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27. *Chemical Composition of Japanese Granites.*
Part 1. Variation Trends of 400 Analyses.

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Abstract

About 400 superior-quality analyses of Japanese granitic rocks are plotted in THORNTON and TUTTLE's variation diagrams and projections in the Q-Or-Ab-An system. In the variation diagrams, concentration of points is fairly good, forming one broad but well-defined petrographic province. As compared with WASHINGTON's 5000 igneous rocks, Japanese granites are slightly higher in SiO_2 and lower in Fe_2O_3, Na_2O, and K_2O. Most of the analyses show considerably high amounts of An when plotted in the Q-Or-Ab-An tetrahedron. Normative compositions of Paleozoic Japanese pelitic sediments are very low in An. It is not possible to form most of the Japanese granitic liquids by partial or total fusion of such pelitic sediments.

1. Introduction and Acknowledgements

This report is the first of a series of studies on chemical composition of granitic rocks with a stress on the genesis of the felsic magmas which might give rise to acid plutonic and volcanic rocks. Recently many superior-quality chemical analyses of Japanese granitic rocks have been published and it is thought that to treat these analyses statistically according to the experimental phase relations now available would be worth while.

The report deals with about 400 analyses whose quality has been evaluated and published in a tabular form by HATTORI and NOZAWA (1959). Variation diagrams are constructed in order to examine the hypothesis of the magmatic origin of Japanese granites, the liquid lines of descent, and feasibility of generation of granitic magmas through partial fusion of pelitic sediments.

We thank Drs. A. SUGIMURA, and M. KATADA whose discussion and

suggestions helped to improve this report greatly.

2. The Q-Or-Ab-An-H_2O System

The granitic rocks mainly consist of quartz, plagioclase, and alkali feldspar rich in K. In their CIPW norms, quartz, orthoclase, albite, and anorthite constitute the bulk of the composition. The rest is mainly femic constituents which may be considered of secondary importance because of their relatively small amounts. When a magma of granitic composition is considered, water (H_2O) becomes another important constituent as it is widely accepted that water is by far the most abundant volatile dissolved in felsic magmas. Therefore the bulk composition of common granitic rocks and magmas may be approximated by points in the quinary system SiO_2(Q)-$KAlS_3O_8$(Or)-$NaAlSi_3O_8$(Ab)-$CaAl_2Si_2O_8$(An)-H_2O.

The liquidus-solidus relations of this Q-Or-Ab-An-H_2O system in the temperature range prevailing in the crust and uppermost part of the mantle have recently been extensively investigated and a fair amount of information useful for consideration of the genesis of granitic magmas and rocks is already available.

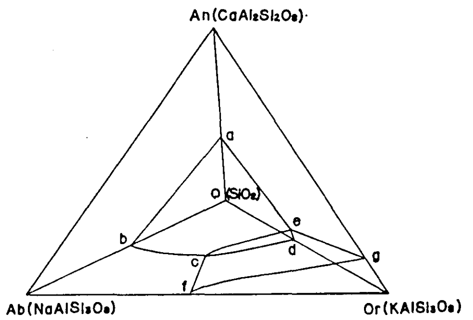


Fig. 1. Schematic phase diagram for the system SiO_2(Q)-$KAlSi_3O_8$(Or)-$NaAlSi_3O_8$(Ab)-$CaAl_2Si_2O_8$(An) saturated with water under moderate pressure. For explanation see text.

In Fig. 1, the shape of primary-phase volumes on the liquidus at a certain fixed pressures is shown schematically (after CARMICHAEL, 1963; BATEMAN *et al.*, 1963; etc.). The system is saturated with H_2O, *i.e.* all the phases shown are in equilibrium with a H_2O-rich gaseous phase. A liquid with a composition falling in the volume Q-a-b-c-d-e crystallizes quartz first upon cooling and reaching the liquidus temperature. A liquid with a composition falling in the volume An-Ab-f-g-e-c-b-a crystallizes plagioclase first. Liquid whose composition falls in the volume Or-d-c-f-g-e first crystallizes alkali feldspar rich in K. These three volumes may be called quartz-, plagioclase-, and K-feldspar primary volumes respectively. The composition of the liquids in equilibrium with quartz and plagioclase is given by points lying on the plane a-b-c-e which is the boundary surface between the quartz and plagioclase primary volumes. Likewise, boundary surface c-d-e gives compositions of liquids in equilibrium with quartz and K-feldspar, and the boundary surface c-f-g-e those of liquids in equilibrium with plagioclase and K-feldspar. Liquids whose composition lying on the boundary line c-e are in equilibrium with three solid phases, quartz, plagioclase and K-feldspar. Increase in total pressure (which equals with water pressure in this case) results in shifting of the quartz-plagioclase and quartz-K-feldspar boundary surfaces (a-b-c-d-e) away from the Q apex towards the Or-Ab-An face of the tetrahedron, and in shifting of the plagioclase-K-feldspar boundary surface away from the Q-Or-Ab face towards the An apex. The detailed discussion of the shapes of these boundary surfaces and lines and the crystallization courses of liquids of various composition are given by CARMICHAEL (1963), BATEMAN *et al.* (1963), WINKLER (1967), JAMES and HAMILTON (1969) and others.

In Fig. 2, traces of boundary surfaces on Q-Or-Ab and Q-Ab-An faces of the tetrahedron at different water pressure (=total pressure)

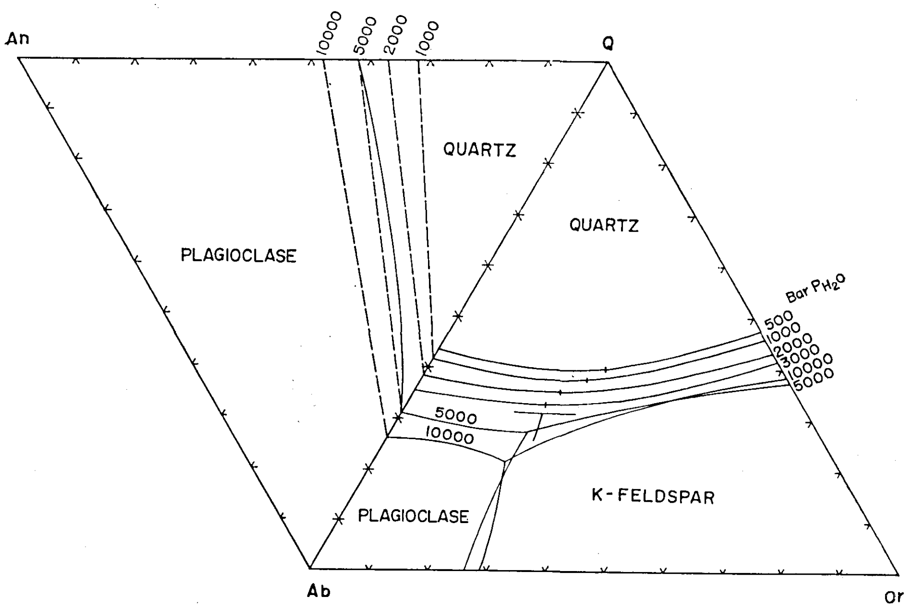


Fig. 2. Traces of boundary surfaces between quartz and feldspar primary volumes on Q-Or-Ab and Q-Ab-An faces of the tetrahedron Q-Or-Ab-An (water saturated). Data for Q-Or-Ab face: after TUTTLE and BOWEN (1958), LUTH *et al.* (1964); for Q-Ab-An face: after STEWART (1957), YODER (1967). Short vertical lines on the boundary lines for 500, 1000, 2000, and 3000 bars water pressure for Q-Or-Ab face indicate the position of the ternary minimum and the 'T'-shaped curves below the 3000 bars boundary curve represent position of the ternary eutectic at 4000 bars (TUTTLE and BOWEN, 1958). The curved solid line on Q-Ab-An face respresents quartz-plagioclase boundary curve at water pressure of 5000 bars (YODER, 1967). The four dashed straight lines connect corresponding eutectic compositions on the Q-Ab and Q-An edges at different water pressure.

are shown as experimentally determined by TUTTLE and BOWEN (1958), LUTH *et al.* (1964), STEWART (1957), and YODER (1967). Dashed straight lines in the Q-Ab-An face are drawn by connecting eutectic points in the systems Q-Ab-H_2O (TUTTLE and BOWEN, 1958; LUTH *et al.*, 1964) and Q-An-H_2O (STEWART, 1957). The shape of the boundary surfaces within the volume of the terrahedron Q-Or-Ab-An at various water pressures is not exactly known. However, information given by WINKLER (1967), WINKLER and VON PLATEN (1960, 1961a, 1961b), VON PLATEN (1965), WEIL and KUDO (1968), JAMES and HAMILTON (1969), and others greatly help to locate the positions of the boundary surfaces, lines, isotherms, etc.

3. Source of Data

The chemical analyses used in this report were taken from the collection published by HATTORI and NOZAWA (1959). The collection includes "granite, aplite, pegmatite, granodiorite, quartz diorite, syenite, monzonite, tonalite, trondjemite, granophyre, granite porphyry, and quartz porphyry. They are restricted to ones which contain SiO_2 more than 55% in weight." (HATTORI and NOZAWA, 1959, p. 7). In the present study, analyses falling in the following categories are omitted.

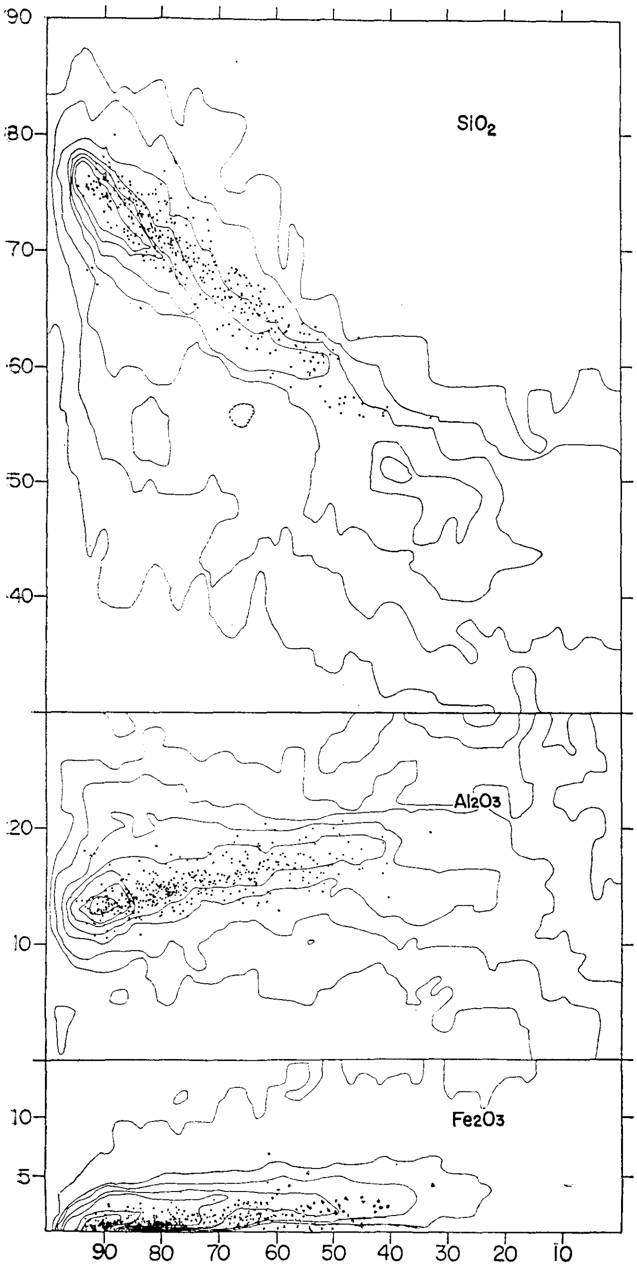
1) Incomplete analyses, whose norms are not given in HATTORI and NOZAWA's table.
2) Analyses showing incompatible values, e.g. a total given does not match the actual total of the oxides. In this case also the norms are not given in their table.
3) Those with rock names of aplite, pegmatite, granite porphyry, and quartz porphyry. Most of the granite porphyries and quartz porphyries given in the table have been recently found to be welded tuffs, hence considered not appropriate.

Out of 528 analyses given in HATTORI and NOZAWA's table, 396 analyses were thus selected and used in the following plottings. The list of the analyses used is given as Appendix in the last part of this report.

4. Variation Diagrams

The HARKER variation diagrams with SiO_2 weight percent as abscissa have already been published by HATTORI *et al.* (1960).

Another set of variation diagrams, proposed by THORNTON and TUTTLE (1960), are given in Fig. 3. The horizontal axes are normative Q+or+ab+ne+lc+ks, originally defined as differentiation index, and the vertical axes the weight percentage of oxides. In the case of the Japanese granitic rocks, ne, lc, and ks are not encountered; the differentiation



90
80
70
60
50
40
20
10
10
5
SiO2
Al2O3
Fe2O3
90 80 70 60 50 40 30 20 10

Fig. 3.

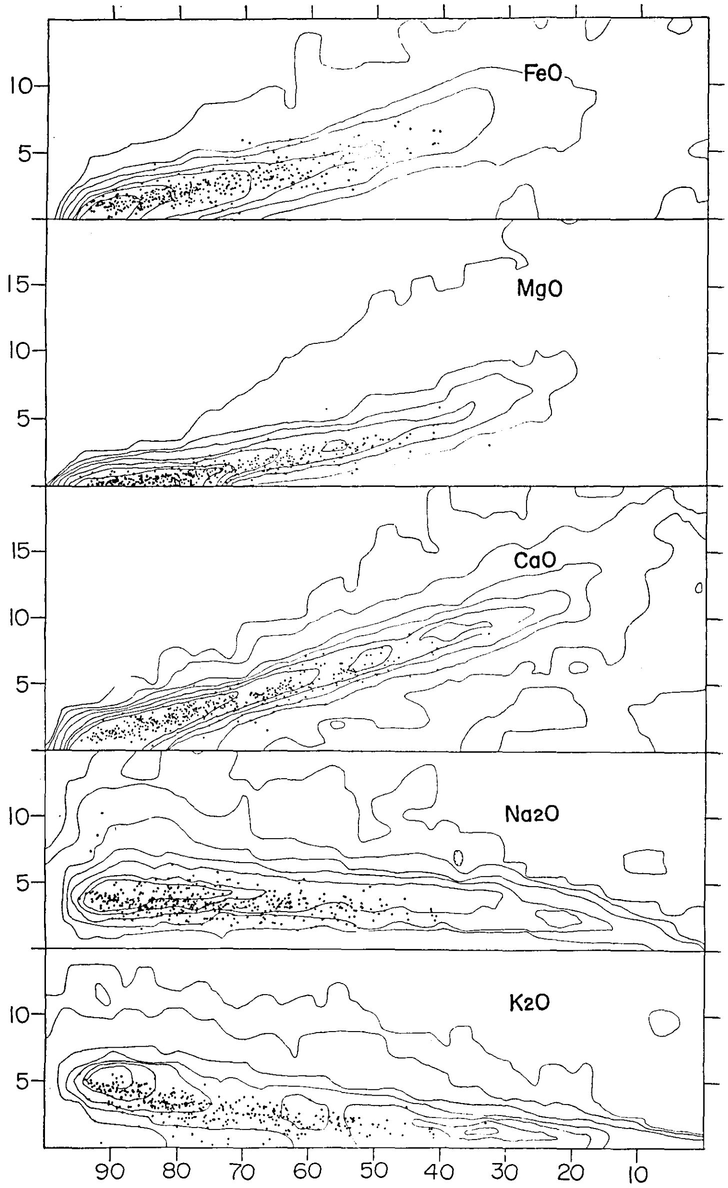


Fig. 3. Variation diagrams of 400 Japanese granitic rocks. Horizontal axis: differentiation index (DI) proposed by THORNTON and TUTTLE (1960); vertical axis: weight percent of oxides. Contours are for WASHINGTON'S 5000 igneous rocks as given by THORNTON and TUTTLE (1960).

index being equal to Q+or+ab.

In plotting chemical composions of granitic rocks, THORNTON and TUTTLE's differentiation index (DI) may be regarded as superior to the weight percent of SiO_2 because DI indicates directly the 'distance' from the petrogeny's residua system while SiO_2 is not necessarily so (see pp. 492–494).

In Fig. 3, contours given by THORNTON and TUTTLE (1960) for the 5000 analyses of igneous rocks in WASHINGTON's tables are also shown. From Fig. 2, it may be observed that the Japanese granites form a fairly well-defined straight-line trend in each oxide. As a first approximation, they are 'normal', falling close to the ridges of the THORNTON and TUTTLE's contours. Slight deviation, mostly parallel shift above or below the ridges of the contours may be observed. Trends of the Japanese granites are:

1) higher in SiO_2, and
2) lower in Fe_2O_3, Na_2O, and K_2O.

Trends for Al_2O_3, FeO, MgO, and CaO show no appreciable deviations.

5. Q-Or-Ab-An Diagrams

The positions in the tetrahedron Q-Or-Ab-An are shown in three different projections (Figs. 4 and 5). In the right-hand part of Fig. 4, points are shown on the base of the tetrahedron, Q-Or-Ab projected from the An apex. This is the projection most widely used in recent papers dealing with the petrology of granitic rocks. In the left-hand part of Fig. 4, the same points are shown on the face Q-Ab-An as they are projected horizontally and parallel with the Or-Ab edge. The projection is *not* from the Or apex but parallel with the basal plane Q-Or-Ab. Therefore the height from the basal plane is directly shown as distance from the Q-(Ab-Or) edge of the projection. This method of projection is useful because it clearly shows the position of the points with respect to those of the quartz-feldspar (plagioclase) boundary surface in the tetrahedron. In the Q-Or-Ab face of Fig. 4, traces of the boundaries between quartz and feldspar primary fields are shown for the H_2O pressures of 1, 2, 5, and 10 kilobars (after TUTTLE and BOWEN, 1958, LUTH *et al.* 1964). Dashed line connecting the Q apex and a point on the Ab-Or edge at $Or_{40}Ab_{60}$ is also shown. The line crosses roughly the center of the cluster of points. In the Q-An-(Ab-Or) projection of Fig. 4, traces of boundary surfaces between quartz and feldspar primary volumes are projected on the plane passing the An apex and the dashed line on the basal plane for different H_2O pressures. Because of the lack of data, they are shown as straight lines as a first approximation like the similar lines in Fig. 2.

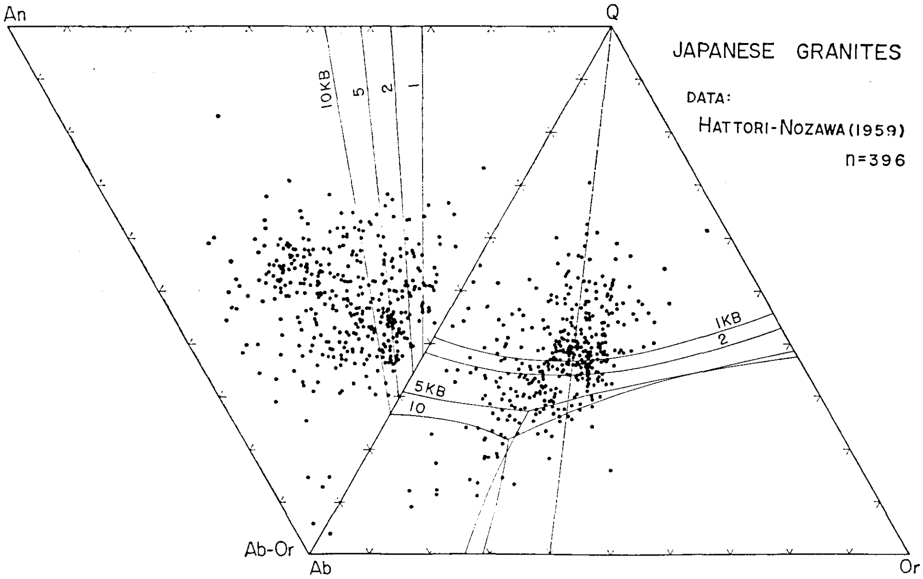


Fig. 4. Normative composition of 400 Japanese granitic rocks plotted in the tetrahedron Q-Or-Ab-An. For explanation see text.

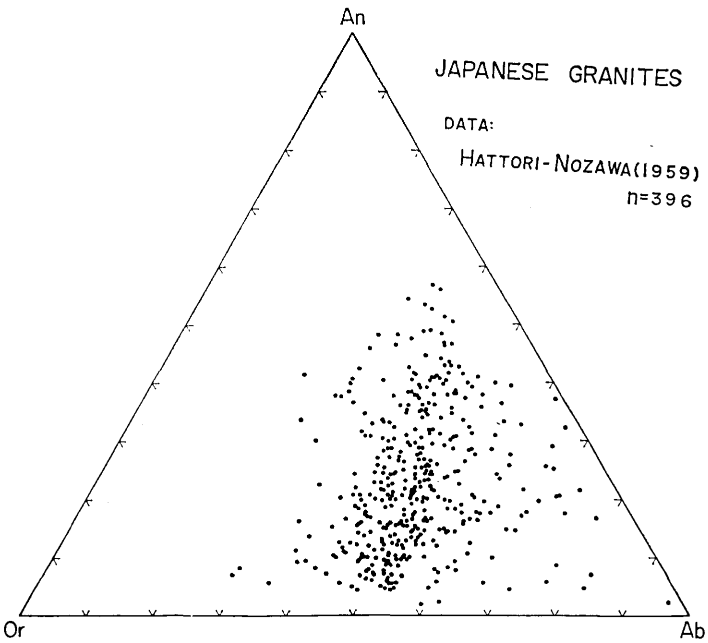


Fig. 5. Plotting of normative feldspars for 400 Japanese granitic rocks.

Positions of these lines on the Q-An edge are given by STEWART (1967) and those on the join Q-$Or_{40}Ab_{60}$ are given by TUTTLE and BOWEN (1958) and LUTH *et al.* (1964). Data for 1) the curvature of these lines, and 2) position of the boundary line quartz-K-feldspar-plagioclase-liquid-vapor are not available, but these straight-line approximations are believed to be useful for the petrological evaluation of the data.

The following characteristics may be observed from Fig. 4:

1) Most points show high An contents. Out of 396, only one point is lower than 1% An in the tetrahedron, and about 33 points, or less than 10% of the data, are below 5% An.

2) Most points fall above the boundary surface quartz-feldspar-liquid-vapor for 1 kilobar H_2O pressure, i. e. most points are in the feldspar primary volume, and as they are richer in Ab than in Or, mostly in the plagioclase volume.

3) In the Q-Or-Ab plotting, center of clustering of points is located closer to the Q-Ab join than in TUTTLE and BOWEN's similar diagrams (1958, Figs. 41 and 42).

In Fig. 5, projection on the Or-Ab-An face of the tetrahedron is shown. The spread of the points is apparent but the general high content of An-component is clearly indicated.

6. Chemical Composition of Some Japanese Pelitic Sediments

In Figs. 6 and 7, some Japanese Paleozoic pelitic sediments are plotted, in the same way as in Figs. 4 and 5. The data are taken from HARAMURA (1961a, 1961b, and 1962). The solid circles represent pelitic rocks from the Tatuno-Sioziri district in Nagano Prefecture (HARAMURA, 1961b) and three areas in the inner zone of Southwest Japan (HARAMURA, 1962). They all belong to zone N of the Japanese Paleozoic geosyncline as defined by MIYASHIRO and HARAMURA (1966). Open circles represent pelitic rocks from the Paleozoic terrains on the Pacific Ocean side of the Sanbagawa metamorphic belt (HARAMURA, 1961a). They belong to zone S of MIYASHIRO and HARAMURA (1966). As pointed out by MIYASHIRO and HARAMURA (1966) pelitic rocks of zone N are richer in K_2O relative to Na_2O than those of zone S. From Figs. 6 and 7, it is apparent that most of the Japanese Paleozoic pelitic rocks are very poor in normative An. The same conclusion may be drawn from Figs. 8 and 9, in which the average compositions of 11 groups of Paleozic pelitic rocks of Japan given by MIYASHIRO and HARAMURA (1966, Table 3) are shown. Points representing groups 9 and 11 are fairly high in An content, but both, belonging to the Hitati facies, may be considered to form a relatively minor portion of the Paleozoic geosynclinal pile.

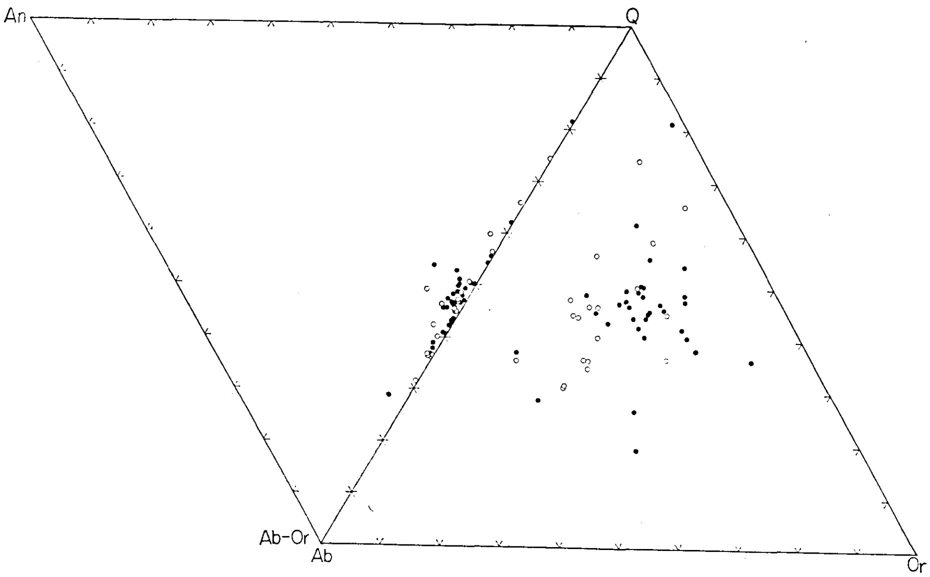


Fig. 6. Normative composition of Japanese Paleozoic pelitic sediments plotted in the tetrahedron Q-Or-Ab-An. Solid circles: Zone N (inner zone) of the Japanese Paleozoic geosyncline defined by MIYASHIRO and HARAMURA (1966); open circles: Zone S (outer zone). Data from HARAMURA (1961a, 1961b, and 1962).

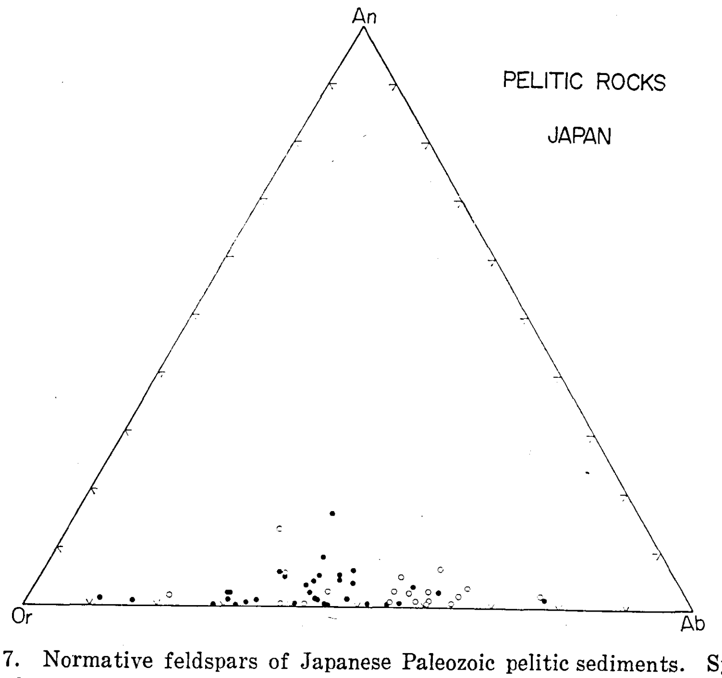


Fig. 7. Normative feldspars of Japanese Paleozoic pelitic sediments. Symbols and source of data same as Fig. 6.

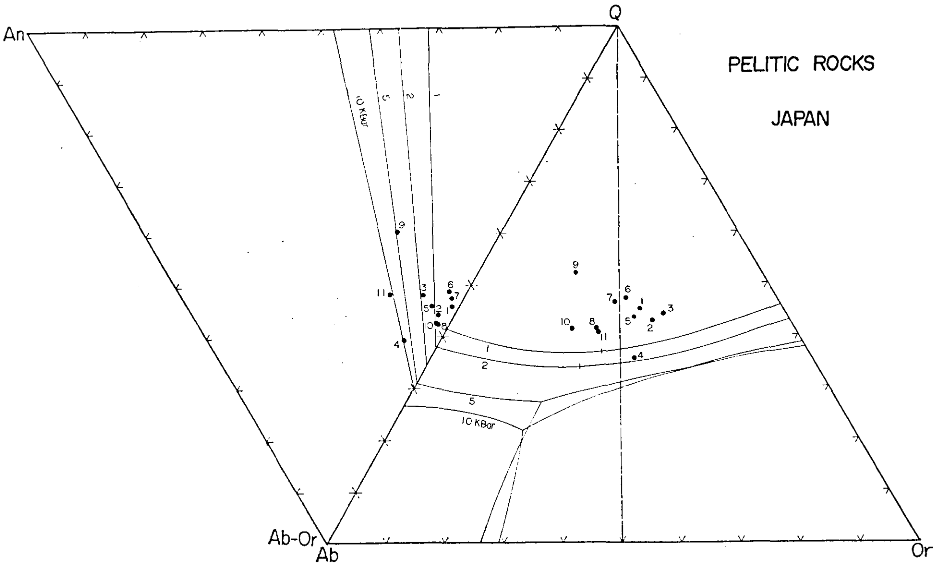


Fig. 8. Average normative composition of 11 groups of Japanese Paleozoic pelitic sediments plotted in the tetrahedron Q-Or-Ab-An. Data and group numbers after MIYASHIRO and HARAMURA (1966) 1: Zone N, 2: northern Kiso area, 3: Dando area, 4: Kiso-Komagane area, 5: Tukuba area, 6: Bessi area, 7: Mibugawa area, 8: Zone S, 9: southern and eastern half of central Abukuma plateau, 10: Kitakami Mountains, 11: Higo area.

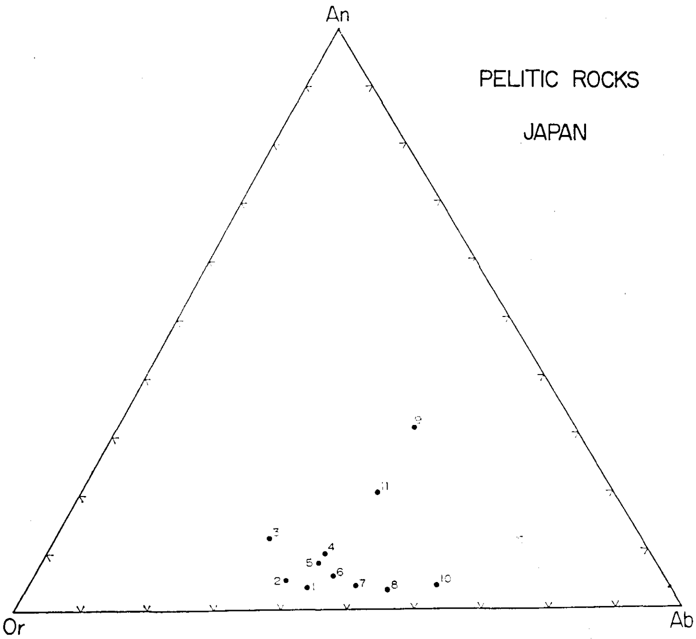


Fig. 9. Average normative feldspars of 11 groups of Japanese Paleozoic pelitic sediments. Data same as Fig. 8.

7. Discussion

Magmatic origin of the Japanese granites

Good concentration of points along simple linear trends in the variation diagrams such as Fig. 3 is strong evidence supporting the hypothesis that most Japanese granitic rocks are products of magmatic differentiation, i.e. a certain process through which granitic material was produced mostly in a liquid state, which then crystallized to form granitic rocks. Processes other than those involving large amounts of silicate melt do not necessarily give rise to a variety of rocks forming a particular trend as shown in Fig. 3. On the other hand, close proximity of the variation trends of acidic volcanic rocks such as shown in THORNTON and TUTTLE's diagrams (1959) with those of Japanese granitic rocks strongly speaks for the magmatic origin of the granites.

Plottings in the Q-Or-Ab-An tetrahedron (Figs. 4 and 5) further support the magmatic origin of the Japanese granites. The dense concentration of points extend from the center of the basal plane (Q-Or-Ab) half-way up the tetrahedron towards the An apex. The points cluster in the space closer to the An-Ab join rather than to the An-Or join. This roughly corresponds with the liquid of descent in the series basalt-andesite-dacite-rhyolite.

Uniformity of the trend

The concentration of the points in Fig. 3 is fairly good and these 400 Japanese granites may be considered to form one broad well-defined petrographic province. Some authors (e.g. SHIBATA *et al.*, 1962, 1967) distinguish very many petrographic provinces for these granites at least partly depending on their major-element abundances.

Statistically speaking, degree of scattering of points within such a province and that indicated in Fig. 3 i.e. 400 points as a whole, appears to be comparable. To sub-divide 400 points into many groups only by their chemical character appears to be very difficult.

Impossibility of the formation of the granites by partial melting of the Japanese Paleozoic pelites

Partial melting of the sialic crust has been one of the most popular hypotheses of the formation of the granitic magma. For example, WYLLIE and TUTTLE (1961) and WINKLER and VON PLATEN (1958) have shown experimentally that the magma of granite-granodiorite composition can be formed by partial melting of water-rich sediments such as shale, graywacke, and arkose under the temperature-pressure conditions prevailing within the crust.

Pelitic sediments, such as shale, slate, and phyllite in the Paleozoic formations of the Japanese islands may be considered one of the most eligible source materials for the production of the granitic magmas. This is because these pelitic sediments constitute the bulk of the Paleozoic geosyncline that once occupied most parts of the Japanese islands where most of the grantic rocks now crop out.

From Figs. 6, 7, 8, and 9, it is clear that most of the pelitic sediments are low in An component. On the other hand, most of the Japanese granites show a much higher An content than that of the Paleozoic pelitic rocks. It is well established from the experiments in the system Q-Or-Ab-An-H_2O that the compositions of the initial liquids formed by fusion of crystalline aggregates of the compositions given in Figs. 6, 7, 8, and 9 are such that their An component is not significantly higher than the original aggregates. Therefore it is concluded that liquids represented by bulk compositions of the Japanese granites (Figs. 4, and 5) can not be formed by either partial or total fusion of crystalline aggregates whose compositions are represented by the Japanese Paleozoic pelitic sediments (Figs. 6, 7, 8, and 9). If an appropriate amount of Ca is added by some means it is naturally possible to form these granitic melts by partial fusion of these sediments. However, apparent low Ca contents of the Japanese Paleozoic pelites would create serious problems on the hypothesis of granite magma formation through partial fusion of pelitic rocks in Japan.

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27. 日本の花崗岩類の化学成分

その1. 分析値400個の成分変化の傾向

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地質調査所 野沢保

服部・野沢 (1959) のまとめた日本の花崗岩質岩石の分析値のうち，適当なもの約400個をTHORNTON・TUTTLE の変化図や Q-Or-Ab-An 系に投影してみた．変化図においては，点は直線上に集中し，分散は比較的小さく，全体として1つの特徴的な岩石区を示す．WASHINGTON の5000個の火成岩の変化図と比較すると，日本の花崗岩類は，SiO_2 にやや富み，Fe_2O_3，FeO, Na_2O, K_2O にやや乏しい．花崗岩質成分をよく近似する Q-Or-Ab-An の4面体に投影すると，点は可成分散するが，An 成分に著しく富むものが多い．また点は Or 側よりも An 側に偏つて集中する．日本の古生層の粘土質堆積岩の組成を同じ4面体に投影すると，An 成分に乏しいのが特徴である．従つて，このような粘土質堆積岩の部分溶融または全溶融によつては，日本の花崗岩質マグマは生じない．

Appendix. Source of analyses.

Analyses used are all taken from HATTORI and NOZAWA (1959). As explained in the text, inferior analyses are omitted. Numbers of the analyses used, appearing HATTORI and NOZAWA's paper, are given below.

1	2	3	4		6	7	8	9	
11	12	13	14	15	16	17	18		
	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41			44	45	46	47		49	50
51		53	54					59	60
61	62	63	64	65	66	67	68	69	70
71					76	77	78	79	80
81	82	83	84	85	86	87		89	
	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120
121	122	123	124	125		127		129	130
131	132	133	134	135	136	137	138	139	
		143	144	145	146	147	148	149	150
151	152	153	154	155		157	158	159	160
161	162	163	164	165	166	167	168	169	170
171	172	173	174	175	176	177	178	179	180
181	182							189	190
191	192	193	194		196	197		199	200
201	202	203	204	205	206	207	208	209	
	212	213	214	215	216	217	218	219	220
221	222	223	224	225	226	227	228	229	230
231	232	233	234	235	236	237	238	239	240
241	242	243	244	245	246	247	248	249	250
251			254	255				259	
	262	263			266	267	268	269	270
	272	273	274		276				280
		283	284	285	286	287	288	289	290
291	292	293	294	295	296	297	298	299	300
301	302	303	304	305	306	307			
311	312	313	314	315	316	317	318	319	
			324			327	328	329	330
331		333	334	335	336		338	339	
341	342		344	345				349	350
351		353	354	355	356	357			360
361	362	363			366	367			370
371	372					377	378	379	
381	382	383	384	385				389	390
391	392								400
401	402		404	405	406	407			410
411	412								
				425	426	427	428		430
		433	434		436	437	438		
441		443		445	446	447	448	449	
451	452	453	454	455	456	457	458	459	460
461	462	463	464	465	466	468	468	469	
471		473	474	475	476				
	A 2	A 3	A 4			A 7	A 8	A 9	A10
A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
A21	A22	A23	A24	A25		A27	A28		A30
A31	A32	A33	A34			A37	A38		A40
A41			A44		A46	A47			

Total: 396 analyses.