Bulletin of the Geological Survey of Japan, vol. 41 (9), p. 473-505, 1990 552.323 : 551.214/.782.1 (521.1)

Middle Miocene back-arc rift magmatism of basalt in the NE Japan arc

Nobuyuki TSUCHIYA*

TSUCHIYA, N. (1990) Middle Miocene back-arc rift magmatism of basalt in the NE Japan arc. *Bull. Geol. Surv. Japan*, vol. 41 (9), p. 473-505.

Abstract: Intense middle Miocene basaltic magmatism took place extensively in the Akita-Yamagata oil field and its surrounding areas in the back-arc region of the NE Japan arc. The basaltic magmatism has similar features in those of continental rift and back-arc basin, and is discussed here especially in relation to the hypothetical Japan Sea spreading of middle Miocene age.

During middle Miocene time, magmatism yielded a huge amount of basaltic lavas and volcaniclastic rocks in a rift zone of the oil field, and a large amount of acid volcaniclastic rocks with a small amount of basaltic lava in the surrounding areas. In the rift zone, the basaltic rocks are widely distributed in an area of 200 km × 30-40 km. Their estimated volume (several thousand km^3) is far larger than that of the Quaternary volcanic rocks in the NE Japan arc.

In the rift zone, the early middle Miocene basaltic rocks extruded from NE-SW trending feeder dikes to form submarine volcanoes under an extensional tectonic environment. They are intercalated with argillaceous sediments of deep marine (bathyal zone) origin. The late middle Miocene basaltic rocks mostly intruded into the marine sediments to formed sills and laccoliths of dolerite. Consequently, the basaltic magmatism in the rift zone changed its mode of activity from eruption to intrusion during middle Miocene time.

In the surrounding areas, bimodal volcanism of the early middle Miocene basaltic rocks and acidic rocks took place mainly on land and shallow water bottom associated with formation of grabens and normal faults under an extensional environment. The bimodal volcanism declined and the surrounding area subsided during late middle Miocene time.

Petrochemistry of the early middle Miocene basaltic rocks show no systematic sense of spatial variation such as the Quaternary volcanic rocks of the NE Japan arc. The basaltic rocks from the rift zone of the oil field have affinities to back-arc basin basalt (BABB) in major and trace element chemistry. Whereas, basaltic rocks in the surrounding areas partly show a similarity to island arc basalt. From the spatial variation in petrochemistry, the basaltic rocks was derived from a source mantle of BABB type with slight metasomatism by subduction components.

The late middle Miocene basaltic rocks show a slight change toward island arc basalt in trace element chemistry. This temporal change in petrochemistry may be interpreted as due to increasing contribution of mantle metasomatism by subduction components to the generation of the basaltic magma.

The size and geotectonic features of the rift zone provide a sound basis to postulate that the rift zone of the oil field was one of failed rifts in and around the Japan Sea. Possibly, the rift zone developed in the peripheral part of the spreading Japan Sea and the middle Miocene basaltic magmatism occurred during the time of Japan Sea spreading.

* Geology Department

1. Introduction

Recent geological and geophygical studies on the Japan arc and the Japan Sea have led to a hypothesis that the Japan arc is a continental fragment split from the Asian continental margin due to spreading of the Japan Sea during middle Miocene time (e. g. OTOFUJI *et al.*, 1985 ; TAMAKI, 1988). During this time, the NE Japan arc became a site of intense magmatism.

The middle Miocene magmatism has distinct features from the Quaternary volcanism in the NE Japan arc as follows: 1) The magmatism yielded a greater volume of the volcanic rocks than Quaternary volcanics (OZAWA, 1963 ; KONDA, 1974). 2) The magmatism produced basaltic rocks in the Akita-Yamagata oil field, whereas it yielded mainly acid volcanic rocks in and around the Ou backbone range (Fig. 1) (CHIHARA, 1967 ; KONDA, 1974 ; OHGUCHI, 1983). 3) The volcanic products contain tholeiitic rocks of oceanic type in places (SHUTO and YASHIMA, 1985). 4) The volcanic rocks show no systematic spatial variation in alkali content (SHUTO *et al.*, 1988 ; TSUCHIYA, 1988a).

The middle Miocene magmatism occurred contemporaneously with extensional tectonic movement in the back-arc region of the NE Japan arc. This movement resulted in formation of normal faults (AMANO, 1982 ; KUWAHARA, 1982 ; SATO *et al.*, 1982). horst and grabens (YAMAJI, 1989). and caused regional subsidence (SATO, 1986).

These features of magmatism and tectonic movement of middle Miocene age are similar to those of continental rift such as the Grate basin (e. g. STUWART, 1978 ; HART *et al.*, 1984) and the Rio Grande rift (e. g. LIPMAN, 1969) in the western North America. Taken this into consideration, the middle Miocene magmatism in the NE Japan arc can be related to rifting in the continent.

The acid magmatism of middle Miocene age yielded Kuroko deposits and has been studied in detail (e. g. SATO, 1974), whereas the basaltic magmatism has been studied a little because the basaltic rocks are mostly overlain by thick sediments in the oil field and are hard to obtain these underground specimens.

Recently, the basaltic rocks have been penetrated by deep drilling for oil exploration, and their subsurface distribution has been unveiled (e. g. OZAWA *et al.*, 1986 and 1988 ; TSUCHIYA, 1988a). The estimated volume (several thousand km^3) is far greater than that of the Quaternary volcanic rocks in the NE Japan arc.

The author has had opportunities to examine borehole-cores of the basaltic rocks in the NE Japan arc, and he attempted to clarify the occurrence and origin of the basaltic magmatism especially in relation to the rifting event of the NE Japan arc.

First, reconstruction of submarine volcanoes in this area was made of the basaltic rocks referring to recent studies on submarine volcanic products. Second, the nature of basaltic rocks is discussed on the basis of analyses of major and trace elements. Then, particular emphasis is directed to the petrochemical features in comparison with those of island arc, mid-oceanic ridge, back-arc basin, and continental rift.

Finally, the author discusses the significance of the basaltic magmatism in rifting tectonics and geologic development of the back-arc region of the NE Japan arc. Conclusively a model for the basaltic magmatism is proposed in relation to hypothetical Japan Sea spreading.

Acknowledgements: This paper is a modified version of the doctoral dissertation submitted to the Geology and Mineralogy Department of Hokkaido University. The author would like to express his sincere gratitude to Professor Emeritus Dr. Yoshio KATSUI of Hokkaido University for helpful guidance and encouragement during this study. He also wishes to thank Professor Dr. Shunzo YUI and Professor Emeritus Dr. Satoru UOZUMI of the same University for helpful advice. His special thanks are given to Professor Dr. Atsushi OZAWA of Yamagata University for his enthusiastic guidance in the field survey. The author is grateful to Dr. Yutaka IKEBE and Dr. Tadami KATAHIRA of Japan Petroleum Exploration Co. Ltd. for providing geological data. This study was carried out at the Geological Survey of Japan. The author is grateful to express my gratitude to Dr. Hitoshi HATTORI, Director of Geology Department for the valuable discussion and helpful advice. The author is acknowledges for the considerable assistance of Mr. Kimio OKUMURA, Chief of petrology section, with EPMA analysis, and Dr. Tsuyoshi TANAKA, Geochemistry Department, with INA analysis.

2. Geological outline

2.1 Stratigraphy of the Akita-Yamagata oil field and surrounding areas

The study area is situated in the Akita-Yamagata oil field and surrounding areas in the back-arc region of the NE Japan arc and includes the eastern margin of Japan Sea (Fig. 1).

The Akita-Yamagata oil field and surrounding areas are underlain by Tertiary volcanic rocks

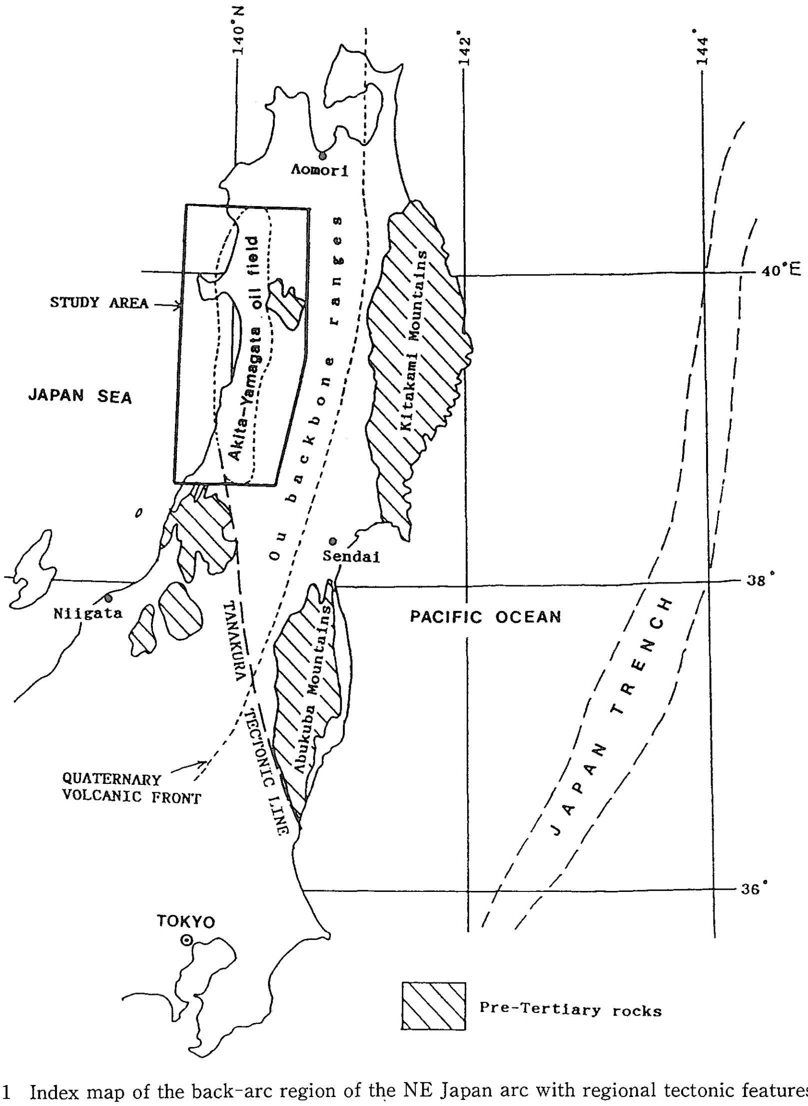

Fig. 1 Index map of the back-arc region of the NE Japan arc with regional tectonic features. The study area (Akita-Yamagata oil field and surrounding areas) is also shown.

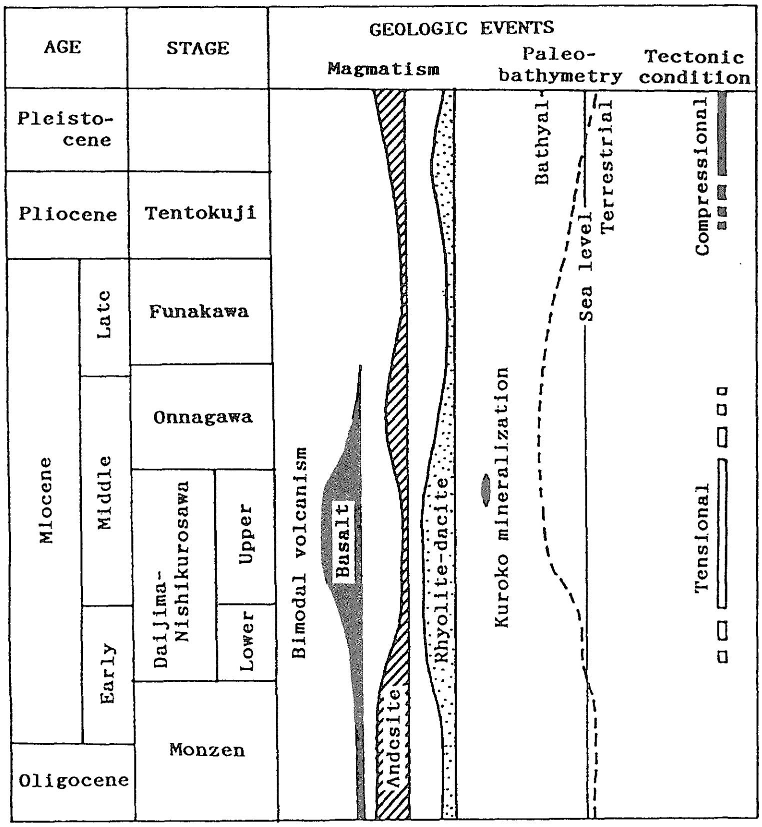

Fig. 2 Stratigraphic divisions of Neogene system and geologic events in the Akita-Yamagata oil field and surrounding areas. This figure is summarized from data of this study and previous studies (e. g. HUZIOKA, 1956 ; KITAMURA, 1959 ; IKEBE, 1962 ; TAGUCHI, 1962 ; OZAWA, 1963 ; MIYAGI, 1963 ; SATO, 1974 ; AMANO, 1982 ; SATO *et al.*, 1982 ; SATO, 1986).

and clastic sediments. The volcanic rocks occur in the lower half of the Tertiary system and commonly turn to greenish-color by conspicuous hydrothermal alteration so that they are called "Green Tuff" in Japan. Volcanism of "Green Tuff" continued from late Oligocene to middle Miocene time and is subdivided into andesite volcanism of the Monzen stage (late Oligocene to early Miocene) and bimodal volcanism of the Daijima-Nishikurosawa stage (early middle Miocene) (Fig. 2).

The clastic sediments occur in the upper half of the Tertiary system and accumulated during middle Miocene to Pliocene time. The sediments are divided into the Onnagawa, Funakawa, Tentokuji and Sasaoka stages, in ascending order.

The middle Miocene basaltic rocks occur mostly in the upper part of the Daijima-Nishikurosawa stage and the lower part of Onnagawa stage (Fig. 3).

The upper part of the Daijima-Nishikurosawa stage abundantly yields index fossils, particularly, *Vicarya* was described from many localities in the NE Japan arc (UOZUMI and FUJIE, 1966). From the comprehensive studies of the index fossils, the age of the upper part of the Daijima-Nishikurosawa stage is considered to be 13-16.5 Ma (OGASAWARA *et al.*, 1986). The lower part of this stage lacks in index fossils and its age remains uncertain. However, the lower part of this stage was dated by K-Ar method at 17-21 Ma (KIMURA, 1986; USUDA and OKAMOTO, 1986). Accordingly, the upper part of the Daijima-

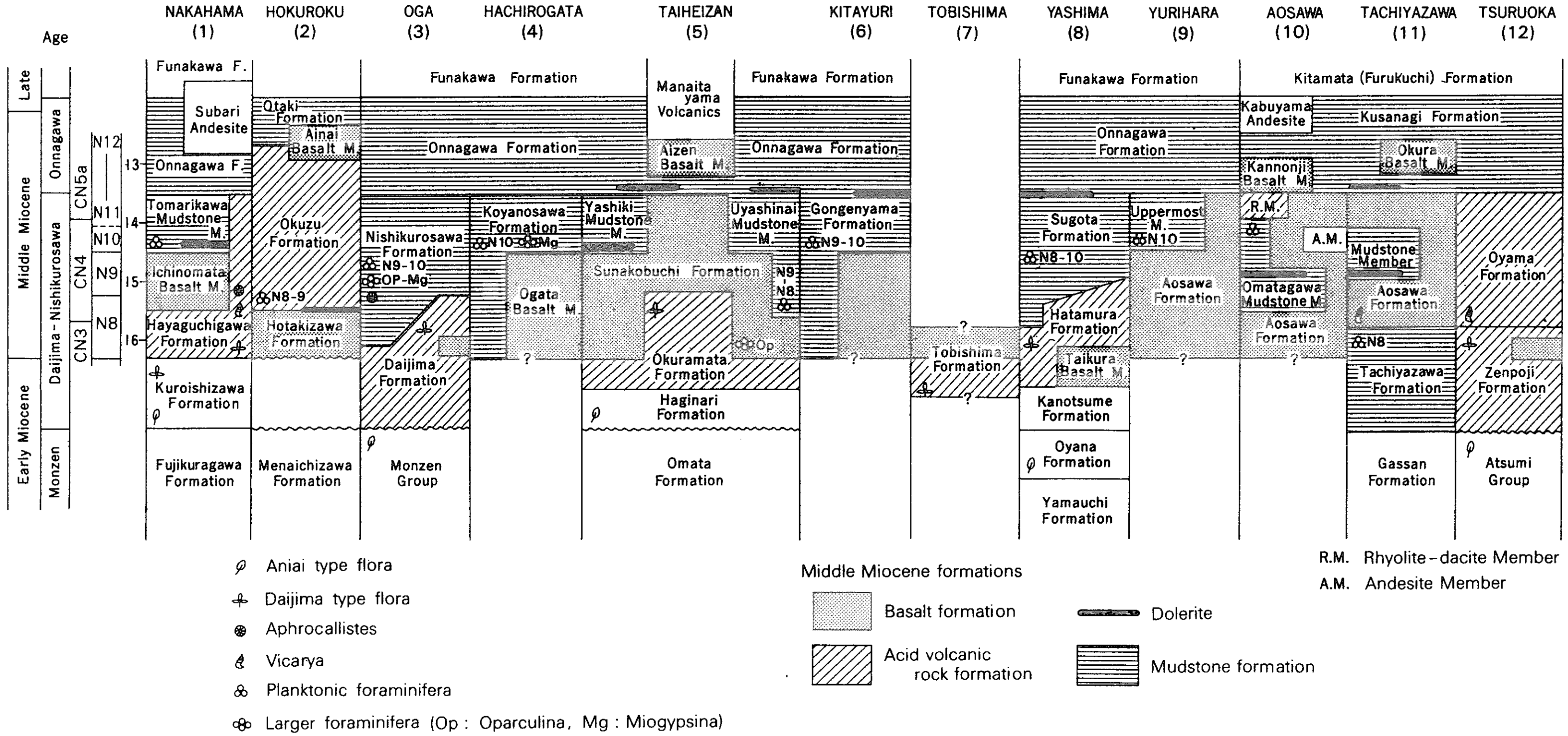

Fig. 3 Stratigraphic table of the middle Miocene formations in the Akita-Yamagata oil field and surrounding areas. Stratigraphic position of basalt and dolerite are shown. Reference (1) : Ozawa *et al.* (1983) ; (2) and (3) : Ogasawara *et al.* (1986) ; (4) : Ozawa *et al.* (1985) ; (5) Ozawa *et al.* (1981) and Tsuchiya (1986) ; (6) : Huzioka *et al.* (1976) ; (7) : Ozawa *et al.* (1982) ; (8) and (9) : Ozawa *et al.* (1988) ; (10) : Tsuchiya (1989) ; (11) : Ozawa *et al.* (1986) and Fujioka *et al.* (1981) ; (12) : Tsuchiya *et al.* (1984).

Nishikurosawa stage is regarded as early middle Miocene in age, while its lower part may be early Miocene in age.

The age of the Onnagawa stage ranges generally from 9 to 13.5 Ma as inferred from the planktonic foraminiferal and nannoplankton fossils (OGASAWARA *et al.*, 1986). Thus, volcanism of the basaltic rocks occurred mainly in middle Miocene time.

The age of the dolerites may not be much delayed from the extrusive rocks of the middle Miocene formations (TSUCHIYA, 1986 and 1989).

2.2 Geologic events in middle Miocene age

In the back-arc region of the NE Japan arc, the basaltic volcanism of middle Miocene age was taken place concurrently with volcanism of rhyolite-dacite, and both represent bimodal volcanism (KONDA, 1974). During the time of the bimodal volcanism, important geologic events occurred in the back-arc region, namely regional subsidence and Kuroko mineralization (Fig. 2).

2.2.1 Regional Subsidence

The formations of the Daijima-Nishikurosawa stage include characteristic fossils of the Daijima type flora (HUZIOKA, 1963), molluscas and foraminiferas.

The molluscan and foraminiferal fossils suggest that most of the back-arc region started to submerge to reach bathyal zone (500-2500 m depth; KITAZATO, 1983; SATO, 1986) since the time of N8 (BLOW, 1969). According to AMANO (1982), the sea level was changed by eustasy during middle Miocene time and reached ca. 300 m above the present sea level. However, the submergence of this region is far larger than this sea level change, suggesting a considerable amount of concurrent crustal subsidence. The basaltic magmatism took place mainly during the time of this subsidence.

2.2.2 Kuroko mineralization

During the later stage of the basaltic magmatism, Kuroko mineralization occurred associated with the coeval acidic magmatism within a few million years around 13 Ma in the NE Japan arc, especially in the Hokuroku district, to the northeast of the Akita-Yamagata oil field (SATO, 1974; CATHLES *et al.*, 1982).

3. Distribution of the basaltic rocks

Simplified figures were made to illustrate a regional lithofacies map of the Daijima-Nishikurosawa stage (early middle Miocene age) and representative cross sections of the Akita-Yamagata oil field (Figs. 4 and 5), on the basis of deep well and field data. Both figures reveal that a thick pile of the basaltic rocks is distributed widely and intercalates mudstone layers mainly in the upper part.

Areal extent of the thick basaltic rocks measures approximately 200 km long in N-S and 30-40 km wide in E-W. The wells were penetrated deeply into the basaltic rocks in the oil field, but mostly did not reach the lower limit of the basaltic rocks. Estimated thickness of the basaltic rocks exceeds 1,000 m and locally 1,500 m. Therefore, the total volume of the basaltic rocks in the oil field is estimated to be several thousand km^3 or more. This volume is far larger than that of the Quaternary volcanic rocks in the NE Japan arc (about 1,500 km^3, ARAMAKI and UI, 1978).

In the surrounding areas of the oil field, volcanic rocks of the Daijima-Nishikurosawa stage consist of a large amount of acid volcaniclastic rocks and a small amount of basaltic rocks whose thickness is mostly less than 300 m (Figs. 4 and 5).

On the other hand, the basaltic rocks of the Onnagawa stage (late middle Miocene) are distributed mainly in the oil field and mostly form intrusive bodies. Total volume of the basaltic rocks of the Onnagawa stage becomes far smaller than that of the Daijima-Nishikurosawa stage.

4. Mode of occurrence and geotectonic feature of the basaltic rocks

As described in the previous chapter, middle Miocene basaltic magmatism was predominant in the Akita-Yamagata oil field, whereas bimodal

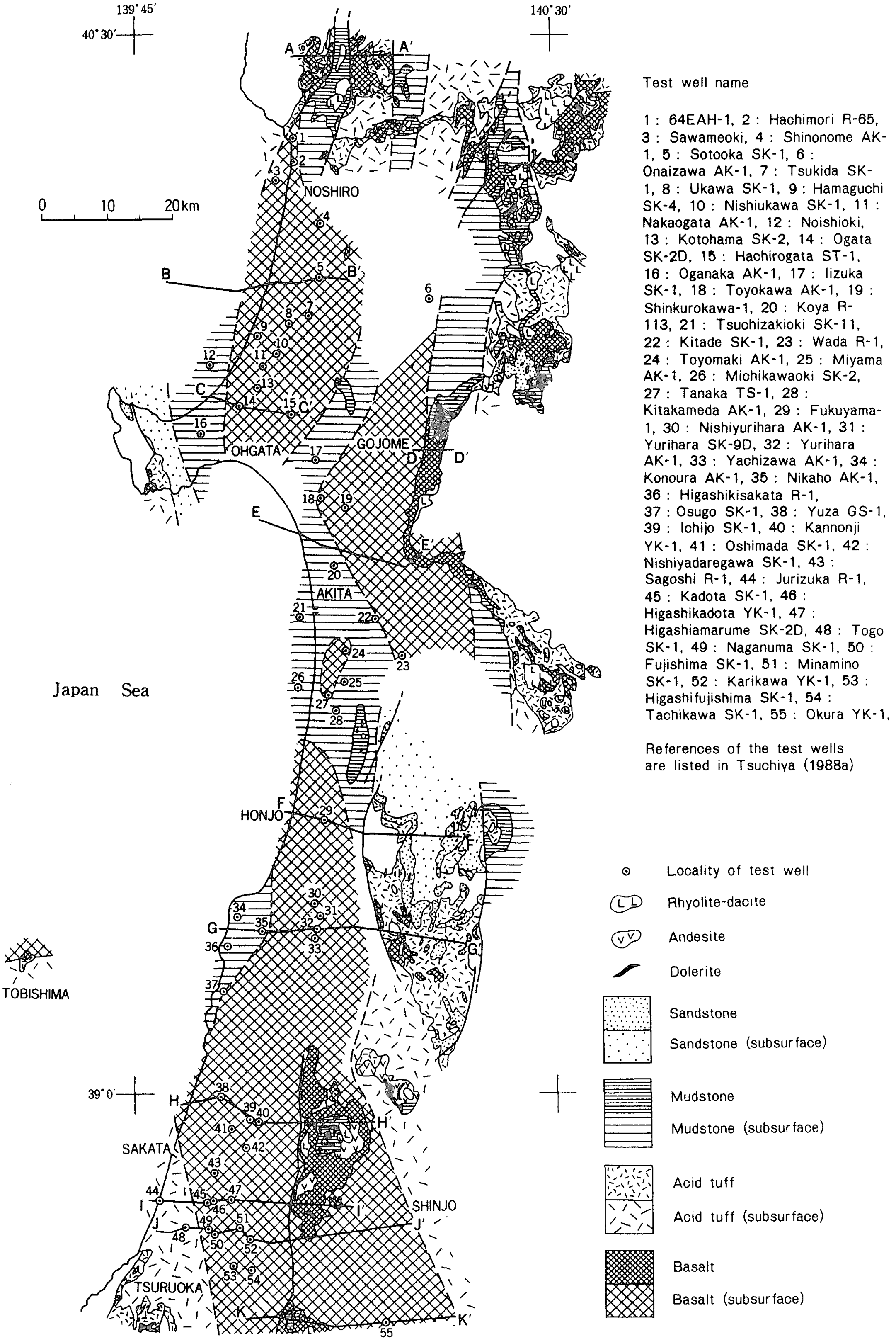

Fig. 4 Lithofacies map of the Daijima-Nishikurosawa stage in the Akita-Yamagata oil field and surrounding areas (modified TSUCHIYA, 1988a).

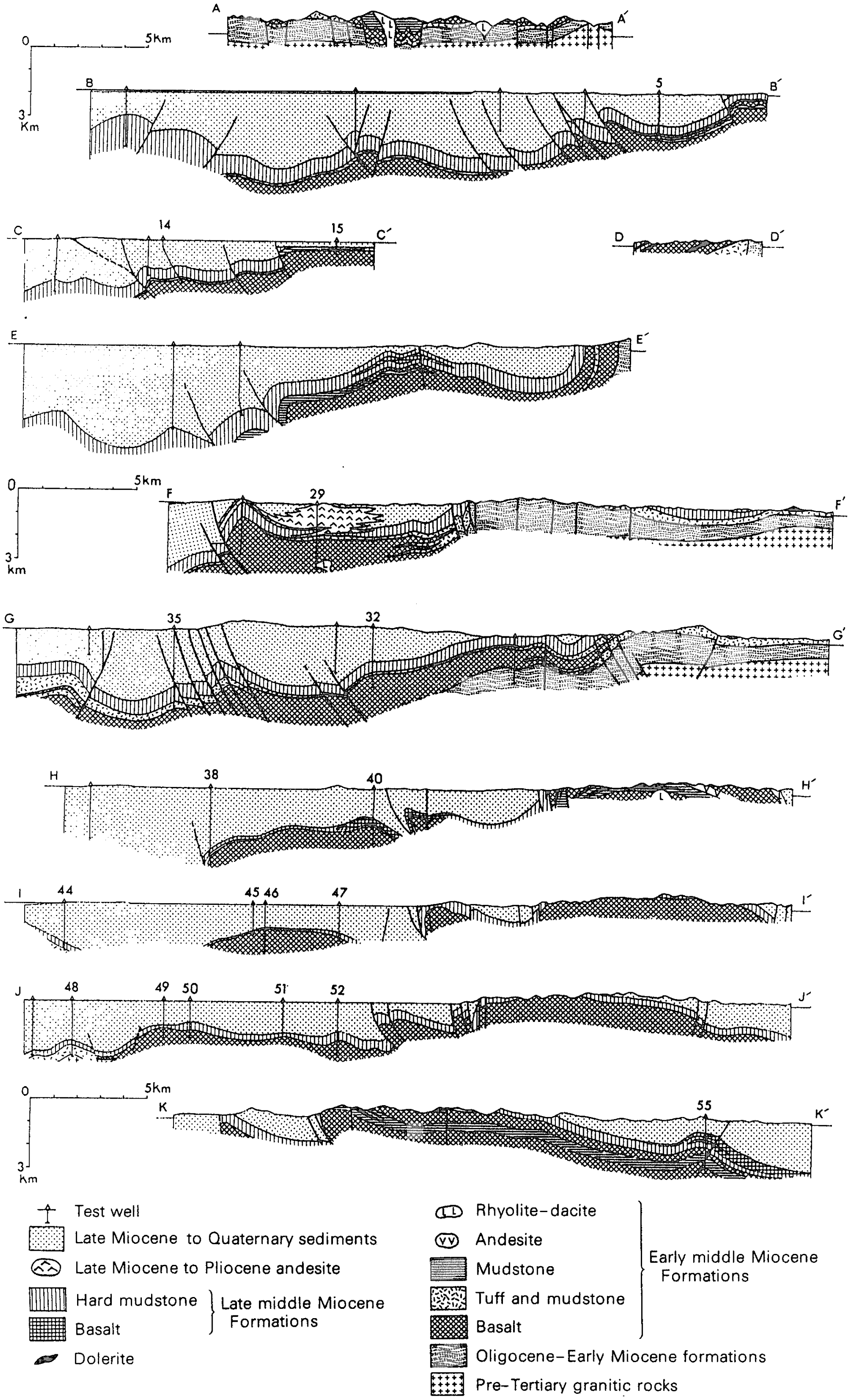

Fig. 5 Geologic cross sections of the Akita-Yamagata oil field (summarized from OZAWA *et al.*, 1983, 1985, 1986 and 1988). The test well nos. are the same as those in Fig. 4.

magmatism occurred in the surrounding areas. The magmatism in the oil field and the surrounding areas occurred contemporaneously with regional subsidence. Particularly, the oil field apparently subsided to form a sedimentary basin, as evidenced by the thick deposits in the oil field.

4.1 Akita-Yamagata oil field

4.1.1 Daijima-Nishikurosawa stage

In the early middle Miocene time (Daijima-Nishikurosawa stage), the basaltic rocks extruded voluminously in the oil field basin to form submarine volcanoes which exceed 1,000 m in maximum height from the bottom. The basaltic rocks are well observed in the Sunakobuchi and Aosawa Formations (TSUCHIYA, 1986 and 1989). Schematic cross sections of the Sunakobuchi and Aosawa Formations (Fig. 6 and 7) were drawn to reconstruct the submarine volcanoes based on the data of field survey and fossils. Basaltic lavas and volcaniclastic rocks built the volcanoes and are intruded by feeder dikes.

The high parts of the volcanoes are composed mostly of vesicular subaqueous volcaniclastic rocks which contain oxidized scoria and molluscan fossils of shallow marine type. Whereas, basaltic volcaniclastic rocks on the flank of the volcanoes intercalate and are covered with the black mudstone which contains foraminiferal fossils of deep marine (bathyal) type. This occurrence shows that the mudstone was deposited mainly on distal parts of the volcanoes during the basaltic magmatism.

The mudstone is well stratified and is gently inclined or nearly horizontal. The mudstone may have been free from compressive faulting and folding during the time of deposition. The basaltic feeder dikes and normal faults, both are of NNE-SSW to NE-SW trend, occur extensively in the basaltic rocks and mudstone. The dikes intruded into open cracks and spaces, some of which were clearly formed by fault displacement. The dikes and normal faults were formed under extensional tectonic condition of NNE-SSW to NW-SE direction during the basaltic magmatism.

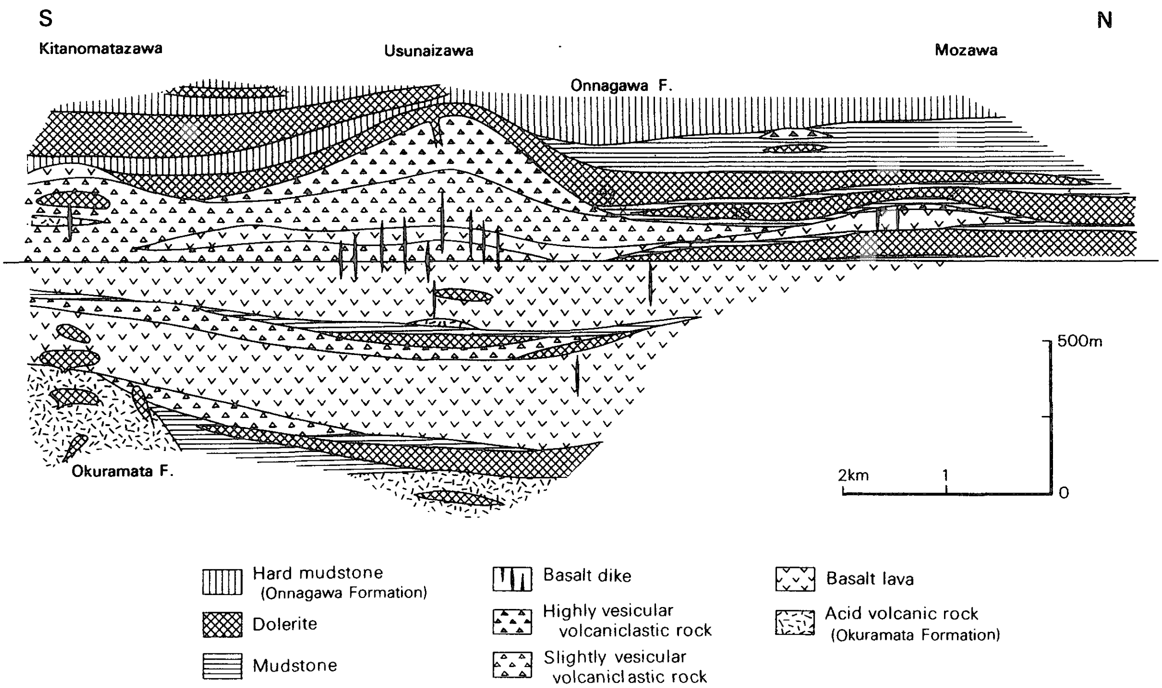

Fig. 6 A schematic cross section of a basalt volcano in the Sunakobuchi Formation (modified TSUCHIYA, 1986).

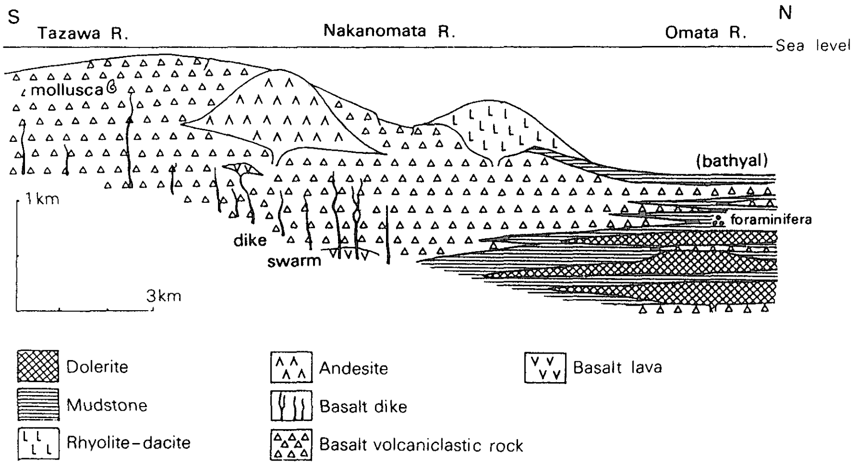

Fig. 7 A schematic cross section of a basalt volcano in the Aosawa Formation (modified TSUCHIYA, 1989).

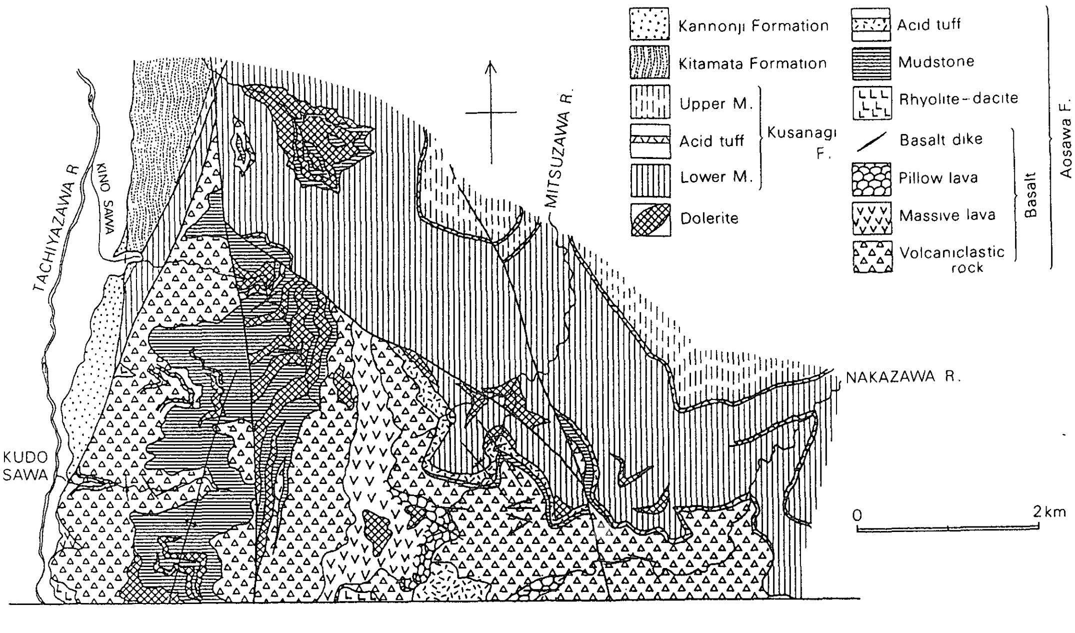

Fig. 8 Geological map of the Tachiyazawa district.

Sills and laccoliths of dolerite occur in the mudstone of the Daijima-Nishikurosawa stage. The dolerite intruded extensively along the bedding and commonly have vesicular chilled margin. In places, they disturbed the bedding plane of the mudstone near the contact and included irregular-shaped fragments of the black mudstone. The occurrence of the dolerite suggest that basaltic magma intruded into unconsolidated sediments (TSUCHIYA, 1986 and 1989).

Similar occurrence of the basaltic rocks of the Daijima-Nishikurosawa stage (Fig. 8) is observed in the Tachiyazawa district, southernmost part of the oil field. Also, the deep-seated basaltic rocks in many boreholes have similar occurrence to those in the Sunakobuchi and Aosawa Formations. (SATO and ANNAKA, 1986; OZAWA *et al.*, 1989; TSUCHIYA *et al.*, 1989).

4.1.2 Onnagawa stage

In the late middle Miocene time (Onnagawa stage), while thick hard mudstone overlay the basaltic rocks and black mudstone of the Daijima-Nishikurosawa stage, the basaltic magmatism of the Onnagawa stage formed a number of dolerite sills and laccoliths mainly in the hard mudstone of the Onnagawa stage (KONDA, 1960).

It is noted that the basaltic magmatism changed its mode from submarine eruption to dolerite intrusion during the deposition of the mudstone of the Daijima-Nishikurosawa and Onnagawa stages. The mudstone may not have been solidified yet at the time of dolerite intrusion. It is noticed that basaltic magmas furnished the dolerite intrusions not ascended to form effusive rocks, but spread out as sills in the soft argillaceous sediments. Because the basaltic magma had higher bulk density than the soft sediments and remained at the lower level of the sediments, as pointed out by MCBIRNEY (1963) and EINSELE (1985). Until late Miocene time, the basaltic magmatism and sedimentation formed a complex unit which cosists mostly of basaltic extrusive rock, intrusive rock and argillaceous sediments.

4.2 Surrounding areas

4.2.1 Daijima-Nishikurosawa stage

In the surrounding areas, the formations of the Daijima-Nishikurosawa stage are made mainly of voluminous acid volcaniclastic rocks and subordinate amounts of basalt lava and volcaniclastic rocks (KONDA, 1974; OHGUCHI, 1983; OZAWA *et al.*, 1983 and 1988; TSUCHIYA *et al.*, 1989). The acid volcaniclastic rocks intercalate welded tuff and contain plant fossils and molluscan fossils of shallow marine type, while the basalt contains oxidized scoria and pillow lava. The lithofacies and biofacies of this stage indicate that the bimodal volcanism occurred on land and shallow water bottom during early middle Miocene time.

Basaltic dikes and grabens of NNE-SSW to NE-SW trend are found in the surrounding areas, as observed in the northernmost part of the oil field (OZAWA *et al.*, 1983) and the northern part of Uetsu Mountains (TSUCHIYA *et al.*, 1984; YAMAJI, 1989). The grabens were formed until early middle Miocene age and were filled rapidly with volcanic rocks and thick sediments of middle Miocene age. The basaltic dikes and grabens are considered to have formed under WNW-ESE to NW-SE tensional tectonic condition during early middle Miocene time.

4.2.2 Onnagawa stage

The formations of the Onnagawa stage are made mainly of hard mudstone and intercalate andesite and a small amount of basalt in places, and intruded by dolerite sills. The mudstone of this stage contain rarely foraminiferal fossils of bathyal type, and may have been deposited on deep sea bottom (SATO, 1986). From the lithofacies and fossil evidence, the bimodal volcanism declined and basaltic magma formed the dolerite sills in the mudstone of the Onnagawa stages. The change in lithofacies and fossils from Daijima-Nishikurosawa stage to the Onnagawa stage suggests a regional subsidence in the surrounding areas during middle Miocene time.

4.3 Magmatism and rifting event

Based on the mode of occurrence of the middle Miocene basaltic rocks, the basaltic magmatism can be summarized schematically as shown in Fig. 9. Geotectonic features of the middle Miocene formations in the Akita-Yamagata oil field and the surrounding areas are summarized as follows:

A) Akita-Yamagata oil field
   1) Intensive subsidence,
   2) Intense basaltic magmatism which formed submarine volcanoes, dike swarm, sills and laccoliths under a tensional tectonic condition.

B) The surrounding areas
   1) Formation of horst and graben
   2) Bimodal magmatism which produced acid volcaniclastic rocks with subor-

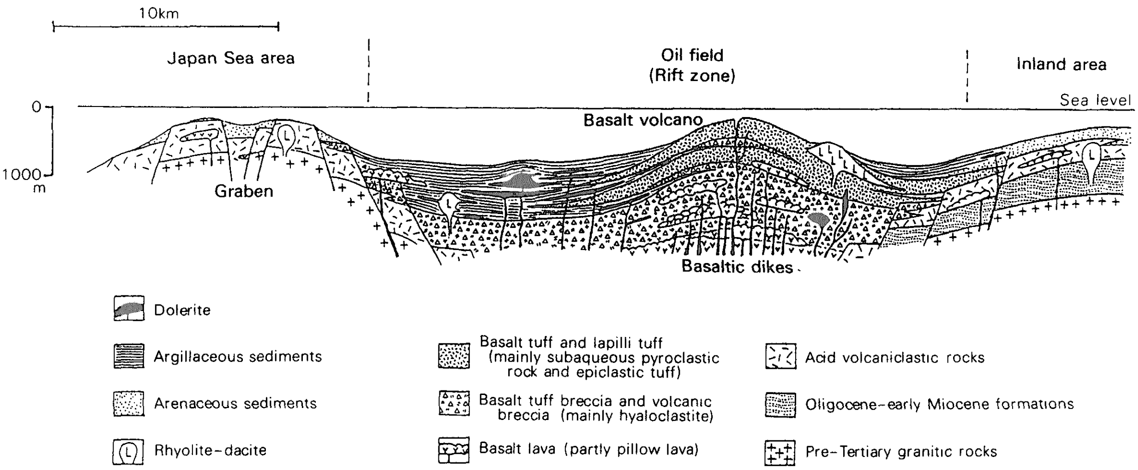

Fig. 9 A schematic cross section showing the mode of magmatism in the Akita-Yamagata oil field and surrounding areas (Japan Sea and inland areas) in early middle Miocene time (Daijima-Nishikurosawa stage).

dinate amounts of basalt lavas and volcaniclastic rocks

Following the magmatism, regional subsidence and sedimentation occurred in both areas.

These geotectonic features strongly suggest that the basin of the Akita-Yamagata oil field has been formed as a rift zone in middle Miocene time and the basaltic magmatism took place related to the rifting. The rifting event of the middle Miocene age in the oil field is quite similar to that of the Rio Grande rift, western North America (LIPMAN, 1969; LIPMAN and MEHNERT, 1979).

5. Petrology of the middle Miocene basaltic rocks

The basaltic rocks of the Daijima-Nishikurosawa and Onnagawa stages were chemically analysed to clarify their petrochemistry and tectonic setting. The petrochemical data of the basaltic rocks of the Daijima-Nishikurosawa stage are examined and divided into those of the oil field and the surrounding areas. Further, the surrounding areas are subdivided into three areas, i. e. the eastern margin of Japan Sea (Japan Sea in short), northern inland (inland N), and southern inland (inland S) (Fig. 12). The basaltic rocks of the Onnagawa stage mostly occur in the oil field.

5.1 Petrographical description

The extrusive basaltic rocks of the middle Miocene age consist mainly of olivine basalt and augite-olivine basalt. The intrusive basaltic rocks are composed chiefly of augite-olivine dolerite associated with hypersthene-augite-olivine dolerite. Both basaltic rocks were altered and contain alteration minerals, such as chlorite, zeolite, carbonate, etc.

The basaltic rocks are classified in terms of rock type and rock series after KUNO (1950) (Table 1). The middle Miocene basaltic rocks consist mainly of the pigeonitic rock series, while the rocks of the Daijima-Nishikurosawa stage involve some of the hypersthenic rock series.

5.2 Major element chemistry

5.2.1 Alteration effect on major element composition

The middle Miocene basaltic rocks have been altered and may have changed their original chemical compositions. As the compositional change of the basaltic rocks can not be estimated quantitatively, the basaltic rocks were classified

Table 1 Rock series and rock types of the middle Miocene basaltic rocks. Sample numbers are to be referred to those in TSUCHIYA (1988a and 1988b).

Stage		Daijima-Nishikurosawa stage				Onnagawa stage
Area		Japan	Oil field	Inland (N)	Inland (S)	
series*	type*					
Alkali rock series	III b		36		58	
	IV b		91	24		
Pigeonitic rock series	III b	27	2 95 96 104		65 70	206 207
	III b → c		94	13 51	60 72 64	
	III c		35 87 89 92 97 105	77 45 50	71 73	217 218
	IV b					221
	IV c	81	32 34 99 111	14 15 16 23 74		201 202 203
	V c		114			
	X c	80		25 49	108	
	b		31 135 57 102	19 20 21 46 48 76	62 67	205 214 219 220
	b → c		5	26		
	c	83 84	103	78 79	66	204
Hypersthenic rock series	III a					
	III d	1 54 82			59	
	IV d			18	107	
	V d	53	90		69	
	X d			47		
	a		10 11 40		68	213
	d					

* : after KUNO (1950)

into two rock groups, slightly altered rocks and considerably altered rocks, in the following discussion.

The slightly altered rock preserve original texture and scarcely contain vein and vesicle, and most of the constituent minerals remain unaltered. Their plagioclase and clinopyroxene have scarcely altered even when their olivine and volcanic glass are altered. The petrochemical characteristics of the basaltic rocks are examined mainly on the basis of the slightly altered rocks.

5.2.2 Characteristics of major element chemistry

The middle Miocene basaltic rocks range 50-54 wt% in SiO_2 content and 1.0-1.8 in FeO^*/MgO ratio (Fig. 10), and are less differentiated than the Quaternary volcanic rocks of the NE Japan arc (KATSUI *et al.*, 1978 ; AOKI, 1983).

Basaltic rocks of the Daijima-Nishikurosawa stage : The basaltic rocks of the Daijima-Nishikurosawa stage are mostly plotted in the field of the low-alkali tholeiite series (LT) and high-alumina basalt series and high-alkali tholeiite series (HA) of KUNO (1968) (Fig. 11). The clinopyroxenes in the basaltic rocks also have the tholeiitic affinity (TSUCHIYA, 1988a).

The basaltic rocks in the Japan Sea area are mainly plotted in the LT field, and the rocks in the oil field area are plotted in the fields of both LT and HA. The rocks in the inland N and S areas are plotted mainly in the fields of LT and HA, respectively (Fig. 11).

The basaltic rocks of the Daijima-Nishikurosawa stage do not show increment in alkali contents from the Pacific side to the Japan Sea side (Fig. 12). Particularly, in the southern part of the study area, the rocks in the inland S area are

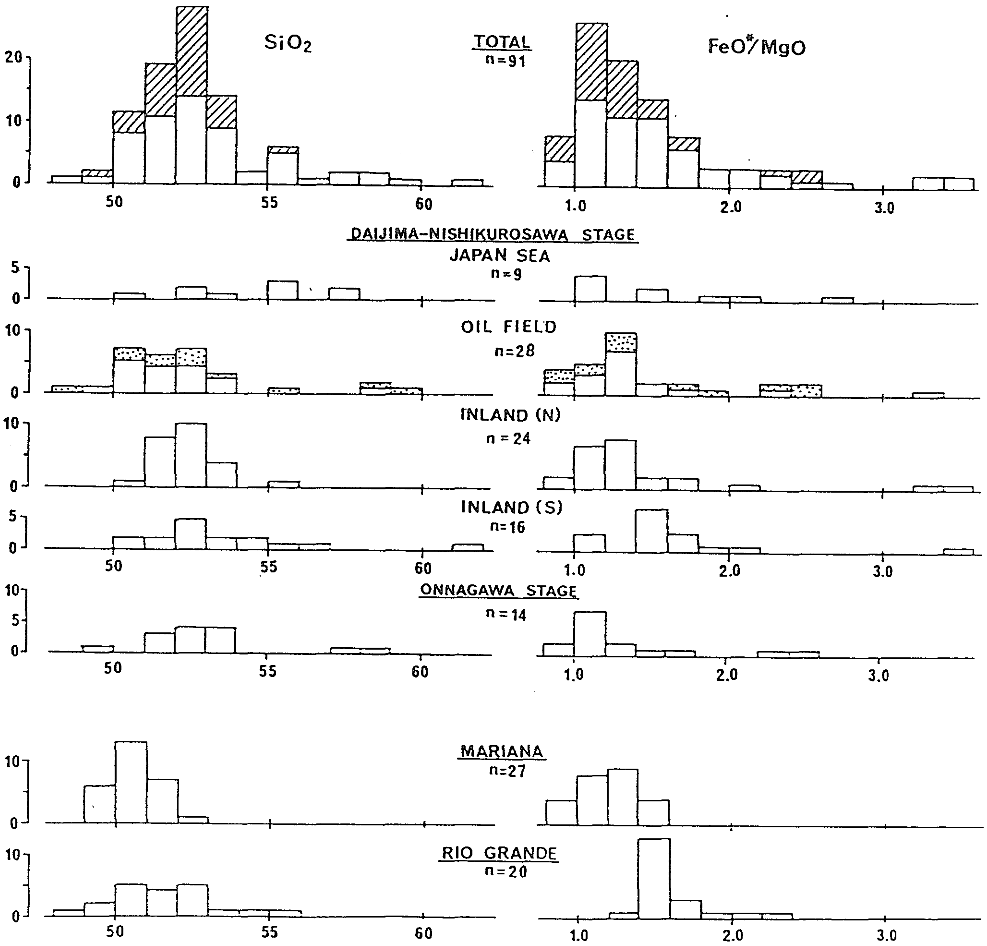

Fig. 10 Frequency distribution of SiO_2 content and FeO*/MgO ratio of the middle Miocene basaltic rocks (slightly altered rocks) (modified from TSUCHIYA, 1988a). Hatched area shows intrusive rocks. Dotted area shows high-alumina basalt and high-alkali tholeiite series (HA) in the oil field. For the comparison, data of Mariana trough basalt (HAWKINS and MELCHIOR, 1985), Rio Grande rift basalt (AOKI, 1967) are shown (modified TSUCHIYA, 1988a).

rather rich in alkali content than those of the Japan Sea area. Therefore, the across arc variation of the basaltic rocks is apparently distinct from that of the Quaternary volcanic rocks in the NE Japan arc (KUNO, 1966; KATSUI *et al.*, 1978; AOKI, 1983).

The basaltic rocks have tholeiitic trends in various differentiation diagrams (TSUCHIYA, 1988a). Plot on the TiO_2 vs. FeO*/MgO diagram (Fig. 13) shows that the rocks from the inland S area notably increase in TiO_2 with increasing of FeO*/MgO, whereas those from other areas slightly increase in TiO_2.

The chemical compositions of the middle Miocene basaltic rocks are normalized at FeO*/MgO=1.4 which is an average value of the basaltic rocks (Table 2). In the normalized values, the basaltic rocks from the inland S area show higher values of TiO_2 (1.5 wt%), K_2O (1.0 wt%) and P_2O_5 (0.4 wt%) contents than the HA basalts from other areas (Table. 2).

Basaltic rocks of the Onnagawa stage: The basaltic rocks of the Onnagawa stage have major element compositions similar to those from the

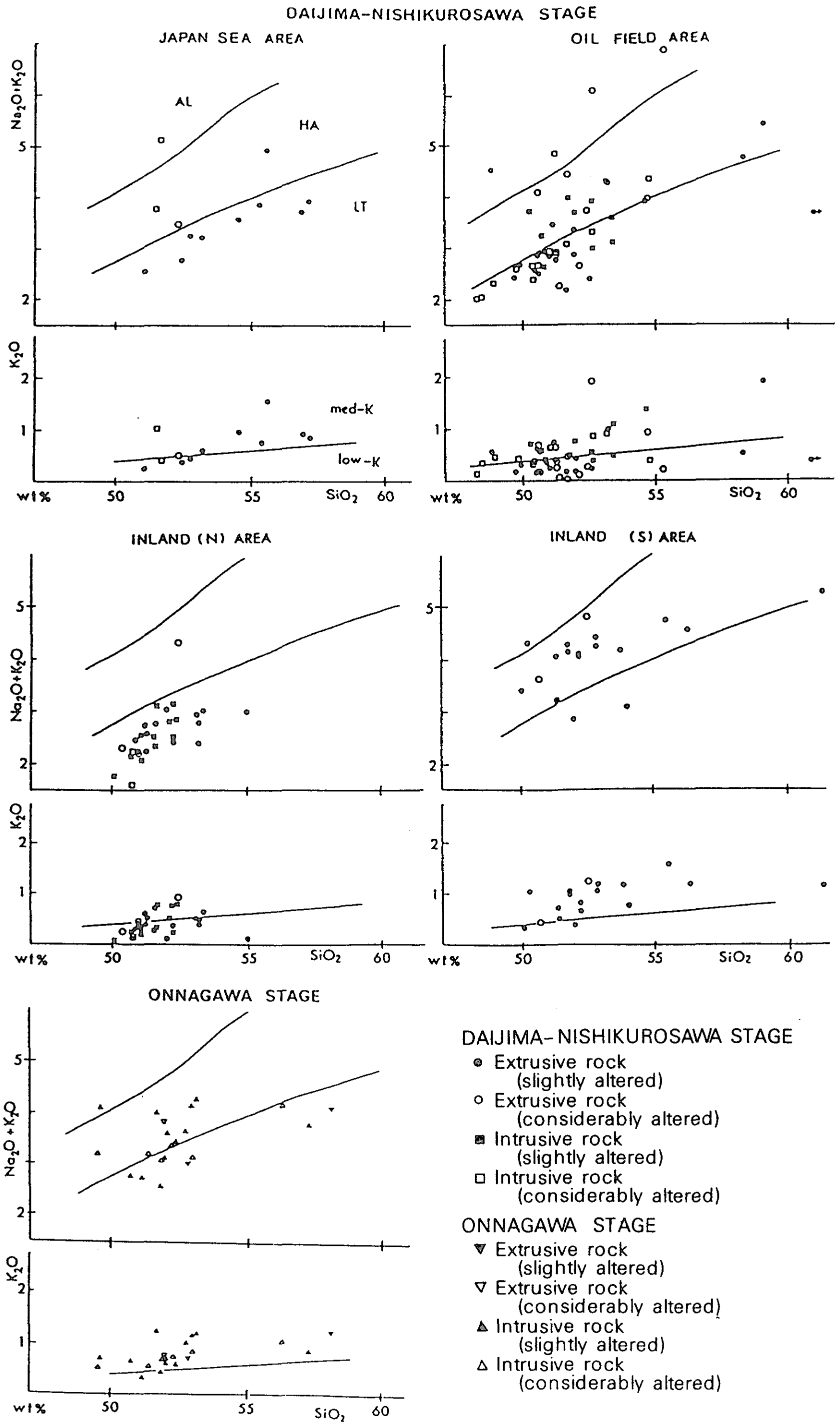

Fig. 11 Na_2O+K_2O vs. SiO_2 and K_2O vs. SiO_2 diagrams for the middle Miocene basaltic rocks (modified from TSUCHIYA, 1988a). AL, HA and LT show the fields of alkali basalt series, high-alumina basalt series (high alkali tholeiite series), and low-alkali tholeiite series of KUNO (1966 and 1968), respectively. The med-K and low-K show the fields of medium K_2O and low-K_2O series of GILL (1981) (modified TSUCHIYA, 1988a).

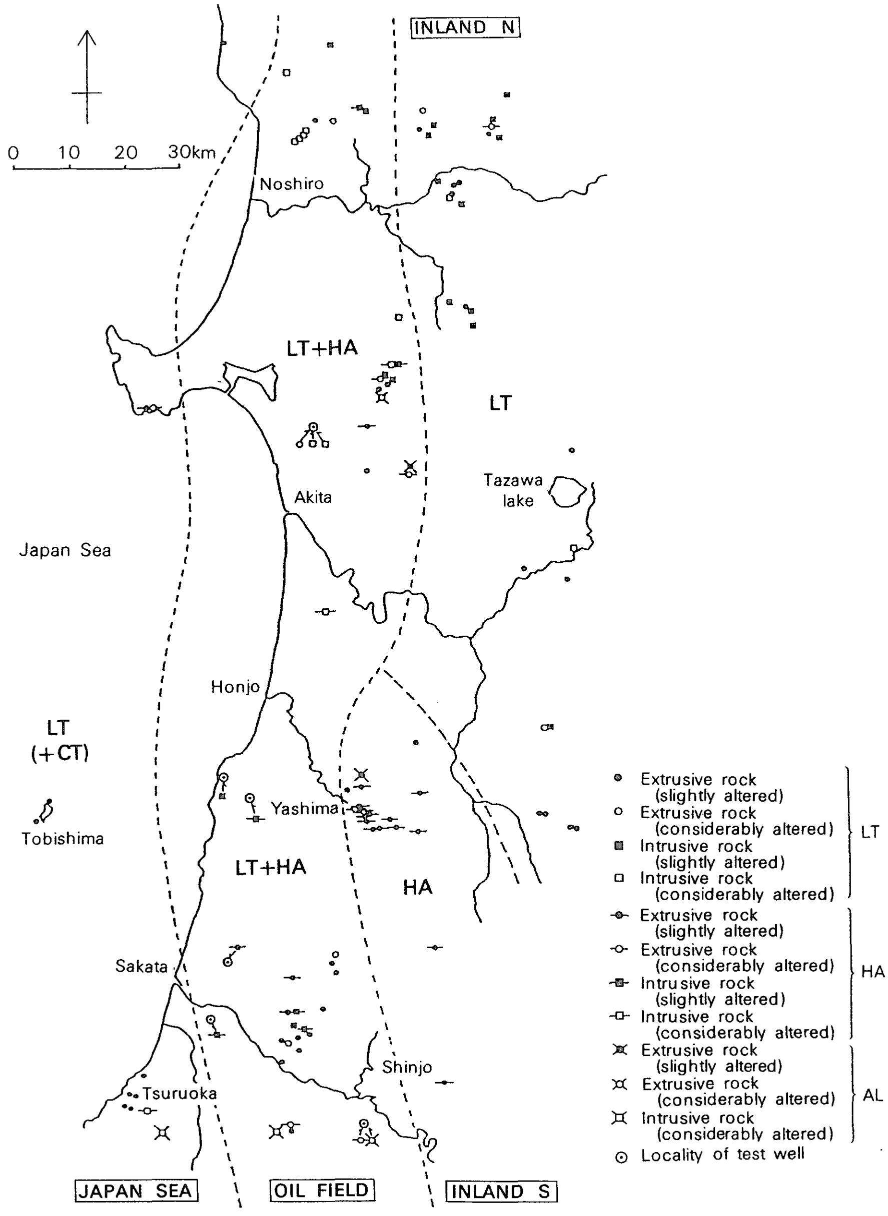

Fig. 12 Regional distribution of the rock series of the basaltic rocks of the Daijima-Nishikurosawa stage (modified from Tsuchiya, 1988a). LT : Low-alkali tholeiite series, HA : high-alumina basalt and high-alkali tholeiite series, AL : Alkali basalt series, CT : Calc-alkali rock series associated with low-alkali tholeiite series (modified Tsuchiya, 1988a).

oil field of the Daijima-Nishikurosawa stage (Table 2 ; Fig 10 and 11). However, the basaltic rocks are slightly rich in K_2O content compared with those of the Daijima-Nishikurosawa stage (Fig. 11).

5.2.3 Comparison with tholeiitic basalts from other geotectonic settings

The middle Miocene basaltic rocks have distinct characteristics from island arc volcanic

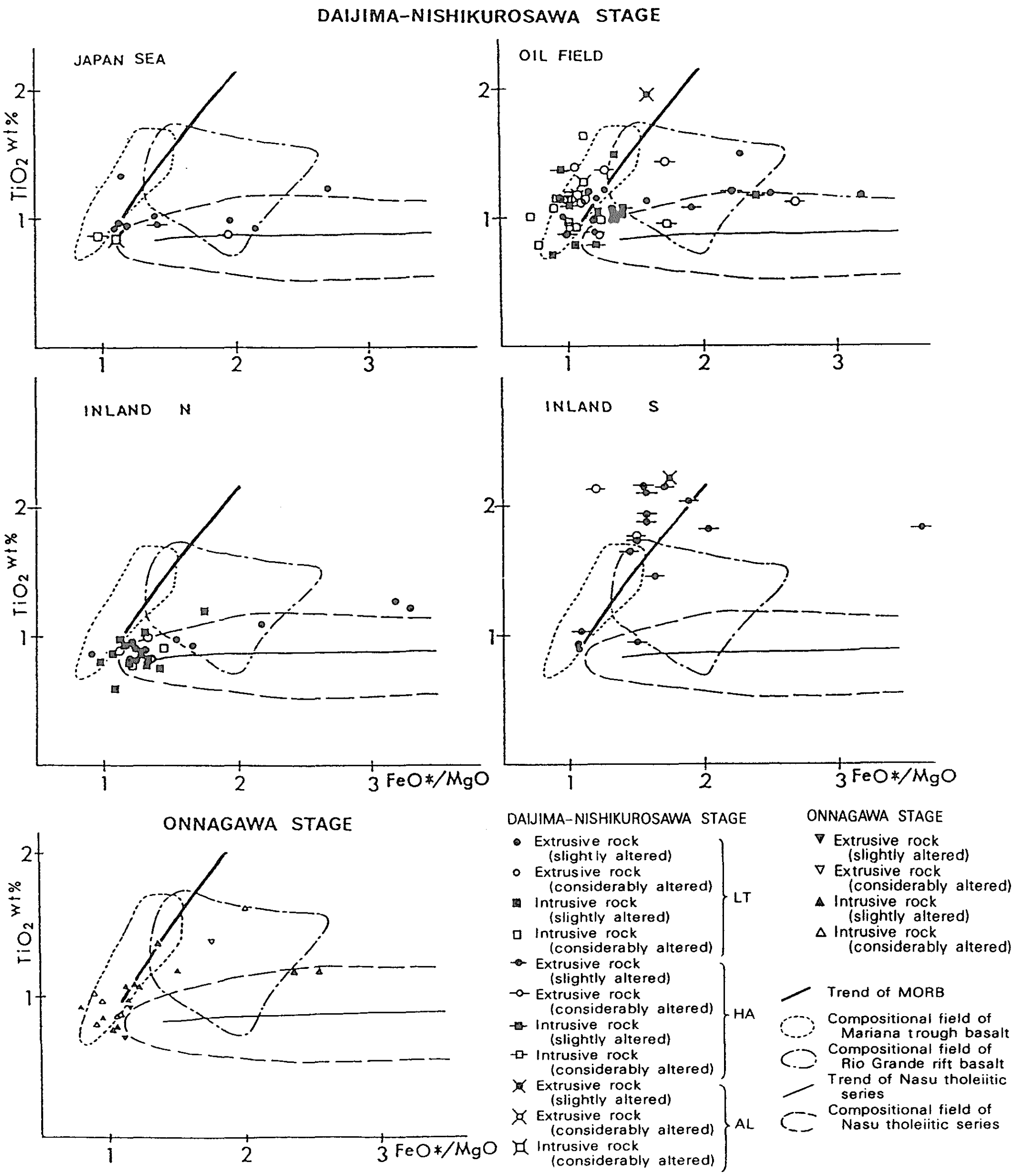

Fig. 13 Plot on TiO_2 vs. FeO*/MgO diagram for the middle Miocene basaltic rocks (modified from TSUCHIYA, 1988a). LT, HA and AL are the same as those in Fig. 12. For the comparison, trends and compositional fields of MORB (MIYASHIRO, 1975), Mariana trough basalt (HAWKINS and MELCHIOR, 1985), Rio Grande rift basalt (AOKI, 1967) and tholeiitic series of the Nasu Volcanic zone are shown (modified TSUCHIYA, 1988a).

rocks such as Quaternary volcanic rocks of the NE Japan arc. The basaltic rocks are the products of the bimodal volcanism (KONDA, 1974) and have no systematic increment of alkali content toward the back-arc side. Bimodal volcanism commonly have occurred in continental rift and back-arc spreading regions, such as Basin and Range and Rio-Grande rift regions, western United States (LIPMAN, 1969; LIPMAN and MEHNART, 1979).

Table 2 Normalized compositions of the middle Miocene basaltic rocks. The data were normalized at $FeO^*/MgO=1.4$ on the diagram of oxides vs. FeO^*/MgO. Data of Mariana trough basalt (HAWKINS and MELCHIOR, 1985), Rio Grande rift basalt (AOKI, 1967) and Nasu tholeiitic basalt (after TSUCHIYA, 1988) are also shown. LT : Low-alkali tholeiite series, HA : high-alumina basalt and high-alkali tholeiite series (modified TSUCHIYA, 1988a).

STAGE	DAIJIMA-NISHIKUROSAWA					ONNAGAWA				
AREA	JAPAN SEA	OIL FIELD		INLAND (N)	INLAND (S)			MARIANA	RIO-GRANDE	NASU
SERIES	LT	LT	HA	LT	HA	LT	HA	HA	HA	LT
SiO_2	54.64	51.66	53.11	52.34	54.29	55.16	52.15	50.66	50.69	51.32
TiO_2	1.07	1.15	1.03	0.93	1.56	0.96	1.12	1.55	1.29	0.84
Al_2O_3	17.43	17.35	17.96	17.14	16.67	18.70	18.05	17.11	16.92	18.98
FeO^*	8.07	9.34	8.04	9.14	8.44	7.36	8.52	8.84	10.76	9.49
MnO	0.17	0.18	0.17	0.15	0.15	0.12	0.14	0.15	0.15	0.17
MgO	5.98	6.89	6.47	6.95	6.13	3.92	6.50	6.27	7.51	6.19
CaO	8.66	10.38	9.07	10.57	8.25	10.31	9.38	11.19	8.62	10.58
Na_2O	2.91	2.43	3.12	2.17	3.08	2.66	2.96	3.45	2.96	2.08
K_2O	0.85	0.38	0.82	0.46	1.00	0.63	0.93	0.50	0.91	0.25
P_2O	0.21	0.20	0.20	0.14	0.43	0.16	0.25	0.18	0.18	0.10
Total	99.99	99.96	99.99	99.99	100.00	99.82	99.75	99.90	99.99	100.00

FeO^* : Total iron as FeO

In order to clarify origin and tectonic setting of the basaltic magmatism, the middle Miocene basaltic rocks are compared in geochemistry with tholeiitic basalts from island arc, mid-oceanic ridge, back-arc basin, and continental rift.

Tholeiitic basalt of island arc, e. g. that of the Nasu volcanic zone of the NE Japan arc, have higher range of FeO^*/MgO ratio than mid-oceanic ridge basalt (MORB), back-arc basin basalt (BABB), and continental rift basalt. Tholeiitic basalt of island arc is generally poor in TiO_2 and rich in K_2O compared with MORB, BABB and tholeiitic basalt of continental rift (e. g. PEARCE and CANN, 1973), while, BABB tends to be slightly poor in TiO_2 and rich in K_2O than MORB (e. g. HAWKINS, 1977 ; HAWKINS and MELCHIOR, 1985).

Tholeiitic basalt of the Rio Grande rift (AOKI, 1967) has erupted at the time of rifing (LIPMAN, 1969) and is similar to BABB in chemistry.

The middle Miocene basaltic rocks are similar in the range of SiO_2 content and FeO^*/MgO ratio to the basalts in the Mariana trough and Rio Grande rift (Fig. 10). In the TiO_2 vs. FeO^*/MgO diagram (Fig. 13), the basaltic rocks from the inland S area of the Daijima-Nishikurosawa stage show a similar trend to that of the Mariana trough basalt. In the normalized values (Table 2), most of the middle Miocene basaltic rocks have intermediate TiO_2 contents between high values of the rocks from Mariana trough and low value of the Quaternary rocks from the Nasu volcanic zone.

The chemical characteristics of the middle Miocene basalt are summarized as follows. Most of the basaltic rocks of middle Miocene age are comprised in tholeiitic series. They do not show systematic increment of alkali contents toward the back-arc side. Most of the basaltic rocks have a range of FeO^*/MgO ratio close to that of BABB. The basaltic rocks of the Daijima-Nishikurosawa stage in the inland S area increase notably in TiO_2 content with increasing in FeO^*/MgO ratio. These characteristics are similar to those of BABB rather than island arc basalt.

5.3 Trace element chemistry

The middle Miocene basaltic rocks are generally rich in Cr content (mainly 20-320 ppm), and have a wide range of Ba content (60-360 ppm)

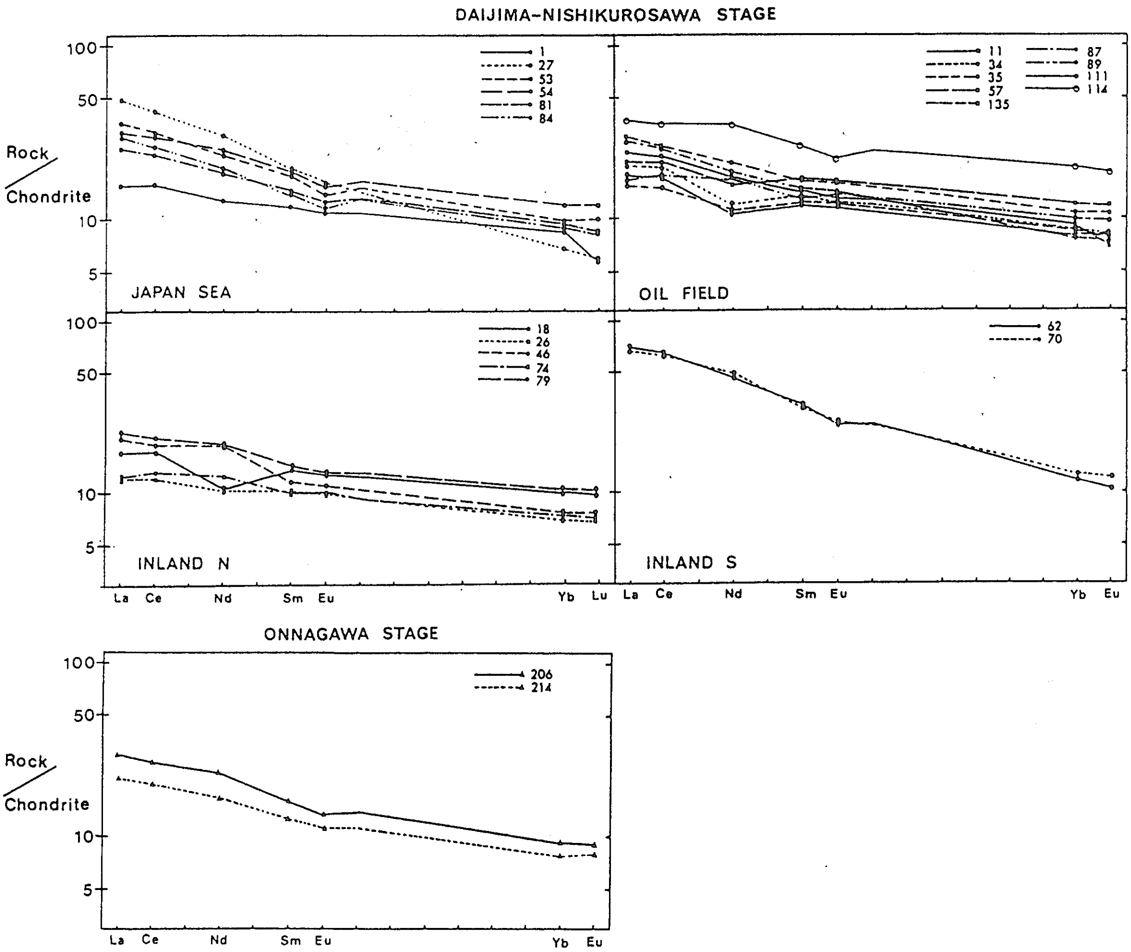

Fig. 14 Chondrite normalized REE patterns for the middle Miocene basaltic rocks. Sample numbers are same as those in TSUCHIYA (1988b).

(TSUCHIYA, 1988b). The basaltic rocks of the Daijima-Nishikurosawa stage show spatial variations in trace elements, particularly the basaltic rocks from the inland S area are fairly rich in Ba, Sr, Hf, Ta and light rare earth elements (LREE) (TSUCHIYA, 1988b).

5.3.1 Examination in terms of diagram

In order to reveal the origin and tectonic setting of the basaltic rocks, four diagrams of incompatible elements are introduced as follows.

Chondrite normalized REE patterns (MASUDA *et al.*, 1973) : In this diagram, the middle Miocene basaltic rocks show nearly linear patterns with slight enrichment of LREE (Fig. 14). However, moderate enrichment of LREE is noted in the basaltic rocks of the Daijima-Nishikurosawa stage from the inland S area. The basaltic rocks from the inland S area have the highest La/Yb ratio (TSUCHIYA, 1988b).

In the Quaternary volcanic rocks of the NE Japan arc, LREE contents and La/Yb ratios increase toward back-arc side (westward) from the present volcanic front (FUJIMAKI and KURASAWA, 1980). To the contrary, the spatial variation in the REE pattern and La/Yb ratio of the basaltic rocks from the southern part of the study area shows an opposite sense to that of the Quaternary volcanic rocks. EBIHARA *et al.* (1984) also recognized that the Tertiary volcanic

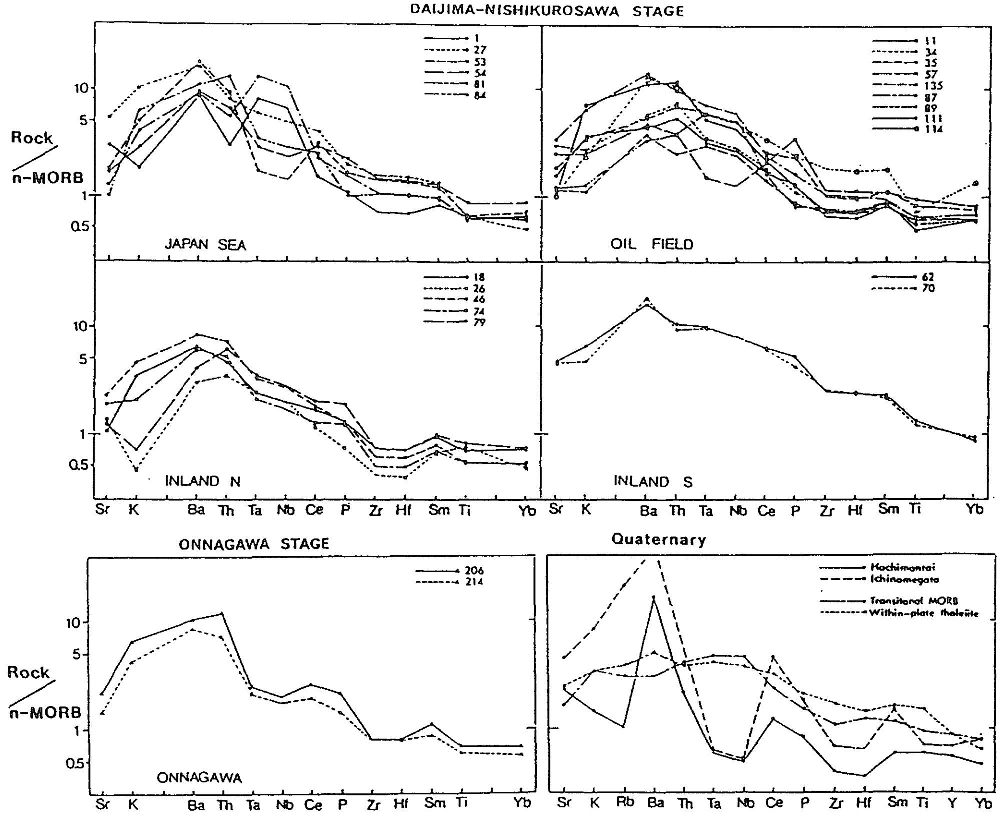

Fig. 15 n-MORB normalized patterns (Pearce, 1982 and 1983) of the incompatible elements of the middle Miocene basaltic rocks (Tsuchiya, 1988b). For the comparison, the patterns of the Quaternary basalts from Hachimantai and Ichinomegata in the NE Japan arc (Yoshida and Aoki, 1984), transitional MORB, and within-plate tholeiitic basalt (Pearce, 1982) are shown. Estimated values of Nb and Zr were calculated based upon the ratios of Nb/Ta=16 and Zr/Hf=39 which were proposed by Gill (1981) as the applicable ratio to basaltic rocks under the various tectonic conditions (modified Tsuchiya, 1988a).

rocks of the NE Japan arc do not show systematic increment of La/Yb ratio toward the back-arc side.

n-MORB normalized pattern of incompatible elements (Pearce, 1982) : Island arc basalts are mostly rich in large ion lithophile (LIL) elements such as K, Sr, Ba and Th, and poor in high field strength (HFS) elements such as Ti, Nb, Hf, and Ta, compared with MORB. The source mantle of island arc basalt is enriched in LIL elements which may have derived from subduction zone. In this normalized diagram (Fig. 15), island arc basalts are characteristically depleted in Ta (Nb) compared with LIL elements. In contrast, transitional MORB and within plate basalt do not show depletion of Ta (Nb) in the normalized pattern, and both basalts commonly observed in continental rift and back-arc basin (Pearce, 1983; Wilson, 1989).

The middle Miocene basaltic rocks are rich in incompatible elements compared with n-MORB, and mostly show smooth slopes from Ba to Yb in the n-MORB normalized patterns (Fig. 15). The basaltic rocks of the Daijima-Nishikurosawa stage do not show intensive depletion of Ta (Nb), and show similar patterns to those of transitional MORB or within plate basalt. The patterns of the basaltic rocks are clearly distinct to

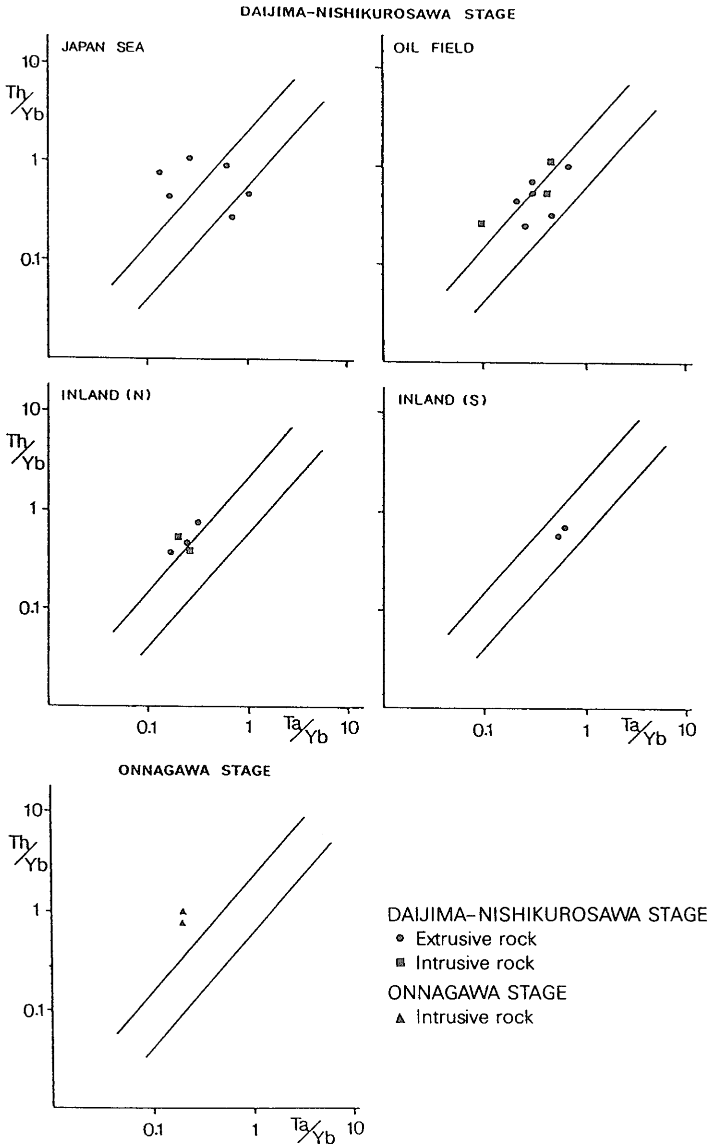

Fig. 16 Th/Yb vs. Ta/Yb diagrams for the middle Miocene basaltic rocks. The zone between two parallel lines is the array of basalts from the non-subduction setting of PEARCE (1982).

those of island arc volcanic rocks and similar to continental rift basalt and BABB. However, a part of the rocks of the Japan Sea area and the rocks of the Onnagawa stage have slight depletion of Ta in the n-MORB normalized patterns (Fig. 15)

Th/Yb vs. Ta/Yb diagram (PEARCE, 1982) : In this diagram (Fig. 16), MORB and within plate basalt are plotted mostly in an array of non-subduction setting. On the other hand, island arc basalt has higher Ta/Th ratio as compared with MORB, and is plotted on the field above the array.

The basaltic rocks of the Daijima-Nishikurosawa stage are plotted on and around the non-subduction setting array (Fig. 16). Therefore,

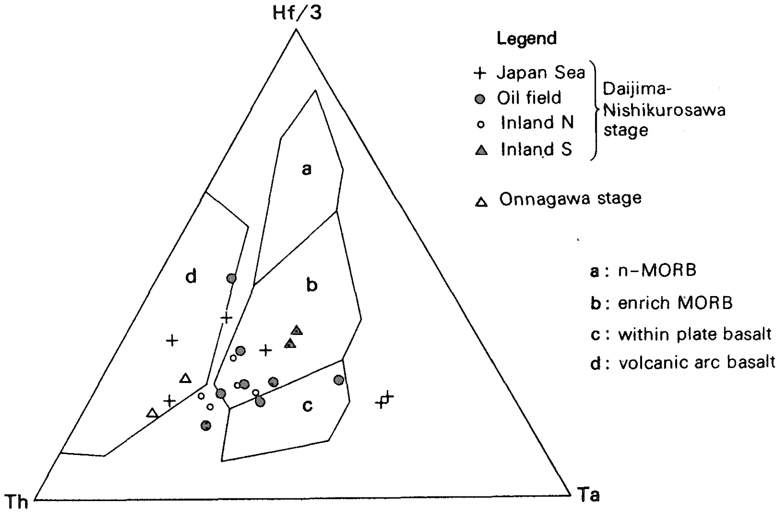

Fig. 17 Th-Hf/3-Ta discrimination diagram (WOOD *et al.*, 1979) for the middle Miocene basaltic rocks. Field of a : normal type MORB, B : enriched type MORB, c : within plate basalts, d : volcanic arc basalts.

the middle Miocene basaltic rocks have a similar feature to basalts in non subduction setting, such as MORB and within plate basalt. The basaltic rocks of the Onnagawa stage apparently are plotted on the field above the array (Fig. 16).

Ta-Hf/3-Th diagram (WOOD *et al.*, 1979) : In this diagram (Fig. 17), basaltic rocks of the Daijima-Nishikurosawa stage are plotted mainly in the field of enriched (transitional) MORB and within plate basalt, whereas those of the Onnagawa stage are plotted in the field of volcanic arc basalts.

5.3.2 Geochemical features and tectonic setting

The basaltic rocks of the Daijima-Nishikurosawa stage have different features in trace element composition from the Quaternary volcanic rocks of the NE Japan arc, as summarized as follows ; 1) the basaltic rocks are rich in Cr content, 2) the light REE content and La/Yb ratio do not increase toward back-arc side (westward), 3) the n-MORB normalized pattern is akin to that of transitional MORB or within plate basalt, 4) the rocks are plotted mainly in and around the array of non-subduction setting in the Th/Yb vs. Ta/Yb diagram. 5) The basaltic rocks are plotted mainly in the field of enriched MORB and within plate basalts in the Ta-Hf/3-Th diagram.

Based on the petrochemical features in these diagrams, the basaltic rocks of the Daijima-Nishikurosawa stage are quite similar to BABB. The basaltic rocks of the Onnagawa stage, however, partly have features of island arc basalt in the n-MORB normalized pattern, Th/Yb vs. Ta/Yb diagram and Ta-Hf/3-Th diagram.

6. Discussion

On the basis of the geological and petrochemical data, the middle Miocene basaltic magmatism and tectonic events are summarized and reconstructed. A rifting model of the basaltic magmatism in the NE Japan arc is proposed in relation to the formation of the marginal sea (Japan Sea).

6.1 Magmatism in the rift zone of the oil field

6.1.1 Geotectonic and petrochemical features of the magmatism

During early middle Miocene time (Daijima-

Nishikurosawa stage), voluminous basaltic rocks erupted from dike swarm to form submarine volcanoes in the rift zone of the Akita-Yamagata oil field under the extensional tectonic condition.

The rift zone has rifting axes which can be recognized from the basaltic dike swarm and normal faults of NNE-SSW to NE-SW trend. The dike swarm in the Aosawa Formation intruded into open cracks and may represent a rifting axis. The dike swarm was conduits through which eruptions occurred to form submarine volcanoes in the Taiheizan and Aosawa districts (Figs. 6 and 7). Thus, an array of the higher parts of the volcanoes presumably represents the trend of rifting axes.

In the rift zone, as shown in lithofacies map (Fig. 4), the basaltic rocks were distributed mainly along NNE-SSW direction. From the subsurface geological data provided by the deep wells (e. g. IKEBE, 1962; INOUE, 1962; OZAWA *et al.*, 1989), it was confirmed that the basaltic rocks built several topographic ridges of N-S to NW-SE trend. The topographic ridges may represent the trend of rifting axes through which the basaltic magmatism occurred. Thus, the rifting axes in the oil field trend mainly NNE-SSW to NE-SW and the rift zone widened in the WNW-ESE to NW-SE direction. The distribution and trend of the rifting axes are shown in Fig. 18.

As the rifting axes are oblique to the N-S elongation of the oil field basin and are arranged en echelon, the basin may have rifted obliquely (Fig. 18) as in the case of the Gulf of California, western North America (e. g. LONSDALE and LAWVER, 1980).

The basaltic rocks in the rift zone have similar composition throughout the oil field. The basaltic rocks are akin to BABB in major and trace element chemistry, and may have formed possibly in a tectonic setting of back-arc basin.

6.1.2 Temporal change in magmatism

The basaltic magmatism of the early middle Miocene age in the rift zone decreased and changed its activity from extrusive to intrusive until late middle Miocene time (Onnagawa stage). The basaltic rocks did not change their major element chemistry throughout middle Miocene time. However, their trace element chemistry was slightly changed toward the island arc type until late middle Miocene time.

6.2 Geotectonic events and magmatism in the surrounding areas

In the surrounding areas (Japan Sea, inland N and inland S areas), characteristic bimodal magmatism took place in early middle Miocene time on land and shallow water bottom, producing a large amount of acid volcanic rocks and a small amount of basalts. During this magmatism, the grabens and normal faults were developed in NNE-SSW to NE-SW trends which are nearly parallel to the rifting axes of the rift zone. Both grabens and normal faults may represent extensional tectonic movement at the time of rifting. Toward late middle Miocene time, the bimodal magmatism declined and was followed by regional subsidence.

In the Japan Sea area, The basaltic rocks consist mainly of LT, and are accompanied with HA and CT. The basaltic rocks generally show features of BABB in trace element chemistry, but a part of them show features of island arc basalt (Fig. 17).

In the inland N area, the basaltic rocks are made up of LT, and their major element composition are similar to island arc tholeiite (Table 2). However, their trace element chemistry is rather similar to BABB.

In the inland S area, the basaltic rocks are mainly comprised in the HA series, and have high contents of TiO_2 and K_2O compared with those in other areas (Table 2). The basaltic rocks are rich in incompatible elements. These features of major and trace elements show a similarity to those of within plate basalt.

6.3 Spatial variation of the basaltic magmatism

The middle Miocene magmatism yielded the voluminous basaltic rocks in the oil field and bimodal volcanic products in the surrounding areas. This spatial variation in magmatism seems to be similar to that of continental rift such

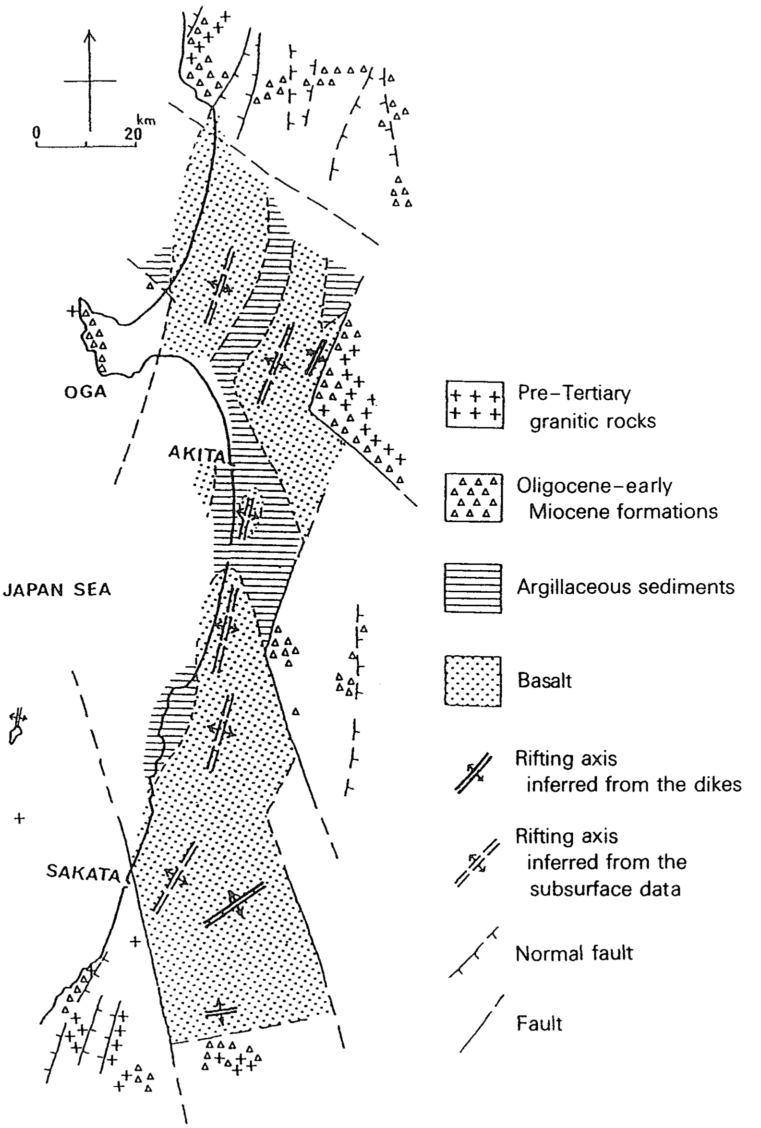

Fig. 18 Distribution of thick basaltic rocks and regional tectonic features in early middle Miocene age in the Akita-Yamagata oil field and surrounding areas, back-arc region of the NE Japan arc.

as the Rio Grande rift (AOKI, 1967; LIPMAN and MEHNART, 1979), although it may be discriminated in some point of petrochemistry as discussed below.

In and around the Rio Grande rift, the basaltic rocks show symmetric spatial variation in petrochemistry, i. e. tholeiitic basalts of BABB type were emplaced in the axial area, while alkalic basalts erupted in the surrounding areas.

The spatial variation in petrochemistry of the basaltic rocks in and around the oil field differs from that of the Rio Grande rift. The basaltic rocks from the rift zone of the oil field have affinities to BABB in major and trace element chemistry, whereas those from the surrounding areas show a similarity in major chemistry to island arc basalt and alkali basalt. Judging from this spatial variation, the basaltic magmatism occurred mainly in the rift zone under an influence of volcanic arc magmatism of middle Miocene age in the NE Japan arc.

6.4 A model of the basaltic magmatism

On the basis of the present study (Figs. 9 and 18) and previous paleogeographic studies of the NE Japan arc (AMANO, 1982; KITAZATO, 1983; SATO, 1986), the geotectonic features in the early middle Miocene of the central part of the NE Japan arc including the oil field and surrounding areas are illustrated in a schematic block diagram (Fig. 19).

During early middle Miocene time, a volcanic front was located possibly along the western margin of the Kitakami Mountains, 30 km to the east of the Quaternary volcanic front (TOGASHI, 1983; OHGUCHI *et al.*, 1989). The central part of the voluminous basaltic magmatism of the oil field was located 100 km back-arc side from the possible volcanic front of middle Miocene age.

In the oil field, the rift zone has several rifting axes of NNE-SSW to NE-SW trend and spread obliquely to the rifting zone during early middle Miocene time. The voluminous basaltic rocks extruded from the dike swarm to form volcanoes along the rifting axes, and intercalates the mudstone layers.

On both sides of the oil field, bimodal volcanism took place extensively producing a large amount of acid volcanic rocks and a subordinate amount of basalt. Grabens and normal faults of NE-SW trend were formed during the magmatism.

Along the Ou backbone range, on the east of the inland area, acid volcanism occurred to accumulate thick piles of lava and volcaniclastic rocks. Related with the acid volcanism, normal faulting and tilting occurred in the Ou backbone range and the inland area (AMANO, 1982) (Fig.

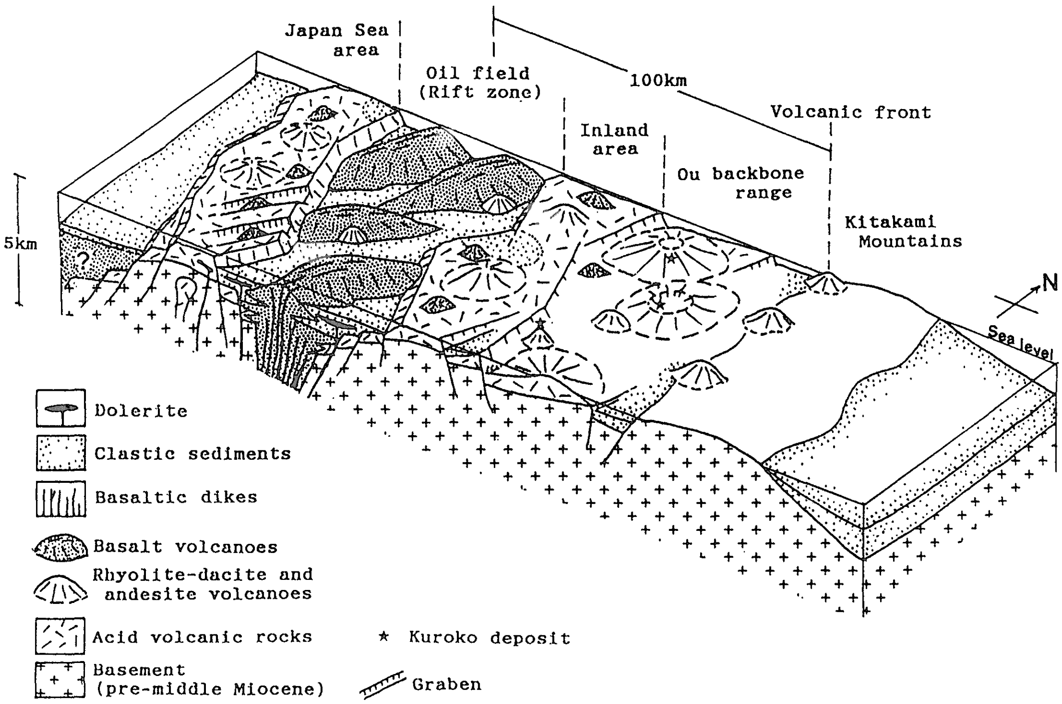

Fig. 19 A block diagram showing the magmatism and tectonic features in early middle Miocene age in the central part of the NE Japan arc including the rift zone of the Akita-Yamagata oil field.

19).

6.5 Relationship to Japan Sea spreading

The rifting event of the Akita-Yamagata oil field may have occurred contemporaneously with hypothetical Japan Sea spreading. Recent paleomagnetic studies suggested that the Japan Sea started to spread rapidly in early middle Miocene time (OTOFUJI *et al.*, 1985; TOSHA and HAMANO, 1988).

In the Japan Sea, two main spreading basins (viz. Japan basin and Yamato basin) and several failed rifts are recognized (TAMAKI, 1988). The failed rifts are about 40 km wide and occur in the peripheral part of the Japan Sea spreading. Since the size and situation of the rift zone of the oil field are comparable to those of the failed rifts, the rift zone can be regarded as one of failed rifts which were formed close to the NE Japan arc. It can be said that the basaltic magmatism has occurred in this rift zone during the time of Japan Sea spreading (Fig. 20).

6.6 Nature and generation of magma

6.6.1 Features of the early middle Miocene basaltic magma

The basaltic magma of early middle Miocene age (Daijima-Nishikurosawa stage) was probably derived from a source mantle of BABB type without extensive differentiation. Based on the isotopic investigations on Tertiary volcanic rocks of the NE Japan arc, KURASAWA and KONDA (1986) showed that the source mantle must have been emplaced beneath the back-arc region of the NE Japan arc until early middle Miocene time. NOHDA *et al.* (1988) also suggested that the asthenosphere injected into the back arc side of the NE Japan arc at the time of Japan Sea spreading.

Although, the basaltic rocks are considered to have been derived from source mantle of BABB type, they partly have a petrochemical affinity to island arc basalt. This evidence may be interpreted in terms of slight metasomatism of LIL

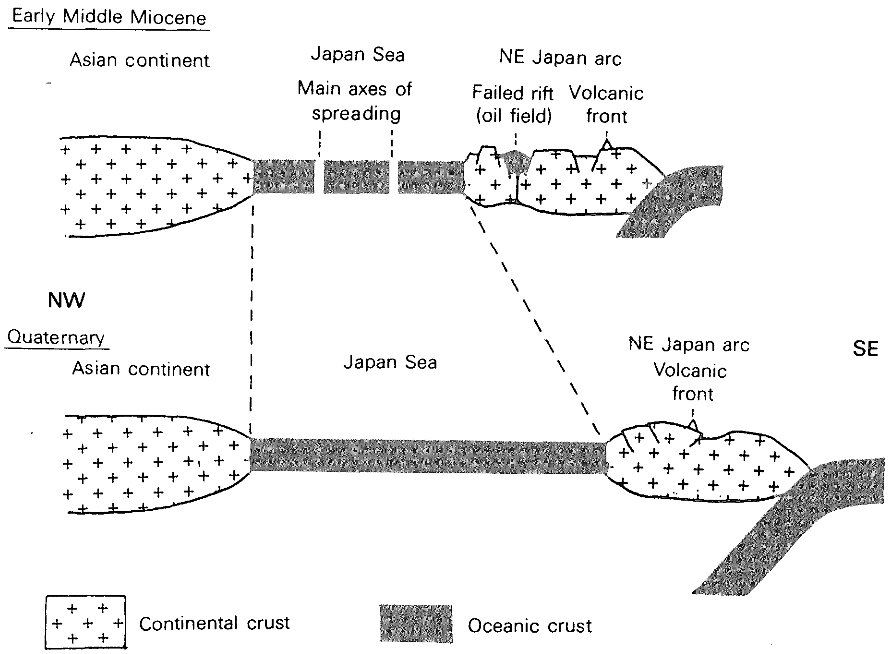

Fig. 20 A model of the rifting of the Akita-Yamagata oil field related to spreading of the Japan Sea.

elements from a subduction zone. Alternatively, contamination of the basaltic magma by crustal material might be another possible explanation. However, the basaltic rocks scarcely show petrographical evidence suggesting contamination of magma, such as the presence of xenoliths and corroded quartz. Therefore, crustal contamination may not be valid for the origin for the basaltic rocks. Conclusively, the basaltic magma was derived from the source mantle of BABB type which has been slightly affected by subduction components.

6.6.2 Temporal change in composition of source mantle

The basaltic magma of late middle Miocene age (Onnagawa stage) may have been derived from the mantle which was more enriched in LIL elements (or depleted in HFS elements) than those of early middle Miocene age. This temporal change incompatible elements can be interpreted as due to increase in the LIL element contribution to the source mantle during middle Miocene age. Such petrochemical change has also been recognized in Tertiary volcanic rocks in southwest Hokkaido (OKAMURA, 1987) and north Honshu (YOSHIDA *et al.*, 1986).

In short, the magma fed the basaltic rocks may have been generated in the BABB type mantle possibly with increase in mantle metasomatism by subduction components with time.

7. Conclusion

Middle Miocene basaltic rocks in the Akita-Yamagata oil field and surrounding areas (Japan Sea, inland N, and inland S areas) in the back-arc region of the NE Japan arc were studied with respect to their distribution, mode of occurrence, and petrochemical characteristics. The relation to rifting of the back-arc region was also considered.

The basaltic magmatism took place in the oil field and surrounding areas which were subsiding due to the rifting under the tensional tectonic environment. The basaltic magmatism yielded a large amount of submarine extrusive rocks in the rift zone of the oil field, whereas bimodal magmatism produced a lesser amount of extrusive rocks in the surrounding areas. Major geotectonic features of the oil field and surrounding areas are similar to those of continental rift. The major features are summarized as follows :

1) In the rift zone of the oil field, the basaltic rocks are distributed in a zone of 200 km in N-S length and 30-40 km in E-W width with a thickness more than 1,000 m. Their estimated volume (several thousand km^3) exceeds that of Quaternary volcanic rocks in the NE Japan arc.

During early middle Miocene time (Daijima-Nishikurosawa stage), the basaltic rocks were erupted from NNE-SSW and NE-SW trending feeder dikes to construct submarine volcanoes, and intercalated with argillaceous sediments of deep marine (bathyal) origin. Dolerite sills and laccoliths are emplaced mainly in the sediments. The feeder dikes and normal faults in the rift zone indicate tensional tectonic movements. Inferred rifting axes of NNE-SSW to NE-SW trend are oblique to the N-S elongation of the rift zone.

During late middle Miocene time (Onnagawa stage), the basaltic magmatism declined and the marine sediments overlay thickly on the basalt volcanoes, and then, the mode of magmatism shifted from eruptive to intrusive activity.

2) In the surrounding areas (Japan Sea, inland N and inland S areas), the bimodal volcanism of middle Miocene age yielded voluminous acid volcaniclastic rocks and a small amount of basalt lava. This volcanism in these areas took place chiefly on land and shallow water bottom. The surrounding areas were also affected by extensional tectonic movements. Grabens and normal faults were formed during early and middle Miocene time.

3) The early middle Miocene basaltic rocks from the rift zone of the oil field (LT and HA series) have affinities to back-arc basin basalt (BABB) in major and trace element chemistry. Whereas, basaltic rocks in the surrounding areas partly show a similarity to island arc basalt. From the spatial variation in petrochemistry, the

basaltic rocks was derived from a source mantle of BABB type with slight metasomatism by subduction components.

The late middle Miocene basaltic rocks show a slight change toward island arc basalt in trace element chemistry. This temporal change in petrochemistry may be interpreted to increasing contribution of mantle metasomatism by subduction components to the generation of the basaltic magma.

4) The rift zone may represent one of the failed rifts which developed in the peripheral part of the spreading Japan Sea. The basaltic magmatism occurred in this rift during the time of Japan Sea spreading.

References

AMANO, K. (1982) Some problems on Neogene Tertiary System in northeast Honshu, Japan. Neogene tectonics of northeast Japan, *Jour. Tectonic Res. Group in Japan*, no. 27, p. 3-18 (in Japanese).

AOKI, K. (1983) Quaternary basaltic rocks in northeastern Japan. *Island arc, marginal seas, and Kuroko deposits, Mining Geol. Special Issue no.11*, p. 79-92 (in Japanese with English abstract).

——— (1967) Petrology and Petrochemistry of latest Pliocene olivine-tholeiites of Taos area, northern New Mexico, U.S.A. *Contr. Mineral. Petrol.*, vol. 14, p. 190-203.

ARAMAKI, S. and UI, T. (1978) Major Element Frequency Distribution of the Japanese Quaternary Volcanic Rocks. *Bull. Volcanol.*, vol. 41, p. 390-407.

BLOW, W. H. (1969) Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In*: P. BRONNINMANN, and H. H. RENZ (eds.), *Proc. 1 st Internat. Conf. planktonic Microfossils*, E. J. Brill, Leiden, vol. 1, p. 199-421.

CATHLES, L. M., GUBER, A. L., LENAGH, T. C. and DUDAS, F. (1982) Failed rift and Kuroko-type massive sulfide deposits. *Mining Geol.*, vol. 31, p. 50-51.

CHIHARA, K. (1967) Some Petrochemical characteristics of late Miocene basalt in the green tuff region of northeastern Japan. *Prof. Shuken Shibata Memorial Volume*, p.119-126 (in Japanese with English abstract).

EBIHARA, M., NAKAMURA, Y., WAKITA, H., KURASAWA, H. and KONDA, T. (1984) Trace element composition of Tertiary volcanic rocks of northeast Japan. *Geochem. Jour.*, vol. 18, p. 287-295.

EINSELE, G. (1985) Basaltic sill-sediment complexes in young spreading centers : Genesis and significance. *Geology*, vol. 13, p. 249-252.

FUJIMAKI, H. and KURASAWA, H. (1980) Lateral variation of REE patterns of basaltic magma across the Japan arc. *Jour. Japan Assoc. Petrol. Miner. Econ. Geol.*, vol. 75, p. 313-322.

FUJIOKA, N., OHGUCHI, T., MAIYA, S., USUDA, M. and BABA, K. (1981) On the sediments of Daijima-Nishikurosawa age in the northeast inner Japan area. *Jour. Japan. Assoc. Petroleum Technol.*, vol. 46, 11-26.

GILL, J. B. (1981) *Orogenic Andesite and Plate Tectonics*. Springer-Verlag., 390 p.

HART, W. K., ARONSON, J. L. and MERTZMAN, S. A. (1984) Areal distribution and age of low-K, high-alumina olivine tholeiite magmatism in the northwestern Great Basin. *Geol. Soc. Amer. Bull.*, vol. 95, p. 186-195.

HAWKINS, J. W. (1977) Petrologic and geochemical characteristics of marginal basin basalt. *Island arc, deep sea trenches, and back-arc basin*, Washington, D. C., Amer. Geophy. Union, p. 355-365.

——— and MELCHIOR, J. (1985) Petrology of Mariana Trough and Lau Basin basalt. *Jour. Geophy. Res.*, vol. 90, p. 11431-11468.

HUZIOKA, K. (1956) The study of green tuff. *Science* (*Kagaku*), vol. 26, p. 440-446 (in Japanese with English abstract).

——— (1963) Aniai flora and Daijima flora. *Fossils* (*Kaseki*), vol. 5, p. 37-50 (in

Japanese).

HUZIOKA, K., OZAWA, A. and IKEBE, Y. (1976) *Geology of the Ugo-wada district*. Quadrangle Series, scale 1 : 50,000, Geol. Surv. Japan, 65 p. (in Japanese with English abstract).

IKEBE, Y. (1962) Tectonic developments of oil-bearing Tertiary and migration of oil, in Akita oil fields, Japan. *Rep. Res. Inst. Underground Resources, Min. Coll. Akita Univ.*, vol. 26, p. 1-59 (in Japanese with English abstract).

INOUE, H. (1962) Neogene Paleogeography of the surrounding Dewa Hilly Lands. *Jour. Japanese Asoc. Petroleum Tech.*, vol. 27, p. 443-464 (in Japanese with English abstract).

KATSUI, Y., OBA, Y., ANDO, S., NISHIMURA, S., MASUDA, Y., KURASAWA, H. and FUJIMAKI, H. (1978) Petrology of the Quaternary volcanic rocks of Hokkaido, north Japan. *Jour. Fac. Sci., Hokkaido Univ.*, Ser. IV, no. 18, p. 449-484.

KITAMURA, N. (1959) Tertiary orogenesis in northeast Honshu, Japan., *Contr. Inst. Geol. Paleont. Tohoku Univ.*, no. 49, p. 1-98 (in Japanese with English abstract).

KITAZATO, H. (1983) Submarine topography of the northeast Honshu arc during the early middle Miocene Nishikurosawa stage, based on benthic foraminifera. *Island Arcs, Marginal Seas, and Kuroko Deposits, Mining Geol. Special Issue*, no. 11, p. 263-270 (in Japanese with English abstract).

KIMURA, K. (1986) Chronostratigraphic classification of the lower and middle Tertiary formations in the Oga, Akita and Honjo-Yuzawa areas : a study based on stratigraphic relations and radiometric age. *Essays in Geology, Prof. Nobu Kitamura Commemorative Volume*, p. 167-173 (in Japanese with English abstract).

KONDA, T. (1960) Geological and petrological studies on the Tertiary Dolerite of the Dewa Hill, Northern Honshu. *Bull. Yamagata Univ., Nat. Sci.*, no. 5, p. 35-87.

——— (1974) Bimodal volcanism in the Northeast Japan arc. *Jour. Geol. Soc. Japan*, vol. 80, p. 81-89 (in Japanese with English abstract).

KUNO, H. (1966) Lateral variation of basalt magma type across continental margins and island arcs. *Bull. Volcanol.*, vol. 29, p. 195-222.

——— (1968) Discussion on the thesis "Rocks in the ocean region, I. High-alumina basalt" by AOKI and ITO. *Earth Science* (*Chikyu Kagaku*), vol. 22, p. 195-197 (in Japanese).

KURASAWA, H. and KONDA, T. (1986) Strontium isotopic ratios of Tertiary volcanic rocks of northeastern Honshu, Japan : implication for the spreading of the Japan Sea. *Jour. Geol. Soc. Japan*, vol. 92, p. 205-217 (in Japanese with English abstract).

KUWAHARA, T. (1982) Miocene strike-slip fault system representing the compressional stress field of E-W to NW-SE direction, in the outer side of the southern part of Northeast Japan Arc, —Miocene fault system and tectonic stress fields of Northeast Japan Arc—. Neogene Tectonics of Northeast Japan, *Jour. Tectonic Res. Group in Japan*, vol. 27, p. 33-54 (in Japanese with English abstract).

LIPMAN, P. W. (1969) Alkali and tholeiitic basaltic volcanism related to the Rio Grande depression, southern Colorado and northern New Mexico. *Geol. Soc. Amer. Bull.*, vol. 80, p.1343-1345.

——— and MEHNERT, H. H. (1979) The Taos plateau volcanic field, northern Rio Grande Rift New Mexico. *Rio Grande rift ; Tectonics and Magmatism*, A.G.U. Washington, D. C., p. 281-311.

LONSDALE, P. W. and LAWVER, L. A. (1980) Immature plate boundary zones studied with a submersible in the Gulf of California. *Geol. Soc. Amer. Bull.*, vol. 91, p. 555-569.

MASUDA, A., NAKAMURA, N. and TANAKA, T. (1973) Fine structure of mutually normalized rare-earth patterns of chondrites. *Geochem. Cosmochemi. Acta*, vol. 37, p. 239-248.

MCBIRNEY, A. R. (1963) Factors governing the nature of submarine volcanism. *Bull. Volcanol.*, vol. 26, p. 455-469.

MIYAGI, K. (1963) Stratigraphy and igneous activities of the green tuff formations in the Oga Peninsula, in northeast Japan (V) —General remarks on the green tuff area of northeast Japan—. *Jour. Geol. Soc. Japan*, vol. 69, p. 51-66.

MIYASHIRO, A. (1975) Classification, characteristics and origin of ophiolites. *Jour. Geol.*, vol. 83, p. 249-281.

NOHDA, S., TATSUMI, Y., OTOFUJI, Y., MATSUDA, T. and ISHIZAKA, K. (1988) Asthenospheric injection and back-arc opening : Isotopic evidence from Northeast Japan. *Chem. Geol.*, vol. 68, p. 317-327.

OGASAWARA, K., ODA, M. and HORIKOSHI, E. (1986) Island Arc Transect Route No. 14 (Oga Peninsula-Gojome-Ani-Ryugamori) -Geological map, cross section and explanatory text, *In*: N. KITAMURA (ed.), *Cenozoic Arc Terrane of Northeast Honshu, Japan*. Vol. 2, Hobundo. Japan. p. 1-21 (in Japanese).

OHGUCHI, T. (1983) Stratigraphical and petrographical study of the late Cretaceous to early Miocene volcanic rocks in northeast inner Japan. *Jour. Min. Coll. Akita Univ., Ser. A*, vol. VI, no. 3, p. 189-258.

———, YOSHIDA, T. and OKAMI, K. (1989) Historical change of the Neogene and Quaternary volcanic field in the Northeast Honshu arc, Japan. *Memor. Geol. Soc. Japan*, vol. 32, p. 431-455 (in Japanese with English abstract).

OKAMURA, S. (1987) Geochemical variation with time in the Cenozoic volcanic rocks of southwest Hokkaido, Japan. *Jour. Volc. Geotherm. Res.*, vol. 32, p. 161-176.

OTOFUJI, Y., MATSUDA, T. and NOHDA, T. (1985) Paleomagnetic evidence for the Miocene counter-clockwise rotation of Northeast Japan, rifting process of Japan Arc. *Earth Plan. Sci. Lett.*, vol. 75, p. 265-277.

Ozawa, A. (1963) Neogene orogenesis, igneous activity and mineralization in the central part of northeast Japan. *Jour. Japanese Assoc. Min. Petr. Econ. Geol.*, vol. 50, p. 167-184 (in Japanese with English abstract).

———, IKEBE, Y., ARAKAWA, Y., TSUCHIYA, N., SATO, H. and KAKIMI, T. (1982) *Geology of the Kisakata district.* (including Tobishima in the Sakata District) Quadrangle Series, scale 1 : 50,000, Geol. Surv. Japan, 73 p. (in Japanese with English abstract).

———, KANO H., MARUYAMA, T., TSUCHIYA, N., ITO, M., HIRAYAMA, J. and SHINADA, S. (1981) *Geology of the Taiheizan district.* Quadrangle Series, scale 1 :50,000, Geol. Surv. Japan, 69 p. (in Japanese with English abstract).

———, KATAHIRA, T., NAKANO, S., TSUCHIYA, N. and AWATA, Y. (1988) *Geology of the Yashima district.* With Geological Sheet Map at 1 : 50,000, Geol. Surv. Japan, 87 p. (in Japanese with English abstract).

———, ——— and TSUCHIYA, N. (1986) *Geology of the Kiyokawa district.* With Geological Sheet Map at 1 : 50,000, Geol. Surv. Japan, 61 p. (in Japanese with English abstract).

———, KUJIRAOKA, A. and AWATA, Y. (1985) *Geology of the Ugo-Hamada district.* With Geological Sheet Map at 1 : 50,000, Geol. Surv. Japan, 57 p. (in Japanese with English abstract).

———, SUMI, K. and TSUCHIYA, N. (1983) *Geology of the Nakahama district.* Quadrangle Series, scale 1 : 50,000, Geol. Surv. Japan, 62 p. (in Japanese with English abstract).

———, TSUCHIYA, N., KATAHIRA, T., KIKUCHI, Y. and OHGUCHI, T. (1989) Subsurface structure under the oil fields in southern Akita and Yamagata Prefectures.

Memor. Geol. Soc. Japan, vol. 32, p. 133-142 (in Japanese with English abstract).

PEARCE, J. A. (1982) Trace element characteristics of lavas from destructive plate boundaries. THORPE, R. S. edit., *Andesites.* John Wiley and Sons, p. 525-548.

——— (1983) Role of the sub-continental lithosphere in magma genesis at active continental margins, *In*: C. J. HAWKESWORTH and M. J. NORRY (eds.) *Continental basalt and mantle xenolith,* Shiva Publishing, Nantwich, p. 230-249.

——— and CANN, J. R. (1973) Tectonic setting of basic volcanic rocks determined using trace element analysis. *Earth. Plan. Sci. Lett.*, vol. 19, p. 290-300.

SATO, H. (1986) Geologic development of the Cenozoic System in Central northeast Honshu (Between Sakata and Furukawa). *Contr. Inst. Geol. Paleont. Tohoku Univ.*, no. 88, p. 1-32 and no. 89, p. 1-45 (in Japanese with English abstract).

———, OTSUKI, K. and AMANO, K. (1982) Neogene tectonic stress field of Northeast Honshu Arc. Neogene Tectonics of Northeast Japan, *Jour. Tectonic Res. Group in Japan*, no. 27, p. 55-80 (in Japanese with English abstract).

SATO, O. and ANNAKA, H. (1986) Reservoir petrography of volcanic rocks from the Shin Kurokawa-1 Well in the Akita Oil Fields. *Contributions to Petroleum Geoscience, Prof. Kazuo TAGUCHI Memorial Volume*, p. 137-148 (in Japanese with English abstract).

SATO, T. (1974) Distribution and geological setting of the Kuroko deposits. *Geology of Kuroko Deposits*, *Mining Geol. Special Issue*, no. 6, p. 1-9.

SHUTO, K., TAKIMOTO, T., SAKAI, A., YAMAZAKI, T. and TAKAHASHI, T. (1988) Geochemical variation with time of the Miocene volcanic rocks in northern part of the Northeast Japan Arc. *Jour. Geol. Soc. Japan*, vol. 94, p. 155-172 (in Japanese with English abstract).

——— and YASHIMA, R. (1985) Rock types of Miocene two petrographic provinces in the Pacific side region of Northeast Japan. *Jour. Japan Assoc. Petrol. Miner. Econ. Geol.*, vol. 81, p. 190-201 (in Japanese with English abstract).

STUWART, J. H. (1978) Basin and range structure in western North America. *A review. Geol. Soc. Amer. Memoir.*, vol. 152, p. 1-31.

TAGUCHI, K. (1962) Basin architecture and its relation to petroleum source rocks development in the region bordering Akita and Yamagata Prefecture and adjoining areas, with special reference to the depositional environment of the petroleum source rocks in Japan. *Sci. Rep. Tohoku Univ.*, ser. III, vol. 7, p. 293-342.

TAMAKI, K. (1988) Geological structure of the Japan Sea and its tectonic implications. *Bull. Geol. Surv. Japan*, vol. 39, p. 269-365.

TOGASHI, S. (1983) Temporal and spatial variation of alkali elements in Miocene igneous rocks of northern Honshu, Japan. *Island Arcs, Marginal Seas, and Kuroko Deposits*, *Mining Geol. Special Issue*, no. 11, p. 93-102 (in Japanese with English abstract).

TOSHA, T. and HAMANO, Y. (1988) Paleomagnetism of Tertiary rocks from the Oga peninsula and the rotation of Northeast Japan. *Tectonics*, vol. 7, p. 653-662.

TSUCHIYA, N. (1986) Submarine igneous activity of basaltic magma during middle Miocene age in the central part of Akita Prefecture, northeast Japan. *Bull. Geol. Surv. Japan*, vol. 37, p. 353-366 (in Japanese with English abstract).

——— (1988a) Distribution and chemical composition of the middle Miocene basaltic rocks in Akita-Yamagata oil fields of Northeastern Japan. *Jour. Geol. Soc. Japan*, vol. 94, p. 591-608 (in Japanese with English abstract).

——— (1988b) Trace element composition of the middle Miocene basaltic rocks in

Akita-Yamagata oil fields, Northeastern Japan Arc. *Jour. Japan Assoc. Petrol. Miner. Econ. Geol.*, vol. 83, p. 486-491 (in Japanese with English abstract).

TSUCHIYA, N. (1989) Submarine basalt volcanism of Miocene Aosawa Formation in the Akita-Yamagata oil field basin, back-arc region of Northeast Japan. *Memor. Geol. Soc. Japan*, vol. 32, p. 399-408.

———, OZAWA, A. and IKEBE, Y. (1984) *Geology of the Tsuruoka district.* Quadrangle Series, scale 1 : 50,000, Geol. Surv. Japan, 61 p. (in Japanese with English abstract).

———, ——— and KATAHIRA, T. (1989) Two types of Miocene basaltic rocks around Yurihara Oil and Gas Field, southeastern Akita Prefecture, Northeast Japan. *Jour. Japan. Assoc. Petroleum Technol.*, vol. 54, p. 179-193.

UOZUMI, S. and FUJIE, T. (1966) Neogene molluscan fauna in Hokkaido, Part 2, Distribution of the Okushiri fauna associated with *Vicarya* from Okushiri Island, southwest Hokkaido. *Jour. Fac. Sci. Hokkaido Univ.*, Ser. IV, no. 3, p. 139-164.

USUDA, M. and OKAMOTO, K. (1986) K-Ar ages of the Neogene volcanic rocks and correlation of the Neogene sequence in the southern part of Akita Prefecture. *Essays in Geology., Prof. Nobu Kitamura Commemorative Volume*, p. 595-607 (in Japanese with English abstract).

YAMAJI, A. (1989) Geology of Atsumi area and Early Miocene rifting in the Uetsu district, northeast Japan. *Memor. Geol. Soc. Japan*, vol. 32, p. 305-320 (in Japanese with English abstract).

YOSHIDA, T. and AOKI, K. (1984) Geochemistry of Major and trace elements in the Quaternary volcanic rocks from northeast Honshu, Japan. *Sci. Rep. Tohoku Univ.*, Ser 3, no. 16, p. 1-34.

———, OHGUCHI, T., CHIBA, T. and AOKI, K. (1986) Geochemical study on the late Cretaceous-early Miocene volcanic rocks in the western part of Northeast Honshu. *Res. Rep. Lab. Nuc. Sci. Tohoku Univ.*, vol. 19, p. 163-177 (in Japanese).

WILSON, M. (1989) *Igneous petrogenesis ; A global tectonic approach*, Unwin Hyman. London, 466 p.

WOOD, D. A., JORON, J. J. and TREUIL, M. (1979) A re-appraisal of the use of trace elements to classify and discriminate between magma series erupted in different tectonic settings. *Earth Planet. Sci. Letters*, vol. 45, p. 236-336.

東北日本弧の中新世中期における玄武岩の背弧リフト火成活動

土谷信之

要　旨

最近の古地磁気学的研究によると，日本列島は中新世中期の日本海拡大によってアジア大陸から分離し，島弧として成立したと推定されている．この時期に東北日本背弧地域の秋田-山形油田地帯では著しい玄武岩火成活動が起こり，その周縁地域では流紋岩-デイサイトと玄武岩とのバイモーダル火山活動が行われた．

秋田-山形油田地帯の中新世中期玄武岩は南北 200 km，東西 30-40 km にわたって分布し，その総体積（数千 km^3）は第四紀東北日本弧の火山岩の総噴出量をはるかに上回る．油田地帯の玄武岩は中新世中期前半（台島-西黒沢期）に多数のフィーダーから断続的に噴出し，漸深海域の泥質堆積物を挟みながら海底火山体を形成して当時の油田地帯の海盆に厚く累積した．玄武岩火成活動は中新世中期後半（女川期）に向けて弱まり，海底火山体は泥質堆積物に覆われた．このとき玄武岩マグマは未固結の泥質堆積物を貫いて多数のドレライトのシルやラコリスを形成した．中新世中期の玄武岩主体の火成活動と堆積作用によって油田地帯には玄武岩の噴出岩と貫入岩，海成泥岩及び少量の酸性-中性の火山岩が複雑に累積した地質体が形成された．

秋田-山形油田地帯の周縁地域では，中新世前-中期にグラーベンや正断層が形成され，同時に玄武岩と流紋岩-デイサイトのバイモーダル火山活動（今田，1974）が陸上ないし浅海底で行われた．このバイモーダル火山活動は中新世中期後半には衰退し，周縁地域も海成層の堆積場となった．

油田地帯とその周縁地域の中新世中期火成活動及び構造運動の諸特徴は大陸リフト地域が背弧拡大地域の特徴と類似点が多く，中新世中期玄武岩類が広域的な引張テクトニクス下で形成されたことを示唆している，すなわち油田地帯とその周縁地域では中新世中期にリフティングが起こり，油田地帯にリフトゾーンが形成され，その中で著しい玄武岩の火成活動が行われたらしい．

中新世中期玄武岩類は主としてかなり未分化なソレアイト玄武岩からなり，その TiO_2 組成は那須火山帯のソレアイトと中央海嶺玄武岩（MORB）との中間的組成を示す．その微量元素組成は，MORB に比べてインコンパティブル元素全体に富み，漸移 MORB やプレート内玄武岩と類似した特徴を持っている．しかし，この玄武岩類は部分的に島弧ソレアイトに類似した岩石も含み，沈み込み帯起源の元素の影響下で火成活動を行ったことを示唆する．このような岩石学的特徴からみて中新世中期玄武岩類は背弧海盆玄武岩に類似し，arc volcanism の活動場付近でリフト火成活動を行ったと解釈できよう．

秋田-山形油田地帯付近の中期中新統に認められる玄武岩岩脈，正断層及びグラーベンはいずれもほぼ北東-南西方向を示し，油田地帯のリフトゾーンがその南北長軸方向に対して斜めに拡大したことを示す．また，このリフトゾーンは日本海拡大の主要拡大軸から周辺部にあって，日本海海底に見いだされたいくつかの failed rift とほぼ同じ規模を持っている．以上のことから推察すると，油田地帯のリフトゾーンは日本海東縁部に生じた failed rift であったらしい．

（受付：1990年 1 月30日；受理：1990年 5 月11日）