, R. E. and Sheriff, R. (1990). *Applied geophysics,* Cambridge, Cambridge Univ Press.

Thanassoulas, C., Tselentis, G. and Traganos, G. (1987). A preliminary resistivity investigation (VES) of the Langada hot springs area in northern Greece. *Geothermics,* **16,** 227-238.

Weerakoon, M., Miyazaki, T., Shuto, K. and Kagami, H. (2001). Rb-Sr and Sm-Nd geochronology of the Eppawala metamorphic rocks and carbonatite, Wanni complex, Sri Lanka. *Gondwana Research,* **4,** 409-420.