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Elemental Analysis and Physical Studies of Magnetic Black Sand (Ilmenite, Ore of Titanium) Found at Lonar Crater, Maharashtra, India

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Abstract: **Representative soil samples from Lonar Crater Lake periphery were investigated to study its nature. Experiments conducted on the soil found that it contains highly different salts prominently being sodium chloride, carbonates and bicarbonates of sodium with silica and magnetic black sand. Due to the presence of magnetic black sand along with silica, it has attained grey white or white black colour to the soil.**

The authors were interested to find out what is this magnetic black sand in sense of its source and origin? It's Physical and chemical properties? And why it existed near Lonar Crater Lake periphery? Experiments conducted for the last 6 years showed that it possesses magnetic attractive property. XRF analysis carried out showed that predominant elemental oxides are Fe_2O_3 and TiO_2. For comparison basaltic rocks have been considered because though this magnetic black sand is associated with basaltic rocks yet, there is a major difference in their physical and chemical properties, but their source and origin is the same i.e., from volcanic eruption.

From the studies conducted, the authors came to the conclusion that the Lonar magnetic black sand under study is the ore of Titanium and iron called as Ilmenite. This mineral Ilmenite was discovered in 1791 by William Gregor. This is the first hand information reported through this paper about findings of Ilmenite, (ore of Titanium) along with Magnetite (ore of iron) and similar species in the soil of Lonar Crater Lake periphery. Since Lonar magnetic black sand words will be used frequently, it will be termed in short as L.M.B.S. (Lonar magnetic black sand). A preliminary investigation was carried out to search what is this component on prima facia basis.

Index Terms: **Ilmenite, Lonar Crater Lake, magnetic attractive property, magnetic black sand, soil.**

I. Introduction

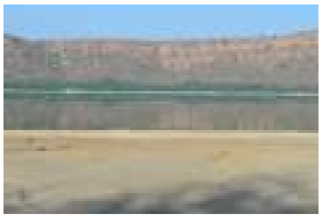
Lonar crater is a circular depression formed on the basaltic rocks of Deccan Plateau formed some 64Ma. The crater is situated in Lonar Taluka of Buldhana District of Maharashtra. The age of the crater is estimated to be 656 Ka (Jourdan et al. 2010). The co-ordinates of the crater are 19º58' N and 78º30' E. The diameter of the crater is 1.83 km and the depth is 150 metres. The crater has a raised rim from the surrounding area. There are gullies on the crater rim. The largest of these is the Dharatirtha, where continuous flow of water is seen. On the outer side of the crater towards south east to south west ejecta blanket is seen, the soil of which is found to be dusty light yellow.

On the inner side of the crater i.e., at the bottom or at the base water body exist, the colour of which is seen to be green and the water is found to be of high salinity and high alkalinity. On the southern side of the crater lake, the soil is found to be of sandy type, which contains black sand and shows attraction towards a magnet. This type of soil has also been mentioned by a local resident Prof. S.T. Bugdane in his booklet (Bugdane 1990).

Fig.1 a. Lonar Crater, Buldhana District, Maharashtra.

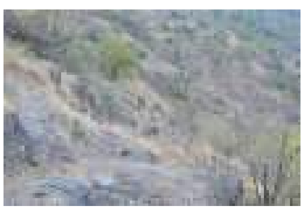
b. C.H. Mali searching for magnetic particles in the soil of Lonar crater lake periphery, using a handheld magnet by magnetic prospecting method in one of the visits to Lonar Crater in 1997. This was the first experiment carried out to search for magnetic particles in the soil of Lonar Crater lake.

c. The dense part of L.M.B.S. towards south side of the crater.



d. Crater rim and the lake at the base of the crater. actual picture of LOnar sandy soil.

e. Dry barren land near lake periphery, observed during summer.



f. Deforestation and soil degradation (lack of green canopy)
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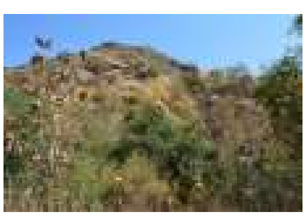
g. Grey type of soil, a dense accumulation of southern side of crater lake.



h. Actual outcrop along the rim inner side of Lonar Crater..

II. Literature Survey

The observations made could not be conclusive about the origin of the lake (Nandy & Deo 1961). The post-impact alteration of the associated basalts might have blurred the parent rock-glass comparisons (Stroube et al. 1978). There are various uncertainties and implications involved in high pressure temperature in an impact event (Nayak 1993). Microscopic examination of silt samples revealed the presence of rich organic remains (Badve et al. 1993). The geochemical results are inconsistent with the meteorite impact hypothesis (Nayak 1999). None of the samples analyzed by us from inside or outside the crater rim shows any definite evidence of impact – induced hydrothermal alterations (Osae et al. 2005). These spherules were probably formed by mixing of target basalt melts and chondritic impactor material (Misra et al. 2009). Fungus, which grows on dead debris of organic matter or decayed organic matter, can produce spectacular colours, and is responsible for pink/red coloration of the Lonar Crater lake (Jadhav & Mali 2020). Low dissolved oxygen of the lake is an indication of the presence of organic matter resulting in higher Biological Oxygen Demand (Pawar 2010). Considerable variations in the quality with respect to their physicochemical characteristics are observed (Borul 2012).

III. OBSERVATIONS

[i] Large quantities of this magnetic black sand (M.B.S.), showing a black colour, are seen on the surface of the Crater Lake periphery towards the southern part of the crater. Fig. 2 a, and b.

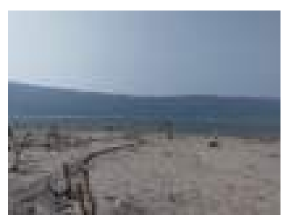


Fig. 2 a. Grey type of sandy soil at crater lake, Lonar. The black strip is the part of magnetic black sand segregates or accumulates known as placers.

2 b. Dense part of the magnetic black sand found at Lonar crater, known as placers.

[ii] The size of the M.B.S., when observed through a student microscope of 20x, shows that they are a millimetre in size or less than that size, i.e., very minute in nature. Fig.2 c (i) and

(ii).

2c (i)

2c (ii)

2c. (i) and (ii). High content of magnetic black sand found in the soil of Lonar Crater lake periphery being the Ilmenite mineral and magnetite mineral (ore of Ti and Fe).

[iii] Their shapes are of uneven nature. 2 c (i) and (ii).

[iv] The M.B.S. of Lonar crater shows attraction towards a magnet, when held near it, Fig.2 d.

2 d. The M.B.S. shows attraction towards a magnet.

[v] When observed through a student microscope of 20x, the M.B.S. of Lonar crater do not remain as a separate entity, but are found to be bonded to one another; most of them form chainlike structures or are clustered together. Fig.2 c (i) and (ii).

[vi] Even after washing them thoroughly and heating them (i.e., after separation, using a standard bar magnet moved smoothly over them) to a temperature of 200ºC and further to 400ºC, their characteristic features or their magnetic properties, i.e., color and attraction, towards a magnet, did not change. .

[ii] When observed through a student microscope of 20x, there are not only 20 mm or less than those components, but also dust particles of similar nature and glassy components, which seem to be of silica, are also seen. Fig.2 c (i) and (ii).

IV. METHODOLOGY AND EXPERIMENTS

The soil was first washed with water thoroughly for 6–7 times and, after washing, was kept in the sun for drying for about 7–8 days. After drying in the sun, the soil was kept on butter paper and was separated using a standard bar magnet by a magnetic prospecting method (i.e., the bar magnet was wrapped in a plastic bag and was smoothly moved over the soil. The attracted particles from a magnet were collected in another polythene bag. For further analysis, 20 gm of M.B.S. was kept in an oven first for heating to a temperature of 400ºC for about 2 hours to remove all contaminants or impurities and volatiles. These particles were then kept for cooling. After that, these particles were sent for XRF analysis. The samples under study were then sent for petrological studies and photomicrographs.

V. EXPERIMENTAL RESULTS

Physical parameters noted down, like colour, shape, size, density and characteristic features are given in table I. Elemental compositions for XRF are given in tables II, III and IV. The major component is Fe_2O_3, SiO_2 and TiO_2 in a more or less percentage with other oxide compositions in lesser percentage. Even after heating to about 400^0C temperature for 2 hours, no change in characteristic features was observed. i.e., the colour and attraction towards a magnet did not show any change but remained as it is, the attraction towards a magnet was observed.

VI. RESULTS OF PETROLOGICAL STUDIES AND PHOTOMICROGRAPHS

The sample under study sent for petrological studies is dark colored, of course to fine sand-sized, moderately sorted, and consists of subangular to angular grain. The majority of the grains are dark colored, along with occasional white colored grains of quartz and zeolite. Since the sample was moderately sorted, it was sieved through BSS 120 and 240 sieves to obtain grains which could be mounted on the slide.

The sediment grains were mounted on the glass slide and the grain mount was studied under petrological microscope. The microscopic examination of the sample reveals the presence of the following.

1. Augite (Clinopyroxene) –This is the most abundant mineral in the grain mountain and constitutes about 55% of the grains. Augite grains are non-pleochroic, pale brown to greenish brown, show hackly, razor-sharp fractures and two sets of cleavages. The grains show bright interference colors and high-angle oblique extinction.
2. Plagioclase feldspar - These grains are colorless in PPL, show gray interference and characteristic lamellar twinning. Plagioclase grains constitute about 2-3% of the grain amount.
3. Quartz - Quartz grains are clear, colorless in PPL. They show very low relief. Since the slide is a grain mount and not a thin section, quartz grains show bright interference colors and undue extinction.
4. Basalt fragments – Basalt fragments are angular, and they consist of plagioclase feldspar, opaques and clinopyroxene. The basalt fragments are commonly seen in the grain mountains.
5. Opaque grains – These grains cannot be identified under transmitted light; however, they seem to resemble ilmenite and magnetite. Opaque grains constitute a significant proportion of the grain amount. They are subangular to angular. This work of petrological studies and photomicrographs was carried out at St. Xavier's College (Autonomous), Geology Department, Mumbai.

Fig 3. Photomicrographs of L.M.B.S.

VII. RESULTS AND DISCUSSIONS

Physical parameters like colour, shape, size, density, lustre, nature and characteristic features of L.M.B.S. have been shown in table I. From table I, it is seen that the density of the sample under study is found to be around 1.8g/cc. Fe and Ti have high density and Si has low density, since the samples under study contain approximately 50:50 Ti, Fe and Si, hence the density is found to be low. It is due to the presence of silica impurities. Ilmenite has a high percentage of Ti and Fe and no Si content. The samples under study are non-consolidated material i.e., it is a loose material derived from basaltic rocks (https://uh.edu-mass). The prominent feature seen in L.M.B.S. is, it is dark black in colour, and it shows attraction towards a magnet when held near it, whereas in basaltic rocks these features are not observed. For comparison basaltic rocks have been considered as L.M.B.S. and basaltic rocks are associated with each other, their source and origin is volcanic eruption, yet they differ from each other physically and chemically. Photomicrographs of the samples under study have been shown in fig. 3, containing Augite (clinopyroxene) mineral constituting 55% of the grains. Plagioclase feldspar, constituting 2-3%. Quartz grains, basalt fragments and opaque grains resemble ilmenite and magnetite.

In table II, elemental composition by XRF analysis of L.M.B.S. has been shown in which Fe_2O_3, SiO_2 and TiO_2 are found in high percentage with respect to other oxide compositions. This magnetic black sand found at Lonar Crater Lake periphery is restricted to a limited area only, i.e., it is found on the southern part of the crater near the lake periphery. It is not found beyond the lake periphery.

In L.M.B.S. XRF analysis carried out showed that these elemental oxides were found to be in high percentage with respect to basaltic rocks Fe_2O_3, TiO_2, MgO, MnO, NiO, Cr_2O_3 and V_2O_5, whereas in basaltic rocks XRF analysis carried out by (Jadhav and Mali 2019), these elemental oxides were found to be in high percentage than L.M.B.S. SiO_2, Al_2O_3, CaO, K_2O, SO_3 and P_2O_5. Cl is present in basaltic rocks, but absent in L.M.B.S., Cr_2O_3 is present in L.M.B.S., but absent in basaltic rocks. CuO and ZrO_2 are found in equal proportion in both components, which infers that though their elemental composition differ, their source and origin is from the same event i.e., volcanic eruption.

Basaltic rocks contain high percentage of Al_2O_3 i.e., avg. 16.775%, whereas L.M.B.S., it is only avg. 6.8%. L.M.B.S. contains 35.27% avg. Fe_2O_3, whereas basaltic rocks contain avg. 11.95% Fe_2O_3. Cr_2O_3 in L.M.B.S. is 0.03% avg., whereas in basaltic rocks it is absent. Hence it is inferred that the presence of high percentage of Fe_2O_3 and less percentage of Al_2O_3 in L.M.B.S. and Cr_2O_3 content in L.M.B.S. being 0.03% avg, due to this L.M.B.S. is considered to be the ore of Titanium and species of magnetite and Haematite.

From petrological studies and photomicrographs (fig. III), usually the minerals found in basaltic rocks are Augite (clinopyroxene), plagioclase feldspar, quartz, basalts etc., whereas in L.M.B.S., the opaque minerals found are Ilmenite, magnetite, titanomagnetite and similar species are present. Basaltic rocks, Ilmenite, Magnetite, Haematite, titanomagnetite, their source and origin though is from volcanic eruption, they are also associated with each other and they are also associated with each other, but they are not altering their characteristic features L.M.B.S. is not a part of basaltic rock, but physio-chemically differ from basalt.

This black sand itself separates from white silica sand and this typical sand is found in placers, i.e., it is segregated or accumulated at certain places on the southern part of the Crater Lake. This type of magnetic black sand found on the surface of the crater lake, Lonar, resembles in similarity to physical properties and elemental composition to the black sand discovered by W. Gregor Sir in 1791, and he named it Ilmenite (ore of Titanium) (Trifonov & Trifonov 1982) (Crelis Annalin).

The black sand discovered by W. Gregor Sir in 1791 was found near a stream (Trifonov & Trifonov 1982) (Crelis

Annalin) i.e., near a water body, similarly L.M.B.S. is also found near a crater lake i.e., near a water body, suggesting that it is Ilmenite. The soil of the crater adjacent to the water body is found to be a mixture of magnetic black sand and silica, which is made up of two sands, black sand and white sand due to this, it appears gray and white. The soil is therefore a mixture of silica (SiO_2) and Ilmenite or rutile (TiO_2). Silica imparts white color and Ilmenite impart gray black color, so the resultant soil color is gray white.

The whole of Deccan Plateau in Maharashtra is formed by volcanic eruption, but throughout the Deccan Plateau, basaltic rocks though exist on a large scale, opaque minerals are found in a limited area i.e., where basaltic rocks and water body is present, opaque minerals are likely to be found. In Lonar, basaltic rocks and water body are present hence the opaque minerals are found. From this it infers that where basaltic rocks and water body exist opaque minerals are likely to be found there.

Isolation of silica from magnetic black sand was carried out by magnetic prospecting method, thinking that interference of silica may cause obstacle in analysis. But from the table II, III, and IV and from petrological studies and microphotographs, it is seen that silica, though in a lesser percentage than Fe_2O_3 in L.M.B.S., yet it reflects in the image 1g(i), (ii), and in fig III, it is because silica is a part of basaltic rock and hence it is found with opaque minerals in basaltic rocks. Silica has been along with the magnetic black sand for a very long time and hence it is possible that it is found to be attached to Fe_2O_3 and TiO_2, which shows that it may be a part of the L.M.B.S. Silica is not attracted towards a magnet, neither Ilmenite is found to be attracted towards a magnet. The attraction to a magnet is due to the presence of magnetite and titanomagnetite.

Magnetite is strongly attracted towards a magnet. It is an opaque mineral. It often contains Titanium oxide (TiO_2) (Hoffman 1987). Ilmenite commonly shows intergrowth with Hematite and Magnetite. Magnetite is a natural magnet, and it is known as a lodestone in the common language. Ilmenite is a weakly magnetic mineral (https://virtual-museum.soils.wisc.edu). But as mentioned above, it occurs along with magnetite or Hematite., It confirms that it is magnetite or Hematite as it shows attraction towards a magnet and also from petrological studies and microphotographs. Hence, from this, it confirms that L.M.B.S. is Ilmenite**.**

The L.M.B.S., which is an Ilmenite mineral, source and origin is from basaltic rocks as the crater excavated is on basaltic rocks, which was formed some 64Ma and named as Deccan Plateau. This mineral is not found on the basaltic rocks existing beyond the Crater Lake. It is found near the Crater Lake only.

In lacustrine sediments from depths 2, 19 and 68m and average Lonar basalts reported by Fudali et al. (1980), it is seen that in sediment from 2m depth, the value of TiO_2 and FeO is found to be in a higher percentage with respect to other sediments and Lonar basalt. This shows that the elemental composition by XRF (this study) and elemental composition by XRF (Fudali et al. 1980) magnetic black sand found on the surface near crater lake (this study) and that found by (Fudali et al. 1980) at 2m depth resembles in similarity, which suggest that L.M.B.S. exist from the surface upto a depth of about 2m below.

Son and Koeberl (2007) reported findings of magnetite, titanomagnetite and a few ilmenite grains (sizes a few of about 150 µm) as the most prominent opaque inclusions in Lonar impactites and impact glasses in both the dense/compact vesicular samples types (Son and Koeberl 2007). This indicates that Ilmenite, mangnetite and titanomagnetite minerals are found at Lonar, which shows that these minerals existed in the Lonar region where the crater stands today. It also infers that the Lonar region was an assemblage of minerals and hence this area may have been excavated to extract mineral ores of Titanium and Iron, i.e., Ilmenite, magnetite and titanomagnetite. (This study), (Son and Koeberl 2007)

It is to be stated that apart from the Lonar crater region, findings of these minerals on the Deccan Plateau have not been reported. Ilmenite is a heavy opaque mineral formed at high temperatures. It occurs in igneous rocks as an accessory mineral and in sediments (https://virtual-museum-soils.wisc.edu).

It is also to be stated that in spite of the crater lake water being highly saline and highly alkaline in nature, these minerals were not affected by the waters, which contain chlorides, fluorides, bromine etc., (halogen group elements) (Pawar 2010), (Borul 2012) and (Jadhav and Mali 2019) and carbonates and bicarbonates of Na (Pawar 2010) and (Borul 2012), which are corrosive in nature and also were not affected by weathering conditions existing at crater.

Geographically, Ilmenite is mainly found with basalts and any water body and it preserves itself from salinity and oxidation because it has Titanium content, which has non-corrosive property and has hard toughness property and hence titanium metal is used in construction of marine boats and ships and also in aviation industry i.e., in aeroplanes.

Findings of magnetic black sand at Lonar crater suggest that some kind of excavation work by ancients may have been carried out to extract these minerals existing in the Lonar region, the remains of which are found lying on the surface of the Crater Lake periphery till date.

Table I Physical parameters of magnetic black sand found at Lonar Crater lake periphery.

Sr. No.	Colour	Shape	Size	density gm/cc.	Lustre	Nature	Characteristic feature
1	black	uneven	less than mm	1.8	semi metallic	opaque	possess attractive magnetic property

Table II Elemental compositions of the magnetic black sand from Lonar crater lake periphery by XRF. (standard sample).

Sr. No.	Element Name	Mass %	Formula	Oxide content
1	Iron	28.466	Fe_2O_3	40.7
2	Silicon	10.938	SiO_2	23.4
3	Titanium	11.622	TiO_2	19.4
4	Aluminum	3.292	Al_2O_3	6.22
5	Calcium	2.866	CaO	4.01
6	Magnesium	2.297	MgO	3.81
7	Vanadium	0.459	V_2O_5	0.82
8	Manganese	0.498	MnO	0.643
9	Potassium	0.298	K_2O	0.359
10	Phosphorus	0.111	P_2O_5	0.254
11	Sulfur	0.066	SO_3	0.166
12	Copper	0.043	CuO	0.054
13	Zinc	0.042	ZnO	0.052
14	Zirconium	0.025	ZrO_2	0.034
15	Nickel	0.021	NiO	0.027
16	Tin	0.013	SnO_2	0.016
17	Chromium	0.01	Cr_2O_3	0.015
18	Barium	0.009	BaO	0.01
19	Niobium	0.003	Nb_2O_5	0.005
20	Arsenic	0.002	As_2O_3	0.002
21	Oxygen	38.919		
	Total	100		99.997

Table III. Elemental Compositions of magnetic black sand of Lonar crater lake periphery by XRF.(Sample No. 1)

Sr. No.	Element Name	Mass %	Formula	Oxide content
1	Silicon	15.098	SiO_2	32.3
2	Iron	21.052	Fe_2O_3	30.1
3	Titanium	7.968	TiO_2	13.3
4	Calcium	5.824	CaO	8.15
5	Aluminum	4.006	Al_2O_3	7.57
6	Magnesium	3.979	MgO	6.6
7	Vanadium	0.348	V_2O_5	0.622
8	Manganese	0.361	MnO	0.466
9	Potassium	0.246	K_2O	0.296
10	Phosphorus	0.106	P_2O_5	0.244
11	Sulfur	0.061	SO_3	0.153
12	Zinc	0.027	ZnO	0.033
13	Copper	0.025	CuO	0.032
14	Nickel	0.022	NiO	0.028
15	Chromium	0.017	Cr_2O_3	0.024
16	Zirconium	0.017	ZrO_2	0.023
17	Tin	0.016	SnO_2	0.02
18	Strontium	0.01	SrO	0.012
19	Oxygen	40.817		
	Total	100		99.973

Table IV. Elemental Compositions of magnetic black sand of Lonar crater lake periphery by XRF.(Sample No. 3)

Sr. No.	Element Name	mass %.	Formula	Oxide content
1	Iron	24.479	Fe_2O_3	35
2	Silicon	13.088	SiO_2	28
3	Titanium	9.526	TiO_2	15.9
4	Aluminum	3.498	Al_2O_3	6.61
5	Calcium	4.645	CaO	6.5
6	Magnesium	3.581	MgO	5.94
7	Vanadium	0.376	V_2O_5	0.671
8	Manganese	0.4	MnO	0.516
9	Potassium	0.224	K_2O	0.27
10	Phosphorus	0.098	P_2O_5	0.224
11	Sulfur	0.056	SO_3	0.14
12	Chromium	0.028	Cr_2O_3	0.041
13	Zinc	0.032	ZnO	0.04
14	Copper	0.029	CuO	0.036
15	Nickel	0.025	NiO	0.032
16	Zirconium	0.018	ZrO_2	0.025
17	Strontium	0.009	SrO	0.011
18	Barium	0.006	BaO	0.007
19	Antimony	0.001	Sb_2O_3	0.001
20	Oxygen	39.881		
	Total	100		99.964

VIII. CONCLUSION

From the studies conducted through this paper, the petrological studies and microphotographs, the conclusion drawn is:

1) The magnetic black sand found on the surface of Lonar crater lake periphery resembles in similarity with respect to

physical features and elemental compositions to the black sand discovered by W. Gregor Sir in 1791, which is Ilmenite (Ore of Titanium) (Trifonov et al. 1982), (Crelis Annalin) which exist along with magnetite and similar species.

2) This magnetic black sand found at Lonar Crater Lake is Ilmenite mineral along with other opaque minerals such as magnetite and titanomagnetite, the source and origin is from volcanic eruption, associated with basaltic rocks, but differ in physical and chemical properties from basaltic rocks.

3) This magnetic black sand of Lonar is found segregated or accumulated in places near the lake periphery, which is in the southern part of the crater lake. Hence, they are observed on the surface of the Crater Lake periphery. These components are found in restricted areas only.

4) In the case of Lonar, from our studies, it shows that percentage of Ilmenite or rutile is very high as compared to other basaltic rocks, so it is concluded that there might be a mine or source of Titanium metal (Ilmenite) in the Lonar region.

5) It is of the opinion that findings of magnetic black sand at Lonar crater lake periphery, suggest that some kind of excavation work was, may have been carried out by ancients in the remote past to extract mineral ores of Titanium (Ti) and Iron (Fe), the remains of which are found lying on the surface of the crater lake.

6) Lonar Crater though it is ecologically sensitive, but it undergoes socio-economic and bio-physical changes.

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