A Contribution to the Knowledge of the Mesozoic Igneous Rocks Developed Around the Tsushima Basin, Japan. (II.)

By

TAKEO KATŌ.

IV. Masanitic and Consanguineous Rocks in the Vicinity of Wakamatsu.

It is very noteworthy that the mountain-land on the northern side of the bay of Dôkai, which is now under consideration, is bordered by a narrow zone of granitic or masanitic rocks. To say more in detail, the masanitic rocks are concealed beneath the green porphyrite complex which makes up the main bulk of the mountain-land, and are exposed, due to erosion, only along the margin of the area. The masanitic rocks are not basal, but evidently intrusive into the overlying porphyrite complex in the form of a batholith (Fig. 1 in the part I. of this paper).

Along the margin of the batholith, the masanitic rocks usually grade into melanocrates which are sometimes hardly distinguishable from the overlying green porphyrite with the unaided eye. Moreover, dykes of leucocrate cutting the masanitic rocks as well as the melanocrates are occasionally found. The epidotization of the green porphyrite, the alteration of the same rock to biotite-hornfels-like rocks, and impregnation with tourmaline in some porphyrite and quartz-porphyry are, as already stated, highly probably connected with the intrusion of the masanitic magma.

Thus the masanitic and allied rocks are intrusive into the porphyrite complex, which is of late Jurassic extrusion,⁽¹⁾ and, on

1) B. Kotô loc. cit., p. 175.

the other hand, they are evidently older in age than the coal-bearing Tertiary formation of this district, because the latter overlies the erosion-surface of the former. Consequently the intrusion of the masanitic rocks is of late Mesozoic, i. e., post-Jurassic, age.

(1) Quartz-masanite poor in groundmass.

The granitic rock, exposed along the coast between Wakamatsu and Wakinoura, is an apparently coarse-grained variety containing abundant feldspar with a diameter of several millimeters, and also abundant biotite, due to the presence of the latter the rock being rather dark-coloured. When decomposed, it readily crumbles to a loose sand, as can be observed in the road-cutting in the environs of the village of Aikawa. On the coast near Koishi, this rock is well exposed in a fresh condition.

Under the microscope, it shows a porphyritic structure with very subordinate holocrystalline groundmass, or rather a granular structure accompanied by an insignificant amount of a fine-grained mesostasis filling up the sparse interstices between the larger constituents. The larger constituents which make up the main bulk of the rock in question are feldspar and quartz. The feldspar occurs in tabular crystals with a length of 2 to 3 mm. Both plagioclase and orthoclase are present, the former being larger in amount than the latter. The plagioclase (oligoclase) is characterized by narrow polysynthetic twin-lamellæ, while the orthoclase occurs in simple crystals or in Karlsbad twins. Both are commonly more or less kaolinized. The phenocrystic feldspars have usually serrated margins frequently with conspicuous embayments, resulted from magmatic corrosion. The quartz occurs rather sparsely in more or less corroded hypidiomorphic grains mingled with the feldspar crystals, the size of the former being commonly smaller than that of the latter.

The interstices between the crystals and grains of the larger

feldspars and quartz are filled with microscopic grains of quartz mixed with small amounts of orthoclase grains. It is very characteristic that fair amounts of strongly pleochroic biotite always in confused aggregates of minute flaky crystals and in scattered flakes are admixed with the interstitial quartz grains. A small quantity of strongly pleochroic green hornblende in minute flakes and granules is closely associated with the biotite. It is especially noteworthy that the biotite and hornblende belong to the last stage of crystallization, being crystallized in the spaces between the quartz grains of the mesostasis (Pl. III, Fig. 1). Zircon in fine short prisms, apatite in slender needles, and magnetite in small crystals and grains occur as accessories.

This rock is not any normal granite, but is a special facies of masanite. It may be classed as quartz-masanite, as called by Prof. Kotô, extraordinarily poor in groundmass, the groundmass having been largely expelled by the aggregation of the phenocrystic components.

(2) Tsingtauite and masano-tsingtauite.

Cutting the above-mentioned quartz-masanite rich in ferromagnesian minerals, a fine-grained leucocrate, macroscopically easily mistaken for an aplite, occurs in large dykes.

Under the microscope, it shows a porphyritic structure with holocrystalline groundmass. It is poor in ferromagnesian minerals and is evidently a leucocrate differentiated from the masanitic magma. It is to be classed as tsingtauite (Pl. III, Fig. 2).

The groundmass is microgranular in structure and consists of xenomorphic grains of quartz and hypidiomorphic and xenomorphic grains of feldspar, the average size of the grains being about 0.05 mm. in diameter. The feldspar in the groundmass is mostly orthoclase, but a small quantity of plagioclase, characterized by narrow polysynthetic twin-lamellæ, is mingled. They are usually

more or less kaolinized. Microscopic scales and flakes of biotite, often altered to chlorite, are confusedly but rather sparsely commingled with the feldspar and quartz in the groundmass.

The only conspicuous phenocryst is feldspar, which occurs in idiomorphic tabular, frequently serrated, crystals with an average size of 1 to 1.5 mm. in length, but its quantity is never large. Both orthoclase and plagioclase are present, but the former, usually in Karlsbad twins, is larger more in amount than the latter which is characterized by polysynthetic twin-lamellæ. They are commonly badly kaolinized and turbid. Specks and prisms of secondary epidote are sometimes developed in the kaolinized feldspar, in some instances the feldspar being entirely replaced by granular aggregates of the same mineral. The feldspar is, moreover, often contaminated with irregular flakes of dark green chlorite.

Biotite and its decomposition-product, chlorite, occur rather sparingly in a phenocrystic size. Quartz does not occur in the form of phenocryst, though it is abundant in the groundmass.

This rock is often traversed by minute veinlets of quartz, and also by fine veinlets and stringers of chlorite.

A similar porphyritic leucocrate, exposed along the coast about $\frac{1}{2}$ km. west of the spot where the above-mentioned tsingtauite occurs, contains also both orthoclase and plagioclase, but the latter is much larger in amount (Pl. III, Fig. 4). It contains also no quartz phenocryst. Thus it is a transitional facies between tsingtauite and masanite, and may properly be called masano-tsingtauite.

(3) Masano-hornblendite.

As can be observed in the reefs along the coast about 1 km. west of Koishi, the masano-tsingtauite is intricately traversed by small dykes and stringers, and in places even by thread-like nets of a dark green, aphanitic to fine-phaneritic rock. In places where

the network is complicated and irregular, a brecciated structure is developed, grading into the massive melanocrate with sporadic remnants of the corroded fragments of the leucocrate.

The melanocrate is more readily attacked by weathering than the leucocrate. Consequently the netted dykes and stringers of the former show a porous, or even slaggy appearance due to the dissolution chiefly of the hornblendic component, while the leucocrate remains quite compact in texture, though it is much decomposed as can be revealed under the microscope.

The melanocrate now under consideration is, under the microscope, holocrystalline granular and consists chiefly of hornblende in association with more or less feldspar and quartz (Pl. III, Fig. 3).

Hornblende, the predominant constituent of the rock, occurs in dense aggregates of irregular flakes, scales and imperfect prismatic crystals. It is light green in colour and distinctly pleochroic, light green to light greenish brown, and is characterized by the prismatic cleavage and a small extinction angle relative to the c axis.

Large idiomorphic and hypidiomorphic crystals of feldspar, sometimes in aggregates, and microgranular aggregates of quartz and feldspar occur in irregular patches filling the spaces between the dense aggregates of hornblende which make up the the main bulk of the rock-mass. The colourless patches of feldspar + quartz are usually contaminated with minute crystals and flakes of hornblende and frequently remain turbid due to the kaolinization of the feldspar. Most of the feldspar is orthoclase, but plagioclase is present subordinately.

Titanite, almost colourless or light brown in colour, in wedge, like crystals is widely scattered through the rock, and particularly it occurs more frequently in the feldspar-quartz patches, usually in clusters.

This melanocrate may properly be called masano-hornblendite.

One can not help conceiving, if he makes a trip along the coast between Wakamatsu and Wakinoura and observes the exposures showing the relation between the q-masanite and tsingtauite and those of the tsingtauite and allied rocks traversed irregularly by the melanocrate in question, that the masano-hornblendite and the tsingtauite represent the differentiation-products from the same masanitic magma, and are complementary in composition. A microscopic examination of these rocks confirms this conception.

(4) Diorite-porphyrity or melano-masanite as marginal facies of the quartz-masanite.

The dark green rock, exposed in the road-material quarries along the coast a few decameters west of the coastal reefs which consist of the above-mentioned masano-tsingtauite and masano-hornblendite in a network, is a marginal facies of the q-masanite developed extensively along the coast between Koishi and Wakino-ura. An aplitic rock, representing an acid residual magma, cuts the melanocrate in question in small dykes. The relation that the melanocrate overlies the quartz-masanite, which passes gradually into the former, is observed in many places on the mountain slope in the environs of Aikawa.

The melanocrate in question is a dark green rock ranging in texture from aphanitic to fine-phaneritic and showing in places large phenocrysts of feldspar and hornblende scattered in a compact groundmass, but sometimes shows a non-porphyrity aphanitic appearance. Every gradation between an aphanitic facies and a phaneritic one is recognizable within a small area.

Under the microscope, it is usually characterized by the predominance of plagioclase phenocrysts in association with sporadic orthoclase, and by the abundance of hornblende as phenocrysts and in the groundmass, and also by the presence of quartz grains in abundance in the groundmass. Thus it belongs to the family

of diorite-porphyrite or tonalite-porphyrite, and may properly be called melano-masanite (Pl. IV, Figs. 1, 2).

The groundmass is composed of xenomorphic and hypidiomorphic grains of feldspar (plagioclase and orthoclase) with more or less quartz grains, the size of the grains ranging from 0.025 to 0.05 mm. Abundant microscopic prisms of green hornblende are mingled with the groundmass.

The phenocrysts of feldspar and hornblende occupy more than half of the whole rock-mass. The average size of the phenocrysts is less than 1 mm. in length, but in places they attain a length of 2 mm. or more. The feldspar is mostly plagioclase belonging to the oligoclase-andesine series, and is characterized by polysynthetic twinning and zonal structure. They are usually idiomorphic, but sometimes show more or less serrated forms due to magmatic corrosion. Sporadically orthoclase is found in the form of phenocrysts, being characterized by low indices of refraction, the lack of polysynthetic twin-lamellæ, and the development of Karlsbad twinning. The mode of occurrence of hornblende is very peculiar. Occasionally it occurs in separate idiomorphic crystals, but usually it occurs in large and small flecks consisting of confusedly aggregated, small idiomorphic and hypidiomorphic crystals, often grading into very irregular aggregates. In some instances, especially when the feldspar phenocrysts make up the main bulk of the rock-mass, the hornblende, in the form of small hypidiomorphic crystals and grains, forms very irregular aggregates in the groundmass, often being densely accumulated around the feldspar crystals and traversing them in veinlets (Pl. IV, Fig. 3). The hornblende in the form of phenocrystic crystals as well as small crystals and grains is evidently of later crystallization than the feldspar phenocrysts. The hornblende is strongly pleochroic, deep bright green to light greenish yellow, and has a small extinction angle, $c : c = 12^\circ$.

Small quantities of biotite in small irregular flakes and hypidiomorphic crystals are scattered through the groundmass, sometimes in microscopic phenocrysts. It is usually closely associated or intergrown with the hornblende. In some instances biotite occurs very abundantly also in association with subordinate hornblende (Pl. IV, Fig. 4), a remarkable example being found in the tonalite-porphyrity near the contact with the porphyry complex in the vicinity of Koishi.

As accessories, magnetite in fine crystals, apatite needles, and zircon in short prisms are of common occurrence.

(5) Pegmatitic leucocrate in dykes through the diorite-porphyrity or melano-masanite.

In the above-mentioned road-material quarries between Koishi and Wakinoura, a leucocrate occurs in small dykes with a width of a fraction of one meter, cutting through the melanocrate, the contrast of colour in these two kinds of rocks being very remarkable. The leucocrate is a pegmatite with a medium to rather coarse grained texture. Under the microscope, the rock is composed mainly of hypidiomorphic feldspar and xenomorphic quartz. The quartz occurs either in rounded grains, enclosed in the feldspar, of the earliest crystallization or in graphic intergrowth with orthoclase. Most of the feldspar is orthoclase, but oligoclase is also found sparingly. Biotite in hexagonal plates is sporadically found.

This leucocrate belongs to the last intrusion in the district in question and represents an acid residual fluid differentiated from the masanitic magma.

(6) Masano-tonalite.

Dark-coloured, medium-grained granitic rock, very rich in biotite, is extensively exposed near Futashima, along the southren

foot of the mountain-district now under consideration. Though the appearance of the rock is somewhat different from those found on the opposite side of the mountains, i. e., along the coast between Koishi and Wakinoura, it is beyond all doubt that they are different phases of one and the same batholith, considered from the fact that they are equally intrusive into the green porphyrite complex.

Under the microscope, the rock shows a granitic structure, being composed essentially of oligoclase, quartz, biotite and hornblende with a small quantity of orthoclase. The oligoclase makes up the main bulk of the rock, and occurs in well-defined tabular crystals showing beautiful zonal structure (Pl. III, Fig. 5). The core of the zonal feldspar is full of inclusions of very fine dusty particles, apatite needles, etc., and is usually kaolinized and turbid. The oligoclase core is commonly covered with a thin layer of limpid feldspar which is far lower in refraction than the inner oligoclase and the adjoining quartz. It is undoubtedly orthoclase, which does not occur in separate idiomorphic crystals in the rock under consideration, though sporadically it occurs in xenomorphic grains filling the interstices between the zonal feldspar crystals.

Next abundant are the ferromagnesian minerals, strongly pleochroic biotite and green, distinctly pleochroic hornblende in varying proportions. They are always hypidiomorphic, being hindered from full crystallization by the feldspar crystals. The two coloured minerals are in close association and frequently occur in confused aggregates. Quartz occurs in xenomorphic grains occupying the interstices between the feldspar and ferromagnesian minerals. As accessories, magnetite crystals and apatite needles are very common, while zircon in short prisms and titanite in well-defined crystals are sporadically found.

This rock, being a facies of the batholith-forming masanite and tonalitic in structure and composition, may properly be called masano-tonalite.

(7) Melanocratic marginal facies of the masano-tonalite.

The above-mentioned masano-tonalite seems to grade into melanocratic rocks toward the contact with the green porphyrite complex. The exposure in a road-material quarry about 2 km. northeast of the station of Futashima shows a dark-green coloured aphanite or fine-phanerite grading into a lighter coloured, fine-granular dioritic rock below. The dark green rock looks quite similar to the green porphyrite at first sight, but a keen observation reveals that this is a phanerite consisting of rather fine-grained constituents.

Under the microscope, it is observed that the rock in question is remarkably similar in character to the masano-tonalite, both having practically the same mineralogical composition and the same texture (Pl. III, Fig. 6). It is composed of tabular and prismatic crystals of oligoclase, frequently, if not always, covered with orthoclase mantle, and abundant ferromagnesian minerals. Idiomorphic orthoclase is sparsely mingled with the oligoclase. In some instances, the interstices between large feldspar crystals are filled with smaller plagioclase and quartz instead of quartz alone, then the smaller plagioclase being hypidiomorphic and the quartz xenomorphic.

The mode of occurrence of the ferromagnesian minerals, biotite and hornblende, is just the same as in the already described masano-tonalite, the crystallization of the coloured minerals being subsequent to that of the larger feldspar, but prior to the smaller plagioclase and quartz grains.

Apatite in slender needles and zircon in minute prisms are very common as accessory minerals. Besides these, pyrrhotite in minute patches and pyrite in small crystals are widely scattered through the rock, both being evidently of secondary infiltration.

The abundance of the ferromagnesian minerals is the most

remarkable character of the marginal facies now in question, the coloured ingredients often occupying about half of the whole mass. The proportion of the biotite and hornblende is markedly different even within a small distance, in general, however, the amount of hornblende increasing toward the contact with the overlying porphyrite complex.

(8) Aplitic leucocrate in association with the
masano-tonalite.

Near the road-material quarry in the vicinity of Futashima, where the above-mentioned melanocratic facies are well exposed, a fine-grained leucocrate is exposed along the road-side. It is evidently a differentiate of the masanitic magma, but the real nature of its mode of occurrence is obscure due to the imperfection of the exposure. Probably it occurs in a dyke. It is whitish in colour, and is composed essentially of light coloured components, commonly with a diameter of a fraction of one millimeter, but widely scattered fine grains of ferromagnesian minerals are recognizable even with the unaided eye.

Under the microscope, the rock consists of orthoclase, quartz, plagioclase (oligoclase), hornblende and biotite, as mentioned in the order of abundance. The oligoclase is the earliest mineral to crystallize and occurs always in idiomorphic form, but usually in small crystals. Some of quartz has crystallized next to oligoclase and occurs in rounded grains enclosed in, or surrounded by, later crystallized orthoclase and ferromagnesian minerals, sometimes showing a poikilitic structure; this mode of occurrence of quartz is characteristic of an aplitic rock (Pl. IV, Fig. 5). Green hornblende and biotite in hypidiomorphic crystals and flakes are widely but rather sparsely scattered through the rock. They are subsequent in crystallization to the oligoclase and the earlier quartz but prior to the orthoclase, which occurs in large hypidiomorphic

crystals, often showing Karlsbad twinning, and fills the interstices between the earlier minerals and encloses them. Some quartz is of the last crystallization, filling up the irregular spaces between the all earlier minerals, but its amount is very small. Slender needles of spatite are very common as an accessory mineral, while zircon is found very sparsely.

Diopsidofels-xenolith found in the aplitic leucocrate. A small subangular xenolith has been found in the above-described leucocrate. It is grayish green in colour and very fine-grained in texture. Under the microscope it is composed essentially of minute hypidiomorphic and xenomorphic grains of diopside associated with more or less green hornblende and biotite. The hornblende and biotite occur in dense aggregates of hypidiomorphic crystals and flakes, usually being intricately mingled. They form irregular patches and veinlets in the diopsidofels, clearly indicating that they are of later introduction. Whether the xenolith is accidental or cognate is not clear, but the former case is the more probable because the diopsidofels shows properties characteristic of that of contact-metamorphic origin.

V. Summary and Conclusions.

The porphyrite complex with associated tuff beds in the Wakamatsu district corresponds to the Upper Keishô Formation developed extensively in Southern Korea. It is of late Jurassic effusion. The effusive igneous complex, sometimes several hundred meters in thickness, has been more or less successively invaded by series of igneous rocks, the order of which, commencing with the earliest, is as follows :—

(1) The effusive quartz-porphyry and allied rocks, in places in dykes and intrusive sheets.

(2) The intrusive masano-gratinic series, consisting of quartz-masanite masano-tonalite etc. with melanocratic marginal facies such as diorite-porphyrite or melano-masanite, and others.

(3) The leucocrate series including tsingtauite and masano-tsingtauite in large dykes cutting the series (2).

The grayish felsite dykes with spheroidal xenoliths found in the quartz-porphyry, exposed in the headland near Wakamatsu City, belong probably to this epoch of intrusion.

(4) The dark green masano-hornblendite traversing the leucocrate series (3) in a network.

(5) The aplitic and pegmatitic rocks in small dykes cutting the masanitic rocks including the marginal melanocrates.

The relation between the effusive quartz-porphyry (1) and the intrusive masanitic rocks (2) is not clearly known, but it is highly probable, from petrological considerations, that both kinds of rocks have been derived from the same magma-basin, the difference in structure being due to the difference of the conditions of solidification. That the four series (2), (3), (4) and (5) are consanguineous has been confirmed by field observations and microscopic study.

The age of effusion and intrusion of the igneous rock series in question is clearly pre-Tertiary—probably Cretaceous, because the coal-bearing Tertiary formation of the Chikuhô coal-field rests on the erosion-surface of them.

At the present time the writer is of the opinion that the green porphyrite complex is a derivative from the same magma-basin as all the other Mesozoic igneous rocks in this district. The former is evidently earlier in the age of effusion and usually more basic in composition than the latter, but on a close examination we can catch a glimpse of their consanguinity. The porphyrite shows in places a structure and mineralogical composition resembling those of the diorite-porphyrite and other melanocratic marginal facies of the masano-granitic mass. On the other hand, sporadic corroded quartz grains found in some portions of the porphyrite cannot be considered to have crystallized from the basic magma at an early stage. They suggest, as in those contained in many lamprophyres,

that the basic magma was derived from the basic lower layers of the magma-basin, into which some quartz crystals sank from the overlying acid magma layers, where they were beginning to form.⁽¹⁾

Briefly, it is suggested that the porphyrite complex and the masanitic rocks together with the melanocratic and leucocratic associates represent a cycle of igneous activity in late Mesozoic periods, which took place around the area now occupied by the Tsushima Basin. The three successive stages of a cycle of igneous activity, viz., (1) volcanic, (2) plutonic, (3) minor intrusions,⁽²⁾ are well represented in the district under consideration, if we conceive that the extensive, effusive porphyrite of a late epoch of the Jurassic period is the forerunner of the igneous activity in the post-Jurassic period.

EXPLANATION OF PLATE III.

(PHOTOMICROGRAPHS)

Fig. 1. Quartz-masanite poor in groundmass. Loc.—Coast between Koishi and Wakinoura.

Ordinary light. Magnified 60 diameters.

F, feldspar (oligoclase and orthoclase); B, biotite in aggregates of flakes; Q, rounded phenocryst of quartz; G, groundmass or granular mesostasis consisting of minute grains of quartz with a little feldspar, associated with biotite.

Fig. 2. Tsingtauite. Loc.—Coast near Koishi.

Nicols crossed. Magnified 60 diameters.

F, kaolinized orthoclase in the microgranular groundmass consisting chiefly of quartz and orthoclase; Ch, chlorite flake, a decomposition-product of biotite.

1) A. Harker, loc. cit., p. 323.

2) Idem, p. 25.

Fig. 3. Masano-hornblendite. Loc.—Coast between Koishi and Wakinoura.

Ordinary light. Magnified 60 diameters.

The rock consists largely of flakes and prisms of hornblende (H) in confused aggregation, associated with insignificant quantities of feldspar and quartz filling the interspaces.

Fig. 4. Masano-tsingtauite. Loc.—Ditto.

Ordinary light. Magnified 60 diameters.

F, kaolinized plagioclase in the microgranular groundmass consisting of very fine grains of quartz and feldspar and minute scales of hornblende; H, aggregate of flakes and prisms of hornblende.

Fig. 5. Masano-tonalite. Loc.—Vicinity of Futashima.

Ordinary light. Magnified 60 diameters.

F, oligoclase with orthoclase mantle; B, biotite; H, hornblend; Q, xenomorphic quartz.

Fig. 6. Marginal melanocrate of masano-tonalite. Loc.—Quarry about 2 km. northeast of the Futashima station.

Ordinary light. Magnified 60 diameters.

F, oligoclase with orthoclase mantle; H, hornblende; Q, quartz.

EXPLANATION OF PLATE IV.

(PHOTOMICROGRAPHS)

Fig. 1. Diorite-porphyrite (melano-masanite), exposed in the road-material quarry along the coast between Koishi and Wakinoura, being a marginal facies of the quartz-masanite. Ordinary light. Magnified 60 diameters.

Fig. 2. Ditto between crossed nicols.

F, plagioclase; B, biotite; H, hornblende. These

phenocrysts are scattered in a holocrystalline groundmass consisting of minute grains of feldspar, quartz, hornblende, etc.

Fig. 3. Another specimen of the diorite-porphprite (melano-masanite) from the same locality, characterized by the abundance of plagioclase phenocrysts which are surrounded by hornblende granules in admixture with feldspar and quartz grains forming the groundmass.

Ordinary light. Magnified 60 diameters.

F, plagioclase; H, hornblende.

Fig. 4. Tonalite-porphyrity (melano-masanite) collected near Koishi, being also a marginal facies of the quartz-masanite.

Phenocrysts of plagioclase (F) are abundantly scattered in a microgranular groundmass consisting of fine grains of feldspar and quartz, and fine scales of biotite and a little hornblende.

Biotite and hornblende in aggregates of larger scales and flakes play a rôle of a phenocryst (BH).

Ordinary light. Magnified 60 diameters.

Fig. 5. Aplitic leucocrate, collected near the road-material quarry about 2 km. northeast of the station of Futashima.

Ordinary light. Magnified 60 diameters.

Q, quartz; F, feldspar; M, biotite, hornblende, etc.