METAMORPHOSED CALCAREOUS CONCRETIONS IN THE HORNFELS AT THE SOUTHERN COAST OF TOKATI PROVINCE, HOKKAIDO

By

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With 3 Plates and 3 Text-Figures

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INTRODUCTION

On both sides of the granite mass which composes the southern part of the main mountain range of central Hokkaidô, comparatively thick zones of a certain sedimentary series extend over in the direction of NNW. to SSE. This sedimentary series is chiefly formed of sandstone, shale and chert, accompanied with a small amount of schalstein and limestone, being unconformably covered by the thick deposits of the Cretaceous formation (Aptian-Senonian) and lying probably upon the crystalline schist formation of the so-called Kamuikotan System.

The sedimentaries of this series have hitherto been correlated to the rocks of the so-called Titibu System (Permian-Carboniferous) on account of their similarities from the petrographical point of view, as there no index fossils have been found in them, however, the age of the series is not quite clear. Accordingly, it is now considered that it may be as well to call the series the "Hidaka System" [1] till their stratigraphical position is surely determined at some time in the future.

The exposures of the Hidaka System are distributed also in a comparatively wide area in northern and western Hokkaidô, though

(1) The name "Hidaka System" is applied to the series on account of the wel developed character and good exposures in the western part of the province of Hidaka, Hokkaidô.

they have been greatly disturbed by igneous eruption, so that their areal distribution in these districts is very irregular and the mutual relationship among them is still obscure. A noticeable thing is that the contact zone between the plutonic mass and the sedimentaries of the system is highly metamorphosed and generally changed to the various kinds of hornfels and injection rocks.

The present article deals with special reference to the interesting metamorphosed calcareous concretions in the hornfels-beds at the southern coast of the province of Tokati.

This district has been visited by few geologists and the literature treating this region is comparatively poor. The geological study of the area was first resumed in 1911 by Prof. S. YAMANE,[1] in his memoir associating a geological map on the scale of 1/10,000. In 1926 Mr. Y. ODAIRA made[2] [3] a lithological survey of the district, and reported especially on the igneous bodies. Lately Messrs. Y. SASA and T. OHASHI made further contribution to the geology and petrography of the same area, though their works are not yet published.

The present writer visited the area twice, in the summer and autumn of 1931 and in the latter time he made his survey with Prof. Z. HARADA. On this occasion, acknowledgement must be made to Prof. Z. HARADA, to whom the writer is indebted for a great deal of help in the field and the laboratory.

A geological map of the district now in question is shown in Fig. 1.

In order to understand the natures of the calcareous concretion, a short sketch of the principal geological features of the area is desirable. According to Messrs. Y. ODAIRA and T. OHASHI, the igneous bodies in the district may be classified by the following types:

(1) biotite granite,
(2) diopside quartz diorite,
(3) diopside tonalite,
(4) aphanitic diorite,
(5) granite aplite, and
(6) biotite olivine gabbro.

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(1) S. YAMANE: The Geology of the Southern Part of the Hidaka Province and the Birô District of the Tokati Province (in Japanese). Mineral Survey Report, Imp. Geol. Surv., No. 4 (1911).

(2) Y. ODAIRA: Igneous Rocks of the Southeastern Coast of Hidaka Province (in Japanese). Journ. Geol. Soc. Tokyô, Vol. XXXIII (1926).

(3) Y. ODAIRA: Geology and Petrology of the Horoizumi District, Prov. Hidaka. Journ. Geol. Soc. Tokyô, Vol. XXXIII (1928).

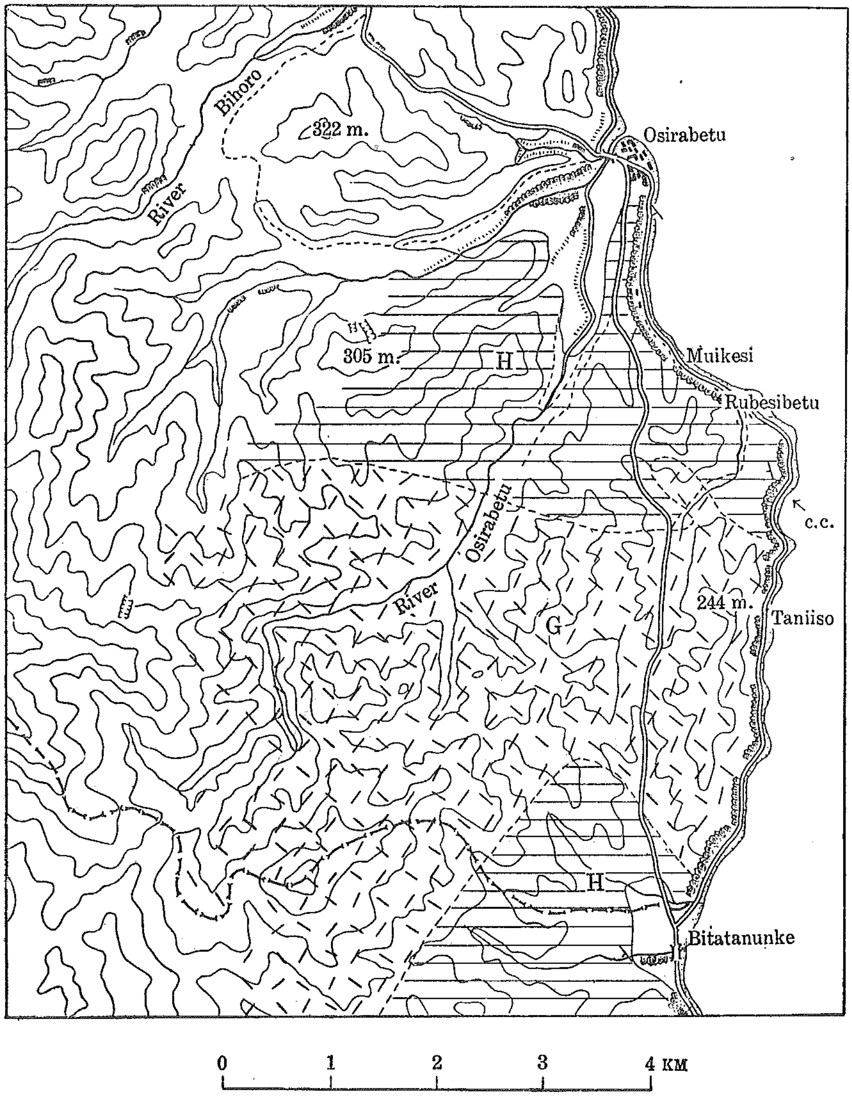

Fig. 1. Sketch map to show the geology of the Osirabetu district, Prov. Tokati. G: Granite, H: Hornfels, C. C: Calcareous concretions.

These rock types with some exceptions, are believed, to be genetically related to each other, indicating that they might have been differentiated from the same magma. Among them, the biotite granite occupies an extensive area on the southern coast of Tokati province and has given a most severe contact effect to the surrounding sediments. The common type of the rock is coarse grained and light coloured, and consists chiefly of quartz, orthoclase, plagioclase (An_{15-20}) and biotite (γ=1.640—1.642) accompanying a minute quantity of sericite, magnetite, epidote and chlorite.

The typical biotite granite from Taniiso[1] in the district was analysed by Mr. T. NEMOTO, of the Geological and Mineralogical Department of the Hokkaidô Imperial University, with the result shown in the following table. A chemical analysis of the biotite granite from Simizu,[2] a good northern locality of the rock in the same igneous mass, was made by Mr. A. KANNARI, of the same department, and is cited in the parallel column in the table for comparison.

TABLE I.

Chemical analyses of granite.

	No. 1		No. 2	
	Per cent	Mol. Prop	Per cent	Mol. Prop
SiO_2	68.75	1140	75.68	1255
TiO_2	0.59	7.4	0.06	0.7
Al_2O_3	14.48	142	12.94	127
Fe_2O_3	1.09	7	0.56	4
FeO	3.30	46	0.86	12
MnO	0.11	2	0.07	1
MgO	1.11	28	0.62	15
CaO	3.28	59	1.05	19
Na_2O	3.11	50	3.91	63
K_2O	2.92	31	4.16	44
P_2O_5	0.34	2.4	tr.	—
H_2O (+)	0.61	—	—	—
H_2O (−)	0.20	—	—	—
Ignition loss	—	—	0.28	—
Total	99.89		100.19	
Sp. gr.	2.67		2.68	

(No. 1) Biotite granite from Taniiso, Prov. Tokati (T. NEMOTO, analyst).
(No. 2) Biotite granite from Simizu, Prov. Tokati (A. KANNARI, analyst).

(1) 谷磯 (2) 清水

The sedimentary complex of the district, now mostly represented by a series of contact metamorphic rocks, is classified into five main types as follows:

(1) biotite hornfels,
(2) cordierite biotite hornfels,
(3) garnet cordierite biotite hornfels,
(4) enstatite biotite hornfels, and
(5) biotite quartzite.

The mineralogical assemblage in these rocks shows that most of them belong to classes 3–5 of the V. M. Goldschmidt's classification.[1]

Besides those hornfels, we find various kinds of lit-par-lit injection rock, biotite- or biotite-hornblende-schist, in the immediate contact zone of the granite mass and sedimentary rock.

The biotite- and biotite-cordierite-hornfels are the predominant members in the metamorphic series in the district, while the enstatite or garnet bearing varieties play but a very subordinate part among them. The calcareous concretionery nodules mentioned later generally occur so far as the writer knows, in the biotite- and cordierite-biotite-hornfels. The hornfels are composed chiefly of fine grains of quartz, plagioclase (An_{35-38}) and minute flakes of reddish brown biotite (γ=1.635–1.640). The biotite is not equally abundant in all portions of these rocks, but is no where entirely lacking. Cordierite, when present, shows irregular rounded, colourless crystals with low double refraction, and in general is partly decomposed to pinite (Plate XLVIII (III), Figs. 1–2).

No. 3 in the following table is an analysis of the cordierite-biotite hornfels from the district, 3 km. south from Osirabetu[2]. The material was carefully taken about 3 cm. from the contact with calcareous concretion. In the table the chemical composition (No. 4) of hardened shale[3] from Ponnikanbetu, Hidaka Province, which seems to belong to the same series of the above cited hornfels, is set forth for comparison.

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(1) V. M. GOLDSCHMIDT: „Die Kontaktmetamorphose im Kristianiagebiet. Vidensk. Skr. I. Mat. Naturv. (1911), No. 1, S. 140.

(2) 音調津

(3) Y. ODAIRA: Journ. Geol. Soc. Tôkyô, Vol. XXXV (1928), p. 310.

TABLE II.

Chemical analyses of hornfels.

	No. 3		No. 4	
	Per cent	Mol. Prop.	Per cent	Mol. Prop.
SiO_2	64.70	1073	65.30	1083
TiO_2	0.60	8	—	—
Al_2O_3	16.03	157	18.88	185
Fe_2O_3	0.07	—	8.37	52
FeO	3.88	54	—	—
MnO	0.43	6	—	—
MgO	3.40	84	1.27	32
CaO	3.00	54	0.85	15
Na_2O	4.47	72	2.76	45
K_2O	1.88	20	0.45	5
H_2O	—	—	(+C) 1.34	—
Ignition loss	1.59	—	—	—
Total	100.05	—	99.22	
Sp. gr.	2.70		—	

(No. 3) Cordierite-biotite hornfels at a point 3 km. south from Osirabetu, Prov. Tokati. (A. KANNARI, analyst).

(No. 4) Hardened shale from Ponnikanbetu, Prov. Hidaka (Y. ODAIRA, analyst).

MODE OF OCCURRENCE OF THE CALCAREOUS CONCRETIONS

The calcareous concretions, which form the subject of the present investigation, are widely distributed in the hornfels at the southmost coast of the province of Tokati and partly at the south-eastern part of the province of Hidaka. The most remarkable outcrops of the hornfels carrying abundant concretions are seen at the sea cliff, 3 km. south from Osirabetu (Fig. 1).

The concretion occurs usually in spherical or ellipsoidal forms from 5 cm. to more than 8 cm. in diameter, but is occasionally seen in long pipe-form with a circular cross section, the length of which ranges from 10 cm. to half a meter and the section being 5–10 cm. in diameter. The boundaries of these concretions are in general fairly well marked and in sharp contact with the surrounding hornfels. Some concretions contain a dark brownish material in the interior which apparently served as a nucleous around which the concretion formed. The original nature of the coloured substance, now mostly represented by a limonite, is not clear.

The concretions lie usually in the middle portion of thin layers of the hornfels and are subparallel with the bedding plane, as is shown in Pl. XLVI (I), Figs. 1–2, though there can be seen some pipe-like bodies crossing obliquely the stratification of the country rock. Some of the concretions are traversed with minor faults showing that some dislocation took place in the district after the recrystallisation of the concretions themselves (Fig. 2).

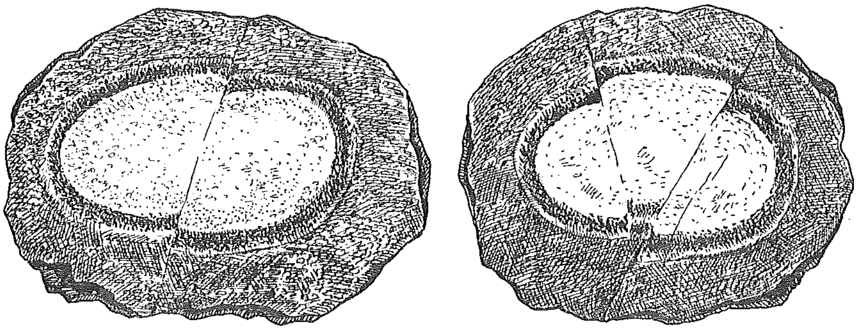

Fig. 2. Nodules traversed by minor faults. $^1/_2$ nat. size.

The central part of the spherical or ellipsoidal concretion is mostly rather white to greyish white in colour, but the marginal shell is greyish to dark green (Pl. XLVII (II), Figs. 1–2). The distinct difference in colour between the two is clearly due to the mineral assemblage of each portion in the concretion. It is worthy of notice that the concretion in the hornfels near igneous mass, carries the thicker marginal shell, 1–2 cm. or more, and consists of the more highly crystalline materials, while the one in the less metamorphosed hornfels at the far distance from the igneous body, has a thinner marginal shell, 1–5 mm. and still contains the unchanged relict substance as its constituent.

The mode of occurrence of the concretion bearing hornfels in the district is diagrammatically shown in Fig. 3.

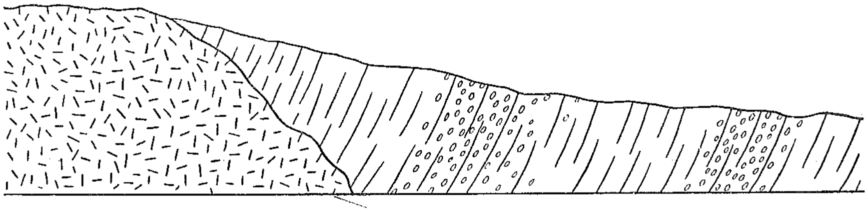

Fig. 3. Diagrammatic sketch showing the relationship between the granite and the concretion bearing hornfels. In zone I the concretion is highly recrystallized and has a very thick marginal shell, while in zone II it is less metamorphosed and has a thinner marginal shell.

MINERAL COMPONENTS OF THE CONCRETION

The concretion is usually fine and compact, and even in the coarser portions all the principal constituent minerals can not be determined by the unaided eye.

Under the microscope, the typical spherical concretion collected at a point 10 m. far from the granite mass is holocrystalline and even grained, being composed of plagioclase, diopside, quartz, and clinozoisite with a minute amount of magnetite. These minerals show none of their original fragmental character, thus indicating that the concretion has been completely recrystallized under the metamorphism.

Plagioclase is by far the most abundant mineral, making up probably more than 30 per cent of the rock. It occurs as rounded grain, 0.15 mm. in mean length. Albite twin is common but zonal structure is rarely seen in the crystal. As determined under the universal stage, it belongs to the labradorite-bytownite (An_{68-72}). Usually it is cloudy and partly altered to minute yellowish particles, probably epidote.

Quartz occurs in irregular grains, and, as a rule, is fresh and colourless, but invariably shows well marked undulatory extinction.

Diopside is subordinate in amount to plagioclase in the concretion. It forms a short prismatic crystal, 0.2–0.3 mm. in length, with distinct cleavage on (110). It is nearly colourless and the maximum extinction angle on (010) is $c \wedge Z = 40°$, indicating that the mineral has the composition $Di_{85}\ He_{15}$.

Clinozoisite occurs as irregular colourless grains which interlock in much the same way as those of diopside.

Very minute grains of magnetite are distributed throughout the concretion, though the quantity is usually not large.

The marginal shell of the concretion is also holocrystalline and granular in texture and is characterized by the presence of coloured minerals, actinolitic hornblende and biotite. It is remarkable that the extreme outermost layer of the marginal shell is, as a rule, more darker. The main constituents in the marginal shell, plagioclase, quartz, diopside and clinozoisite possess an almost identical natures with those in the central core of the concretion.

Actinolitic hornblende, the important in the shell next to the above mentioned minerals occurs in the form of short prisms, 0.2 mm. in mean length. The cleavage on (110) is distinct and the maximum extinction angle on (010) is $c \wedge Z = 16°$. The pleochroism and absorption of the mineral are as follows: X=light yellow, Y=light yellowish brown and Z=light greenish brown, $Z > Y > X$.

Biotite forms a very small flake with a yellowish brown to dark brownish colour. The optical properties of the mineral closely resemble those of the surrounding hornfels.

The calcareous concretions effected under a less metamorphic condition are collected in the hornfels, one and half km. to the north from the boundary of the granite mass. A pecularity of the type is the presence of a considerable amount of fragments of relict calcite. The marginal shell of the less metamorphosed concretion is usually very thin and sometimes almost absent.

The microscope reveals the following minerals in the central core and the marginal shell of the concretion, named in order of abundance in the thin section. Central core: plagioclase, quartz, sericite, calcite and magnetite. Marginal shell: plagioclase, quartz, biotite, actinolitic hornblende and magnetite. Most of these minerals show an almost identical physical character to those in the highly metamorphosed concretion which have been already described. Calcite, a special constituent in the type, occurs as irregular grains, 0.1–0.15 mm., but presents no new or unusual nature.

For the sake of brevity, the mineral assemblages in the representative hornfels and concretions in the district now in question may be shown in the following table:

TABLE III.

Mineral composition of the concretions and surrounding hornfels.

Rock \ Zone		In the highly metamorphosed part (Zone I in Fig. 3)	In the less metamorphosed part (Zone II in Fig. 3)
Concretion	Central core	(a) plagioclase, diopside, quartz, clinozoisite, magnetite.	(a′) plagioclase, quartz, sericite, calcite, magnetite.
	Marginal shell	(b) plagioclase. diopside, quartz, clinozoisite, hornblende, biotite, magnetite.	(b′) plagioclase, quartz, biotite, hornblende, magnetite.
Surrounding hornfels		(c) plagioclase, quartz, biotite, cordierite, magnetite.	

The difference in the mineral assemblage of each rock, as is seen in the above-cited table, seems to be due to the chemical composition of each original rock and also to the metamorphic grade during the thermal contact action of the igneous mass. In this case, it is remarkable that the calcareous concretion occurs as a variable form on account of the metamorphic effect, though the surrounding hornfels shows a comparatively simple form throughout the whole area. This fact indicates that calcareous material is effected more sensibly than argillaceous material under the same metamorphic condition, as has been frequently pointed out by Prof. P. ESKOLA in the examples from Finland.[1)]

It seems probable that the metamorphosed calcareous concretions in the Hidaka System shows a very close similarity from the lithological stand point of view to those in the Archean formation in Finland, the Cambrian formation of the Ducktown district, Tennessee, and the pre-Cambrian sediments of the Black Hills, South

(1) P. ESKOLA: Petrographische Charakteristik der kristallinen Gesteine von Finnland. Forts. Min. Krist. Bd. 11 (1927) and Conditions during the Earliest Geological Times, etc. Ann. Acad. Sci. Fennicae. Ser. A. Vol. XXXVI, No. 4 (1932.).

Dakota. The calcareous concretion from Finland, according to Prof. P. ESKOLA,[1] occurs in the Archean varved schists and shows various mineralogical assemblages due to the different metamorphic conditions: quartz, plagioclase, hornblende, and diopside in the highly metamorphosed part, and calcite, quartz and epidote in the less metamorphosed part, though there are many intermediate types.

Calcareous concretions in the Lower Cambrian formation of the Ducktown district were described and discussed by Dr. A. KEITH[2] and F. B. LANEY[3], and are said to be composed of quartz, plagioclase, ranging from albite to labradorite, orthoclase, hornblende, biotite, calcite, zoisite, muscovite, garnet, sulphide and titanite. In early descriptions by A. KEITH, this rock was called quartz diorite, but it was later shown by him to be a metamorphosed sediment. Recently the rock is referred by F. B. LANEY as "pseudo-diorite" of sedimentogeneous.

A photograph of a polished surface of a typical concretional nodule in graywacke taken from the LANEY's paper is shown for comparison in the same plate as the photographs of the concretions in the Hidaka System, to show how they resemble each other in appearance (Pl. XLVII (II), Fig. 3).

According to Messrs. J. J. RUNNER and R. G. HAMILTON[4], the calcareous concretions in the younger pre-Cambrian sediments of of the Black Hills, South Dakota, occur only in beds of siltones now metamorphosed to quartz feldspar biotite schists and show triaxial ellipsoidal masses of lime-plagioclase grossularite diopside quartz rock.

CHEMICAL COMPOSITION OF THE CONCRETION

Chemical analyses of the concretion in the highly metamorphosed hornfels at a short distance north of the granite mass were made by Mr. A. KANNARI, with the following results. No. 5 in the table is an analysis of the whitish central part of the concretion and No. 6

(1) P. ESKOLA: Condition during the Earliest Geological Times etc. op. cit. p. 19.

(2) A. KEITH: Production of Apparent Diorite by Metamorphism: Geol. Soc. Am., Bull., Vol. 24 (1913), p. 684.

(3) F. B. LANEY: Geology of the Southern Appalachian Region. Prof. Paper, 139, U. S. G. S. (1926), p. 19.

(4) J. J. RUNNER and R. G. HAMILTON: Metamorphosed Calcareous Concretions and Their Genetic and Structural Significance. Am. Jour. Sci. 4 Ser. Vol. XXVIII, No. 163 (1934), p. 51.

represents the dark greenish outer zone of the same concretion in which hornblende and biotite are sparingly present.

TABLE IV.

Chemical analyses of concretions.

	No. 5		No. 6	
	Per cent	Mol. Prop.	Per cent	Mol. Prop.
SiO_2	58.75	974	57.45	953
TiO_2	0.70	9	0.45	6
Al_2O_3	12.98	127	15.61	153
Fe_2O_3	none	—	0.25	2
FeO	4.31	60	6.17	86
MnO	0.85	12	0.28	4
MgO	2.84	70	2.75	68
CaO	9.17	164	10.99	196
Na_2O	4.16	67	2.86	46
K_2O	4.45	47	0.75	8
P_2O_5	none	—	tr.	—
CO_2	0.22	5	—	—
Ignition loss	1.34	—	2.86	—
Total	99.77		100.42	
Sp. gr.	2.79		2.79	

(No. 5) Central part of the concretion in the hornfels at 3 km. south of Osirabetu, Prov. Tokati (A. KANNARI, analyst).

(No. 6) Outer zone of the concretion in the hornfels at 3 km. south of Osirabetu, Prov. Tokati (A. KANNARI, analyst).

The chemical compositions show significant differences between the concretion and the surrounding hornfels, differences which were also revealed by the microscope. The results of the analyses in Tables II and IV show that the concretions are much richer in lime and comparatively poorer in silica than the hornfels in which the concretions occur. The outer zone of the concretion is in a general way comparable in chemical composition with its own central core, though the former shows a slightly higher amount of alumina, which may be considered to be due to diffusion from the surrounding hornfels during the metamorphic action.

If we take $Al_2O_3 + (MgO + FeO) + CaO = 100$, the following relationship can be shown between the concretion and the hornfels. In this case, it is considered that there is isomorphous replacement of Al_2O_3 by Fe_2O_3.

TABLE V.

Molecular percentages of Al_2O_3, $MgO+FeO$ and CaO in the rocks.

	Concretion		Surrounding hornfels
	Central core	Outer zone	
Al_2O_3	29	30	44
$MgO+FeO$	33	31.5	41
CaO	38	38.5	15
Total	100	100	100

If the calculated values of the concretions and the hornfels in question are plotted in the diagram showing contact metamorphic assemblage in the system $CaO–MgO–Al_2O_3–SiO_2$[1], the loci of the concretions lie in the quartz-anorthite-enstatite-diopside-field and the latter falls into the quartz-anorthite-cordierite-enstatite-field.

From the chemical composition and the mode of occurrence, the calcareous concretions in question might have been developed by the metamorphism of irregularly distributed calcareous concretions in the original sediments. It seems to be genetically analogous to the rounded calcareous nodules which are found in sandstone and shale of Tertiary or Mesozoic formation at many localities in north-eastern Japan, Hokkaidô and Saghalin. The Tertiary or Mesozoic nodules from these localities usually show no trace of metamorphism and are chiefly composed of a high amount of calcium carbonate and a comparatively small amount of silica and alumina. In general, they are characterized by the fact that they carry special calcite crystal, the so-called gen'nôisi or hammer-stone, or fossil remain in the interior part of the nodule as a nucleus.

(1) C. E. TILLEY: Contact-metamorphic Assemblages in the System $CaO–MgO–Al_2O_3–SiO_2$. Geol. Mag. Vol. LXII (1925), p. 363, and U. GRUBENMANN–P. NIGGLI: Gesteinsmetamorphose. I (1924), S. 289.

A detailed explanation of the properties of the nodule and the unclear calcite is omitted here. Their chemical compositions, however will be set forth below for comparison with the metamorphosed concretion in the Hidaka System. The analysis of the nodule in the Horonai shale (Tertiary) at Ikusyunbetu, Prov. Isikari, Hokkaidô, was made by Mr. A. KANNARI, and that of gen'nôisi from Sinano is quoted from the Hiki's paper[1].

TABLE VI.

Chemical analyses of calcareous nodule and gen'nôisi (hammer-stone).

	No. 7		No. 8	
	Per cent	Mol. Prop.	Per cent	Mol. Prop.
SiO_2	30.62	508	0.64	11
TiO_2	0.20	3	—	—
Al_2O_3	6.55	64	1.00	10
Fe_2O_3	1.71	11	3.44	22
FeO	2.39	33	—	—
MnO	0.14	2	—	—
MgO	1.98	49	0.48	12
CaO	29.27	522	52.33	932
Na_2O	0.37	6	—	—
K_2O	—	—	—	—
P_2O_5	—	—	—	—
H_2O	0.50	28	—	—
CO_2	26.00	591	37.00	841
Total	99.73		94.89	

(No. 7) Calcareous nodule in Horonai shale at Ikusyunbetu, Prov. Isikari, Hokkaidô (A. KANNARI, analyst).

(No. 8) Gen'nôisi from Urazato-mura near Ueda city, Prov. Sinano (analyst unknown).

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(1) T. HIKI: On the Gen'nôisi. Mem. Coll. Eng. Kyôto Imp. Univ., Vol. I, No. 2 (1915), p. 58.

Comparing the chemical composition of the nodule in the Horonai shale with the concretion in the Hidaka System, the former shows a very much higher amount of lime and carbon dioxide and a lower amount of silica and alumina, indicating that it bears abundant calcite grains as its important constituent.

The concretion in the Hidaka System might originally have contained a large quantity of calcite as the case of the young nodule, but presumably lost all its carbon dioxide during the metamorphic crystallisation. The lime silicates, such as basic plagioclase, clinozoisite, diopside, in the metamorphosed concretion are believed to be possibly derived from a combination of the lime in the original calcite with silica and alumina.

SUMMARY

In the hornfels of the so-called Hidaka System at the southernmost coast of Tokati Province, there are peculiar ellipsoidal, occassionally pipe-like concretionary bodies of sedimentary origin. The interesting point is that the concretions are recrystallized product under the contact actoin of the igneous rock which intruded in the sedimentaries of the Hidaka System. Such a metamorphosed concretion has not been described and discussed in Japan, in spite of the abundance of the reports on the calcareous concretions in the Tertiary or Mesozoic formations in northern Japan. In general the concretion presents a marked contrast in the chemical as well as mineralogical composition to the surrounding hornfels: that is the latter has an argillaceous nature and consists chiefly of quartz, plagioclase, biotite and cordierite, while, on the other hand, the concretion is mainly composed of quartz, plagioclase, clinozoisite, diopside. The concretion in the less metamorphosed part farthest from the igneous body, is characterized by the presence of relict calcite and the lack of diopside and clinozoisite.

The marginal zone of the concretion bears hornblende and biotite as essential constituents and shows somewhat hybrid nature of the calcareous concretion and argillaceous hornfels, this being due to the diffusional action between them.

The occurrence of abundant diopside in the concretion indicates that they are produced under the comparatively high temperature of metamorphism.

Briefly the concretion and the surrounding hornfels which are discribed above are considered to be a good example of a selective

metamorphism and provide a rather interesting problem from the view-point of the mineral facies principle.

In conclusion, it may be stated again that their lithological properties suggest the following three important points:

1. The calcareous concretions under a metamorphic condition sensibly changed their natures compared with the siliceous and argillaceous hornfels in which the concretions occur. For, even the isochemical concretions locally show the noticeable variation in their mineral assemblages, due to the different grades of metamorphism, yet the surrounding hornfels shows, on the whole, a simple mineral composition and general appearance, throughout the whole area in question.

2. The distinct difference of mineral assemblage between the concretion and the surrounding hornfels which were recrystallized under isophysical metamorphic conditions is due mainly to the primary chemical difference in their original rocks.

3. The diffusional zone between the concretion and the surrounding hornfels is more remarkable in the higher metamorphosed part.

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Plate XLVI (I)

Plate XLVI (1)

Figs. 1–2. Metamorphosed calcareous concretions in the hornfels at sea cliff, 3 km south of Osirabetu, Prov. Tokati, Hokkaidô.

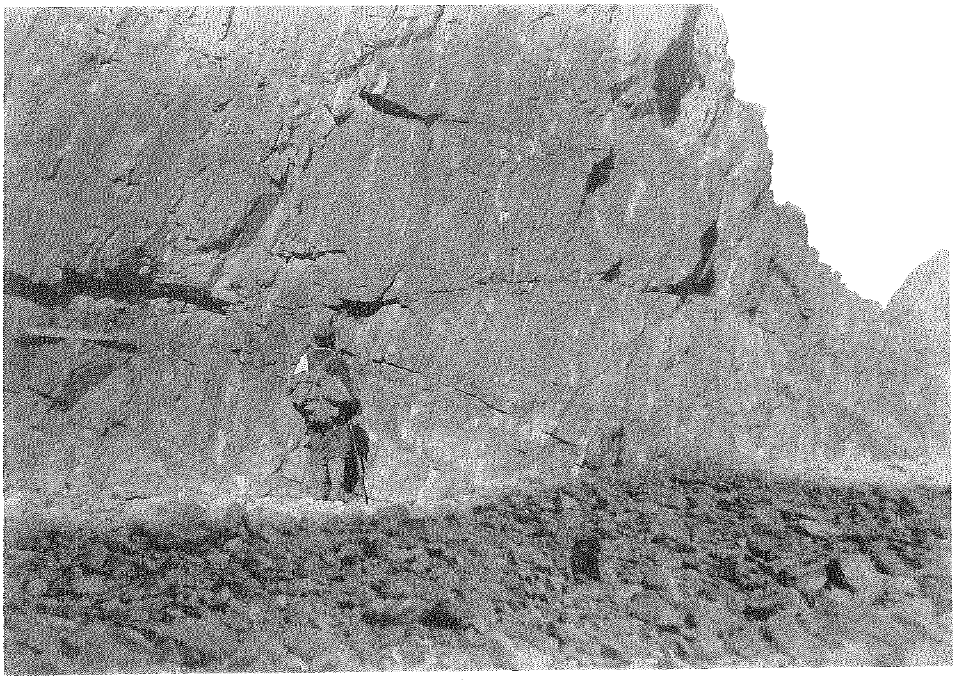

Fig. 1.

Fig. 2.

(*Harada Photo.*)

J. Suzuki: Metamorphosed Calcareous Concretions in the Hornfels.

Plate XLVII (II)

Plate XLVII (II)

Figs. 1–2. Polished surface of metamorphosed calcareous concretions in hornfels from the Osirabetu district, Hokkaidô. Slightly less than natural size.

Concretion: central core–plagioclase, diopside, quartz, clinozoisite, magnetite, and outer zone–plagioclase, diopside, quartz, clinozoisite, hornblende, biotite, magnetite. Surrounding hornfels: plagioclase, quartz, biotite, cordierite, magnetite.

Fig. 3. Nodule of pseudo-diorite in graywacke of the Ducktown district, Tennessee. Slightly less than natural size.

This photograph is quoted from Laney's report (Prof. Paper, 139, U. S. G. S. 1926, Plate XIV).

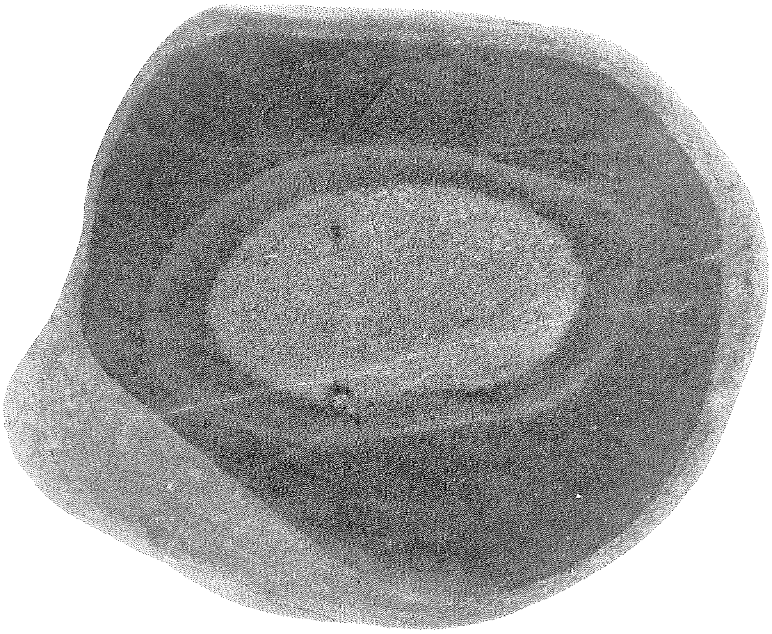

Fig. 1.

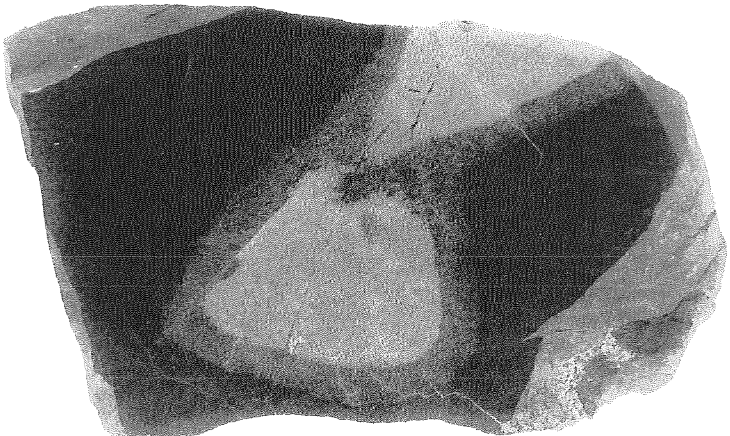

Fig. 2.

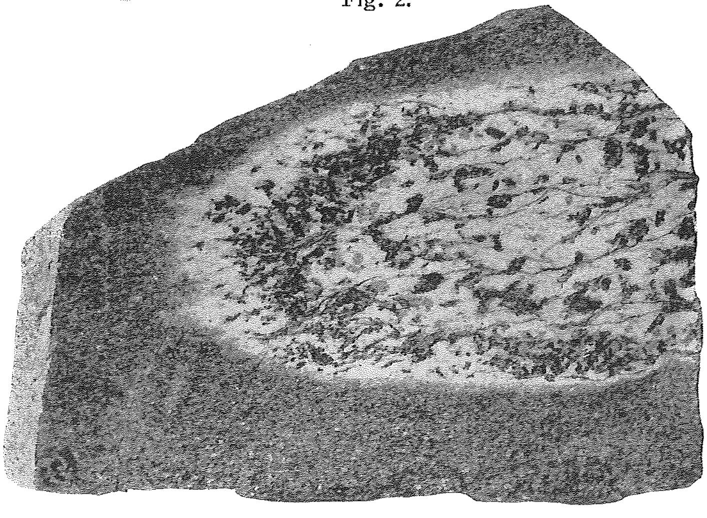

Fig. 3.

J. Suzuki: Metamorphosed Calcareous Concretions in the Hornfels.

Plate XLVIII (III)

Plate XLVIII (III)

Figs. 1-2. Hornfels.

Ordinary light. Magnified 45 diameters. Composition: plagioclase, quartz, biotite, cordierite and magnetite.

Fig. 3. Central core of the concretions in the highly metamorphosed zone.

Ordinary light. Magnified 45 diameters. Composition: plagioclase, diopside, quartz, clinozoisite and magnetite.

Fig. 4. Marginal shell of the concretion in the highly metamorphosed zone.

Ordinary light. Magnified 45 diameters. Composition: plagioclase, diopside, quartz, clinozoisite, hornblende, biotite and magnetite.

Fig. 5. Central core of the concretion in the less metamorphosed zone.

Ordinary light. Magnified 45 diameters. Composition: plagioclase, quartz, sericite, calcite and magnetite.

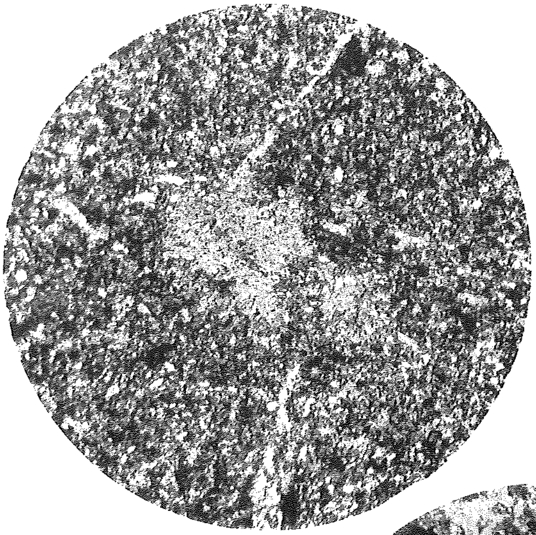

Fig. 1.

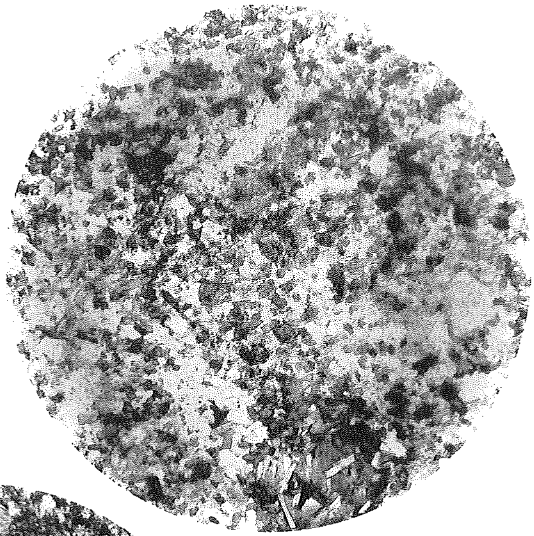

Fig. 2.

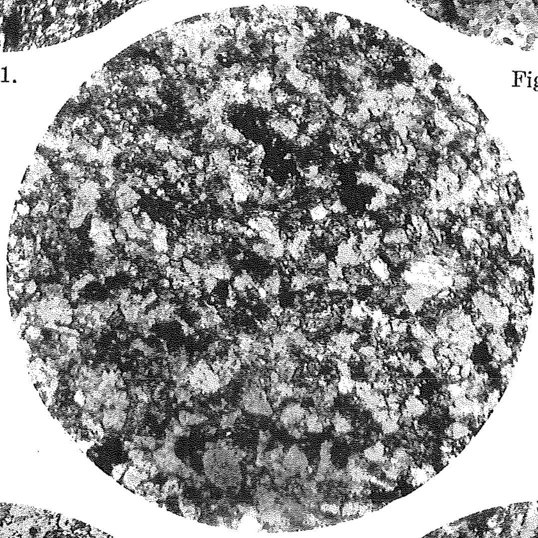

Fig. 3.

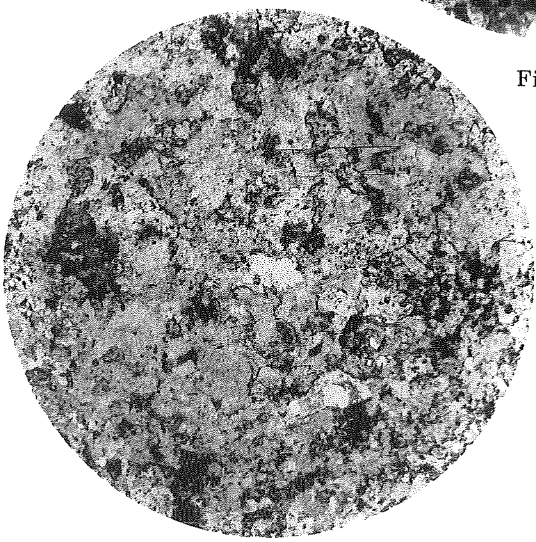

Fig. 4.

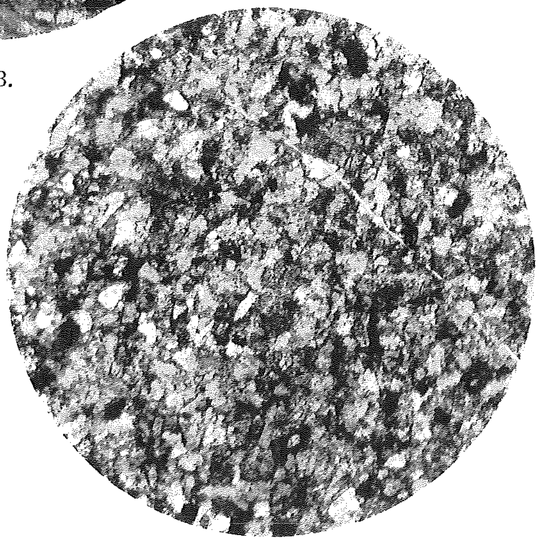

Fig. 5.

J. Suzuki: Metamorphosed Calcareous Concretions in the Hornfels.