

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Potassium-Rich Silica-Poor Igneous Rocks: A Distinct Group, Different from Basaltic Rock Series	1
1.2	Minor, Rare Earth and Trace Element Characteristics	2
1.3	Mineralogical Peculiarities	6
1.4	Scope of This Volume	6
<b>2</b>	<b>Mineralogy</b>	<b>11</b>
2.1	Leucite	11
2.2	K-Feldspar	16
2.3	Plagioclase	21
2.4	Clinopyroxene	22
2.5	Mica	29
2.6	Amphibole	35
2.7	Olivine	38
2.8	Nepheline	41
2.9	Kalsilite	45
2.10	Analcite	46
2.11	Melilite	49
2.12	Haüyne	53
2.13	Apatite	55
2.14	Spinel	55
2.15	Priderite	60
2.16	Wadeite	61
2.17	Roedderite-Like Mineral $[(\text{Na}, \text{K})_2(\text{Mg}, \text{Fe})_5(\text{Si}_{12}\text{O}_{30})]$	64
2.18	Pseudo-Brookite	64
2.19	Perovskite	65
2.20	Ilmenite	65
2.21	Melanite	67
2.22	Carbonate-Bearing Phases	67

<b>3</b>	<b>Classification</b>	69
3.1	Classification Based on Chemistry	69
3.1.1	Potassium Content as a Basis of Classification.	69
3.1.2	Total Alkali Versus Silica Classification	69
3.1.3	Chemical Classifications Based on Chemistry and Mineralogy of Type Localities.	71
3.1.4	Major Oxides as Basis of Classification	72
3.2	Classification on the Basis of Mineralogy	74
3.2.1	Kamafugitic Rocks Without Plagioclase	75
3.2.2	Leucitic Rocks with Feldspars	77
3.3	Classification Based on Niggli Values	78
3.3.1	Various Lamproitic Assemblages and Their Heteromorphic Relations to Each Other	82
3.3.2	Distinctive Criteria to Differentiate Among Kimberlites, Lamproites and Lamprophyres.	87
<b>4</b>	<b>Different Localities of Potassium-Rich Silica-Undersaturated Igneous Rocks and Their Silica-Rich Variants</b>	89
4.1	Ultrapotassic Silica-Deficient Rocks from Asia	90
4.1.1	Leucite-Bearing Rocks of Manchuria, China	90
4.1.2	K-Rich Volcanics from Yangbajin Rift, Tibet	93
4.1.3	Occurence of K-Rich Silica-Deficient Rocks from Turkey	95
4.1.4	Potassium-Rich Lamprophyres and Lamproites from Bokaro, Jharia and Raniganj Basins, East India	96
4.1.5	Leucite-Bearing Rocks of Indonesia	104
4.2	Ultrapotassic Rocks of Australia	110
4.2.1	West Kimberley.	110
4.2.2	New South Wales, Australia	113
4.3	Potassium-Rich Silica-Deficient Rocks from Africa	117
4.3.1	Birunga Volcanic Field.	117
4.3.2	Korath Range, Ethiopia	125
4.3.3	The Kapamba Lamproites of the Luangwa Valley, Eastern Zambia	125
4.3.4	Leucite Lamproites from Pniel, Post Masburg, Swartruggens, South Africa.	126
4.3.5	K-Rich Rocks from Mt. Etinde, West Africa	128
4.4	The Lamproitic Rocks from Antarctica	128
4.5	Potassium-Rich Silica-Undersaturated Igneous Rocks of the United States of America	129
4.5.1	Volcanic Fields of Highwood Mountains, Montana	129
4.5.2	The Bearpaw Mountains	133

4.5.3	Smoky Butte . . . . .	137
4.5.4	Potassic Rocks of Navajo-Hopi Province . . . . .	138
4.5.5	Dulce Dike . . . . .	140
4.5.6	Spanish Peaks . . . . .	140
4.5.7	Two Buttes, Colorado. . . . .	142
4.5.8	Potassic Rocks from Leucite Hills, Wyoming . . . . .	142
4.5.9	The Potassic Lava Suite from Central Sierra Nevada, California, U.S.A. . . . .	145
4.5.10	Pliocene Potassic Volcanic Rocks from Deep Springs Valley, California. . . . .	147
4.5.11	Other Localities in U.S.A . . . . .	148
4.6	Potassium-Rich Silica–Under Saturated Rocks from Brazil . . . . .	148
4.7	Silica–Undersaturated Potassic Lavas from Canada . . . . .	152
4.7.1	Kirkland Lake, Ontario. . . . .	152
4.7.2	Spotted Fawn Creek, Yukon . . . . .	153
4.8	The K-Rich Silica–Poor Lavas of Europe. . . . .	153
4.8.1	Ultrapotassic Rocks of Germany . . . . .	153
4.8.2	Tertiary and Quaternary Magmatism in Massif Central France. . . . .	156
4.8.3	K-Rich Rocks from Lower Austria. . . . .	160
4.8.4	Potassic Volcanism in Italy . . . . .	161
4.8.5	Volcanic Province of Spain. . . . .	185
4.8.6	Late Cenozoic Leucite Lamproites from the East European Alpine Belt (Macedonia and Yugoslavia). . . . .	186
4.9	Lamproitic Rocks from Greenland. . . . .	188
4.9.1	Bathjerg Complex . . . . .	188
4.9.2	Holtsteinberg Lamproit from Greenland . . . . .	188
4.9.3	Kap Dalton (69°24'N, 24°10'W) . . . . .	191
4.10	K-Rich Feldspathoidal Rocks from Colima, Mexico . . . . .	192
4.11	K-Rich Rocks from Paraguay . . . . .	193
4.12	K-Rich Feldspathoid-Bearing Rocks from the Former U.S.S.R. . . . .	194
4.12.1	Tezhsar (40°41'N, 44°39'E). . . . .	194
4.12.2	Elpinskii (39°27'N, 46°09'E). . . . .	194
4.12.3	Pkhrutskii (38°51'N, 48°10'E) . . . . .	195
4.12.4	Talyshskii (38°45'N, 48°22'E) . . . . .	195
4.12.5	Ishimskii Complex (51°17'N, 66°33'E). . . . .	195
4.12.6	Daubabinskoe (42°28'N, 70°07'E) . . . . .	195
4.12.7	Kaindy (42°21'N, 70°35'E) . . . . .	196
4.12.8	Irisu (42°20'N, 70°27'E) . . . . .	196
4.12.9	Kolbashinskii (42°20'N, 73°44'E). . . . .	197
4.12.10	Synnyr (56°55'N, 111°20'E) . . . . .	197
4.12.11	Yaksha (56°55'N, 111°48'E) . . . . .	197

4.12.12	Molbo (59°05'N, 118°49'E) . . . . .	198
4.12.13	Tommot (58°23'N, 125°13'E) . . . . .	198
4.12.14	Yakokut (58°27'N, 125°29'E) . . . . .	199
4.12.15	Rhododendron (58°22'N, 125°36'E) . . . . .	199
4.12.16	Lomam (57°07'N, 128°05'E) . . . . .	201
4.12.17	Tokko (55°36'N, 130°00'E) . . . . .	201
4.12.18	Dezhnevski Complex (66°05'N, 169°47'W) . . . . .	201
4.12.19	Andriyanovka (54°45'N, 158°30'E) . . . . .	202
4.12.20	Pyatistennyl (67°52'N, 161°36'E) . . . . .	202
4.12.21	Artem (43°46'N, 132°28'E) . . . . .	202
4.13	Potassium-Rich Rocks from Oceanic Islands . . . . .	203
4.13.1	Volcanic Activity in the Aeolian Arc Region. . . . .	203
4.13.2	K-Rich Rocks of the Tristan da Cunha Islands . . . .	204
4.13.3	Trachyte-Phonolite-Bearing Lavas of Ulleung Island, South Korea . . . . .	206
<b>5</b>	<b>Minor and Rare Earth Element Geochemistry of K-Rich Silica-Undersaturated Igneous Rocks . . . . .</b>	<b>211</b>
5.1	The Minor and Rare Earth Element Characteristics of Lamproites from Damodar Valley Coal Fields . . . . .	211
5.1.1	Nitrogen Content of Gondwana Potassic Rocks . . . .	212
5.1.2	Major and Trace Elements . . . . .	212
5.2	The REE and Minor Element Geochemistry of Birunga and Toro-ankole Rocks . . . . .	215
5.3	The Rare Earth Element and Trace Element Geochemistry of Lamproites from Western Australia, Leucite Hills (U.S.A.) and Gaussberg (Antarctica) . . . . .	222
5.4	Minor Element Geo-chemistry of Potassium-Rich Silica-Deficient Volcanic Rocks from Italy . . . . .	224
5.5	The REE and Trace Element Geochemistry of K-Rich Volcanic Rocks of Smoky Butte . . . . .	232
5.6	Minor and REE Geochemistry of K-Rich Silica-Deficient Volcanic Rocks from Highwood Mountains . . . . .	234
5.7	Minor Element Contents of Potassic Volcanic Rocks from N.E. China . . . . .	235
5.8	Trace Element Geochemistry for Ringgit-Beser Complex (Indonesia) . . . . .	239
5.9	Synthesis of Trace Element and Isotopic Data by Nelson (1992) . . . . .	243

<b>6</b>	<b>Chemical and Physical Constraints for Crystallization of Feldspathoids and Melilite in Potassium-Rich Rocks . . . . .</b>	<b>245</b>
6.1	P-T Conditions Related to Leucite Stability . . . . .	245
6.1.1	Stability of Leucite. . . . .	245
6.1.2	Melilite Stability . . . . .	247
6.1.3	Appearance of Melilite in the Join Diopside–Nepheline . . . . .	248
6.2	Partial Pressure of Oxygen Related to Genesis of K-Rich Volcanic Rocks . . . . .	252
6.2.1	Oxygen Fugacity Related to Stability of Annite . . . . .	252
6.2.2	The $\text{Fe}^{3+}/\text{Fe}^{2+}$ Ratio for Determination of Oxygen Fugacity in Potassic Rocks . . . . .	252
6.2.3	Oxide Phases as an Indicator for $f(\text{O}_2)$ Condition of Formation of Potassic Rocks . . . . .	253
6.3	Determination of Oxygen Fugacity in Potassic Rocks Based on the Presence of Picroilmenite . . . . .	255
6.4	Oxidation Path of a Leucitite Magma with Respect to $\text{CO}_2$ Solubility . . . . .	255
6.5	The Ascent Rate of Diamond and Phlogopite-Bearing Olivine Lamproite or a Kimberlitic Magma . . . . .	257
<b>7</b>	<b>Ternary Systems with Feldspathoids . . . . .</b>	<b>259</b>
7.1	The System Nepheline–Kalsilite– $\text{SiO}_2$ Under Variable P–T Conditions at or Below 5 Kb in Presence of Excess Water. . . . .	259
7.2	Phase Relations in the System Nepheline–Kalsilite– $\text{SiO}_2$ at 2 Gpa [ $P(\text{H}_2\text{O}) = P(\text{Total})$ ]. . . . .	265
7.3	Genesis of Pseudoleucite with Reference to Nepheline–Kalsilite–Silica System. . . . .	271
7.4	Survival of Leucite; Alteration to Analcite . . . . .	273
<b>8</b>	<b>Incompatible Mineral Pairs in K-Rich Rocks . . . . .</b>	<b>277</b>
8.1	Incompatibility Between Leucite and Orthopyroxene . . . . .	277
8.2	Incompatible Relation Between Leucite and Sodic-Plagioclase . . . . .	279
8.2.1	Phase Relations in the Join Leucite–Albite under Atmospheric Pressure . . . . .	279
8.2.2	The Leucite–Albite–Anorthite Join . . . . .	281
8.2.3	Petrological Implications. . . . .	282
8.3	Incompatibility Between Melilite–Plagioclase in Leucite-Bearing Lavas . . . . .	284
<b>9</b>	<b>Leucite- and Feldspar-Bearing Systems . . . . .</b>	<b>289</b>
9.1	Study of the System Diopside–Nepheline–Leucite The Join Diopside–Nepheline–Sanidine Under Atmospheric Pressure . . . . .	290

9.2	Experimental Study of the System Diopside–Nepheline–Sanidine at 0.1, 1 and 2 GPa and Variable Temperatures . . . . .	291
9.2.1	Phase Relations in the System Diopside–Nepheline–Sanidine at 0.1 GPa [ $P(\text{H}_2\text{O}) = P(\text{Total})$ ] . . . . .	292
9.2.2	Experimental Study of the System at 1 and 2 GPa [ $P(\text{H}_2\text{O}) = P(\text{Total})$ ] . . . . .	294
9.2.3	Petrological Significance . . . . .	295
9.3	The System $\text{KAlSi}_3\text{O}_8$ – $\text{CaAl}_2\text{Si}_2\text{O}_8$ – $\text{KAlSiO}_4$ at 0.5 GPa. . . . .	301
9.4	The System Forsterite–Diopside–Leucite–Anorthite . . . . .	303
9.4.1	The Join Forsterite–Diopside–Anorthite . . . . .	303
9.4.2	The Join Forsterite–Anorthite–Leucite. . . . .	303
9.4.3	The Join Diopside–Leucite–Anorthite . . . . .	304
9.4.4	Paragenesis . . . . .	304
9.5	The System Diopside–Leucite–Anorthite– $\text{SiO}_2$ . . . . .	306
9.5.1	Course of Crystallization of Liquid in the System Diopside–Leucite–Anorthite– $\text{SiO}_2$ . . . . .	306
<b>10</b>	<b>Melilite- and Leucite-Bearing Systems . . . . .</b>	<b>311</b>
10.1	Melilite- and Leucite-Bearing Systems Without Nepheline . . . . .	311
10.1.1	The System Forsterite–Diopside– Akermanite–Leucite . . . . .	311
10.2	Melilite- and Leucite-Bearing Mafic and Ultramafic Rocks Containing Nepheline . . . . .	317
10.2.1	The System Diopside–Nepheline– Akermanite–Leucite . . . . .	317
10.3	Experimental Study of the Joins Forsterite–Diopside– Leucite and Forsterite–Leucite–Akermanite up to 2.3 GPa [ $P(\text{H}_2\text{O}) = P(\text{Total})$ ] and Variable Temperatures . . . . .	324
10.3.1	Introduction. . . . .	324
10.3.2	The Join Forsterite–Diopside–Leucite at 0.1 GPa [ $P(\text{H}_2\text{O}) = P(\text{Total})$ ] . . . . .	326
10.3.3	The Join Forsterite–Diopside–Leucite Studied under 2.3 GPa and Variable Temperatures . . . . .	327
10.3.4	The Join Forsterite–Leucite–Akermanite Studied at 2.3 GPa and Variable Temperatures . . . . .	330
10.3.5	The Paragenetic Sequence in the Kalsilite–CaO–MgO– $\text{SiO}_2$ – $\text{H}_2\text{O}$ System . . . . .	330
10.4	Petrological Significance . . . . .	332
10.4.1	The Join Forsterite–Diopside–Leucite Studied under 0.1 GPa [ $P(\text{H}_2\text{O}) = P(\text{Total})$ ] . . . . .	332

10.4.2	The Join Forsterite–Diopside–Leucite Studied under 2.3 GPa at Variable Temperatures . . . . .	333
10.4.3	The Join Forsterite–Leucite–Akermanite Studied at 2.3 GPa and Variable Temperatures . . . . .	334
<b>11</b>	<b>Phase Relations in the System Leucite-Akermanite-Albite-SiO<sub>2</sub> . . .</b>	<b>337</b>
11.1	Phase Relations in the System Leucite-Akermanite-SiO <sub>2</sub> . . . .	339
11.2	Study of the Joins Lc <sub>75</sub> Ab <sub>25</sub> -Ak <sub>75</sub> Ab <sub>25</sub> -Q <sub>75</sub> Ab <sub>25</sub> and Lc <sub>60</sub> Ab <sub>40</sub> -Ak <sub>60</sub> Ab <sub>40</sub> -Q <sub>60</sub> Ab <sub>40</sub> . . . . .	340
11.3	Petrological Significance of the System Leucite-Akermanite-Albite-SiO <sub>2</sub> . . . . .	341
11.4	Experimental Study of the Joins Leucite-Akermanite-Albite with or Without Anorthite in Air or Under 1 GPa in Presence of Excess Water. . . . .	344
11.4.1	The Join Leucite-Akermanite-Albite Under One Atmospheric Pressure . . . . .	345
11.4.2	The Join Leucite-Akermanite-Albite <sub>50</sub> Anorthite <sub>50</sub> Under Atmospheric Pressure . . . . .	346
11.4.3	The Join Leucite-Akermanite-Albite <sub>50</sub> Anorthite <sub>50</sub> at 1 GPa Under H <sub>2</sub> O-Saturated Condition . . . . .	348
<b>12</b>	<b>P-T Stability of Phlogopite, K-Richterite and Phengite, as a Source of Potassium in the Mantle . . . . .</b>	<b>351</b>
12.1	Phase Relations in the System Forsterite–Kalsilite-SiO <sub>2</sub> -H <sub>2</sub> O at Variable Temperatures up to 0.3 Gpa. . . . .	351
12.2	P-T Stability of Phlogopite. . . . .	355
12.2.1	P-T Stability of Phlogopite up to 7 GPa in Presence of Excess Water . . . . .	356
12.3	The Join KAlSiO <sub>4</sub> -Mg <sub>2</sub> SiO <sub>4</sub> -SiO <sub>2</sub> up to 3.0 Gpa in Presence or Absence of H <sub>2</sub> O . . . . .	357
12.4	Investigation of the System KAlSiO <sub>4</sub> -Mg <sub>2</sub> SiO <sub>4</sub> -SiO <sub>2</sub> in Presence of H <sub>2</sub> O and CO <sub>2</sub> up to 2 Gpa . . . . .	364
12.5	Investigation of the System Forsterite–Kalsilite-SiO <sub>2</sub> at 2.8 Gpa under Dry or Volatile Present Conditions, (in Presence of H <sub>2</sub> O or CO <sub>2</sub> ) . . . . .	366
12.6	Phase Relations in the System KAlSiO <sub>4</sub> -Mg <sub>2</sub> SiO <sub>4</sub> -SiO <sub>2</sub> at 2.8 Gpa in Presence of Fluorine . . . . .	371
12.7	Investigation on the Assemblage Phlogopite-Diopside up to 17 Gpa . . . . .	374

12.8	K-Richterite as a Source Mineral of Potassium in the Upper Mantle . . . . .	375
12.8.1	P-T Stability of K-Richterite . . . . .	375
12.8.2	Investigation on High Pressure Stability of Phengite . . . . .	378
<b>13</b>	<b>Experimental Studies on K-Rich Rocks . . . . .</b>	<b>381</b>
13.1	Investigations of Leucite-Bearing Rocks Under Atmospheric Pressure . . . . .	381
13.2	Investigation on a Synthetic Leucite Basanite and Melilite-Nepheline Leucitite up to 2.5 Gpa and Variable Temperatures . . . . .	383
13.2.1	Investigation on a Natural Leucite Basanite and a Tephrite . . . . .	383
13.2.2	Investigation on a Synthetic Melilite Nepheline Leucitite in Presence of Excess Water . . . . .	387
13.2.3	Experimental Study on a 79 AD Vesuvian Lava Flow . . . . .	389
13.2.4	Phase Relations on Katungites . . . . .	389
13.2.5	Investigation on a Leucite Lamproite from Gaussberg, Antarctica . . . . .	396
13.2.6	Phase Equilibria Studies on (Lamproites from Damodar Valley, India . . . . .	398
13.2.7	Experimental Investigation on a Natural Wolgidite . . . . .	402
13.2.8	Phase Relations on a Biotite Mafurites under High P-T Conditions . . . . .	404
13.2.9	Phase Relations in an Olivine Ugandite under High P-T Conditions . . . . .	410
13.2.10	Experimental Investigation on a Phlogopite-Bearing Minette . . . . .	412
13.2.11	Experimental Studies on a Phlogopite-Pyroxenite Nodule from South-West Uganda . . . . .	413
13.2.12	High P-T Investigation on an Armalcolite-Phlogopite Lamproite from Smoky Butte, Montana . . . . .	414
13.2.13	Phase Relations in a Sanidine Phlogopite Lamproite under High P-T Conditions . . . . .	416
13.2.14	Experimental Study on an Olivine Leucitite up to 3.5 GPa at Variable Temperatures . . . . .	419



<b>14</b>	<b>Structural and Tectonic Evolution of K-Rich Silica-Deficient Volcanic Provinces of Different Continents.</b>	421
14.1	Tectonism in European Volcanic Provinces	421
14.1.1	Development of the Rhine Rift Valley	421
14.1.2	Structure and Tectonic History Associated with Potassic Volcanism in Italy	426
14.1.3	Neogene Tectonics of Southern Spain.	427
14.1.4	Mantle Upwelling Beneath Eastern Atlantic and Western and Central Europe	429
14.2	Deep-Seated Plumes Underneath the East African Rift Valleys	432
14.3	Tectonic Evolution of Silica-Deficient Potassic Rocks from Brazil with Reference to Trinidad Plume	439
14.4	Structural Control and Tectonic History of Potassium-Rich Volcanic Province of Asia	442
14.4.1	The East Indian Rift Zone.	442
14.4.2	Tectonic Setting of K-Rich Rocks from Indonesian Archipelago.	444
14.5	Plate Tectonic Model for Potassic Volcanism in the USA	446
14.5.1	Tectonic History of Potassic Volcanism in the Highwood Mountains Region.	446
14.5.2	Generation of Potassic Rocks Associated with Rio Grande Rift	449
<b>15</b>	<b>Genesis of Ultrapotassic Rocks</b>	453
15.1	Assimilation Processes.	453
15.2	Subtraction of Eclogite from a Picrite Magma.	455
15.3	Zone Refining Hypothesis	456
15.4	Genesis of Potassic Rocks by Volatile Transport.	456
15.5	Phlogopite–Richterite-Bearing Peridotitic Mantle.	457
15.6	Production of Fertile Source Rocks by Mantle Metasomatism	459
15.7	Crust–Mantle Mixing.	460
15.8	Metasomatic Fluid Source	461
15.9	Crustal Contamination	462
15.10	Recycling of Nitrogen from Crust into the Mantle.	465
15.11	Recycling of Potassium from Subducted Oceanic Crust	467
15.12	Metasomatic Fluid Transport	469

15.13	Potassic Volcanism Associated with Rift and Tectonic Processes . . . . .	470
15.14	Possible Causes for the Frequent Occurrence of K-Rich Silica-Poor Volcanic Rocks in the Recent Evolutionary History of the Earth . . . . .	473
<b>16</b>	<b>Petrologic Conclusions . . . . .</b>	<b>475</b>
	<b>References. . . . .</b>	<b>479</b>
	<b>Author Index . . . . .</b>	<b>511</b>
	<b>Subject Index . . . . .</b>	<b>521</b>

<http://www.springer.com/978-81-322-2082-4>

Origin of Potassium-rich Silica-deficient Igneous Rocks

Gupta, A.K.

2015, XXIII, 536 p. 229 illus., Hardcover

ISBN: 978-81-322-2082-4