Reserves of Rock Phosphate Deposit at Eppawala, Sri Lanka

Report presented to the

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Executive Summary

The mineral apatite [$Ca_5(PO_4)_3(OH,F,Cl)$] is considered as one of the major sources of phosphate for fertilizer Industry. Eppawala rock phosphate deposit with the association of carbonatite in Sri Lanka was discovered by Geological Survey Department (predecessor to the Geological Survey and Mines Bureau) in 1971 during the detailed geological mapping work and it is considered as the largest and most economical phosphate deposit in Sri Lanka with an aerial extent of approximately 4 km^2.

This survey on reserves estimation of the phosphate deposit was initiated under the directives of the Supreme Court decision (FR petition No. 884/99), which verdicts state parties to refrain from engaging in any contract with other parties until comprehensive exploration is done on the phosphate deposits in Sri Lanka. Hence, the Geology Division of the Geological Survey and Mines Bureau carried out the field surveys in two stages towards the estimation of reserves. As the initial stage, field work commenced at northern part of the Eppawala phosphate deposit (devided as north and south parts by Jayaganga) from mid-2019 to 2021 March. Later, followed up survey was extended to the southern part of the deposit from July-September 2022 completion of the main task.

The Geological Survey Department (Predecessor of GSMB) has undertaken an exhaustive exploration work during 1972-1975, to estimate the tonnage of apatite rich-leached phosphate reserves in the northern part using analytical data of 20 drill holes and geological work. The proven reserve has been estimated as 25 million tonnes by Jayawardena 1976. Using the same data of drill holes with GIS technology including Surfer software, Weerakoon (1998, unpublished thesis) has calculated proven reserves of apatite-rich leached phosphate at northern part of deposit is about 26 million tonnes.

However, the reserve of whole deposit was not calculated so far. Yet again a fresh detailed survey was started to estimate reserves at northern and southern parts of Rock Phosphate at Eppawala. The survey was initiated from Northern part including a level survey, geological mapping and land use pattern. For estimation of reserve at Northern Part, core drilling and geochemical analysis of core samples at 30 drill holes were conducted to understand the nature of the subsurface and to identify the potential mineralization model for the reserve estimation. Eighteen (18) out of thirty (30) drill holes were inclined (65^0-70^0) holes put down

in varying azimuth (180^0-275^0) in order to capture more details on the subsurface geology. Core recovery was very poor at some of the drill holes exhibiting the unconsolidated nature of subsurface. The rock phosphate deposit was clustered into 5 Blocks by using leveling data (morphology), detailed sub-surface geology along with core logging data for the convenience of calculate phosphate rich reserves. To fulfill the task one hundred and seventy two (172) selected samples from all drill holes were subjected to chemical analysis (oxides of Mg, Si, Ca, P, Al, Fe^{3+}, K, Na, Mn, Ti and LOI). The P_2O_5 percentage of each core sample was classified owing to apatite-rich formations as leached apatite zone and apatite rich in-situ and float zone. After calculation of average P_2O_5% content of leached zone and apatite rich in-situ and float zone of each drill hole, it is applied to calculate average P_2O_5% content of these two zones at separate 'Block' s using the data of each drill hole (within each Block) . The Inverse Distance Weighted (IDW) method was used for the calculation. Modeling of leached apatite and apatite rich in-situ and float zones was performed using computer based three Dimensional (3D) modeling software. The estimated reserve down to the level 117 m above MSL, (targeting surface mining) is 12.8 million tonnes (averaging 34% of P_2O_5). But the reserves are about 24 million tonnes (averaging 34% of P_2O_5), if mining is carried out down to the level of 92 m MSL.

A different approach was made to quantify the Sothern Sector of the Eppawala Phosphate deposit; a model has developed based on geophysical responses (resistivity and magnetic measures) in correlation with a very limited number of drill-holes.

Resistivity technique has been considered as the primary method in this model development, as the target mineral is having a resistivity contrast to the background rocks. Further, the weathered products of the phosphate rich components reflect very low resistivity values with the formation of phosphate-leachate beneath the apatite-crystal rich hard cap. Magnetic measurements over the phosphate occurrences produced an anomaly as the magnetite is found as gangue mineral of phosphate/carbonatite formations.

The survey outcome of the Northern Sector of the deposit is based on comprehensive result of surface/ subsurface geological conditions of phosphate rich deposit, was analyzed in model development for the Southern Sector via correlating and calibrating of geophysical response with the ground truths.

A precise height at Southern part of the terrain of phosphate/carbonatite deposit was obtained by RTK to synthesize detailed Digital Terrain Model (DTM). DTM is used to obtain the depth to the basement, thickness of the leached zone and the thickness of the apatite cap. In presence of these different formations, appropriate geophysical responses were developed to screen the same enabling for reserve estimation. It revealed that, a mineable reserve of 7.5 million tonnes of rock phosphate is confined to the Southern Part.

The initial observations reveal that the Southern Sector is dominated by apatite depleted carbonated “host-rock”, whereas the high phosphate concentration is confined to the Northern Sector. Based on the knowledge and pattern estimated the reserves of leached rock phosphate reserve at southern Part. The total mineable reserve of Rock phosphate deposit at Eppawala is 31.5 million tonnes.

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DEM	Digital Elevation Model
DTM	Digital Terrain Model
DGPS	Differential Global Positioning System
DHN	Drill Hole at Northern Part of Phosphate Deposit
GSD	Geological Survey Department
GSMB	Geological Survey and Mines Bureau
IDW	Inverse Distance Weighted
LOI	Loss of Ignition
MSL	Mean Sea Level
RTK	Real Time Kinematics
3D	Three dimension
VES	Vertical Electrical Sounding

1.0 Introduction

1.1 Phosphate deposits of Sri Lanka

The apatite [$Ca_5(PO_4)_3(OH,F,Cl)$] composed rock phosphate is one of the major sources of producing phosphate for fertilizer Industry. Types of fertilizer could be produced are super phosphates, basic slag rock phosphate, and ammonium phosphate (Jayawardena, 1976). Furthermore, apatite is used to produce artificial bones, pharmaceuticals, paint industries, ceramics and lime in addition to producing chemicals.

This valuable rock phosphate deposit found in Sri Lanka is located at Eppawala in the Anuradhapura district. Eppawala Rock Phosphate deposit was discovered by the geologists of the Geological Survey Department (predecessor to the Geological Survey and Mines Bureau) in 1971 during the detailed geological mapping work. The total surface extent of Eppawala deposit is expected about 4 km^2 and the host rock was identified as carbonatitic intrusion (Jayawardena, 1976).

The mining of the deposit as a pilot project was started on a very small scale in 1973. Since then to date, mining of the deposit was continued to produce rock phosphate to use as a fertilizer material. Presently, mining is carried out by Lanka Phosphate Limited under the licenses IML/A/HO/2470 and IML/B/HO/1462 issued by the GSMB. Its present annual production of rock phosphate is around 40 000 tonnes.

Apart from this deposit, there are two (02) other known phosphate occurrences only of academic interest, located at Kawisigamuwa in Kurunegala District and Karawila in Hambantota District.

Since the Eppawala deposit is the only known phosphate deposit of economic significance found in Sri Lanka, it is the responsibility of all concerned parties to develop this deposit and use its material in a sustainable and prudent manner.

Figure 1.1: Locations of phosphate deposit and other occurrences in Sri Lanka

1.2 Background of the present study

Back in the latter part of the 1990's, there was an attempt to produce phosphate fertilizer (Diammonium Phosphate or equivalent) locally, with the assistance of a multi-national fertilizer manufacturer. In this regard Freeport Mc Moran of USA and its affiliate IMCO Agrico and the representatives of the Government finalized and agreed upon a draft Mineral Investment Agreement in 1997. However, seven residents of Eppawela (Bulankulama and 6 others) filed a petition in the Supreme Court in 1999 under SC (FR) Application No. 884 /99, seeking relief from alleged infringement of their fundamental rights under Articles 12(1), 14(1)(g) and 14(1)(h) of the Constitution by reason of the proposed agreement. After hearing this case, the three Judges of the Supreme Court declared a unanimous decision on 02nd June, 2000.

They ordered the respondents to desist from entering into any contract relating to Eppawala phosphate deposit up to the time,

(1) To carry out a comprehensive exploration and study relating to the (a) locations, (b) quantity, moving inferred reserves into the proven category, and (c) quality of apatite and other phosphate minerals in Sri Lanka is made by .the third respondent, the Geological Survey and Mines Bureau, in consultation with The National Academy of Sciences of Sri Lanka and the National Science Foundation, and the results of such exploration and study are published; and

(2) Project proponents must obtain the approval of the Central Environmental Authority according to law, including the decisions of the superior Courts of record of Sri Lanka.

However, there was no proper arrangement to address this issue during the past for a longtime until the commencement of the present investigation in mid-2019. The decision was to explore and estimate all phosphate deposits in Sri Lanka. Since the only economically viable phosphate deposit discovered in our country is at Eppawala, GSMB initiated this investigation to carry out a fresh estimate of the reserves of the northern at the first stage. Later, we have carried out the 2^{nd} stage work at Southern Part of the deposit as follow up of 1^{st} stage.

2.0 The Eppawala Rock Phosphate deposit

2.1 General Geography

The physiography around the area is characterized by a deeply weathered terrain dominated by low turtle back ridges exposing 6 hillocks with heights ranging from 90 to 170 m and elongated in N-S direction. Kiriwelhinna Hill is the highest elevated point of this area. Previously, the phosphate deposit area was bounded to east, south and west by the Yoda Ela; the major irrigation canal flowing around in this area. No perennial rivers have been observed across this area. Jaya Ganga is the presently developed water canal from Yoda Ela, which flows across (figure 2.1) the phosphate deposit changing the previous path of irrigation canal. This irrigation canal has been developed for carrying excess water from Thisa wewa to Kala wewa, surrounding Eppawala area.

Hence the deposit is considered in two parts as Northern and Southern for administrative purpose, as has divided into northern part and southern part by Jaya Ganga. The northern part of the deposit shows a horse-shoe type feature, characteristic in carbonatites found in African countries. In general the area lies in dry-zone of Sri Lanka having an annual rainfall <1500 mm. Eppawala area does not experience a significant rainfall from the two major monsoonal periods and it receives heavy rain falls during October to January.

2.2 Geological Setting

About nine-tenths of the area of Sri Lanka is underlain by metamorphic rocks of Precambrian age. The sedimentary rocks of Miocene age and some small occurrences of Jurassic age are limited to the north-western sector of the Island (Cooray, 1984). Precambrian metamorphic rocks of the Island are composed of four lithological units as the Highland Complex, Vijayan Complex, Wanni Complex and Kadugannawa Complex. The four different units were distinguished on the basis of isotopical, geochronological, geochemical and petrological constraints (e.g. Kröner et al., 1991; Cooray 1994; Milisenda et al., 1994) (Figure 2.2). The area surrounding Eppawala belongs to Wanni Complex (WC) rocks. The lithological units found around the area is broadly subdivided into three groups as follows (Jayawardena, 1976); (i) Hornblende biotite gneiss zone (ii) Granite and granitoid gneisses (iii) Undifferentiated charnockitic biotite gneisses

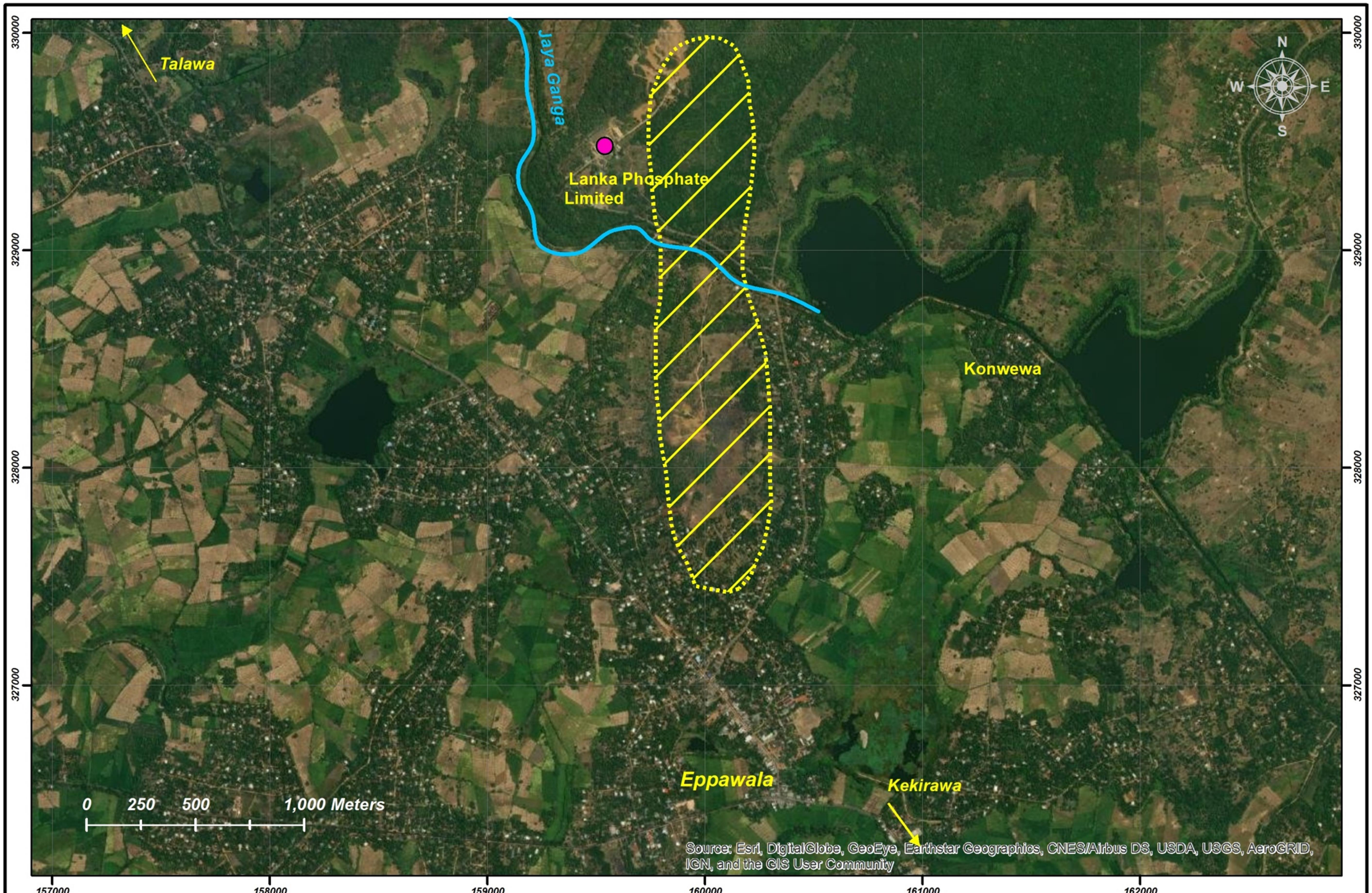


Fig- 2.1 : General Setting of Eppawala Phosphate Deposit on a Satellite Photograph

Most of the area around Eppawala is occupied by hornblende biotite gneiss and the rock units occur as larger than 5 km broad band running N-S direction (Figure 2.3). The hornblende biotite gneiss shows alternate bands of light and dark materials and development of both minerals is variable (uneven %). Mafic minerals contained in this rock show preferred orientation affected to a banding feature. Well exposed prominent outcrops of hornblende biotite gneiss occur at some locations namely Hammeliwetiya, Gonungama, Kumbukwewa and Weheragala. A few bands of granitic gneisses (some with pink feldspar) and charnockitic biotite gneisses are encountered within Hb. Bt gneiss zone forming anticlinal feature. Granitc outcrops occur at Nallachchiya, Galviharaya and Rajapakshayagama.

Granite and Granitoid Gneisses occupy the northern, south-eastern and eastern parts to the deposit area of the map together with some minor quartzite, biotite gneiss, calc gneisses and undifferentiated felsic orthogneisses. Granitic gneisses exhibit massive leucocratic quartzo feldsphatic gneissic nature with quartz >20% and few mafics.

The deformed pegmatitic granitoid gneisses are usually ridge forming and contain quartz rich white or pink, pegmatitic layered gneisses. The undifferentiated calc gneisses occur to the southeast of rock phosphate deposit, variable sequences of well layered gneisses with interlayer biotite gneiss or quartzo feldsphatic gneiss. Undifferentiated felsic orthogneisses occur at extreme south-east are massive to thickly layered and lacking of Al-rich minerals but <10% of garnet.

The undifferentiated charnockitic biotite gneisses occur surrounding the phosphate deposit. This unit exhibits extensive sequences of charnockitic looking grey gneisses usually lacking hypersthenes, commonly with boudinaged orthopyroxene bearing mafic layers but may comprise some paragneisses. A prominent charnockitic gneiss band is running to the west of the boundary of deposit in N-S direction. Charnockitic gneisses here are typically coarse grained, lacking of hypersthene with characteristically brown or greasy lustre. Prominent outcrops of charnockitic gneisses are found at Kiwulapitiya, Pahala Siyambalawela and Kattiyawa area. Pachy appearance charnockites, as well as partially retrogressed, bleached ‘ex-charnockites’ stipple indicates local charnockitization commonly observed within this unit.

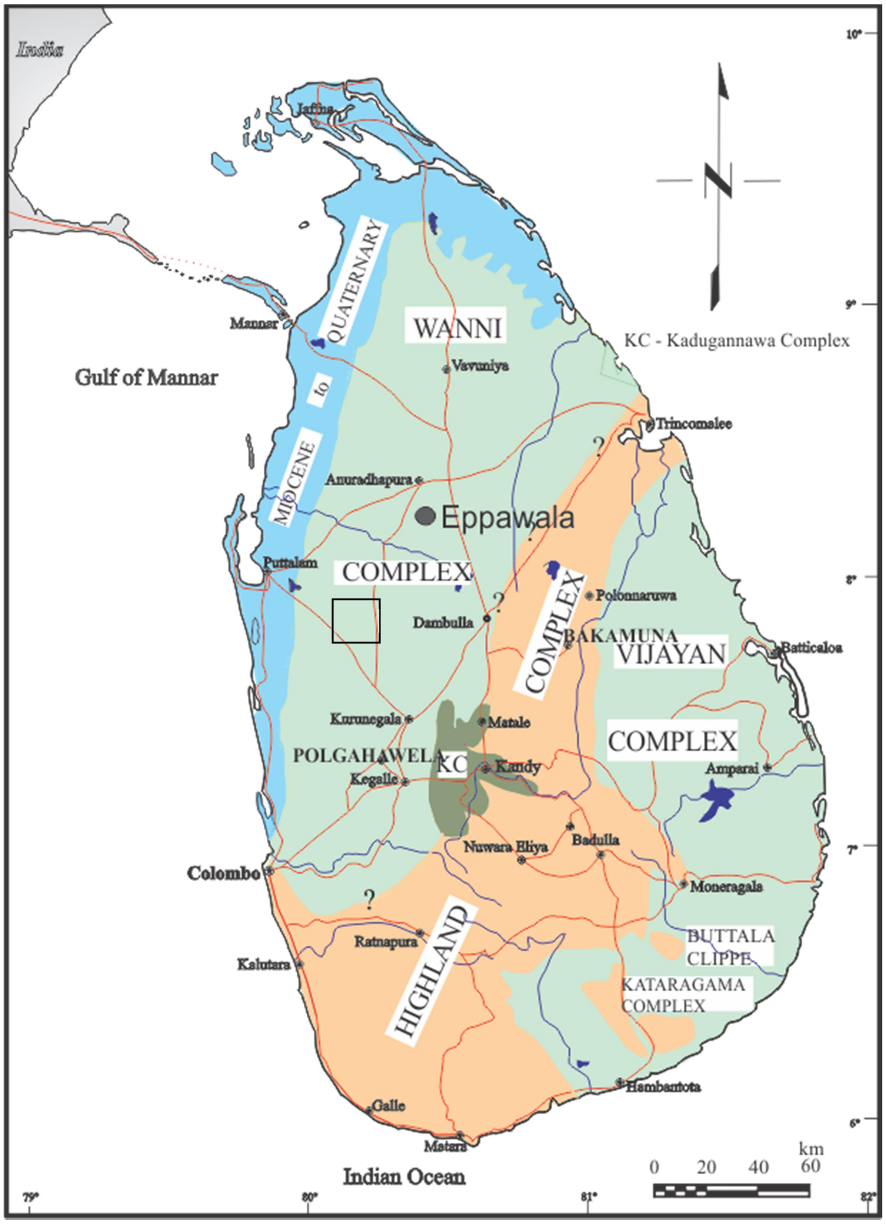


Figure 2.2: Generalized geological map of Sri Lanka (after Cooray, 1994)

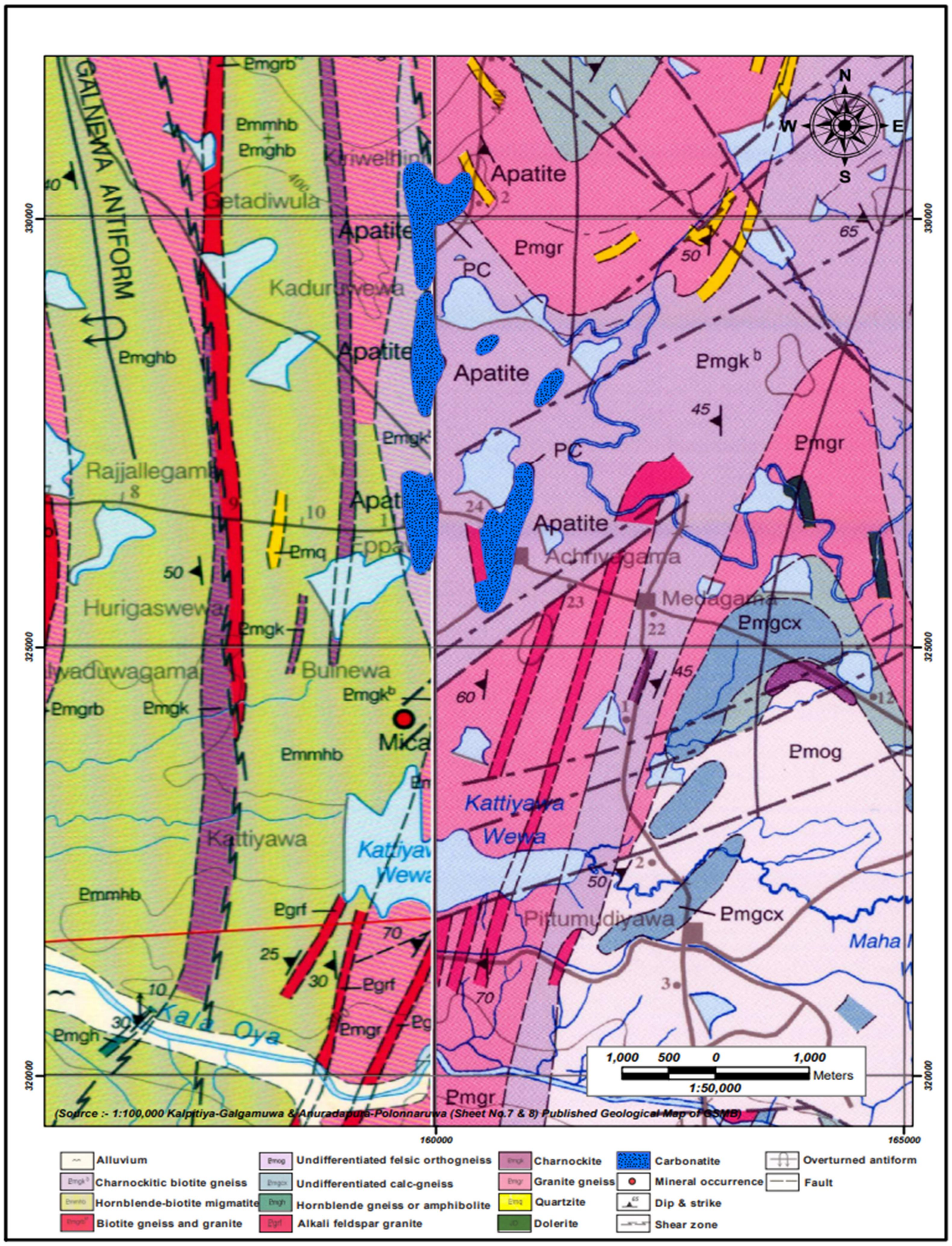


Figure 2.3: Geology and structure around Eppawala (after GSMB, 1995)

2.3 Previous work on the Eppawala Deposit

2.3.1 Geological Survey Department

Geological Survey Department (the predecessor of GSMB) conducted an extensive survey to estimate the reserves of Eppawala rock phosphate deposit in the early and mid 1970's. As constituent part of this survey, detailed mapping was carried out at the scale of a chain to an inch (approximately 1: 6336). The base map also includes all the topographical features roads, footpaths and contours at 20 ft intervals.

The geological mapping was followed up with, a programme of trenching and core drilling. For the purpose of further investigations, the area had been sub divided into seven Blocks namely A, B, C, D, E, F & G (Figure 2.4) based on hilly topographic features observed within the northern part of deposit. Nevertheless, drilling and trenching works were done only in B, C, D, E & F Blocks as the other areas were being mined. The main objective of this program was to obtain the realistic estimate of the available reserves of apatite-rich leached rock phosphate of northern part area (Jayawardena, 1976).

The drill holes were placed within a 120 m x 120 m grid. Apparently most of these drill holes were placed along 03 north-south trending lines. However, due to the undulating topography, some locations had to be relocated from hill slopes and high elevations towards valley bottoms. The data of 20 drill holes are available. The deepest of them DH 01 was drilled down to a depth of 166 m from the surface. Two other drill holes had been completed to a depth of more than 100 m. The total length of these 20 drill holes is 1580 m. The core recovery of some drill holes was very poor as of the unconsolidated nature and weathering conditions of the ore body. Cavities were commonly identified in the apatite rich leached phosphate rock. Four trenches each with average depth of 1.8 m have been put down from the crests of B, C, D, E & F Blocks to aware the lateral extents of leached zones. Trench samples collected at 4.5 m intervals were analyzed and the average grade of rock phosphate was 37% P_2O_5. In addition same samples were analyzed for Al_2O_3 and Fe_2O_3. From these results fresh phosphate rock (carbonatite) found at 5 drill holes DH 01, DH 04, DH 05, DH 11 and DH 14 while leached and re-precipitated apatite rich phosphate zones observed at all drill holes except DH 18 (drill hole data page 32 of Jayawardena, 1976). The estimated proven reserves of the northern part of deposit using the data of these 20 drill holes were 25 million tons.

2.3.2 Research studies on Eppawala Deposit

Many research oriented work have been carried out by Universities, Institutes such as National Institutes of Fundamental Studies and National Science Foundation. Along with these research studies, three Ph.D's, four M.Sc's and three M.Phil have been earned by the local scientists. Those studies are mainly on genesis, mineralogy, geochemical condition, estimate the reserves, solubility, and agricultural applications of apatite-bearing phosphate rock. Some information on two concepts on the origin of the deposit is given below.

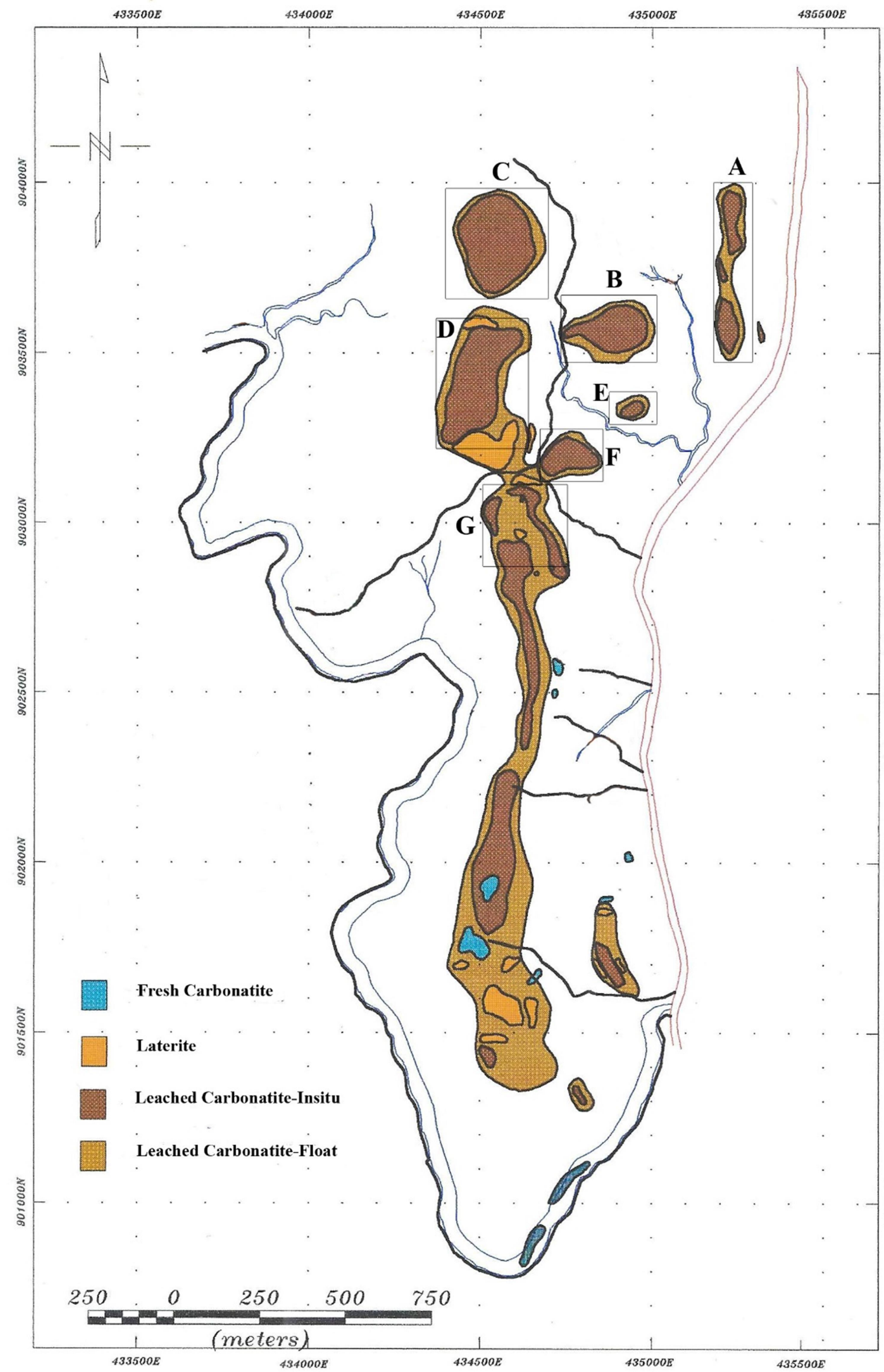


Figure 2.4: Selected Areas for resource estimation in 1970's

Detailed work on Eppawala carbonatite was first published by Jayawardane (1976) describing its origin as a carbonatite. From the findings of research studies, carbonatitic origin of the Eppawala phosphate rock was confirmed by Weerakoon (1998, unpublished thesis) as well the total reserves estimated to ~26 million tonnes with an average 32% P_2O_5 of apatite rich leached phosphate rock. Based on geochemical, isotopic and petrographic data, it was also confirmed that the apatite bearing parent rock of the Eppawala phosphate deposit is a carbonatite (Weerakoon *et al.*, 2001, Pitawala *et al.*, 2003).

However, there was another consideration of the genesis by Dahanayake and Subasinghe (1989) suggesting the Eppawala deposit could be a secondarily enriched phosphorite ore developed over an apatite-bearing marble formation. Furthermore, Manthilake *et al.* (2008) have elucidated supporting above theory that, the source of the carbonated eclogite may have been recycled subduction related oceanic crust containing associated inorganic carbonate.

Jayawardena (1976) and Pitawala *et al*. (2003) revealed that the Eppawala area contains a series of individual carbonatite outcrops and dyke like carbonatite bodies intruded through the metamorphic rocks. Field evidence as well as Rb-Sr and Sm-Nd isotopic data indicate that Eppawala carbonatites were emplaced after the high-grade metamorphism of the surrounding country rocks (Weerakoon *et al*., 2001). Moreover, Weerakoon (1998 unpublished thesis) has concluded that, the emplacement of carbonatite magma had been taken place as a concordant body after the peak metamorphism (<610 Ma) and afterward happen to brittle shear fault toward ENE-WSW direction during 550-500 Ma. Later, Manthilaka *et al.* (2008) also suggested that, the carbonatite magmas were emplaced within Wanni complex before the regional metamorphic event between 650-550 Ma. Thickness of the phosphate-rich regolith extends down to 50 m in some profiles (Dinalankara, 1995). There are mainly two types of horizons in the regolith named as leached zone and weathered top zone. Uppermost weathered zone is deeply decomposed and residual apatite crystals separated from the bedrock are embedded in a soil matrix (Dahanayake and Subasinghe, 1989).

3.0 Present Survey

The survey was included leveling, land use mapping and detailed geological mapping for the whole deposit area. The estimation of reserve at Northern part and Southern part was done separately using different approaches since, mid 2019 to September 2022.

3.1 Field Surveys

Mining activities starting from small scale to significant level are being carried out at Eppawala area since 1974**.** The mining activities have left heavily uneven topographical features with abandoned pits. Therefore, it was required to determine the surface levels of the whole area along with the field geological mapping. Hence, a leveling survey of the area was carried out using a differential GPS, within a 2 month period (from February to March 2020). The details were used to produce a digital elevation model (DEM). Also, this data are essential for the estimation of reserves of apatite rich leached phosphate rock, and for the preparation of digital models using software packages. Field survey was also carried out to find the land ownership of deposit and surrounding areas for future usage. This information would be very important for the reservation of the phosphate deposit for any future development activity. Officers of GSMB have completed this task within two months with the assistance of a villager. Initial base maps were prepared using relevant topographic maps.

3.2 Geological Mapping

The detailed geological mapping programme and boundary demarcation were initiated in mid, 2019. The geological mapping work was completed within a period of 3-4 months. During the fieldwork, identification of rock types, collection of representative samples and geological measurements were carried out. After the fieldwork exposed leached apatite and the fresh carbonatite exposed on the surface, were marked and their boundaries were demarcated (Figure 3.1). Different rock types, such as pegmatitic-granitoid-gneiss, undifferentiated-charnockitic-biotite-gneiss, quartzite, homblende-biotite-gneiss, granite gneiss, charnockitic-gneiss, and biotite-gneiss were observed as basement rocks during the fieldwork. In addition to that two types of apatite-bearing rocks were observed.

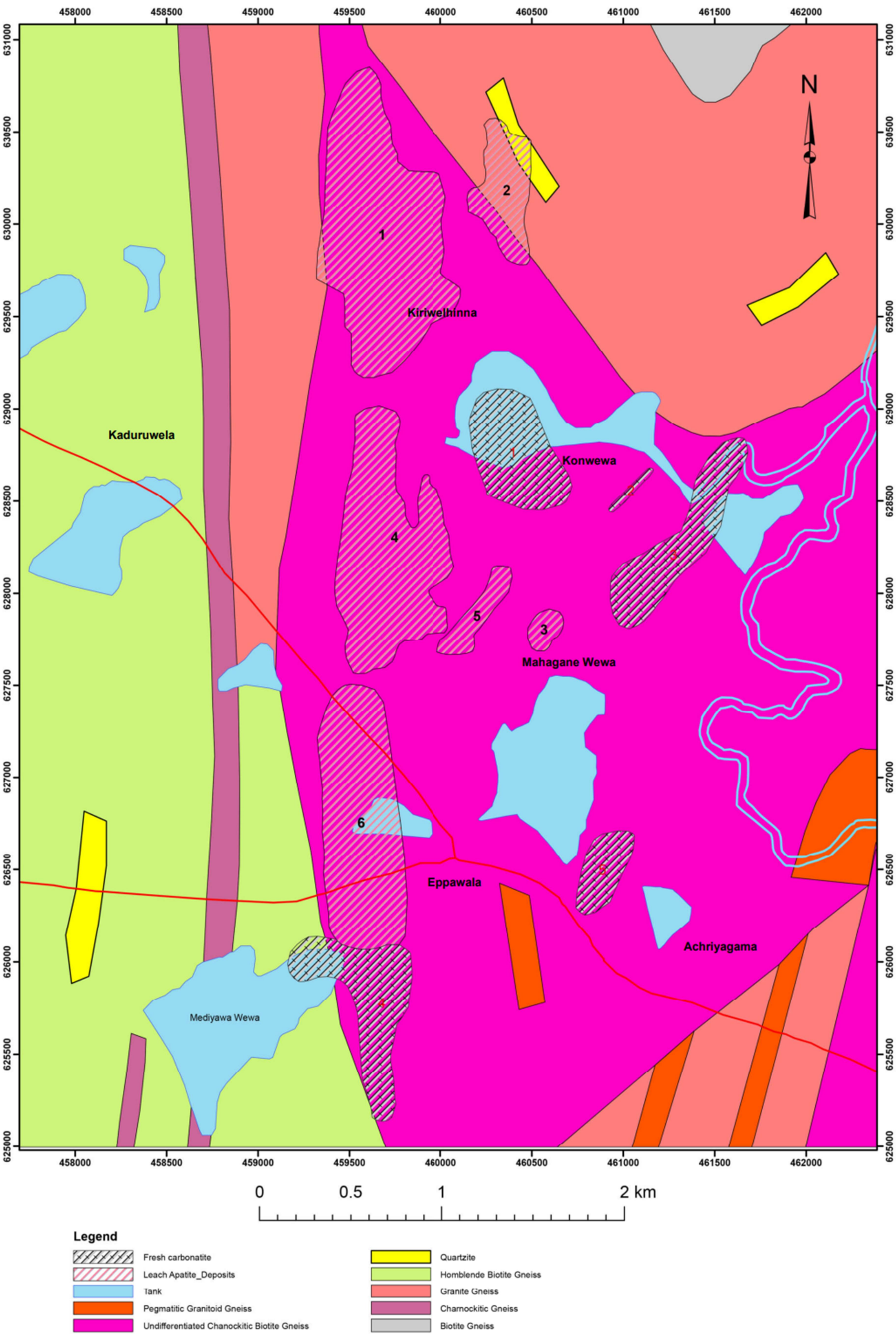


Figure 3.1:The detailed geology map with the fresh carbonatite and leached apatite rich ore

Generally, fresh carbonatite was white colour and the observed outcrops of fresh carbonatite are slightly to moderately weathered with a comparatively lesser amount of apatite crystals. Figure 3.2a shows such carbonatite out crop identified at the field. The size of the embedded apatite crystals in the fresh carbonatite bodies varies from 1cm to 15 cm and most of them were well-developed crystals. Fresh carbonatite contains about 2-5% of magnetite and some of them formed as well defined crystals (Figure 3.2b). Rutile content of rock samples is about 1-5% and it is formed as flakes and some of them show folded nature (petrological studies).

Figure 3.2. a) Fresh carbonatite exposure (mainly at southern part of the area); b) magnetite crystals in the fresh carbonatite body, c) fresh carbonatite boulders

In addition to that in some places the olivine and diopside are present in minute quantities. The fresh carbonatite present in the survey area can be identified as the Apatite-Magnetite variety of the carbonatite (Pecora, 1956). Few fresh carbonatite outcrops can be found in the northern part of the area but, more exposures are observed in the southern and eastern parts of the survey area (shown in Figure 3.1)

The leached apatite consists of apatite crystals held together with a brown or white colour matrix (Figure 3.3.a). This zone consists of a mixture of different size apatite crystals varying from 1cm to 30cm and the matrix is variable in composition depending mostly on the rate of weathering and the mineralogy. The leached apatite zone contains about 5% of magnetite and rutile. The lateritic boulders occur as chief material and can be observed as in-situ boulders and some are slightly transported. The lithology of the boulders is similar to the leached apatite zone and is derived from the leached apatite zone (Figure 3.3a & b).

Figure 3.3: Leached apatite boulders and lateritic boulders

As a result six leached apatite bearing areas were identified (Figure 3.1). The boundary of each leached block was demarcated using field data. The total surface area of leached apatite deposits is 2.23 km^2. This area includes both leached apatite rock and leached apatite float area. According to the previous work done in 1970’s, the total surface area of explored leached apatite was about 0.72 km^2. Therefore, the present study explored a comparatively larger area of the deposit. Also, during the present survey, five fresh carbonatite bodies were explored (Figure 3.1). However, the surface geological mapping revealed a very little detail about the deposit. Surface areas of both leached apatite and fresh carbonatite are given in Table 3.1.

Table 3.1: Identified surface areas of fresh carbonatite and leached, apatite rich rock phosphate

Identified areas (present survey)	Fresh Apatite containing carbonatite (km^2)	Leached, apatite rich phosphate rock (km^2)
1	0.25	0.80
2	0.01	0.17
3	0.24	0.03
4	0.28	0.60
5	0.09	0.07
6		0.56
Total	0.88	2.23

4.0 Reserve Estimation at Northern Part of Deposit

Using the details obtained from geological, structural and morphological data, it was aimed to capture subsurface geological data placing sufficient amount of drill holes. Core logging details of drill holes and their subsurface geochemical behavior, it was divided into several blocks and use of software to model and estimate reserve of each blocks represent the rock phosphate at Northern Part.

4.1 Core Drilling Investigations

This drilling campaign to estimate reserve at Northern Part of Eppawala area was commenced in August 2020 and continued till mid-March 2021.

The drilling programme was planned to collect essential information required to compute the reserves and for modeling the apatite-bearing carbonatite deposit. Three (03) drill machines were simultaneously operated with three (03) drilling crews. Thirty (30) drill holes were put down in the northern part of deposit. Among them, eighteen (18) of them are inclined (inclinations 60^0, 65^0 and 70^0) drill holes and other twelve (12) holes are vertical. The drill hole locations are shown in Figure 4.1. A total of 1214.69 meters were drilled. Summarized details of drill holes data are given in the Table 4.1.

Table 4.1: Summarized details of the total of thirty (30) Drill Holes

Drill Hole No	Coordinate		Inclination	Bearing (Azimuth)	Final Depth(m)	Collar Elevation(m)
	Easting	Northing				
DHN - 1	460429	630144	-65^0	270^0	49.50	132
DHN – 2	460343	630146	-65^0	270^0	60.00	141.3
DHN – 3	460133	630139	-90^0	0	15.00	129.1
DHN – 4	459926	630126	-90^0	0	20.80	159.2
DHN – 5	460294	630143	-70^0	275^0	73.40	141.3
DHN – 6	459928	630126	-65^0	120^0	25.00	159.3
DHN –7	459822	630104	-65^0	270^0	50.00	143.96
DHN – 8	460316	630500	-65^0	270^0	25.10	134.07
DHN – 9	460239	630143	-65^0	90^0	102.14	129
DHN - 10	459738	630050	-90	0	47.20	138
DHN-11	460284	630366	-65^0	90^0	58.30	135
DHN–12	459607	630085	-65^0	270^0	45.00	142
DHN–13	459514	630079	-90^0	0	50.00	137
DHN–14	460283	630505	-65^0	90^0	45.00	136
DHN-15	459453	629864	-90^0	0	41.70	131
DHN-16	459956	630140	-90^0	0	38.00	164
DHN-17	460359	629771	-90^0	0	9.80	119
DHN–18	460070	630137	-90^0	0	34.50	143
DHN–19	459900	630060	-90^0	0	39.20	143
DHN–20	460030	629971	-65^0	135^0	31.00	133

DHN-21	459496	630406	-60^0	90^0	44.55	136
DHN-22	459716	629400	-65^0	270^0	40.50	145
DHN–23	459851	629700	-65^0	270^0	44.65	143
DHN–24	459750	629524	-90^0	0	32.15	144
DHN-25	459777	629715	-65^0	135^0	9.75	140
DHN- 26	459597	630429	-65^0	270^0	50.00	164
DHN- 27	459851	629604	-90^0	0	26.45	134
DHN- 28	459638	629511	-65^0	90^0	26.50	136
DHN- 29	459611	629595	-90^0	0	50.00	127
DHN- 30	460037	629883	-65^0	270^0	29.50	127

The details of each drill holes including core logging data and coloured photographs of core boxes are given in Annexure 1 and Annexure 2 respectively. The core recovery of some drill holes was very poor as of the unconsolidated nature and weathering conditions of the ore body. Cavities were commonly identified in the apatite rich leached phosphate rock (refer Annexure 1)

4.2. Modeling of the leached apatite and apatite rich zones

Based on the data obtained from leveling survey and detailed geological mapping, the deposit was subdivided into five Blocks for the purpose of modeling and estimating the reserves. Drilling data was also useful to confirm the subdivisions of 5 Blocks. Here, the base level of the Blocks was considered at 117 m above MSL (general ground level of the area) and the elevations of identified leached apatite bodies at each Block were prepared contouring at 1 m intervals (Figure 4.2). Core logging data and chemical analysis data (P_2O_5% contents) of core samples of each drill hole, were used in 3D modeling software to formulate models of each Block. Also the core recovery percentages of each drill hole was highly considered when taking the thickness of apatite rich zones (data feeding to the software) for modeling of each Block. Then, the reserve of each Block was calculated separately.

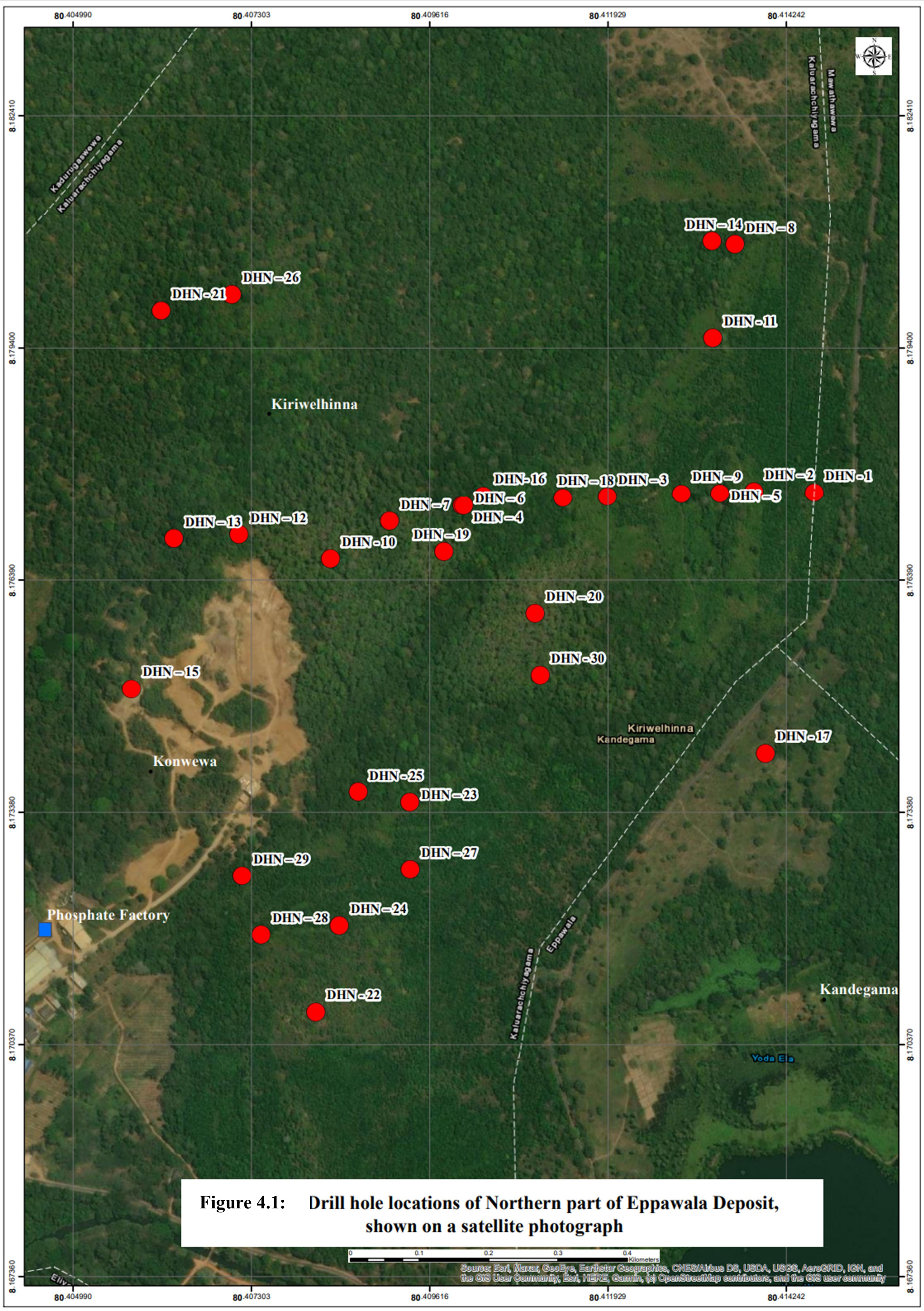


Figure 4.1: Drill hole locations of Northern part of Eppawala Deposit, shown on a satellite photograph

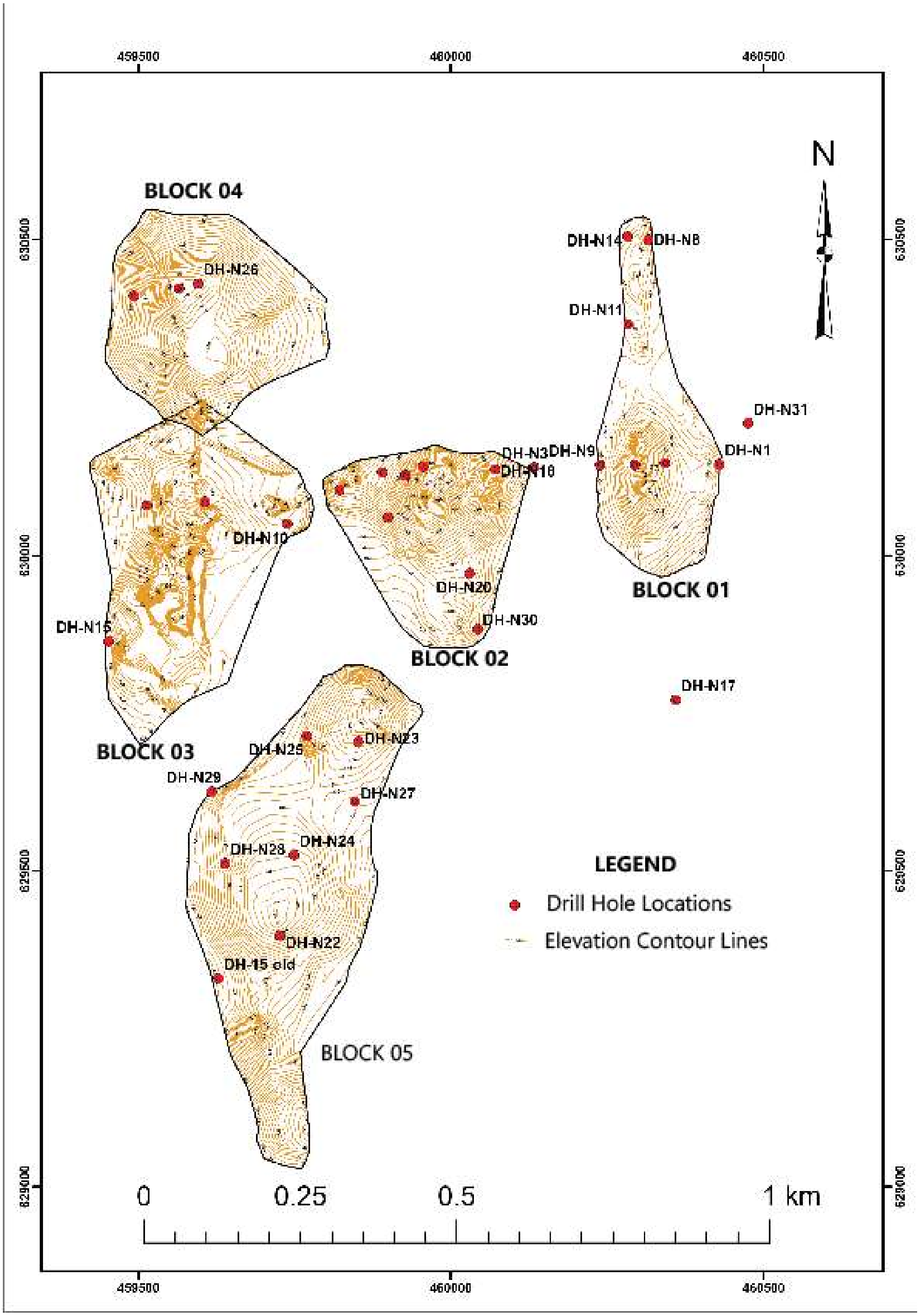


Figure 4.2: Simplified Blocks of leached and apatite rich in-situ and float zones

4.2.1. Modeling of Block 1

A total of eight drill holes DHN 1, DHN 2, DHN 5, DHN 8, DHN 9, DHN 11, DHN 14 and DHN 17 are placed within Block 1. All drill holes are inclined (65^0 and 70^0) except for DHN 17; which is vertical hole. Description of each drill hole is given in Table 4.1.

Chemical analysis of forty five (45) samples selected from different depths of drill holes located within this block was performed. Each sample was analyzed for oxides of Mg, Si, Ca, P, Al, Fe^{3+}, K, Na, Mn and Ti and all particulars are tabulated and given in Annexure 3. The average P_2O_5% content of leached apatite zone and apatite rich in-situ & float zone were calculated using Inverse Distance Weighted (IDW) method. The drill hole DHN-2 was not considered due to lack of apatite in that hole. According to the P_2O_5 content of core samples, two categories (apatite rich in-situ & float zone and leached apatite zone) of the apatite formation have been identified. The average value of P_2O_5 content for Block 1, was calculated using the analytical results of the P_2O_5 content of each drill holes belong to Block 1 given as Annexure 4-Block 1. The average P_2O_5 content was calculated separately for apatite rich in-situ & float zone (Table 4.2a) and leach apatite zone (Table 4.2b).

Table 4.2a: The average P_2O_5 content in the apatite rich in-situ and float zone of Block 1

DH No	Thickness (m)	P_2O_5 content	The average value of P_2O_5 % content
DHN - 1	4.00	14.17	12.40
DHN - 2	-	-	
DHN - 5	1.60	39.06	
DHN - 8	5.00	16.42	
DHN -11	4.50	5.44	*High amount of apatite crystals consist in the float zone of DHN-5.*
DHN -14	5.00	4.70	
DHN -17	-	-	

Table 4.2b: The average P_2O_5 content in the leached zone of Block 1

DH No	Thickness (m)	P_2O_5 content	The average value of P_2O_5% of Block 1
DHN - 1	15.25	37.38	37.20
DHN - 2	0.20	28.72	
DHN - 5	65.00	37.01	
DHN - 8	3.60	36.03	
DHN -11	28.60	36.18	
DHN -14	25.50	38.94	
DHN -17			

The above data were used to build a model for Block 1. The sketches of the model of Block 1 prepared using 3D modeling software is shown in Figures 4.3a and 4.3b.

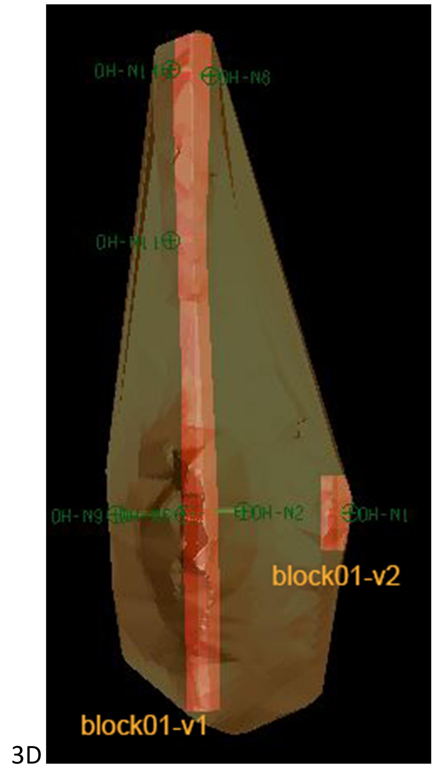


Figure 4.3 a. Plan view of apatite body of the Block 1

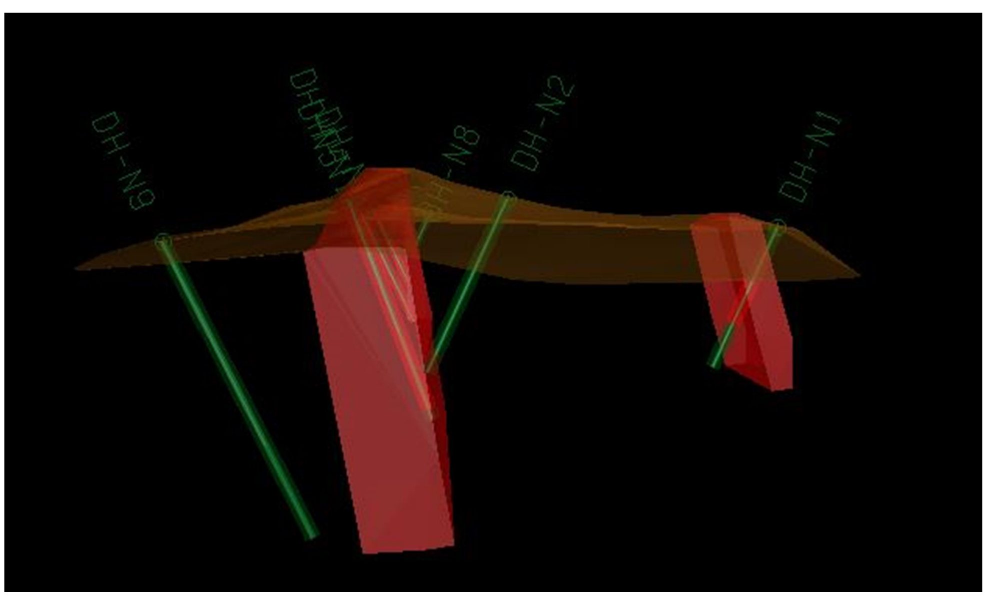


Figure 4.3b: A three dimensional (3D) model of the apatite body and drill hole locations of Block 1

4.2.2 Modeling of Block 2

The Block 2 is covered by nine drill holes namely DHN 3, DHN 4, DHN 6, DHN 7, DHN 16, DHN 18, DHN 19, DHN 20 and DHN 30. While four of them were inclined holes (65^0 and 70^0) five holes are vertical (Table 4.1). The core logging data of each drill holes and photographs of core boxes of each drill hole are given in Annexure 1 and Annexure 2, respectively.

Fifty one (51) samples were collected from 9 drill holes for chemical analysis. The details of the sampling and percentage of P_2O_5 content of each sample are given in Annexure 5-Block 2. Similar to Block-1 apatite rich in-situ & float zone and a leached apatite zone were identified in Block 2. The average P_2O_5 percentage of leached apatite zone and apatite rich in-situ & float zone was calculated using the IDW method.

The average value of P_2O_5 content for Block 2, was calculated separately using the P_2O_5% content of each drill hole belongs to Block 2. Calculated average P_2O_5 contents for apatite rich in-situ & float zone and leached apatite are given in Table 4.2c and Table 4.2d.

Table 4.2c: The average P_2O_5 content in the apatite rich in-situ & float zone of Block 2

DH No	Thickness (m)	P_2O_5% content	The average value of P_2O_5% of Block 2
DHN - 3	-	-	36.05
DHN - 4	2.30	39.31	
DHN - 6	4.80	33.84	
DHN - 7	2.60	33.10	
DHN - 16	0.60	40.35	
DHN - 18	1.85	34.93	
DHN - 19	2.00	37.72	
DHN - 20	--	-	
DGN - 30	3.00	38.41	

Table 4.2d: The average P_2O_5 content in the leached zone of Block 2

DH No	Thickness (m)	P_2O_5% content	The average value of P_2O_5 % of Block 2
DHN - 3	-	-	37.82
DHN - 4	8.10	37.77	
DHN - 6	8.80	37.80	
DHN - 7	40.75	38.14	
DHN - 18	32.65	39.98	
DHN - 16	19.85	35.16	
DHN - 19	-	-	
DHN - 20	-	-	
DHN - 30	16.40	36.02	

The above data were used to build a model for Block 2. The plan of the model of Block 2 prepared using 3D modeling software is shown in Figure 4.3c.

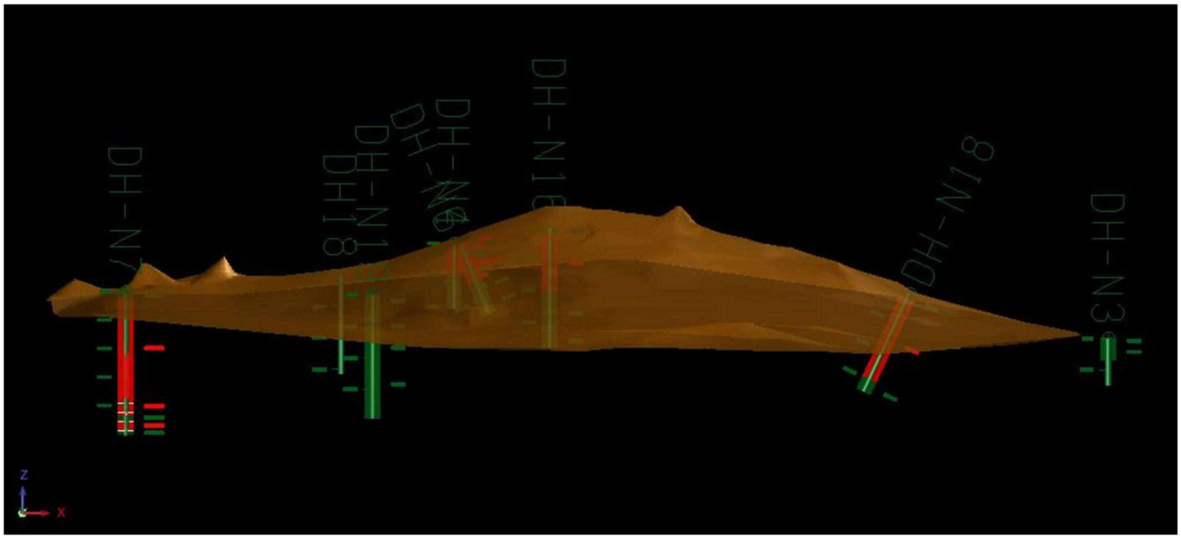


Figure 4.3 c. A 3D model of the leached apatite body with drill hole placement of Block 2 (sub parallel to E-W direction)

4.2.3 Modeling of Block 3

Four drill holes DHN 10, DHN 12, DHN 13 and DHN 15 are located within Block 3 and three of them were vertical and the fourth one is an inclined (65^0) hole. Also the details of core logging data and photographs of all core boxes are given in Annexure 1 and 2, respectively. The general description of each drill hole is given in Table 4.1.

Thirty one (31) samples were selected from the drill holes in Block 3. The samples from DHN13 were not selected for chemical analysis because of the absence of apatite containing material. The details of sampling and percentage of P_2O_5 content of each sample are given in annexure 4-Block 3. Also in this Block, two formations of the apatite-rich zones as leached apatite and apatite rich in-situ & float zone were identified. The average P_2O_5 percentages of both leached apatite zone and apatite rich float zone were calculated using IDW method.

The calculated average P_2O_5 percentage values of apatite rich in-situ & float zone and leached apatite zones are given in Tables 4.2e and 4.2f.

Table 4.2e: The average P_2O_5% contents in apatite rich in-situ & float zone of Block 3

DH No	Thickness (m)	P_2O_5% content	The average value of P_2O_5% of Block 3
DHN -10	4.85	37.99	33.86
DHN -12	6.65	29.88	
DHN -13	-	-	
DHN -15	12.33	34.39	

Table 4.2f: The average P_2O_5 % content in leached apatite zone of Block 3

DH No	Thickness (m)	P_2O_5% content	The average value of P_2O_5% of Block 3
DHN -10	42.85	40.21	36.68
DHN -12	38.35	33.24	
DHN -13	-	-	
DHN -15	22.52	35.85	

Using above data, a model for apatite mineralization in Block-3 was prepared. The sketches of the model of Block 3 are given in Figures 4.3d and 4.3e.

Figure 4.3 d: A plan view of apatite body of Block 3

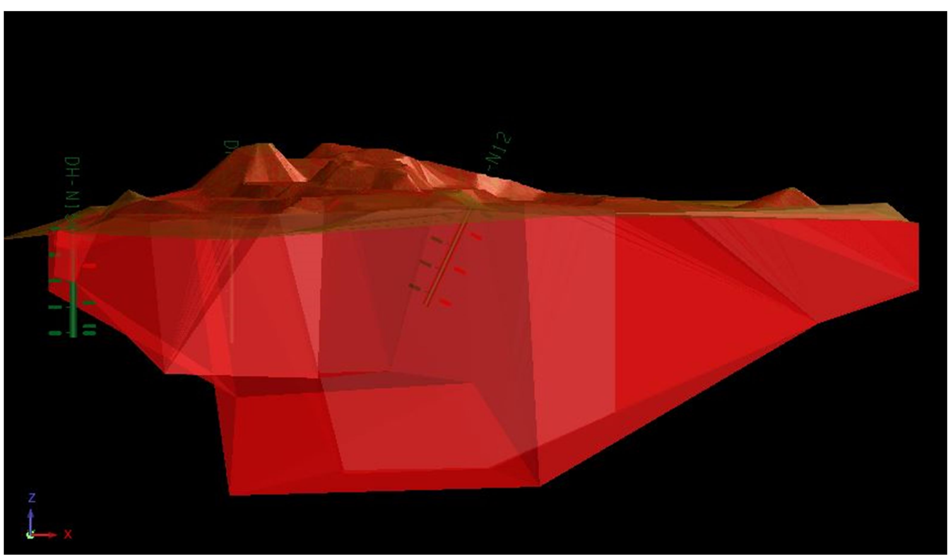


Figure 4.3 e: A 3D view of apatite body with drill hole placement of Block 3

4.2.4 Modelling of Block 4

The two drill holes; DHN 21 and DHN 26 were put down in Block 4. Both are inclined holes (60^0 and 65^0). The general details of these drill holes are given in Table 4.1. The core logging data and photographs of core boxes are also given in Annexure 1 and 2.

Seven (7) samples were analyzed chemically. The details of the sampling and percentage of P_2O_5 content of each sample are given in Annexure 4-Block 4. The average P_2O_5 contents were calculated separately for apatite rich in-situ & float zone and leached apatite zones and given in the tables 4.2g and 4.2h.

The average value of P_2O_5 content for Block 4, was calculated using the P_2O_5 content of each drill hole put down in Block 4.

Table 4.2g: The average P_2O_5 % content in apatite rich in-situ & float zone of Block 4

DH No	Thickness (m)	P_2O_5% content	The average value of P_2O_5% of Block 4
DHN-21	-	-	39.62
DHN-26	5.00	39.62	

Table 4.2h: The average P_2O_5 % content in leached zone of Block 4

DH No	Thickness (m)	P_2O_5% content	The average value of P_2O_5% of Block 4
DHN-21	3.88	37.86	39.36
DHN-26	29.20	39.56	

Using the above data and geological map, a model for apatite mineralization was prepared. The sketch of the apatite mineralization in Block 4 is given in Figure 4.3f.

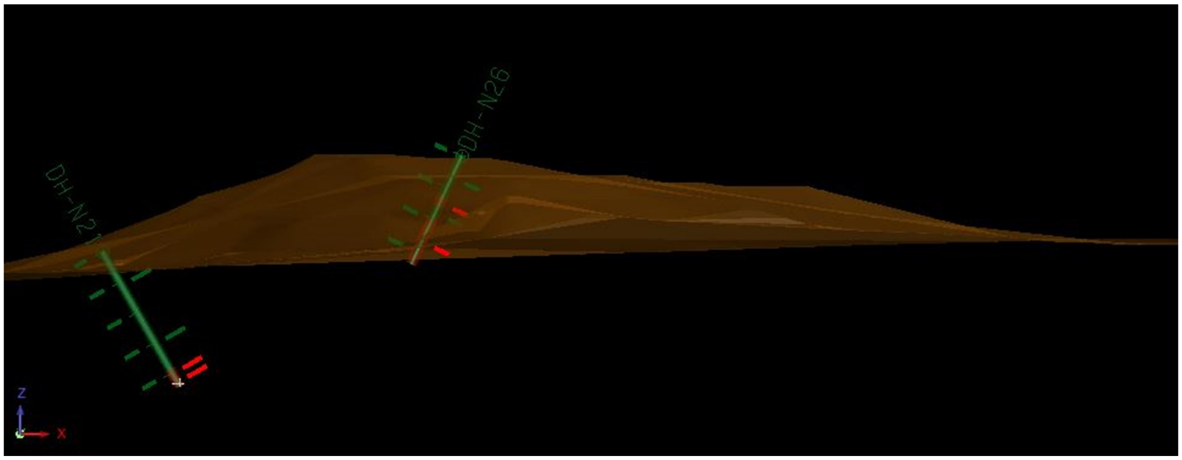


Figure 4.3 f : A 3D model of apatite body with drill hole placement of Block 4 (sub parallel to E-W)

4.2.5 Modelling of Block 5

Seven drill holes namely DHN 22, DHN 23, DHN 24, DHN 25, DHN 27, DHN 28 and DHN 29 are placed within Block 5. Four drill holes were put down at an angle of 65^0. Three were vertical holes (refer Table 4.1). The drilling data of each drill holes including core log sheets and photographs of core boxes are given in Annexure 1 and Annexure 2 in respectively.

Thirty eight (38) samples selected from 7 drill holes were subjected to chemical analysis (Annexure 3). The details of the sampling and percentage of P_2O_5 content of each sample are given in Annexure 4-Block 5. The average P_2O_5 percentages of leached apatite zone and apatite rich in-situ & float zone were calculated using the IDW method.

The average value of P_2O_5 content for Block 5, was calculated using the P_2O_5 content of each drill hole put down in Block 5. The average P_2O_5 content was calculated separately for leached apatite and apatite rich in-situ & float zones. The calculated values of the average P_2O_5 content is given in Tables 4.2i and 4.2j.

Table 4.2i: The average P_2O_5 % content in apatite rich in-situ & float zone of Block 5

DH No	Thickness (m)	P_2O_5 % content	The average value of P_2O_5 % of Block 4
DHN - 22	3.00	39.78	28.49
DHN – 23	1.00	34.35	
DHN – 24	2.50	35.45	
DHN - 25	2.40	31.60	
DHN – 27	6.00	22.11	
DHN – 28	2.00	14.24	
DHN – 29	2.70	29.32	

Table 4.2j: The average P_2O_5 % content in leached zone of Block 5

DH No	Thickness (m)	P_2O_5 % content	The average value of P_2O_5 % of Block 4
DHN - 22	37.50	39.27	38.78
DHN – 23	40.60	39.82	
DHN – 24	35.45	39.40	
DHN - 25	4.19	36.73	
DHN – 27	20.45	38.83	
DHN – 28	25.50	34.31	
DHN – 29	27.05	40.26	

Using the above data and geological maps, the apatite mineralization model for Block-5 was prepared. The sketch of the model for apatite body of Block 5 is given in Figure 4.3g.

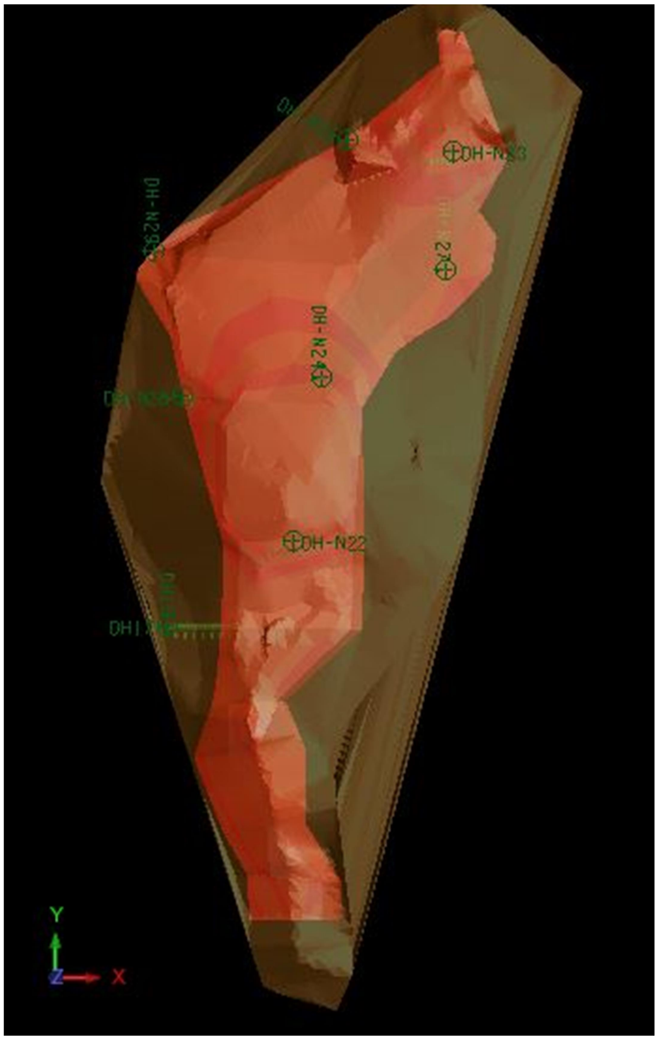


Figure 4.3 g: A plan view of apatite body of Block 5

4.3 Calculation of reserve at Northern Part of deposit

In this survey, computer based 3D software was used for modeling apatite rich mineralization zones. Apparently, the volume of apatite rich in-situ & float zone is comparatively smaller than leached apatite zone and there is no noteworthy difference in P_2O_5% content in both of these zones.

Nevertheless the average values of P_2O_5 content of the apatite rich in-situ & float zone and the leached apatite zone of each Block were calculated separately for reserve estimation. Specific gravity of apatite was obtained as 2.93, by analyzing 10 samples from both apatite rich in-situ & float zone and leached apatite zones. Following two methods were selected for reserve estimation.

1. The reserves between the ground surface of hillocks and the plane of 117 m above MSL (The benchmark Jaya Ganga river bank is 117 m MSL taken as the general ground level). The estimated tonnage is given in Table 4.3.

2. The reserves between ground surface of hillocks and the plane of 92 m above MSL. The estimated tonnage is given Table 4.4.

Table 4.3: Reserves between ground surface of hillocks and 117m MSL - for surface mining

Block	Volume (m^3)	Specific gravity	Average P_2O_5%	Reserves (Million tonnes)
Block 1	187887	2.93	34.04	0.550509
Block 2	278418	2.93	37.99	0.815765
Block 3	1461400	2.93	36.15	4.281902
Block 4	745592	2.93	35.53	2.184585
Block 5	1694040	2.93	37.82	4.963537
			Total	**12.8 Million tonnes**

Table 4.4: Reserve between ground surface of hillocks and 92 m MSL (mining 25 m below the surface)

Block	Volume (m^3)	Specific gravity	Average P_2O_5%	Reserves (Million tonnes)
Block 1	396691	2.93	34.04	1.162304
Block 2	343578	2.93	37.99	1.006683
Block 3	2677745	2.93	36.15	7.845792
Block 4	1342563	2.93	35.53	3.933709
Block 5	3413251	2.93	37.82	10.000825
			Total	**23.95 Million tonnes**

5.0 Reserve Estimation of the Southern Part of deposit

Considering the physical characters of the target mineral and based on the previous experiences, DC resistivity technique has been consider as the primary technique for this survey fulfilling the set objective. Two types of resistivity measurement modes were deployed in the field; 1D Vertical Electrical Sounding (VES) in Schlumberger Array (*Keary., P, et al 2002)* and 2D resistivity imaging. AGI Super-Sting system is considered for the 2D resistivity survey, which consists of 100 electrodes with maximum spread of 500m. ABEM SAS 300 Terameter is the equipment deployed in the field for raw data acquisition. The maximum current electrode spread has been maintained at 200m with depth detection limits of 60-70m. At locations which the ground resistivity is very high, the input current was kept at minimum possible range enabling high depth penetration. At conductive earth-formations, maximum current input has been maintained enabling the highest resolving power of different lithological formations in the subsurface.

Magnetite forms as a gangue mineral of the apatite formation and a high magnetic signature is expected to observe where apatite is highly concentrated. Hence, as an auxiliary method, magnetic measurements were conducted in the study area to investigate potential occurrence of phosphate beneath the overburden, which apatite is not exposed. Magnetic measurements across the boundary were conducted with an aid of GEM's GSM-19 Overhauser magnetometer. The two components; rowing and the base have been synchronized and the base was kept at a relatively quiet location to acquire data enabling to calculate the temporal variations of the total magnetic field.

For the purpose of reserve estimation, the material volume of the study area needs to be estimated accurately. Further, 2D resistivity inversion required terrain heights for accurate results. Fulfilling the both requirements, a detailed survey has been conducted to synthesize a Digital terrain Model (DTM), with an assistance of high-accurate RTK (Real-Time Kinematic) survey system. Pre-existing contour lines were digitized and the data extracted to populate the grid, after scrutinizing the level of accuracy of the secondary data sources.

5.1. Model Syntheses using northern part drill logs

Thirty drill-holes which were located in the Northern Sector of the previous survey were studied in the process of building the model. Resistivity measurements were taken at the locations coinciding with the drill holes. Two-D resistivity profiles were completed across the bore-holes for comparison of results. Each and every drill-hole location is surveyed with

Vertical Electrical Sounding (VES) technique and the results were compared with the ground truths, prior to initiation of quantification process of Southern Sector.

The resistivity responses for the presence of apatite/leached zone and the background responses are synthesized via an initial model. The studies conducted in the Southern Sector reveal a significant difference of geological formations as the high relief ridges of the Southern Sector is dominated by carbonatite rocks, whereas the hillocks of the Northern Sector are composed of apatite bearing formations. The following model explains the apatite occurrence in general and the appropriate resistivity signatures also mapped for such occurrences.

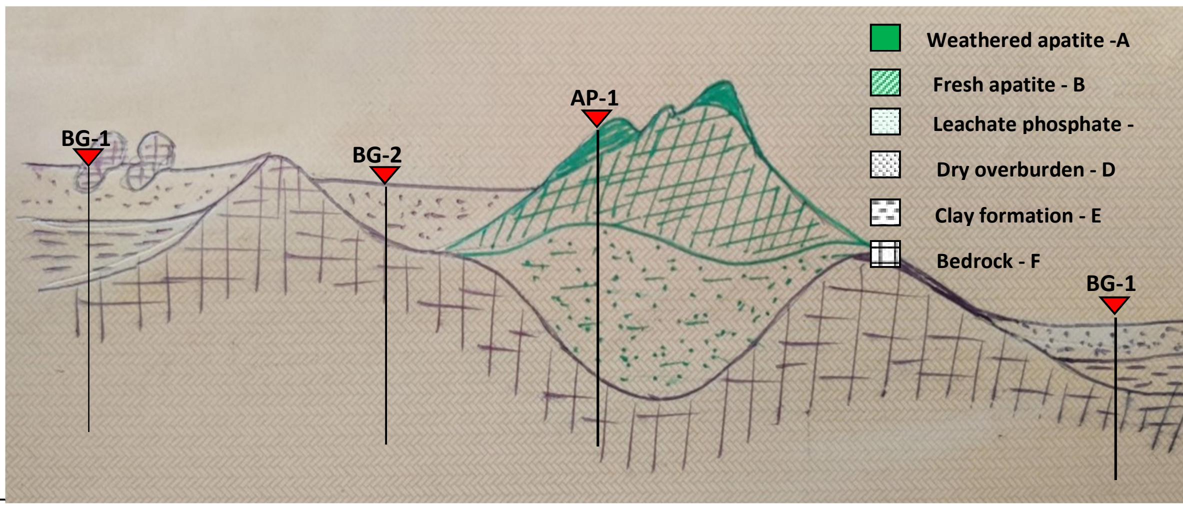


Figure 5.1: Model constructed for Northern Sector, based on drilling information and geophysical outcome

(A) Weathered apatite: the green colored weathered overburden is the product of apatite wreathing and usually found as the first layer of the phosphate bearing formation. This layer is not present at locations where the apatite-cap is exposed to the surface.

(B) The apatite rich partially fresh layer lies beneath the weathered thin overburden and/or exposed to the surface. Fresh apatite crystals are visible in this horizon. This layer reflects relatively high resistivity values.

(C) The apatite rich hard-cap is followed by the leachate, the weathered products of the apatite bearing formation possibly due to ground action and accumulation of water, laterally and through the cracks of the hard top formation.

(D) Dry overburden: This is the overburden of the background host rock, product of bedrock weathering.

(E) Clay formation: Same formation as of (D), yet the below the groundwater level, and the gradual change between the two formations.

(F) Bedrock: The bottom most formation extended throughout the area. This formation could be marble, granite or hornblende-biotitic genesis.

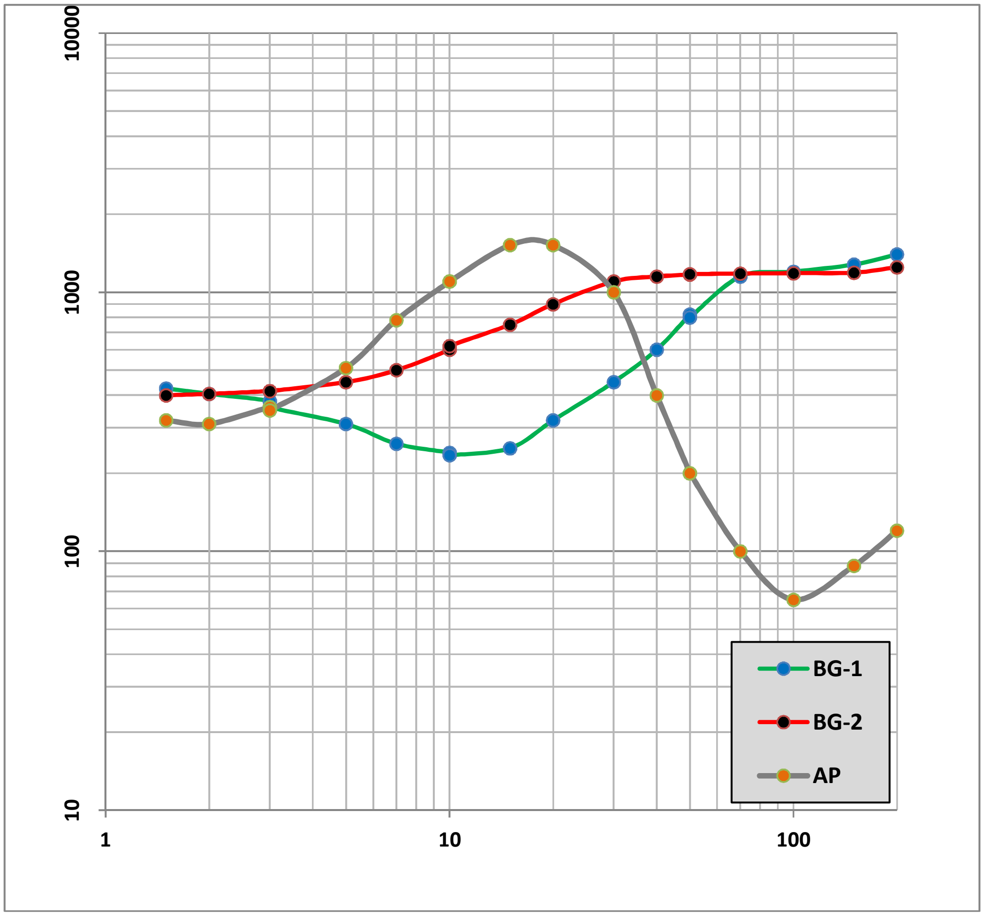


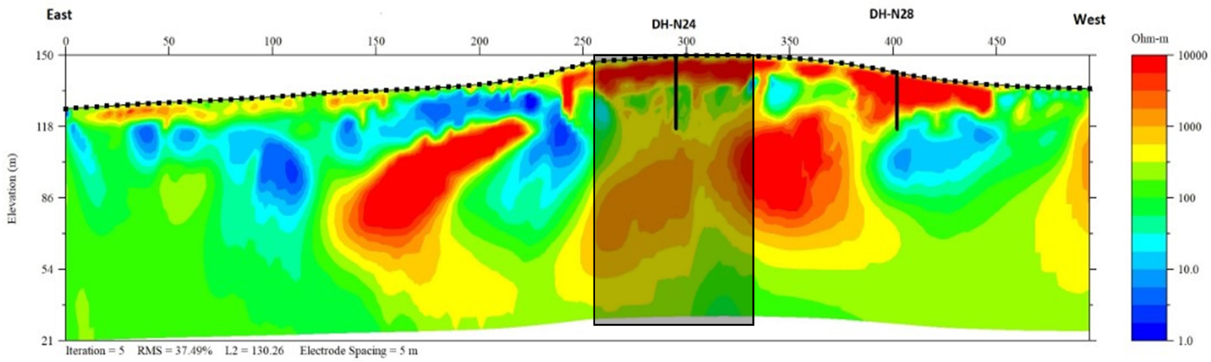
Figure 5.2-

BG-1: This curves represents three-layer case and in the background. The gradual weathering of bedrock produces this type of common response. The second layer which is having low resistivity is the water bearing potion of the weathered material.

BG-2: The two layer case again representing the background host-rock sans the water-water bearing second layer. Such response is observed when the weathered overburden is above the groundwater level and when VES surveys are conducted under dry conditions.

AP: This curve represents a four-layer case: weathered apatite bearing overburden, apatite rich hard-cap and the phosphate-leachate. The bottom layer is the bedrock that is common throughout the area. This typical resistivity response is one of the guiding principles to identify the apatite formations in the subsurface. Depending on the thickness of the layers the inversion points of the curves deviate, accordingly.

The model is further evaluated with comparing drill-holes with 2D resistivity. Resistivity data were gathered along a 2D resistivity profile that cut across the two bore-holes, which were drilled during the study of Northern Sector.



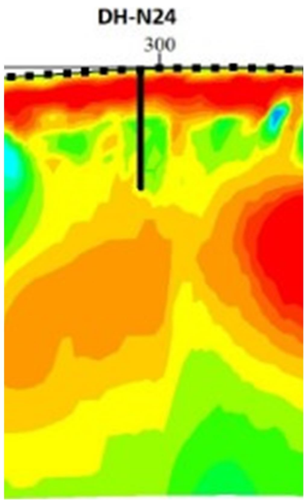


Figure 5.3: Comparison of 2D resistivity and drilling results

The drill-hole results and outcome of the 2D inversion is comparable to each other. Very thin weathered apatite layer represents by 400 **Ω***m (yellow colored) horizon, whereas the hard apatite-cap reveal by red-colored horizon (in the resistivity range of 3000-4000* **Ω***m. The leachate, weathered phosphate-rich matrix of the host, is having very low resistivity values below 100* **Ω***m. The bedrock is in the depth range of 30-35m, which is having high resistivity vales with gradual weathering character. The drilling reveals the bedrock as marble.*

- Both 1D and 2D results match with the drill-hole logs and confirm the applicability of resistivity technique in model synthesize.

- The proposed model, Figure 07, is a fair representation for the apatite occurrence and background geology of the Northern Sector of the Deposit.

- The bedrock is hornblende-biotitic gneissic rock that is common for the entire region and the occurrence of granite is yet to be fully explained with geological relations.

- Though the proposed model I to be applied for the Southern Sector, there are marked difference of geology of two sectors, as carbonatite exposures are prominent in south and Northern Sector is dominated by apatite rich phosphate.

Prepared the following map acquiring resistivity profiles, magnetic lines and VES data points along with the RTK measurements

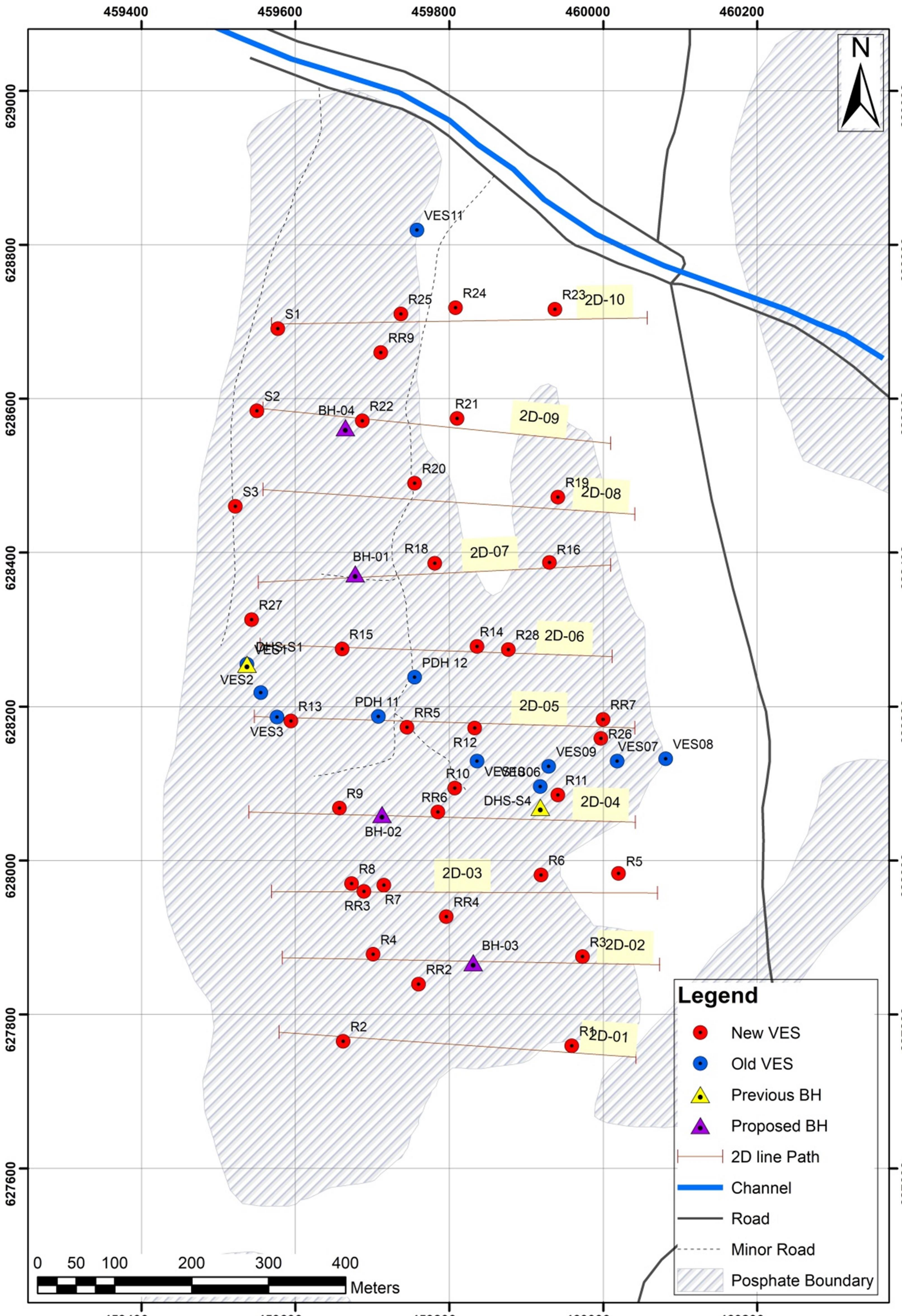


Figure 5.4: map of raw data acquisition: resistivity profiles, magnetic lines and VES data points along with the area that RTK measurements were conducted.

5.2. Correlation of Resistivity Data

During the studies that were conducted for the Northern Sector, two drill-holes were drilled in the Southern Sector to assess the bedrock characters. These two locations were purposely selected in the background and close to the carbonatite/apatite formations, enabling to assess the boundary. Outcome of drill-hole logs were correlated with the resistivity signatures and response curves developed for appropriate earth models.

The resistivity analysis almost perfectly matched with the drill-hole data assuring the appropriateness of resistivity technique for the set objective.

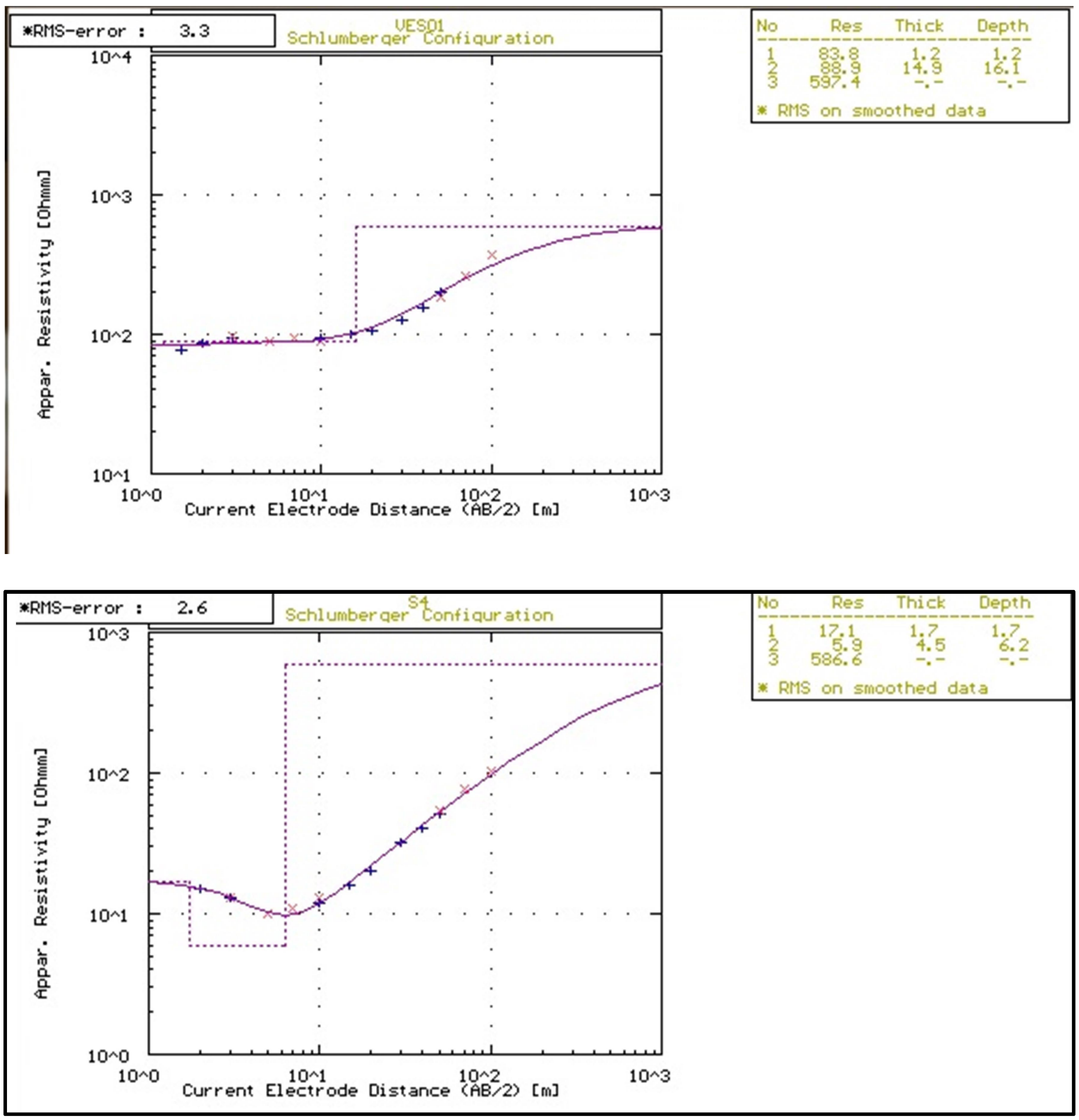


Figure 5.5: Resistivity response for earth-models in the Southern Sector of the apatite occurrence. An additional curve to represent near-surface carbonatite occurrence

5.2.1.One-D resistivity analysis

The 1D VES responses of over 50 VES locations, aquired under this project and previous work, have been analyzed and catergorized into five groups while compaing with the response obtained in the Northen Sector. The responses received in the Southern Sector could be explain with an additional curve, that is representating carbonatite occurrence at the surface and/or near surface levels, which is not observed in the Northern Sector, prominently.

The four groups that are identified for the Southern Sector is representing the background (Three-layer and two-layer curves, BG-1 and BG-2, respectively) and the apatite occurrence. Depending on the presence of hard cap of apatite and only the apatite crystal rich weathered martial, the resistivity responses vary slightly, though the general curvy pattern is preserved with lesser positive gradient for the presence of hard apatite cap just beneath the apatite-rich overburden.

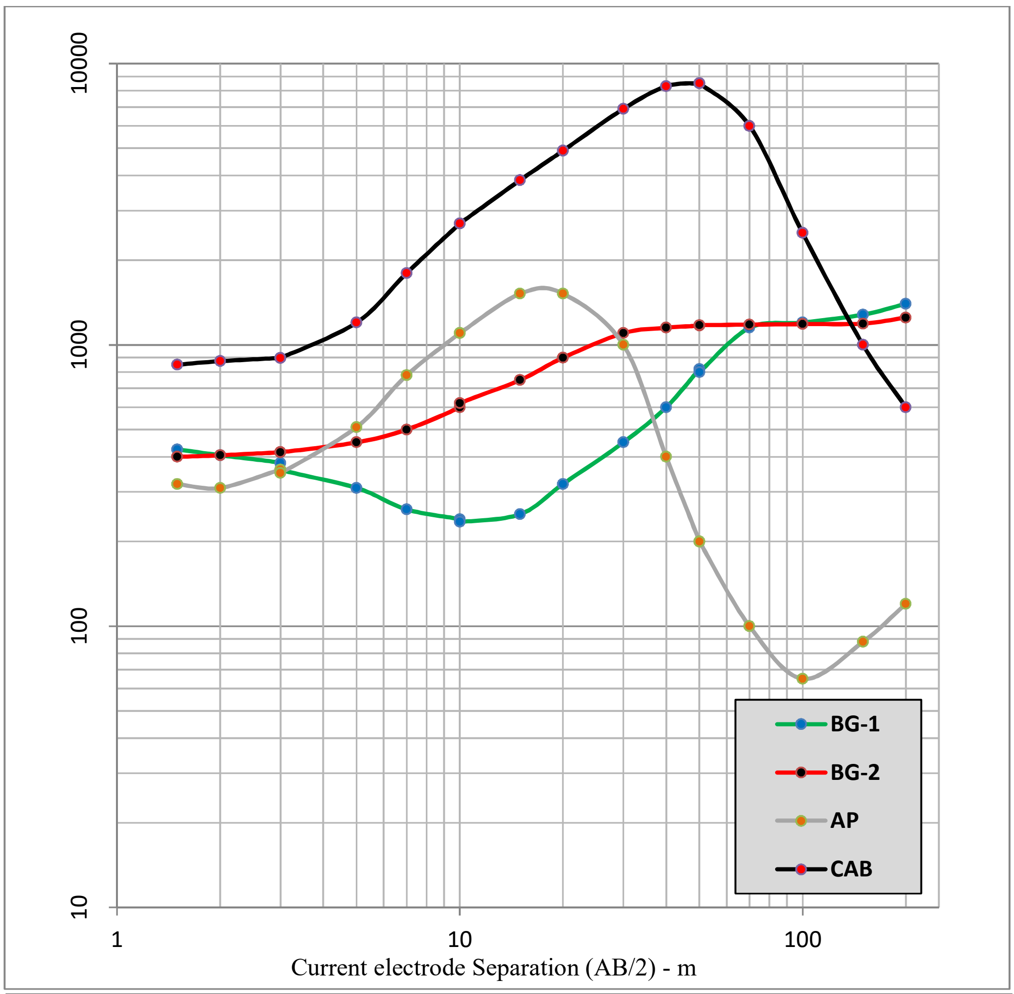


Figure 5.6: One D Resistivity response for earth-models in the Southern Sector of the apatite occurrence. An additional curve to represent near-surface carbonatite occurrence

BG-1, BG-2 and AP responses have already been explained in previously in section (4), in "Model synthesis and resistivity signature", and similar characters are observed in the Southern Sector as well, except CAB.

CAB: The curve represents three-layer case and in some locations two layer case as well. The overburden is usually apatite rich partially weathered matrix and the bottom layer is ultra-resistive carbonatite. The thickness of the carbonatite varies significantly, and in some location low resistive intermediate layer is observed, possible the contact zone between the apatite/carbonatite horizon and the general bedrock, which is hornblende biotitic gneiss.

The analyses of the 1D VES curves are presented in the Annexure-1. VES data is analyses with the assistance of RESIST freeware and the outcome of this analysis is tabulated in the Table-X. The following table, Table-1, summarizes the different responses as of the locations enabling to screen-out the apatite/carbonatite occurrence from the background particularly with subsurface extension.

Table-5.1: Resistivity response for earth-models in the Southern Sector of the apatite occurrence. An additional curve to represent near-surface carbonatite occurrence

Type	VES Locations	Description
BG-1	R3,R5,R10,R12,R14,R16,R18, R19,R20,R21,R23, R24,R25,R27,R28,S2,VES2, VES06, VES07, VES08	Background response for three-layer general case, which is very common throughout the metamorphic terrains in Sri Lanka.
BG-2	R6,R11,R17,S1,S3,VES1, VES09,VES10	Two-layer response for background response
AP-1	R4,R7,R8,R9,R22,VES3, BH1	Prominent for phosphate occurrence with a hard apatite cap
AP-2	R1, R2, R26, BH2	Potential for phosphate occurrence.
CAB	R13, R15, BH1?	Carbonatite occurrence at and/or near-surface.

5.2.2 Two D analysis of Southern Sector of Eppawala phosphate deposit

As outlined in the Figure-5.4, ten 2D resistivity profiles were obtained along ten almost parallel lines with 100m nominal line pacing. Outcome of the 2-D resistivity analysis imply clearly outlines the occurrence of high resistive area of the study that resembles for the presence of carbonatite/apatite formations (Annexure 5-2D resistivity profiles across the study area and table)

5.3. Digital Elevation Model (DTM)

As a prior requirement for reserve estimation, morphology of the study area has been analyzed with an aid of DTM (Digital Terrain Model). As outlined in the methodology, the TDM has been constructed based on the point-data acquired along the profile lines and random locations where access is permissible.

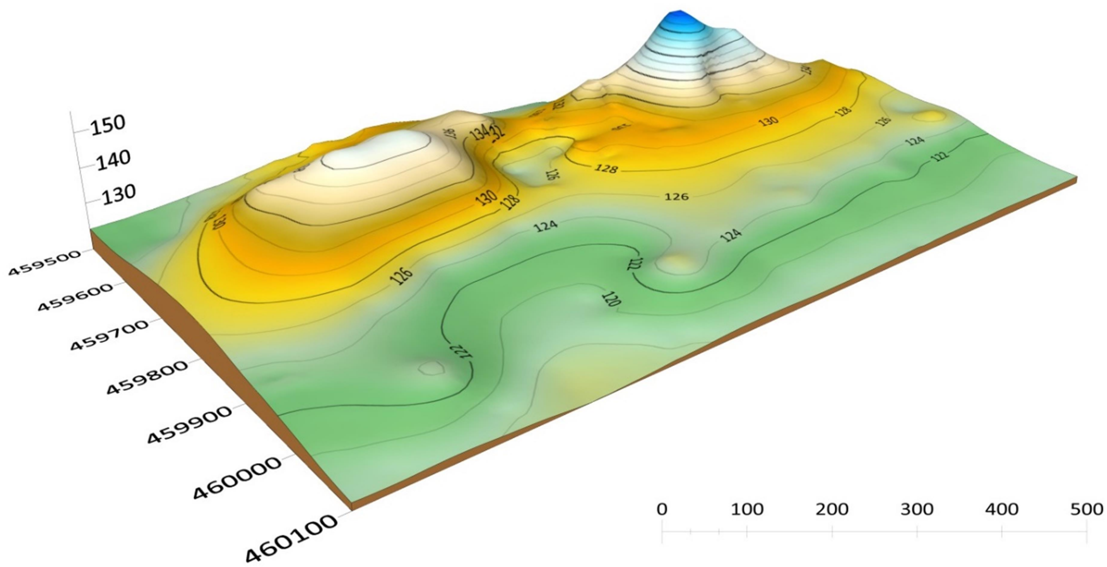


Figure 5.7: Digital Terrain Model (DTM) of the Southern Sector synthesized by spot data acquired from the RTK survey

The general surface elevation of the study area is considered to be 124m from the Mean Sea Level (MSL) and the highest point of the survey area is 155m and the general surface level is approximately 20m above the height of the Jaya Ganga left-bank. A parallel less prominent positive undulation is observed east of the main hillocks with surface exposures of fresh and partially weathered apatite crystals.

The natural terrain is disturbed by quarry operations and substantial amount of material has been removed from Profile-5 to Profile-8.

5.4. Generation of a model for Southern Part

The resistivity analysis and auxiliary data from magnetic measurements were synthesized along with terrain model to generate generalized model for the apatite occurrence of Southern Sector of the deposit. The presence of carbonatite is considered in synthesizing this model.

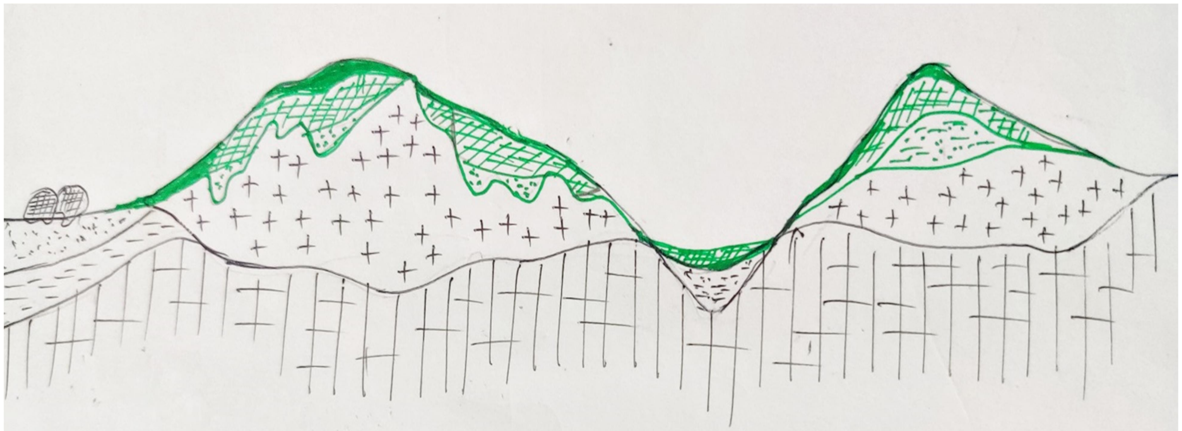


Figure-5.8: Model for the apatite occurrence in Southern Part: The apatite bearing zone, both leachate and the fresh part of the apatite material, is marked in green color. The apatite bearing package is resting on carbonatite and inclusion of apatite material into carbonatite host also observed on random basis.

In the process of constructing of cross-sections and surfaces for reserve estimation, the following main three categories were considered:

(a) Surface layer – based on RTK measurements (Digital Terrain Model)
(b) Apatite bearing layer: based on moderate resistivity values coupled with drill-hole information
(c) Bottom layer: this layer either could be the carbonatite host and/or bedrock of the area. The carbonatite host is identified due to ultra-high resistivity values. The presence of the bedrock is identified by VES curve characters.

These three main surfaces were constructed numerically and reserve calculations were conducted based on the relative thickness of these main layers. The 120m contour line is considered as the base level the calculations were done for positive and negative surfaces, as the apatite occurrence extent below the general ground level and above the left-bank level of Jaya Gaga which is the agreeable level for mining.

Construction of main surfaces obtained by using amalgamated field data as given in following figure.

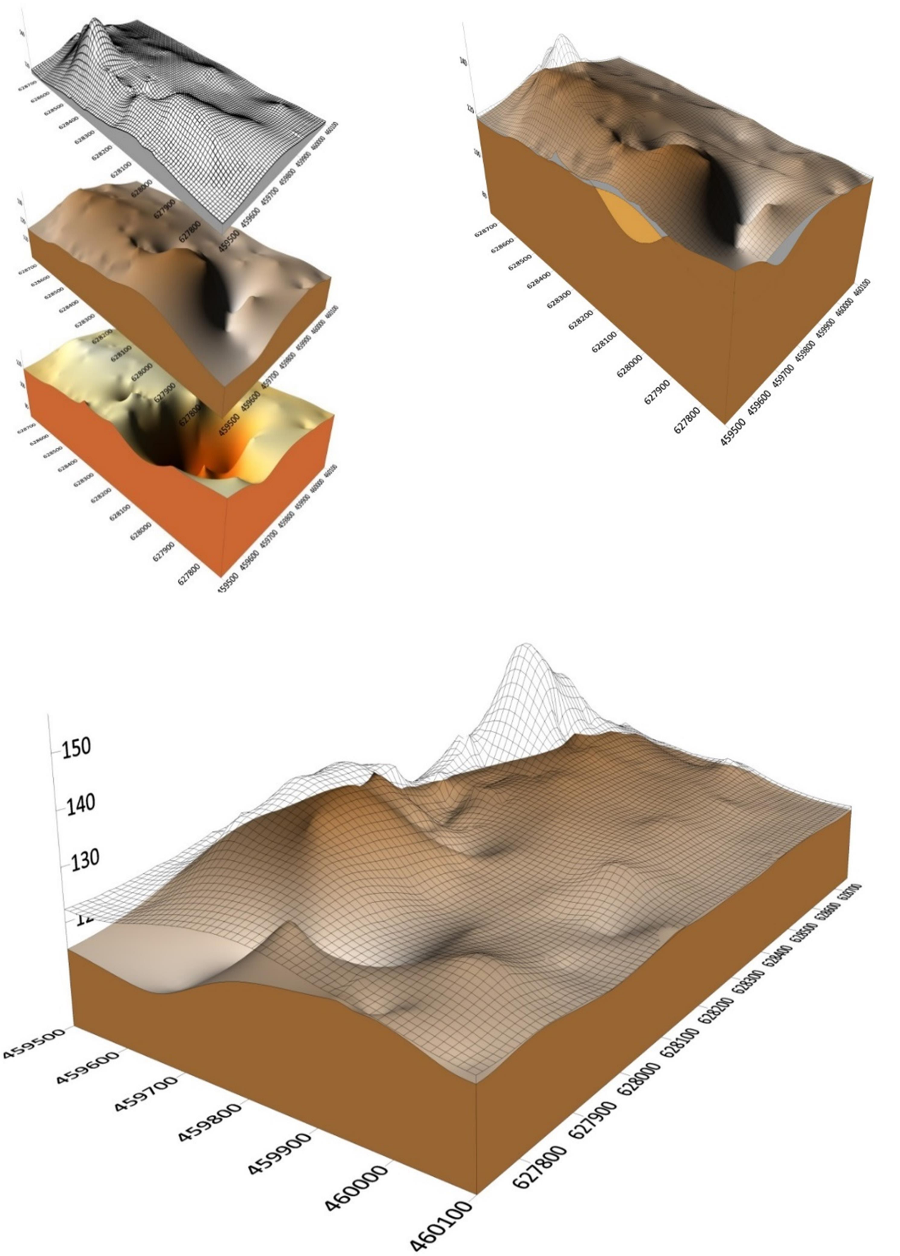


Figure-5.9: The three main surfaces superimposed with the bottom layer of carbonatite/bedrock. The material in-between has been calculated with analysis of the three surfaces

5.5.Calculation of reserve at Southern Part of deposit

As of the constructed surfaces, the minable volume has been calculated considering 124m contour level as the general surface. The Jaya Ganga bank level is far below the survey area, hence the minable volume below the general surface also considered as operable quantity.

Table 5.2: Grid calculations based on the constructed surfaces

Grid Volume Computations

Wed Sep 28 22:59:30 2022

Upper Surface

Grid File Name:	D:\Desktop\Surfer\EPPAWALA.grd
Grid Size:	100 rows x 58 columns
X Minimum:	459500
X Maximum:	460100
X Spacing:	10.526315789474
Y Minimum:	627730
Y Maximum:	628760
Y Spacing:	10.40404040404
Z Minimum:	116.44944591939
Z Maximum:	156.70722914903

Lower Surface

Level Surface defined by Z = 124

Volumes

Z Scale Factor:	1

Total Volumes by:

Trapezoidal Rule:	1845212.1388607
Simpson's Rule:	1845643.7444793
Simpson's 3/8 Rule:	1845693.1143436

Cut & Fill Volumes

Positive Volume [Cut]:	2559180.5234692
Negative Volume [Fill]:	714000.3862584
Net Volume [Cut-Fill]:	1845180.1372108

Planar Areas

Positive Planar Area [Cut]:	390212.17736076
Negative Planar Area [Fill]:	227787.82263924
NoData Planar Area:	0
Total Planar Area:	618000

Surface Areas

Positive Surface Area [Cut]:	392874.30310813
Negative Surface Area [Fill]:	228059.92190085

Grid Volume Computations

Wed Sep 28 23:01:02 2022

Upper Surface

Grid File Name:	D:\Desktop\Surfer\APcap.grd
Grid Size:	100 rows x 58 columns
X Minimum:	459500
X Maximum:	460100
X Spacing:	10.526315789474
Y Minimum:	627730
Y Maximum:	628760
Y Spacing:	10.40404040404
Z Minimum:	100.80253277901
Z Maximum:	137.00423531523

Lower Surface

Level Surface defined by Z = 124

Volumes

Z Scale Factor:	1

Total Volumes by:

Trapezoidal Rule:	-516538.43137798
Simpson's Rule:	-516481.58314162
Simpson's 3/8 Rule:	-516267.59157996

Cut & Fill Volumes

Positive Volume [Cut]:	1161783.3026468
Negative Volume [Fill]:	1678307.3525237
Net Volume [Cut-Fill]:	-516524.0498769

Planar Areas

Positive Planar Area [Cut]:	267671.73312037
Negative Planar Area [Fill]:	350328.26687963
NoData Planar Area:	0
Total Planar Area:	618000

Surface Areas

Positive Surface Area [Cut]:	268571.92963297
Negative Surface Area [Fill]:	351540.61772541

Total minable volume (above the surface) = 1845693 m^3

Total minable volume (below the surface) = 516267 m^3
(The negative values are displayed in the grid calculation as the base contour level is considered to be 124m of MSL
The total minable volume = 2361960 m^3
(L) The average specific gravity of rock phosphate is 3.18 *(JW Brinck, 1978).*
(M) The total minable reserves = 2361960 m^3 * 3.2
(N) The total minable reserves in the Southern Sector = **7,511,033 t (Metric tons)**

6.0 Discussion

The first estimation of the reserves of leached rock phosphate was carried out in 1970's using core data. Since around 1974, Eppawala rock phosphate deposit is being mined up to date. Hence, a vast area of the ground exhibits uneven topography due to unsystematic mining conducted. However, the previous drilling data is apparently not possible to use in the present estimation due to incompleteness of details. Perhaps some areas are totally mined out and it is hard to recognize the drill hole locations due to severely disturbed ground surface. Therefore, a fresh intergraded survey was planned to carry out for reserve estimations of Rock Phosphate deposit in two successive stages as survey for northern and southern parts in this assignment.

During the survey at Northern Part, investigation included a level survey, detailed geological mapping and a drilling campaign. Based on the results of leveling and mapping, about thirty new drill hole locations were identified to cover the entire northern part of the deposit. Here 18 out of 30 drill holes are inclined holes (65^0-70^0) put down in different directions in order to capture more details on the subsurface geology, for estimate rock phosphate reserve at Northern Part. The core recovery of some drill holes was very poor as of the unconsolidated nature and weathering conditions of the ore body. Cavities were commonly identified in the apatite rich leached phosphate rock. Based on field measures phosphate deposit at Northern Part was clustered into 5 Blocks, using the leveling data (morphology), detailed geology map and drill hole data to make easier the calculation of reserves. About 172 samples were collected from all drill holes and each of them was analyzed for oxides of Mg, Si, Ca, P, Al, Fe^{3+}, K, Na, Mn, Ti and LOI (Annexure 3).

The P_2O_5 percentage of each sample of each drill hole was used to classify the apatite rich formation as leached zone and the other one as apatite rich in-situ & float zone. The in-situ & float zone is softer than the leached apatite zone. Also, the average P_2O_5% content of leached zone and apatite rich in-situ & float zone of each drill hole was calculated. Then the average P_2O_5% content of leached zone and apatite rich in-situ & float zone of each "Block" was calculated using the data of drill holes located within each Block. The core recovery percentage of each drill hole was highly considered to calculate the thicknesses of zones. Modeling of these zones was conducted using computer based 3D modeling software. Further it was used to calculate the reserves above 117 m MSL, concentrating for surface mining activities. The level 117 m above MSL is considered as the general ground surface level. Then the reserves calculated up to the level 92 m above MSL, endorsing below surface excavations till 25 m down from the general surface level. Accordingly, it was found that, mineable reserves of rock phosphate at northern part up to general ground level for surface mining is 12.78 million tonnes (averaging 34% of P_2O_5), and the amount of **reserves** for below surface mining is 23.95 million tonnes (averaging 34% of P_2O_5) 25m down from general surface level. A different approach was made to quantify the Sothern Sector of the Eppawala Phosphate deposit; a model has developed based on geophysical responses (resistivity and magnetic measures) in correlation with a very limited number of drill-holes.

In Southern Part, resistivity technique has been considered as the primary method in this model development, as the target mineral is having a resistivity contrast to the background rocks. Magnetic measurements over the phosphate occurrences produced an anomaly as the magnetite is found as gangue mineral of phosphate/carbonatite formations.

The survey outcome of the Northern Part of the deposit is based on comprehensive result of surface/ subsurface geological conditions of phosphate rich deposit, was analyzed in model development for the Southern Part via correlating and calibrating of geophysical response with the ground truths. A precise height at Southern part of the terrain of phosphate/carbonatite deposit was obtained by RTK to synthesize detailed Digital Terrain Model (DTM). In presence of these different formations, appropriate geophysical responses were developed to screen the same enabling for reserve estimation. It revealed that, a mineable reserve of 7.5 million tonnes of rock phosphate is confined to the Southern Part. Based on the knowledge and pattern estimated the reserves and **the total mineable reserve of Rock phosphate deposit at Eppawala is 31.5 million tonnes.**

The main difference that observed in the Southern Sector compared to the Northern Sector is in the pattern of intrusion of fresh carbonatite along with bulk apatite rich zones. Apatite crystal embedded carbonatite is composed of calcium carbonate. Considered the demand for pure calcium carbonate, raw material for many local industries, the potential of the carbonatite shall be considered thoroughly as a secondary industry to operate in parallel with phosphate mining.

A large part of the areas with apatite occurrences has been heavily encroached by dwellers over the period of last two decades (Mahaweli settlements). Though these areas are outlined as phosphate bearing zones in consecutive maps, the minable reserves in the encroached areas remain very low. The main rock phosphate appeared in the Southern part is confined to the hillocks. Some of the prospective areas remain untouched were under short-term chena cultivation. The studies in both sectors reveal that there is a specific morphological control for apatite occurrences with minable quantities.

7.0 Conclusions and recommendations

* Mineable quantity of apatite rich and leached rock phosphate zones (averaging 34% of P_2O_5) at northern part of Eppawala Deposit is **12.76 million tonnes**, if exploit rock phosphate up to the general ground level (117m above MSL).for surface mining
* Also the mineable reserves of apatite rich and leached rock phosphate zones (averaging 34% of P_2O_5) at northern part of Eppawala Deposit is about **24 million tonnes as mineable reserves** confirmed by core logging data for below surface mining (up to 92 m above MSL).
* Survey at Southern Part revealed the mineable phosphate reserve as **7.5 million tonnes.**
* **Total mineable tonnage** of rock phosphate reserve at **Eppawala Deposit is 31.5 million tonnes.**
* Surface geological mapping revealed that, the presence of exposures of apatite rich boulders and leached zone is comparatively larger in southern part than in the present study area.
* Majority of land area of the southern part of the deposit is prominently residential according to the field survey.

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