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Geology and Mineralization of Bikilal phosphate deposit, Western Ethiopia, implication and outline of gabbro intrusion to East Africa zone

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Abstract

The Bikilal layered gabbro-complex is composed of zones/layers of olivine/ pyroxene gabbro and hornblende gabbro. Within the hornblende gabbro, repeated lens-like thin and elongated bodies of hornblendite are found intimately associated with massive and disseminated ilmenite-magnetite bodies, in places with apatite. Petrological examination of the hornblende gabbro shows 50-55% hornblende, 40-45% plagioclase, 5-7% opaque minerals/ilmenite + magnetite/, and 5-15% apatite and that of hornblendite shows 75% hornblende, 10-15% apatite, 10-15% ilmenite and rare sulphides, and traces of Uranium. Regardless of the type of lithological units, two main zones of phosphate mineralization ,the upper and lower zones, were identified and delineated entirely based on phosphate (P_2O_5) assay values of chip, channel and, core samples, .

The strike length of the upper zone is 1600m. There are two main layers of phosphate mineralization in the upper zone; the average thickness of each layer is 30m and 40m respectively. The strike length of the lower zone is 3000m having a thickness of 60m – 200m. The mineable reserve of Soji-Bikilal phosphate deposit is estimated to be 181 million tons, at a grade of 3.5% P_2O_5 . Preliminary beneficiation trial reveals commercial grade concentrate, at which the overall weight recovery, is in the range of 3-5%. The Radioactivity of Uranium has not been determined and hence re-evaluation of the phosphate rock for Uranium content should be carried out. Similar Gabbro intrusions occur in Western Ethiopia and in East Africa which should be assessed for phosphate potential to develop the fertilizer potential of the East Africa Region.

Keywords: Phosphate, Apatite, Hornblende gabbro, Hornblendite, Soji Bikilal.

1. Introduction

A project was initiated to locate and assess local phosphate resources in Ethiopia. Investigations were made on some of the potential resources of phosphate, namely, the Mesozoic-Cenozoic rocks, the Precambrian metasedimentary sequences and the intrusive rocks of alkaline basic-ultrabasic rocks. Consequently, the Bikilal layered gabbro complex has been found promising [1, Table1] and systematic exploration activities for apatite were conducted on it since 1986. Soji-Bikilal is located in the western Welega zone of the Oromia National Regional State, 24-km NNE of Gimbi town. Gimbi is 440 km west of Addis Abeba. The project area is geographically bounded by long. $35^{\circ}52'37''E$ - $35^{\circ}53'41''E$, and lat. $9^{\circ}18'30''N$ - $9^{\circ}19'42''N$.

Robertson Research Minerals, Ltd (RRM Ltd.) in conjunction with, the Geological Survey of Ethiopia (GSE) was able to conduct project preparation that included data evaluation, field exploration and laboratory analysis.

However, RRM faced financial bankruptcy and Consult 4 International, a South African Mining Consulting firm, took over the study.

As a result of successive geological exploration work, a target area of 4 km² was selected and 18 profile lines of 200 m. spacing were cut and a number of pits dug at an interval of 40 m. along the lines. Fifteen trenches were also excavated between the profile lines to confirm the strike continuity of the apatite bearing bodies [2].

Drilling work was started to determine the strike, dip angle and direction as well as the thickness of the apatite-bearing hornblende gabbro and hornblendite units on the selected upper and lower zones of the target area, along with core sampling for chemical analysis, petrographic study and mineral separation trials.

A total of thirty boreholes were drilled to a total meterage of 7159.73Lm and 5534 core samples were collected.

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Table1. Average chemical composition of core samples from bore holes drilled in the Bikilal layered Gabbro Complex

Borehole	Sampling Interval	Length	Recovery	Weighted mean values (%)					Range of P ₂ O ₅	Equivalent %		No of samples
				P ₂ O ₅	TiO ₂	Fe ₂ O ₃	FeO	V ₂ O ₅		Apatite	Ilmenite	
103	148.82-256.50	10768	91.90	3.19	6.37	4.79	14.11	0.09	1.90-5.10	7.82	12.48	47
210	92.50-101.90	940	9.40	2.65	6.71	5.96	16.41	0.045	2.22-3.33	6.50	12.75	4
208	118.62-140.82	22.20	22.20	2.88	5.27	4.03	13.89	0.07	1.90-3.90	7.06	10.01	12
9	170.40-150.55	10.15	10.15	3.28	5.26	5.22	14.57	0.069	2.44-4.48	8.04	9.99	8
9	185.40-193.05	7.91	7.91	3.08	6.28	5.11	17.43	0.045	2.44-3.97	7.55	11.93	8
9	199.90-202.30	2.40	2.40	2.14	5.87	4.74	17.97	0.045	2.14	5.25	11.15	1
12	154.44-157.14	2.70	2.70	2.13	9.85	9.35	20.65	0.045	2.13	5.22	18.72	1
206	26.97-76.22	42.50	42.05	3.80	8.37	8.52	15.80	0.102	2.28-5.30	9.31	15.90	26
205	48.1042.50	14.40	8.12	3.07	7.77	5.83	18.55	0.10	2.00-3.75	7.52	14.63	9
304	288.94-293.3	4.00	4.00	3.40	6.02	8.85	17.19	0.089	3.14-4.03	8.33	11.44	3
302	62.67-110.60	47.93	9.02	4.70	5.60	7.75	14.86	0.089	2.10-5.80	11.52	10.64	9
310	47.96-59.92	11.96	11.96	2.52	5.27	3.81	12.26	0.07	2.27-2.80	6.18	11.74	6
310	166.12-79.12	13.00	13.00	2.05	6.90	7.49	16.53	0.108	0.29-3.20	5.02	13.11	8
307	89.66-93.50	3.90	3.90	1.98	4.34	5.27	15.86	0.069	1.83-2.15	4.85	8.25	2
309	171.95-190.7	18.80	18.85	3.85	3.15	5.69	14.23	0.058	2.39-4.64	9.44	9.79	7
308	90.00-103.75	13.75	5.67	3.99	3.41	7.27	15.03	0.029	3.79-4.90	9.78	10.28	4
402	213.08-220.02	6.94	6.94	3.78	4.41	4.70	14.97	0.061	2.75-4.27	9.26	8.38	6
401	149.35-152.31	2.96	2.96	3.69	4.06	4.14	15.72	0.045	3.59-3.74	9.04	7.71	2
401	159.15-165.35	6.10	6.10	4.63	6.07	7.32	16.76	0.045	3.43-6.18	11.35	11.53	4
406	242-244.53	2.53	2.53	2.61	5.89	9.30	13.55	0.045	2.29-2.82	6.40	11.19	2
407	13.17-42.74	29.16	29.16	3.93	7.01	6.91	14.68	0.068	2.97-5.10	9.63	13.32	13
408	10.62-28.68	18.06	14.78	4.06	11.5	8.61	14.98	0.058	2.68-5.51	9.95	21.98	9
411	11834-159.02	40.68	17.78	3.63	7.23	7.92	15.69	0.09	2.60-4.40	8.90	13.74	13
412	114.88-124.78	9.95	9.95	3.63	7.49	5.68	17.07	0.098	2.80-4.20	8.90	14.23	6 ¹

Source: Apatite and Magnetite-Ilmenite Resource of the Bikilal layered Gabbro Complex [1]

2. Methodology

As the target is located at the northern extreme curvature of the gabbroic complex, three base lines, with an E-W, NW-SE and N-S orientation were constructed to start with the detailed exploration activities.

A total of eighteen profile lines were surveyed perpendicular to each base line, at a spacing of 200m; pitting was conducted at 40m interval along each profile line. Trenching was conducted in between the profile lines, in order to confirm the strike continuity of the apatite bearing zones. The weighted mean P₂O₅ assay values of channel and chip samples from pits and trenches were considered to delineate and select the

two main zones (upper and lower zones) of phosphate mineralization for drilling.

The channel, chip and core samples were analyzed for five oxides (P₂O₅, TiO₂, Fe₂O₃, FeO and V₂O₅). The majority of analytical work was conducted at the central laboratory of the Geological Survey of Ethiopia (GSE). Two methods of analyses were used, wet chemical tests (Aqua Regia) with Atomic Absorption Spectroscopy (AAS) and X-ray fluorescence (XRF) analysis. Sample preparation for core samples consisted of crushing the whole sample of split core to – 5mm, riffle splitting to 250g and then milling. Selected check samples were analyzed at the Lakefield laboratory in Johannesburg, South-Africa, for check analysis. Overall, the P₂O₅ comparisons between the GSE laboratory and Lakefield were good. The quality

of assay information regarding laboratory accuracy has been assessed, and is considered acceptable.

Apart from various petrographic analyses conducted for the main lithological units in the central laboratory of the GSE, Consult 4 selected 20 samples from a selection of rock types encountered in the drill core. Samples were selected to cover both upper and lower phosphate zones and a variety of rock types and were collected as 10 cm samples from within selected intervals. These samples were submitted to MINTEK for analysis by polished thin sections to pay particular attention to the distribution of apatite.

Detailed examination of each sample was made using both reflected and transmitted light microscopy to identify mineral phases and to describe the rock texture. According to Consult 4 International 2001, the modal percentages of apatite were estimated by visual inspection and apatite grains were measured in section and parallel to the long axis using a graticule.

Mineral separation (beneficiation) process was developed by Bateman Phosphate Technologies (BPT), South Africa, to determine the recovery. The following beneficiation procedure was conducted:

- The ore was subjected to four stage dry crushing to 100% finer than 0.3mm size.
- Dry screening
- The crushed phosphate ore was classified into size of 45 μ with an air classifier; some portions of the ore being discarded as finer reject.
- The deslimed size fraction of - 300 / + 45 μ was consequently subjected to two stages of dry magnetic separation, achieving significant upgrading.

Two strategies were designed to determine the strike and dip of the lithological units, which were the basis to decide the angle and azimuth of drilling. The drilling work was conducted by truck mounted drilling rigs fitted with diamond bits. As the area is covered by the gabbroic complex and the dips vary from place to place within a short distance, the general attitudes of the lithology need to be determined prior to intensive drilling. "Three point problem method" was applied to determine the strike and dip of the lithological units of the upper zone while, the "intersection angle measurement method" was applied for the lower zone to determine the dip of the lithology.

The average dip angle was calculated to be 43⁰ towards 225⁰ (SW) and the strike measured to be 315⁰ (NW-SE). Accordingly, 10 vertical boreholes were drilled, at an interval of 70m following the strike and down dip of the apatite-bearing lithology of the upper zone.

Concerning the lower zone, a vertical test borehole designated as BK 603, (Fig.1) and an inclined test borehole, BK604, (Fig.1) were drilled to determine the dip of the lithology of the lower zone by an intersection angle measurement method. Shallow angles of intersection (15⁰-20⁰) were measured from the core samples of the vertical test borehole, while an

intersection angle ranging from 45⁰-50⁰ were measured from the core samples of the inclined test borehole. This implies that the dip of the lithology in the lower zone is steep (70⁰-75⁰).

Therefore, it was decided to drill the successive boreholes at 60⁰ inclinations so as to intersect different lithological units, with a minimum depth of drilling. Accordingly, 15 inclined boreholes were drilled at 60⁰ inclination towards N and NE azimuth, following the strike of the apatite bearing lithology of the lower zone, at a spacing of 200m.

3. Geology

As part of a syn- to post-tectonic intrusion, the Bikilal gabbro complex intrudes the Precambrian gneiss, low-grade metamorphic rocks and minor ultramafics [3].

The Bikilal Ghimbi gabbro is the largest and well-documented, and hence is used as a comparison for the other bodies. It is elliptical in shape and covers an area of 350km². It consists of olivine gabbro in its center and hornblende gabbro and hornblendite at the perimeter [4].

The gabbroic complex is emplaced close to the boundary of the low-grade and high-grade Precambrian gneiss. The Precambrian rocks comprise mainly granite, meta-diorites, schists, phyllites and amphibolites. At places younger granites intrude the sequence. There are also localized exposures of meta-sedimentary rocks and amphibolite that occur as xenoliths [1]. The northern extreme part of the intrusive body was selected for detailed exploration of phosphate prospect, at a scale of 1:2000. Based on surficial and subsurface (pitting and trenching) information, field phosphate tests and visual examination of apatite mineralizations, three major and three minor favorable lithological units were identified in the target area. The major lithological units are olivine/pyroxene gabbro, hornblende gabbro and hornblendite. The minor lithological units are pegmatites, anorthosite, and meta-sediment (Fig.1). The gabbroic complex is composed of zones/layers of olivine gabbro, leuco-gabbro and hornblende gabbro making up the bulk mass. Within the hornblende gabbro, repeated lens-like thin and elongated horizons of hornblendite are found intimately associated with massive and disseminated ilmenite-magnetite bodies, in places with apatite. All units generally dip towards the center of the intrusive with dip angles ranging from 45⁰-75⁰ [1]. The major structural trends are reflected in the regional lineaments of the study area trending NWW – SEE, NW – SE and NE – SW. The NWW – SEE trend is assumed to predate the NW – SE trend which in turn predates the NE – SW trend. Faults do not display pronounced displacement. However, fault zones are marked by brecciation and altered clays as fracture fill [5]. The Bikilal-Ghimbi Complex consists

of apatite-free olivine gabbro, hornblende gabbro, and hornblendite suites and their apatite-bearing equivalents [4]. Description of each lithological unit supported by petrological examination is described as follows:

Pegmatites

Pegmatitic veins were intersected by drilling in the lower zone. They are dull – white and coarse grained with a grain size of 5 – 6mm and composed of quartz, plagioclase and muscovite. The thickness of pegmatite veins intersected is not usually greater than 10m.

Olivine /pyroxene Gabbro

The unit is encountered in two distinct varieties namely porphyritic (towards the center) and massive (outer). The latter variety is identified and exposed in the southwest part and at the central and southern – parts of the target area. It is dark grey to grey and medium grained (2–4mm). Petrological examination of the specimens from the unit showed the following composition; from 5-10% olivine, 20-30% pyroxene, 55-70% plagioclase, 3-5% opaques, with dominant subhedral to anhedral texture.

Hornblende gabbro

The unit is the dominant lithological unit in the target area. From apatite mineralization point of view, the unit is sub-divided into hornblende gabbro and apatite-bearing hornblende gabbro.

It is generally greenish grey to dark greenish grey. Coarser and finer varieties of the unit are observed; generally medium grained with an average grain size of 3-4mm. It is characterized by leucocratic to melanocratic varieties and composed of plagioclase, hornblende and variable amounts of ilmenite and sulphides with rare apatite grains.

As the unit is the outermost one, several inclusions of diorite, migmatite and amphibolite; dikes of microgranite and pegmatite veins are observed. Petrological examination of the specimens showed the following composition: 50-70% plagioclase, 25-40% hornblende, 5-10% opaque minerals (ilmenite + magnetite), with a dominant subhedral – anhedral texture.

Apatite bearing hornblende Gabbro

The major apatite-bearing hornblende gabbro bodies are distributed at the southwestern and northern part of the project area, with an E-W, NW-SE and N-S strike and southerly and south westerly dip at 40⁰-45⁰, in the southwestern part and dipping at 70⁰-75⁰ in the central northern and northeastern parts of the target area.

The unit is generally greenish grey with an average grain-size of 2-3 mm (medium-grained). It varies from mesocratic to melanocratic with an average mineral composition of 50-55% hornblende, 40-45%

plagioclase, 5-15% apatite, 5-7% ilmenite+magnetite, and rare sulphides. The melanocratic variety is the dominant lithological unit in the lower zone and is the chief host for apatite mineralization, where the apatite content reaches up to 15%. The mesocratic variety is more common in the upper zone and with relatively less content of apatite, usually not exceeding 5-7% [6]. Chloritization and typical plagioclase and amphibole bandings, making up the light and dark layers are observed in the lower zone at megascopic level [6]. Petrological examination of the samples from the unit shows: 50-55% hornblende, 40-45% Plagioclase, 5-15% apatite, 5-7% Ilmenite + Magnetite, with dominant subhedral-anhedral texture [7].

Apatite bearing hornblendite

The major apatite bearing hornblendite bodies are distributed in the central and southeastern parts of the target area.

The apatite-bearing hornblendite is dark greenish-grey, and is very fine grained (< 1mm). It generally shows orientation of minerals and banding but is rarely massive. It occurs as concordant, elongated, sub-parallel lenticular bodies of variable dimensions separated by meso- to melanocratic hornblende gabbro. Contacts are usually abrupt but gradational composition is also known. The mineral contents are identified as 75% hornblende, 10-15% apatite, with 10-15% ilmenite and rare sulphides.

Gray-coloured and fine-grained apatite-magnetite-ilmenite-tremolite-actinolite-disseminated ore assemblage is restricted to the lower zone in association with the apatite-bearing hornblendite. In some places such a variety is slightly chloritized in which the chlorite and hornblende intermix together.

Petrological examination of the samples also shows mineral compositions of 70-75% tremolite-actinolite, 15-18% ilmenite + magnetite and 5-12% apatite with hypidic-xenoblastic texture [7].

Anorthosite

The unit is encountered as patches within the hornblende gabbro unit, at the eastern side of the olivine/ pyroxene gabbro and it is the least extensive of all units. It is dull-white and fine- to medium- grained. It is usually composed of plagioclase up to 90% and hornblende makes up the rest.

Metasediment

The unit is encountered as a xenolith and identified in the core samples. It is schistose, greyish and very fine grained with grain size of < 1mm. Calcite veinlets and fractures are very common features.

Petrological examination shows the following composition: 60% quartz, 18-20% biotite, 5% garnet, 7% plagioclase, 4% K-feldspar and 4% opaque, with a dominant xenoblastic texture.



Plate-1 Apatite-Magnetite-Ilmenite Bearing Rock



Plate-2 Excavation of Trenching on Phosphate Rock Area

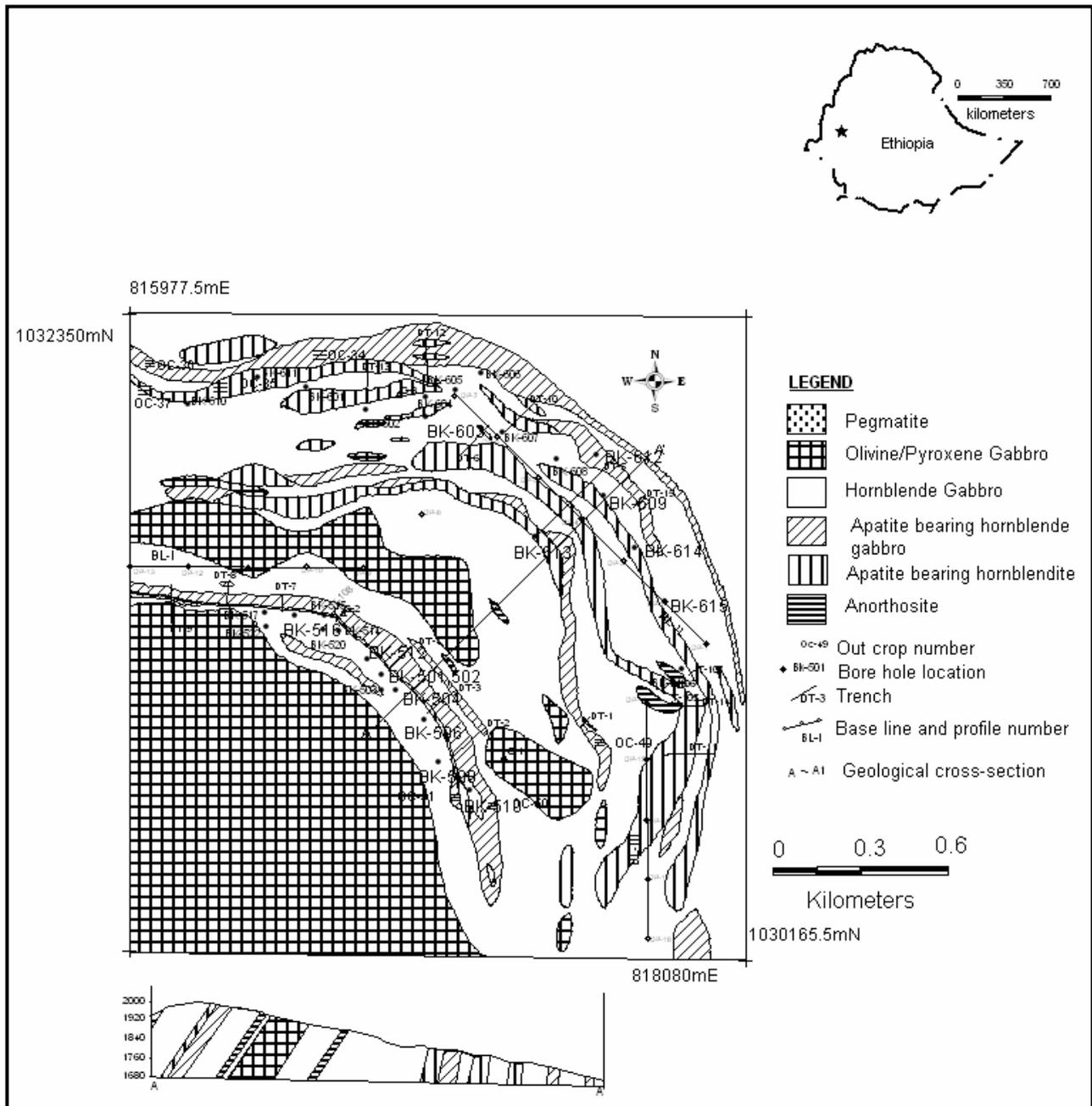


Fig. 1. Geology and Mineralization Map of Soji-Bikilal phosphate Deposit

4. Results and Interpretation

4-1. Geochemistry

From trenches totalling 1996.05 linear meters, a total of 919 channel samples were collected and analyzed for P_2O_5 , TiO_2 , Fe_2O_3 , FeO and V_2O_5 . Moreover 30 boreholes having a linear length of 7159.73 m were drilled and 5534 core samples were collected and analyzed. The geochemical anomalous

zones correspond with the major apatite bearing lithological units of upper and lower zones and the relatively elevated values of P_2O_5 represent patches of anomalies corresponding with the lenticular apatite-bearing lenses of hornblendite and hornblende gabbro.

Geological mapping has shown that the igneous banding is inward towards the center of the intrusion, and corresponds closely with the swing of the geochemical anomaly. The inference from this is that the apatite mineralization is strata bound [6].

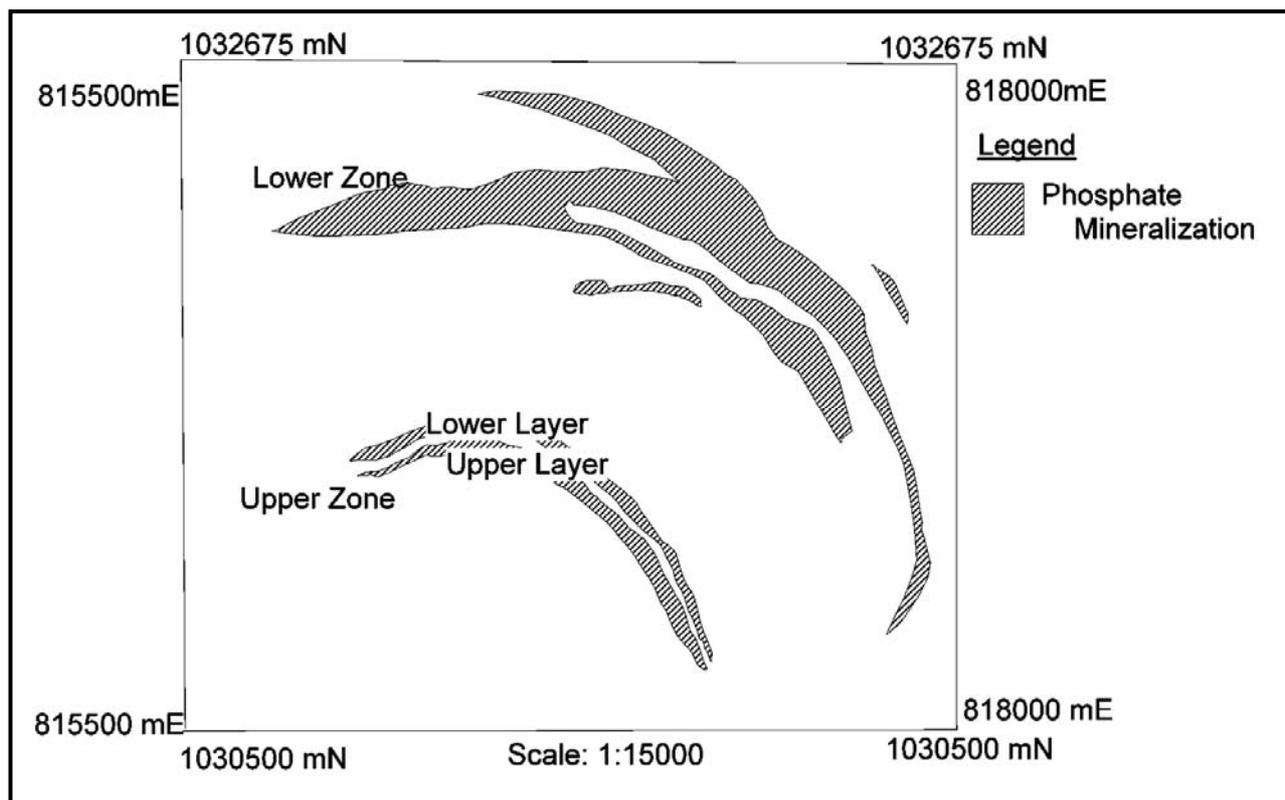


Fig. 2. Zones of phosphate mineralization of Soji-Bikilal (extracted from [8]).

Considering combined sections of boreholes and trenches, regardless of the litho-type of the lithological units, the P_2O_5 assay values of channel and core samples enabled us to delineate two main zones of phosphate mineralization (Fig. 2). The 3D-wire frame of the mineralized layers of both zones was outlined, by applying “Gemcom” software as processed by the consultant.

The P_2O_5 assay values were considered and plotted on each section of boreholes and trenches. The subsurface anomalous values of P_2O_5 were extrapolated and showed two main and one minor layers of phosphate mineralization in the upper zone. The lower layer of the upper zone was identified only on the boreholes sections. Based on surficial projection of the layer with the calculated dip angle 43° of the upper zone lithology, trench DT2, DT3, DT4 and DT8 were recommended to be extended 60m towards NE and N. The P_2O_5 assay values of channel samples from these trenches have therefore confirmed the surficial extension of the lower layer. Accordingly, the geological and mineralization map was refined.

The strike length of the upper zone was 1600 m. The thickness of the upper and lower layers of phosphate mineralizations are 30m and 40m respectively, separated by a 35m barren zone.

Similar interpretation of the data collected from boreholes and trenches of the lower zone revealed that in the southeastern part the zone reaches a thickness of

60m. In the middle of the strike extent, the zone splits into two with the inner layer being up to 100m thick and the outer layer up to 200m thick, separated by a 60m barren zone. In the northwestern end the deposit is over 100m thick. The strike length of the lower zone was 3000m [8, Fig. 2].

In the upper zone layers, the phosphate grade over the thickness of the layers is fairly consistent with occasional high grade patches and low grade patches. Overall, the mean grades of the upper and lower layers of the upper zone are 2.35% P_2O_5 and 2.62% P_2O_5 respectively.

In the lower zone, the phosphate grades are generally higher. The northern part of the lower zone is the best mineralized part of the deposit with phosphate grades averaging 3.7% over a width of 160m [8]. The main phosphate distribution is normal with an excess of low values. The mean grade of this zone is 2.78% P_2O_5 .

4-2. Mineralization

Apatite, ilmenite-magnetite, sulphides, and calcite constitute the common ore assemblage encountered in the phosphate deposit.

Apatite

It is hosted mostly in hornblendites, hornblende gabbro and apatite-ilmenite- magnetite- tremolite-

actinolite disseminated ores. Mostly the highest percentage of apatite mineralization is found in hornblendites and in melanocratic- hornblende gabbro, usually containing up to 15% apatite. There are generally two groups of size and shape of apatite crystals namely, long and thin (prismatic) and short and stumpy. Grain size varies between 0.14 and 0.31mm [1]. The apatite is of hydroxyfluor- apatite type with 40.05- 41.52% P_2O_5 content.

Apatite occurs as euhedral to subhedral elongate prismatic grains, probably formed early in the crystallization sequence. There is an intimate association between apatite and the oxide minerals, ilmenite and magnetite which either partially or entirely enclose euhedral apatite grains [5].

Magnetite-ilmenite

Although the proportion of ilmenite and magnetite is not well established, they are commonly associated with the lithologies of the area. They are mostly hosted in the apatite-magnetite-ilmenite-tremolite-actinolite disseminated ore, hornblende gabbro, and some olivine/pyroxene gabbro.

Sulphides

Sulphides (pyrite and chalcopyrite) are common accessory minerals within the hornblende gabbro as small grains and stringers constituting up to 4%. The sulphide minerals (pyrite and chalcopyrite) are distributed and found as coatings and fillings on apatite and ilmenite crystals as secondary deposition. This may be explained as late stage fluid injection into the original gabbro layering that causes severe alteration of the lithological units.

Calcite

Calcite is found along fractures and as thin veinlets, mostly common in the metasedimentary unit.

4-3. Mineral Separation (Beneficiation) Results

Three bulk samples from weathered ore and four from the hard rock (25 kg each) were collected from drill core material and submitted to Bateman Phosphate Technologies (BPT), South Africa, to undertake beneficiation process.

Following the previously mentioned beneficiation procedures, commercial grade concentrate was achieved at which the overall weight recoveries were in the range of 3-5%. In other words, 20-30 tons of ore is required to obtain one ton of phosphate concentrate. Assaying of the concentrate shows 33% P_2O_5 at 38% recovery. The magnetic separation steps enriched the phosphate from 4.9% P_2O_5 to 33% P_2O_5 . The concentrates produced from the Bikilal phosphate are high grade and contain low levels of contaminants and deleterious material. The phosphate appears to be acid

grade and was indeed of phosphoric acid specification [9].

5. Conclusions and Recommendations

The most abundant phosphate deposits in East and Southeast Africa region are related to igneous rocks. These deposits can be broadly divided into four categories. Carbonatite-related deposits are the most important category but apatite may also be found in association with basic intrusions, syenitic intrusions, and pegmatite bodies [10].

As a part of the Bikilal layered gabbro-complex, the Soji-Bikilal apatite-bearing zones in the hornblende gabbro and hornblendite are considered to be promising as igneous phosphate resources.

Apatite concentrations in igneous complexes are mainly confined to carbonatites, some nepheline - syenite complexes and small alkaline ultramafic intrusive complexes. Buddington and Lindsley [11], Lister [12], Philpotts [13], and Kolker [14], have studied the association of apatite with Fe - Ti oxides among others. All researchers studying the association of Fe - Ti oxides and apatite stated that there seems to be a genetic link between the Fe - Ti oxides and apatite mineralization.

Many of the Fe - Ti oxide - apatite mineralizations are associated with intrusions of anorthosite, gabbro, pyroxenites, and alkaline rocks. The Soji - Bikilal Fe - Ti - apatite mineralization appears to have many similarities with the known igneous phosphate deposits around the world. For the purpose of comparison, the Phalaborwa and Schiel igneous complexes of South-Africa are considered and described below.

The Soji-Bikilal phosphate deposit is a low-grade and a high tonnage deposit, at which the average grade of phosphate is within the range of 3.0%- 4.0% P_2O_5 .

Regardless of the type of lithological units, two main zones of phosphate mineralization are delineated, namely upper and lower zones, entirely based on P_2O_5 assay values of chip, channel and core samples.

The mineable reserve of Soji Bikilal Phosphate deposit is 181 Mt, at a grade of 3.5% P_2O_5 .

The Phalaborwa igneous phosphate deposit is known to have been mined since 1930. Apatite has been mined continuously since 1955 by Foskor Ltd. The phosphate ore is extracted from the Loolekop area. The Loolekop body has a carbonatite core which grades outwards into a zone of magnetite - olivine - apatite rich rock called **foskorite** and then into pyroxenite. The ore reserve exceeds 300 Mt at an average grade of 7.45% P_2O_5 , [Notholt et. al., 1990, in 15].

The Schiel complex is the largest alkaline plutonic occurrence known in the Northern Province of South -

Africa. A large deposit of apatite, associated with magnetite and vermiculite, was discovered at Schiel in 1953, and prospected by Foskor between 1965 and 1968. An ore reserve of 36 Mt at 5.1% P_2O_5 was estimated for the weathered zone to a depth of 39.6m. The average phosphate contents found in the diamond drill cores were

found to be 7.4% in the Foskorite, 4% in the Pyroxenite, 4.2% in the carbonatite and 1.6% in the syenite within the ore body [15].

Moreover, *the Sukulu (Uganda) carbonatite and the Villa-Nora (South - Africa) basic – layered – gabbro complexes* are similar igneous phosphate deposits, with an average grade of 13.1% P_2O_5 and 6.00% P_2O_5 , and reserves of 130 Mt and 25Mt, respectively [5, 7]

Therefore, the aforementioned information can give a clue about the exploitable grade of phosphate from igneous sources, so that it can be compared with that of Soji – Bikilal phosphate deposit.

Similar gabbro intrusions occur in Western Ethiopia and in East Africa which should be assessed for phosphate potential to develop the fertilizer potential of the East Africa Region.

The pre feasibility study by the consultant reveals that the Soji-Bikilal Phosphate deposit is to be technically feasible. To prove the economic viability of the deposit, the pre-feasibility study could be upgraded to feasibility study with the following investigations to be undertaken:

- Excavation of long trenches connecting the upper and lower zones.
- Excavation of closely spaced parallel trenches on upper and lower zones.
- Infilling drilling on the phosphate mineralization of the lower zone.
- Geo-technical works to determine the slope stability of the pits, down slope to the lower zone.
- Topographic mapping far beyond the target area is recommended to construct a tailing dam [8]

Table 2. Grade and tonnage of igneous phosphate deposits

No	Deposit Name	Country			Grade % P_2O_5	Reserve Mt
1	Cargill	Ontario	Carbonatite Geological Association		19.60	62
2	Khibiny	Russia	Ijolite		18.00	2700
3	Singhbhum	India	Granite/Hydrothermal		17.50	1.5
4	Sukulu/ Bukusu	Uganda	Carbonatite		13.10	130
5	Palabora	South Africa	Carbonatite		6.90	486
6	Villa Nora	South Africa	Basic-layered-Gabbro		6.00	25
7	Schiel 54LT	South Africa	Carbonatite		5.10	36
8	Kovdor	Russia	Basic, Apatite Forsterite		4.75	708
9	Oshurkov	Russia	Basic-Bt-Hb-Diorite		4.50	1000
10	Siilinjärvi	Finland	Carbonatite		4.00	465
11	Soji Bikilal	Ethiopia	Basic layered gabbro*	Indicated Resource	3.00	435
				Inferred Resource	3.1	145
				Mineable Reserve	3.5	181
12	Saint Honore	Quebec	Carbonatite		3.70	12
13	Ekstrom sbergpattok	Sweden	Fe-P, Iron-Phosphate		2.29	1.22
14	Kiirunav aara	Sweden	Fe-P, Iron-Phosphate		2.22	-
15	Gallivare	Sweden	Fe-P, Iron-Phosphate		1.54	6.6
16	Savappa vaara	Sweden	Fe-P, Iron-Phosphate		1.35	6.0

Data Source * Interim Report No- 2, Consult 4, International Bikilal Phosphate Project, pre- feasibility study [8].

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