SOME PETROLOGICAL CONSIDERATIONS ON THE MIOCENE VOLCANIC ACTIVITIES IN GREEN-TUFF REGIONS IN JAPAN

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Abstract

The so-called "green-tuff regions" characterized lithologically by green-coloured tuff are distributed widely in the inner zone of Japan; they were the scenes of violent volcanic activities in the Miocene. Especially at the lower and middle parts of the Miocene series, volcanic rocks of mafic to felsic characters occur predominantly among the normal sediments. Also ore deposits of hydrothermal origin are frequently found in those regions. Propylites are exposed characteristically even in no relation with ore deposits; most of the volcanics are more or less altered. Lava flows are associated closely with shale, and pillow lavas are often found among them. The above facts suggest that submarine eruptions predominated throughout this period of the Miocene.

The author considers that the propylites are of primary origin and derived from the hydrous magma or the magma rich in water. The green-tuff must have been formed as its explosive phase. Abundant hydrothermal solution which carried ores may have originated from the hydrous magma.

According to MINATO et al. (1956), the green tuff regions suddenly changed from upheaving erosional areas to subsiding zones of sedimentation in the beginning of the Miocene, with resultant formation of numerous faults in the earth crust, parallel to boundaries of the zones. The green tuff regions were the geosynclinal basins in the Miocene (HUZIOKA 1956). The hydrous magma in question may have been formed due to the contamination of water-contained sedimentary rocks under the above stated condition.

Introduction of the Miocene volcanic activities in the green-tuff regions

In Japan the Miocene formations characterized by green-coloured tuffs are distributed widely along the Japan Sea coast from south-western

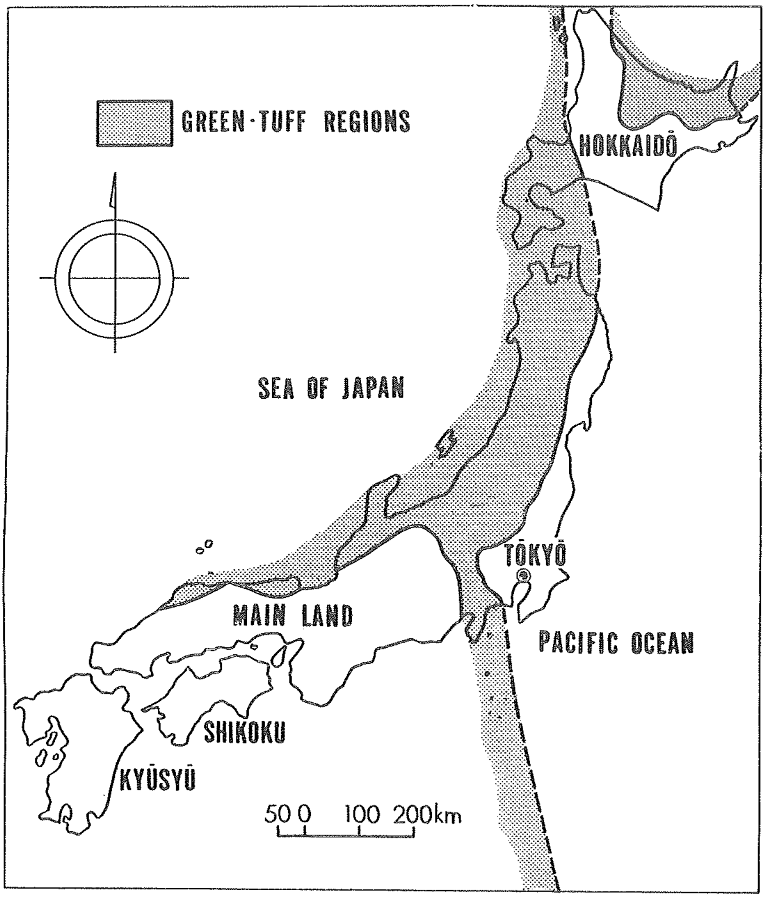

Fig. 1. Map showing the distribution of the green tuff regions in Japan (Huzioka 1956, Minato et al. 1956)

Hokkaido to the western part of the Mainland (Honsyû), in the Fossa magna region in central Japan and along the Okhotsk Sea coast of Hokkaido, as shown in Figure 1. These regions have been called green-tuff regions, and are composed geologically of the lower thick volcanic products and the upper oil bearing formations deposited during the period ranging from the Miocene to the older Pliocene. The green-tuff regions were geosynclinal basins in the Neogene, and they have been the scenes of violent volcanic activities since the dawn of the Neogene. In the Miocene, lava flows and volcanic ejectas of various petrographical characters were erupted repeatedly and piled thickly alternating with the normal sediments such as shale, sandstone and conglomerate deposited in the geosynclinal basins. Tertiary metallic or non-metallic ore deposits of hydrothermal origin such as those of gold, silver, cupper, lead, zinc, gypsum, barite etc. are mostly found in the green-tuff regions, so these regions are regarded to be one of the most important mineralized provinces in Japan.

About thirty years ago the so-called green-tuff attracted the interest of some geologists (TAKAHASHI 1932 etc.). Since 1953 many research workers have collaborated to study the green-tuff regions from the view points of stratigraphy, paleontology, petrology and economic geology.

TABLE 1. The Miocene volcanic rocks and ore deposits in the green tuff regions in Japan.

Age	Stages	Volcanic rocks (Huzioka, 1958)	Ore deposits (Ômachi, 1958, Huzioka*)
Miocene	Funakawa	Rhyolite Dacite *Andesite* Basalt	Vein-typed ore deposit
	Onnagawa	*Dolerite*, *Basalt*, Spilite Dacite Andesite Basalt Anorthoclase rhyolite, Dacite	*Black ore deposit*
	Nishikurosawa	*Rhyolite*, *Plagioliparite* *Dacite* *Andesite*, Basaltic andesite, *Propylite* *Basalt*, Spilite	*Black ore deposit* *Vein-typed ore deposit*
	Daijima	Rhyolite, Plagioliparite *Dacite* Andesite, Basalt Trachytic andesite	*Vein-typed ore deposit*
	Monzen	*Anorthoclase rhyolite*, Rhyolite Dacite Andesite, *Trachy- and trachytic-andesite* Basalt, *Trachytic-basalt*	Vein-typed ore deposit
	Aikawa	Altered rhyolite Altered dacite *Altered andesite*, *Propylite* Altered basalt	Vein-typed ore deposit

This table shows the main types of volcanic rocks erupted at each stage of the Miocene and the stages of mother rocks containing ore deposits. Volcanic rocks and ore deposits in *Italic* occur abundantly and characteristically.

* Private communication

HUZIOKA (1956, 1958), the leader of the research group, divided the Miocene series of the green-tuff regions stratigraphically and paleontologically into six stages, calling them Aikawa, Monzen, Daijima, Nishikurosawa, Onnagawa and Funakawa from the older to younger. Green coloured tuffs are found in each stage from Aikawa to Funakawa, but they occur predominantly in pre-Onnagawa stages. So the expression "green tuff" is used to indicate the horizons ranging from Aikawa to Nishikurosawa stages and means generally deposits mainly of volcanic origin overlying the basal granite.

The main types of volcanic rocks erupted at each stage are shown in Table 1 (HUZIOKA 1956, 1958). Volcanic rocks of the Aikawa stage are characterized by altered volcanic rocks of various petrographic characters and propylite intercalated into the terrestrial deposits containing plant fossils. In the next Monzen stage, volcanic and pyroclastic rocks of weak alkalic character alternate with the terrestrial deposits rich in plant fossils and coal seams.

In the Daijima stage the region began to subside from east to west, and nearly the whole area of the so-called green-tuff regions was covered with normal and pyroclastic sediments containing marine fossils in some places and plant fossils or coal seams elsewhere. There exists the relation of sharp unconformity between Monzen and Daijima beds except at a few points. Volcanic rocks at this stage are mostly of calc-alkaline character, especially of the pigeonitic rock series defined by KUNO (1950), though trachy-andesite is occasionally found in the basal part.

In the Nishikurosawa stage, the depressional zone was further deepened increasingly and the green-tuff regions were as a whole submerged. Consequently the sediments are rich in marine fossils, often important to the correlation of the geological age. Volcanic activity was generally of the submarine type, so lava flows and volcanic ejectas of various characters are associated closely with the marine sediments. Basalt and spilite often exhibit pillow structure characteristic to the submarine eruption related to geosynclinal movement. Volcanic rocks are of calc-alkaline series, especially those of the hypersthenic rocks series of KUNO (1950). Propylite and the more or less altered volcanic rocks are characteristically found throughout the formation of this stage. It is also to be noted that intrusions of plutonic rocks took place at the end of the Nishikurosawa or at the beginning of the Onnagawa stage.

Onnagawa and Funakawa stages are those of deep geosyncline; the Onnagawa siliceous shale covers the Nishikurosawa bed conformably at some points and unconformably at others. Volcanic activity was less intense than at the former stage. Dolerite sills or dikes intruding into shales are characteristically frequent in the sinking zone. Basalt and spilite flows exhibiting pillow structure are sometimes found. The Onnagawa formation transits gradually into the Funakawa formation composed chiefly of sandstone, tuff and mudstone. Andesite and rhyolite were rather abundantly formed in the Funakawa stage.

It is an important fact that ore deposits are very often found in the so-called green-tuff regions as already stated. But in any stage of the Miocene under consideration, they do not frequently occur. ÔMACHI (1959) and HUZIOKA (private communication) determined the stages where the black ore and the vein-typed ore deposits occur, as shown in Table 1. Ore deposits are often found in volcanic and sedimentary rocks of the Daijima to Onnagawa stage, especially the most abundantly in the Nishikurosawa stage rocks.

Concerning the age of mineralization, there is not yet a concrete theory. The predominant occurrence of the ore deposits at a certain stage seems to suggest that the stage in question is the main mineralization age.

Some petrological characteristics of the Miocene volcanic rocks in the green-tuff regions

The main volcanic rocks erupted during the Miocene in the green-tuff regions are mostly basalt, andesite, dacite and rhyolite of calc-alkalic character, though only volcanic activity in Monzen stage is characterized by eruption of slightly alkalic rocks such as trachytic-basalt, trachy- or trachytic-andesite and anorthoclase rhyolite. Pyroclastic rocks such as tuff, tuff breccia and agglomerate are correspondent to the abovenamed various sorts of volcanic rock in composition. There seem to be generally repetitions of the volcanic cycle beginning with the eruption of the mafic rock and changing gradually to that of the felsic, though the succession is not always identical.

It is of special interest that propylites and the more or less altered volcanic rocks occur predominantly in intimate association with green tuffs horizontally and vertically in the pre-Onnagawa stages. Especially the Nishikurosawa and Aikawa stages are remarkably characterized by frequent occurrences of propylite and green-tuff. This fact suggests that the then environments were favourable for the production of such rocks.

Propylite is megascopically grayish green to dark green or dark blueish in colour. Porphyritic texture is often shown, but phenocrystic minerals are pseudomorphs of felsic or mafic minerals replaced by so-called secondary minerals. Some propylite looks like brecciated lava, though that appearance is sometimes due to the sporadical distribution of patches different in colour.

Microscopically propylite is composed of the so-called secondary minerals such as chlorite, uralite, calcite, saussurite, epidote, zoisite, kaoline, quartz, iron ore and other clay-minerals. Especially chlorite and uralite are always contained abundantly and these minerals give green appearance to propylite. Sometimes pyrite is disseminated. The groundmass is never glassy, and basaltic texture is sometimes regarded. There are all transitional types between propylite and the fresh rocks.

SATO and KAGAWA (1959) analyzed about fifty specimens of propylites from southwestern Hokkaidô, which are regarded as such megascopically and microscopically. According to them, propylite contained SiO_2 content of about 46 to 69 percent and (+) H_2O content of about 1 to 5 percent. It is noticed that propylite is far richer in water content than the usual type of volcanic rock. If the chemical composition of propylite is recalculated as 100 percent in total, excluding the excess of water content over that contained in the common volcanic rocks ($H_2O<1\%$), that composition does not very differ from the calc-alkalic volcanic rocks which contain 48 to 72 percent of SiO_2. Only the Fe_2O_3 content of propylite is generally lower than that of the normal calc-alkalic rocks. Such chemical character suggests that propylite is not a variety of andesite, but volcanic rock rich in water. Consequently in respect to composition there are rhyolitic-propylite, dacitic-propylite, andesitic-propylite and basaltic propylite, as already stated by the author. (ISHIKAWA 1955).

ROSENBUSCH (JOHANNSEN 1937), BECKER (1882) and COATS (1940) considered propylite to be an alteration product of andesite and called the process of alteration propylitization. Wilshire (1957) regarded as propylitization any alteration of any rock by a process which produces some combinations of the above-named secondary minerals.

Some of propylites may be volcanic rocks altered by any action, for example by hydrothermal action related with ore deposit, but considerable amount of propylite occur in non-relation with any ore deposit. This phenomenon suggests that most propylites are not volcanic rocks altered secondarily, but primarily consolidated rocks. The name "propylite" was given by von RICHTHOFEN (1868) to certain green-stone like rocks found in the Washoe district in the Sierra Nevada. He believed the propylites to have been formed by consolidation of a propylitic magma and to be the oldest of the Tertiary extrusives. The present author agrees that propylite is of geological significance.

According to the experiment by YODER and TILLEY (1956), tholeiitic basalt from Kilauea had been converted to an amphibolite-like assemblage of amphibole, plagioclase, sphene and magnetite at 750°C at 5000 bars water pressure. While it was all crystalline (olivine, pyroxene, feldspar, magnetite) at 1090°C at 1 atmosphere. Water serves to lower the temperature of solidification of magma and leads to a crystallizing out of the minerals belonging to the later stage. Consequently it seems that in nature the magma abnormally rich in water forms such an assemblage of the so-called secondary minerals as already noted, the former crystallized minerals being successively replaced, if the conditions are favorable. Thus propylite may be formed primarily.

In the Nishikurosawa stage, the green-tuff regions began to subside to great depth and the submarine eruptions frequently occurred. As stated by RITTMANN (1958), the different environments of subaerial and of deep sea eruptions cause fundamental difference in the eruptive mechanism and in the nature of the products. Under the hydrostatic pressure at the deep sea bottom, the magmatic water can not escape from the out-flowing lava and it produces the process of hydration during the cooling..

The hydrous magma or the magma abnormally rich in water may be apt to consolidate as propylite in the deep sea bottom. In the course of propylite formation, variously altered volcanic rocks may be formed, depending upon either the amount of water content or physical conditions.

There are also many sills and dikes of propylite as well as those of various volcanic rocks in the pre-Onnagawa stage formations. Intrusive volcanism manifested in the form of sill and dike may further facilitate the formation of propylite from the hydrous magma. In some cases it is difficult to distinguish lava flow from intrusive sill. KLÜPFEL (1941) stated that intrusive volcanism predominated in pre-Quaternary epoch.

Some workers in this field consider that auto-metamorphism is an important action for propylite formation. Sometimes auto-metamorphism may cause propylitization. Originally the hydrous magma is considered itself to provide for favorable conditions for auto-metamorphism.

The pillow lava characteristic to a geosynclinal basin is not vesicular; it exhibits coarse holocrystalline texture, though glassy at the marginal part as a result of rapid cooling. So-called secondary minerals such as chlorite, serpentine, calcite, sericite, zeolite and epidote are often contained in such pillow lava (SUZUKI, 1954). Above-stated characters and even the so-called spilitization may be related to the magma rich in water.

Green tuffs range from basaltic to rhyolitic in composition, although the chemical data are not yet satisfactory (TAKAHASHI 1932). They are generally rich in the secondary minerals such as chlorite, uralite, calcite, saussurite etc. The author (ISHIKAWA 1955) considers that green tuff represents the explosive phase of propylite. There may be rhyolitic, dacitic, andesitic and basaltic green-tuffs.

Ore deposits of epithermal origin may be carried up by hydrothermal solution and deposited at comparatively shallow depth below the earth surface under the hydrostatic pressure. The fact that ore deposits are the most frequently found in the Nishikurosawa stage rocks, indicates that the hydrothermal activity was the greatest intense at that stage, though it took place throughout the Miocene. The Nishikurosawa stage is characterized by the predominant occurrences of propylite and green-tuff which are considered to have been originated from the hydrous magma. Also hydrothermal solution may have been derived readily from the hydrous magma after the solidification of its most part.

How is the hydrous magma formed? Magma may be rich in water due to the assimilation of the water-containing sediments deposited in deep subsided zone of a geosynclinal basin. According to HUZIOKA (1958), some volcanic rocks of the Nishikurosawa stage, whose groundmass minerals are rather fresh and able to be discerned, belong to the hypersthenic rock series considered by KUNO (1950) to be of contaminated origin.

According to MINATO, YAGI and HUNAHASHI (1956), green-tuff regions suddenly changed from upheaving erosional areas to subsiding zones of sedimentation in the Miocene, resulting in the formation of numerous faults in the earth crust, parallel to the marginal boundaries of the zones. Under such a complicated condition magma may be ready to assimilate the basal sediments containing water and change into the hydrous magma. Therefore also initial volcanic activity manifested at the Aikawa stage is characterized by propylite and altered volcanic rocks. But a few occurrence of ore deposit in the Aikawa stage may be due to the limited distribution of that stage formation.

The author considers that the eruption of propylite and green tuff took place at the sea bottom of the geosynclinal area and it was specially remarkable at the Aikawa and Nishikurosawa stages when sudden sinking or subidnece began.

The geological environments control the volcanic activities, to whose characteristics the formation of ore deposit is essentially related.

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References cited

BECKER, G. F. (1882): Geology of the Comstock Lode and the Washoe district. U.S. Geological Survey, Monograph, 3, 90.

COATS, R. (1940): Propylitization and related types of alteration on the Comstock Lode, Nevada. Economic Geology **35**, 1–16.

HUZIOKA, K. (1956): Researches on the green-tuff. Science (Kagaku) **26**, 440–446 (in Japanese).

HUZIOKA, K. (1958): The Neogene volcano-stratigraphy of the green tuff region in inner Japan. Jubilee Publication in Commemoration of Professor Jun Suzuki, M.J.A. Sixtieth Birthday, 511–518. (in Japanese)

ISHIKAWA, T. (1955): Some characteristics of volcanic activities in the Miocene green-tuff age. Bulletin of the Geological Committee of Hokkaidô. No. 30, 29–31. (in Japanese)

JOHANNSEN, A. (1937): A descriptive petrography of the igneous rocks. Vol. II, 177.

KLÜPFEL, W. (1941): On the old type volcanoes and the new type volcanoes and their origin. Research and Progress **17**, 191–193.

KUNO, H. (1950): Petrology of Hakone volcano and the adjacent areas, Japan. Bulletin of the Geological Society of America **60**, 957–1020.

MINATO, M., YAGI, K. and HUNAHASHI M. (1956): Geotectonic synthesis of the green-tuff regions in Japan. Bulletin of the Earthquake Research Institute **34**, 237–265.

ÔMACHI, H. (1959): Compiled table of the stratigraphical position of the Tertiary ore deposits. Symposium on ore deposit at the 66th annual meeting of the Geological Society of Japan. (in Japanese)

RICHTHOFEN, F. von. (1868): The natural system of volcanic rocks. Memoir of California Academy of Science, I Pt., 2, 20–24.

RITTMANN, A. (1958): Some aspects of geosynclinal and deep sea volcanism. Bulletin volcanologique, Ser. II, **19**, 36–37.

SATO, F. and KAGAWA, Y. (1959): Chemical compositions of propylites. Journal of the Geological Society of Japan. **65**, 453. (in Japanese)

SUZUKI, J. (1954): On the pillow lavas from Hokkaidô. Bulletin of the Geological Committee of Hokkaidô. No. 26, 11–20. (in Japanese)

TAKAHASHI, J. (1932): Green tuff developed in the inner zone of northern Japan. Bulletin of the Volcanological Society of Japan. Ser. I, vol. 1, No. 2, 9–21. (in Japanese)

WILSHIRE, H. G. (1957): Propylitization of Tertiary volcanic rocks near Ebbetts Pass, Alpine County, California. University of California Publications in Geological Sciences. 37, 243–272.

YODER, H. S. and TILLEY, C. E. (1956): Natural tholeiite basalt-water system. Program of 1956 annual meeting of the Geological Society of America, 101–102.