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EVALUATION, BENEFICIATION AND UTILIZATION OF KOGA NEPHELINE SYENITE AS GLASS AND CERAMICS RAW MATERIAL

Part I-Geochemical Evaluation and Concentration Studies

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Economically important and sizeable reserves of nepheline syenite occur in the Koga area near Mardan. The rock after beneficiation and market evaluation was found to be in demand for local glass, ceramic and other industries. It has been found to be an excellent substitute for conventional feldspar in view of its low cost, large and consistent reserves, operative advantages; low melting; decrease in devitrification of glass; and chemical durability.

Detailed mineralogical, textural and chemical studies show that the factors important in beneficiations are the texture of iron minerals and not the Fe percentage of the head-ore as considered previously. The rock mass was not found homogeneous and contains certain deleterious minerals in sample. However, proper sampling technique which can result in desirable product recovery has been suggested.

Key words: Ne. Syenite; Beneficiation; Geochemistry

INTRODUCTION

Conventional procelain includes feldspar as a flux which aids in the formation of glass. Most common minerals commercially employed in glass and ceramic industry are potash feldspar (microcline or orthoclase), soda feldspar (albite) and lime fedspar (anorthite). The production of feldspar in NWFP during 1978-82 period was 30,000 tons worth Rs 50 million [1], mostly originating from the Mansehra area. The demand for high and consistent grade of feldspar (mostly potash bearing) is not being fully met due to its shortage and the supply position will aggravate further considering the projected future demand. There is a general practice in countries where nepheline syenite rocks are available to use them as substitutes for feldspar in view of their advantages due to lower melting, chemical durability, and decrease in devitrification of glass. Nepheline syenite and other feldspathoid syenites are rare types of rocks, but occurs in Pakistan as intrusive bodies of various sizes and composition in the so-called Ambela granitic complex, which is spread over the Buner, Chamla and Khudakel areas in southern Swat.

The Ambela complex is largely composed for granodioritic gneiss, granites and peralkaline syenite in which dykes and bodies of feldspathoid syenites of variable chemical and mineralogical composition has intruded [2,3]. An attempt [4] was made to find and delineate potential low iron bearing zones of nepheline syenite, suitable for the glass and ceramic industry, using grid pattern of 100 feet for sampling. However, the study showed that suitable grade material could not be obtained without beneficiation. Later a geochemical study [5] of samples obtained from adits at shorter distances has shown that there is significant variation at shorter distances in chemical and mineralogical composition.

This study [5] underscores the need for a detailed chemical and mineralogical evaluation of these rocks so that the future utilization of these rocks could be made possible after beneficiation. With this aim in view the present study was undertaken as a collaborative effort between the Sarhad Development Authority and the PCSIR.

Laboratory studies described here have essentially established various parameters in term of chemistry, mineralogy, liberation size, magnetic susceptibility etc., required to control subsequent beneficiation studies on pilot scale.

Geological background and sampling proceedures. Alkaline rocks in the Swat Chamla area were first reported by Siddiqui [2,3] to consist of a suite of complex peralkaline

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and silica deficient rocks. Nephelene syenite was a part of this so-called Ambela alkaline complex.

In a preliminary mineralogical, chemical and labora-tory beneficiation study on two adit samples [5] it was noted that there is considerable variation in grade and mineralogy at shorter intervals. Bulk samples for benefi-ciation and utilization were, therefore, collected after careful assaying and evaluation of ore reserves in the field. A bulk sampling programme was formulated after an evaluation of types of rocks of Koga and Landi Patao Body-I and 2 areas.

Three bulk samples weighing 10 tonnes each were collected from low-iron zones in Agarai, Landi Patao body I and Landi Patao body II (Fig. 1). The samples were representative of the area and they are composed of almost all type of rocks exposed in a particular area and sampled by the procedure of unrestricted random sampling. In addition, test samples were prepared from each type loca-lity by extracting representative samples and also by hand sorting to extract samples with typical mineralogical and textural characteristics. The later mode of sampling was based on field studies by keeping in view the potential reserve of each type of the rock and its mineability.

Samples collected from the Koga area were examined with the hand lens to get an approximate idea about the nature of the ore. At first, samples were collected for thin and polished section examination. The ore was then passed through jaw and roll crushers. A 0.5 kg ore sample was ground in a Teema mill for mineral separation and minera-logical and chemical examination. The rest of the ore was kept for mineral processing.

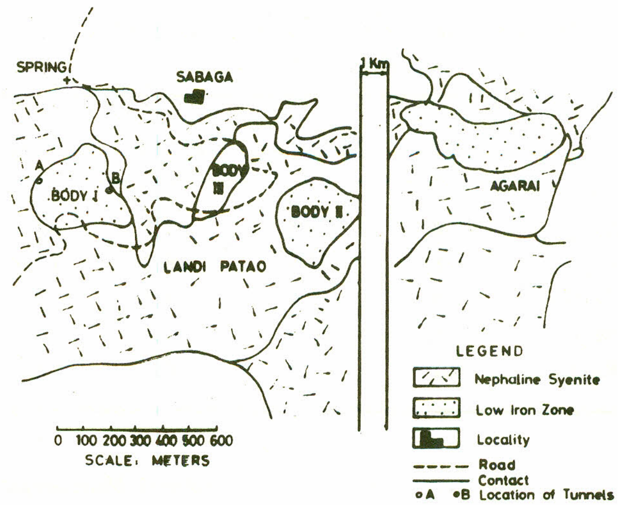

Fig. 1. Location of nephline syenite rocks investigated.

Chemical Evaluation. Chemical analyses of random (hand) samples show (Table 1) a wide range of values for iron. This may be due to the disseminated nature of biotite and other iron bearing minerals in these rocks. The Fe_2O_3 content ranges from 1.8 to 3.8 percent. On the whole the Agarai sample show comparatively lower SiO_2, Fe_2O_3 and K_2O contents than the Landi Patao samples. In order to estimate the relationship between chemical composition and distribution of mineral phases in these rocks, pure mineral phases separated by mineralogical techniques were analysed. The chemical analyses of pure sodalite, nepheline crystals, biotite, microcline in these rocks are presented in Table 2. The analyses represent a few random samples picked from the bulk rock and may not represent

Table 1. Chemical composition of nepheline syenite head (bulk) and random samples (range of values in hand samples).

	Agarai area		Landi Patao Body-I		Landi Patao Body-II	
	Range in hand samples	Head sample	Range in hand sample	Head sample	Range in hand sample	Head sample
SiO_2	54.5 – 55.5	55.2	56.5 – 58.0	54.9	56.8 – 60.0	59.5
Al_2O_3	21.5 – 24.8	22.8	22.5 – 24.6	23.5	20.1 – 23.2	22.2
Fe_2O_3	1.8 – 3.0	2.8	2.2 – 3.8	3.5	1.9 – 3.8	3.2
Na_2O+K_2O	13.0 – 15.0	–	13.0 – 15.0	–	13.0 – 16.0	–
Na_2O	–	8.52	–	9.98	–	9.1
K_2O	–	4.92	–	5.4	–	5.9
CaO	–	0.05	–	0.08	–	0.12
MgO	–	0.04	–	0.05	–	0.06
LOI	–	1.3	–	1.5	–	1.4

Table 2. Chemical analyses of separated mineral phases in Koga syenite rocks

	Sodalite	Nepheline	Biotite	K-feldspar
SiO_2	42.4	50.8	37.1	64.5
Al_2O_3	26.8	22.5	16.2	18.9
Fe_2O_3	0.8	2.4	24.5	0.4
Na_2O	20.1	10.5	0.1	5.8
K_2O	0.1	3.8	8.9	8.5

the general composition in the area. However, it may provide adequate information required for mineral processing.

Mineralogy. The most commonly occurring rock of the Koga nepheline Syenite showed microcline(mi) as the dominant mineral in association with albite(al), nephelene (ne), aegerine augite(cpy) and biotite(bit). The accessory minerals were zircon, garnet, sphene, ilmenite and fluorite. At restricted places sodalite(sd), cancrinite(cn) and plagioclase(An) rich rocks were observed. The general texture was medium grained protoclastic and foliated rocks while at places pegmatitic texture (showing up to 6 cm size

Table 3. Mineralogical composition of and samples.

(bt. = biotite, fel. = Na-K, feldspar, Ne = Nepheline pyb. = Na Pyroxene (aegirine augite) & Na-amphibole, ap. = aplitic type antiperthite. Sd. = sodalite, mi-Microcline, X = major amounts 0 = minor amounts)

S. No.	bt.	fel.	Ne.	pyb.	py.	sd.	ap.	Remarks
1	O	x	x	–	O	O	Ne 20% Ab 30%, Mi 40% bt 6%	Accessories Zircon, pyb
2	O	x	O	–	–	–	–	
3	O	x	–	–	–	–	–	Course grained bt. & fel.
4	O	x	O	–	O	–	–	– do –
5	x	x	–	–	–	–	–	
6	x	O	O	O	–	–	–	Ab replacing pyroxen and biotite
7	O	x	O	–	O	–	–	
8	O	x	–	–	–	O	–	
9	O	x	O	–	–	O	–	
10	O	x	–	–	–	–	–	Ab., mi, Garnet ore, Zr.
11	O	O	–	O	–	–	O	Ab replacing mi, pyrite needles
12	x	O	–	x	–	–	x	– do –
13	–	–	–	x	–	–	x	
14	x	–	–	x	–	–	x	
15	–	–	–	x	–	–	x	
16	x	–	–	O	–	–	x	
17	O	–	–	x	–	–	x	
18	O	–	–	O	–	–	x	
19	O	–	–	x	–	–	–	
20	O	–	–	x	–	–	x	
21	–	–	–	x	–	–	x	
22	–	–	–	O	–	–	x	
23	O	–	–	O	–	–	x	
24	O	x	–	O	O	x	x	
25	O	x	–	–	O	–	–	

(Continued .....)

(Table 3 Continued)

26	O	x	–	–	O	–	–	
27	x	O	x	–	–	x	x	Albite replacing microcline
28	O	x	O	–	–	–	–	
29	O	x	–	–	–	–	–	
30	x	O	–	–	–	–	–	
31	x	O	–	O	–	–	–	

of feldspar and nepheline) and at other places aplitic texture sometime showing lichfieldite composition due to the replacement of microperthite with albite, were observed. The mineralogical composition found in hand samples is given in Table 3.

The Koga nepheline syenite can be divided into the following major types of mineral assemblages on the basis of mineralogy and chemical composition :

1. Syenite
   (i) mi + ne + al + bit + cpy
2. Feldspathoid Syenite (Silica deficient)
   (a) Nepheline syenite
      (ii) mi + ne + al + cpy + bt
   (b) Sodalite syenite
      (iii) mi + ne + sd + al + bt
   (c) Cancrinite syenite
      (iv) mi + cn + ne + al + Sd + An + bt
3. Altered rocks
   (a) Albitized (Soda rich)
      (v) al + mi + bt + cpy
   (b) Hydrothermally altered rocks
      (vi) Hydromusiovite + al + mi
   (c) Biotized rocks
      (vii) Bt + mi + al + ne

Assemblages 1 and 2 are the more dominant rock types in the area and could be of economic importance if iron bearing minerals could be removed by beneficiation.

Petrological Studies. Microscopic studies of thin and polished sections have shown that the chief minerals in the bulk samples are alkali feldspars such as microcline, albite and coarse grained feldspathoids such as nepheline and sodalite. Microclines show perthetic texture due to the exclusion of albite lamellae. The minor mineral phases recognised in the bulk samples are cancrinite, soda pyroxene (aegirine augite), soda amphibole, zircon, garnet and clay minerals. A brief petrographic description of typical hand samples is given below.

Sample 1: A thin section examination of the sample showed coarse microcline perthite crystal cut nearly parallel to 010 which is phenocrystic and slightly turbid. The white areas in thin section under cross polar were soda feldspar and the dark areas are K-feldspar. Lamellae of microperthite albite lie at an angle of 75^{O} to the trace of 001 cleavege in a section.

Sample 2. Petrographic examination showed coarse grained primary and secondary biotite (0.5mm), pleochroic in nature with zircon present as accessory minerals in association with feldspar. Fine grained biotite and pyroxene microlites as inclusion in feldspar have also been noted.

Sample 3. Most of the rock specimen is antiperthite seen as white areas in thin section. This is probably formed through replacement of microcline by albite. Plagioclase is seen surrounding the replaced core of microperthite.

Sample 4: The rock is an alkali aplite showing Na-feldspar with fine inclusions of aegirine microlite. Coarse grained biotite and ore minerals are seen in thin section.

Sample 5: Crystals of plagioclase with characteristic twining are seen in thin sections with microcline in an antiperthite matrix with cancrinite and needle shaped aegerine.

Sample 6: Needles of aegirine microperthite of 0.1-0.3 mm length and 0.005-0.01mm thickness showing an extinction angle of 20^{O} and pleochroic cores occur with some biotite, showing pleochroic shades of brown and green in alkali aplite rocks. Although such rocks have low iron content, their beneficiation is not possible due to fine needle shaped iron minerals.

Sample 7: Nepheline of up to 1.5 mm with albite forms a mosaic structure. The larger grains contain acicular inclusions of pyroxene. Albite occurs as clear twined crystals and microcline is phenocrystic. Its modal composition has been established as :

Microcline	42%
Albite	26%
Nepheline	20%
Pyrebole	8%
Biolite sphene, garnet etc.	4%

Mesh-of-libration studies. During the studies of the mesh-of-liberation of nepheline syenite it was found that the selection of samples seriously affects grade/recovery of the product. In order to use the nepheline syenite rock in glass and ceramic industry its Fe_2O_3 content should be brought down to about 0.1 percent. This was achieved by comminution and the separation of iron mineral phases from the rock in the laboratory by magnetic separation. The grinding was precisely controlled by stage grinding as overgrinding tends to produce fines (less than 200 mesh size fraction) not desired by the glass and ceramics industry.

Condition for magnetic separation. The bulk sample was ground to 100 percent -30 mesh. It was sized through 60, 80, 150 mesh sieves. These fractions were passed through an isodynamic magnetic separator at 1.0, 1.5 and 2.0 amp. current at an angle of 13^o and tilt of 17^o. The Fe content in the concentrate was found to be 0.5, 0.36 and 0.32 percent respectively. The current of 2.0 amp. was therefore found more ideal.

Effect of mesh size. A 1 kg sample was ground in a laboratory ball mill for 10 and 20 mins. The ground material was sieved and passed through a magnetic separator. The results are given in Table 4.

Laboratory concentration of hand samples. 1 kg weight of samples was ground in a ball mill for 20 mins. and sieved through 200 mesh. The sample retained on the sieve is subjected to magnetic separation at 2.0 amp. using an isodynamic magnetic separator. The purity of the product with respect to Fe_2O_3 content is given in Table 5. The concentrate with an Fe_2O_3 percentage of 0.15 or below is considered suitable for the glass and ceramics industry, whereas concentrates of Fe_2O_3 between 0.15-0.3 are unsuitable (x). Higher concentration in a cleaner concentrate makes the ore deleterious for use in the industry.

DISCUSSION

Foyaite-type dioritic plutonic rock consists of nephylene and alkali feldspar as major minerals with cancrinite, sodalite, augite, hornblende or biotite in minor amounts. The extrusive analogue (phonolite) also occurs in the area. Such rocks contain silica deficient high alkali minerals (feldsparhoids such as nepheline, sodalite, cancrinite etc.). In term of Si:Al ratio alkali feldspar has 3:1 ratio, whereas in feldspathoids the Si:Al ratio ranges between 2:1 and 1:1. The nepheline commonly found in rocks is potash bearing with high SiO_2 content. It is massive, granular, grey or highly coloured, cloudy or opaque and greasy mineral. The nepheline composition can be expressed as 1/3 $(SiO_4/AlO_{4/2})$ Na and 1/70.8 $(Si_{25.2}Al_{22.8}O_{96})$ $Na_{18}K_{4.8}$ (Niggli). Replacement of Na_2 by Ca in these rocks sometimes leads to the calcium bearing nepheline. Cancrinite $(Na_3CaCO_3(AlSiO_4)_3 \cdot nH_2O)$ is generally a pearly, columnar variety with a variable composition. Sodalite often seen associated with nepheline with the composition of $Na_4Cl(AlSiO_4)_3$ is usually blue in collour.

The chemical composition of sodalite in these rocks shows a high amount of SiO_2 and Fe_2O_3 whereas Al_2O_3 and soda are a little less than reported for pure minerals of sodalite in the literature [6]. This may be due to contamination of these rocks by other minerals such as albite which is associated with sodalite.

The potash feldspar in the area is soda bearing and the composition of biotite and K-feldspar falls close to the values given in the literature. However, the composition of nepheline crystals which were dirty light green and pearly show much high SiO_2, iron and lower alumina and alkalis. This may be due to the altered nature of the mineral in these rocks.

The Koga nepheline syenite is medium to coarse grained, but locally pegmatitic and aplitic zones are present. Microcline, nepheline, biotite, and albite with some anorthite contents is the common mineral assemblage in the rocks of the area. Pure albite occurs as clear twined crystals and microlcline microperthite with Carlsbad twining is phenocrystic and slightly turbid. Texturally nepheline syenite is characterized by a prominent flow structure which is usually planar, but locally it may be curved or wavy.

At certain zones concrinite may attain concentration up to 20 percent in the rocks. Cancrinite shows a platy habit and is sometimes associated with plagioclase. In some soda rich zones the medium grained massive rock may

Table 4.

Mesh size	Weight retained	Fe (%) in conc.	Recovery weight(%)
10 min. grinding			
– 30+50	42	0.15	60
– 50+150	35	0.14	76
– 150+200	16	0.12	84
– 200	4	–	–
20 min. grinding			
– 30+50	16	0.13	65
– 50+150	39	0.1	82
– 150+200	27	0.06	88
– 200	18	–	–

Table 5. Amount of Fe_2O_3 in the ore and concentration and beneficiability of Ne-Syenite

Sample No.	Ore Fe_2O_3(%)	Primary conc. Fe_2O_3(%)	Cleaner concentrate Fe_2O_3(%)	Beneficiation: s suitable, xx deleterious, x not suitable
1	3.25	0.25	0.11	s
2	2.18	0.13	0.07	s
3	2.96	0.23	0.07	s
4	3.16	0.15	0.06	s
5	3.30	0.30	0.15	x
6	5.13	0.18	0.12	s
7	2.08	0.16	0.08	s
8	2.78	0.13	0.06	s
9	3.47	0.2	0.09	s
10	2.00	0.96	0.81	xx
11	3.13	0.45	0.38	xx
12	2.68	0.65	0.36	xx
13	2.92	0.7	0.42	xx
14	2.6	0.95	0.88	xx
15	2.9	0.7	0.78	xx
16	1.95	0.72	0.55	xx
17	2.65	0.98	0.83	xx
18	2.6	0.89	0.72	xx
19	2.3	0.80	0.61	xx
20	1.6	0.72	0.38	xx
21	1.8	0.68	0.38	xx
22	2.2	0.72	0.39	xx
23	2.5	0.45	0.25	xx
24	3.30	0.38	0.28	x
25	2.17	0.25	0.15	
26	2.26	0.25	0.15	
27	3.82	0.51	0.37	xx
28	2.78	0.15	0.06	s
29	2.34	0.15	0.08	s
30	5.73	0.2	0.11	s
31	2.08	0.36	0.18	x

contain bluish sodalite mineral occassionally pegmatitic in nature. Minerals present include antiperthite, albite, sodalite, cancrinite and biotite. Antiperthite is of the replacement type with relict patches of microcline inside albite.

There was considerable variation in grade, mineralogy and texture at shorter intervals in the field, which stresses the need for special sampling technique for bulk processing in the production of glass and ceramics raw material. It was noted that the rock mass of nepheline syenite in different localities was not homogeneous and contained (i) zones which were suitable for mineral separation at coarser mesh size (50-80 mesh), and (ii) dykes, intrusious or altered zones which need extreme fine grinding and are therefore unfeasible.

Comparision of the results of the laboratory concentration (Table 3) with mineralogy (Table 5) and texture, suggest that mineralogy and texture are of primary importance in beneficiation. Coarse biotite bearing rocks though rich in Fe_2O_3 are easily beneficiable as compared to fine grained aegerine bearing rocks commonly encountered in aplitic and altered zones. On the basis of exposed rock masses the potential economic reserves of nepheline syenite can be calculated to be around 10 million tons. The rocks can be mined for beneficiation and utilization by careful selection of suitable zone by petrographic methods.

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