

MINERALOGICAL AND CERAMIC PROPERTIES OF WEST PAKISTAN FELDSPARS

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Feldspar samples collected in Hazara District were studied for mineralogical classification and ceramic utility. Specific gravity, chemical composition, IR spectrum, softening temperature, colour of the softened products, thermal expansion and petrography were investigated. Most of the feldspars could be used in the glass and ceramics industries.

The purpose of this investigation was to find out the properties of the newly discovered feldspars and to present some new information relating to their commercial exploitation in ceramic industries. The minerals investigated were potash feldspars or soda feldspars. All the three samples of potash feldspar namely D.C., D.T., and D.T.B. were collected from large deposits situated near Dadar, a place about 35 miles north of Abbottabad, District Hazara. The Sandasar deposits (S) are located two furlongs north-east of village Sandasar along the Hazara Trunk Road, about 22 miles from Abbottabad. In the same area further four miles away from Sandasar near Phagla Village are found soda feldspar Nos. 1,2,3B, 3W, 8 and A. A considerable quantity of white variety is available in this area. A bluish variety of soda feldspar deposits is located some 3 to 10 miles south-west of Garhi Habibullah along Khairabad Katha. It is only two miles up Khairabad from its junction with the Kunhar river. The feldspar occurs in discontinuous layers and ranges in thickness from 6 in stringers to 12 ft. Sample Nos. 5,6 and 7 from this area, and a white variety of soda feldspar from the Oghi area, about 35 miles north-east of Abbottabad, have been selected for study. All the above mentioned feldspars with their locality are given in Table 1.

Experimental

Specific Gravity.—The true specific gravity of the powdered raw feldspars was determined with pycnometer¹ and is given in Table 2.

Solubility in Water.—All the samples were subjected to the action of water for 50 hr, and the solubilities were measured by determining the increase in the pH value of the suspension according to the method followed by Parmelee and Monack.² The rate of solution of any material is a function of the total surface which is exposed to the solvent. Hence, in order to make comparison, carefully screened materials have been used.

Petrographic Study.—The feldspars were examined petrographically. Thin sections were made from

the raw feldspars and from the feldspars fired at various temperatures. These sections were examined under microscope for studying their structure and for identification of the minerals present.

Infrared Technique.—IR spectra of the samples were recorded according to the procedures adopted by Hunt and Wishard.³

Chemical Composition.—The samples were chemically analysed in accordance with the standard methods^{4,5} and their chemical compositions are shown in Table 2.

Pyrometric Cone Equivalents.—To obtain the cone-softening temperatures of the feldspars, the ground material, bonded with a dilute solution of dextrin, was pressed hard in a steel mould to form the standard-size three sided pyramid cones of $2\frac{7}{8}$ in height and $9/16$ in across the base of each face. The dried cones were, then, heated in an electric muffle furnace at a uniform rate of 150°C per hr.⁶ Results are given in Table 2.

Thermal Expansion.—Standard thermal expansion apparatus⁶ was used for the measurement of percentage thermal expansion of the raw and that of the vitrified pieces of soda and potash feldspars fired to 1250°C . The results are presented in Figs. 1,2,3 and 4.

Results and Discussion

On the basis of specific gravity, the feldspar may be classified into various groups. For example albite feldspars have specific gravity 2.615–2.635; microcline have 2.572–2.574; orthoclase 2.55; anorthoclase 2.59 and anorthite 2.75. From the results of the specific gravity, of the samples as shown in Table 2 it may be concluded that sample Nos. 1,2,3B, 3W, 5,6,7,8, Ogi and S are albite feldspars as their specific gravity varies from 2.615 to 2.63, whereas the other three samples i.e. D.T., D.C. and D.T.B., are microcline because they have a higher specific gravity of around 2.573.

Structurally, feldspar Nos. 2,5, and A are fine-grained and compact, while feldspar Nos. 2, S,

TABLE I.

Sample No.	Area	Feldspar	Mineralogy	
D.C.	Dadar	Potash feldspar	Microcline Albite Orthoclase	65% 15% 20%
D.T.	"	"	Microcline Albite Orthoclase Opaque minerals	75% 10% 14% 1%
D.T.B.	"	"	Microcline Albite Orthoclase Opaque minerals	80% 8% 10% 2%
S	Sandasar	Soda feldspar	Albite Biotite	99% 1%
1	Phagla	"	Albite Biotite Opaque minerals	96% 3% 1%
2	"	"	Albite Opaque minerals	99% 1%
3B	"	"	Biotite Albite	99% 1%
3W	"	"	Albite Natrolite Opaque minerals	97% 2% 1%
8	"	"	Albite Opaque minerals	98% 2%
A	"	"	Albite Biotite Opaque minerals	97% 2% 1%
5	Near Khairabad	"	Albite Hornblende Biotite Opaque minerals	76% 18% 4% 2%
6	"	"	Albite Biotite Opaque minerals	96% 2% 2%
7	"	"	Albite Biotite Opaque minerals	98% 1% 1%
Ogi	Oghi	"	Albite Opaque minerals	99% 1%

and Ogi are coarse and fragile. Feldspars 3B, 3W, D.C.; D.T.; and D.T.B., are medium to coarse-grained and somewhat compact. The characteristic feature of all the feldspars is the presence of very fine grained disseminated opaque minerals. The development of mica is very common in the cracks of feldspar Nos. 2, 3W, D.C., D.T., D.T.B., and Ogi. Under the microscope, feldspars are the hypidiomorphic to allotriomorphic with coarse, medium and fine grains.

The data obtained through IR spectrum was compared with the standard graphs^{3,7,8} of typical feldspars and it may be observed that there are two distinct regions of bands, one extending from 8.5 to 10.5 microns and the other from 13.0 to 13.8 microns. The bands in the region 8.5 to 10.5 microns are characteristic for all feldspars irrespective of their being soda, potash or lime feldspars. But the sharp bands observed in the region 13-13.7 μ in the case of samples D.T., D.C., and D.T.B. indicate that these are microcline feldspars. Similarly when sample Nos. 1, 2, 3B, 3W, 5, A, Ogi and S were examined they turned out to be of albite composition as four sharp bands were observed in the region 12.8-13.7 microns.

It may be seen from the chemical analyses (Table 2) that majority of the feldspars have SiO₂ ranging from 65 to 68% and are in accordance with the foreign feldspars,⁹ whereas the Al₂O₃ is slightly on the higher side. MgO in most of the samples is less than 0.5% and Fe₂O₃ is generally low—even less than 0.1% in some feldspars. The total alkalis in soda feldspars are according to specifications, while in the potash feldspars they are about 3 to 5% less. Thus from the chemical point of view the feldspars seem quite suitable for commercial exploitation.

Softening temperature as determined shows (Table 2) that sample Nos. 1, 2, 3B, 3W, 5, A, Ogi and S are soda feldspars as their softening temperatures are in the range of 1190-1240°C. Samples D.T., D.C., and D.T.B; are potash feldspars as their softening temperatures are much higher and lie in the range of 1275-1285°C. Pyrometric cone-equivalent shows that high potash feldspars are comparatively more refractory than high soda-feldspars and that they are distinguished by various characteristic properties, such as specific gravity, softening point and influence upon viscosity. Sample Nos. 2, D.T., D.C., D.T.B., and A are snow-white to white in colour after firing to 1250°C while sample Nos. 1, 3B, 3W and Ogi are cream or light cream coloured. Sample No. 5 is light brown and S is cream coloured (Table 2). In the glass and ceramic industries snow to snow-white feldspars are preferred, but in some cases

TABLE 2.—CHEMICAL AND PHYSICAL PROPERTIES OF VARIOUS FELDSPARS.

	1	2	3B	3W	5	6	7	8	A	Ogi	S	D.C.	D.T.	D.T.B.	*Micro- cline New York	Albite Italy
Ig. Loss%	0.40	0.26	0.22	0.21	0.23	0.92	0.60	0.40	0.42	0.30	0.48	0.30	0.25	0.22	0.12	1.52
SiO ₂ %	66.47	66.00	68.06	67.12	65.80	72.62	67.50	67.42	66.00	63.20	68.46	66.31	65.10	65.40	66.10	66.26
Al ₂ O ₃ %	21.77	22.27	21.24	20.40	23.98	17.89	21.54	21.56	22.38	23.72	19.57	22.45	22.19	19.85	18.80	20.16
Fe ₂ O ₃ %	0.23	0.03	0.07	0.17	0.11	0.44	0.06	0.04	0.02	0.15	0.09	0.05	0.11	0.037	0.10	—
CaO%	0.48	1.00	1.40	1.40	0.58	0.70	0.93	0.70	0.60	2.40	0.70	0.61	0.26	0.48	0.02	0.62
MgO%	0.06	0.50	0.16	0.26	0.08	1.09	0.84	0.34	0.20	1.01	0.50	0.40	0.06	0.50	0.09	0.10
Na ₂ O%	10.68	10.38	9.60	9.50	8.56	6.06	8.33	10.06	10.11	8.76	9.51	1.93	1.88	2.00	1.99	10.80
K ₂ O%	0.12	0.24	0.10	0.18	0.09	0.10	0.12	0.10	0.30	0.36	0.62	7.50	9.80	10.80	14.14	0.62
Total%	100.21	100.68	100.85	100.23	99.97	99.82	99.92	100.62	100.03	99.90	99.93	99.55	99.65	99.83	100.36	100.28
Specific gravity	2.62	2.62	2.62	2.62	2.63	2.618	2.62	2.621	2.615	2.62	2.63	2.573	2.572	2.573	—	—
Solubility in water(pH)	8.80	9.00	8.70	9.40	8.28	9.00	8.80	8.90	8.50	9.08	8.90	8.65	8.60	8.78	—	—
Fusion tem- perature°C	1230	1190	1240	1235	1195	1240	1240	1235	1230	1200	1195	1275	1285	1285	—	—
Colour of the fused product	Cream	Snow white	Light cream	Light cream	Light brown	Dark brown	Milky white	White	White	Light cream	Cream 60	Snow white	Snow white	White	—	—
Percentage Linear	0.325 (G)	0.320 (G)	0.376 (G)	0.280 (G)	0.250 (G)	0.375 (G)	0.335 (G)	0.355 (G)	0.275 (G)	0.260 (G)	0.300 (G)	0.325 (G)	0.327 (G)	0.328 (G)	—	—
Thermal Expansion at 500°C.	0.526 (R)	0.750 (R)	—	—	0.575 (R)	—	—	—	—	—	0.640 (R)	0.500 (R)	0.120 (R)	0.357 (R)	—	—

(G) Glass *Analysts Rosenholtz & Smith 1942, Analysis No: 9 "Rock Forming Minerals" Vol. 4, 39 by Deer *et. al.* Longmans, London, 1962.

(R) Crystalline *Analysts Pagliani 1937, Analysis No. 6 "Rock Forming Minerals" Vol. 4, 108, Deer *et. al.* Longmans, London, 1962.

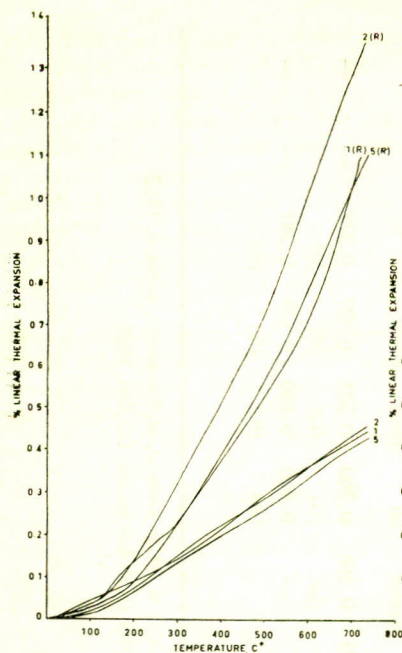


Fig. 1.—Thermal expansion of raw and glassy soda feldspars.

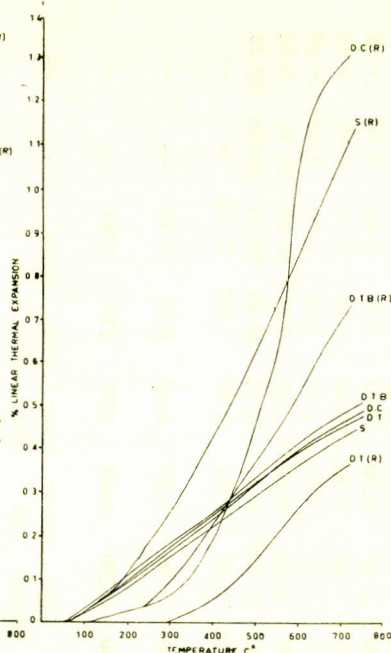


Fig. 2.—Thermal expansion of raw potash and glassy feldspars.

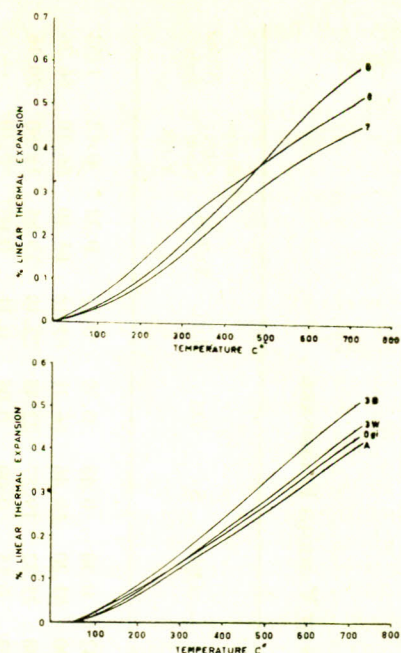


Fig. 3.—Thermal expansion of glassy soda feldspars.

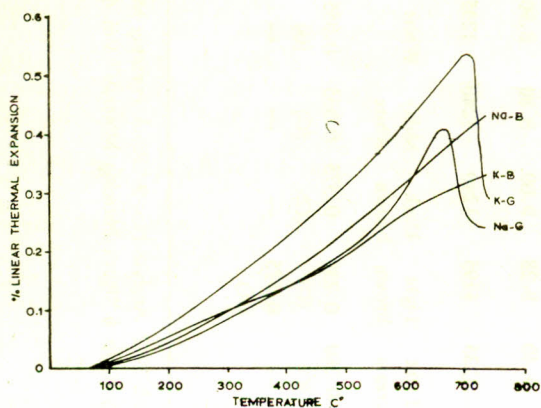


Fig. 4.—Thermal expansion of soda and potash body and glaze compositions.

cream or light cream feldspars may also be acceptable.

The thermal expansion of seven raw (R) and eleven glass(G) soda feldspars and three potash feldspars has been determined and presented in Figs 1, 2 and 3. For comparison a sample of soda feldspar S (raw and glass) has been included in Fig. 2 along with the potash feldspars. From these figures it may be seen that in the case of soda feldspars (Fig. 1), the percentage of thermal expansion of crystalline material (R) is much greater than the expansion of the same when fired to 1250°C. In the crystalline state the expansion at 500°C varies from 0.5 to 0.6%, whereas in

the glassy state it varies from 0.1 to 0.3% (Table 2). It may be seen that there is a reduction of 50% of the total expansion in the later case. In the case of potash feldspars the thermal expansion of the crystalline feldspars varies from 0.1 to 0.03%, whereas of the partly glassy state (after melting at 1250°C) it is between 0.3 to 0.4%. It may, therefore, be concluded that in the crystalline state the thermal expansion of the soda feldspars is much greater than those of potash ones, whereas in the glassy state the expansion of the potash feldspars is slightly greater than that of the soda feldspars.

In order to find out the effect of thermal expansion of the soda and potash feldspars in the bodies and glazes, one glaze and body composition with the soda feldspar and another such composition by replacing the soda-feldspar with the potash feldspar in the former composition were prepared. The molecular formulae of all the four compositions are given as follows:

Soda Glaze; Na₂O 0.344; CaO 0.234; ZnO 0.201; PbO 0.221; Al₂O₃ 0.355; B₂O₃ 0.109; SiO₂ 2.879; SnO₂ 0.154;

Soda Body; Na₂O 0.038; Al₂O₃ 0.290; SiO₂ 0.982.

Potash Glaze; K₂O 0.297; CaO 0.251; ZnO 0.215; PbO 0.237; Al₂O₃ 0.308; B₂O₃ 0.114; SiO₂ 2.657; SnO₂ 0.164.

Potash Body; K_2O 0.036; Al_2O_3 0.288; SiO_2 0.970.

The thermal expansion of the two bodies and glazes (soda and potash) is given in Fig. 4. It may be seen that the expansion of the potash body is less than that of the soda body but the expansion of potash glaze is higher than that of the soda glaze. This behaviour is very similar to that of the soda and potash crystalline and glass samples shown in Fig. 1, 2 and 3. These results also indicate that a potash body, usually desirable in the ceramic industry, due to its long vitrification range, might do well so far as crazing is concerned, if a soda glaze is applied on it as their expansions are identical.

In the case of soda feldspars, it appears that the expansion of crystalline substance has been reduced to about half when it is converted to glass at $1250^\circ C$ —a temperature high enough for albite feldspars to be converted into glass. But in the case of potash feldspar, a temperature of $1600^\circ C$ is necessary to convert them to complete glass.¹⁰ Potash feldspar has been established as melting incongruently at $1150 \pm 20^\circ C$ to form crystals of leucite ($K_2O \cdot Al_2O_3 \cdot 4SiO_2$) and a viscous liquid which is more silicious than the feldspar¹¹. With the potash feldspar, there is a long temperature-interval during which leucite and the liquid may co-exist at equilibrium; above the temperature of $1530^\circ C$ the leucite crystals disappear.¹² In the present case when they were heated to $1250^\circ C$ most of the substances, in fact, changed to leucite.¹² another crystalline material and, therefore, the expansion instead of decreasing (for glass) increased.

Conclusions

Soda feldspar Nos. 2, 3B, 7, 8, A and S are suitable to be used in the manufacture of glass-ware but samples 2, 8 and A are preferred. All the soda feldspars investigated may be used partly with potash feldspars in the body com-

positions of ceramic-wares. The potash feldspars, i.e., D.C. D.T. and D.T.B. are quite good and may be used partly or wholly in the ceramic-body compositions. All the potash and soda feldspars containing iron oxide less than 0.1% may be used in the glazes, though an iron content of 0.05% is usually preferred and recommended. In porcelain enamels all the potash and soda feldspars having iron content less than 0.1% may be used but those having 0.05% F_2O_3 are preferred.

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References

1. *A.S.T.M. Standards Part 13* (Philadelphia, Pa; U.S.A., 1964), p. 305.
2. C.W. Parmelee and A.J.M. Monack, *J. Am. Ceram. Soc.*, **13**, 386(1930).
3. J.M. Hunt and K. Wishard, *Anal. Chem.*, **22**, 1478 (1950).
4. H. Bennet and W.G. Hawley, *Methods of Silicate Analysis* (Academic Press, London, 1965), second edition.
5. H.A. Flaschka, *E.D.T.A. Titrations* (Pergamon Press, New York, 1959), pp. 100–102.
6. J. Mahmood, A. Haq and F.A. Faruqi, *Sci. Ind.*, **2**, 27 (1964).
7. F.A. Miller and C.M. Wilkins, *Anal. Chem.*, **24**, 1253(1952).
8. W.D. Kellu, J.M. Spolt and D.L. Biggs, *Am. J. Sci.* **250**, 453(1952).
9. F. Singer and S.S. Singer, *Industrial Ceramics* (Chapman and Hall Ltd. London, 1963), first edition, p. 101.
10. P.J. Vergano, D.C. Hill and Uhlmann J. *Am. Ceram. Soc.*, **50**, 1(19567).
11. G.W. Morey and N.L. Bowen, *Am. J. Sci.*, **4**, 1(1922).
12. H.J. Orłowski and C.J. Koenig, *J. Am. Ceram. Soc.*, **24**, 80 (1941).