Mem. Fac. Educ., Shimane Univ. Vol. 1, pp. 75—115. December, 1967.

LATE MESOZOIC TO PALEOGENE IGNEOUS ACTIVITY IN THE CENTRAL SAN-IN REGION

By

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I. Introduction

Since 1958 the writer has been studying the igneous activity which took place in and around the central part of the San-in region during the period from late Mesozoic to Paleogene. This activity was the severest of all igneous activities of the Paleozoic, Mesozoic and Cenozoic eras, and was characterized by the accumulation of enormous quantities of acidic igneous rocks occupying a vast area.

The writer (1963) already reported part of his study of this region. The western end of the region was studied by MURAKAMI (1958), the area adjacent on the south was studied by YOSHIDA (1961), and their results were published. As to the area belonging to Tottori Prefecture, geologic maps were published by MURAYAMA et al. (1961) and by YAMADA (1961). Concerning the geologic interpretation of the San-in region, there has been a divergence of views among these geologists.

Lately, KAWANO et UEDA (1965a, 1965b, 1966) have published their results of age determination by the K-A method. Concerning the central San-in region, too, they have presented highly suggestive data.

II. Outline of the late Mesozoic to Paleogene igneous activity

The igneous activity which took place in the central San-in region during the period from late Mesozoic to Paleogene can be roughly classified into two aspects. One is effusion of the so-called volcanics, comprising Togusagamine rhyolite, Iwami rhyolite-the dacite, and Kuchiba andesite. The other is the intrusion of rocks that occur as batholiths, stocks and dykes.

The noticeable characteristic of this igneous activity is that the volume of the resultant igneous rock is extremely enormous and the rocks are dominantly acidic. Most of the volcanic rock are within the range from rhyolite to dacitic, and andesites are very scarce. All of these volcanics belong to the calc-alkali rock series. The intrusive rocks, on the other hand, are mostly granites and grnodiorites.

As seen in Fig. 1, the activity of these acidic rocks of great quantities took place from late Mesozoic to Paleogene, not only in central San-in but also in the whole area of the Inner Zone of Southwest Japan.

The Tokusagamine rhyolite, oldest of all these effusive rocks, covers unconformably the Muikaichi formation which corresponds to the Inkstone group. Together with the

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Iwami rhyolite-dacite and in an intrusive contact with it, the Tokusagamine rhyolite represents the remarkable activity of the acidic volcanics over the period from Gyliakian to urakawan.

Similar acidic igneous activity is known in Korean Peninsula, where the Bukkokuji acidic rocks, comprising volcanics and granites, are distributed over the Keisho group which coresponds to the Inkstone group, thus indicating that the geologic history of the Cretaceous period in Korea was nearly the same as that in Southwest Japan.

However, according to HUANG (1960) such a large scale activity of acidic rocks, accompanied by granites, had appeared already in the late Jurassic Tunglingtai-kalgan series and in the upper part of the Fuhsin series, in eastern China.

It can be said, therefore, that igneous activities of similar nature occurred during the period from Mesozoic to Paleogene in the regions of East Asia, including the Inner Zone of Southwest Japan, though varying in time and place.

From about the end of Permian to the early part of Triassic, the Inner Zone of Southwest Japan is known to have turned from a geosynclinal zone to an orogenic zone, due to the so-called Akiyoshi orogenic movement. Since the latter half of the Triassic period through the Jurassic period, the Inner Zone served as a stage for marine basins, subsidence of which was locally great, and for basins that were alternately marine and nonmarine. Then, as time lapsed into the Cretaceous period, the basins changed to locally lacustrine or inland basins, until the large scale igneous activity to be discussed here began to take place.

In other words, the first half of the Mesozoic era, on the whole, was not a geosynclinal period, so that the igneous activity represented by the great amounts of acidic rocks was not the kind to be preceded by development of a large scale normal geosyncline.

Neverthless, considering the enormous energy expressed by the accumulation of such large amounts of acidic igneous rocks over the vast area including East Asia, the igneous activity cannot be related to a small scale subsiding movement of only the Mesozoic era.

It would be natural, therefore, to assume an igneous activity such as the one preceded by the formation of the Chichibu geosyncline having the history of a normal geosyncline, and the Mesotectonics as a whole should be understood as a subsequent stage of the Akiyoshi orogenic movement.

Should the age of effusion of the Tokusagamine rhyolite in central San-in be assigned to the end of the Miyakoan, it would be approximately 110×10^6 years according to the table compiled by KULP (1961) from various sources, and if the major period of the Akiyoshi orogeny was at the and of Permian, the absolute age would become 230×10^6 years, showing a difference of 120×10^6 years from the former value. This difference indicates that the acidic igneous activity in question proceeded on an extremely large scale in both time and space.

III. Relationship between the intrusion of magma and the geologic structure of Paleozoic system

KOBAYASHI (1950) pointed out that the Paleozoic system in the Chugoku region shows a multiaxial echelon arrangement, and KOJIMA (1953) distinguished five belt, namely, San-in branch of the Sangun metamorphic belt, Central non-metamorphic belt, Sanyo branch of the Sangun metamorphic belt, Intermediate non-metamorphic belt, and the Ryoke metamorphic belt, from north to south.

In the western half of central San-in, the Sangun metamorphic rocks are exposed together with the unmetamorphosed Paleozoic formation, and their distribution is cut on the south by the Iwami tectonic line of a NE-SW trend. It was reported by KIMURA (1960) that the Sangun metamorphic rocks in the vicinity of Masuda are thrust upon the unmetamorphosed Paleozoic formation by the San-in tectonic line, and that the unmetamorphosed Paleozoic formation in this neighborhood presents a synclinorium on the whole.

The San-in tectonic line is an eastern extension of the Nagato tectonic line, and has an intimate relation with the Akiyoshi orogenic movement in that the Sangun metamorphic rocks were thrust over the unmetamorphosed Paleozoic formation by this tectonic line.

The San-in tectonic line appears to extend farther east, passing through the north of Kuchiba and reaching the vicinity of Tottori in Tottori Prefecture, as shown in Fig. 2. In this area, ultrabasic rocks are exposed, flanked with metamorphic rocks on the north and unmetamorphosed paleozoic formation on the south. These ultrabasic rocks are considered to have intruded from a deeper part of the ground, due to the abovementioned tectonic movement. They continue to the northern part of Okayama Prefecture, and also extend eastward, passing through the Tottori-Okayama prefectural border, and probably joins the Maizuru structural belt.

The San-in tectonic line, having this ENE-WSW trend, is the most fundamental structure of the Paleozoic system in central San-in. The zonal arrangement of the

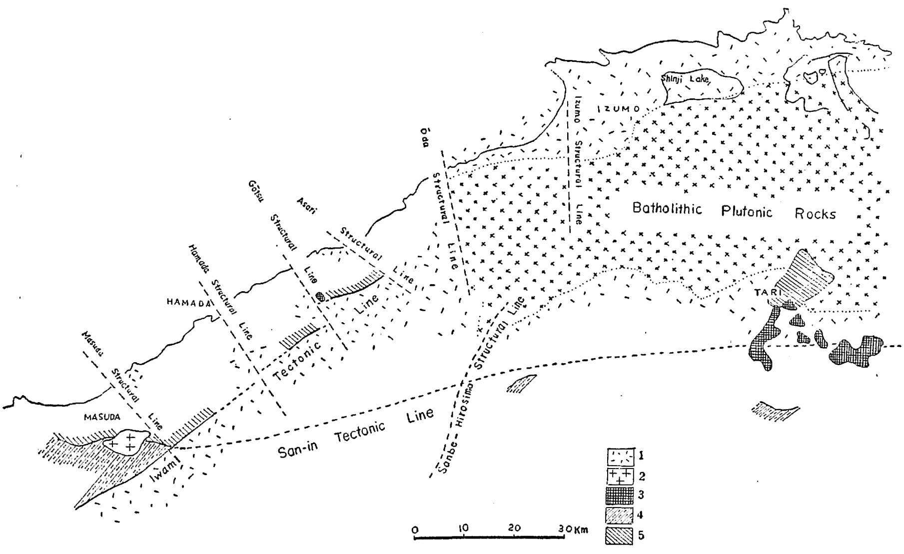

Fig. 2. Relation between the batholithic plutonic rocks and geostructural units
1. Late Mesozoic volcanic rocks. 2. Masuda granite. 3. Ultrabasic intrusives.
4. Non-metamorphosed Paleozoic rocks. 5. Sangun metamorphic rocks.

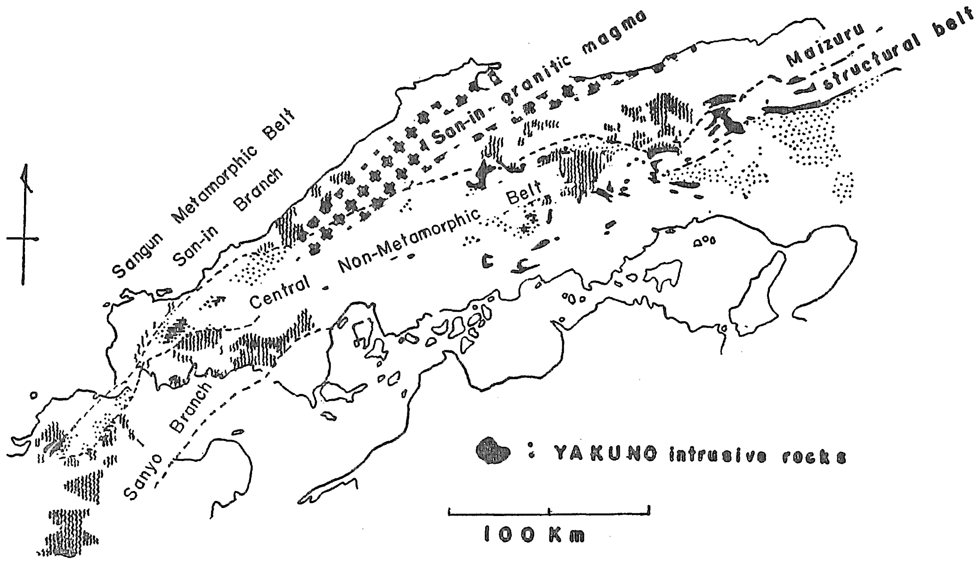

Fig. 3. Zonal distribution and direction of intrusion of the San-in granitic magma.

Paleozoic system reported by KOJIMA (1953) is roughly parallel with this line.

On the other hand, the intrusive rocks of batholithic occurence show a NE-SW direction of intrusion, obliquely intersecting the San-in tectonic line. As will be mentioned later, this direction is the fundamental trend of the late Mesozoic to Paleogene igneous rocks inclusive of volcanics, and it suggests some change in the nature and direction of the tectonic movement of the basement, which began in the latter part of Mesozoic. The relation is illustrated in Fig. 3.

IV. Relationship between the intrusion of plutonic rocks and the volcanic activity, as seen in the late Mesozoic to Paleogene igneous rocks

Order of volcanic activity

Tokusagamine rhyolite

The writer proposes the name Tokusagamine rhyolite for the leucocratic, compact, rhyolitic rock occuring as a single cooling unit with a thickness several hundred meters in the vicinity of Muikaichi at the southwestern end of the region. This rhyolite rests directly, on the Muikaichi formation with an unconformable relation, and is intruded by the Iwami rhyolite-dacite, which will be described later. Similar rocks are widely distributed also in Yamaguchi Prefecture.

The Tokusagamine rhyolite is supposedly the oldest of all acidic vocanic rocks of late Mesozoic age.

Iwami rhyolite-dacite

The writer proposes the name Iwami rhyolite-dacite for large body of rhyolitic to dacitic rock, which is variable in texture and is widely distributed with a NE trend. To the north of Muikaichi, the Iwami rhyolite-dacite contacts the Tokusagamine rhyolite with an intrusive relation. The northern end of its distribution is cut by the

Iwami tectonic line.

The Iwami rhyolite-dacite occupies the widest area of all the late Mesozoic acidic volcanics. So far as the writer's observation goes, it is directly underlain by granites.

Kuchiba andesite

The name is given to the andesitic rocks unconformably covering the Iwami rhyolite-dacite near Kuchiba in the southern end of the region and the northern areas of Kawamoto. Distribution of the Kuchiba andesite is extremely limited.

The above-mentioned is the order of the late Mesozoic volcanic activity in the central San-in region. When this sequence is compared with the result of YOSHIDA (1961) who studied the adjacent area belonging to Hiroshima Prefecture, the Togusagamine rhyolite and Iwami rhyolite-dacite put together seem to correspond to the Takada rhyolite, and the Kuchiba andesite may be correlated with the Sakugi volcanic rocks.

In the tuffaceous facies of the Sakugi volcanic rocks, *Cycadocaulis hondoensis* ENDO was found. IMAMURA (1960) considered that this fossil indicates an age nearly contemporaneous with the Hakobuchi sandstone, so he assigned the age of the Sakugi volcanic rocks to Hetonaian of latest Mesozoic. Accordingly, the period of activity of the Kuchiba andesite may have been also Hetonaian.

As the Tokusagamine rhyolite unconformably covers the Muikaichi formation which corresponds to the Inkstone group, the activity of the enormous amounts of acidic volcanic rocks, comprising the Togusagamine rhyolite and Iwami rhyolite-dacite, is understood to have taken place during the period ranging from Gyliakian to Urakawan.

Mechanism of volcanic activity

As shown in Tables 1 and 2, most of these acidic rocks are markedly porphyritic, so that they have often been called quartz porphyry.

The general characters of the Tokusagamine rhyolite are as follows : In the first place, there is an important field evidence that the rhyolite is a yellowish white, compact, effussive rock, occurring as a single cooling unit, several hundred meters thick, without any noticeable stratification, and it unconformably overlies the Muikaichi formation.

Under the microscope, the rhyolite is observed to contain phenocrysts of colorless minerals, such as quartz, potssium feldspar and plagioclase, 1–3 mm in diameter. The plagioclase is either oligoclase or andesine, and shows the characteristic lamellar structure. In general, the plagioclase is altered to calcite, chlorite or sericite, and is often broken or corroded. Occasionally, this mineral and the potassium feldspar occur together in a single fragment.

Table 1. Modal compositions of Tokusagamine rhyolite, calculated by point counter.

	1
Quartz	16.30
Potash feldspar	10.05
Plogioclase	22.28
Biotite	0.27
Hornblende	
Pyroxene	0.27
Groundmass	47.57
others	3.26

1. Kabadani, Kakinoki-village.

The potassium feldspar shows a perthitic structure and is generally

Table 2. Modal compositions of Iwami rhyolite-dacite, calculated by point counter.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	5.48	10.79	4.24	11.64	6.97	4.87	14.83	11.87	0.24	4.53	17.76	12.42	0.41
Potash feldspar	2.28	13.65	0.67	0.39	4.56	1.54	11.96			0.22	7.76		
Plagioclase	32.65	29.84	31.70	23.47	27.88	27.96	17.46	28.54	35.48	15.51	18.16	25.06	24.79
Biotite	0.91	3.81		3.94	2.95	1.79	1.20	3.28	3.57			1.77	
Hornblende	7.08	1.27	7.14						2.14		0.20	0.22	0.41
Groudmass	51.60	40.64	55.80	59.57	57.64	62.05	54.55	52.27	58.57	77.15	55.30	58.98	73.98
others			0.45	0.99		1.79		4.04		2.59	0.82	1.55	0.41

	14	15	16	17	18	19	20	21	22	23	24	25
Quartz	0.42		1.37	10.46		14.86	12.27	1.09	10.22	10.81	3.93	3.73
Potash feldspar				4.31		7.03	6.02		1.02			0.93
Plagioclase	4.40	13.49	17.35	23.69	18.69	17.85	14.81	32.16	43.93	24.33	17.95	28.20
Biotite			0.23	0.31	0.31	4.32	0.46	0.66				4.43
Hornblende	0.21				0.31			5.91	4.91	0.77	0.34	5.13
Groudmass	94.34	85.98	79.45	54.77	79.13	54.59	66.44	59.30	39.06	63.90	77.10	56.41
others	0.63	0.53	1.60	6.46	1.56	1.35		0.88	0.86	0.19	0.68	1.17

1. Tsugawa, Asahi-village.
2. Haza, Kanagi-village.
3. Futakawa, Mito-town.
4. Igaya, Mitoya-town.
5. Ichiibara, Kawamoto-town.
6. Yadani, Kawamoto-town.
7. Mitikawa, Hikimi-town.
8. Mt. Azuma, Yokota-town.
9. Mt. Azuma, Yokota-town.
10. Yakawa, Yokota-town.
11. Ai, Nita-town.
12. Yakami, Iwami-town.
13. Inbara, Kawamoto-town.
14. Inbara, Kawamoto-town.
15. Kawamoto, Kawamoto-town.
16. Kawamoto, Kawamoto-town.
17. Kamedani, Mizuho-town.
18. Utsui, Hasumi-village.
19. Utsui, Hasumi-village.
20. Kutiba, Hasumi-village.
21. Iwasaka, Yakumo-village.
22. Yugakae, Ochi-town.
23. Yadani, Kawamoto-town.
24. Ikeda, Oda-city.
25. Kakinoki, Kakinoki-village.

Table 3. Modal compositions of Kuchiba andesite, calculated by point counter.

	1	2	3	4
Quartz		6.40		
Potash feldspar				
Plagioclase	23.84	22.75	18.60	24.79
Biotite		0.95		
Hornblende	0.20	2.13	2.98	1.27
Pyroxene	0.20		1.99	2.75
roundmass	75.56	67.30	75.93	70.34
others	0.20	0.47	0.50	0.85

1. Mt. Tomokura, Hasumi-village.
2. Syobu, Hasumi-village.
3. Mt. Tsurubu, Oda-city.
4. Mt. Tsurubu, Oda-city.

fresh. The quartz, occurring mostly as broken pieces, sometimes shows conspicuous corrosion. In some cases, several small fragments, having been derived from cracks that developed inside a single crystal, are seen to scatter in the groundmass.

As mafic mineral phenocrysts, biotite is recognized. It is tabular, or shows an elongate and warped shape keeping the parallelism with the flow structure of the groundmass. The biotite is remarkably chloritized.

The groundmass is vitreous, and the flow structure is well developed around the phenocrysts. On rare occasions, a microspherulitic texture is observed in the groundm-ass.

The general characters of the Iwami rhyolite-dacite are as follows : It is in intrusive contact with the Tokusagamine rhyolite. But, on the whole, the rock shows evidence of the effusive rock like lava or tuff. So far as the writer's observation is concerned, the base of the Iwami rhyolite- dacite directly contacts the granites.

Under the microscope, the groundmass reveals variable textures, ranging from cryptcrystalline to micropegmatitic.

The rock in the vicinity of Motoso exemplifies the cryptocrystalline groundmass, which shows a mircospherulitic texture and contains quartz, potassium feldspar, plagioclase and biotite, as phenocrysts. The quartz occurs as broken pieces of 2 mm in maximum diameter, showing conspicuous corrosin. The potassium feldspar occurs as long prismatic crystals, 0.7–0.8 mm in length, and shows a perthitic structure, but no microcline structure is observed. This mineral is mostly broken and shows advanced corrosion. The plagioclase is about 2 mm in maximum diameter, and their shapes are all fagmental. The biotite is altered to aggregates of fine-grained opaque iron minerals and minute scales of biotite.

It is worthy of note here that many of the colorless phenocryst minerals are broken pieces showing advanced corrosion, ans that some of the phenocrysts, after they were broken *in situ* and the resultant fragments have moved a little, still retain their phen-ocrystic outline.

A microgranitic texture of groundmass will be exemplified by the rock near Haza. The rock's groundmass has a holocrystalline equigranular texture consisting of 0.1–0.2 mm grains of quartz, potassium feldspar and plagioclase. As phenocrysts, quartz, potassium feldspar, plagioclase, hornblende and biotite are recognized.

The quartz is 2–3 mm in longer diameter, and the rim of the crystals is markedly corroded. The potassium feldspar is long prismatic, 4 mm in maximum length ; the crystal rim is markedly corroded and replaced by the groundmass material, and the entire surface of the crystals is coated with kaoline-like substance.

The plagioclase occurs as long prismatic hypidiomorphic crystals, about 0.4 mm long, showing a lamellar structure. The crystal rim is remarkably corroded and replaced by the groundmass material. The hornblende is a green hornblende occurring as 1.5 mm long hypidiomorphic prismatic crystals. The biotite occurs as clotty aggre-gates, showing X=light yellow and Y, Z=reddish brown.

Another type of groundmass, intermediate between the above-mentioned two types, is observed in the rocks near Kakinoki. The groundmass is holocrystallin, consisting chiefly of quartz, potassium feldspar and plagioclase, 0.01 – 0.03 mm in grain diameter, accompanied by a small amount of scaly biotite. As phenocrysts, quartz, potassium feldspar, plagioclase, biotite, hornblende, augite and orthorhombic pyroxene are found.

The quartz is 1.5 mm in maximum size, occurring generally as broken pieces, and the crystal rim is corroded by the groundmass material.

The potassium feldspar, in the most case, is also fragmentary, and corroded by the groundmass material along the rim. The maximum diameter is about 1 mm. A perthitic structure is developed, but no microcline structure is recognized.

The plagioclase, 2–3 mm in maximum diameter, is usually fresh, and occurs very often as broken pieces, occasionally idiomorphic. It shows a zonal structure and a lattice structure. The crystals are corroded and replaced along the rim by the groundmass material.

The biotite occurs as aggregates of tabular or scaly crystals, 0.2–0.3 mm in diameter. In general, it is associated with hornblende, X=light yellowish brown and Y, Z= redish brown.

The hornblende has a lepidoblastic shape and shows a green to bluish green tint. It may have altered from pyroxene.

The augite occurs as 0.5–0.7 mm long hypidiomorphic prismatic crystals, which are replaced by green hornblende along the rim, or are intensely uralitized from the exterior toward interior.

The orthorhombic pyroxene, occurring as 0.5 mm long, hypidiomorphic, prismatic crystals, is replaced along the crystal rim by scaly biotite. Uralitization is recognized throughout.

A noteworthy fact is that the colorless phenocryst minerals are mostly broken to pieces, and a considerable number of small pieces have slightly moved from the initial position of the phenocrysts, and that the biotite and the hornblende are newly formed minerals.

Where the Iwami rhyolite-dacite rests, as a roof rock, directly on the biotite granite, the groundmass shows a micropegmatitic texture with intergrowth of quartz and feldspar of about 0.1 mm in grain size, and contains plagioclase phenocrysts, 1 mm in diameter. The grain size of the groundmass gradually decrease outward to present a microgranitic or felsitic texture.

The phenocrysts are less broken where they directly contact the granite and the fragmentation becomes more conspicuous with increasing distance from the granite, but the phenocrysts have suffered corrosion.

It is noticeable also that the Iwami rhyolite-dacite locally contains a large amount of granite blocks (generally biotite granite), which range in diameter from several centimeters to several tens of centimeters. Sometimes the rock-forming minerals of the granite reveal the process of their becoming scattered phenocrysts in the Iwami rhyolite-dacite.

These acidic volcanic rocks of great quantities, extending for several hundred kilometers with a width several tens of kilometers in central San-in, cannot be explained by such ordinary volcaism as differentiation of a basaltic magma. Besides, the fact that this volcanic activity took place almost all over the Inner Zone of Southwest

Japan must be taken into consideration.

What can be a reasonable explanation of the origin of these acidic volcanic rocks which show a very close relation in the field with granites and which are characterized by broken and corroded phenocrysts?

A most plausible interpretation would be that the acidic volcanic rocks are a result of out flow of a granitic magma onto the ground surface in the process of its batholithic intrusion and crystallization, or a result of the magma's solidifcation in the vent.

Where the granitic magma was intruding up to a considerably shallow depths to the form a batholith and was crystallizing there, a part of its roof was broken first and a large amount of magma was effused out instantaneously, thus forming the Togusagamine rhyolite.

After that, the Iwami tectonic line and some tectonic line obliquently intersecting it were formed by deroofing occurred atop the batholith. Through these events, the granitic magma, which was in the course of crystallization under the gound, was effusive out or has gradually soldified while slowly migrating upward.

The Iwami rhyolite-dacite is found sometimes to contain cognate angular blocks. This may be interpreted that the magma, once solidified in the course of its ascent, was broken again by the succeeding unsolidifid portion, and the resultant broken pieces were taken into the magma and ascended together.

Occurrence of abundant granite blocks, as seen locally, in the rhyolite-dacite may also indicate that some parts of the intruding granitic magma were comletely crystallized and solidified, and such hard parts were captured by still liquid magma, to be gradually broken in the course of ascent.

The Iwami rhyolite-dacite also contains, though only locally in the supposedly uppermost part, thin beds of shale and tuff. This may suggest that minor eruptions continued, breaking through the already solidified supperficial part, and that a small scale deposition of shale may have taken place there.

There are field evidences such as that the Iwami rhyolite-dacite contains remarkable amounts of broken pieces of phenocrysts which are corroded, that the rock is always underlain by, and occasionally grades into, granite, and that the groundmass varies in texture, ranging from micropegmatitic to micrograniticor to felsitic. Also, there are the following facts : The rock-forming minerals, occurring either as single crystals or as aggregates of several minerals, are scattered in the Iwami rhyolite-dacite. The rock, as a whole, is a very compact and massive rock, but often contains cognate angular blocks which are irregularly oriented. The rock is very extensively distributed, and always situated as a roof of the batholithic granite body.

All these features are favorable to interprete as follows : A granitic magma in a liquid state was intruding and crystallizing ; in the early stage, it passed through several long fissures and effused as lava flows onto the ground surface ; in the later stage, the magma was gradually pushed through wide and long vents up to the ground surface, and it began to solidify while it was still moving upward.

The broken pieces of phenocrysts occurring in great amounts in the Togusagamine rhyolite and the Iwami rhyolite-dacite are understood as a result of mechanical destruction of already crystallized phenocrysts, and the corroded structure may indicate some changes in physical and chemical conditions in the process of the magma's ascent.

DALY (1933) considered that if the roof over the top of a batholith becomes thinner, it may be broken and the magma below may happen to flow out to the ground surface. With this theory he explained the origin of the thick rhyolitic lava flows in Yellowstone Park. According to him, deroofing occured atop the batholith, resulting in the extensive exposure of the rhyolitic lavas, which may be grading downward into granite. The present writer thinks that the mechanism of the volcanic activity of the acidic volcanic rocks in the central San-in bears a close resemblance to the mechanism proposed by DALY.

In contrast with the above-mentioned rhyolitic rocks, the Kuchiba andesite is understood to have been resulted from the outflow of a liquid magma which was of a verysmall scale and of a dioritic composition. Its effusion is supposed to have occured after the differentiation in the batholith, to be mentioned later, had advanced. Therefore, the Kuchiba andesite should be considerd somewhat younger than the rhyolitic rocks. Table 3 shows the mode of the Kuchiba andesite.

It the above-mentioned things should be true, it is quite natural that these volcanic rocks have their chemical compositions similar to those of the intrusive rocks.

Table 4. Bulk chemical compositions of late Mesozoic volcanic rocks in Central San-in.

	1	2	3	4	5	6	7	8
SiO_2	74.71	69.85	74.93	73.66	75.58	71.86	67.49	56.00
TiO_2	0.14	0.36	0.28	0.28	0.15	0.26	0.49	1.12
Al_2O_3	13.52	15.80	13.62	12.91	12.94	14.06	14.96	19.42
Fe_2O_3	0.37	1.51	0.45	1.67	1.68	0.47	2.42	3.61
FeO	2.05	1.58	1.30	0.97	0.98	2.01	8.42	5.60
MnO	0.08	0.17	0.09	0.26	0.08	0.07	0.14	0.23
MgO	0.20	0.71	0.50	0.39	0.41	0.41	0.57	2.17
CaO	0.42	3.05	1.46	1.27	1.14	2.15	3.70	7.68
Na_2O	2.94	4.03	4.69	3.84	2.53	4.23	3.32	2.07
K_2O	4.01	1.93	3.10	3.34	4.55	2.23	3.00	0.82
P_2O_5	0.05	0.05	0.08	0.16	0.14	0.07	0.17	0.24
$H_2O(-)$	0.11	0.06	0.11	0.13	0.09	0.16	0.11	0.08
$H_2O(+)$	0.86	0.42	0.31	0.60	0.36	1.17	0.66	0.37
Total	99.47	99.52	100.92	99.48	100.63	99.15	100.45	99.41
Norm Sal	93.63	92.85	96.10	93.99	95.73	92.40	89.53	79.79
Norm Fem	4.79	6.14	4.34	4.73	4.39	6.10	10.12	18.97
Total	98.42	98.99	100.44	98.72	100.12	98.50	99.65	98.76

1. Kabadani, Kakinoki-village (Tokusagamine Rhyolite).
2. Hiwa, Iwami-town (Iwami Rhyolite-Dacite).
3. Dangyo, Iwami-town (Iwami Rhyolite-Dacite).
4. Ashidani, Yoshida-village (Iwami Rhyolite-Dacite).
5. Miinohara, Yokota-town (Iwami Rhyolite-Dacite).
6. Yadani, Kawamoto-town (Iwami Rhyolite-Dacite).
7. Yadani, Kawamoto-town (Iwami Rhyolite-Dacite).
8. Mt. Tomokura, Hasumi-village (Kuchiba Andesite).

Table 4 shows the chemical compositions of the volcanic rocks. Fig. 4 is the CaO variation diagram and Fig. 5 is the MgO variation diagram of the volcanic rocks in comparison with the intrusive rocks.

These results indicate a close relationship between the volcanic rocks and the intrusive rocks.

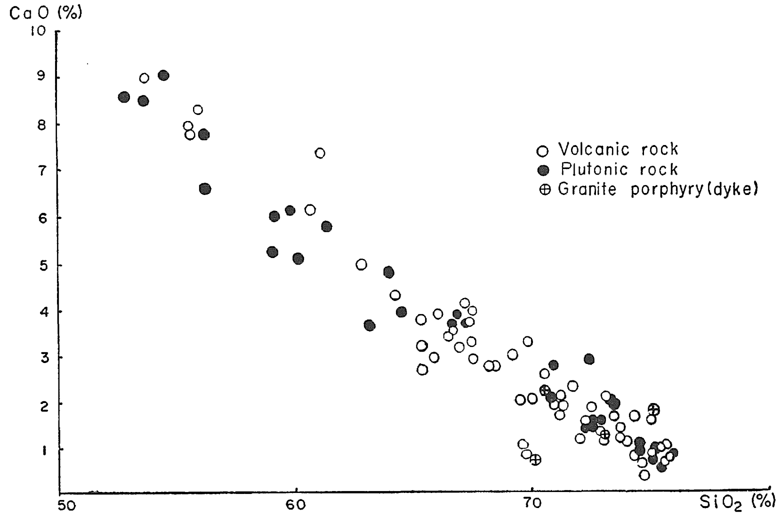

Fig. 4. CaO variation diagram of Late Mesozoic and Paleogene igneous rocks from this region.

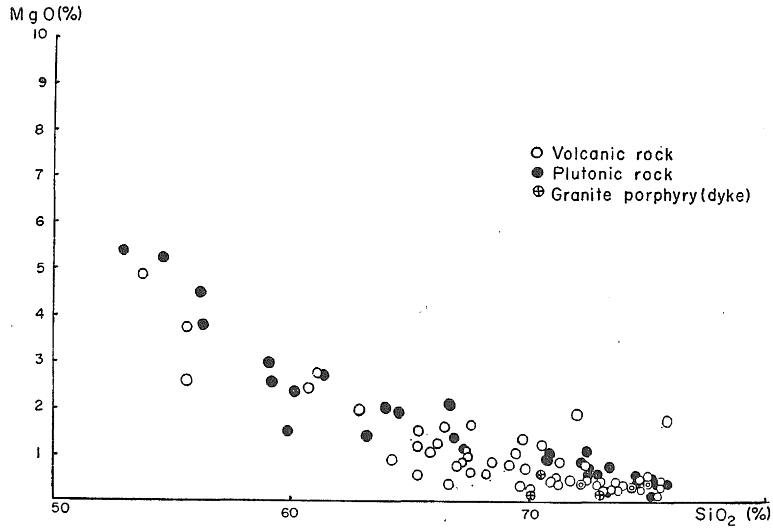

Fig. 5. MgO variation diagram of Late Mesozoic and Paleogene igneous rocks from this region.

V. Mechanism of plutonic activity

As has been stated so far, the acidic volcanics of great quantities are understood as the lavas and the pyroclastics of a granitic magma, which was effused out to the ground surface when it was beginning to crystallize, or as the solidified magma itself within the large vents.

Consequently, the parental granitic magma comprises the magma that crystallized as granites and also the magma that formed all the volcanic rocks inclusive of the Kuchiba andesite. For the sake of convenience, the writer proposes the collective name "San-in granitic magma" for these magma.

At any rate, the igneuos activity ranging in age from late Mesozoic to Paleogene in central San-in made its start by the batholithic intrusion of this voluminous "San-in granitic magma" in the direction of NE-SW system, which somewhat obliquently intersects the ENE-WSW trend of the basement structure represented by the San-in tectonic line.

In this "San-in granitic magma", intruding even up to a very shallow depth of the ground, crystallization was going on actively. In parts, the magma may have already turned granite.

Under such situation, the deroofing occurred in the rock atop the magma of a batholithic shape. Then, the magma was instantaneously effused out to the ground surface, and the vents gradually broadend by deroofing the roof rock. Through this vents, the "San-in granitic magma" was being pushed upward,

The plutonic activity in central San-in cannot be separated fundamentally from the volcanic activity in this sense.

The writer has also mentioned about the Masuda granite as an older granite. This granite is not accompanied by acidic volcanic rocks, and is situated on an older tectonic line. Such granites may have been formed when a granitic magma intruded directly into pre-existent rocks, without going through the process of effusion to the ground surface or solidification in the vent. Therefore, the age of the Masuda granite may be roughly older than the Togusagamine rhyolite.

In this region are found some other granites which differ from the Masuda granite in the mode of occurrence. These granites occur as stocks intruding the Iwami rhyolite-dacite widely exposed in the western half of the region.

Through the process of deroofing mentioned above and the succeeding process of magma's ascent, some tectonic lines were created with the Iwami tectonic line. The Writer names these toctonic lines as follows, from the west : Masuda structural line, Hamada structural line, Gotsu structural line, Asari structural line, Oda structural line, Izumo structural line. Since they cut the Iwami tectonic line, they must have been already existent in the course of deroofing and have been active up to the later process of magma's ascent. In fact, some effusive rocks corresponding to the Iwami rhyolite-dacite have issued from these structural lines. And, after such effusion of rocks the structural lines have been still active. The granite stocks have selectively intruded through these structural lines.

While the batholithic granites show a character rather continuous with the Iwami rhyolite-dacite, the stocky granites are apparently of intrusive character and are younger in age than the former.

There is another granite body which shows a typical "spalten pluton" shape. It intruded from the Sanyo region side, choosing similar structural lines, after the "San-in granitic magma" had solidified. This granite, however, is quite different from the "San-in granite magma", and is perhaps genetically related to the Hiroshima granite.

The influence of intrusion of this gigantic "San-in granitic magma" may have been expressed already as the San-in tectonic line. This is highly possible, judging from the fact that the direction of intrusion of the "San-in granitic magma" intersects the San-in tectonic line at a very low angle, and from the comparisn of their scale. And, this possibillity is closely related to the general aspect of the igneous activity mentioned before.

VI. Classification and petrographic characters of plutonic rocks

The plutonic rocks in the central San-in region are classified by the mode of occurrence as follows :

Older granites

Batholithic plutonic rocks

Stocky plutonic rocks

Fisure-intruding plutonic rocks ("Spalten pluton")

These rocks are described below in detail.

Older granites

The older granites are found as stocks intruded into the Paleozoic formation along the San-in tectonic line, as observed in the south of Masuda. They are called Masuda granite in this paper. In respect that it is not accompamied by the so-called acidic volcanic rocks and that it intruded along an older tectonic line, the Masuda granite is entirely different from other granites. It is a porphyritic biotite granite, containing potassium feldspar crystals several centimeters across, and is accompanied by pegmatitic mineral deposit.

It seems natural to assume that part of the "San-in granitic magma" was already intruding along the old tectonic lines, before it effused out due to the deroofing of the roof rock. The writer thinks that the older granites were thus formed.

KAWANO et UEDA (1966) determined the absolute age of the older granites as 92×10^6 years.

Batholithic plutonic rocks

The "San-in granitic magma", accompanied by the deroofing of the roof rock, formed the effusive rocks of enormous volume and the rocks solidified in the vent. These vocanic rocks are intruded by cognate great batholithic plutonic rocks, which are classified and named by the writer as follows : Coarse-grained biotite granite named Minari granite, coarse-grained granodiorite named Yokota granodiorite, medium-grained granodiorite named Daito granodiorite, medium-grained biotite granite named Yoshida granite, and a series of basic to intermediate plutonic rocks which are variable in rock ranging from gabbro to quartz diorite, and are respectively named Yumura gabbro and Hakami quartz diorite. These plutonic rocks forms a composite batholith.

In the lower part the axes of intrusion of these batholithic plutonic rocks are merged into one axis, which runs near Akana and extends northeast, perhaps as far as Tottori. But, the observation on the present ground surface reveals that the rocks are intruded with parallel axes.

One of the two axes shows a conspicuous NE-SW direction, passing through Tamatsukuri, Daito and Kisuki, to reach Kakeai. In the vicinity of Kakeai the axis abruptly chages its direction to N-S along the Izumo structural line and seems to extend toward Akana.

The other axis runs from the vicinity of Akana, passing through Yokota, toward Kurayoshi of Tottori Prefecture, It is much larger in scale than the former, and intrusion along this axis may have reached shallower depths than that along the former. The two axes are named by the writer, for the sake of convenience, the former is called here the northern zone of intrusion and the latter the southern zone of intrusion.

The main area of the southern zone of intrusion is composed of the Minari granite which, according to the observation near Yokota, grades into the Yokota granodiorite.

On the outer side of the Minari granite and Yokota grnodiorite are found the Yoshida granite, and the boundary between the two is sharp. The Yoshida granite contains intensely contaminated xenoliths of the quartz dioritic rocks. On the outer side of the Yoshida granite, the Iwami rhyolite-dacite, serving as the roof rock, constitutes the backbone mountainland.

However, the granodioritic facies correspnding to the Yokota granodiorite is seen to grade and disappear into the biotite granite corresponding to the Minari granite, in such parts the Minari granite is directly contacting the Yoshida granite.

When the above-mentioned results are summarized, the following zonal distribution will be revealed :

Central area ——————— Outer area
Minari granite Yoshida granite Iwami rhyolite-dacite
Yokota granodiorite

In the northern zone of intrusion, the leading role is played by the Daito granodiorite in the north, which is intruded by the Yoshida granite along the outer sides. On the outer side of the Yoshida granite, the Iwami rhyorite-dacite distributes as a roof rock. The latter is intruded by the former.

The writer thinks that the Yumura gabbro and the Hakami quartz diorite were originally the same rock, the latter having been derived from the former as a result of contamination by granite. These rocks occur as masses of various sizes, ranging from several tens of kilometers to several tens of meters across, and their distribution shows an intimate relation with the Yoshida granite. They are found sometimes as basic inclusions several tens of centimeters in diameter in the Yoshida granite, sometimes showing the effect of intense contamination.

Summarizing the above results, the following zonal distribution will be revealed :

Central area ——————— Outer area
Daito granodiorite Yoshida granite Iwami rhyolite-dacite
Hakami quartz diorite
Yumura gabbro

As will be described later, the Minari granite, as well as the Yokota granodiorite, contains microcline, whereas the Daito granodiorite and Yoshida granite does not.

This fact suggests some difference in the crystallizing condition.

From the above-mentioned results, it is understood that the batholithic intrusive rocks in the central San-in are zonally arranged as revealed by the respective rock types. This relation is idealized in Fig. 6. As revealed by this figure, it seems natural to assume that these plutonic rocks were formed by the differentiation in the process of development of a batholith.

The microscopic characterd of the rocks constituting these batholithic bodies are given below.

(a) Minari granite

This is a leucocratic, coarse to medium-grained rock. On account of pink potassium feldspar crystals that are developed in a more or less porphyritic pattern, the rock has a pinkish tint on the whole.

Under the microscope, the rock is seen to consist chiefly of quartz, potassium feldspar, plagioclase and biotite, accompanied by small quantities of apatite, titanite, iron ore and allanite.

The potassium feldspar occasionally shows a microcline structure or has the so-called moire appearance. In general, it shows a very distinct perthitic structure. The plagiclase is slightly turbid. The biotite is clear deep brown and is not much chloritized. Table 5 shows the mode of the Minari granite.

(b) Yokota granodiorite

This is a medium to coarse-grained rock consisting of quartz, potassium feldspar, plagioclase, biotite, hornblende, zircon, apatite, titanite and iron ore. It often grades into the Minari granite.

The potassium feldspar sometimes shows a microcline structure or presents a moire appearance.

Except for the occurrence of hornblende, the Yokota granodiorite closely resembles the Minari granite in composition. Table 6 shows the mode of the Yokota granodiorite.

(c) Daito granodiorite

When compared with the Yokota granodiorite, this rock has a somewhat homogen-

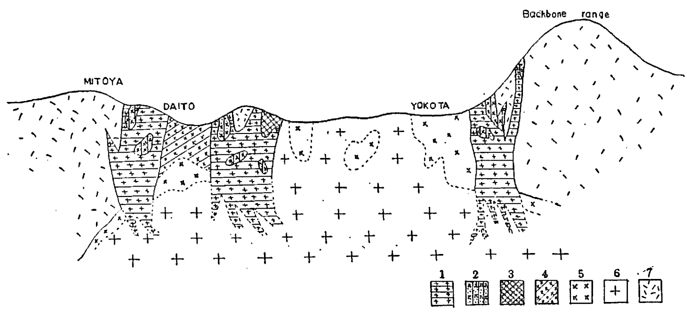

Fig. 6. Schematic section through Yokota and Daito, showing the geological relation of various rock types in a composite batholith.
1. Yoshida granite. 2. Hakami quartz diorite. 3. Yumura gabbro.
4. Daito granodiorite. 5. Yokota granodiorite. 6. Minari granite.
7. Iwami rhyolite-dacite.

Table 5. Modal compositions of Minari granite, calculated by point counter.

	1	2	3	4	5	6	7	8	9	10	11
Quartz	30.34	19.08	27.39	45.55	35.27	37.45	29.34	34.93	32.62	27.14	45.58
Potash feldspar	40.53	21.49	32.30	12.62	31.69	37.87	38.37	25.00	17.85	23.56	8.31
Plogioclase	26.70	54.21	39.27	39.85	29.44	24.47	26.94	39.39	47.07	48.11	41.82
Biotite	1.46	2.41	1.04	1.73	3.37	0.21	4.61	0.68	1.85	0.95	4.02
Hornblende		1.61									
Pyroxene											
others	0.97	1.20		0.25	0.23		0.74		0.61	0.24	0.27

1. Mt. Tamamine, Yokota-town.
2. Yuno, Yokota-town.
3. Yashikibara, Yokota-town.
4. Umenokibara, Yokota-town.
5. Hida, Hirose-town.
6. Yokota, Yokota-town.
7. Kurotani, Akaki-town.
8. Minari, Nita-town.
9. Amegawa, Yokota-town.
10. Bijobara, Nita-town.
11. Fuse, Nita-town.

Table 6. Modal compositions of Yokota granodiorite, calculated by point counter.

	1	2	3	4	5	6	7	8	9	10
Quartz	28.35	35.67	27.73	47.16	27.36	26.54	21.52	30.57	32.11	35.20
Potash feldspar	16.72	16.96	13.10	11.16	16.61	15.64	7.09	10.19	25.59	11.40
Plagioclase	49.55	43.27	52.19	36.45	49.51	52.60	58.48	46.41	36.03	46.00
Biotite	4.18	3.22	3.71	1.82	4.89	4.03	5.57	12.83	6.27	6.20
Hornblende	0.60	0.58	2.18	2.73	1.30	0.95	7.09			0.40
Pyroxene										
others	0.60	0.30	1.09	0.68	0.33	0.24	0.25			0.80

1. Hanaidani, Yokota-town.
2. Hanaidani, Yokota-town.
3. Kamedake, Yokota-town.
4. Torigami, Yokota-town.
5. Nishihida, Hirose-town.
6. Nishihida, Hirose-town.
7. Kamedake, Yokota-town.
8. Uyama, Tonbara-town.
9. Namishiki, Tonbara-town.
10. Tonbara, Tonbara-town.

eouscomposition and is slightly smaller in grain size, being generally medium-grained.

The principal component minerals are quartz, potassium feldspar, plagioclase, biotite and hornblende, accompanied by small quantities of zircon, allanite, titanite, apatite and iron ore.

A noticeable difference from the Yokota granodiorite is that potassium feldspar in this rock does not show a microcline structure nor a moire appearance. Table 7 shows the mode of the Daito granodiorite.

(d) Yoshida granite

It comprises a series of fine to medium-grained granitic to aplitic rocks, generally having a pink tint. A graphic structure is occasionally observed. Locally, the rock abounds in fragmental basic rocks (Yumura gabbro and Hakami quartz diorite), and aften presents a hybrid facies with these basic rocks.

The molybdenium deposites distributed at Kakeai and Daito and in the vicinity of

12	13	14	15	16	17	18	19	20	21	22	23	24
32.32	31.12	30.96	34.93	42.58	39.43	31.41	50.56	38.87	37.61	42.66	20.27	34.35
27.33	19.48	29.44	26.27	21.65	35.63	28.01	27.39	28.15	26.47	17.61	22.78	39.75
38.18	44.65	36.81	35.51	33.09	24.05	37.70	21.32	30.03	31.09	36.79	47.49	24.64
2.17	4.04	2.79	2.39	2.19	0.89	2.62	0.73	2.68	3.57	2.94	8.30	0.72
	0.71		0.90	0.49		0.26		0.27	1.26		1.16	0.54

12. Torihara, Hirose-town.
13. Yokota, Yokota-town.
14. Yokota, Yokota-town.
15. Yokota, Yokota-town.
16. Fube Dam, Fube-village.
17. Hirose, Hirose-town.
18. Fube, Fube-village.
19. Ouchidani, Daito-town.
20. Yokota, Yokota-town.
21. Uokiri, Akaki-town.
22. Yamani, Nita-town.
23. Ai Dam, Nita-town.
24. Akaya, Hakuta-town.

11	12	13	14	15	16	17	18	19	20	21	22
16.08	34.28	27.87	28.28	16.53	39.24	27.78	29.56	26.99	33.74	43.84	14.73
24.76	12.37	18.03	12.60	21.13	20.04	13.49	9.56	25.10	17.48	18.28	27.08
45.98	48.40	47.95	47.04	56.90	31.43	50.59	53.77	40.17	37.61	32.82	50.11
8.04	4.24	4.93	6.68	4.18	6.12	6.35	5.78	6.07	4.37	0.66	2.14
4.82		0.82	3.60	1.05	1.69	1.39	1.11	1.67	5.34	2.64	4.04
0.32	0.71	0.40	1.80	0.21	1.48	0.40	0.22		1.46	1.76	1.90

11. Ai, Nita-town.
12. Ai, Nita-town.
13. Tsuga, Daiwa-village.
14. Shimoyokota, Yokota-town.
15. Maruyama Dam, Akaki-town.
16. Shiotani, Akaki-town.
17. Shiotani, Akaki-town.
18. Shımoakana, Akaki-town.
19. Nagatani, Tonbara-town.
20. Fukuhara, Nita-town.
21. Yanyu, Yoshida-village.
22. Ai, Nita-town.

Table 7. Modal compositions of Daito granodiorite, calculated by point counter.

	1	2	3	4	5	6
Quartz	22.27	23.16	28.27	30.60	25.10	31.75
Potash feldspar	10.45	17.02	14.85	25.08	21.85	11.02
Plagioclase	57.76	50.61	48.57	39.26	48.30	47.52
Biotite	5.53	6.75	6.27	4.39	4.61	6.26
Hornblende	3.53	1.69	1.76			3.02
Pyroxene						
others	0.46	0.77	0.28	0.67	0.14	0.43

1. Enjo, Daito-town.
2. Higashidani, Kamo-town.
3. Awadani, Mitoya-town.
4. Otake, Kamo-town.
5. Otake, Kamo-town.
6. Tamatsukuri, Tamayu-town.

Table 8. Modal compositions of Yoshida granite, calculated by pointucounter.

	1	2	3	4	5	6	7	8	9	10	11
Quartz	37.23	29.24	35.73	35.34	42.39	29.43	36.52	37.56	42.75	36.20	37.75
Potash feldspar	27.82	27.88	39.06	31.80	36.07	23.32	40.07	26.47	22.82	42.40	14.46
Plagioclase	30.51	39.21	22.75	30.73	19.47	41.52	22.81	32.80	29.40	20.00	41.91
Biotite	4.03	3.83	1.82	1.89	1.68	4.49	0.47	2.49	5.03	0.80	0.49
Hornblende											
Pyroxene											
others	0.41	0.34	0.64	0.24	0.39	1.24	0.13	0.68		0.60	5.39

1. Hiyodori, Daito-town.
2. Shinji, Shinji-town.
3. Otake, Kamo-town.
4. Igaya, Mitoya-town.
5. Iwasaka, Yakumo-village.
6. Taenaka Mine, Daito-town.
7. Kisugi, Kisugi-town.
8. Yugakae, Ochi-town.
9. Motoyama, Ochi-town.
10. Hamahara, Ochi-town.
11. Hamahara Dam, Ochi-town.

Yamasa, and those at Sanbe and Komaki, occur in this granite or in its hybrid facies.

The main component minerals are quartz, potassium feldspar, plagioclase and biotite, with small quantities of zircon, allanite and iron ore.

The potassium feldspar does not show a microcline structure nor a moire appearance. The plagioclase is strongly idiomorphic, generally porphyritic and turbid. The biotite is mostly chloritized. An X-ray examination reveals that some parts have completely turned chlorite, and in such parts the color is greenish.

In many cases, potassium feldspar and plagioclase occur in nearly equal volumes, so that is adamellitic, although in some cases the rock can be defined as a normal granite.

In mineral composition, this granite is different from the Minari granite in that the potassium feldspar does not show a microcline structure nor a moire appearance, that the volume of potassium feldspar is larger, and that the chlolitization of biotite is generally advanced. Another characteristic is that this rock is often associated with basic plutonic rocks. Table 8 shows the mode of the Yoshida granite.

(e) Yumura gabbro, Hakami quartz diorite

The Yumura gabbro and Hakami quartz doirite occur mostly as xenolithic masses or blocks in the Yoshida granite. The rock type varies in various manners, ranging from gabbroic to quartz dioritic.

The rock near its type locality Odakara in the lower reaches of the Yumura Hot spring, is a melanocratic medium-grained rock, somewhat porphyritic, having hornblende and plagioclase as the principal constituents.

The hornblende is a green common hornblende. It is generally fresh, and develops a poikilitic texture including various minerals such as plagioclase and chloritized biotite. The hornblende also contains monoclinic pyroxene as relict mineral.

The plagioclase occurs as 2−3 mm long, rectangular, idiomorphic to hypidiomorphic crystals, showing a marked zonal structure. The crystals contain, in their core part,

12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
34.86	38.03	37.36	32.65	30.64	32.72	31.78	31.24	34.12	37.51	29.00	35.89	30.51	34.45	40.46
44.27	33.12	36.98	38.11	39.75	30.08	23.32	26.79	22.53	33.33	32.96	35.70	26.74	45.69	22.27
17.81	28.21	22.26	32.20	28.16	34.36	36.74	37.95	38.20	28.17	35.59	26.59	38.80	19.38	31.60
2.04		3.02	1.59	0.88	2.64	6.41	3.35	4.51	0.99	1.51	1.46	3.20	0.48	5.45
						0.29	0.22							
1.02	0.64	0.38	0.45	0.82	0.20	1.46	0.45	0.64		0.94	0.36	0.75		0.22

12. Hamahara Dam, Ochi-town.
13. Aikawa, Oda-city.
14. Ashidani, Ylshida-village.
15. Seikyu Mine, Daito-town.
16. Akiyoshi, Yakumo-village.
17. Mt. Tengu, Yakumo-village.
18. Nakano, Mitoya-town.
19. Mue, Mitoya-town.
20. Kamitani Mine, Daito-town.
21. Onya, Kakeai-town.
22. Umenoki, Yoshida-village.
23. Tanino, Kisuki-town.
24. Mt. Gongen, Kisuki-town.
25. Ayo, Daito-town,
26. Nagayadani, Tonbara-town.

ferromagnesian minerals and others as inclusions, but outer part is fresh.

The groundmass plagioclase is fresh. Quartz is found, though in a small volume, filling the interstices of other minerals. The rock on the whole is intruded by epidote veins.

The rock in the vicinity of Yumura Hot spring contains a considerable volume of quartz in association with plagioclase, biotite and hornblende, so that the rock is dioritic.

There are two kinds of biotite, differing in origin ; one is a primary biotite, and the other is a newly formed biotite due to secondry alteration.

The primary biotite occurs as coarse-grained, idiomorphic to hypidiomorphic crystals, occasionally showing a poikilitic texture, and is chloritized. The secondary biotite occurs as scaly crystals, deriving from the primary biotite or replacing hornblende. Formation of the secondary biotite may be ascribed to the contact metamorphism by granite.

In the vicinity of Misawa, Nita-cho, a dioritic rock body is found. In this rock, biotite is found in association with medium-grained fresh plagioclase and hornblende, interstices of which are filled with a considerable volume of quartz ; the biotite occurs as coarse-grained hypidiomorphic crystals showing a poikilitic texture with hornblende, plagioclase, etc. The rock also contains phenocrysts of plagioclase, whose core part is strongly altered and replaced by a mica-like mineral. It is comon that the biotite in one phenocryst consists of very fresh portions and epidotized or chloritized portions.

From these observations it is assumed that there were two stages of crystallization of rock-forming minerals ; one was the time when the rock body was first formed, and the other was the time when the rock body was contaminated by granite.

Suffering contamination from granite, the rock would come to have variable characters, ranging from a highly unhomogeneous quartz diorite to an aplitic rock. The rock thus formed is called here the Hakami quartz diorite. As compared with the above-

Table 9. Modal compositions of Yumura gabbro and Hakami quartz diorite, calculated

	1	2	3	4	5	6	7	8	9
Quartz	25.35	18.90	16.80	18.18	12.64	14.81	1.83	10.20	29.09
Potash feldspar	3.17	25.34	8.70	7.41	5.75		1.22	5.40	2.28
Plagioclase	60.35	40.75	59.48	55.72	62.99	61.26	58.87	67.00	41.07
Biotite	8.03	0.27		8.59	2.30	9.97	1.83	2.80	
Hornblende		9.79	13.24	6.57	12.64	11.97	31.16	12.00	5.89
Pyroxene				1.68					15.78
others	3.10	4.95	1.78	1.85	3.68	1.99	5.09	2.60	5.89

1. Taenaka Mine, Daito-town.
2. Makihara, Oda-city.
3. Saitani, Oti-town.
4. Ayo, Daito-town.
5. Zakka, Nita-town.
6. Mizawa, Nita-town.
7. Odakara, Kisugi-town.
8. Ayo, Daito-town.
9. Ayo, Daito-town.

Table 10. Modal compositions of Yakami granite, calculated by point counter.

	1	2	3	4	5
Quartz	32.34	30.35	36.79	41.78	29.02
Potash feldspar	16.17	18.97	29.43	21.38	30.39
Plagioclase	39.94	44.72	30.77	34.21	36.96
Biotite	9.57	3.79	3.01	2.63	3.63
Hornblende		2.17			
Pyroxene					
others	1.98				

1. Mimata, Kanagi-village.
2. Haza, Kanagi-village.
3. Tsugawa, Asahi-village.
4. Haza, Kanagi-village.
5. Uchidani, Nita-town.

mentioned gabbro or diorite, the volume of quartz becomes much larger in this rock. The rock is medium-grained or fine-grained, consisting chiefly of plagioclase, quartz, hornblende and biotite ; myrmekite is often developed. The accessary minerals are generally magnetite, apatite, zircon, sphane and pyrite. Rarely, it contains small quantities of clinozoisite.

The plagioclase occurs as 2–3 mm long, rectangular, idiomorphic to hypidiomorphic crystals, showing zonal structure. The plagioclase is often albitized, whose albite is generally regarded as secondary in the sense that it has formed recrystallization, replacement, or some other process after the major process of formation of the solidified dioritic rock. Quartz is found, filling the interstices of other minerals.

The hornblende is a green common hornblende. It occurs as 1–3 mm long, rectangular, idiomorphic to hypidiomorphic crystal, sometimes showing aggregate crystals in intimate relations with the biotite.

The biotite occur as idiomorphic or hypidiomorphic crystals. Z=Y=greenish brown. Often the biotite is replacing the hornblende in a lepidoblastic pattern. Potassium feldspar is contained small quantities, filling intergranular apaces.

by point counter.

10	11	12	13	14	15	16	17	18	19	20	21
5.03	18.76	27.08	5.78	13.16	13.79	22.39	8.09	4.95	18.95	22.80	12.24
		6.40				0.61	5.52	0.27	11.87	41.50	0.42
66.93	42.33	59.91	54.22	72.17	63.79	67.49	57.39	64.56	64.38	30.75	68.35
13.15	14.65	5.97	2.65	6.77	8.05	3.07				0.43	3.80
13.54	24.26		34.94	6.39	9.77	6.44	15.98	23.90	2.05	3.44	8.86
				0.38	1.44		5.72				0.84
1.35		0.64		1.13	3.16		7.30	6.32	2.75	1.08	5.49

10. Yumura, Kisugi-town.
11. Kitasanbe, Oda-city.
12. Tihara, Oti-town.
13. Odakara, Kisugi-town.
14. Ashidani, Yoshida-village.
15. Ashidani, Yoshida-village.
16. Koyakawa, Yokota-town.
17. Kutiba, Hasumi-village.
18. Tabisako, Hasumi-village.
19. Kutiba, Hasumi-village.
20. Kutiba, Hasumi-village.
21. Asuna, Hasumi-village.

If the rock gets more contaminated by granite, the volume of quartz increases, and biotite becomes the only mafic mineral, often showing a fluidal arrangement.

As has been described so far, the rocks ranginging from the Yumura gabbro to the Hakami quartz diorite were originally one sequence of basic rocks. The time when they were formed is at least older than the Yoshida granite, because they occur as xenoliths, some are blocks and others are small fragments, in the Yoshida granite, and at same time they were metamorphosed or contaminated by the latter. When a rock suffers a simple contact metamorphism the component minerals would merely alter to secondary minerals of various kinds according to the degree of metamorphism, but under a large scale comtamination the rock would become a more acidic type, like quartz diorite that is injected by the granitic rock in a network form and is granitized in many places. For that reason, the rock type represened by the Hakami quartz diorite is very unhomogeneous in both mineral composition and chemical composition. The xenoliths of basic rocks, sometimes occurring in large volumes, in the Yoshida granite may have a genetic history that they are the fragments of quartz diorite which was contaminated by such mechanism as mentioned above.

Sadashivaiah (1954) reached a similar conclusion on the dioritic rocks contaminated by the granite from a study of the granite-diorite complex.

Judging from above results, it may well be said that after the Minari granite, the Yokota granodiorite and the Daito granodiorite intruded into the Iwami rhyolitedacite, many masses of the mafic rocks intruded separatly in the area between the northern zone and the southern zone and in the outer areas of these zones. Successively, these areas suffered the intrusion of the biotite granite (Yoshida granite) magma accompanied with zonal arrangement. as a result, the mafic rocks was contaminated by the biotite granite, and it was converted to the rocks ranging from the Yumura gabbro to the Hakami quartz diorite. Accordingly, it would be natural to assume that some of them were taken into the biotite granite magma and ascended together.

Table 9 shows the mode of the Yumura gabbro and the Hakami quartz diorite.

Stocky plutonic rocks

The plutonic rocks occurring as stocks, intruding the Iwami rhyolite-dacite, are found mostly in the western half of the region, and comprise two kinds, dioritic and biotite granitic.

The Stocky intrusive rock bodies of dioritic type are collectively called by the writer the Okami diorite, and those of biotite granitic type the Yakami granite. Both are closely related to the Masuda structural line, Hamada structural line, Gotsu structural line and Asari structural line.

These structural lines surely retain their original forms but are supposed to have been largely revived due to the intrusion of the batholithic plutonic rocks occupying the eastern half of the region. Therefore, the main part of the period of their formation may be nearly contemporaneous with the period when the batholithic plutonic rock bodies occupied their present position.

Should this assumption be right, the intrusion of the above-mentioned stocky plutonic rocks along the structural lines thus formed would naturally be later than the intrusion of the batholithic plutonic rocks.

The microscopic observation of these stocky plutonic rocks reveals the following characters :

(a) Yakami granite

The greater portion of this rock is medium-grained biotite granite occurring as stocks intruding the Iwami rhyolite-dacite in the area west of Gogawa. The rock often shows a porphyritic texture.

The principal constituents are quartz, plagioclase, potassium feldspar and biotite. The porphyritic texture is attributed chiefly to quartz and plagioclase, The plagioclase is, in many case, intensely altered and secondarily decomposed into a sericitic mineral. The biotite is also chloritized in general.

The groundmass shows a fine-grained granular texture, and consists of quartz and potassium feldspar, with small volumes of plagioclase and biotite. The quartz and the potassium feldspar in the groundmass sometimes show a graphic texture.

When compared with the Yoshida granite or with the Minari granite, this granite contains a larger volume of plagioclase. Table 10 shows the mode of the Yakami granite.

(b) Okami diorite

The Okami diorite comprises granodioritic, dioritic and gabbroic rocks. It is represented by the rock bodies found at Okami, Misumi, Gōtsu, Kawamoto and Haza areas.

The Okami rock body, whose intrusion is related to, the Masuda structural line, is markedly variable in rock facies, ranging from dioritic to granodioritic. The dioritic part is a fine-grained compact rock, consisting of 0.5–0.7 mm long, hypidiomorphic, slender prismatic plagioclase, and about 0.3 mm long, slender prismatic hornblende, with small volumes of chloritized biotite, quartz potassium feldspar. Replacing this, a somewhat coarser-grained granodioritic rock occus. The granodioritic rock consists of plagioclase, hornblende, biotite, quartz and a considerable volume of potassium feldspar. On the whole, the constituent minerals are larger than in the dioritic rock, and the plagioclase is tabular and shows a marked zonal structure. The biotite is fresh.

There is a general tendency that the rocks of earlier formation are of basic and compact dioritic nature, whereas the rocks of later formation become more acidic, medium-grained, granodioritic rocks replacing the former, and the dioritic rocks are injected by the granodioritic rocks in a network form and is granodioritized in many places.

As a rock of the latest formation, biotite granite is poorly exposed at the eastern end of the Okami rock body.

The Gōtsu rock body is generally dioritic, but becomes granodioritic at its eastern end. When compared with the Okami rock body, this rock is generally coarser-grained, and hornblende locally contains relict crystals of monoclinic pyroxene. The rock, consisting of plagioclase, hornblende, biotite and quartz, accompanied by

Table 11. Modal compositions of Okami diorite, calculated by point counter.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	21.30	23.85	30.45	21.51	20.27	21.97	30.41	29.50	12.77	9.54	20.4	15.84	7.69
Potash feldspar	14.61	4.59	23.93	3.20	4.27	5.49	16.44	9.14			15.25		
Plagioclase	43.84	55.97	37.59	56.11	60.26	59.28	43.46	48.08	62.23	67.31	50.12	58.60	66.90
Biotite	8.77	5.20	5.64	4.65	3.47	7.01	6.53	11.80	9.57	7.08	1.74	5.43	1.40
Hornblende	8.98	9.17	0.88	11.34	11.20	5.68	2.48	1.18	15.16	4.63	9.15	19.00	21.45
Pyroxene	1.46			1.45					0.27	8.99	2.85		
others	1.04	1.22	1.51	1.74	0.53	0.57	0.68	0.30		2.45	0.85	1.13	2.56

1. Kawamoto, Kawamoto-town.
2. Kawamoto, Kawamoto-town.
3. Okami, Misumi-town.
4. Koyashiki, Gotsu-city.
5. Okami, Misumi-town.
6. Okami, Misumi-town.
7. Okami, Misumi-town.
8. Shimohikimi, Hikimi-town.
9. Shimohikimi, Hikimi-town.
10. Ichigi, Mizuho-village.
11. Inbara, Kawamoto-town.
12. Haza, Kanagi-village.
13. Arifuku, Gotsu-city.

Table 12. Modal compositions of Izuwa granite, calculated by point counter.

	1	2	3	4	5	6	7	8
Quartz	38.42	38.30	26.77	29.09	23.81	44.25	31.96	37.11
Potash feldspar	33.20	47.78	40.81	37.40	37.19	27.45	41.57	39.38
Plagioclase	25.68	11.41	31.69	28.57	32.43	25.53	23.73	20.68
Biotite	1.93	1.93	1 23	4.16	3.40	2.77	1.76	2.55
Hornblende							0.20	
Pyroxene								
others	0 77	0.58		0.78	3.17		0.78	0.28

1. Ushio, Ochi-town.
2. Ushio, Ochi-town.
3. Kamedani, Mizuho-town.
4. Asuna, Hasumi-village.
5. Shimotui. Mizuho-town.
6. Takanashi, Daiwa-village.
7. Sakedani, Ochi-town.
8. Mt. Inoko, Asahi-village.

potassium feldsar, intruded along the Gotsu structural line.

The Kawamoto rock body varies from the dioritic type, consisting of plagioclase, hornblende and monoclinic pyroxene, with small volumes of quartz and potassium feldspar, to the granodioritic type as seen at the eastern and, in which the volume of quartz and potassium feldspar increase. The Kawamoto rock body is intruding the Iwami rhyolite-dacite. Its intrusion is probably related to the Gōtsu structural line.

The Haza rock body is similar to the above rocks in petrographic characters, and its intrusion is supposed to be related to the Hamada structural line. It is associated with intrusive bodies of biotite granite.

Table 11 shows the mode of the Okami diorite.

"Spalten pluton"

After the batholithic plutonic rock bodies were consolidated and the Gotsu structural line was formed, a rock having the character of a true "spalten pluton" intruded zonally from the side of the Sanyo region. The intrusion took place along the Hiroshima-Sanbe tectonic line named by the writer (1961). The writer calls this rock the Izuwa granite. The rock is in lateral contact with the surrounding rocks.

The Izuwa granite is generally medium-grained and is characterized by a pinkish tint. The main constituent minerals are quartz, potassium feldspar, plagioclase and biotite. Sometimes, the biotite is entirely chloritized, and the plagioclase is secondarily sericitized. Where the quartz and the potassium feldspar show a graphic texture, the rock becomes a graphic granite.

Table 12 shows the mode of the Izuwa granite. Mentioned above is the outline of the plutonic rocks.

It must be added here that there is a granite porphyry occurring as dykes, intruding the Togusagamine rhyolite and the Iwami rhyolite-dacite. The writer names these dykes collectively the Muikaichi granite-porphyry.

As phenocrysts, quartz and plagioclase are common, but the rocks near Haza contains pink microcline as phenocrysts.

The groundmass *consists* chiefly of quartz and potassium feldspar forming a graphic texture, and the granular parts are composed of quartz, plagioclase, potassium feldspar and biotite, occasionally accompanied by hornblende.

Judging from the mode of occurrence and the mineral composition, these dykes of granite-porphyry are probably related directly to the acidic volcanic rocks.

The chemical analyses of the Minari granite, Yokota granodiorite, Daito granodiorite, Yoshida granite, Yumura gabbro, Hakami quartz diorite and Okami diorite are respectively given in Tables 13, 14, 15, 16, 17, 18 and 19.

Fig. 7 shows the relations of normative plagioclase, quartz and potassium feldspar of the batholithic plutonic rocks, calculated from the above analytical values. The figure indicates that the Minari granite and Yoshida granite form one group, and the Yokota granodiorite and Daito granodiorite form another group. The Yumura gabbro shows scattering values according to the degree of contamination by granite, and partly shows a character similar to the Hakami quartz diorite.

Fig. 8 is the $(FeO+Fe_2O_3) - (Na_2O+K_2O) - MgO$ relation in the same batholithic plutonic rocks. The figure shows a tendency that the plotted values are generally located on one curve. The group formed by the Minari and Yoshida granites grade into the group formed by the Yokota and Daito granodiorites. The Yumura gabbro is

Table 13. Bulk chemical compositions of Minari granite.

Element	1	2
SiO_2	75.64	75.80
TiO_2	0.18	0.17
Al_2O_3	12.24	12.90
Fe_2O_3	1.84	0.68
FeO	0.36	0.88
MnO	0.05	0.10
MgO	0.51	0.52
CaO	0.73	1.31
Na_2O	3.58	3.01
K_2O	3.81	3.99
P_2O_5	0.02	0.10
$H_2O(-)$	0.34	0.09
$H_2O(+)$	0.44	0.49
Total	99.74	100.04
Q	37.90	39.20
C	0.93	1.45
Or	22.52	23.57
ab	30.52	25.47
an	3.53	5.92
Sal total	95.40	95.61
Wo		
en	1.26	1.29
fs		0.95
mt	0.79	1.00
hm	1.30	
il	0.35	0.32
ap	0.03	0.24
Fem total	3.73	3.80
Total	99.13	99.41

1. Akaya, Hakuta-town,
2. Fube, Fube-village.

Table 14. Bulk chemical compositions of Yokota granodiorite

Element	1	2
SiO_2	69.35	68.47
TiO_2	0.49	0.18
Al_2O_3	14.96	15.23
Fe_2O_3	0.99	1.36
FeO	2.34	2.92
MnO	0.03	0.04
MgO	1.25	1.05
CaO	3.72	3.33
Na_2O	3.92	4.05
K_2O	2.84	2.87
P_2O_5	0.03	0.28
$H_2O(-)$	0.16	0.13
$H_2O(+)$	0.40	0.45
Total	100.48	100.36
Q	25.45	24.08
C		0.01
Or	16.79	16.96
ab	33.06	34.27
an	14.87	14.85
Sal total	90.17	90.17
Wo	1.41	
en	3.10	2.60
fs	2.72	4.01
mt	1.44	2.00
hm		
il	0.93	0.35
ap	0.07	0.67
Fem total	9.67	9.63
Total	99.84	99.80

1. Hanaidani, Yokota-town.
2. Mt. Misen, Akaki-town.

Analyst : K. YAMAGUCHI (1957).

scattered in a considerably wide range, from a part closer to the Hakami quartz diorite to a more basic part, according to the degree of contamination by granite.

The volumetric relations of quartz, potassium feldspar and plagioclase in the Minari granite, Yokota granodiorite, Daito granodiorite, Yoshida granite, Yumura gabbro and Hakami quartz diorite, Okami diorite, Yakami granite and Izuwa granite are shown in Fig. 9, 10, 11, 12, 13, 14, 15 and 16, respectively.

According to the classification by CHAYES (1957), based on the above figures, the Minari granite belongs mostly to type II*, although the rock has some parts specially abounding in quartz and other parts falling in the border area between type II* and type IIP. The Yokota granodiorite is, for the most part, a granite of type IIP. These two granite are grading into each other, as will be known from Fig. 12 and 13.

Table 15—a. Bulk chemical compositions of Daito granodiorite.

Element	1 *	2 *	3 *	4	5	6	7
SiO_2	66.71	69.22	65.22	66.03	66.63	67.27	66.43
TiO2	0.48	0.51	0.55	0.38	0.40	0.14	0.24
Al_2O_3	14.82	14.74	15.70	15.75	14.74	16.81	17.39
Fe_2O_3	1.07	0.83	1.00	1.62	3.39	2.09	1.69
FeO	2.61	2.34	2.75	2.33	2.26	2.08	1.71
MnO	0.07	0.06	0.05	0.08	0.13	0.10	0.13
MgO	2.23	1.56	2.14	1.74	2.07	2.03	1.88
CaO	3.84	3.92	4.20	3.69	3.66	3.65	8.86
Na_2O	3.45	3.38	4.28	4.12	3.66	3.10	3.44
K_2O	2.59	2.80	2.53	2.42	2.13	2.46	2.00
P_2O_5	0.08	0.13	0.10	0.20	0.14	0.10	0.08
$H_2O(-)$	0.36	0.13	0.20	0.37	0.22	0.23	0.37
$H_2O(+)$	1.73	0.35	0.65	1.29	1.12	0.39	0.30
Total	100.04	99.97	99.37	100.02	100.55	100.45	99.52
Q	24.16	27.52	18.01	21.65	26.28	28.40	26.21
C				0.05	0.15	2.71	2.84
Or	15.29	16.51	14.96	14.29	12.57	14.51	11.79
ab	29.19	28.61	36.21	34.85	30.97	26.20	29.08
an	17.29	16.76	16.12	17.18	17.07	17.29	18.38
Sal total	85.93	89.44	85.30	88.02	87.04	89.11	88.30
Wo	0.52	0.80	1.72				
en	5.58	3.87	5.31	4.32	5.13	5.03	4.66
fs	3.25	2.88	3.41	2.46	0.94	2.03	2.65
mt	1.55	1.21	1.46	2.34	4.92	3.04	2.06
hm							
il	0.91	0.97	1.05	0.73	0.76	0.26	0.46
ap	0.20	0.30	0.24	0.47	0.34	0.24	0.20
Fem total	11.96	10.03	13.19	10.32	12.09	10.60	10.03
Total	97.89	99.47	98.49	98.34	99.13	99.71	98.33

1. Tamatsukuri, Tamayu-town.
2. Kisugi, Kisugi-town.
3. Hataya, Daito-town.
4. Daito, Daito-town.
5. Enjo, Daito-town.
6. Higashidani, Kamo-town.
7. Awadani, Mitoya-town.

* Analyst : K. YAMAGUCHI (1957).

As to the Daito granodiorite, the greater part is a granite of type IIP, although the marginal part is a granite of type II*.

The Yoshida granite is almost entirely type II*. But it locally contains a part belonging to type IIA, and this is the important difference from the Minari granite.

The characters of the Yumura gabbro and Hakami quartz diorite vary with the degree of contamination. The gabbro grades into a dioritic rock and, in some cases, into a granite of type IP.

The Okami diorite is also variable in character, widely ranging from a dioritic rock to a granite of type IP, IIP or II*. In the Okami rock body, the parts formed earlier belong to the dioritic rock or type IP, the parts of later formation show type IIP or II* (312) ; occasionally, the earlier ones are remarkably injected by the later ones in a

Table 15-b. Bulk chemical compositions of marginal part of Daito granodiorite.

Element	1
SiO_2	73.42
TiO_2	0.11
Al_2O_3	14.85
Fe_2O_3	0.98
FeO	1.11
MnO	0.01
MgO	0.72
CaO	1.85
Na_2O	3.63
K_2O	2.60
P_2O_5	0.23
$H_2O(-)$	0.13
$H_2O(+)$	0.36
Total	100.00
Q	37.42
C	3.23
Or	15.35
ab	30.71
an	7.78
Sal total	94.44
Wo	
en	1.79
fs	1.06
mt	1.42
hm	
il	0.21
ap	0.54
Fem total	5.02
Total	99.46

1. Otake, Kamo-twno.

Table 16. Bulk chemical compositions of Yoshida granite.

Element	1	2	3	4	5
SiO_2	73.62	72.30	73.78	72.21	74.52
TiO_2	0.30	0.39	0.07	0.20	0.08
Al_2O_3	13.11	14.80	13.91	15.62	13.31
Fe_2O_3	0.33	1.31	0.69	1.59	1.03
FeO	1.28	1.23	0.92	0.94	0.96
MnO	0.02			0.04	0.09
MgO	0.61	0.93	0.25	0.83	0.36
CaO	1.51	1.68	1.41	1.43	0.88
Na_2O	3.95	4.10	4.24	3.00	4.03
K_2O	4.14	3.00	3.73	2.69	3.48
P_2O_5	0.25	0.04	0.09	0.03	0.07
$H_2O(-)$	0.12	0.22	0.11	0.30	0.25
$H_2O(+)$	0.36	0.55	0.59	0.34	0.43
Total				99.22	99.49
Q	30.56	31.79	31.16	40.32	35.05
C		1.84	0.52	5.30	1.47
Or	24.46	17.74	22.02	15.56	20.52
ab	33.43	34.69	35.89	25.36	34.11
an	5.78	8.09	6.48	7.12	3.95
Sal total	94.23	94.15	96.07	93.66	95.10
Wo	0.08				
em	1.51	2.31	0.62	2.06	0.89
fs	1.62	0.53	1.00	0.24	1.02
mt	0.46	1.90	1.00	2.32	1.48
hm					
il	0.58	0.74	0.14	0.40	0.15
ap	0.60	0.10	0.20	0.06	0.17
Fem total	4.85	5.58	2.96	5.08	3.71
Total	99.08	100.50	99.03	98.74	98.81

1. Mt. Seikyu, Daito-town.
2. Ayo, Daito-town.
3. Onbara, Kawamoto-town.
4. Shinji town.
5. Igaya, Mitoya-town.

network form. The distribution of these networks is quite random as far as can be judged. There is no sign of any major feeding channels, nor is there evidence of a linear distribution of the complexes such as one might expect if the injection of the acidic magma were guided by a fissure system from the different magma. These acidic and basic components of Okami rock body were simultaneously intruded as a magma, it may have split away from one another during the process of intrusion. WELLS (1954) discussed on the role of gases and differential pressure in the formation of net-veining. It suggest that the composite intrusives composed of basic and acidic rocks may have been produced by similar process.

Table 17. Bulk chemical compositions of Yumura gabbro.

Element	1	2	3 *	4
SiO_2	59.23	53.60	56.89	49.80
TiO_2	1.56	1.42	0.95	0.87
Al_2O_3	15.21	17.68	16.39	7.18
Fe_2O_3	2.83	2.43	3.36	15.66
FeO	4.26	6.81	5.09	5.75
MnO	0.14	0.21	0.12	0.16
MgO	2.49	2.82	3.37	5.33
CaO	5.90	6.80	7.36	9.97
Na_2O	4.21	3.31	3.46	2.23
K_2O	2.18	1.38	1.16	0.98
P_2O_5	0.77	0.08	0.20	0.12
$H_2O(-)$	0.29	0.40	0.39	0.57
$H_2O(+)$	0.63	2.61	1.04	0.98
Total	99.70	99.55	99.78	99.61
Q	12.40	7.40	11.71	13.16
C				
Or	12.84	8.17	6.84	5.78
ab	35.63	27.98	29.29	18.86
an	16.15	29.27	25.74	6.67
Sal total	77.02	72.82	73.58	44.47
Wo	3.51	1.65	3.99	17.55
en	6.18	6.99	8.36	13.22
fs	3.18	8.55	5.23	
mt	4.11	3.53	4.87	16.56
hm				4.27
il	2.96	2.71	1.81	1.66
ap	1.81	0.20	0.47	0.27
Fem total	21.75	23.63	24.73	53.58
Total	98.77	96.45	98.31	98.00

1. Yumura, Kisugi-town.
2. Kuchiba, Hasumi-village.
3. Mizawa, Nita-town.
4. Yumura, Kisugi-town.

* Analyst : K. YAMAGUCHI (1957).

Table 18. Bulk chemical compositions of Hakami quartz-diorite.

Element	1
SiO_2	61.90
TiO_2	1.78
Al_2O_3	17.30
Fe_2O_3	1.79
FeO	4.11
MnO	0.13
MgO	1.58
CaO	3.24
Na_2O	4.44
K_2O	1.47
P_2O_5	0.32
$H_2O(-)$	0.11
$H_2O(+)$	1.03
Total	99.20
Q	20.36
C	3.21
Or	8.67
ab	37.57
an	14.15
Sal total	83.96
Wo	
en	3.92
fs	3.35
mt	2.62
hm	
il	3.39
ap	0.77
Fem total	14.05
Total	98.01

1. Ayo, Daito-town.

The Yakami granite belongs to type II*, although the type is dominantly II (231), II(213) and II (123), with occasional type IIA. In other words, the Yakami granite is rich in potassium feldspar.

Referring to the theory of HALL (1956) and using the method of SMITH - YORDER (1956), the writer determined the composition of plagioclase in the above-mentioned plutonic rocks. The X-ray analysis showed the following results :

In the Minari granite the mean value of nine samples is $Ab_{78.9}An_{21.1}$; in the Yokota granodiorite, the mean value of nine samples is $Ab_{74.2}An_{25.8}$; in the Daito granodiorite the mean value of four samples is $Ab_{71.2}An_{28.8}$; in the Yoshida granite

Table 19. Bulk chemical composition s of Okami diorite.

Element	1	2
SiO_2	64.04	56.11
TiO_2	0.69	1.33
Al_2O_3	15.82	16.72
Fe_2O_3	1.49	2.84
FeO	3.52	6.22
MnO	0.15	0.13
MgO	2.02	4.47
CaO	4.79	7.71
Na_2O	3.15	2.85
K_2O	2.80	1.04
P_2O_5	0.05	0.76
$H_2O(-)$	0.11	0.14
$H_2O(+)$	1.41	0.09
Total	100.04	100.41
Q	20.44	11.94
C		
Or	16.51	6.12
ab	26.67	24.10
an	20.74	29.75
Sal total	84.36	71.91
Wo	1.11	1.66
en	5.00	11.09
fs	4.38	7.13
mt	2.16	4.13
hm		
il	1.31	2.52
ap	0.13	1.81
Femtotal	14.09	28.34
Total	98.45	100.25

1. Kawamoto, Kawamoto-town.
2. Haza, Kanagi-village.

the mean value of nine samples is $Ab_{78.4}An_{21.6}$; in the Yumura gabbro the value, for one sample only, is $Ab_{52}An_{48}$; in the Hakami quartz diorite the mean value of two samples is $Ab_{72.5}An_{27.5}$; and in the Izuwa granite the mean value of two samples is $Ab_{83.7}An_{16.3}$. These values indicate that the composition of plagioclase in the Minari and Yoshida granites is almost the same, while the Izuwa granite is more acidic, despite that all of them are biotite granite. In comparison of the Yokota granodiorite and the Daito granodiorite, the plagioclase composition of the former is more acidic. Such difference in composition are reflect well in the quartz-potassium feldspar-plagioclase diagram.

Fig. 17, 18, 19, 20, 21, 22, 23, and 24 show the relationship between salic minerals and mafic minerals in the Minari granite, Yokota granodiorite, Daito granodiorite, Yoshida granite, Yumura gabbro and Hakami quartz diorite, Okami diorite, Yakami granite and Izuwa granite, respectively.

In the Minari granite, biotite is the principal mafic mineral, having the refractive index $\gamma = 1.643 \sim 1.645$. The mafic volume does not show an increase with increasing plagioclase.

In the Yokota granodiorite the principal mafic minerals are biotite and hornblende. The refractive index of the biotite is $\gamma = 1.643$, and the optic axial angle of the hornblende is $2Vx = 68°$.

As in the case of the Minari granite, mafic minerals in the Yokota granodiorite do not increase even when plagioclase increases.

The principal mafic minerals in the Daito granodiorite are biotite and hornblende. The biotite's refractive index is $\gamma = 1.645 \sim 1.646$. The optic axial angle of hornblende is $2Vx = 70° \sim 72°$. The volume of mafic minerals increases somewhat sensitively with increase of plagioclase.

In the Yoshida granite, biotite is the principal mafic mineral, having refractive index $\gamma = 1.648 \sim 1.650$. The mafic volume sensitively changes with the volume of the plagioclase.

In fhe Yumura gabbro and Hakami quartz diorite the principal mafic minerals are

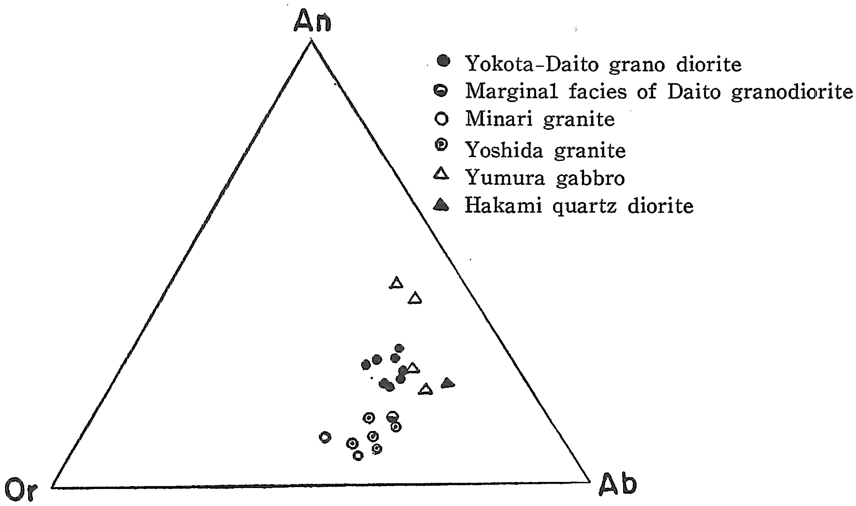

Fig. 7. Relation among normative anorthite, albite and potassium fel dspar in various rock types from a composite batholith.

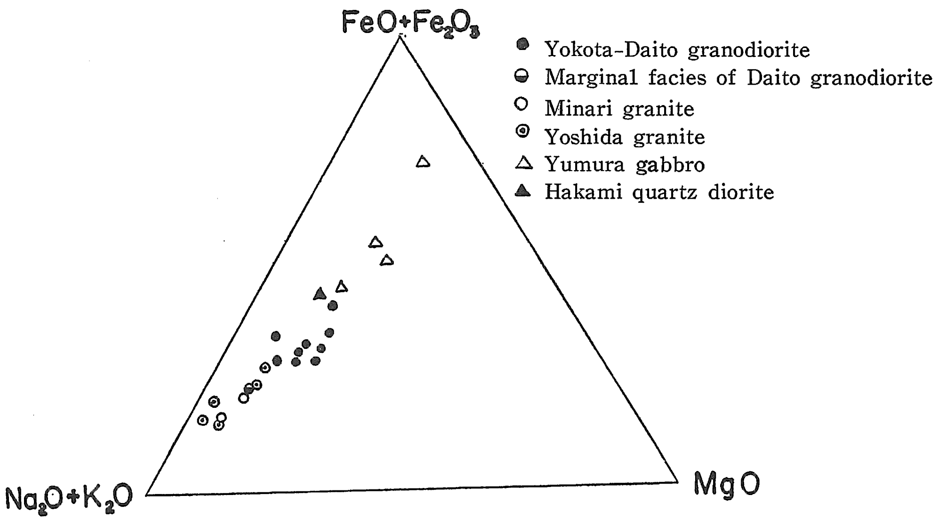

Fig. 8. Relation of $FeO+Fe_2O_3$—Na_2O+K_2O—MgO in chemical compositions of various rock types from a composite batholith.

biotite, hornblende and pyroxene. With increase of plagioclase the mafic minerals increase.

In the gabbroic rock at Odakara, Kisuki-cho, the refractive index of biotite is γ = 1.643, the optic axial angle of hornblende is 2Vx = 78, the refractive index of monoclinic pyroxene occurring as relict mineral is γ = 1.692, and that of orthorhombic pyroxene is γ = 1.720.

In the Okami diorite, mafic minerals increase with increasing plagioclase. The same

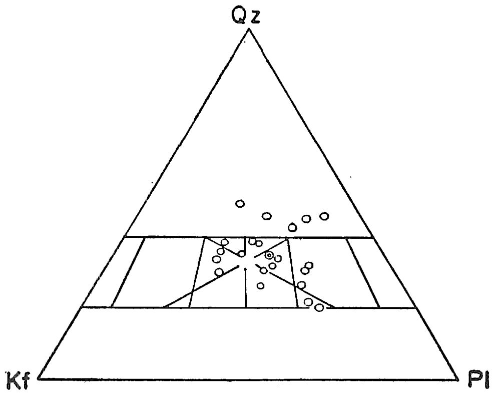

Fig. 9. Volumetrical relation of quartz, potassium feldspar and plagioclase in Minari granite.

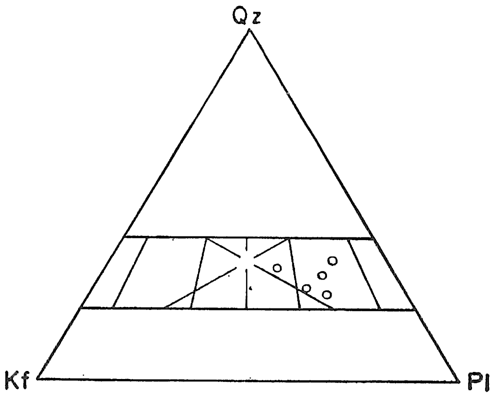

Fig. 11. Volumetrical relation of quartz, potassium feldspar and plagioclase in Daito granodiorite.

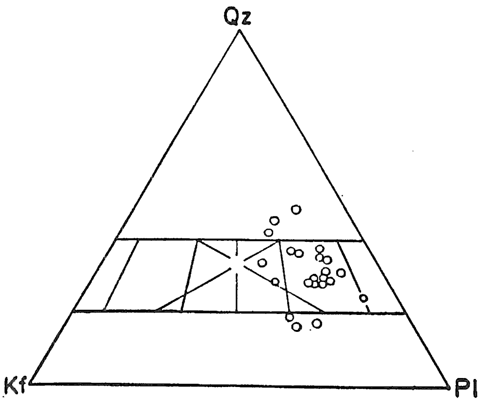

Fig. 10. Volumetrical relation of quartz, potassium feldspar and plagioclase in Yokota granodiorite.

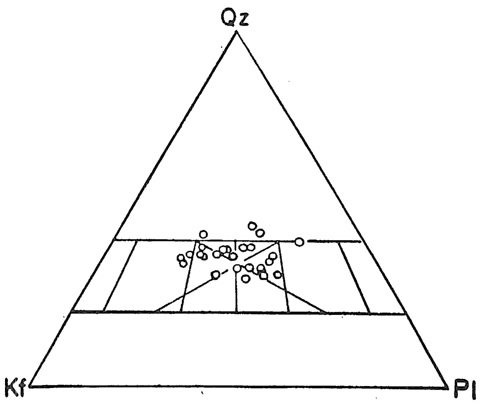

Fig. 12. Volumetrical relation of quartz, potassium feldspar and plagioclase in Yoshida granite.

applies to the Yakami granite and Izuwa granite.

Fig. 25, 26, 27, 28, 29, 30, 31 and 32 show the relation of quartz, potassium feldspar and plagioclase, against all salic minerals, in the Minari granite, Yokota granodiorite, Daito granodiorite, Yoshida granite, Yumura gabbro and Hakami quartz diorite, Okami diorite, Yakami granite and Izuwa granite, representively.

In both Minari granite and Yokota granodiorite, the volume of quartz, potassium feldspar and plagioclase does not seem to have any particular relation with the volume of all salic minerals. This may have some connection with the facts thatt increase of plagioclase does not cause increase of mafic minerals, and that the potassium feldspar always contains microcline and shows a moire appearance.

In the polymorphism of potassium feldspar, GOLDSMITH et LAVES (1954) recognized two types, sanidine of monoclinic symmetry and microcline of triclinic symmetry, and

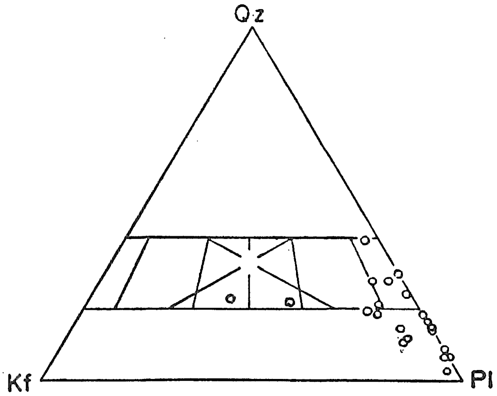

Fig. 13. Volumetrical relation of quartz, potassium feldspar and plagioclase in Yumura gabbro and Hakami quartz diorite.

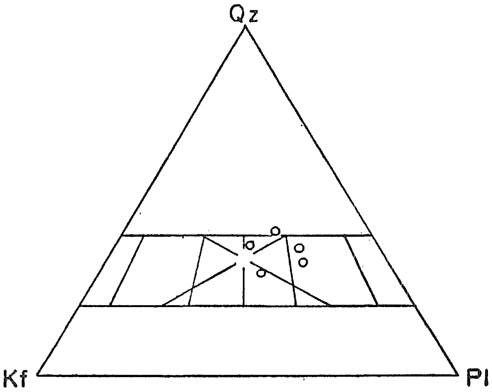

Fig. 15. Volumetrical relation of quartz, potassium feldspar and plagioclase in Yakami granite.

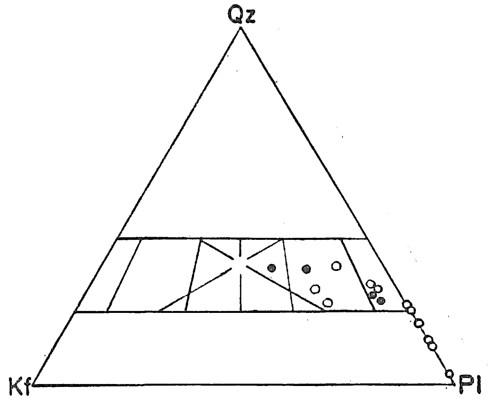

Fig. 14. Volumetrical relation of quartz, potassium feldspar and plagioclase in Okami diorite. (Black circle : Okami rock mass).

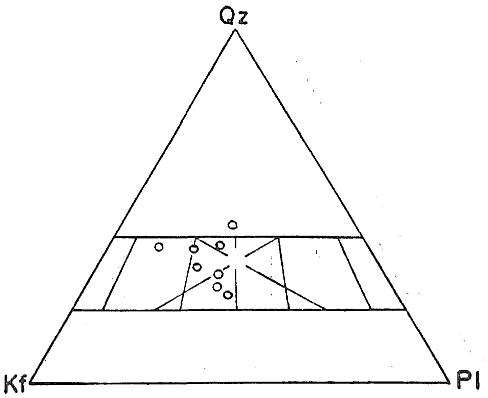

Fig. 16. Volumetrical relation or quartz, potassium feldspar and plagioclase in Izuwa granite.

considered that a structurally intermediate type should exist between the two. According to them, sanidine is dis-order and high-temperature type, while microcline is order and low-temperature type. They considered that orthoclase is an unstable potassium feldspar occurring where sanidine partly approaches microcline.

The Minari granite and Yokota granodiorite are a series of rocks grading into one another. They constitute the southern axial zone of the batholithic plutonic rocks. They must have cooled down slowly and gradually, so that the potassium feldspars which are high in order were formed. Other rock-forming minerals also must have crystallized out at the most stable ratio. This will account for the difference between these rocks and other plutonic rocks. MARMO (1958), too, says that microcline crystallizes slowly in the process of orogenic movement.

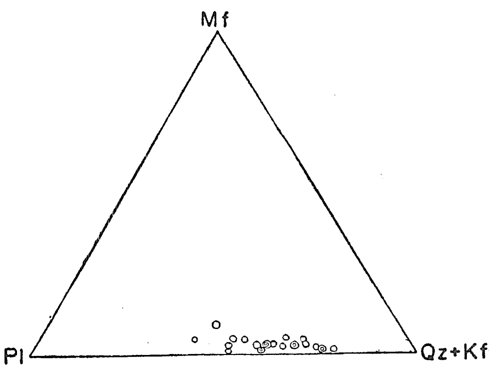

Fig. 17. Volumetrical relation of mafic and salic minerals in Minari granite.

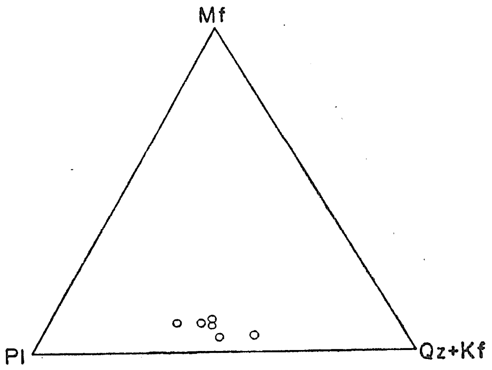

Fig. 19. Volumetrical relation of mafic and salic minerals in Daito granodiorite.

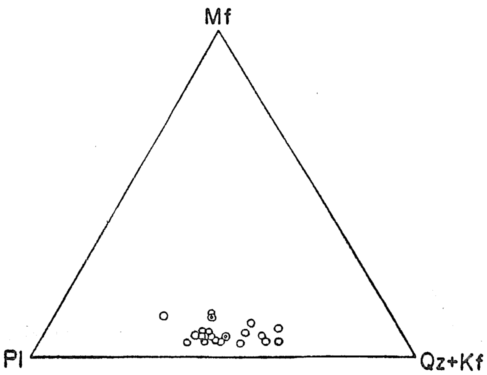

Fig. 18. Volumetrical relation of mafic and salic minerals in Yokota granodiorite.

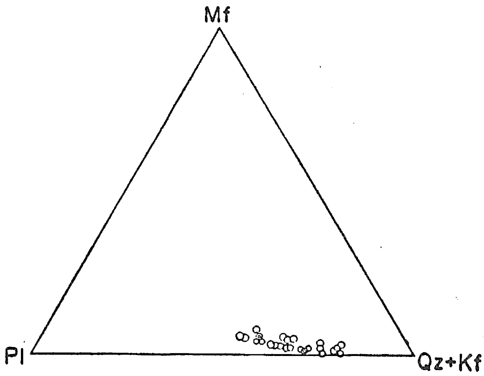

Fig. 20. Volumetrical relation of mafic and salic minerals in Yoshida granite.

The Daito granodiorite, Yoshida granite, Yumura gabbro and Hakami quartz diorite, Okami diorite, Yakami granite and Izuwa granite all show a general tendency that quartz and potassium feldspar increase and plagioclase decrease with increase of all salic minerals.

VII. Age of intrusion of plutonic rocks

KAWANO et UEDA (1966) reported their results of K-A dating for absolute ages of the granites at several localities of central San-in, as in the following :

Masuda granite (Shimohada, Masuda city)	92×10^6 years
Daito granodiorite (Awadani, Mitoya-cho)	51×10^6 years
Yoshida granite (Igaya, Mitoya-cho)	63×10^6 years
Okami diorite (Okami, Misumi-cho)	36×10^6 years

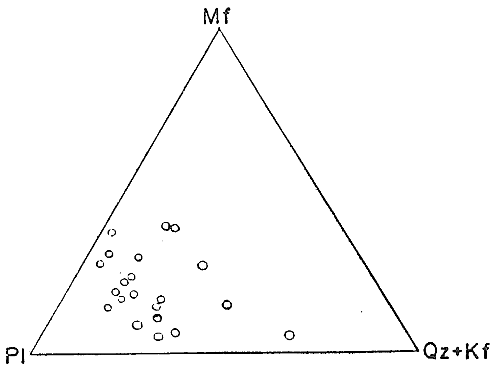

Fig. 21. Volumetrical relation of mafic and salic minerals in Yumura gabbro and Hakami quartz diorite.

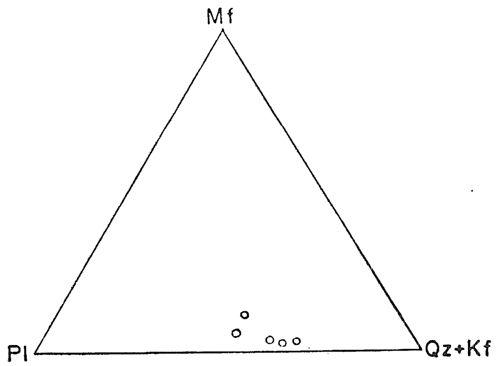

Fig. 23. Volumetrical relation of mafic and salic minerals in Yakami granite.

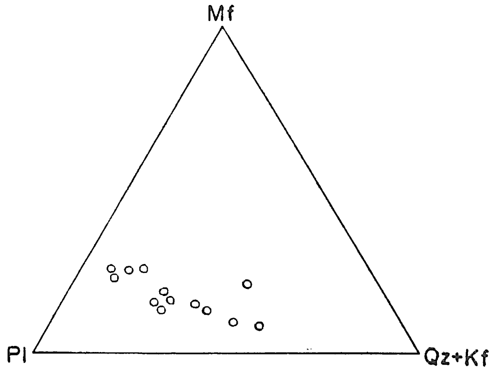

Fig. 22. Volumetrical relation of mafic and salic minerals in Okami diorite.

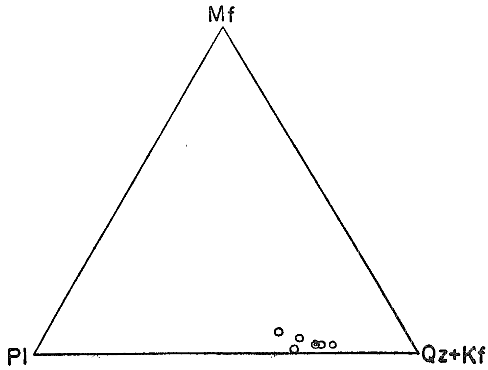

Fig. 24. Volumetrical relation of mafic and salic minerals in Izuwa granite.

Izuwa granite (Asuna, Hasumi-mura) 34×10^6 years

The Masuda granite is the one which the writer defined as an older granite, and agrees with the result of K-A dating.

According to KAWANO et UEDA (personal communication), the same Daito granodiorite shows 50×10^6 years in some parts and 42×10^6 years in other parts, and the Yokota granodiorite shows 39×10^6 years.

The Daito granodiorite is a batholithic plutonic body consisting the northern zone of intrusion. According to the field observation, the Daito granodiorite is intruded by the Yoshida granite. That is, the result of the K-A dating is not agree wtih the the result of the field observation. The writer think that this problem relate to the genesis of granodiorite itself.

The Yokota granodiorite is a batholithic plutonic body constituting the southern zone of intrusion, cooled more slowly, as can be inferred from the nature of the potassium feldspar contained therein. It is most likely therefore, that this difference in the cooling condition is clearly expressed in the result of dating.

The Okami rock body intruded through the Masuda structural line. The age of the rock bodies that intruded through such a structural line seems to reveal similar age to the Okami rock body.

The Izuwa granite is of a different nature from the "San-in granite magma". Its intrusion took place along the Hiroshima-Sanbe tectonic line, after the batholithic plutonic rocks were consolidated. This granite may be related with the Hiroshima granite. Its age dermined by the K-A dating coincides well with the field evidence.

VIII. Summary

Hitherto described is the successive igneous activity, which continued from late Mesozoic to Paleogene, in the central San-in region.

ESKOLA (1932) stated that the formation of a granitic magma is intimately related to an orogenic movement, and that a granitic magma is formed when a granitic material having the lowest melting temperature is squeezed out of a deeper part of a geosyncline. The present writer considers that the parental "San-in granitic magma"

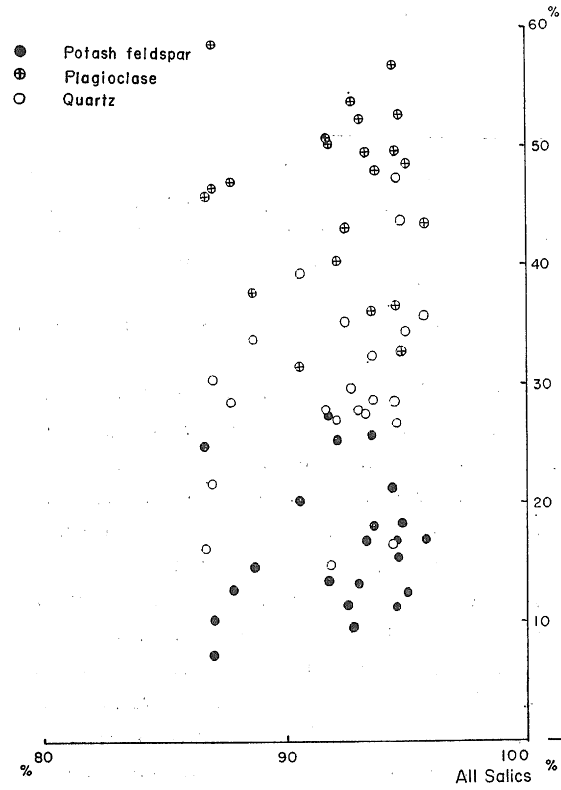

Fig. 25. Relationship between the salic minerals of the Yokota granodiorite to the salics in percent.

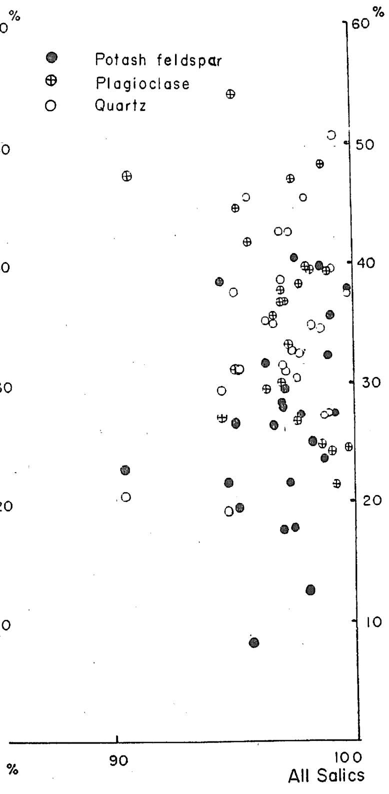

Fig. 26. Relationship between the salic minerals of the Minari granite to the salics in percent.

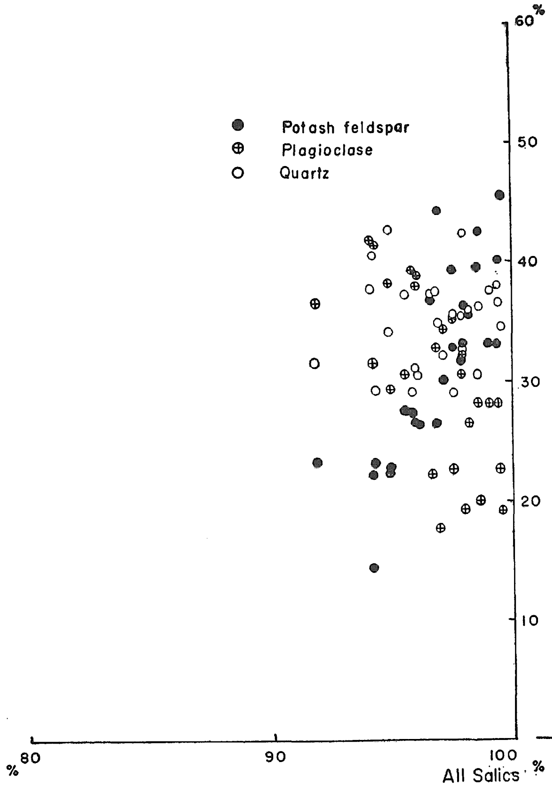

Fig. 27. Relationship between the salic minerals of the Yoshida granite to the salics in percent.

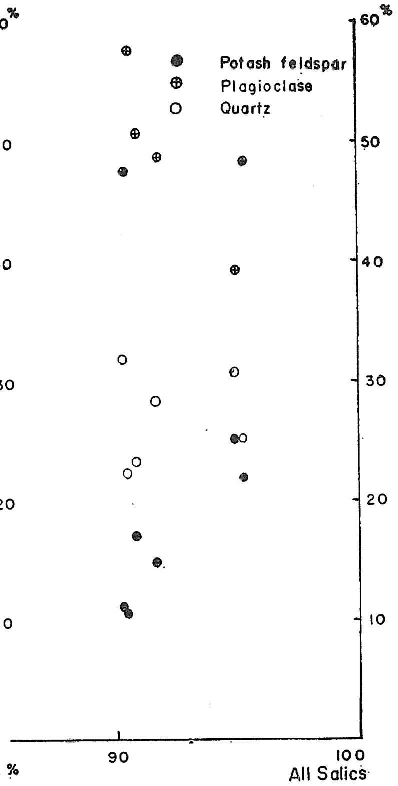

Fig. 28. Relationship between the salic minerals of the Daito granodiorite to the salics percent.

in the central San-in began to intrude in connection with some orogenic movevement, perhaps the Akiyoshi orogenic movement.

This enormous "acidic granitic magma" ascended up to near the ground surface, mostly in late Mesozoic, and effused out, due to deroofing of the roof rock, or partly consolidated in the vents, thus forming the great quantities of late Mesozoic acidic vocanic rocks. Although these acidic volcanic rocks are intruded by granitic plutonic rocks, it can be said that the volcanic rocks and the plutonic rocks were originally the same material constituting the enormous acidic "San-in granitic magma".

PERRIN et ROUBAULT (1949), RAMBERG (1944), and others have long stressed the role of metasomatism in the genesis of granite, and they have minimized the part played by magma. In central San-in, the plutonic rocks are associated with greatly predominant acidic volcanic rocks intimately. Therefore, the granitic plutonic rocks are regarded as magmatic origin. Their general composition is granitic to granodioritic, and is closer to the lowest crystallizing point shown in the experiments of Ab-Or-Qz-H_2O system by TUTTLE et BOWEN (1958). Consequently, it will be easier to explain that largely liquid granitic and granodioritic magmas, formed by almost complete fusion, of deep-seated rocks or squeezed upward from deep zones of partial fusion,

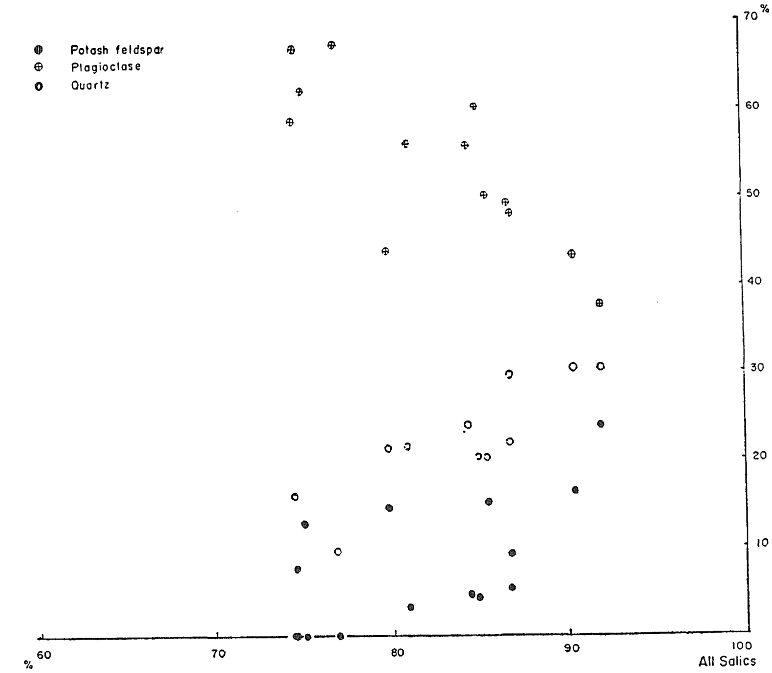

Fig. 29. Relationship between the salic minerals to the salic s of the Yumura gabbro and the Hakami quartz diorite in percent.

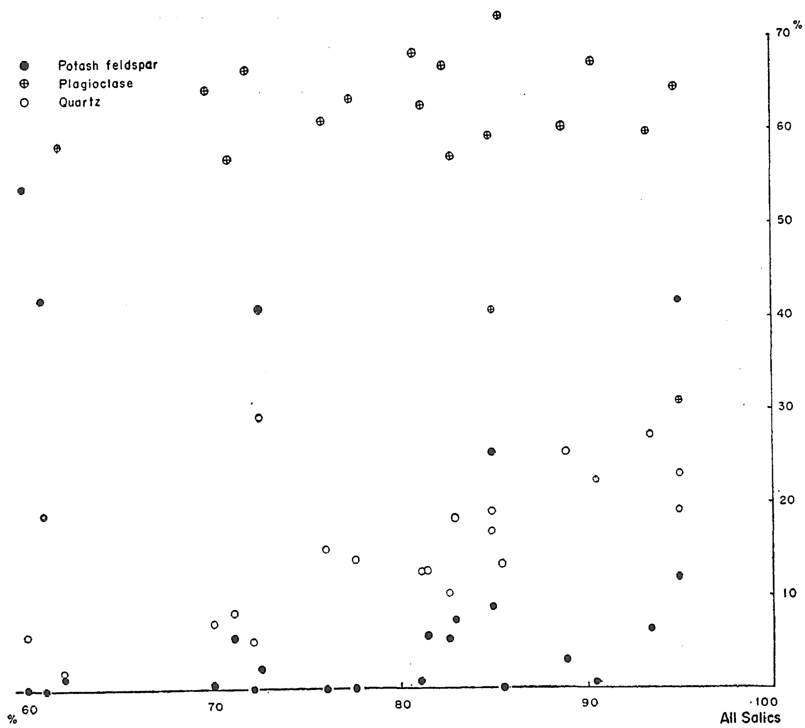

Fig. 30. Relationship between the salic minerals of the Okami diorite to the salics in percent.

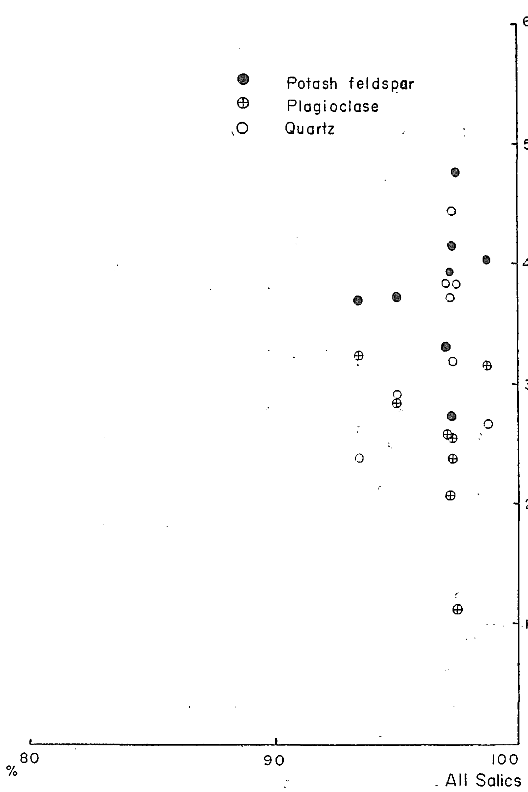

Fig. 31. Relationship between the salic minerals of the Izuwa granite to the salics in percent.

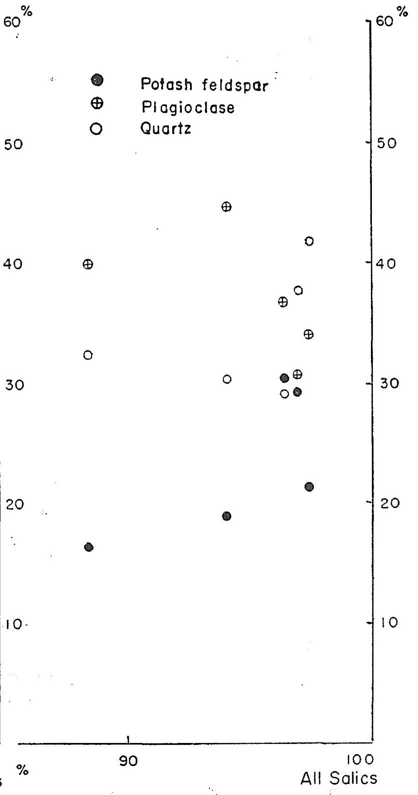

Fig. 32. Relationship between the salic minerals of the Yakami granite to the salics in percent.

have repeatedly effused out or invaded the upper crust on a large scale.

The batholith is composite, having been formed by the successive emplacement of at least four major intrusives. According to the K-A dating by KAWANO et UEDA (1966), these batholithic activities may have been a short-continued process.

The results of K-A dating by KAWANO et UEDA (1966) indicate that the crystallization and consolidation of these plutonic rocks extend over the Paleogene period. This results satisfactorily explain the field evidences.

IX. Acknowledgements

The writes's sincere gratitude is expressed to former Professor Yoshinori KAWANO of Tohoku University, for continuous guidance and kind suggestions. From Professor Yoshio UEDA of the same university, the writer was given valuable instruction and help in preparing this paper.

Professor Kotora HATAI of Tohoku University has kindly guided the writer in many ways.

The writer has been constantly guided and encouraged by Dr. Ichiro HAYASAKA, former President of Shimane University, and by Dr. Kamaji YAMAGUCHI, former Professor at Shimane University.

Continual guidance, in both field and laboratory, was given from Drs. Shozo NISHIYAMA, Junichi KITAHARA, Kanae YOKOYAMA and Hideo MII of the Geological Institute, Shimane University.

The late Dr. Shinji YAMANE, former president of Shimane University, kindly instructed the writer officially and privately.

To all these people the writer is greatly indebted.

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Fig. 1. Geological map of the central San-in region

1. Alluvium. 2. Dacites belonging to the Daisen volcanic zone. 3. Pleistocene formation. 4. Neogene Tertiary formation. 5. Izuwa granite. 6. Yakami granite. 7. Okami diorite. 8. Yoshida granite. 9. Hakami quartz diorite. 10. Yumura gabbro. 11. Daito granodiorite. 12. Yokota granodiorite. 13. Minari granite. 14. Kuchiba andesite. 15. Muikaichi granite porphyry. 16. Iwami rhyolite-dacite. 17. Togusagamine rhyolite. 18. Masuda granite. 19. Muikaichi formation. 20. Seimi ultrabasic intrusives. 21. Non-metamorphosed Paleozoic rocks. 22. Sangun metamorphic rocks.