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Tertiary Volcanic Activity, Geotectonic History and their Characteristics in the Northern District of Aomori Prefecture*

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Abstract: The Neogene rocks occurring in the Tsugaru Peninsula and those in the Shimokita Peninsula show considerable contrasts in many respects to each other. The submarine Shimokita-kaigan Fault, which is located under the Tairadate Straits separating two peninsulas, is tectonically of prime importance for the contrasts.

The Neogene in the Tsugaru Peninsula consists of the Gongenzaki, Isomatsu, Fuyube, Nagane, Lower Kodomari, Upper Kodomari, Shiwokoshi and Kanita Formations from the base upwards, while that in the Shimokita Peninsula lacks in the formations equivalent to and lower than the Fuyube and is composed of the Kimpachizawa, Hinokigawa, Lower Kozawa, Upper Kozawa, Yagen and Ohata Formations generally in ascending order. Most of the formations in both peninsulas, like the Neogene rocks in other districts of the so-called Green Tuff Region of Northeast Honshu, contain volcanic substances more or less, and some formations are essentially composed of volcanic products. Moreover, thick piles of lavas and coarse-grained pyroclastic rocks locally intervene among the Neogene formations; they are distinguished as the Basalts, the Mimmaya Rhyolite, the Horozuki Volcanic Rocks and the Imabetsu Andesite in the Tsugaru Peninsula, and Yunomatagawa Dacite and the Ikokuma Andesite in the Shimokita Peninsula.

Structurally, gentle domes with longer axis of northwest trend are well-developed, and the broad dome around the pre-Tertiary basement rocks in the Shimokita Peninsula and the local dome near the northeast coast in the Tsugaru Peninsula are their good examples. The doming areas bear the intrinsic nature of uprising block movements, which has caused to decrease the thicknesses of Neogene sediments as coming nearer to the domes and to let the lands emerge at earlier age in the dome areas than in other areas. The uprising movements are connected with and particularly remarkable just before the eruptions of volcanic rocks such as the Horozuki Volcanic Rock in the Tsugaru Peninsula, and the rhyolitic and dacitic rocks of the Hinokigawa and Yagen Formations and the Ikokuma Andesite in the Shimokita Peninsula.

Anticlines, synclines and faults trending nearly from north to south are conspicuously specific in the Tsugaru Peninsula and under the Tairadate Straits, being combined with the dome structures, whereas they are ill-developed in the Shimokita Peninsula, where the structure is generally under the sway of above-noted broad dome. The Shimokita-kaigan Fault is one of the most outstanding of this kind of structures. Passing through the fault from Tsugaru side to Shimokita side, the Neogene formations excepting the volcanic parts rapidly decrease in thickness and the gravity anomalies which are reverse to the underground depths of the basement suddenly increase in value.

Historically speaking, the eruption of andesite and the simultaneous subsidence commenced in the Tsugaru Peninsula at the beginning of Miocene Epoch after the long period of terrestrial and denuding environments, and caused to accumulate the Gongenzaki, Isomatsu and Fuyube Formations generally of volcanic rocks, which are mostly marine, but partly non-marine. However, the Shimokita Peninsula was still under the land condition. The substantial transgression began with the deposition of the Nagane Formation generally of fine-grained tuffaceous and muddy sediments characterized by many intercalations of submarine basalt lavas in the Tsugaru Peninsula. It gradually expanded to create a large sedimentary basin,

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and the sea invaded also onto the Shimokita Peninsula, where the Kimpachizawa Formation corresponding to the Nagane was deposited, although small in thickness.

From this time onwards, the two sides bounded by the Shimokita-kaigan Fault subsided differentially from each other. On the Tsugaru side, the conspicuous subsidence continued to have resulted in the widespread and thick beds of hard shale and black-coloured massive mudstone ranging from the Lower to Upper Kodomari Formations. On the Shimokita side, the subsidence diminished in rate because of setting out and the gradual progress of uplifting movements to form the broad dome structure, and instead of sedimentation, the eruption of acid rocks took place from many centers and accumulated the Hinokigawa and Yagen Formations. Consequently, the pelitic Lower and Upper Kozawa Formations on this side, which were equivalent to the Lower and Upper Kodomari on the Tsugaru side, were limited out of the doming terrain and as thin beds. But, the uplifting was rather confined in extent, so that the thickness of pelitic sediments was rapidly increasing as going away from the dome structure.

The area of the Hinokigawa Formation widely covering the broad dome structure in the Shimokita Peninsula is made up of a number of depressions or subsided basins which are several kilometers in diameter and overlap one after another. Some of the basin structures are testified also by gravity surveys and test-borings. A similar structure is also observed in the area of the Yagen Formation. Each of these structures was originated from an eruptive center of acid rocks, which carried out an uniform cycle of volcano-tectonic process having consisted of the commencement of depressional movements with minor eruptions, then the substantial depression and violent eruptions of lavas and pyroclastic flows, and finally the ceasing of depression soon after the repetition of minor pumice flows.

After the deposition of Upper Kodomari and corresponding Upper Kozawa Formations, the Tsugaru side was subjected to the uplifting movements which formed a dome structure in the north and an anticlinal belt in the axial part of the peninsula, and the Shimokita side was continuously under the influence of doming movements, which expanded more to the north and the south. The wide sedimentary basin which had been present on the Tsugaru side was differentiated into the west zone facing the Japan Sea and the east zone including the Tairadate Straits because of the uplift in between, and the marine Shiwokoshi and Kanita Formations composed of siltstone and sandstone were thickly deposited in both zones owing to the continuous subsidence. The successive enlargement of uplifting belt on the Tsugaru side has gradually contracted from the west the width of sedimentary basin of east zone, and now confines the basin only under the Tairadate Straits.

The Tsugaru Peninsula and the Shimokita Peninsula have been currently regarded as the extensions of so-called Dewa Hillylands and Backbone Range of the geotectonic divisions proposed in the Green Tuff Region of Akita and Iwate Prefectures, respectively. But, this view is not sound because of the discrepancy of the geotectonic characters revealed from the Neogene constitutions. The thick accumulations ranging wholly from the lowermost to the uppermost of the Neogene in the Tsugaru Peninsula are rather correlative to those in the Oga Peninsula and the Akita Plain which are tectonically considered to compose the so-called Japan Sea Coastal Zone of the geotectonic divisions of Green Tuff Region. With regard to the Shimokita Peninsula, the fine-grained sediments ranging from the Kimpachizawa up to the Upper Kozawa are surely thin in the areas of broad dome structure, but are known as quite thick in the northern as well as southern extensions of the peninsula. The actual existence of the Neogene rocks suggests that the Shimokita Peninsula lies within the extension of Dewa Mountains and that the head part of peninsula is very like the uprised portions of the Mountains.

1. Introduction and Acknowledgement

The northern district of Aomori Prefecture dealt with in this paper comprises the northern part of the Tsugaru Peninsula and the head part of the Shimokita Peninsula (abbreviated as the Tsugaru and Shimokita Peninsulas on the later pages, respectively) which are separated by the Tairadate

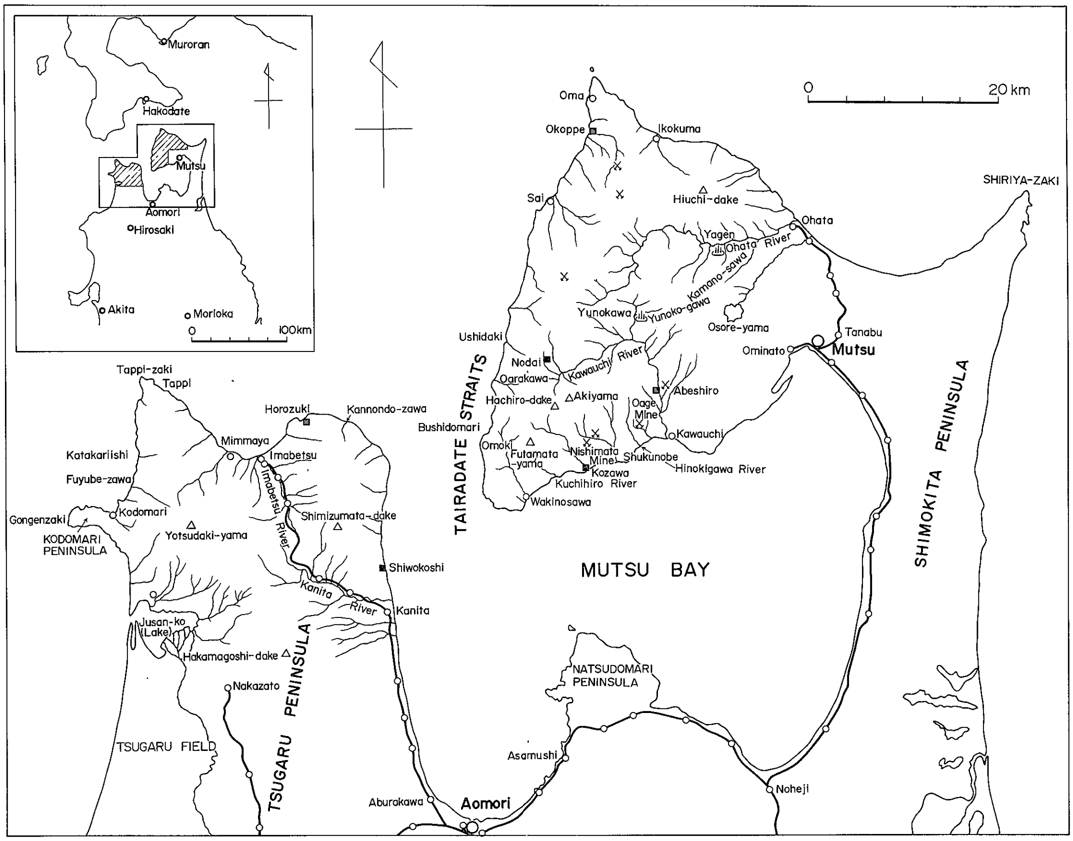


Fig. 1 Index map.

Straits (Fig. 1). It is a part of the so-called Green Tuff Region of Northeast Honshu, where the Neogene consists largely of volcanic products which are considerably subjected to deuteric and hydrothermal alterations.

Many geologic studies have been performed in this district so far. They were, however, limited to the stratigraphic researches of either the Tsugaru Peninsula or the Shimokita Peninsula, and never considered both of the peninsulas together. The author has been interested in the regional setting of the Neogene geology over the whole district, and has pursued the surveys in the following eight areas one after another; namely, Ohata of the Shimokita Peninsula at first, then Kodomari, Horozuki and Kanita of the Tsugaru Peninsula, and Sai, Oma and Mutsu-Kawauchi of the Shimokita Peninsula.

Having summarized not only the stratigraphy, the characters of volcanic products and the geologic structures but also the gravity survey and the drillings, the author arrived at an idea about the Neogene geotectonic evolution of this district that differs from the currently accepted view. Namely, he recognized the considerable contrasts between the characters of the Neogene rocks occurring on the Tsugaru side including the sea-floor of the Tairadate Straits and those on the Shimokita side. He elucidated the crustal movements and volcanic activities on the two sides which had brought about the contrasts, and reached to a new opinion on the relation between the present district and the typical Green Tuff district in Akita and Iwate Prefectures.

The discussions on the tectonic movements in the Green Tuff Region were chiefly based upon the researches in the Akita-Iwate districts so far. It would be desirable, however, that the characters of the Neogene in the Aomori district as well as the southwestern Hokkaido should be consolidated into the discussions. The author hopes that this paper will serve as an aid for this field of research.

Taking the opportunity of drafting this paper the author expresses heartfelt appreciation to Professor Keiji NAKAZAWA, Professor Tadao KAMEI and Professor Ichikazu HAYASE of the Faculty of Science, Kyōto University, for the kind guidance provided to him. The author also would like to express his sincere gratitude to Dr. Masatsugu SAITO, the former director of the Geological Survey of Japan and Professor Iichiro TAKAHASHI of the Iwate University, for the guidance in many ways including the field surveys and laboratory works. Useful discussions and advice were rendered daily by Dr. Shigeru SATŌ, Dr. Konroku TSUSHIMA, Dr. Sachio IGI, Dr. Yasuji KITA, Dr. Kiyoshi SUMI of the Geological Survey constant encouragements were extended by all members of the Geology Department of the Survey, and to all these people the author's deep appreciation is tendered herewith.

2. History of the Research

The reconnaissance in the northern part of Aomori Prefecture was performed firstly by SATŌ (1919) of the Geological Survey of Japan, and disclosed the outline of the geology as presented in the "Mimmaya" and "Shiriyazaki" geological maps on the scale of 1: 200,000, including the descriptions of mineral deposits such as Nishimata and Abeshiro in the Shimokita Peninsula where the mining proceeded at that time.

In the beginning of Showa Era, as the demand for the underground resources increased, the Geological Survey conducted the detailed survey on the petroleum fields of Tsugaru province and issued the Daishaka oil field map surveyed by IIZUKA (1929) and the Kanita oil field map by SUZUKI (1936/1937). IIZUKA (1930) made the stratigraphic classification of the Neogene with the correlation to that of the Akita oil field. TAKAHASHI and YAGI (1936a, b) of the Tohoku University researched the Neogene in the entire Tsugaru province and expressed a new comment on the geologic structure, especially on the Tsugaru Fault. NOMURA and HATAI (1936) and YABE and HATAI (1941) of the same University studied many Neogene fossils and considered the geochronologic problem. During the above-mentioned period, no papers were announced in regard to the Shimokita Peninsula except the research on the Yagen Formation and the fossils obtained by OTUKA (1939) of the University of Tokyo.

Right after the last war, the Aomori Prefectural Office requested to the Hokkaido University to undertake the geologic survey over the entire prefecture, and issued the geologic map on the scale of 1: 200,000 with the text entitled "The underground resources of Aomori Prefecture" (1954). The author's geologic works started in 1954 and some of the results were published as the geological maps "Ohata" (UEMURA and SAITO, 1957) and "Oma, Sai" (UEMURA, 1962) on the scale of 1: 50,000 and their explanatory texts. In the same period of the author's survey, Institute for Natural Resources engaged in the study of the overall Shimokita Peninsula, and presented "The geology of Osoreyama Volcano" by GŌHARA, KUWANO and OIDE (1957), and "Tertiary of the west part of the Shimokita Peninsula" by SUZUKI and KUWANO (1962).

The basic survey for the construction of the Seikan submarine tunnel to connect Hosnhū and

Hokkaido commenced in 1955 by the Japan National Railways. The Geological Survey of Japan participated in the survey of the Tsugaru Peninsula and the adjoining sea bottom at the request of the National Railways, and a part of the results was summarized in the geological map "Mimmaya" on the scale of 1: 50,000 and its explanatory text by OTA, OZAWA and ONO (1957). Successively the Geological Survey extended the works into the areas of "Horozuki" surveyed by SAITO and the author (1957), "Kanita" by the author, TSUSHIMA and SAITO (1959) and "Kodomari" by TSUSHIMA and the author (1959).

During the approximately same period of the above, Petroleum Development Corporation was active on the researches in the Tsugaru province, and the results were reported by IWASA (1962) entitled "Study on the oil bearing Tertiary in the Tsugaru province of Aomori Prefecture and its structural development". He summarized geology, gravity, seismic prospectings, test borings, etc. and presented many new facts and problems; for instance, he summarized the structural history of the Tsugaru province from a viewpoint of tectonic development of the Uetsu Geosyncline.

Based upon such rapidly increased informations, KITAMURA, IWAI and NAKAGAWA revised "Geological map of Aomori Prefecture" on the scale of 1: 200,000 and its explanatory document (1963).

The author extended his geologic survey to the Mutsu-Kawauchi and Wakinosawa areas of Shimokita Peninsula, and also participated in the regional prospecting project in the peninsula planned by the Metallic Mineral Exploration Agency. The project included not only geologic surveys but also gravity measurements, marine sonic prospectings and test borings, and the results were partly announced as "Report of regional survey in the Shimokita district" by TAKAHASHI and 13 others (1969–1971) from the Ministry of International Trade and Industry.

3. Outline of the Neogene

The stratigraphic classification of the Neogene rocks in the district with special reference to the widely accepted Neogene sequence established in the Oga district of Akita Prefecture is given in Table 1. The rock facies in the Shimokita and Tsugaru Peninsulas are considerably different from each other. The volcanic products prevail all over the Neogene column in the Shimokita Peninsula, while as far as the middle and upper parts of the Neogene are concerned, they occur in lesser amounts or in local areas in the Tsugaru Peninsula. Consequently, the stratigraphic division is determined separately in each peninsula.

Most of the lavas and the pyroclastic rocks are treated together with the sedimentary rocks as the constituents of the Neogene formations. They are differentially developed in the Neogene columns either in the Tsugaru or Shimokita Peninsula, and are thickly accumulated particularly in the areas where the sedimentary beds are poorly developed. But, some of the volcanics are local or cover one or more formations, and they are named after their petrographic characters. Such volcanic bodies are also more particular in the Shimokita Peninsula than in the Tsugaru Peninsula.

The geologic map of the district, which is chiefly based on the present author's field works, is shown in Fig. 2. The younger formations than the Fuyube cover the major parts of both peninsulas. The Fuyube and lower formations occur only as inliers of dome structures or other small exposures

Table 1 Stratigraphic relation of the Neogene formations and rocks in the area.

Oga Peninsula Akita Prefecture	Tsugaru Peninsula	Shimokita Peninsula SW Part	Shimokita Peninsula NE Part
Shibikawa Formation	Kanita Formation		Ohata Formation
Wakimoto Formation			
Kitaura Formation	Shiwokoshi Formation / Imabetsu Andesite	Ikokuma Andesite	Ikokuma Andesite
Funakawa Formation	Upper Kodomari Formation	Upper Kozawa Formation	Yunomatagawa Dacite
Onnagawa Formation	Lower Kodomari Formation	Lower Kozawa Formation	Yagen Formation
	Horozuki Volcanic Rocks	Hinokigawa Formation	Hinokigawa Formation
Nishikurosawa Formation	Nagane Formation / Mimmaya Rhyolite / Basalt	Kimpachizawa Formation	
Daijima Formation	Fuyube Formation		
	Isomatsu Formation		
Monzen Formation	Gongenzaki Formation		
	Basement Rocks	Basement Rocks	

in the Tsugaru Peninsula, while the corresponding formations are absent in the Shimokita Peninsula.

3.1 Stratigraphy

3.1.1 Tsugaru Peninsula

1) Pre-Tertiary Basement Rocks

The basement rocks are exposed at Gongenzaki Cape of a small peninsula of Kodomari projecting west from the Tsugaru Peninsula, and at Katakariishi-zawa in the northeast side of the Tsugaru Peninsula. In the former, they consist of phyllitic slate, chert and limestone, and in the latter they are phyllitic slate.

2) Gongenzaki Formation

The formation crops out not only at Gongenzaki but also in the Isomatsu-zawa and Yotsudaki-zawa valleys. Stratigraphically, it starts with the basal conglomerate containing the pebbles of slate and chert, and is composed mainly of purplish grey-green tuff breccia, of which lower part is welded tuff containing purple, lenticular rock fragments. Altered andesites are interbedded at various horizons in the tuff breccia.

Fagus sp. and *Quercus* sp. are discovered at Gongenzaki by SAIKAWA (1954; MS). They belong to the Aniai Fossil Flora, which is known as early Miocene in age and indicative of relatively cold climate.

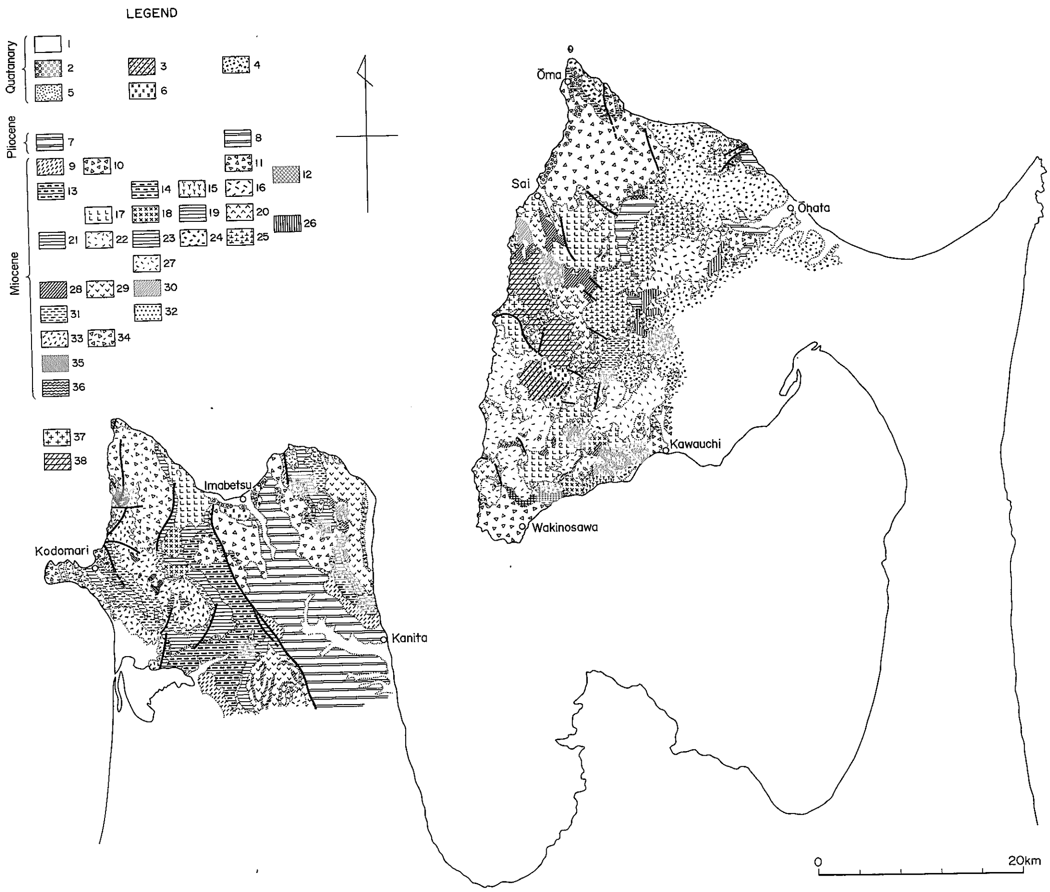


Fig. 2 Geological map of the northern part, Aomori Prefecture.

Quaternary: 1. Alluvium; 2. Terrace Deposits; 3. Nodai Formation; 4. Volcanic Rocks (Osoreyama Volcano, Hiuchidake Volcano, Gobōdake Volcano); 5. Hamana Formation; 6. Hantarō-zawa Formation.
Pliocene: 7. Kanita Formation; 8. Ohata Formation.
Miocene: 9. Shiwokoshi Formation; 10. Imabetsu Andesite; 11. Ikokuma Andesite; 12. Granodiorite porphyrite; 13. Upper Kodomari Formation; 14. Upper Kozawa Formation; 15. Kuzusawa Tuff Member; 16. Yunomatagawa Andesite; 17. Rhyolite; 18. Dacite; 19. Kuchihiro Andesite; 20. Andesite; 21. Lower Kodomari Formation; 22. Mimmaya Rhyolite, Horozuki Volcanic Rocks; 23. Lower Kozawa Formation; 24. Ginnanboku Tuff Member; 25. Yagen Formation-Yunokawa Member; 26. Yagen Formation-Yunokawa Member, Kamanosawa Member; 27. Hinokigawa Formation; 28. Nagane Formation-Mudstone facies; 29. Basalts; 30. Kimpachizawa Formation; 31. Nagane Formation-Tuffaceous sandstone facies; 32. Kimpachizawa Formation-Basal conglomerate; 33. Fuyube Formation; 34. Tappi Andesites; 35. Isomatsu Formation; 36. Gongenzaki Formation.
pre-Tertiary: 37. Quartz diorite; 38. Phyllite, limestone, etc.

3) Isomatsu Formation

The distribution is limited to the southwest of the dome structure of Yotsudaki-yama. But in the peninsula of Kodomari, the Gongenzaki Formation is overlain directly by the Fuyube Formation. The lower part of the formation is mainly composed of conglomerate carrying the pebbles of slate and chert, and the upper part consists of tuffaceous sandstone and siltstone, interbedded by greyish green coloured tuff. There is no structural difference between the Isomatsu and the Gongenzaki Formations, but the presence of pebbles of basement rocks particularly abundant in the conglomerate of the Isomatsu suggests that two formations are unconformable in a part at least.

Forty four species of molluscan fossils including *Vicariya tyosenica* and *Patinopecten kobiyanai* were reported by Mizuno (1964). According to him they belong to the Kadonosawa fossil fauna, which indicates mild current and brackish environment.

The Isomatsu Formation was once referred to Oligocene in age by Nomura and Hatai (1936) and Kotaka (1955). But this opinion is not correct, because it now becomes apparent that the formation is younger than the Gongenzaki Formation and bears many molluscan fossils common to the overlying Fuyube Formation.

4) Fuyube Formation

The formation is extensively developed from the central part of the dome structure of Yotsudaki-yama to the north up to Tappi-zaki, and crops out also in the peninsula of Kodomari, on the dome structure near Horozuki, and in Hakamagoshi-dake. It is composed of green andesitic pyroclastics, intercalated with basaltic and dacitic pyroclastics, tuffaceous sandstone, mudstone, and lavas of rhyolite, andesite and basalt.

The size of andesitic pyroclastics occurring in the north is large, while that in the south is small, and such a tendency continues to the overlying Nagane Formation. Ota, Ozawa and Ono (1959) distinguished the coarse-grained pyroclastic rocks occurring in the Mimmaya area, that is the northernmost of the peninsula, as the Tappi Andesites. It is conceivable that the volcanic centers may be in that area.

The Fuyube Formation conformably overlies the Isomatsu Formation around Yotsudaki-yama. And, it directly covers the Gongenzaki Formation in the peninsula of Kodomari, indicating an unconformity. *Zelkova ungeri*, *Castanea kanekoi*, and five other species of plant fossils identified by Tanai were reported by Tsushima and Uemura (1959), and twenty three species of molluscan fossils including *Ampullina* sp., *Crepidula jimboana* and *Chlamys nisataiensis* were reported by Mizuno (1964). The plant fossils belong to the Daijima Fossil Flora of mild climate and the molluscan fossils show warm oceanic environment, being middle Miocene in age.

5) Nagane Formation

This formation is exposed around the dome structures of Yotsudaki-yama and Horozuki, and is also seen along the anticlinal axis in Hakamagoshi-dake and in the north of Kanita.

The rock facies is variable. Around the Yotsudaki-yama Dome, main rocks are green tuffaceous sandstone and andesitic tuff, intercalated with basalt lavas. Around the Horozuki Dome, tuffaceous sandstone and andesitic tuff occur, accompanied by a basal conglomerate with pebbles mostly of chert. On the anticlines of Hakamagoshi-dake and in the north of Kanita, the rocks are composed chiefly of basalt, with intercalations variable in features from abundant tuffaceous sandstone and tuff and subordinate black mudstone to vice versa.

The Nagane Formation conformably overlies the Fuyube Formation, except for the area around Horozuki where the basal conglomerate unconformably covers the erosion surface of black mudstone constituting the upper part of the Fuyube Formation.

Twenty three species of molluscan fossils including *Shichiheia yabei* and *Patinopecten yamasakii iwasakiensis* have been discovered by Mizuno (1964). These fossils indicate neritic environment under warm climate.

6) Lower Kodomari Formation

The formation occurs mostly in the southern half of the district, particularly in the area from dome structure of Hakamagoshi-dake to the adjacent north, and along the anticline north of Kanita. It is also seen as small exposures along the synclinal axis near Kodomari. Hard shale with clear bedding of about 10 cm thick characterizes the formation. The lowermost part is interbedded by flinty or siliceous shale. Intercalations of bluish grey acid tuff occur at several horizons, and they laterally increase in thickness and change to the Horozuki Volcanic Rocks or the Mimmaya Rhyolite. The marlitenodules are sporadically contained in the hard shale.

Sagarites chitanii, diatom fossils such as *Coscinodiscus* and *Arachnoidiscus*, and benthonic foraminifera such as *Bathysiphon* sp. and *Haplophragmoides* sp. have been discovered from this formation.

7) Basaltic Rocks

They comprise basalt and dolerite contemporaneous with the Nagane and Lower Kodomari Formations. Basalt occurs as lavas, tuff breccia, intrusive sheets and dikes, and dolerite intrude into the Lower Kodomari Formation. A dike swarm trending north or northeast is known in the east of Horozuki. A part of the dikes is gabbroic.

8) Horozuki Volcanic Rocks and Mimmaya Rhyolite

Although differently named, both are acid rocks contemporanous with the Lower Kodomari Formation. The chief constituents are lavas of glassy rhyolite with few phenocrysts, and the remainders are intercalating lavas comprising rhyolite with phenocrysts of potassium feldspar and biotite or plagioclase. Aphyric dacite and beds of dacite tuff breccia are also contained.

9) Upper Kodomari Formation

The formation is extensive particularly in the surroundings and the north of the Hakamagoshi-dake dome structure, and in the area north of Kanita. It conformably overlies the acid tuff bed or the hard shale of the Lower Kodomari Formation. Dark grey massive mudstone without clear bedding but with sporadic intercalations of siliceous shale is the main constituent. It becomes fragile by weathering. It includes marlite nodules, attaining about 1 m in length in the lowermost part of the formation.

The fossils are scarce in this formation, although *Sagarites chitanii* is popular and *Cyclamina japonica* and *Martinottiella communis* are reported by IWASA (1962).

10) Shiwokoshi Formation

The formation occurs mainly in the west wing of anticline extending from Shiwokoshi north of Kanita to the northwest, and also in small areas northeast of Kodomari and east of the Lake Jūsan.

In the environs of Shiwokoshi, the formation starts with the massive diatomaceous siltstone and pumice tuff showing slumping structures, and gradually changes upwards to the alternations of siltstone with conglomerate, tuffaceous sandstone and pumiceous tuff. This facies continues until the environs of Shimizumata-zawa, but changes to the Imabetsu Andesite in the farther north. In the areas near Horozuki which is farther north of the aforementioned area, near Kodomari and near Lake Jūsan, the lowermost part is represented by alternations of siliceous shale and tuffaceous sandstone, and the main part consists of diatomaceous siltstone with lenses of siliceous shale and diatomaceous mudstone, which in turn is overlain, excepting near Lake Jūsan, by the Imabetsu Andesite.

Under the microscope, many fragments of organisms are seen in the siltstone. Radiolarians such as Liosphaeicae and Ellipsidiicae, and diatoms such as *Arachnoidiscus* and *Coscinodiscus*, in addition to *Sagarites chitanii* and sponge spicules, have been identified.

The relation with the Upper Kodomari Formation is conformable in the north of Kanita, and any difference of geologic structure is not seen also in other exposures.

11) Imabetsu Andesite

Mostly andesitic and partly dacitic rocks widely distributed in the synclinal belt along the Imabetsu River are the same as the Upper Kodomari and Shiwokoshi Formations in age. They are generally not altered. Andesite occurs usually as tuff breccia containing black andesite blocks in a yellowish brown matrix and rarely as lavas. Dacite occurs as tuff breccia and lavas. Lavas crop out in the northeast of Kodomari, at Shimizumata-dake and in other places.

12) Kanita Formation

The formation composes a syncline in the hills along the Kanita and Imabetsu Rivers. Near Kanita, the lower part consists of grey, medium-grained, tuffaceous sandstone and mudstone, the middle part is bluish grey massive sandy siltstone interbedded by sandstone and pumice tuff, and the upper part is coarse-grained, tuffaceous sandstone interbedded by mudstone and fine sandstone. As going up along the Kanita River, tuffaceous sandstone and siltstone of the lower and middle parts gradually become coarser-grained and increase in the conglomerate interbeds with the pebbles of andesite and siliceous shale. Contorted structure, slump structure and other structures due to abnormal sedimentation are developed at every basal portion of the lower, middle and upper parts of the formation. They are available for horizon-indicators in the Kanita River area, but cannot be applied for in the Imabetsu River area because of randam distribution.

Seventeen species of molluscs including *Acila* sp. and *Glycymeris yessoensis* have been discovered from the upper part.

The Kanita Formation in the middle and southern areas of its distribution is conformable to the underlying Shiwokoshi Formation. But in the northernmost exposure west of Horozuki, conglomerate and coarse-grained sandstone yielding molluscan fossils covers the dacite tuff breccia of Shiwokoshi Formation, unconformably. This facies and molluscs correspond to those of the upper part of Kanita Formation occurring in the Kanita area to the south. Therefore, the Kanita Formation overlaps on the Shiwokoshi Formation in the Imabetsu River area which lies between the above-mentioned two areas.

3.1.2 Shimokita Peninsula

1) Pre-Tertiary Basement Rocks

The basement rocks are extensive from Chōgo-Fukuura along the west shore of the peninsula to the upper stream of the Kawauchi River. They comprise the strata mainly of pelitic and tuffaceous phyllite and partly of chert, sandstone and limestone, and quartz diorite intruded into the strata. Limestone is crystalline and yields no fossils. Quartz diorite is greenish, coarse or medium grained, and carries hornblende and biotite. It is wholly altered and slightly mylonitized. These phyllites and quartz diorite are studied by UEMURA (1964). The thermal metamorphism is remarkable at the contact. The absolute age is 108 million years according to K-A method by KAWANO and UEDA (1966) from the muscovite in the metamorphic aureole.

2) Kimpachizawa Formation

This formation is distributed in the environs of the basement rocks and also in the belt extending from east to west through Aki-yama and Hachiro-dake to the south of the basement rocks. The basal conglomerate, which is usually one or two meters thick, but several meters thick in the south of

Sai, carries the pebbles of chert and diabase. Dark grey or black colourd mudstone and basalt are the main constituents of the formation. Mudstone is of same kind with that of the Nagane Formation in the Tsugaru Peninsula, though extremely hardened at some places. Basalt occurs chiefly as lavas alternating with mudstone. Mudstone is abundant in the south of Sai, but basalt is predominant in other areas, excepting the places from the Yabitsu River to the Otokogawa River, where mudstone is locally thick in the upper part of the formation.

Bathysiphon sp. from the mudstone at Wajiro-zawa is the only fossil discovered.

3) Hinokigawa Formation

This formation is extensively developed in the Sai and Mutsu-kawauchi areas, surrounding the exposure of basement rocks. Rhyolitic and dacitic pyroclastics and lavas characterize the formation. Basaltic and andesitic lavas and tuff breccia, and mudstone occur subordinately. The rock facies is somewhat different from place to place. In the Sai area rhyolitic lavas are dominant, the lower part being accompanied by dacitic lavas and the upper part being perlitic. In the Kawauchi River area, pyroclastic rocks of rhyolite and dacite are predominant and lavas are subordinate in amount.

The following four types of rock facies are recognized. The Ushidaki Facies, the Otokogawa Facies and the Hinokigawa Facies overlap upwards in this order, while the Wakinosawa Facies interchanges with the uppermost Hinokigawa Facies.

The Ushidaki Facies is mainly composed of lavas and pyroclastic rocks of dacite with abundant phenocrysts of quartz and plagioclase, and is locally interbedded by andesite lavas, tuff breccia and mudstone; this facies is well seen in the Nodai basin and its environs.

The Otokogawa Facies is composed of pyroclastics and lavas of rhyolite without marked phenocrysts; main occurrence is from the mid-stream of the Otokogawa River to the upper stream of the Shukunobe River.

The Hinokigawa Facies is of lavas and pyroclastic rocks of reddish brown rhyolite with rare phenocrysts and perlite; it is widely developed from the lower stream of the Shukunobe River, through the Hinokigawa River to the Kawauchi River.

The Wakinosawa Facies is of dacitic lavas and pyroclastics, both being light green coloured and carrying medium-grained phenocrysts of quartz and plagioclase; it is seen in the upper stream of the Wakinosawa River and near Futamata-yama.

Basalt is present in the Hinokigawa Facies. It is extensively developed in the Omoki area along the west coast of the Shimokita Peninsula, where it is mostly represented by lavas, some of them being pillow lavas. Mudstone is relatively extensive, interbedded between the Otokogawa Facies and the Hinokigawa Facies in the middle stream of Hinokigawa River.

Twelve species of foraminifera, namely *Haplophragmoides renzi*, *Martinottiella communis*, *Cyclamina ezoensis*, etc. have been discovered from the mudstone, and they are common to the fossils from the Lower Kodomari Formation in the Tsugaru Peninsula.

4) Lower Kozawa Formation

This formation occurs in the hills near Kozawa of Wakinosawa Village on the southern coast of the peninsula, and also in the axial part of anticline to the east of Oma near the north cape.

It is variable in lithofacies. In the Kozawa area the formation is relatively thick, and is composed of hard shale intercalated with andesite lavas. It becomes thinner in the west and finally thins out at Wakinosawa. Going to the east from Kozawa, it changes into the alternation of hard shale and massive mudstone, then in the east of the Shukunobe River it is divisible into the lower part consisting of pumice tuff and the upper part composed of hard shale and massive mudstone. Finally in the east of the Hinokigawa River it turns to pumice tuff and massive mudstone. The pumice tuff further east of the Shukunobe River is specified as the Ginnanboku Tuff Member. This member is pale greyish white in colour and is characterized with the abundance of large crystals of quartz 1 cm in size.

The fossils of *Haplophragmoides* cf. *emaciation* and *Martinottiella communis* have been discovered in the hard shale around Kozawa.

In the Oma area the formation is composed of hard shale interbedded by thin layers of acid tuff, and conformably overlies the Hinokigawa Formation.

5) Upper Kozawa Formation

This formation is exposed widely in the Kuchihiro River area west of Kozawa and narrowly around Oma.

In the Kuchihiro River area, massive mudstone is interbedded by tuff. To the east the facies changes into pumiceous tuff and tuffaceous sandstone with intercalations of mudstone, and is named the Kuzusawa Tuff Member. The pumice tuff apparently resembles to that of the Ginnanboku Tuff Member of the lower formation, but is different in the smaller size of quartz crystals and the sporadic presence of hornblende crystals.

In the Oma area the formation is mainly composed of massive mudstone intercalated by platy black shale, and interfingers with the tuff breccia of Ikokuma andesites. No fossils have been discovered so far from this formation.

6) Yagen Formation

The Yagen Formation unconformably overlies the Kimpachizawa Formation and the Hinokigawa Formation in the upper streams of the Nakagawa and Yunokogawa Rivers, but may be conformable with the Hinokigawa Formation in other vast areas, because any indication of time interval between them is hardly noticeable.

The Yagen Formation is divided into the Yunokawa, the Yunokogawa and the Kamanosawa Members. The latter two are contemporaneous with the upper part of the first.

The Yunokawa Member is extensive in the central part of the peninsula, namely in the upper streams of the Kawauchi River such as in the valleys of Yunokawa and Nakagawa and in the upper stream of the Ohata River. In the Nakagawa valley, conglomerate overlying the Kimpachizawa Formation is succeeded by dacite tuff, tuffaceous sandstone, siltstone and dacite tuff breccia in ascending order, but in other areas conglomerate of several meters in thickness overlies the Hinokigawa Formation, and dacite tuff breccia overlaps on the conglomerate. In the Ohata area this member is interbedded by lavas of andesite and dacite with a small amount of andesite tuff breccia. Six species of plant fossils such as *Betula onbaraensis* and *Liquidamber endoi* were collected from siltstone and sandstone in a tributary of the Nakagawa River, and were reported by Suzuki and Kuwano (1962). Ten species of molluscan fossils, namely *Anadara* cf. *ninohensis, Chlamys arakawai*, etc. were reported by Hanzawa (1954) in the lower reaches of Ohata River.

The Yunokogawa Member is relatively thick in the area from the upper reaches of Wajiro-zawa, through the Nayoshi River up to the Yunoko-gawa and the Shinsuke-zawa. In this area, the lower part is represented by conglomerate and tuffaceous sandstone containing molluscan fossils, the middle part is of pumice tuff with large crystals of quartz, and the upper part consists of greyish white, massive or platy tuffaceous mudstone containing plant fragments, siltstone, tuffaceous sandstone and pumice tuff. The pumice tuff is the same kind as that of the Ginnanboku Tuff Member of the Lower Kozawa Formation. In the Menagawa River to the west, this member becomes thinner, and finally the pumice tuff which is the uppermost of the member is only present. Sixteen species of molluscs including *Panope japonica* and *Chlamys swifti* were reported by GŌHARA, KUWANO and OIDE (1957) from the sandstone in the lowermost part of the member in the Nayoshi River, and are regarded to be of the Daijima and Nishikurosawa Stage.

The Kamanosawa Member is exposed only in the Kamanosawa which is a tributary of the Ohata River. The composing rocks are light green pumice tuff, tuffaceous sandstone and mudstone, and this feature is similar to that of the upper part of the Yunokogawa Member. The thickness is decreasing towards the main stream of the Ohata River in the north, and finally tuffaceous mudstone beds corresponding to the uppermost of Yunokogawa Member are only present. The molluscan fossil of *Limopsis* sp. has been discovered from this member.

7) Yunomatagawa Dacite

This dacite extensively occurs as pyroclastic rocks and lavas in the central part of the peninsula, unconformably resting on the Yagen Formation. The pyroclastic rocks are characterized by abundant crystals of plagioclase and quartz of 5 mm in size scattered in pale green or grey matrix, and carry pumice fragments and dacite blocks, too. Some parts are welded tuff. The lavas are augite dacite rich in phenocrysts.

8) Ikokuma Andesite

This andesite consists mostly of andesite and partly of dacite. At many outcrops they unconformably cover the Hinokigawa Formation or the Yagen Formation. Yet in the Kuchihiro River area west of Kozawa, and in the Oma area, they laterally change into the upper part of the Upper Kozawa Formation.

The rocks are almost same as the Imabetsu Andesite in the Tsugaru Peninsula, and are not altered, excepting for the argillized portions in the environs of Aomori Mine in the upper stream of Okoppe River.

9) Ohata Formation

Covering unconformably the Yagen Formation, the Yunomatagawa Dacite and the Ikokuma Andesite, the Ohata Formation occurs in the Komena area along the lower stream of Ohata River and the upper stream area of Ohata River. In the former area, the basal part is conglomerate, and main part is pumice tuff, into which tuffaceous sandstone and mudstone are interbedded. In the latter area, also the basal part is pumice tuff. The pumice tuff is soft, and includes the fragments of dacite, mudstone and mud ball. No fossils have been discoverd from this formation as yet.

3.2 Correlation

The Gongenzaki Formation in the Tsugaru Peninsula is correlated with the Monzen Formation, namely the so-called lower Green Tuff Formation in the Oga district of Akita Prefecture, because of the presence of the Aniai type flora.

The Isomatsu and Fuyube Formations are correlative with the Daijima Formation in the above-mentioned district on the basis of the similar rock facies, the Daijima type flora and the molluscan

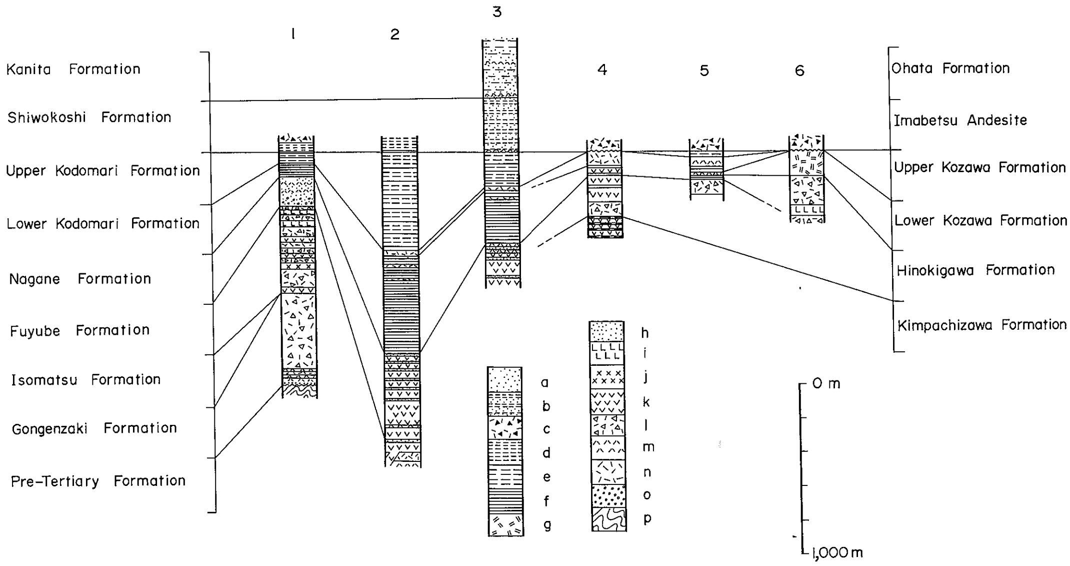


Fig. 3 Columnar section of the Neogene in the northern area, Aomori Prefecture.

1. Kodomari Peninsula; 2. Imaizumi River; 3. North of Kanita; 4. Wakinosawa River; 5. Kuchihiro River and the vicinity of Kozawa; 6. Kawauchi.
1-3:Tsugaru Peninsula 4-6:Shimokita Peninsula
a. Sandstone; b. Siltstone and sandstone; c. Diatomaceous siltstone; d. Siltstone; e. Mudstone; f. Siliceous mudstone; g. Dacite pumice tuff; h. Tuffaceous sandstone i. Rhyolite; j. Dacite; k. Basalt; l. Tuff breccia; m. Andesite; n. Tuff; o. Conglomerate; p. pre-Tertiary strata

fossils.

The Nagane Formation in the Tsugaru Peninsula corresponds to the Nishikurosawa Formation because of the same species of molluscs. It is regarded to be identical to the Kimpachizawa Formation in the Shimokita Peninsula from the lithologic character and the stratigraphic situation.

Siliceous shale and hard shale of the Lower Kodomari Formation in the Tsugaru Peninsula are lithologically the same as those of the upper part of the Hinokigawa and the Lower Kozawa Formations in the Shimokita Peninsula, and most of the foraminifera fossils in all formations are common to each other. The formations are correlated with the Onnagawa Formation in the Oga district.

The volcanic piles specified as the basaltic rocks in the Tsugaru Peninsula and the basaltic intercalations in the Kimpachizawa and Hinokigawa Formations in the Shimokita Peninsula are derived from the volcanic activities of nearly same age. They are contemporaneous with the Nagane Formation and the lower part of Lower Kodomari Formation.

The Mimmaya Rhyolites and the Horozuki Volcanic Rocks in the Tsugaru Peninsula are the local acid rocks corresponding to the Hinokigawa Formation of mostly rhyolitic character in the Shimokita Peninsula.

The Yagen Formation in the Shimokita Peninsula is nearly contemporaneous with the Lower Kozawa Formation because of the common presence of characteristic pumice tuff. Therefore it is correlated with the Onnagawa Formation, nevertheless it is rich in volcanic rocks and different in the sedimentary environment.

The Upper Kodomari Formation in the Tsugaru Peninsula and the Upper Kozawa Formation in the Shimokita Peninsula are correlated to the Funakawa Formation in the Oga District from their lithologic natures. The Yunômatagawa Dacite is probably the same as the Upper Kodomari

Formation in age, because they cover the Yagen Formation and are covered by the Ikokuma Andesite, although the actual relation to the Upper Kozawa Formation is not seen in the field. They are correlated from the petrographical and chronological viewpoints to the Tamagawa Dacite, which is well-known in the border district between Akita and Iwate Prefectures.

The Shiwokoshi Formation in the Tsugaru Peninsula can be approximately correlated to the Kitaura Formation in the Oga district from the stratigraphic situation and the composing rocks. The Imabetsu Andesite in the Tsugaru Peninsula and the Ikokuma Andesite in the Shimokita Peninsula are equivalent to each other, and are mostly contemporaneous with the Shiwokoshi Formation.

The Kanita Formation in the Tsugaru Peninsula corresponds to the Wakimoto and Shibikawa Formations of the Oga district in the molluscan fossils discovered, and is regarded to be equivalent to the Ohata Formation in the Shimokita Peninsula, lithologically and stratigraphically.

3.3 Distribution and Petrographic Characters of Volcanic Rocks

On account of the widespread alteration of the Green Tuff Region, the most rocks in the formations from the Gongenzaki up to the Lower Kodomari in the Tsugaru Peninsula, and from the Kimpachizawa up to the Yunomatagawa Dacite in the Shimokita Peninsula, are usually not qualified for the strict petrography. The author summarizes here the rock types of lavas and essential volcanic fragments so far determined under the optical microscope.

1) Basalt

Beside the basaltic rocks as specified in the Tsugaru Peninsula, basalt is also prevalent in the Kimpachizawa and Hinokigawa Formations in the Shimokita Peninsula. Both of basalt and dolerite occurring in the Tsugaru Peninsula carry olivine with or without augite as phenocryst and clinopyroxene with or without olivine as groundmass mineral. Consequently, four types, namely IIIb, IVb, IIIc and IVc according to KUNO's (1954) classification are detected. In both the peninsulas the rocks containing hypersthene are missing. It is considered that such rocks are originally in small amount, although they might be failed to be noticed because of the alteration.

2) Andesites

The andesites constitute the major parts of the Gongenzaki and Fuyube Formations but these formations are restricted only in the northern part of the Tsugaru Peninsula. The andesites contemporaneous with the Shiwokoshi Formation in the Tsugaru Peninsula, that is the Imabetsu Andesite, are rather limited in the areas around the Yotsudaki-yama and Horozuki Domes, whereas the equivalent rocks, the Ikokuma Andesite in the Shimokita Peninsula, occurs extensively around the areas of the Hinokigawa and Yagen Formations. In addition, the Hinokigawa and Yagen Formations are participated by andesite in a small amount.

The andesite of the Gongenzaki Formation is hypersthene-augite andesite, whose mafic minerals of the groundmass are wholly altered. There are olivine-augite andesite, augite-hypersthene andesite, olivine-anorthite andesite, etc. in the Fuyube Formation, and they belong to IVd, Vd or IIId type, all containing clinopyroxene and orthopyroxene with no reaction rim as groundmass minerals.

The Imabetsu Andesite consists mainly of hypersthene-augite andesite and partly of quartz-bearing andesite and hornblende-hypersthene-augite andesite. Rock fragments in tuff breccias are mostly hyalopilitic, while lavas intercalated in tuff breccias show intergranular texture in which clinopyroxene and orthopyroxene without the reaction rim, denoting the rocks to belong mostly to Vd or VId type. However, some of the lavas at Hakamagoshi-dake south of Horozuki belong to augite-hypersthene andesite of Vc type, containing pigeonite but no hypersthene as groundmass pyroxenes.

The Ikokuma Andesite is mainly of hypersthene-augite andesite and partly of olivine-augite-hypersthene andesite. Rock fragments in tuff breccias are hyalopilitic, while the lavas are intergranular. Many of the lavas which carry no olivine as phenocryst are of Vd type, but some lavas occurring along the Metaki-zawa Valley are of Vd→c type, which bears pigeonite in the groundmass and shows the reaction rim of clinopyroxene around orthopyroxene. The andesite with olivine as phenocryst is usually of Vd→c type, too.

3) Dacite

In the Tsugaru Peninsula, dacite occurs as the constituents of the Fuyube Formation, the Horozuki Volcanic Rocks, the Imabetsu Andesite and the Shiwokoshi Formation, but their amount is small. In the Shimokita Peninsula, the major parts of the Yagen Formation and the Yunomatagawa Dacite are pyroclastic rocks and lavas of dacite, and also the Hinokigawa Formation, the Lower Kozawa Formation and the Ikokuma Andesite are partly dacite lavas.

Dacites in both the peninsulas are relatively rich in phenocrysts. They are mainly augite-hypersthene dacites, accompanied by hornblende and biotite-bearing variety, hornblende dacite (in the Ushidaki Facies of the Hinokigawa Formation) and hornblende-biotite dacite (in the Lower Kozawa Formation). The groundmass is usually glassy or microcrystalline in texture with flow structure.

4) Rhyolite

Rhyolite composes the Mimmaya Rhyolites and the Horozuki Volcanic Rocks in the Tsugaru Peninsula, and the major part of the Hinokigawa Formation in the Shimokita Peninsula. The phenocrysts are quartz, plagioclase, hornblende and rarely biotite and the groundmass is glassy or microcrystalline in texture, showing flow structure.

5) Summary of petrographic character

Judging from the mineral assemblages described above the basalts are usually of tholeiitic rock series, the andesites are mainly of calc-alkali rock series and partly of tholeiitic rock series, and the rhyolites and dacites are of calc-alkali rock series.

The chemical compositions of volcanic rocks occurring in this district are unknown, except for the basalt of Hakamagoshidake dome reported by Yagi (1937).

4. Geologic Structures, and the Changes of Rock Facies and Thickness of Formation

4.1 Folds and Faults

Separated by the Tairadate Straits, the structural pattern of the Neogene on the Tsugaru side and that on the Shimokita side are remarkably different from each other (Fig. 4).

The Tsugaru side is, as a whole, a folding tract extending from north to south, in which four anticlinal belts are arranged in parallel rows. The westernmost belt consists of the Yotsudaki-yama Dome and a dome structure around the Katakariishi-zawa, each being individually in northwest or north-northwest trend, but being arranged as a whole in echelon to form the general trend from north

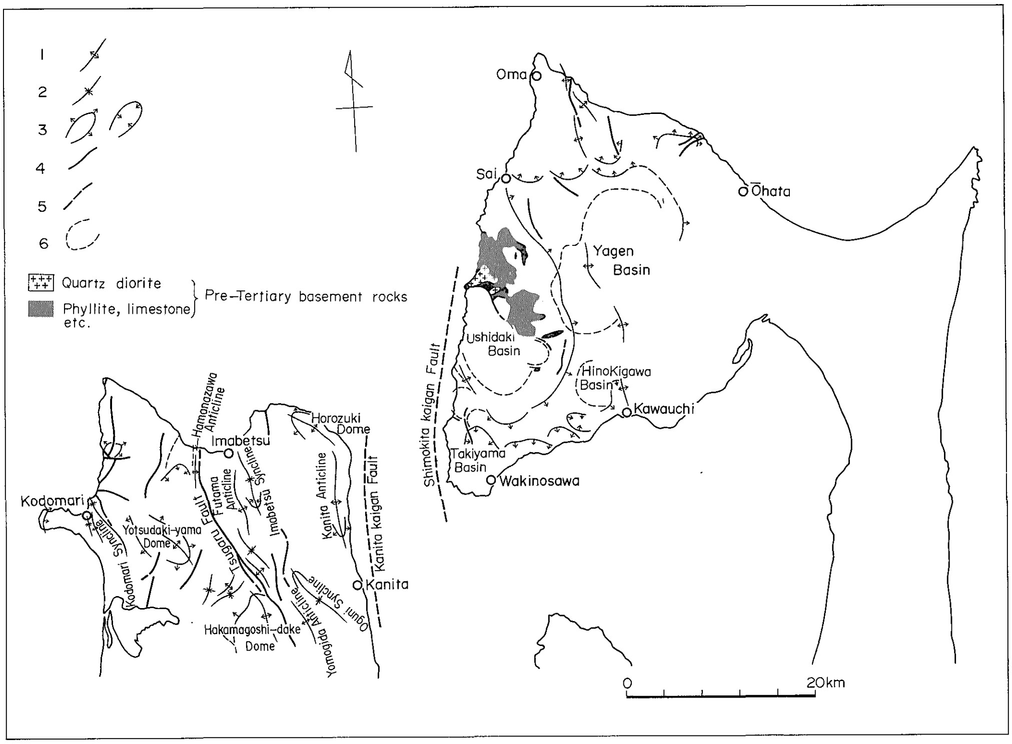


Fig. 4 Map showing the distribution of the main structure.
1. Anticline; 2. Syncline; 3. Dome and basin structures; 4. Fault; 5. Concealed fault; 6. Volcanic basin structure

to south. This anticlinal belt extends southwards to the row of latent dome structures known under the Tsugaru Plain beyond the present field. The next belt in the east links the Hakamagoshi-dake Dome with the Hamanazawa Anticline. Its eastern wing shows steep dips, and is cut by the Tsugaru Fault. This fault is a reverse fault, traverses the peninsula and extends over 60 km from the west of Imabetsu towards the west of Aomori City. On the east of the fault, the Yomogida Anticline and the Futamata Anticline are disposed in echelon in the areas of Shiwokoshi and Kanita Formations. The easternmost belts is represented by the Kanita Anticline running from north to south and its northern extension named the Horozuki Dome with the longer axis of northwest trend. The east side of this belt is cut by the Kanita-kaigan Fault. The eastern wings of all the Yomogida, Futamata and Kanita Anticlines are also steeply dipping.

The major structure of the Neogene on the Shimokita side is represented by two broad dome structures located in the south of Sai and in the upper stream of the Ohata River. Their cores are made of the pre-Tertiary rocks and the Yagen Formation, respectively. The anticlines of north-south trend intermittently appear in a row of the same direction traversing the peninsula from the east of Oma, through the Yunokawa River area to Kawauchi. The inclinations of the Neogene rocks are generally gentle all over the Shimokita Peninsula excepting particular places close to the anticlines.

Local basin structures of various extents such as the Ushidaki, Yagen, Hinokigawa and Takiyama Basins are recognized in the areas of the Hinokigawa and Yagen Formations. They are derived from the volcanic structures and will be described in Chapter V.

A submarine fault called here the Kanita-kaigan Fault, which runs along north-northeast direction and lies off the east coast of the Tsugaru Peninsula, is presumed topographically from the coastal cliffs of linear arrangement and geologically from the steep inclinations of the Neogene rocks along the shore. The coast of north-northeast trend on the west side of the Shimokita Peninsula exhibits typical fault scarps standing very steep and high from the shore, and the existence of submarine Shimokita-kaigan Fault is confirmed by the sonic prospecting conducted at the time of a regional survey project for mineral deposits. It is clear that the Tairadate Straits between the two peninsulas is a trough bounded by the parallel faults. According to the drillings for underground water in the Aomori Plain, which is situated to the south of the strait, the loose sediments of sand and gravel probably of the Quaternary are accumulated upon the beds equivalent to the Kanita Formation, and attain more than 400 m in thickness at several places. It is suggested that the Tairadate Straits and the Aomori Plain lie in a continuous zone of submergence, which is quite young in geologic age.

4.2 Gravity Anomalies and Geologic Structures

The Bouguer anomalies so far known in this district are reproduced in Fig. 5.

The highest gravity anomaly is restrictively on the exposures of the basement rocks and in their neighbourhood, revealing clear connection with the depth of the basement rocks of high density from the surface.

To the northwest of Kanita in the Tsugaru Peninsula, the gravity shows higher anomaly towards

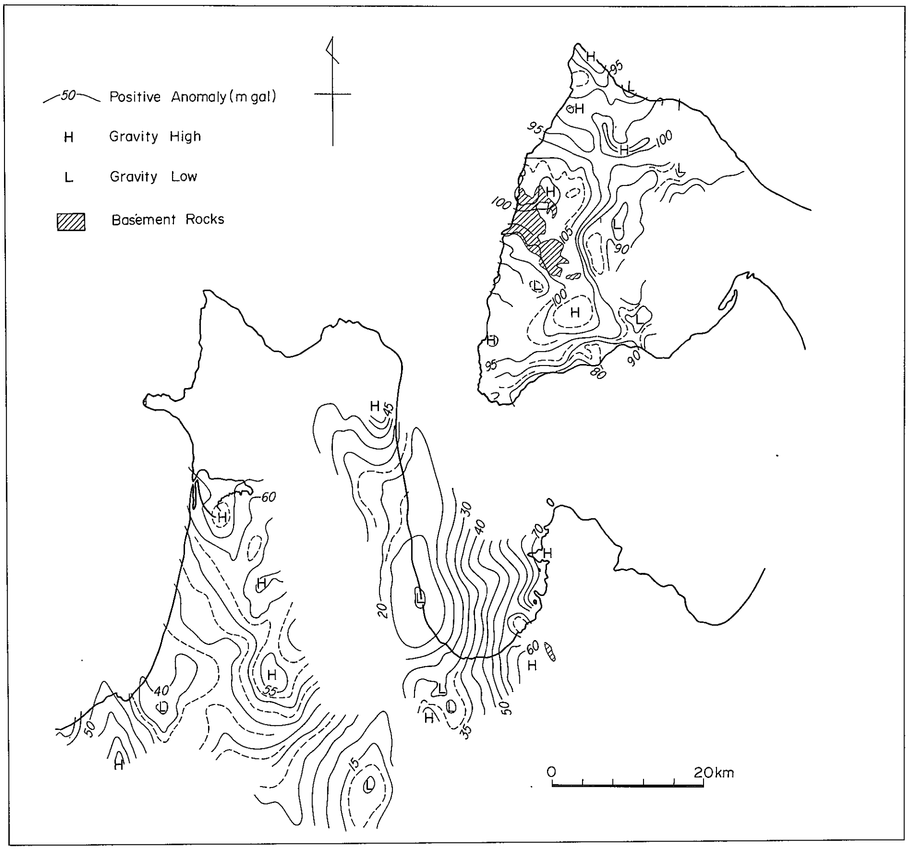


Fig. 5 Bouguer anomalies.

the north and concordant to the dome structure of the Neogene, suggesting the rise of subsurface basement rocks towards the Horozuki Dome. Another high gravity of dome-like pattern is observed to the south of the Lake Jūsan. It represents the northernmost extension of the high anomaly belt, typically developed in the central part of Tsugaru Plain to the south, where several prominent domes of high anomaly in a north-south direction are known. IWASA (1962) named this belt as Jūsanko-Goshogawara-Hirosaki high gravity zone, and concluded from the seismic and drilling prospectings that the basement rocks lie not deeply in this zone and that the oil-bearing Tertiary strata are thin as compared with those in other places.

Gravity anomalies in the Shimokita Peninsula, excepting the remarkable lows of the Ushidaki and Yagen Basins, are generally positive. The highest is on the basement rocks south of Sai as noted before and another prominent high is in the upper stream of the Ohata River. The anomalies gradually fall from these areas outwards in accordance with the down slopes of geologic dome structures.

The gravity values in the Tairadate Straits are not yet known. The anomaly contours in Mutsu Bay on south of the strait and in the adjoining Aomori Plain have a pattern of nearly north-south trend and show sudden fall, whose decreasing gradient is as steep as 60 mgal for about 10 km from east to south. At Higashi-dake on the east side of Aomori Plain there is a gravity high on the exposure of basement rocks surrounded by the Neogene. It is suggested that a fault running from north to south is concealed under the eastern margin of the plain and that the basement rocks suddenly fall on the west of the fault. The inferred fault could be connected with Shimokita-kaigan Fault, by which the basement rocks step down into the bottom of Tairadate Straits. The down-throws of both faults are possibly quite large.

4.3 Facies and Thickness

The author compares here the rock facies and the thickness of the Neogene Formations in the Tsugaru Peninsula and those in the Shimokita Peninsula with each other, and intends to conclude that they have close relation with the undulation of the basements. The Neogene rocks mainly composed of volcanics such as the Hinokigawa Formation, the Yagen Formation and the Horozuki Volcanic Rocks, are excluded here, and they will be mentioned in the next chapter.

In the small peninsula of Kodomari, the Gongenzaki and Fuyube Formations are exposed successively, reaching more than 1,500 m in total thickness. Although in other places of the Tsugaru Peninsula the base of Gongenzaki does not crop out, two formations together presumably reach to about 2,000 m thick at the most developed place. On the other hand, the strata corresponding to these formations are missing in the Shimokita Peninsula where the exposures of basement rocks are comparatively wide.

The Nagane Formation around the Yotsudaki-yama and Horozuki Domes in the Tsugaru Peninsula is mostly of tuffaceous sandstone, and as going away from the domes it changes the facies to the alternation of fine-grained tuff and black mudstone intervened by basalt and becomes greater in thickness. The border of two facies coincides with the isopach line of about 200 m (Fig. 6–A). The Kimpachizawa Formation in the Shimokita Peninsula is correlative to the Nagane Formation and is dominantly basaltic, but is abundant in mudstone in a certain places. This formation also becomes thicker as going away from the dome structure surrounding the basement exposure.

The Lower Kodomari Formation in the Tsugaru Peninsula does not change so much the facies,

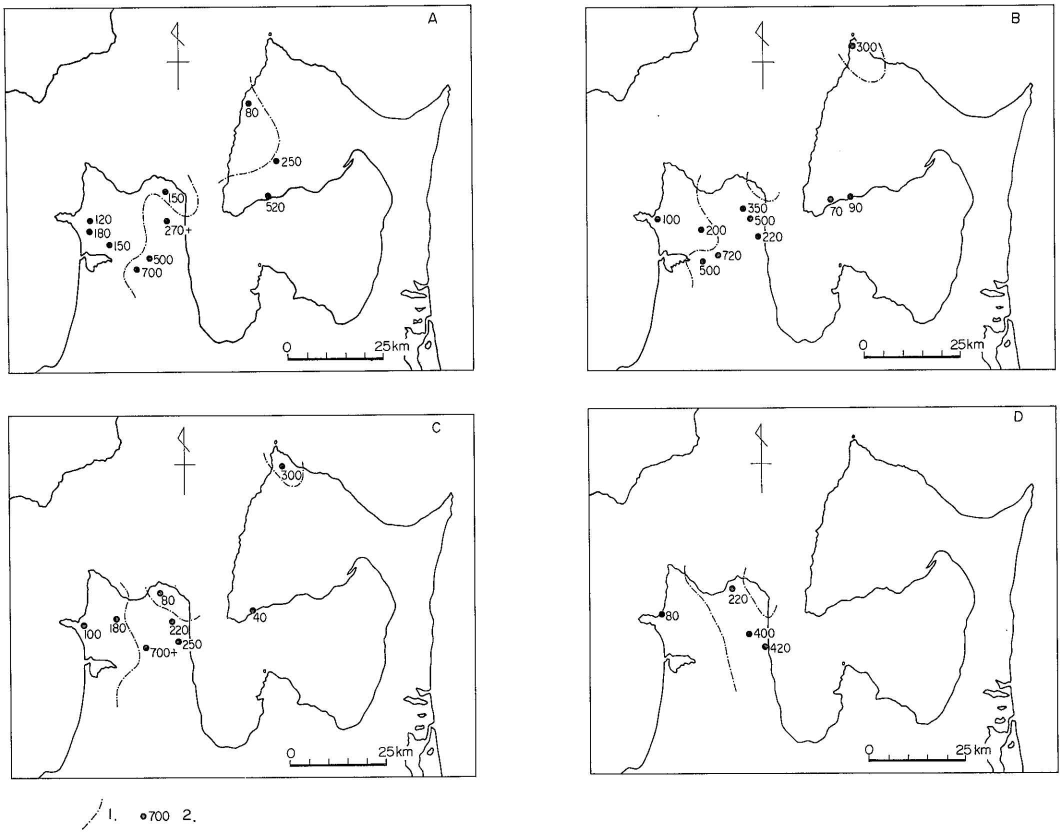


Fig. 6 Map showing the thickness of the Neogene Formations.

A. Nagane Formation and Kimpachizawa Formation
B. Lower Kodomari Formation and Lower Kozawa Formation
C. Upper Kodomari Formation and Upper Kozawa Formation
D. Shiwokoshi Formation
1. Isopach line of 200m thick; 2. Thickness(m)

but varies the thickness. It is thin in the area surrounding the Yotsudaki-yama Dome and is estimated to be less than 200 m thick in the zone of high gravity anomaly south of the Lake Jūsan, while it is thick in the areas around Hakamagoshi-dake Dome and in Kanita Anticline. In other words, it is thicker on the east side of isopach line of 200 m in Fig. 6–B, that is the east side of anticlinal belt linking the dome structures of Katakariishi-zawa, Yotsudaki-yama and others to the south of the Lake Jūsan. The Lower Kozawa Formation in the Shimokita Peninsula, which corresponds to the Lower Kodomari Formation, is the thickest at the axial part of the Oma Anticline, but is missing in the Sai area located near the exposure of basements. The change of thickness is also noticed in the formation of the southern coastal areas of the peninsula; the thickness around Kozawa where the formation is typically exposed is 150 m, and becomes thinner towards north, east and west from the semi-basin structure located there, and finally vanishes to the west of Wakinosawa. It will be said that the Lower Kozawa Formation becomes thicker as going outwards from the dome structure surrounding the basement rocks.

The thickness of the Upper Kodomari Formation in the Tsugaru Peninsula is also variable, though the facies change is not remarkable. The isopach line of 200 m given in Fig. 6–C shows similar tendency to those of the Nagane Formation and the Lower Kodomari Formation, but the width of submerged zone of the Upper Kodomari Formation is narrower than that of the Lower Kodomari. The thickest part is in the northeast of Hakamagoshi-dake Dome. In the neighbourhood of Horozuki Dome, the formation becomes thicker as going away from the dome. The Upper Kozawa Formation mostly of muddy facies in the Shimokita Peninsula, equivalent to the Upper Kodomari, is narrowly distributed. In the Oma Anticline, where the exposure is relatively wide, the formation including the part interfingering with the Ikokuma Andesites measures 300 m in thickness. But in the type locality north of the Kuchihiro River it is much thinner, diminishing to the west and interchanging with the pumice tuff of the Kuzusawa Member to the east.

The 200 m isopach line of Shiwokoshi Formation in the Tsugaru Peninsula excluding the area where the Imabetsu Andesite is distributed, is shown in Fig. 6–D. The formation is thick on the east side of the Tsugaru Fault, and is thickest in the south of the Kanita Anticline, but becomes thinner northwards to the Horozuki Dome. According to Iwasa (1962) a drilling for oil at the Amatanai Anticline, which lies on the southern extension of Yomogida and Futamata Anticlines, reveals the Shiwokoshi Formation to be more than 1,200 m in thickness. The stratigraphic boundary of the Shiwokoshi Formation by the author is slightly different from that by Iwasa, but at any rate it is obvious that the maximum submergence in the sedimentary basin stretches from north to south on the east side of Tsugaru Fault and it can be presumed that the thickness of the sediments around there is 1,000 m or more. In the Shimokita Peninsula, no formations corresponding to the Shiwokoshi are present.

The Kanita Formation is distributed only on the east side of Tsugaru Fault. It is especially thick on the east of anticlinal belt including the Yomogida and Futamata Anticlines, measuring 800 m or more on the south of Kanita and being estimated to be more than 1,000 m thick along the axis of syncline between the Yomogida and Kanita Anticlines. The formation increase in coarse-grained sandstone and conglomerate approaching to the margin of sedimentary basin. The pebbles of conglomerate are chiefly siliceous shale and basalt, and the kinds of pebbles are directly influenced by local rock facies of the formations from the Nagane up to the Upper Kodomari occurring on the west side of the Tsugaru Fault. For instance, they are mostly of basalt in the neighbourhood of Hakamagoshi-dake where numerous basaltic bodies intervene. This fact indicates that the most parts of the west terrain of Tsugaru Fault are uplifted and eroded prior to the sedimentation of the Kanita Formation. No remarks are given on the Ohata Formation in the Shimokita Peninsula, which is correlative with the Kanita Formation, as it is narrowly distributed.

5. Volcano-Tectonic Features of Acid Rocks

5.1 Acid Volcanic Rocks and Basin Structures

A number of local basin structures are identified in the field composed of the acid volcanic rocks in the Shimokita Peninsula. The typical ones are the Ushidaki and Yagen Basin Structures constructed by the mostly dacitic Ushidaki Facies of the Hinokigawa Formation and by the remarkably dacitic Yunokawa Member of the Yagen Formation, respectively. The acid rocks are thickly accumulated

Fig. 7 Schematic diagram showing the outcrop of the Hinokigawa Formation along the coast from Fukuura to Yakeyama.

a. Dacite lava; b. Tuff breccia; c. Tuff breccia including mud ball; d. Accidental tuff breccia; e. Basalt; f. Quartz diorite; g. Phyllite

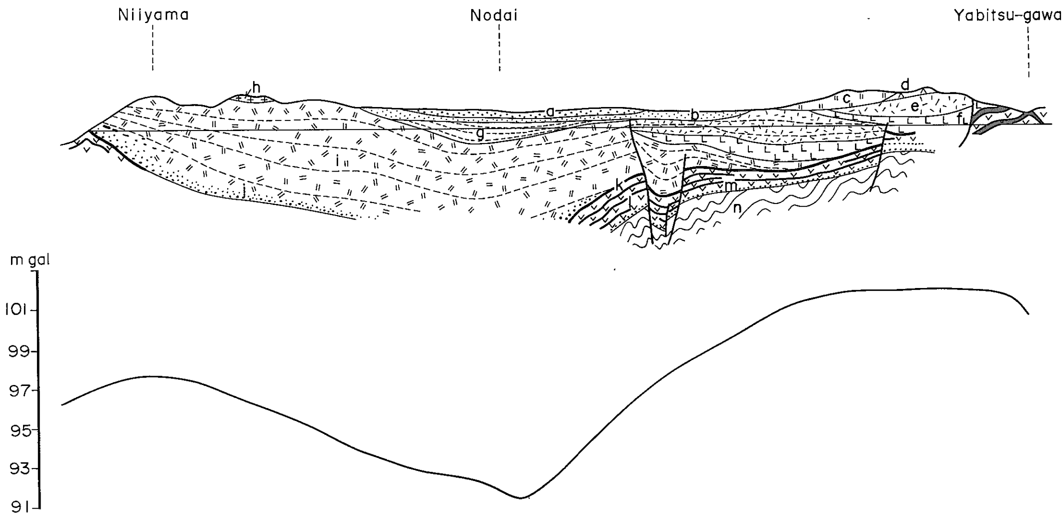


Fig. 8 Geological and gravity profiles showing the Ushidaki Basin of the Hinokigawa Formation in the vicinity of Nodai.

Quaternary:a. Nodai Formation; b. Hantarozawa Welded Tuff
Yagen Formation-Yunokawa Member; c. Dacite tuff breccia; d. Andecite lava
Hinokigawa Formation: e. Rhyolite tuff breccia; f. Rhyolite lava; g. Pumice tuff and sandy tuff; h. Dacite lava; i. Dacite tuff breccia; j. Accidental tuff breccia
Kimpachizawa Formation: k. Black mudstone; l. Basalts; m. Conglomerate
Pre-Neogene Basement Rocks: n. Phyllite

within the basins, but become thinner towards the periphery of the basins, and finally vanish; for instance, on the south of Ushidaki Basin Structure, the Ushidaki Facies is missing and the rhyolitic Otokogawa Facies younger than the Ushidaki directly overlies the Kimpachizawa Formation; on the northwest of Yagen Basin Structure, the Ikokuma Andesites directly cover the Hinokigawa Formation, entirely lacking in the Yagen Formation in between. These facts indicate that the basin structures are built by depressional movements simultaneous with depositional sequence of specific volcanic rocks. Therefore, the structures may be given the names such as the Ushidaki Basin and the Yagen Basin like sedimentary basins.

The fault scarps facing the Tairadate Straits dissect the Ushidaki Basin, providing a good profile useful to understand the inner constitution of the basin (Fig. 7). Near Oarakawa at the southern end of the profile, the basal conglomeratic tuff of the Hinokigawa Formation rests on the basalt of the Kimpachizawa Formation. As going along the scarps northwards, thick beds of dacitic tuff and tuff breccia, and then dacite lavas crop out in ascending order. The basal conglomeratic tuff carries many

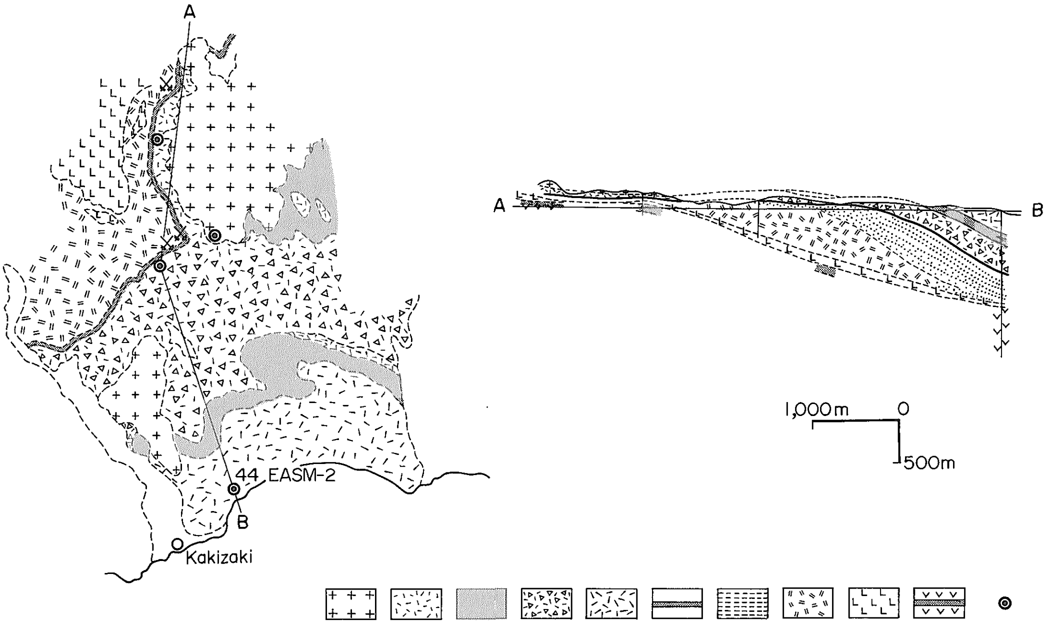


Fig. 9 Geological map and profile showing the Otokogawa Basin of the Hinokigawa Formation in the vicinity of the Nishimata Mine.

Kozawa Formation: a. Dacite lava; b. Pumice tuff; c. Hard shale
Hinokigawa Formation-Hinokigawa Facies: d. Rhyolite tuff breccia; e. Pumice tuff; f. Hard shale
Otokogawa Facies: g. Alternation of pumice lapilli tuff and tuff; h. Rhyolite tuff breccia; i. Rhyolite lava
Kimpachizawa Formation: j. Basalt with intercalations of black shale
k. Drilling site

blocks of mudstone supplied from the underlying Kimpachizawa Formation. Most blocks are angular, but some are flat-shaped or somewhat rounded, attaining as large as 3m in thickness or in diameter. They are as a whole the kind of mud fragments and mud balls which are very popular in the deposits due to turbulent flows associated with slumping phenomena. The beds of tuff and tuff breccia are spotted by quartz crystals which are characteristic of the Ushidaki Facies, and compose the principal part of the basin. They are subaqueous pyroclastic flow deposits whose fragments are ill-sorted. The units of flows are from 50 to 60 m in thickness, and the absence of any sediments and weathering products between them suggests that the flows are formed successively without long time intervals. The flows show overlapping features towards the periphery of the basin. The dacite lavas are also typical ones of the Ushidaki Facies rich in phenocrysts. They are in contact with the pre-Tertiary rocks at the northern limit of the profile near Fukuura. Although the deposits above the flows are not exposed on the scarps, they consist of alternating beds of pumiceous lapilli tuff and tuff as seen in the uppermost stream of the Ushidaki River (Fig. 8).

Other basins of similar character, such as the Otokogawa, Takiyama and Hinokigawa Basins, are recognized in the areas of the Hinokigawa Formation. They are semi-basin in shape from 2 to 5 km in diameter and with openings to the south, and appear in a row overlapping one after another.

Among them, the Otokogawa Basin is composed of the rhyolitic Otokogawa Facies. As shown in Fig. 9 its inner constitution is elucidated from the drillings performed in the Nishimata and Iwadaki Mining Fields and at Nagahama (44 EASM-2). Resting upon the mudstone of the Kimpachizawa Formation, mud flow deposits containing rhyolite pumice and lithic fragments, lavas of rhyolite with rare phenocrysts of quartz and plagioclase, tuff breccia carrying accidental fragments, and well-sorted beds consisting of tuff breccia-lapilli tuff, sandy tuff and fine-grained tuff are successively accumulated, and they as a whole manifest sedimentary imbrication structure suggesting migration of sedimentary center. Among them, tuff, tuff breccia and pumice tuff carrying accidental fragments are subaqueous pyroclastic flow deposits, which comprise at least several flow units; individual unit measuring 50 to 130 m thick at the thickest place. In the uppermost beds, cyclic assemblages from tuff breccia to lapilli tuff or from sandy tuff to fine tuff indicate that one assemblage corresponds to one unit of pyroclastic flow. According to the drilling performed at Nagahama, twenty five units are revealed.

The deposits of the Otokogawa Basin are overlain by the mudstone of the Lower Kozawa Formation, which spreads beyond the basin, and therefore the completion of the basin is prior to the sedimentation of the Lower Kozawa Formation.

The main part of Yagen Basin in the area of Yagen Formation is superposed on the top of the general dome structure in the upper stream of the Ohata River. In the marginal part of the basin, talus conglomerate is present, but in the rest of the basin, dacitic tuff or tuff breccia covers the Hinokigawa Formation. The tuff breccia is unsorted and includes accidental fragments of andesite, rhyolite and mudstone, suggesting the deposit of subaqueous pyroclastic flow. The thickness of one flow is presumed to be about 30 m or more all over the basin in so far as the observations, except for the uppermost part of the pyroclastic flows which consist of alternating beds, each being 2 or 3 m thick and separated with a seam of fine-grained tuff. The existence of dacite lavas approximately 60 m thick is proved beneath the tuff breccia by the drilling (44 EASM-1).

5.2 Cycle of the Volcanic Activity

A regular sequence of volcanic deposits is recognized throughout the above-enumerated basins. Namely, it consists from the base upwards of (1) pebbly tuff, mud-flow deposits and talus conglomerate, containing angular blocks and balls of mudstone coming from the underlying formations such as the Kimpachizawa Formation, (2) lavas, (3) subaqueous pyroclastic flow deposits of tuff breccia containing ill-sorted accidental fragments and pumice, and intercalations of lava; the unit of pyroclastic flows is several ten meters or locally more than a hundred meters in thickness, and (4) well-sorted fine-grained subaqueous pyroclastic flow deposits; one unit of flow is from several meters to nearly ten meters thick.

In some basins, one or two of the above-mentioned sequence are missing, but the order of succession never changes.

Judging from the regularity of deposits, the sequence of volcanic activities of acid rocks associated with the crustal movements is concluded as follows. (1) It begins with the eruption of a small amount of pyroclastics and the simultaneous subsidence or depression to form the basin. On the slopes of the marginal part of the basin, slumping phenomena take place. The mud fragments and the mud balls are supplied from unsolidified parts of the underlying formations into the pyroclastic deposits in the marine area, while the conglomerate beds are originated from the talus deposits in the land area. (2) Then, the lavas are erupted within the basin, and a large amount of coarse-grained pyroclastic flows gush out and fill up the basin. (3) In proportion to the weakening of volcanic activity, pyroclastic flows gradually decrease in volume as well as in grain size of fragments. The good sorting and clear stratification of the deposits show the comparatively calm state of depositional environments with slow rate of subsidence. The eruptions and the movements repeat for several or several tens of times until the completion of basin.

After one cycle of volcanic activity mentioned above is over, the basin is covered by the thin beds of mudstone during the pause of activity, and in turn by new volcanic products of the next repeated activity.

The Mimmaya Rhyolites in the Tsugaru Peninsula are the deposits in a similar basin. They are very thick, but as leaving from the basin they abruptly thin away to become the interlayers between the Lower Kodomari and Upper Kodomari Formations. This basin is constructed by one cycle of very violent volcanic activity, and by a rapid depression in a short time as compared with the general subsidence in the surrounding areas, where muddy sediments are deposited.

6. History and Characters of Geotectonic Movements and Volcanic Activities

6.1 Geotectonic History

Like other areas in the Green Tuff Region of Northeast Honshu, this district was under the terrestrial and erosional environments for a long time since Cretaceous period.

At the earliest Miocene, the subsidence associated with the volcanic activities broke out, and since that time the sedimentary and volcanic rocks were thickly accumulated mostly under the marine environment. Lately, the general uplifting took place resulting in the completion of present land topography. The historical transitions of the geotectonic movements and volcanic activities are classified into the successive ages as follows.

1) Gongenzaki Age

This age corresponds to the opening age of tectonic movements and volcanic activities all over the Green Tuff Region of Northeast Honshu.

In the Tsugaru Peninsula, the Gongenzaki Formation, mostly of coarse-grained pyroclastic rocks and lavas of andesite are accumulated. The presence of Aniai Fossil Flora and the welded tuff indicates that the depositional environment is cold in climate and still terrestrial. On the other hand, the Shimokita Peninsula where the equivalent formation is absent, may have been an eroded land area.

2) Isomatsu-Fuyube Age

This age is the beginning of marine transgression in the Tsugaru Peninsula. Firstly a narrow zone stretching from the west wing of Yotsudaki Dome to the Katakariishizawa is subsided, and the Isomatsu Formation consisting of conglomerate, sandstone and siltstone is deposited. Then, the subsidence is advanced, covering almost all over the peninsula. The volcanic eruption continuous from the previous age becomes violent, and the Fuyube Formation composed of andesitic pyroclastic rocks intercalated by sandstone and siltstone is piled up. The marine Kadonosawa Fauna in the Isomatsu Formation and the Daijima Flora in the Fuyube Formation imply the climate to have changed to warm one. However the existence of welded tuff which is discovered in the Katsuragawa River area indicates that the subsidence is almost stopped at the end of the age, leaving a local land near Yotsudaki Dome.

In the Shimokita Peninsula, the relatively stable state without any subsidence and volcanism is

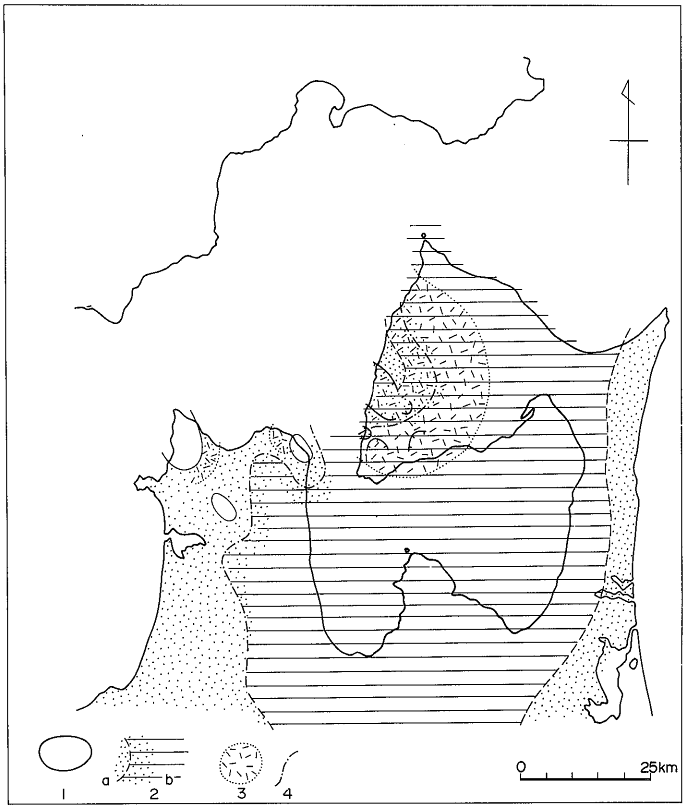


Fig. 10 Paleogeographical map of the northern area of Aomori Prefecture.

Nagane Age

1. Land; 2. Marine basin: a. Sandy facies; b. Muddy facies; 3. Volcanic center; 4. Isopach line of 200m thick

still maintained.

3) **Nagame Age** (Fig. 10)

As entering in this age, the Tsugaru Peninsula is subjected to the subsidence on a full scale, and the Shimokita Peninsula also begins to submerge and to undergo an eruption of basalt. Thus the marine areas expand largely over the district.

In the Tsugaru Peninsula, the volcanic activity of andesite which has been intensive in the previous age becomes local, and produces lapilli tuff and sandy tuff, and the Nagane Formation characterized by green-coloured tuffaceous sandstone and black mudstone is accumulated. The subsidence, however, is not uniform over the peninsula, leaving the northern part of the Yotsudaki Dome, the east end of the Kodomari Peninsula and the neighbourhood of Horozuki Dome, unaffected from notable subsidence. Tuffaceous sandstone which contains the molluscan fossils indicating warm and neritic environment is deposited in the above-noted areas, while black mudstone intercalated with tuffaceous sandstone and fine-grained tuff is deposited under the deeper waters far away. Simultaneously with the sedimentation, a large amount of the basalts are erupted as lavas and tuff breccia. The dike swarm northeast of Horozuki Dome shows a close relation between the fractures and the eruptive feeders.

The Kimpachizawa Formation consisting of siliceous shale and black mudstone associated with

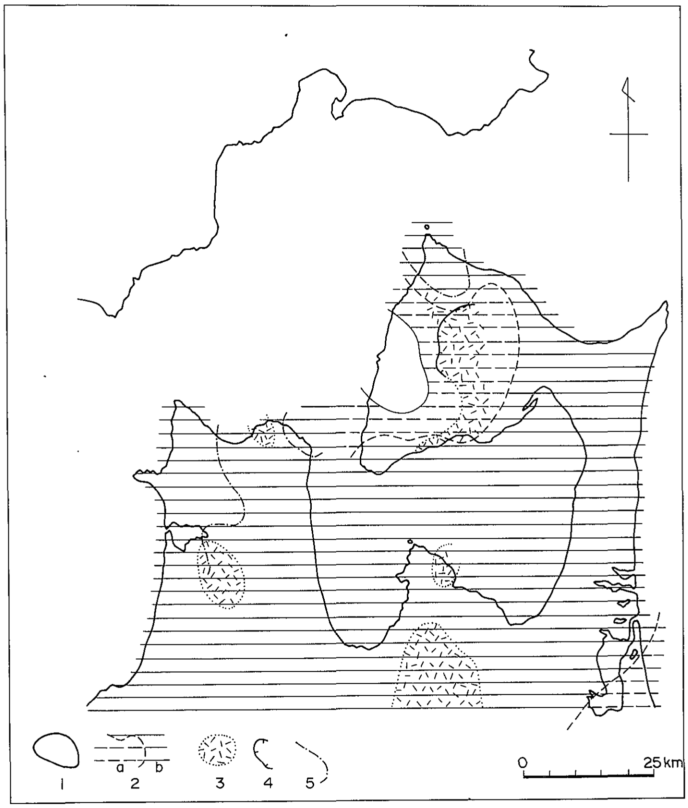


Fig. 11 Paleogeographical map of the northern area of Aomori Prefecture.

Lower Kodomari Age.
1. Land; 2. Marine basin: a. Sandy facies; b. Muddy facies; 3. Volcanic center; 4. Volcano-tectonic basin; 5. Isopach line (200m)

basalt represents the early course of this age in the Shimokita Peninsula. The increasing thickness of the formation from center to outside of the gentle dome structure in the peninsula signifies that the dome movements start already in this age. In the later course of this age, the volcanic activity of basalt is gradually weakened, and that of acid volcanic rocks takes place instead, accumulating the lower part of the Hinokigawa Formation, and keeps on also in the following Lower Kodomari Age. It occurs firstly in the central part of the broad dome structure, producing the dacitic Ushidaki Facies, which fills up the Ushidaki Basin and a small basin north of Bushidomari as well. The activity expands outwards from the broad dome structure, extruding the rhyolite in the Otokogawa, Takiyama and other basins, each of which is a center of eruption. During the short intervals between the cycles of the volcanic activity, thin beds of black mudstone are deposited as seen in a tributary of the Otokogawa River. As the mudstone is the same in character as that of the Kimpachizawa Formation, it is conceivable that the sedimentary environments in the earlier and the later courses of this age are almost unchanged.

4) **Lower Kodomari Age** (Fig. 11)

This age is correlated to the Onnagawa Age, which is widely known as the typical age of the largest transgression in the Green Tuff Region. The well-stratified beds of hard shale which denote the Onnagawa Age are quite extensive also in the present district, except the central part of the Shimokita Peninsula.

In the Tsugaru Peninsula, the Lower Kodomari Formation is of this age. The beds of extremely siliceous shale are followed by thick accumulations of a little more muddy, hard shale. At the same time, rhyolites and dacites are extruded locally in the areas south of Imabetsu, near Horozuki and west of the Hakamagoshi-dake Dome, and are piled up as lavas and coarse-grained pyroclastic beds. The intercalations of pumice tuff occurring throughout the shales of the Lower Kodomari Formation are also derived from this volcanic activity.

The effusion of basalt which has been remarkable in the previous age is gradually weakened, and the basic rock appears mostly as dolerite occurring as intrusive sheets into the beds of hard shale.

In this age, the general structural trend from north to south in the Tsugaru Peninsula gradually comes to appear. The terrain on the east side of anticlinal belt linking the Yotsudaki Dome and the gravitationally high anomalies is greatly submerged. At the same time the west side of Shimokita-kaigan Fault, presumably generated in advance, is submerged, giving rise to a subsiding zone stretching from north to south and including the Tairadate Straits. Exceptionally the subsidence is weak in the environs of Horozuki Dome, and a volcanic basin structure is formed by lavas and coarse-grained pyroclastics of rhyolite which is erupted in the neighbourhood of the 200 m isopach line of the lower Kodomari Formation.

In the Shimokita Peninsula, the Lower Kodomari Age is chiefly demonstrated by the volcanic activities of rhyolite and dacite continuously active from the previous age, and the beds of hard shale, namely the Lower Kozawa Formation occur only near Oma at the northwest corner of the peninsula and near Kozawa along the southern coast. The volcanic activities are divided into the earlier and later stages as follows.

The volcanic activity which has constructed the Ushidaki and Otokogawa Facies of the Hinokigawa Formation in the previous Nagane Age is considered to halt for a while, as suggested by thin deposition of hard shale as seen in the Nishimata mining area. After that, the activity revives violently, and this is the earlier activity in the Lower Kodomari Age. The upper part of the Hinokigawa Formation, that is, the Hinokigawa Facies consisting of perlitic rhyolite lavas and pyroclastic rocks are accumulated mainly in the areas east of the Nishimata River, filling up the volcanic basin.

The sedimentation of hard shale of the Lower Kozawa Formation follows the above-mentioned volcanic activity. On the other hand, the activity continues to the later age to the northeast of Kozawa and accumulates the Yagen Formation of mostly dacitic rocks.

The dacites are effused firstly as lavas and then abundantly as pyroclastics from the eruptive centers which are now known as the local lows of gravity anomaly in the upper streams of the Ohata and Kawauchi Rivers. They compose the Yunokawa Member, filling the Yunokawa Basin which is formed by the subsidence simultaneous with the volcanism. This basin is located in the slope of general dome structure in the Shimokita Peninsula. It is conceivable that the central part of the dome is already a land at this age, because the lowermost part of the Yunokawa Member contains plant fossils. Contemporaneously with the latest course of constructing the Yunokawa Basin, the Yunokogawa and Kamanosawa Members mostly of finer-grained deposits are accumulated in local sedimentary basins located in the areas of the Yunokogawa and the Kamanosawa Rivers, respectively.

The pumice beds in the Lower Kozawa Formation, namely the Ginnanboku Member, are pumice

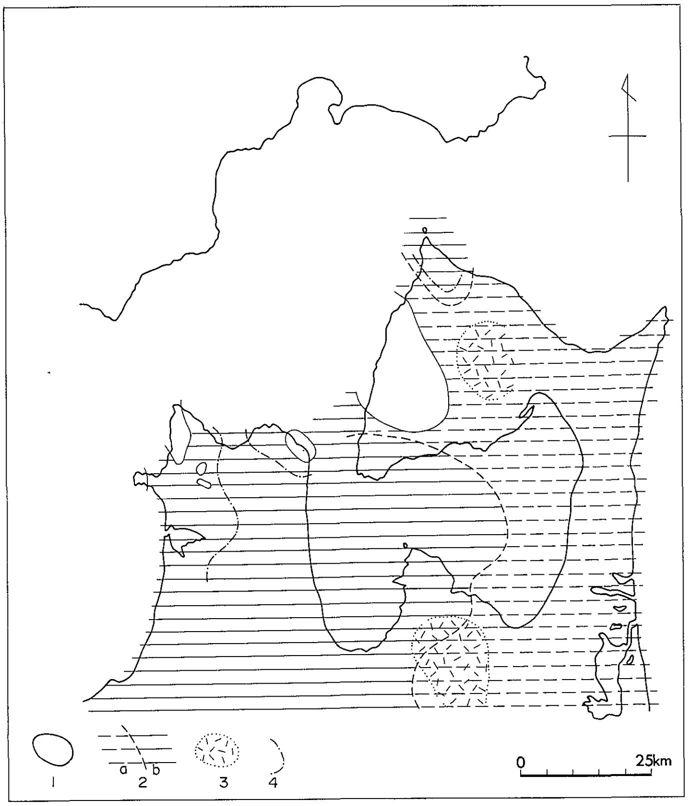


Fig. 12 Paleogeographical map of the northern area of Aomori Prefecture.

Upper Kodomari Age.

1. Land; 2. Marine basin: a. Sandy facies; b. Muddy facies; 3. Volcanic center; 4. Isopach line (200m)

flows from the eruptive centers near Abeshiro. They interfinger with the hard shale in the Shukunobe area, and grade into the lower part of the Yunokogawa Member of the Yagen Formation in the Yunokogawa River area, providing the key to disclose the contemporaneity of the two formations.

Regarding the sedimentary environments of this age in the Shimokita Peninsula it can be deduced that the dome structure surrounding the basement rocks, which has been the area of least subsidence in the previous age, gradually reveals the character of an elevating land-block, and that the Yagen Formation is accumulated mostly in the neritic sea enclosing the land, while the Lower Kozawa Formation is deposited under the deeper sea in the distance.

5) **Upper Kodomari Age** (Fig. 12)

The subsidence in the zone covering the Tsugaru Peninsula and the Tairadate Straits is continuous from the previous age and much more advanced in this age, extending as far as the periphery of the general dome structure in the Shimokita Peninsula. The massive argillaceous sediments same in lithologic character as the so-called black shale of the Funakawa Formation in Akita Prefecture are the representative of this age. The greatest subsidence is along the west side of Tsugaru Fault. Dark grey, massive mudstone which indicates a stagnant sedimentary environment is thickly deposited in the belt, which is now manifested by 200 m isopach line of the Upper Kodomari Formation.

In the Shimokita Peninsula, the beds of dark grey-coloured mudstone composing the Upper

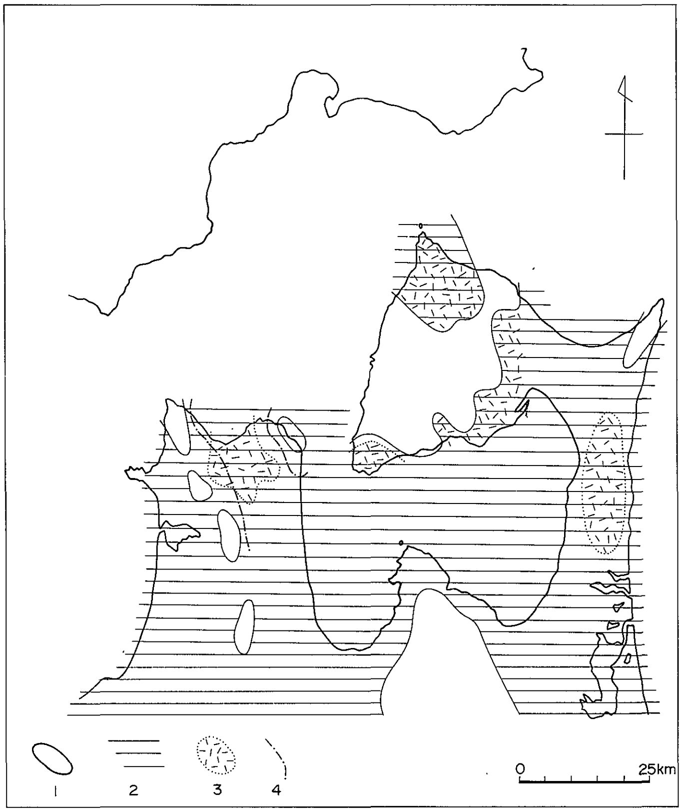


Fig. 13 Paleogeographical map of the northern area of Aomori Prefecture.
Shiwokoshi Age.
1. Land, 2. Marine basin; 3. Volcanic center; 4. Volcano-tectonic basin; 5. Isopach line(200m)

Kozawa Formation are thin and seen only in such areas as near Oma, north of the Kuchihiro River and west of Kozawa. The pumiceous tuff of the Kuzusawa Member of the same age is also limited in the coastal area from Kozawa to Kawauchi. In the major central part of the peninsula, the land is gradually expanding since the previous age, as shown by the intercalations of welded tuff in the Yunomatagawa Dacites of this age.

6) **Shiwokoshi Age** (Fig. 13)

During the interval between the preceding age and this age, uplifting movements begin to occur from the west in the subsiding zone which has subsisted since the Nagane Age in the Tsugaru Peninsula. The area of Hakamagoshi-dake and its north, which has been a part of subsiding zone, turns to an uplifting belt of north-south trend, which extends to Umanokami-yama (mountain) in the south, and gradually uprises particularly along the axis of the Hakamagoshi-dake Dome and Hamanazawa Anticline. The Yotsudaki-yama where the subsidence has been weak until the previous age also turns into the uplifting area. TheTsugaru Fault is generated on the east side of the uplifting belt, and the terrain between the fault and the Shimokita-kaigan Fault remains as a new subsiding zone of north-south direction. On the west side of the uplifting belt, a shallow sedimentary basin is left, covering the Lake Jūsan area and its south. The Shiwokoshi Formation is of the sediments in the differentiated basins.

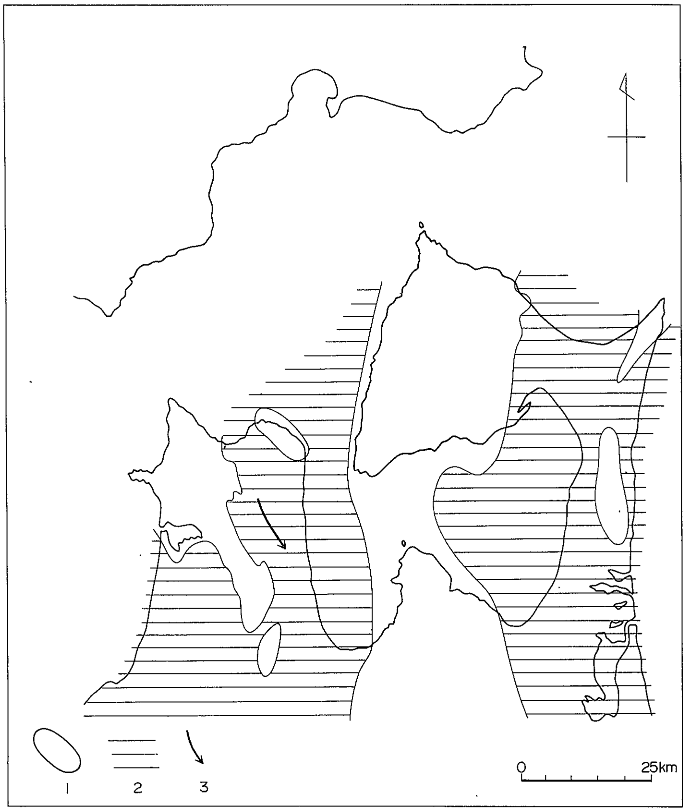


Fig. 14 Paleogeographical map of the northern area of Aomori Prefecture.
Kanita Age.
1. Land; 2. Marine basin; 3. Trend of palaeocurrent

The Shiwokoshi Formation is made up of diatomaceous siltstone, and some intercalations of pumice tuff, tuffaceous sandstone etc., although the lowermost part consists of siliceous shale and tuffaceous sandstone as seen in the uplifting belt and on the Horozuki Dome. In the later course of this age, the volcanic activity of the Imabetsu Andesites takes place in the areas of the Yotsudaki Dome and the Horozuki Dome.

In the Shimokita Peninsula, the land due to the general upheaval expands as far as the coast of Mutsu Bay in the south and covers the wide areas from Sai to the north of the Ohata River in the north. Covering the land and the surrounding shallow sea the thick accumulation mainly of agglomerate is produced by the volcanic activity of the Ikokuma Andesite. The Oma and other anticlines in the peninsula are possibly formed in this age, although actual evidences are insufficient.

7) Kanita Age (Fig. 14)

The upliftings in both peninsulas advance more in this age, and the sea is retreating.

In the Tsugaru Peninsula, the uplifting extends onto the east side of Tsugaru Fault, and the Yomogida Anticline and its extension arise within the belt which has been the subsiding center in the Shiwokoshi Age. The terrain east of the uplifting belt remains as subsiding zone which shows the opening to the south and has the center nearly along the present axis of the Oguni and Imabetsu Anticlines. The Kanita Formation is deposited in this zone.

The Kanita Formation mainly consists of sandstone. The grain size gradually increases towards the upper part of the formation, implying the regression of the sea. However, a temporary transgression is noticed in the later course of this age because the formation shows the overlapping feature towards the north and finally in the south of the Horozuki Dome it covers the dacitic tuff of Shiwokoshi Formation with an unconformity.

The Shimokita-kaigan Fault is the eastern limit of the sedimentary basin of the Kanita Formation. It is thought that the movements on the Tsugaru and Shimokita sides bounded by the fault are contrary with each other. The Shimokita side is mostly the land, and here the sea much retreats. The Ohata Formation is the deposits in the open shallow sea on the opposite side of the land in this age.

8) Post-Kanita Age

The Horozuki and Kanita Anticlinal belt in the Tsugaru Peninsula gradually uprise and, joining with the areas having uplifted before, emerge as lands which are now mountains and hills. The Shimokita Peninsula has changed to the land almost as it is now. Osoreyama and Hiuchidake Volcanoes are erupted since the beginning of Quaternary Period. The Noheji Formation is deposited and emerges as the coastal terraces.

The Tairadate Straits lying between the gradually uprising two peninsulas, however, rapidly submerge after the sedimentation of the Kanita Formation. The subsidence on the Tsugaru side which has been greater than that on the Shimokita side throughout all ages is gradually decreasing in extent from the west owing to the progressive uplift since the Shiwokoshi age. But, the Tairadate Straits continues to depress even in the post-Kanita Age, when the present disposition of land is almost completed. The Kanita-kaigan Fault is possibly generated in this age along the border between the uplifting Tsugaru Peninsula and the submerging Tairadate Straits. In the area between the fault and the Shimokita-kaigan fault, the sediments of post-Kanita Age are thick as seen in the Aomori Plain to the south, suggesting that the subsidence is lasting even now. A striking negative of gravity anomaly reflects this subsidence.

The great thickness of Quaternary deposits proved in the Aomori Plain shows this subsiding zone is one of the deepest depressed areas of Quaternary Period in the Green Tuff Region of Northeast Honshu. The well-known Hanawa, Yokote and other large inland basins located in the Akita Prefecture and to the south are similar in nature to this subsiding zone. They are sporadically distributed in the north-south direction along the western margin of the so-called "Backbone Range," one of the geotectonic divisions of the Green Tuff Region. They are also related with faultings closely and exhibit negative gravity anomaly remarkably.

The transitions of the geotectonic movements described above are summarized in Table 2 and shown in Fig. 15 by a series of schematic profiles.

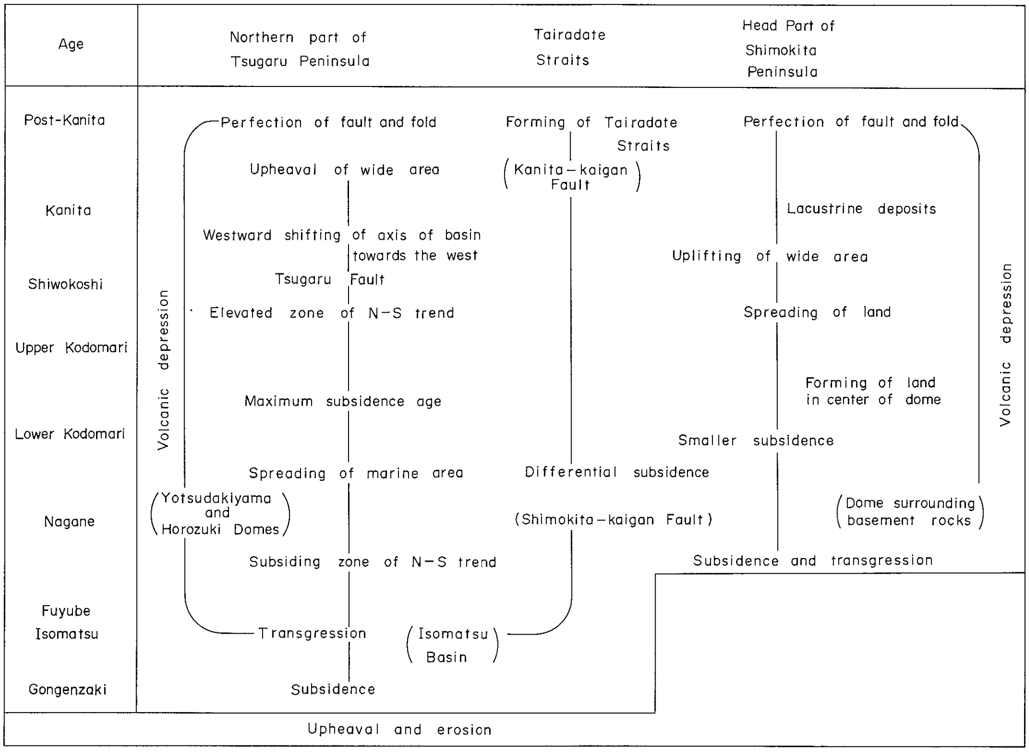
6.2 Specific Characters of Geotectonic Movements

1) Comparison to the movements in the Akita–Iwate District

The conception on the Neogene tectonism hitherto described includes several points differing from the opinions ever expressed by other investigators, whose works are principally based upon the researches in the Akita–Iwate District and with little attention to the present author's field.

The elaborated geologic works are made by Kitamura (1959), Inoue (1960), Ikebe (1962), and others. Notwithstanding some discrepancies among their stratigraphic classifications, the views on the

Table 2 Scheme of the volcanic activity and geotectonic evolution in the northern area, Aomori Prefecture.



tectonic movements are generally in accord with each other. Here, the view of Kitamura, who summarizes the history of Neogene tectonism referring to the wide areas over the Akita–Iwate District, will be briefly presented.

He divides the tectonic evolution into seven stages. In his Stage I and the earlier half of Stage II which correspond to the author's Gongenzaki and Isomatsu-Fuyube Ages, respectively, the volcanic activity and subsidence begin simultaneously in both the Backbone Range and the Dewa Mountains, another tectonic division of Green Tuff Region. A trough of north-south trend is formed along the center of this primeval subsidence, and extends to the Backbone Range and the Kitakami River Area on the east. The sea transgresses from the east, and expands to the west as far as the Dewa Mountains. In the later half of Stage II which corresponds to the Nagane Age, the sea reaches to the coastal areas of the Japan Sea. Consequently, the subsiding center is shifted to the west, being successively filled with the thick beds of fine-grained sediments by rapid submergence; the deepest subsidences are in the Dewa Mountains in Stage III which corresponds to the Lower Kodomari Age, and in the west coast in Stage IV which corresponds to the Upper Kodomari Age. On the contrary, the Backbone Range where the first subsiding center is located gradually changes to the shallow sea in Stage III, and emerges as land, being accompanied by the wide-spread eruptions of dacite during the period from the later half of Stage III to Stage IV. After Stage V which corresponds to the Shiwokoshi Age, the Dewa Mountains turns to uplift, leaving the basins between the emerged zone and the Backbone Range. These basins continue to subside independently of the uplifting on both

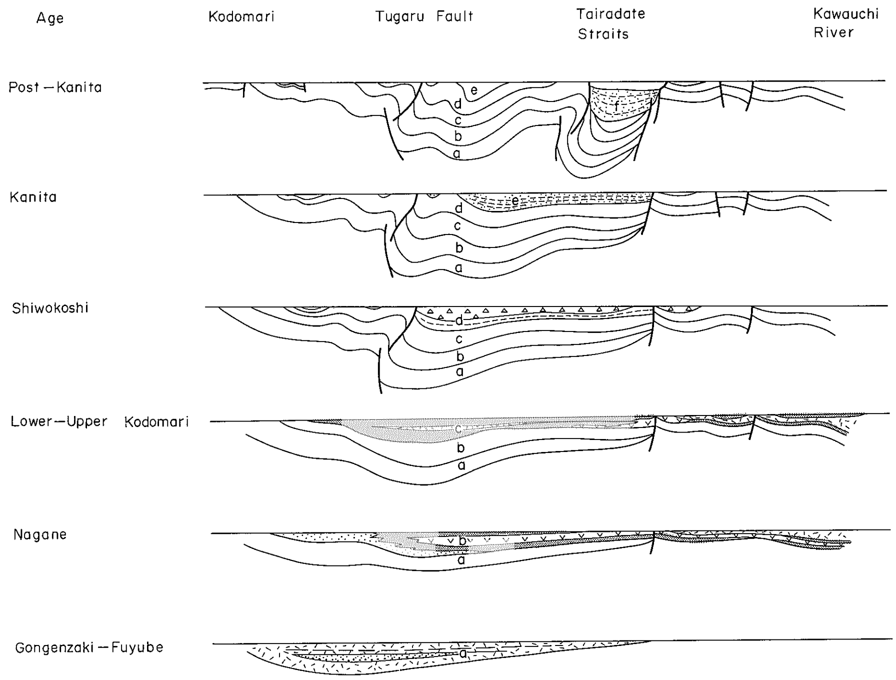


Fig. 15 Schematic profile showing the geotectonic evolution of the Neogene in the northern area, Aomori Prefecture.

a. Gongenzaki, Isomatsu and Fuyube Formations;
b. Nagane, Kimpachizawa and Hinokigawa (lower) Formations;
c. Lower Kodomari, Lower Kozawa and Hinokigawa (upper) Formations;
d. Shiwokoshi Formation and Imabetsu and Ikokuma Andesites;
e. Kanita Formation;
f. Quaternary Formation

sides, but finally in Stage VI and VII corresponding to the Kanita Age are filled up by lake deposits.

The Tsugaru Peninsula and the head part of Shimokita Peninsula have been structurally treated as the northern extensions of the Dewa Mountains and the Backbone Range, respectively, but the author recognizes the specialities of tectonic movements in two peninsulas, which is remarkably different from the current views, as summarized below.

In the Gongenzaki and Fuyube Ages, the volcanic activity and the transgression are limited only in the Tsugaru Peninsula, and the Shimokita Peninsula together with the Natsudomari Peninsula to the south as well as the Kameda Peninsula of Southwestern Hokkaido, all hitherto regarded as the extension of the Backbone Range, are left as an extensive land. In the Nagane Age, the sea expands across both the Tsugaru and Shimokita Peninsulas except the areas of dome structures of the northwest trend where the subsidences are less in amount. Iwasa (1962) states that black mudstone and siltstone of his Stage III, which corresponds to the Nagane Age, are thickly deposited in a trough-like sedimentary basin extending in north-south direction from Oani through Odate in Akita Prefecture to the mountain range of the Tsugaru Peninsula in the Aomori Prefecture. But it is rather properly assumed that the sedimentary basin of this age extends far to the east in Aomori Prefecture, because the black mudstone is widespread not only in the Nagane Formation in the Tsugaru Peninsula but also in the Kimpachizawa Formation in the Shimokita Peninsula as well as the equivalent formation in the Natsudomari Peninsula.

During the period from the Lower Kodomari Age to the Upper Kodomari Age, the Tsugaru Peninsula deeply submerges like other districts of the Dewa Mountains, and here hard shale and black mudstone are thickly deposited. In the Shimokita Peninsula, the areas surrounding the exposures of the basement emerges as land. But the Oma area in the north and the coastal area facing Mutsu Bay in the south continue to subside, and to deposit the shale and the mudstone same in character as those in the Tsugaru Peninsula. It shows a striking contrast to the Backbone Range of Akita–Iwate District, where the environments are turning in this age to a shallow sea depositing coarse-grained sediments and then to a land.

In the Shiwokoshi Age, the central part of the Tsugaru Peninsula turns to uplift. The sedimentary basins gradually decrease in width and are differentiated. But, the areas covering the Kanita River and the Tairadate Straits which correspond to the inland basins of the Akita–Iwate District, remain in neritic environments, and among them the Tairadate Straits continues the subsidence up to the present.

As far as the above-mentioned geotectonic evolution since the beginning of the Nagane Age is concerned, the conception that the Shimokita Peninsula and the Tsugaru Peninsula are structurally the extensions of Backbone Range and the Dewa Mountains in the Akita–Iwate District, respectively, is not accepted, because the common sequences of tectonism between the respective districts are quite scarce. It is rather recognizible that the Shimokita Peninsula as well as its extensions to the north and south beyond the sea and the axial zone of the Tsugaru Peninsula are similar to the Dewa Mountains, and that the remaining areas of the Tsugaru Peninsula such as the Tsugaru Plain and the Kanita River area combined with the Tairadate Straits are similar to the Japan Sea Coastal Zone in the Akita District, which is another geotectonic division of the Green Tuff Region.

KITAMURA (1959) makes a conclusion about the Neogene orogenesis in Northeast Honshu as follows. "It is clear that the parallel geanticlinal and narrow subsiding zone of sedimentation in this geosyncline was shifted from the east to the west during the course of orogenic evolution". But when the Aomori District is put together into Northeast Honshu, the tectonic movements are not fully expressed only by his conclusion. The author considers that the Green Tuff Region of Northeast Honshu is subjected to an overall slow subsidence since Neogene Period. The so-called Morioka–Shirakawa Tectonic Line which practically defines the east border of the region might have a certain connection with this general subsidence. The region, however, is differentiated into a number of tectonic zones due to the local difference of subsiding rate, which is resulted from the mutual relationship of the general subsidence and the local upliftings. In the Backbone Range and the Dewa Mountains of the Akita–Iwate District, the amount of uplift exceeds the general subsidence and the lands emerge since early ages, while in the Aomori District the subsidence overwhelms the uplift and as a whole the subsidence continues up to the later ages.

2) Uplifting movements of northwest trend and volcanic activities

As already stated, the acid volcanic rocks and the andesites of the Nagane and later ages occur around the uplifting zones of northwest trend such as the Yotsudaki-yama and Horozuki Domes in the Tsugaru Peninsula and the dome structure enclosing the pre-Tertiary basement in the Shimokita

Peninsula.

The occurrences of the basement rocks generally at the centers of the uplifting zones of northwest or north-northwest trend in the Green Tuff Region of Northeast Honshu have been noticed by many investigators, and moreover, the coincidence of the uplifting zones with the volcanic activities of acid rocks has been pointed out by KITAMURA (1959), IKEBE (1962), FUJITA (1960) and others. According to KITAMURA (1963), the structure of northwest trend is essentially connected with the pre-Tertiary fracturings. The blocks surrounded by the fractures continue to tilt towards the northeast by means of a certain rotating movements since the beginning of Neogene Period. He says the localization of volcanic activity is particular in such structure, although no further comments about the detailed process are given.

The author will explain, hereunder, the relations between the uplifts of the basement in the Shimokita Peninsula and the occurrence of volcanic deposits such as the Hinokigawa Formation, the Yagen Formation and the Ikokuma Andesite. The Hinokigawa Formation directly overlaps on the basement rocks at the top of the general dome structure to the northeast of Fukuura. Its basal part is conglomerate containing the pebbles of basement rocks. Likewise, the Yagen Formation covers the eroded surface of the Kimpachizawa or Hinokigawa Formation occupying the slope of the dome structure in the upper stream of the Yunokawa River. The basal part of the Yagen Formation is of conglomerate and sandstone containing the pebbles of black mudstone and basalt of the Kimpachizawa Formation or rhyolite of the Hinokigawa Formation. Similarly, the Ikokuma Andesite unconformably rest on the Hinokigawa Formation composing the further down slope of the dome structure in the north of the Kozai River or on the Yagen Formation in the upper stream of the Ohata River. They begin with the beds of granule conglomerate at the base. The existence of unconformity with conglomeratic beds at the base of above-mentioned volcanic deposits suggest that the basemental block is exceedingly uplifted just before every volcanic activity. Moreover, it is understood that a subsidence occurs afterwards in wide areas, extending into the uplift region, because the volcanic deposits are, in turn, overlain by subsequent formations including marine deposits.

Unconformity and basal conglomerate are not observed at the base of the Imabetsu Andesite in the Horozuki Dome area of the Tsugaru Peninsula. It might be due to the lesser amount of uplifting from the Lower Kodomari Age to the Shiwokoshi Age and to the meagreness of resultant transformation to the land.

The volcanic rocks directly connected with this kind of uplifting belong mainly to the calc-alkali rock series ranging from rhyolite to andesite.

7. Conclusion

The characters of the Neogene including the stratigraphy, the petrography of volcanic rocks, the changes of rock facies and thickness of formation, the geologic structures, the gravity distribution, the volcano-tectonic features of acid rocks, and the cycle of volcanic activities are studied, and by summarizing them the geotectonic evolution of the district is elucidated. The results to be particularly emphasized are as follows.

1) It was clarified that the Neogene histories of the Tsugaru and Shimokita Peninsulas considerably differ from each other. The Neogene in the Tsugaru Peninsula consists of eight formations from

the Gongenzaki to the Kanita, which are correlated with the type formations from the Monzen to the Shibikawa in the Oga District of Akita Prefecture. On the other hand in the Shimokita Peninsula, it lacks the formations older than the equivalent to the Nagane in the Tsugaru Peninsula, correlated with the Nishikurosawa Formation in the Oga District, and is classified into the formations from the Kimpachizawa to the Ohata.

2) Volcanic substances are more or less developed throughout the Neogene, and occur as the constituents of the sedimentary formations and as local, volcanic bodies. They are widely subjected to the alterations characteristic of the Green Tuff Region, except for those younger than the Upper Kodomari Formation in the Tsugaru Peninsula and the Upper Kozawa Formation in the Shimokita Peninsula, both of which are of the upper Miocene.

Petrographically, the volcanic rocks are mainly of calc-alkali rock series except for basalt and a part of andesite which belong to tholeiitic rock series.

3) The facies and the thickness of Neogene formations are remarkably different between the Tsugaru and Shimokita Peninsulas from each other, and this fact indicates the differentially subsiding movements of the two. The subsidence is greater throughout the Neogene on the Tsugaru side than on the Shimokita side, bounded by the submarine Shimokita-kaigan fault which is inferred to lie along the eastern margin of the Tairadate Straits.

4) As to geologic structures, gentle domes with longer axis of northwest trend and anticlines and faults of nearly north-south trend are well developed. The domes of Yotsudaki-yama and Horozuki in the Tsugaru Peninsula and the broad dome around the pre-Tertiary rocks in the Shimokita Peninsula are good examples of the former, and the Kanita Anticline and the Tsugaru Fault in the Tsugaru Peninsula are of the latter. Beside, a number of local basin structures of various extents such as the Ushidaki Basin and the Yagen Basin are recognized in the Shimokita Peninsula.

These basins were formed by a regular cycle of volcano-tectonic process closely relating to the acid volcanism. The process began with depressional movements with minor eruptions, passed substantial depression following violent eruptions of lavas and pyroclastic flows, and ended with cessation of depression soon after eruptions of repeated minor pumice flows. It is noteworthy that these movements are, therefore, genetically in close relation with the volcanic activities of acid rocks.

5) There are uplifted zones of northwest trend such as the above-mentioned gentle domes in the Neogene areas of the district. They are closely related with the occurrence of volcanic rocks of calc-alkali rock series, and such uplifting is most active just before every volcanic activity.

6) The gravity anomaly reveals the depth of the basement rocks from the surface. In Mutsu Bay and the adjoining Aomori Plain the anomaly shows a pattern of nearly north-south trend, and declines as steep as 60 mgal for about 10 km from east to west suggesting the sudden fall of the basement rocks upon which the Neogene rocks and the loose sediments of the Quaternary are thickly deposited. This movement is lasting even now. It is considered that these areas and the adjacent Tairadate Straits as a whole represent one of the remarkable subsiding zones like other inland basins of the Green Tuff Region.

7) The Tsugaru and Shimokita Peninsulas have been generally considered as the extensions of the so-called Dewa Mountains and Backbone Range by other works up to this time, respectively. But, the actual features of the Neogene suggest that it is more appropriate to correlate the Tsugaru Peninsula with the Japan Sea Coastal Zone and the Shimokita Peninsula with the Dewa Mountains.

The geotectonic evolution in the northern Aomori District is somewhat distinctive as compared with that known in the Akita–Iwate District, and such areal speciality can be explained to have been caused from the mutual relationship of the general subsidence covering the whole Green Tuff Region of Northeast Honshu and the variable rates of local upliftings within the region.

The discussions on the tectonic movements in the Green Tuff Region have been chiefly based upon the researches in the Akita–Iwate District so far. It would be desirable, however, that the characters of the Neogene in the Aomori District as well as the southwestern Hokkaido should be consolidated into the discussions. The author hopes that this paper will serve as an aid for this field of research.

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青森県北部地域における新第三紀の火山活動，構造発達史およびその特性

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要　旨

下北半島と津軽半島のあいだでは，新第三系は多くの点でかなり対照的である．両半島の間の平館海峡に覆在する下北海岸断層の存在は，このような対照的構造に対してもっとも重要である．

津軽半島では新第三系は，下位から，権現崎・磯松・冬部・長根・下部小泊・上部小泊・塩越・蟹田の各層からなり，いっぽう下北半島では，冬部層およびそれ以下の地層を欠いて，概ね下位から，金八沢・桧川・下部小沢・上部小沢または，桧川・薬研・大畑の各層の順に重なっている．これらの地層の大部分は，いわゆる東北地方グリーンタフ地域のほかの地方と同様に，火山源物質を大なり小なり含み，ある層のごときは，実はほとんど火山岩類からなっている．それのみではなく，厚い溶岩や粗い火山砕屑岩類が，局地的に新第三系の地層の間に喰込んでいる．津軽半島で，玄武岩類・三厩流紋岩類・母衣月火山岩類・今別安山岩類，下北半島で，湯ノ股川石英安山岩類・易国間安山岩類として特に区別した．

構造的には，北西方向に延びた緩いドーム構造が顕著であり，その好例は下北半島の基盤岩類のまわりに拡がっているドーム構造や，津軽半島の北東に近い局地的なドーム構造にみられる．これらのドーム地域は，本来隆起上昇地塊の性格を持っていたもので，その結果新第三系の堆積岩類は，ドームに近づくに従って厚さを減じていることからみて，ドーム地域はほかより早くから陸化したことを示している．ドームの隆起は，津軽半島の母衣月火山岩類や下北半島の桧川層と薬研層との流紋岩ないし石英安山岩，また易国間安山岩類の噴出と関係があり，これらの火山岩類の各活動の直前では特に著しかった．

津軽半島と平館海峡においては，南北に近い方向の背斜・向斜および断層が顕著で，これらが上記のドーム構造と組合わさっている．しかし下北半島ではこの種の構造は発達が悪く，前記の広いドーム構造が支配的である．下北海岸断層は，南北方向の構造のなかで最も顕著なものであり，津軽側から下北側へ向かって断層を越えると火山岩類を除く新第三系は厚さを減じ，また重力異常も急に増加して，基盤岩が急に浅くなっていることを示している．

地史的にいえば，この地域では，長い陸化削剝の時代を経て中新世のはじめに，津軽半島にまず安山岩の噴出と沈降が起こり，海成の火山岩類を主とする権現崎・磯松・冬部の各層が堆積した．やがて本格的な海侵が津軽半島で起こり，概して細粒の凝灰質ないし泥質の堆積岩からなり，玄武岩の水中溶岩を多数挾有することを特徴とする長根層が堆積した．海侵は徐々に拡大して，広い堆積盆を形成するようになり，海域は下北半島の側まで拡がり，長根層に比べると層厚がやや薄い金八沢層が堆積した．

この時期以来，下北海岸断層の両側は，互いに差別的な沈降を始めた．津軽側では著しい沈降によって，下部小泊層から上部小泊層までの硬質頁岩と黒色塊状泥岩との厚層が広く堆積した．いっぽう下北側では現在の広いドーム状構造の隆起が始まり，徐々に進行した．ドーム構造の周囲では，酸性火山岩類が多くの中心から噴出し，火山活動に伴う一時的な沈降により桧川層と薬研層が累積したが，津軽側の下部小泊・上部小泊の両層に相当する下部小沢・上部小沢両層の泥質岩は，それよりも外側に薄く堆積した．しかし，ドームの隆起はそれほど広くはなく，泥質岩の厚さはドームから離れるに従って増している．

下北半島のドーム構造の周囲に分布している桧川層は，これは互いにオーバーラップしている直径数 km の，多数の陥没ないし沈降盆地からなっている．このような盆状構造のうち，あるものは重力調査やテストボーリングによって確認されている．これらの盆状構造は，それぞれ一様な火山構造性の，一輪廻の噴出の中心に形成されたものである．その輪廻とは，まず小規模な火山噴火に伴う陥没で始まり，次に多量の溶岩と火砕流の噴出と本格的な陥没がそれに続き，最後に少量の軽石流の噴出を繰返した後に陥没が終るまでを指している．

上部小泊層およびそれに相当する上部小沢層の堆積以後，津軽側では北部のドーム構造と中軸部の背斜構造の隆起が始まり，いっぽう下北側では同じ頃からドーム状隆起が北と南に拡がった．津軽側に存在していた広い堆積盆地は，中間に隆起地帯を生じたことによって，日本海に面する西側地帯と，平館海峡を含む東側地帯とに分化し，両地帯の沈降の進展に応じて，主としてシルト岩と砂岩からなる海成の塩越層と蟹田層が厚く堆積した．隆起帯が次第に拡張するにともなって，東側の沈降帯は西側から次第に幅を狭め，現在では平館海峡だけが沈降を続けている．

津軽半島と下北半島は，秋田・岩手両県のグリーンタフ地域において構造区分されている，いわゆる出羽丘陵帯と脊梁帯の延長にそれぞれ相当するものと考えられて来たが，この考えは妥当ではない．津軽半島では新第三系は，最下部から最上部まで全層が厚く，とくに塩越層以上の海成の地層が広くかつ厚く堆積していることからみて，グリーンタフ地域のうち，秋田県の男鹿半島と秋田平野を含む日本海沿岸地帯にむしろ一致している．また，下北半島については，金八沢層から上部小沢層までの細粒の堆積岩は，広いドーム構造の地域では薄いが，半島の南と北の延長ではかなり厚く堆積しており，かつ津軽半島の塩越層以上に相当する地層は，大畑層がわずかに分布しているに過ぎない．このような特徴から，下北半島を含む南北方向の地帯は出羽丘陵帯の延長にあり，かつ半島の頭部は同地帯の隆起部に比較できる．

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