2(1)

Ceylon Journal of Science: Physical Sciences, 2(1), 1-9 (1995)

SOME GEOLOGICAL AND GEOCHEMICAL ATTRIBUTES OF THE PHOSPHATE DEPOSIT AT RIDIGAMA, N-W SRI LANKA

A.L.T. HEWAWASAM
Institute of Fundamental Studies, Hantana Road, Kandy, Sri Lanka.
and
K. DAHANAYAKE
Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka.

ABSTRACT

Ridigama phosphate deposit occurs in the form of apatite rich veins that have intruded into the Precambrian granitic gneisses. Weathering processes active in the tropical Sri Lankan environment have given rise to a residual deposit. This deposit which is a weathering profile contains large primary apatite crystals in a fine matrix composed of ferruginous, siliceous, aluminous secondary phosphate minerals. Chemical studies have revealed that the primary apatite crystals of Ridigama have total P_2O_5 contents varying from 39% to 41% whereas it is less than 35% in the matrix. The 2% citric acid and water solubilities of primary apatite crystals are around 7% P_2O_5 and 0.05% P_2O_5 respectively; for the matrix the values were approximately 4% P_2O_5 and 0.04% P_2O_5. Neutral ammonium citrate (NAC) solubility exceeds 2.5% P_2O_5 for crystals and less than 2% P_2O_5 for the matrix. The primary apatite crystals of this deposit showed higher solubility than those of Eppawala. However, the matrix at Eppawala was more soluble than that of Ridigama. The major components in the primary crystals are hydroxyl chlorapatite and carbonate fluor-apatite. Both these apatite types are associated with crandallite, quartz, feldspar, hematite and magnetite in the fine matrix.

1. INTRODUCTION

Phosphate rock is a term used to describe mineral assemblages with high concentrations of phosphate minerals such as fluorapatite, chloroapatite, hydroxylapatite, carbonate fluorapatite, etc. The world production of phosphate rock is dominantly consumed as a fertilizer and the rest is for animal feeds, detergents, chemicals, etc. Sedimentary phosphate deposits produce about 80% of the total world production of phosphate whereas igneous and metamorphic deposits supply 20%. Sedimentary deposits show a wide range of chemical composition and significant variation in physical form. They contain a variety of carbonate fluorapatite minerals that are typically called francolite. Usually, igneous phosphate deposits are low in grade but can be upgraded to high concentrates. They are characterised by fluorapatite and hydroxylapatite varieties and or intermediate compositions[1].

Sri Lanka has a large and important phosphate deposit which is presently being mined as a fertilizer with an average P_2O_5 content of 35% (by weight). This deposit was discovered at Eppawala (Anuradapura district) in 1971 by the Geological Survey Department and it extends to about 10km^2.

a fertilizer with an average P_2O_5 content of 35% (by weight). This deposit was discovered at Eppawala (Anuradapura district) in 1971 by the Geological Survey Department and it extends to about $10km^2$. Jayawardana (1976) attributed an igneous carbonatite origin to this phosphate deposit whilst conceding that metasedimentary characteristics are also present in the ore body[2,3]. Appleton[4] (1994) also considered it to be of igneous origin. It is a leached apatite-bearing phoscrete type phosphorite ore which has developed on an apatite-bearing carbonate rock of an uncertain origin and it forms a series of low hills trending in N-S directions across the Eppawala-Talawa road[5,6].

If solubility of apatite crystals can be used to assess the origin of phosphate deposits, Neutral Ammonium Citrate (NAC) solubility of typical African igneous phosphate deposits have values of less than 2% P_2O_5. However apatite crystals of both Eppawala and Ridigama gave superior values ranging from 2.2% to 2.7% P_2O_5. This finding suggests an origin intermediate between igneous and sedimentary phosphate deposits for both Eppawala and Ridigama Ores[7]. The phosphatic weathering profile at Eppawala consists of large primary apatite crystals (i) in the lowermost parts occurring in situ in the parent carbonate rock (ii) on the downward slope of the hillock in loose residual siliceous-aluminous and fine primary-apatite rich matrix and (iii) in the core of the hillocks ingrained in hard siliceous ferruginous matrix[3]. The area is characterised by several lithological units such as granite, granite gneiss, charnockite, hornblende-biotite gneiss, quartzite, amphibolite and apatite-bearing crystalline limestone[2].

The Ridigama phosphate deposit occurs in the village of Kawisigamuwa on the Mallawapitiya-Ridigama road, near Kawisigamuwa, South-East of the town of Kurunegala 105km away from the Sri Lankan capital city of Colombo. The deposit is in the form of a turtle back ridge with local relief of 2 to 6m and surrounded by paddy-fields. This deposit trends in a NS direction and contains primary and secondary phosphate materials. Ridigama phosphate deposit consists of large primary apatite crystals in the matrix which contains secondary phosphate minerals, aluminous-ferruginous and siliceous materials and finer primary apatite crystals[8].

2. GENERAL GEOLOGY

Geologically, Sri-Lanka consists dominantly of Precambrian crystalline metamorphic rocks and the rest belongs to Mesozoic, Tertiary and Quaternary. The crystalline metamorphic terrain can be subdivided into three main lithological units (i) the Highland Series (ii) the Southwestern Group and (iii) the Vijayan Complex[9] (Figure 1). The Highland Series is composed of granulite facies interbanded metamorphosed sediments such as quartzite, marble, calc-gneiss and charnokitic gneiss. The Vijayan Complex is further subdivided into Eastern Vijayan and Western Vijayan Complexes[10].

Amphibolite facies rocks such as granites, hornblende biotite gneisses, migmatites and calc-silicate gneisses are dominant in the Western Vijayan Complex. Some pegmatitic dikes, veins, small granitic bodies, dolerite dikes have been intruded into the granitic terrain during different episodes[9]. The Ridigama deposit is located in the transitional zone between the Highland Series and the Western Vijayan Complex whereas Eppawala deposit falls in the marginal zone of the Western Vijayan complex.

Kroner et al. (1991) and Cooray (1994) have now revised the existing classification and have introduced four lithotectonic units[11,12]: (i) The Highland Complex (HC), (ii) The Vijayan Complex (VC), (iii) The Wanni Complex (WC) and (iv) The Kadugannawa Complex (KC).

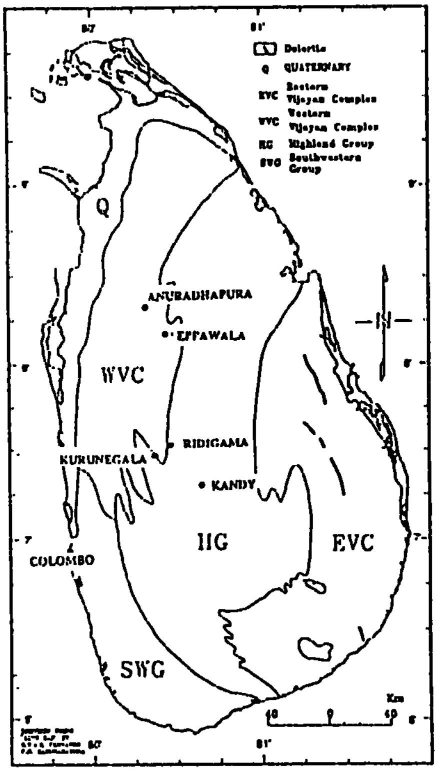


Fig. 1 Generalized geological map of Sri Lanka (after Cooray, 1984 and Milisenda et al., 1988).

3. MATERIALS AND METHODS

The aerial photographs of Ridigama and Kawisigamuwa areas (Scale: 1:40,000) were studied and interpreted. Detailed geological mapping of the deposit was carried out on the scale of 1:10,000 with emphasis on economic mineral occurrences. The variation in foliation/bedding and dip, minor structures such as faults and folds and the distribution of minor vein patterns were analyzed.

Several samples of primary apatite crystals and matrix from different locations of the deposit were selected for chemical and mineralogical analysis. During the sampling the emphasis was on size, weathering condition and abundance of primary apatite crystals. The mineralogical composition of primary apatite and matrix were determined by X-ray powder diffraction method(XRD), using Shimadzu XD-7A instrument under ordinary operating conditions[13]. The secondary phosphate minerals in the clay-size fraction of selected matrix were identified by X-ray diffractometry. Before the XRD analyses, pre-treatments were carried out to remove organic matter and iron oxides in the matrix. Na-hexametaphosphate was added as a dispersing agent and pipette analyses were done to separate the clay-size fraction. Then, the glass slides of oriented clay mineral aggregates were prepared using filter transfer method for XRD studies[14].

Powdered fractions of primary crystals and matrix (<0.063 mm) were used for chemical analyses. The total P, 2% citric acid and water solubilities of phosphate samples were measured by colorimetric methods (Table 1). The powdered samples of phosphate were digested using HNO_3, $HClO_4$ and HF to determine the major cations. After the sample was completely dissolved, the solution was filtered into a volumetric flask and volumarized upto 100ml[15]. Some cations of the samples were detected by atomic absorption spectrophotometer and inductively coupled plasma spectrophotometer (Table 2).

4. GEOLOGY AND STRUCTURE OF THE PHOSPHATE DEPOSIT

The general strike direction of the Ridigama area is NS to NW-SE and the deposit extends along NS. Two sets of regional joint patterns were recognised trending N45 W and N45 E. According to surface observations, the ore extends upto 500m in length and the width is about 50m. The area is characterised by NS trending amphibolite facies rocks such as hornblende biotite

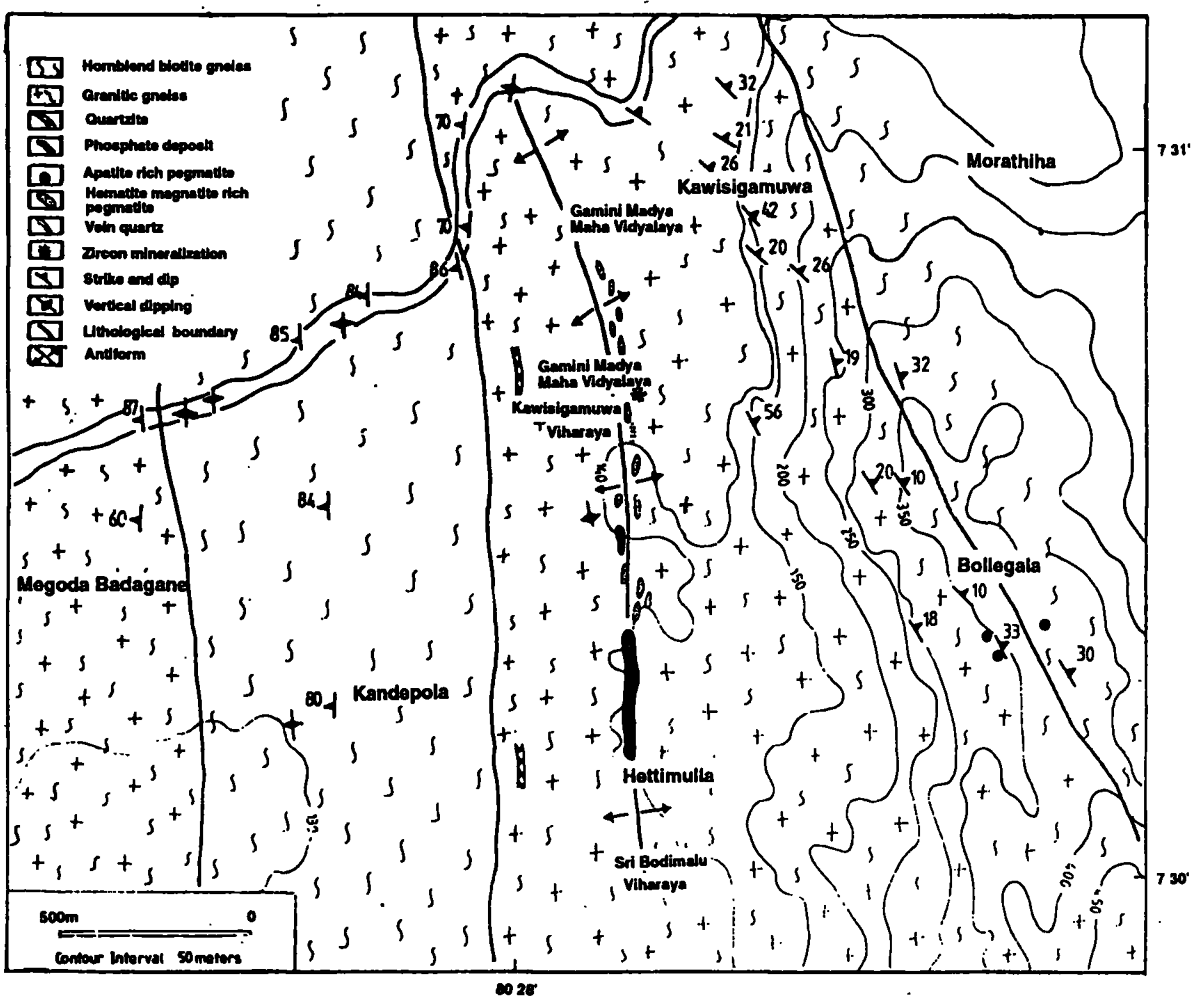


Fig.2 Map showing general geology around the Ridigama Phosphate Deposit.

gneisses and granitic gneisses. Some discontinuous bands of quartzite, outcrops of vein quartz, pegmatitic feldspar, biotite, hematite, magnetite, residual apatite crystals and detrital zircon were also recognised in the granitic gneiss (Figure 2). Hornblende biotite gneisses have highly foliated, biotite grains. In the granitic gneiss, significant amounts of mafic minerals are present. It is rather difficult to trace the sharp contact of granitic gneiss and hornblende biotite gneiss. Some mobilized structures suggestive of partial melting were also observed in both gneisses. Several acidic and porphyritic dikes are common in the study area. In the vicinity of the phosphate deposit a number of cross cutting dikes with core width varying from 10 to 30 cms have intruded into the migmatitic granitic gneiss. They show two dominant trends N20°W and N50°E and contain coarse grains of K-feldspar, hornblende and quartz. Yellowish green large apatite crystals occur in one of the N20°W trending veins and it is about 30cm thick and shows iron oxide bearing minerals such as hematite and magnetite. This observation suggests an igneous origin for the apatite crystals.

Table 1. Comparison of mineralogy, total P_2O_5 and solubility of two phosphate deposits

	Mineralogy	Total P_2O_5%	water solubility (P_2O_5%)	2% citric acid solubility (P_2O_5%)
Eppawala	Primary Apatite: hydroxyl-chlor-fluorapatite (major) fluorapatite (francolite) (minor)	39.0 - 40.6	0.02 - 0.06	5.43 - 6.04
	Matrix: carbonate fluorapatite (major) hydroxyl-chlor-fluorapatite (minor) + goethite + rutile and crandallite	28.4 - 35.6	0.02 - 0.07	3.71 - 4.79
Ridigama	Primary Apatite: hydroxyl-chlorapatite (major) carbonate fluorapatite (minor)	39.4 - 41.4	0.03 - 0.06	6.43 - 7.32
	Matrix: carbonate fluorapatite (francolite) (major) hematite and crandallite hydroxyl-chlor-fluorapatite (minor)	16.1 - 33.2	0.02 - 0.06	1.48 - 4.33

The dip of the foliation/bedding planes in the east and north east of the deposit is generally trending east with average values of 30 with variable strike. In the west and north west of the deposit the dip is nearly vertical. These lithological units are folded to form a minor antiform that has a NS axis. Along the structurally weak axis of the antiform, vein type mineralization of apatite, quartz, hematite, magnetite and zircon was noted.

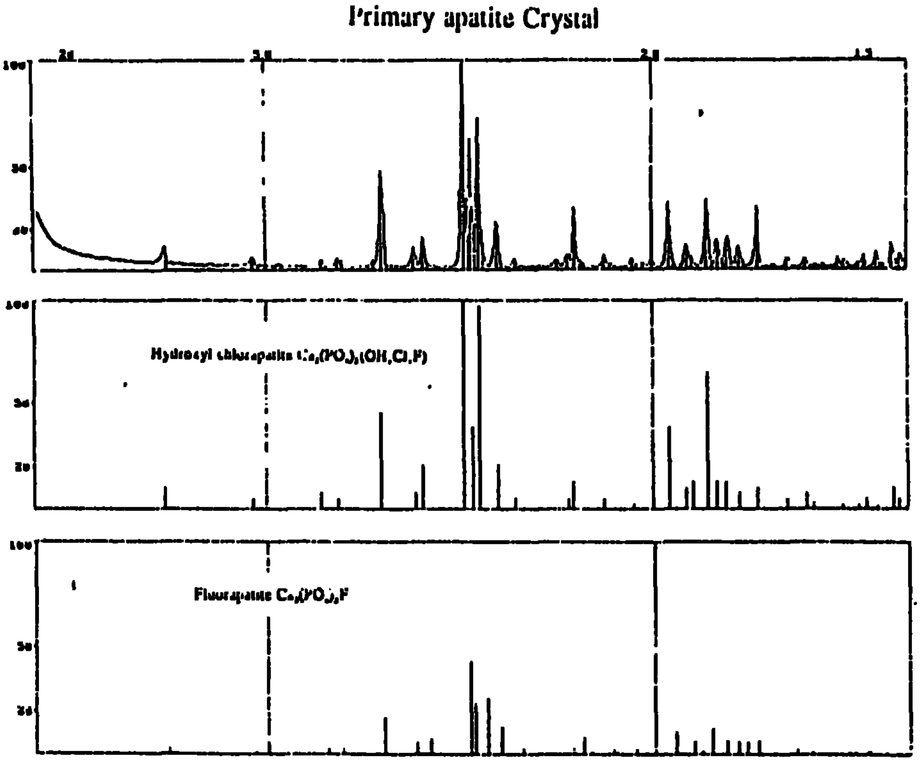
5. MINERALOGY AND GEOCHEMISTRY OF THE DEPOSIT

Yellowish green, subhedral primary apatite crystals are found in a fine grained sedimentary matrix which is composed of secondary phosphate minerals, aluminous, ferruginous and siliceous materials. The size of the primary apatite crystals varies from a few mm to several cms. In the matrix, high amounts of hematite and magnetite are present and secondary phosphate enrichments are noted in and around the primary apatite crystals as well as in the secondary matrix. The colour of the secondary matrix varies from yellow, yellowish brown to dark brown. At points, primary crystals are absent in the matrix.

A random sampling of the deposit shows that it consists of 30% large primary apatite crystals and 60% secondary matrix with fine primary apatite and 10% hematite and magnetite by volume. The XRD studies revealed that hydroxyl chlorapatite and carbonate fluor-apatite(francolite) are the major components in the primary crystals. In the mostly weathered fine matrix, quartz, feldspar, hematite, magnetite and crandallite are present together with the two types of apatite (Figure 3). The presence of hydroxyl chlorapatite and francolite in some crystals suggests weathering within and around the crystals. Optical microscopy reveals such leaching phenomena along the cracks and the margins of the crystals.

Table 2 Chemical Analysis of some representative samples of Primary Apatite and the matrix of Ridigama Phospahte Deposit

	Primary Apatite A1	Primary Apatite A2	Matrix A3	Matrix A4
TP_2O_5 (%)	39.89	40.28	31.13	30.91
CaO (%)	53.57	54.05	39.63	39.24
F (%)	1.46	1.43	1.38	1.42
SiO_2 (%)	0.15	0.08	0.25	0.44
Al_2O_3 (%)	0.28	0.11	2.07	2.20
Fe_2O_3 (%)	0.83	0.70	19.30	19.81
Na_2O (%)	0.08	0.07	0.22	0.22
K_2O (%)	0.02	0.01	0.02	0.02
MgO (%)	0.03	0.04	0.06	0.06
Cl (%)	2.27	2.41	1.30	1.06
TS (%)	0.30	0.28	0.19	0.19
MnO (%)	0.01	0.01	0.03	0.03
TiO_2 (%)	<0.01	<0.01	0.38	0.37
CaO/P_2O_5	1.34	1.34	1.27	1.26
($Al_2O_3+Fe_2O_3$) %	1.1	0.81	21.37	22.01
NAC	2.7	2.6	1.5	1.6


Primary apatite Crystal

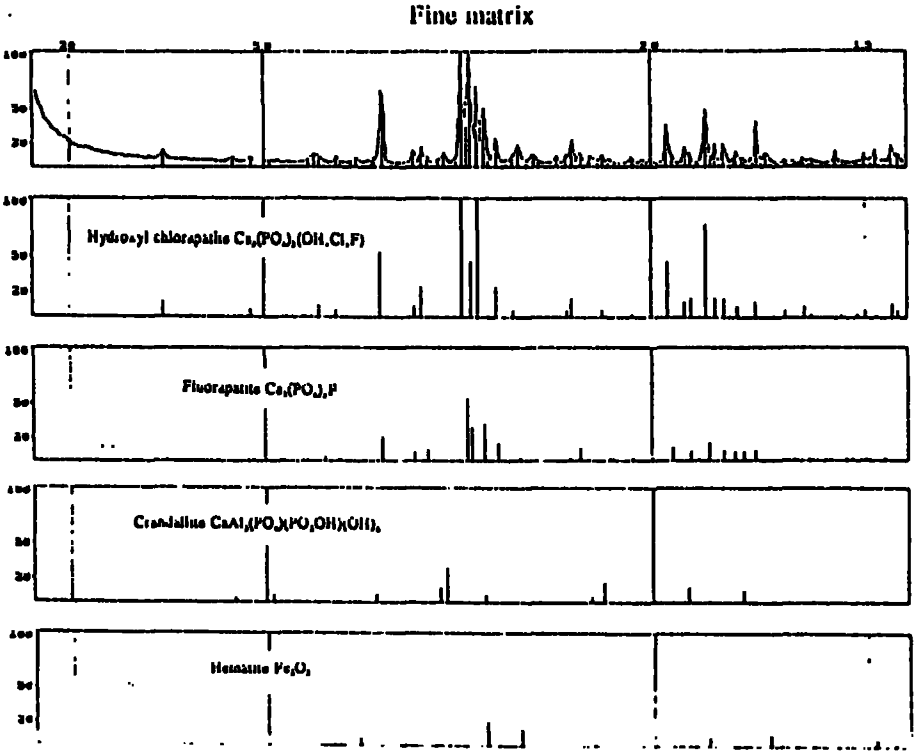

Fine matrix

Fig.3 XRD diagrams for Primary apatite crystals and fine matrix of Ridigama showing their mineralogical compositions.

The total P_2O_5 of primary apatite is around 40% (by weight) whereas it varies from 25-35% (by weight) in the matrix. The 2% citric acid solubility of primary crystals is around 7% P_2O_5 and it is around 4% P_2O_5 for the matrix. The water solubilities of primary crystals and matrix are c.a 0.05 P_2O_5% and 0.04 P_2O_5% respectively (Table 1).

6. DISCUSSION AND CONCLUSIONS

According to field investigations, several veins of igneous origin have intruded into Precambrian granites and gneisses and the major one is found along the structurally fractured NS axis of the minor antiform. In the axis, mineralization of apatite, hematite, magnetite and zircon is noted. In the Eppawala deposit, the apatite rich intrusions were emplaced into a gneissic terrain closely interbanded with carbonate rocks and had mobilized them in the process[16]. As such, apatite is found in a calcite-dolomite bearing carbonate parent rock. Due to weathering phenomena, apatite has separated out as at least two types of residual deposits:(a) large primary apatite crystals (centimetric size) and (b) fine primary apatite and secondary phosphate with aluminium, feruginous and siliceous components[3]. The present study reveals that Ridigama phosphate deposit also contains two types of residual phosphate occurrences: (a) The primary apatite crystals and (b) Secondary phosphate minerals formed due to weathering associated with aluminium, feruginous and siliceous fractions. Due to recent tropical weathering processes active on the apatite-bearing parent rocks; primary apatite crystals have separated out, dissolved and leached. Secondary phosphate in the matrix represents the weathered and recrystallized fractions. However, underlying the residual phosphate, no carbonate parent rock was noted as in Eppawala.

The total P_2O_5 content, the 2% citric acid solubility and neutral ammonium citrate (NAC) solubility of primary crystals from Ridigama are relatively higher than those from Eppawala. However, the Eppawala matrix showed better P_2O_5 and higher solubility (Table 1). The difference in total P and solubility between Ridigama and Eppawala crystals could be attributed to different rates of weathering as well as amount of impurities in the parent rock. The primary crystals from Ridigama also showed very low amounts of ferruginous and aluminous materials with low R_2O_3 values whereas high values of R_2O_3 were recorded for the matrix (Table 2).

ACKNOWLEDGEMENTS

The authors wish to thank Mr. M.W.K. Weerakoon for the assistance rendered during the field work. A generous research grant (No-91-1032-02) from the International Development Research Centre (IDRC), Canada is thankfully acknowledged.

REFERENCES

1. Van Kauwenbergh, *(personal communication) In: International training workshop on Direct application of phosphate rock and appropriate Technology fertilizers in asia: what hinders acceptance and growth, Sri Lanka* (1995).
2. Jayawardana, D.E.de S., *Sri Lankan Geol.survey Dept.,Econ.Bull.* **3,** 9-10 (1976).
3. Dahanayake, K., *Abs. Proceed in The second national symposium on the Eppawala phosphate deposit : Recent advances in knowledge,* 1-7 (1994).
4. Appleton, J.D., *Industrial Minerals in Developing Countries,* eds. S.J. Mathers and A.J.G. Notholt, AGID report series, **18,** 223-256 (1994).

5. Dahanayake, K. and Subasinghe, S.M.N.D., *Sediment. Geol.*, **61**, 311-316 (1989).
6. Dahanayake, K. and Subasinghe, S.M.N.D., *Mineralium Deposita*, **24**, 169-175 (1989).
7. Dahanayake, K., Ratnayake, M.P.K. and Sunil, P.A., *Fertilizer Research* (in press), (1995).
8. Hewawasam, A.L.T., *Abs. Proceed in The second national symposium on the Eppawala phosphate deposit : Recent advances in knowledge*, 12-13 (1994).
9. Cooray P.G., *National Museums of Sri Lanka publication*, second edition, 78-114 (1984).
10. Milisenda, C., Liew, T.C., Hofmann, A.W. and Kroner, A., *J. Geol.*, **96**, 608-615 (1988).
11. Kroner, A., Cooray, P.G. and Vitanage, P.W., *Summary of the Research of the German-Sri Lanka consortium*, Geol.Surv. Dept., Sri Lanka, **5**, 5-21 (1991).
12. Cooray P.G., *Precambrian Res.*, **66**, 3-18 (1994).
13. Whiston Clive, *Analytical chemistry by open learning*, John Wiley & sons (sea) pte Ltd, Singapore, 81-165 (1987).
14. Moore, D.M. and Reynolds, R.C., *Oxford New york*, Oxford university press, 193 (1984).
15. Page A.L. and Miller R.M., *American society of Agronomy*, Soil science society of America, Madison, wisconsin, USA, 7-8 (1982).
16. Dahanayake, K. and Subasinghe, S.M.N.D., *Economic Geology*, **83**, 1468-1474 (1988).