THE SYSTEM, LEUCITE—DIOPSIDE—SILICA.

J. F. SCHAIRER AND N. L. BOWEN.

ABSTRACT.

Several silicate systems have been investigated or are now being studied to ascertain what compositions residual liquids from fractional crystallization approach. The system now presented combines the simple pyroxene, diopside, with potash-alumina silicates. Phase equilibrium data show that diopside is almost quantitatively removed, leaving liquids that approach in composition a mixture of potash feldspar and silica.

INTRODUCTION.

For many years we have been investigating in the laboratory the mutual melting relations of the mineral molecules which constitute the igneous rock magmas. We have been particularly interested in the melting phenomena of the olivines and pyroxenes, which are among the early minerals to crystallize from a cooling magma, and in the alkali-alumina silicates which are among the late minerals.

Recently we have been studying the melting behavior of systems which combine one of the early-formed minerals with late-forming minerals to ascertain the nature of the residual liquids from fractional crystallization of such systems. The system, $NaAlSiO_4$—FeO—SiO_2, with fayalite as the early-forming mineral, and albite and silica or albite and nepheline as the minerals rich in the residual liquids, has already been published[1]. Liquidus data for the system, leucite—anorthite—silica, are nearly complete and will be published soon. We now present the equilibrium data for the system, leucite—diopside—silica, which combines one of the simplest pyroxenes, diopside ($CaMgSi_2O_6$), with the potash-bearing alkali-alumina silicates, leucite ($KAlSi_2O_6$), and potash feldspar ($KAlSi_3O_8$), and with the several forms of SiO_2.

PREPARATION OF THE TERNARY MIXTURES.

In the preparation of silicate mixtures containing K_2O, special care must be used to avoid loss of K_2O and consequent departure from composition. Several K_2O-SiO_2 glasses with

[1] Bowen, N. L., and Schairer, J. F.: J. Geol., 46, 397-411, 1938.

different K_2O contents were made from $KHCO_3$ and purified quartz. The loss of K_2O is minimized by first sintering at low temperatures and then gradually raising the temperature to about 1400° C. The small loss was determined by weighings and corrected by adding the appropriate amount of $KHCO_3$.

Diopside was prepared by melting together specially purified $CaCO_3$, MgO, and quartz, and presents no difficulties.

The ternary mixtures were prepared by fusing together in platinum crucibles one of the several K_2O-SiO_2 glasses, specially purified Al_2O_3, diopside, and quartz. It is necessary to fuse a mixture several (usually five to eight) times, with intermediate grinding, to secure a homogeneous glass. The homogeneity of the glass is checked under the microscope by an absolutely uniform index of refraction of the glass grains.

EQUILIBRIUM STUDIES.

Investigation of the melting relations of the ternary mixtures was carried out entirely by the method of quenching,[2] which consists in holding a small charge of known composition at a measured temperature for a period of time adequate for attainment of equilibrium between the several phases, and then chilling instantly to room temperature to "freeze" the equilibrium. Quenched charges are examined with a petrographic microscope to determine the nature and number of crystalline and liquid phases. Crystals are identified by their optical properties. On quenching, these liquids "freeze" to a glass.

Special precautions were taken to have only small crystals present in the various mixtures before making the quenching experiments, in order to hasten attainment of equilibrium between crystals and liquid. For those compositions near a boundary curve, care was taken to have both kinds of crystals present in the initial charge.

Equilibrium is reached rather promptly in the ternary system except below 1350° in the leucite field, below 1300° in the tridymite field, and below 1200° in the diopside field. With the exceptions noted, equilibrium is reached in a few hours, although longer times were usually given to be on the safe side.

Quenching experiments were conducted in platinum-wound electric furnaces whose temperature was controlled ($\pm 2°$) with the Geophysical Laboratory furnace thermostat,[3] some-

[2] Shepherd, E. S., Rankin, G. A., and Wright, F. E.: This Journal, 28, 308, 1909.

[3] Roberts, H. S.: J. Optical Soc. Am., 11, 171-186, 1925.

what modified from the original design but identical in principle.

The temperature was measured with a thermocouple placed nearly in contact with (about 1 mm. distant from) the small charge wrapped in a tiny platinum envelope, which is suspended in that part of the furnace determined as the "hot point." In a well insulated furnace there is a range of about 5 mm. on either side of the "hot point" where the temperature falls off only about one-half degree. The small platinum envelope containing the charge hangs entirely within this zone.

The Pt—Pt 90 Rh 10 thermoelement was calibrated frequently at several fixed points defined in degrees Centigrade as follows:

Anorthite melting point	1550°
Diopside melting point	1391.5°
Li_2SiO_3 melting point	1201°
Gold melting point	1062.6°

THE BINARY SYSTEMS.

The ternary system, leucite—diopside—silica, is bounded by the limiting binary systems, leucite—diopside, diopside—silica, and leucite—silica. There are no binary systems within the ternary system.

The System, Leucite—Diopside.

This system has been described in a previous paper.[4] Leucite ($KAlSi_2O_6$) melts congruently at 1686 ± 5° and diopside ($CaMgSi_2O_6$) congruently at 1391.5°, and they form a eutectic at 61.5 weight per cent diopside and at the temperature 1300 ± 2°. The equilibrium diagram is reproduced in Fig. 1.

The System, Diopside—Silica.

Data for this system are given in two previous papers. Bowen[5] shows the eutectic relation between diopside and tridymite at 84 weight per cent diopside and at the temperature 1362°. Greig[6] gives data for the region of two immiscible liquids in the ternary system, CaO—MgO—SiO_2, from which the binary relations for diopside—SiO_2 may be interpolated. Greig[7] places the melting point of cristobalite at 1713 ± 5°.

[4] Bowen, N. L., and Schairer, J. F.: This Journal, 18, 301-312, 1929.
[5] Bowen, N. L.: This Journal, 38, 209-210, 1914.
[6] Greig, J. W.: This Journal, 13, 28-33 and 36, 1927.
[7] Greig, J. W.: Op. cit., p. 12.

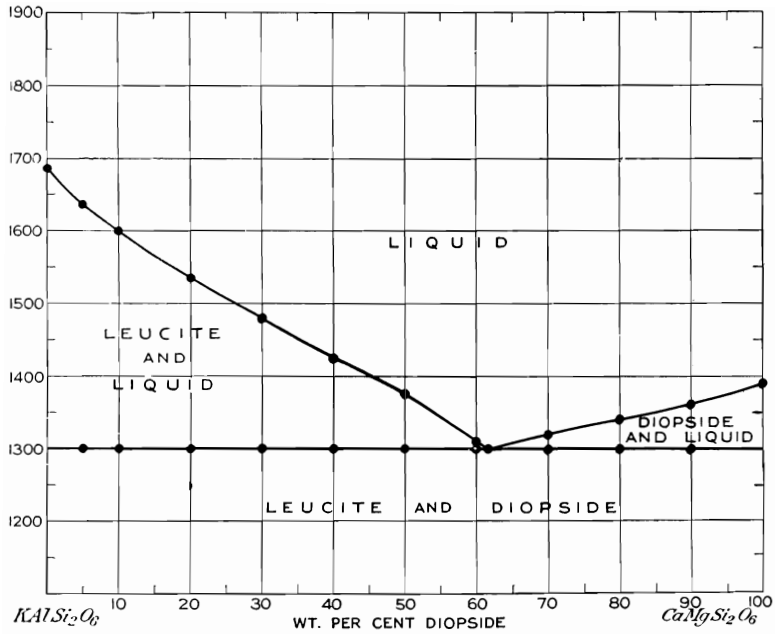

Fig. 1. Equilibrium diagram of the binary system, leucite—diopside (after Bowen and Schairer).

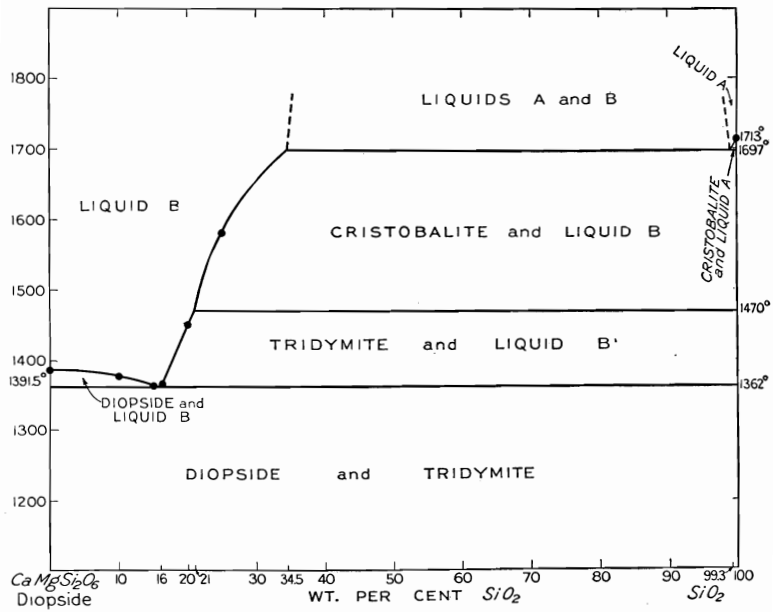

Fig. 2. Equilibrium diagram of the binary system, diopside—silica (after data of Bowen and of Greig).

A diagram for the binary system using the data of Bowen and of Greig is given in Fig. 2.

The System, Leucite—Silica.

Morey and Bowen[8] give data showing the incongruent nature of the melting of potash feldspar ($KAlSi_3O_8$) to leucite and liquid, presenting a hypothetical diagram for the system, leucite—silica. As a result of the great viscosity of the mixtures

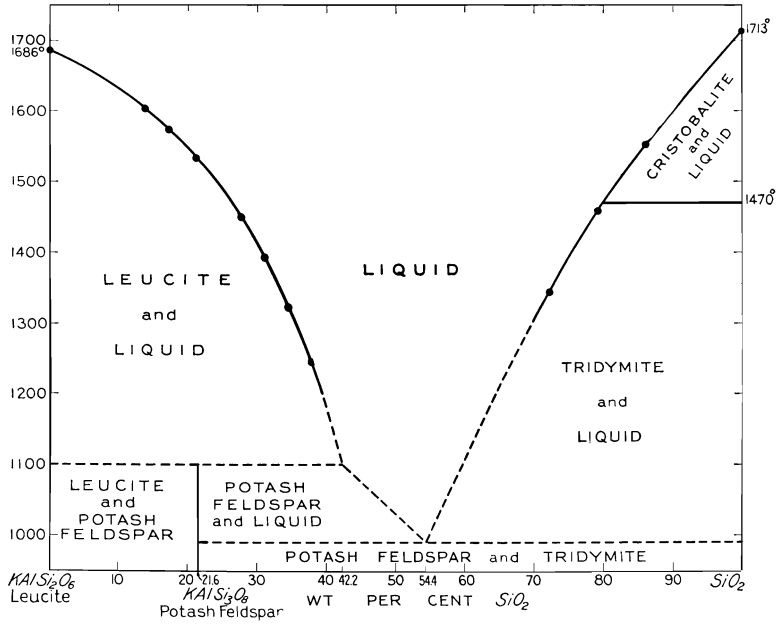

Fig. 3. Preliminary diagram of the binary system, leucite—silica.

and the difficulties in crystallizing them, the best data for this system may be obtained from direct quenching experiments on those compositions rich in leucite and those rich in silica; and from intermediate compositions the best data may be obtained by interpolation from the ternary data in the system, K_2O—Al_2O_3—SiO_2, to be published later.[9] A preliminary diagram is given here in Fig. 3. The data on which it is based will be

[8] Morey, G. W., and Bowen, N. L.: This Journal, 4, 1-21, 1922.

[9] The system, K_2O—Al_2O_3—SiO_2: unpublished work of J. F. Schairer and N. L. Bowen.

given later with those of the system, K_2O—Al_2O_3—SiO_2. Broken lines indicate the portions of the diagram based on data from this ternary system.

THE TERNARY SYSTEM.

To determine the liquidus temperatures, the slopes of the liquidus surface and the fields of stability of the primary crystal-

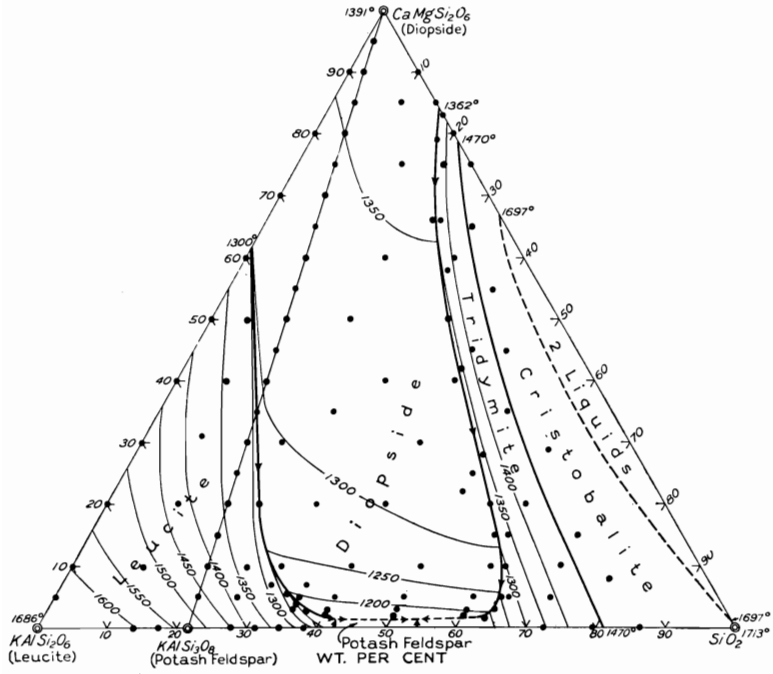

Fig. 4. Equilibrium diagram of the ternary system, leucite—diopside—silica.

line phases with their boundary curves, quenching experiments were made on eighty-nine different ternary compositions. These data are assembled in Table I and presented graphically in Fig. 4. All compositions are expressed in weight per cent. Boundary curves are indicated by heavy lines. Broken lines indicate some uncertainty as to their precise location. Isotherms are given as lighter lines with the temperature indicated on each. The triangle representing the whole system is divided

into two smaller triangles by the line joining potash feldspar and diopside. Black dots represent the eighty-nine compositions actually studied, and double open circles the compositions of compounds. Arrows on the boundary curves indicate the direction of falling temperature.

A noteworthy feature of the ternary system is the extension of the field of diopside from pure diopside itself nearly down to the binary bounding system, leucite—silica. Even with less than two per cent diopside in the total composition of a mixture, diopside may be the first crystalline phase to appear on cooling. For mixtures in this system, diopside is removed, on cooling, almost quantitatively (with some leucite or some silica also for appropriate compositions), leaving a residual liquid which is almost pure potash-alumina silicate in composition.

In many silicate systems, cristobalite often crystallizes and persists metastably for long periods of time at temperatures within the stability range of tridymite. In this ternary system, tridymite always appears in its temperature range of stability and grows beautiful thin hexagonal plates, flattened parallel to the base (0001). If the temperature is raised above 1470°±, these readily invert to cristobalite and re-form on holding the temperature for several hours below 1470°±.

It will be noted that the field of diopside crowds down so close (to less than two per cent diopside) to the leucite-silica side line that the field of potash feldspar in the ternary system is very small. As has been previously noted, compositions in this region of low temperatures are exceedingly viscous,[10] impossible or almost impossible to crystallize in dry melts and so slow in reaching equilibrium as to be impractical experimentally. The temperatures and compositions of the ternary reaction point and ternary eutectic in the system, leucite—diopside—silica, cannot be much different in temperature or composition from those of the binary reaction point and binary eutectic, respectively, in the binary system, leucite—silica. The best values for these binary points and their compositions will be given with the data on which they are based, when the data for the ternary system, K_2O—Al_2O_3—SiO_2 are published.

There are no solid solutions in the system. The optical properties of the crystalline phases agree with those reported in pre-

[10] For data on viscosities of silicate glasses, see N. L. Bowen: Trans. Am. Geophys. Union, 15, 249-255, 1934.

TABLE I.
Results of Quenching Experiments.

Refractive index of glass ± .003	Composition in wt. per cent			Temp. ° C.	Time	Phases
	Leucite	Diopside	Silica			
				Points on Cristobalite Surface		
1.553	5	65	30	1505	5 hrs.	Small amount cristobalite in glass
				1515	5 hrs.	Very rare cristobalite in glass
1.539	7	55	38	1550	8 hrs.	Rare cristobalite in glass
				1555	8 hrs.	All glass
1.525	10	45	45	1530	4 hrs.	Rare cristobalite in glass
				1535	4 hrs.	All glass
1.503	12	29	59	1540	8 hrs.	Rare cristobalite in glass
				1545	6 hrs.	All glass
1.484	15	15	70	1505	5 hrs.	Small amount cristobalite in glass
				1510	8 hrs.	Very rare cristobalite in glass
				1515	5 hrs.	All glass
1.475	14	8	78	1530	4 hrs.	Rare cristobalite in glass
				1535	4 hrs.	All glass
				Points on Tridymite Surface		
1.568	4	75	21	1359	4 hrs.	Very rare diopside and much tridymite in glass
				1395	18 hrs.	Small amount tridymite in glass
				1405	24 hrs.	Very rare tridymite in glass
				1410	48 hrs.	All glass
1.557	9	66	25	1345	5 hrs.	Small amount diopside and moderate amount tridymite in glass
				1347	3 hrs.	Moderate amount tridymite in glass
				1360	20 hrs.	Rare tridymite in glass
				1365	18 hrs.	All glass
1.547	10	60	30	1405	24 hrs.	Rare tridymite in glass
				1410	72 hrs.	All glass

1.546	12	58	30	1340	3 hrs.	Small amount diopside and much tridymite in glass
				1344	3 hrs.	Much tridymite in glass
				1365	18 hrs.	Rare tridymite in glass
				1370	4 hrs.	All glass
1.527	15	45	40	1405	24 hrs.	Rare tridymite in glass
				1410	72 hrs.	All glass
1.523	18	42	40	1325	3 hrs.	Much diopside and tridymite in glass
				1328	4 hrs.	Much tridymite in glass
				1340	17 hrs.	Rare tridymite in glass
				1345	20 hrs.	All glass
1.515	15	35	50	1465	24 hrs.	Rare tridymite in glass
				1470	24 hrs.	All glass
1.505	22	28	50	1335	15 hrs.	Rare tridymite in glass
				1340	17 hrs.	Very rare tridymite in glass
				1345	20 hrs.	All glass
1.493	20	20	60	1410	72 hrs.	Much tridymite in glass
				1416	24 hrs.	Very rare tridymite in glass
				1420	24 hrs.	All glass
1.487	25	15	60	1340	24 hrs.	Rare tridymite in glass
				1345	24 hrs.	All glass
1.480	28	10	62	1290	72 hrs.	Moderate amounts both diopside and tridymite in glass
				1295	24 hrs.	Rare tridymite in glass
				1300	24 hrs.	All glass
1.478	20	10	70	1440	24 hrs.	Small amount tridymite in glass
				1445	24 hrs.	All glass
1.476	31	5	64	1250	24 hrs.	Very rare diopside and moderate amount tridymite in glass
				1260	48 hrs.	Rare tridymite in glass
				1265	72 hrs.	All glass
1.476	30	5	65	1250	72 hrs.	Rare diopside and much tridymite in glass
				1260	72 hrs.	Much tridymite in glass
				1290	19 hrs.	Very rare tridymite in glass
				1295	18 hrs.	All glass
1.475	24	5	71	1395	48 hrs.	Rare tridymite in glass
				1400	48 hrs.	All glass

TABLE I—Continued.

Refractive index of glass ± .003	Composition in wt. per cent			Temp. ° C.	Time	Phases
	Leucite	Diopside	Silica			
1.475	33	3	64	1210	72 hrs.	Very rare diopside and much tridymite in glass
				1225	7 days	Small amount tridymite in glass
				1230	6 days	All glass
1.474	35	2	63	1160	7 days	Rare diopside and much tridymite in glass
				1185	10 days	Rare tridymite in glass
				1190	10 days	All glass
				Points on Diopside Surface		
1.603	3.92	*95.00	1.08	1378	4 hrs.	Very rare diopside in glass
				1382	2 hrs.	All glass
1.594	7.83	*90.00	2.17	1370	4 hrs.	Very rare diopside in glass
				1372	3 hrs.	All glass
1.588	11.75	*85.00	3.25	1359	4 hrs.	Rare diopside in glass
				1361	3 hrs.	All glass
1.586	5	85	10	1364	4 hrs.	Much diopside in glass
				1370	4 hrs.	All glass
1.580	15.67	*80.00	4.33	1350	3 hrs.	Very rare diopside in glass
				1352	4 hrs.	All glass
1.573	19.58	*75.00	5.42	1344	3 hrs.	Rare diopside in glass
				1347	3 hrs.	All glass
1.571	10	75	15	1356	3 hrs.	Moderate amount diopside in glass
				1359	4 hrs.	All glass
1.567	23.50	*70.00	6.50	1335	3 hrs.	Rare diopside in glass
				1338	3 hrs.	All glass
1.559	10	66	24	1340	5 hrs.	Moderate amount diopside and rare tridymite in glass
				1345	5 hrs.	Rare diopside in glass
1.562	27.42	*65.00	7.58	1325	3 hrs.	Moderate amount diopside in glass
				1329	3 hrs.	All glass

1.555	31.33	*60.00	8.67	1322	5 hrs.	Rare diopside in glass
				1324	6 hrs.	All glass
1.552	20	60	20	1340	3 hrs.	Very rare diopside in glass
				1344	3 hrs.	All glass
1.552	35.25	*55.00	9.75	1317	4 hrs.	Moderate amount diopside in glass
				1321	5 hrs.	All glass
1.546	39.16	*50.00	10.84	1309	5 hrs.	Small amount diopside in glass
				1312	5 hrs.	All glass
1.543	30	50	20	1322	5 hrs.	Small amount diopside in glass
				1324	6 hrs.	All glass
1.542	43.08	*45.00	11.92	1303	5 hrs.	Much diopside in glass
				1307	5 hrs.	All glass
1.533	47	*40	13	1300	48 hrs.	Small amount diopside in glass
				1303	18 hrs.	All glass
1.527	30	40	30	1320	48 hrs.	Much diopside in glass
				1322	5 hrs.	All glass
1.522	20	40	40	1325	24 hrs.	Very rare diopside in glass
				1330	24 hrs.	All glass
1.522	40	35	25	1310	5 hrs.	Small amount diopside in glass
				1313	5 hrs.	All glass
1.515	50	30	20	1295	18 hrs.	Moderate amount diopside in glass
				1300	18 hrs.	All glass
1.511	30	30	40	1317	4 hrs.	Moderate amount diopside in glass
				1321	5 hrs.	All glass
1.500	25	25	50	1317	4 hrs.	Moderate amount diopside in glass
				1321	5 hrs.	Very rare diopside in glass
				1325	24 hrs.	All glass
1.498	28	22	50	1310	24 hrs.	Moderate amount diopside in glass
				1313	5 hrs.	Rare diopside in glass
				1315	24 hrs.	All glass
1.503	50	20	30	1280	24 hrs.	Much diopside in glass
				1285	24 hrs.	Very rare diopside in glass
				1290	72 hrs.	All glass
1.500	40	20	40	1300	24 hrs.	Rare diopside in glass
				1305	24 hrs.	All glass

TABLE I—Continued.

Refractive index of glass ± .003	Composition in wt. per cent			Temp. ° C.	Time	Phases
	Leucite	Diopside	Silica			
1.488	27	15	58	1305	24 hrs.	Rare diopside in glass
				1310	24 hrs.	All glass
1.495	60	10	30	1230	24 hrs.	Moderate amount diopside in glass
				1235	24 hrs.	Rare diopside in glass
				1240	72 hrs.	All glass
1.493	50	10	40	1250	72 hrs.	Small amount diopside in glass
				1255	24 hrs.	All glass
1.487	40	10	50	1265	24 hrs.	Rare diopside in glass
				1270	24 hrs.	All glass
1.481	30	10	60	1285	72 hrs.	Moderate amount diopside in glass
				1290	24 hrs.	All glass
1.488	58	7	35	1215	48 hrs.	Moderate amount diopside in glass
				1220	72 hrs.	All glass
1.487	60	5	35	1180	7 days	Moderate amount diopside in glass
				1185	10 days	Very rare diopside in glass
				1190	10 days	All glass
1.485	55	5	40	1200	48 hrs.	Small amount diopside in glass
				1205	48 hrs.	All glass
1.483	45	5	50	1215	24 hrs.	Moderate amount diopside in glass
				1220	48 hrs.	Very rare diopside in glass
				1225	24 hrs.	All glass
1.478	35	5	60	1235	24 hrs.	Small amount diopside in glass
				1240	72 hrs.	Very rare diopside in glass
				1245	24 hrs.	All glass
1.484	57	3	40	1150	48 hrs.	Small amount diopside in glass
				1155	6 days	All glass
1.480	47	3	50	1160	4 days	Moderate amount diopside in glass
				1165	5 days	Very rare diopside in glass
				1170	48 hrs.	All glass

1.475	37	3	60	1205	48 hrs.	Rare diopside in glass
				1210	48 hrs.	Very rare diopside in glass
				1215	72 hrs.	All glass
1.483	58	2	40	1080	10 days	Moderate amount diopside in glass
				1090	10 days	Small amount diopside in glass
				1095	10 days	All glass
1.479	53	2	45	1100	7 days	Moderate amount diopside in glass
				1105	7 days	Rare diopside in glass
				1110	7 days	All glass
1.477	48	2	50	1110	7 days	Rare diopside in glass
				1115	7 days	All glass
1.475	38	2	60	1140	7 days	Moderate amount diopside in glass
				1145	7 days	Rare diopside in glass
				1150	7 days	All glass
				Points on Leucite Surface		
1.546	45	50	5	1303	5 hrs.	Rare diopside and much leucite in glass
				1307	5 hrs.	Much leucite in glass
				1315	18 hrs.	Rare leucite in glass
				1320	18 hrs.	All glass
1.535	53	40	7	1345	48 hrs.	Very rare leucite in glass
				1350	24 hrs.	All glass
1.522	61	31	8	1370	48 hrs.	Rare leucite in glass
				1375	48 hrs.	All glass
1.521	54.83	*30.00	15.17	1300	48 hrs.	Rare leucite in glass
				1303	18 hrs.	Very rare leucite in glass
				1305	72 hrs.	All glass
1.513	58.75	*25.00	16.25	1320	4 days	Rare leucite in glass
				1325	7 days	All glass
1.512	70	20	10	1410	48 hrs.	Rare leucite in glass
				1415	48 hrs.	All glass
1.509	62.66	*20.00	17.34	1340	72 hrs.	Rare leucite in glass
				1345	48 hrs.	All glass
1.503	66.58	*15.00	18.42	1365	72 hrs.	Rare leucite in glass
				1370	48 hrs.	All glass

TABLE I—Concluded.

Refractive index of glass ± .003	Composition in wt. per cent			Temp. ° C.	Time	Phases
	Leucite	Diopside	Silica			
1.504	80	10	10	1510	5 hrs.	Small amount leucite in glass
				1515	8 hrs.	Rare leucite in glass
				1520	5 hrs.	All glass
1.499	70.50	*10.00	19.50	1410	48 hrs.	Small amount leucite in glass
				1415	48 hrs.	All glass
1.496	65	10	25	1310	4 days	Small amount leucite in glass
				1315	6 days	All glass
1.490	63	7	30	1280	72 hrs.	Small amount leucite in glass
				1285	24 hrs.	All glass
1.488	61	6	33	1200	7 days	Small amount diopside and much leucite in glass
				1205	7 days	Moderate amount leucite in glass
				1210	7 days	Small amount leucite in glass
				1215	7 days	All glass
1.493	74.41	*5.00	20.59	1465	24 hrs.	Rare leucite in glass
				1470	24 hrs.	Very rare leucite in glass
1.490	69	5	26	1370	48 hrs.	Small amount leucite in glass
				1375	48 hrs.	All glass
1.486	61	4	35	1215	7 days	Small amount leucite in glass
				1220	7 days	All glass
1.485	62	3	35	1230	7 days	Small amount leucite in glass
				1235	12 days	All glass
1.484	60	3	37	1160	8 days	Small amount leucite in glass
				1165	10 days	Very rare leucite in glass
				1170	7 days	All glass
				Points on Boundary Curves		
1.576	3	79	18	1361	3 hrs.	Much diopside and much tridymite in glass
				1364	3 hrs.	All glass

1.536	16	50	34	1330	4 hrs.	Much diopside and rare tridymite in glass
				1333	4 hrs.	All glass
1.495	25	20	55	1310	24 hrs.	Moderate amount diopside and small amount tridymite in glass
				1315	24 hrs.	All glass
1.525	50.91	*35.00	14.09	1295	18 hrs.	Rare diopside and very rare leucite in glass
				1300	18 hrs.	All glass
1.508	58	20	22	1265	4 days	Moderate amount diopside and small amount leucite in glass
				1270	4 days	All glass

* Compositions so designated lie on the join, potash feldspar—diopside.

vious papers from this Laboratory.[11] At temperatures below about 1200°, diopside tends to form as long needle-like crystals. No further work was done in the region of two immiscible liquids, and for a discussion of liquid immiscibility in the system, CaO—MgO—SiO_2, the reader is referred to the work of Greig.[12]

THE INVARIANT POINTS.

In the three binary systems bounding the ternary system, there are seven binary invariant points—three of them binary eutectics, one a binary reaction point[13] (potash feldspar+leucite+liquid), one a binary point of equilibrium between cristobalite, two liquids, and vapor, and two binary transition points of tridymite to cristobalite.

There are two ternary invariant points, one a eutectic between potash feldspar, tridymite, and diopside, the other a ternary reaction point with leucite and potash feldspar as the reaction pair. The phases at the ternary reaction point are leucite, potash feldspar, diopside, liquid, and vapor.

The data for the invariant points are given in Table II.

THE JOIN, POTASH FELDSPAR—DIOPSIDE.

The join, potash feldspar—diopside is a line across the ternary system representing all mixtures of potash feldspar[14] and diopside. It is not binary because of the appearance of leucite crystals whose composition does not lie in this join and the consequent departure of the composition of liquids from this line when the solid phase, leucite, is present. The data (marked with an asterisk in Table I) are plotted in Fig. 5 as a partial representation of the melting behavior of mixtures

[11] For diopside, see Ferguson, J. B., and Merwin, H. E.: This Journal, 48, 87, 1919.

For leucite, see Bowen, N. L., and Schairer, J. F.: This Journal, 18, 308-309, 1929.

For tridymite and cristobalite, see Fenner, C. N.: This Journal, 36, 351-356, 1913.

[12] Greig, J. W.: This Journal, 13, 28-33, 1927.

[13] For a discussion of the reaction principle, see Bowen, N. L.: J. Geol., 30, 177-198, 1922.

[14] In this paper, the term potash feldspar is used advisedly for the compound $KAlSi_3O_8$ ($K_2O.Al_2O_3.6SiO_2$). The relations of the two crystalline forms of this compound, orthoclase (monoclinic) and microcline (triclinic), have not been determined. So far, our crystals are too small, or not suitable, to determine which form crystallizes from melts in the ternary system, K_2O—Al_2O_3—SiO_2.

TABLE II.

Invariant Points.

Temp. °C.	Phases
	Unary
1713 ± 5	Cristobalite and liquid SiO_2 (Greig)
1686 ± 5	Leucite and liquid $KAlSi_2O_6$ (Bowen and Schairer)
1391.5*	Diopside and liquid $CaMgSi_2O_6$
	Binary
1300 ± 2	Leucite, diopside, and liquid (61.5% diopside) (Bowen and Schairer)
1362 ± 2	Diopside, tridymite, and liquid (84% diopside) (Bowen)
990 ± 20	Potash feldspar, tridymite, and liquid (unpublished work of Schairer and Bowen)
1100 ± 20	Leucite, potash feldspar, and liquid (unpublished work of Schairer and Bowen)
1698 ± 5	Cristobalite and two liquids (Greig)
1470 ± 10	Tridymite, cristobalite, and liquid { 79% diopside / 21% SiO_2 } (Bowen)
1470 ± 10	Tridymite, cristobalite, and liquid { 80% SiO_2 / 20% leucite } (unpublished work of Schairer and Bowen)
	Ternary
below 1100°	Leucite, potash feldspar, diopside, and liquid (ternary reaction point)
below 990°	Potash feldspar, diopside, tridymite, and liquid (ternary eutectic)

* By definition.

between diopside and potash feldspar. The diopside liquidus is shown as a heavy line and the liquidus of leucite as a light line. The crystallization of these mixtures is discussed later.

INDICES OF REFRACTION OF GLASSES.

Homogeneous glasses were prepared for the eighty-nine ternary compositions studied, and the index of refraction of each glass was measured at 25° C. with the petrographic microscope by comparison with standardized immersion liquids. The values obtained are given in the first column of Table I. The values are accurate to ± 0.003. No attempts were made to anneal the glasses or relieve strains. The data are plotted in Fig. 6. The compositions measured are indicated by black dots. Isofracts or curves of equal index of refraction are plotted in the composition triangle.

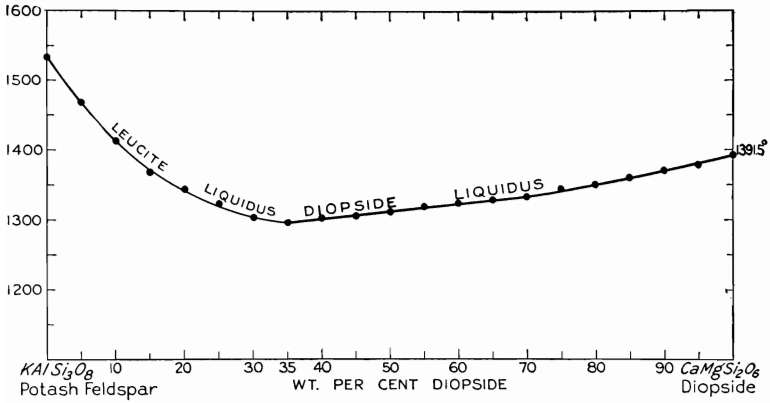

Fig. 5. The join, potash feldspar—diopside (not binary).

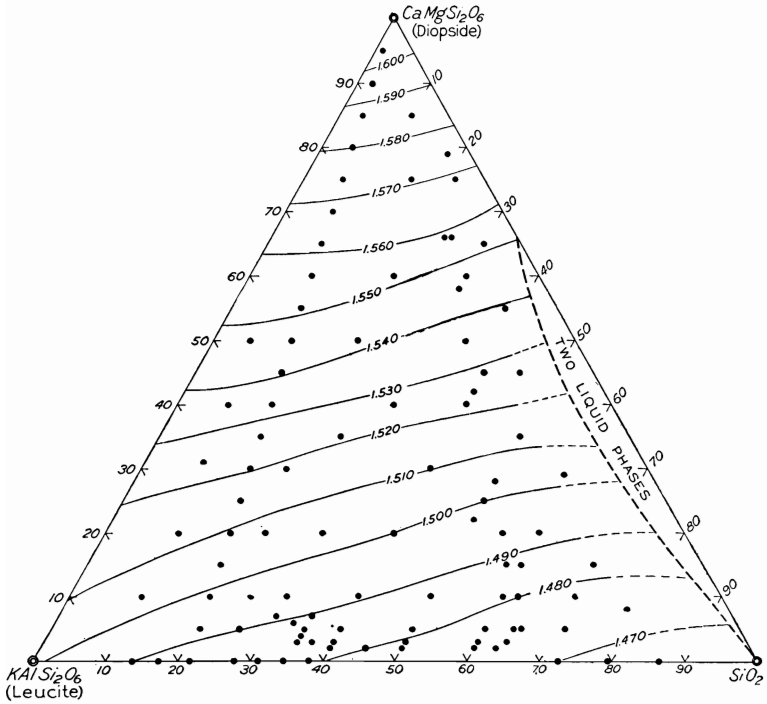

Fig. 6. Refractive indices of glasses at 25° C.

CRYSTALLIZATION OF TERNARY MIXTURES.

With perfect equilibrium, all mixtures (see Fig. 4) whose compositions lie in the triangle, leucite—potash feldspar—diopside, when completely crystalline consist of leucite, potash feldspar, and diopside. For those which lie in the field of diopside, on cooling from the completely molten state, diopside crystals appear first. When the composition of the liquid reaches the boundary curve, leucite—diopside, a second solid phase, leucite, appears. With falling temperature, leucite and diopside continue to separate with the composition of the liquid following the boundary curve, leucite—diopside, to the ternary reaction point where the temperature remains constant until all the liquid has been used up by reacting with the leucite crystals to form potash feldspar. For all compositions in the triangle, leucite—potash feldspar—diopside, all the liquid is used up at the reaction point before all the leucite has been transformed to potash feldspar by reaction with liquid. Thus the final completely crystalline product consists of the three phases leucite, potash feldspar, and diopside.

The join, potash feldspar—diopside, is a limiting case. For all mixtures whose composition lies in this join, the cooling history is similar to those in the triangle described above except that the amount of leucite crystals at the reaction point is such as to react completely with all the liquid so that leucite and liquid are exhausted simultaneously and the completely crystalline product consists of only two solid phases, potash feldspar and diopside.

All mixtures whose compositions lie in the triangle, potash feldspar—diopside—silica, with perfect equilibrium, become completely crystalline, on cooling, only at the temperature of the ternary eutectic, where they consist of potash feldspar, diopside, and tridymite. If their composition lies in the leucite field they approach the ternary eutectic along the boundary curve, leucite—diopside, or leucite—potash feldspar, to reach the ternary reaction point where *all* leucite is redissolved by reaction with liquid at constant temperature, then they follow the boundary curve, diopside—potash feldspar, to the ternary eutectic. If the composition of the mixture lies in one of the fields of silica, it approaches the ternary eutectic along the boundary curve, tridymite—diopside, or along the boundary curve, tridymite—potash feldspar. Mixtures whose compositions lie in the diopside field approach the ternary eutectic either

along the boundary curve, leucite—diopside, to the ternary reaction point and then along the boundary curve, potash feldspar—diopside, to the eutectic, or along the boundary curve, diopside—tridymite, to the eutectic. For the additional high-temperature complications of those mixtures whose compositions lie in the area of two liquid phases, the reader is referred to the excellent paper of our colleague J. W. Greig[15] on immiscibility in silicate melts.

With perfect equilibrium, crystals of leucite and silica are incompatible. For a discussion of the potentialities of fractional crystallization with failure of equilibrium, the reader is referred to the paper by Bowen, Schairer, and Willems[16] on the system, Na_2SiO_3—Fe_2O_3—SiO_2, especially pages 439-445.

PETROLOGIC CONSIDERATIONS.

In our report[17] on the binary system, leucite—diopside, some attention was given to the problems of natural leucite-bearing rocks. In a short time, we expect to report on the ternary system, leucite—anorthite—silica. At that time we shall consider more fully the petrologic problems involved in the origin of leucite rocks.

We wish to emphasize here that our results on the ternary system, leucite—diopside—silica, show that for simplified rock compositions of this type, the pyroxene (diopside) is removed first, almost quantitatively, on cooling and crystallizing, leaving a low-melting liquid whose composition approaches a mixture of potash feldspar and silica (alkali-alumina silicate). One of us[18] has already discussed crystal $\rightleftarrows$ liquid equilibrium and its bearing on the problems of rock origin by crystal fractionation, and presented a preliminary diagram for this system. For systems approaching rock compositions, residual liquids of fractional crystallization are enriched in the alkali-alumina silicates and tend to approach the low-melting region of the ternary system, $NaAlSiO_4$—$KAlSiO_4$—SiO_2,[19] which one of us[20] has called petrogeny's "residua" system.

[15] Greig, J. W.: This Journal, 13, 1-154, 1927.
[16] Bowen, N. L., Schairer, J. F., and Willems, H. W. V.: This Journal, 20, 405-455, 1930.
[17] Bowen, N. L., and Schairer, J. F.: This Journal, 18, 309-312, 1929.
[18] Bowen, N. L.: This Journal, 33, 1-21, 1937.
[19] Preliminary report—Schairer, J. F., and Bowen, N. L.: Trans. Am. Geophys. Union, 16, 325-328, 1935.
[20] Bowen, N. L.: This Journal, 33, 11, 1937.

SUMMARY.

Melting data for the system, leucite—diopside—silica are presented by means of tables and a ternary diagram. There are no ternary compounds. There are two ternary invariant points, one a reaction point and the other a ternary eutectic. The field of diopside occupies a large part of the ternary diagram, and with mixtures containing even less than two per cent diopside in their total composition, diopside appears as the primary phase. On fractional crystallization, residual liquids approach in composition a mixture of potash feldspar and silica. A diagram showing the indices of refraction of ternary glasses is given, and also a preliminary diagram for the binary system, leucite—silica.