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Middle Miocene rift magmatism of basaltic rocks in the Japan arc

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RESUMEN

En el Mioceno Medio ocurrió un intenso magmatismo basáltico ampliamente distribuido dentro y adyacente al campo petrolero de Akita-Yamagata, localizado en el flanco oeste del arco del NE de Japón. Este magmatismo está distribuido dentro de un área de 200 km x 30 x 40 km. Se estima que posee un volumen de 6,000 km^3, que es mucho mayor que los 1,500 km^3 estimados para las vulcanitas cuaternarias en el arco del NE de Japón. Consiste en rocas basálticas extrusivas e intrusivas que muestran composiciones de elementos mayores y traza típicos de basaltos asociados a cuencas retro-arco. Esta composición sugiere una fuente del manto con poco metasomatismo de los componentes de subducción.

El tipo de magmatismo basáltico que ocurre dentro de la zona de rift cambió de extrusivo a intrusivo del Mioceno Medio temprano al Mioceno Medio tardío. Durante el Mioceno Medio temprano, estas rocas fueron extruidas en un ambiente tectónico extensional, en forma de diques alimentadores con tendencia NNE-SSW a NE-SW. La lava asociada a este magmatismo ocurre intercalada con sedimentos batiales y formó numerosos volcanes submarinos. Durante el Mioceno Medio tardío, rocas basálticas fueron intrusionadas en los sedimentos como mantos doleríticos.

En el área alrededor de la zona de rift, ocurrió un magmatismo Mioceno Medio temprano ampliamente distribuido, en un ambiente extensional. Este magmatismo fue bimodal, produciendo rocas félsicas y máficas. La lava asociada fue emitida en forma subaérea y subacuática (en ambiente somero).

Con base en los rasgos geotectónicos de la zona rift, se postula que ésta es un rift continental abortado, posiblemente desarrollado durante el Mioceno Medio a lo largo de la periferia del entonces sistema de esparcimiento activo del Mar del Japón.

PALABRAS CLAVE: Rift abortado, dique alimentador, subsidencia, extensión, basaltos de cuenca retro-arco, Japón.

ABSTRACT

Intense and widespread Middle Miocene basaltic magmatism occurred within and adjacent to the Akita-Yamagata oil field, located on the west flank of the NE Japan arc. This magmatism is distributed over a 200 km x 30 to 40 km area. Its estimated volume is 6,000 km^3, much larger than the 1,500 km^3 estimated for the Quaternary volcanics in the NE Japan arc. It consists of extrusive and intrusive basaltic rocks that exhibit major and trace element compositions commonly associated with back-arc basin basalt. This composition suggests a mantle source with slight metasomatism by subduction components.

The type of basaltic magmatism changed from extrusive to intrusive from early to late Middle Miocene. In early Middle Miocene, these rocks were extruded in an extensional tectonic environment, as feeder dykes trending NNE-SSW to NE-SW. The lava associated to this magmatism occurs intercalated with bathyal sediments and formed numerous submarine volcanoes. During the late Middle Miocene, basaltic rocks were mostly intruded into the sediments as dolerite sills.

In the area surrounding the rift zone, widespread early Middle Miocene magmatism occurred in an extensional regime. This magmatism was bimodal, producing both acidic and basaltic rocks. The lava associated was subaerial and subaqueous (shallow water environment).

We suggest that the rift zone is a failed continental rift possibly developed during the Middle Miocene along the periphery of the then actively spreading Japan Sea.

KEY WORDS: Failed rift, feeder dike, subsidence, extension, back-arc basin basalt, Japan.

1. INTRODUCTION

The Japan arc is a continental fragment split off the Asian continental margin due to spreading of the Japan Sea in early to late Middle Miocene time (Otofuji *et al.*, 1985; Jolivet and Tamaki, 1992). Intense Middle Miocene magmatism occurred along the NE Japan Arc. This magmatism exhibits features distinct from those of the Quaternary volcanism in the arc. Middle Miocene magmatism (1) was of greater volume, producing oceanic tholeiites in places (Shuto *et al.*, 1988) and (2) produced basaltic rocks within the Akita-Yamagata oil field rift zone (AYRZ), whereas it produced mainly acid volcanic rocks and basalts in the surrounding area (Figure 1).

Middle Miocene magmatism occurred contemporaneously with extensional tectonic movement on the west side of the NE Japan Arc. This movement produced normal

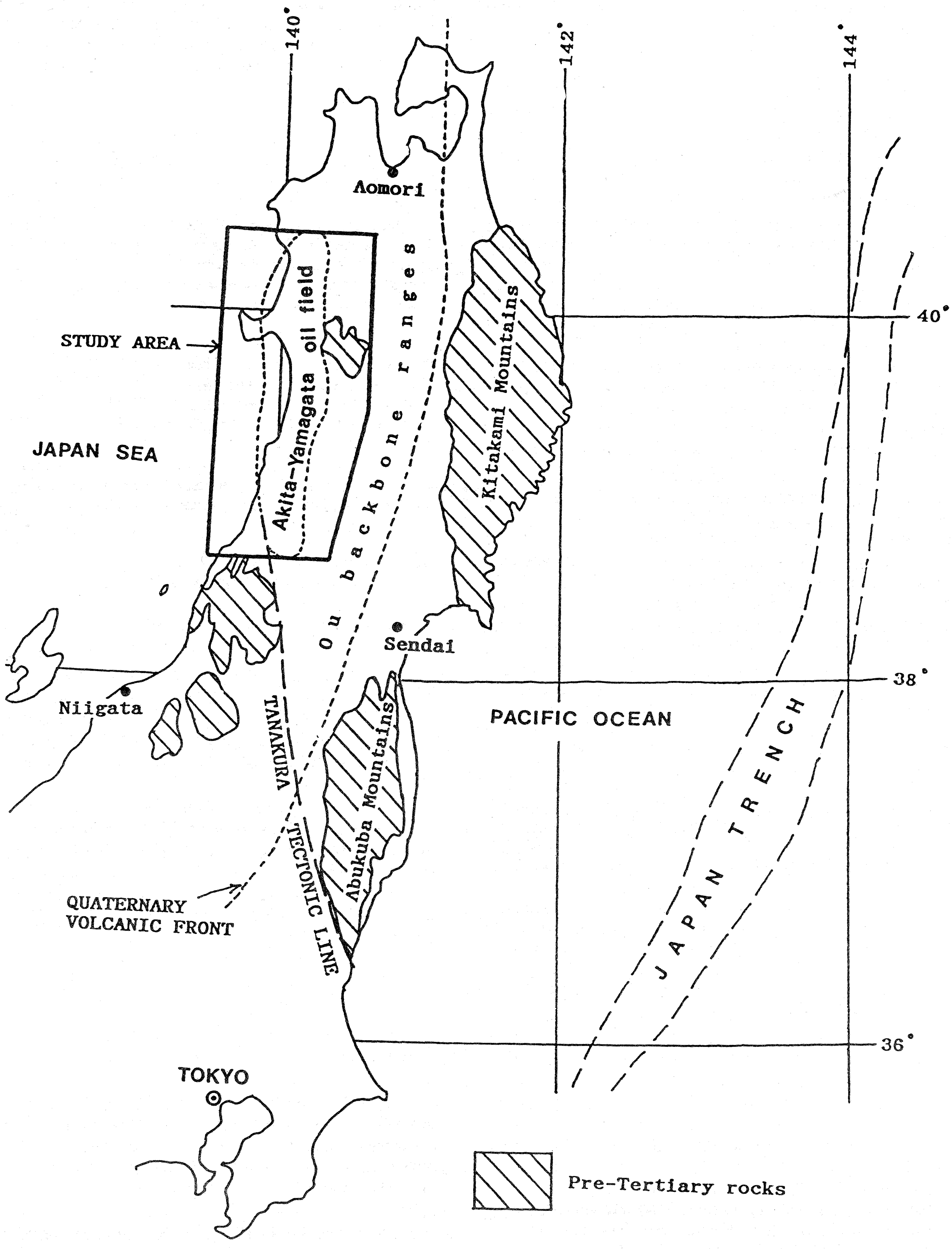

Fig. 1. Index map of the Akita-Yamagata oil field in the NE Japan arc with regional tectonic features.

faults, horsts, grabens and regional subsidence (Sato and Amano, 1992; Yamaji, 1990). The basaltic rocks are mostly overlain by thick sediments in the AYRZ; however, they have been penetrated by wells drilled for oil exploration.

The purpose of this paper is to define the significance of Middle Miocene basaltic magmatism in relation to the formation of the Japan Sea. Subsurface distribution of submarine volcanoes and the geochemistry of the Middle Miocene basalts are analyzed and compared to basalts found in island arcs, back-arc basins and continental rifts. The analysis indicates that this magmatism was most likely produced within a failed continental rift related to the formation of the Japan Sea.

2. GEOLOGICAL SETTING

The study area is situated on the Japan Sea side of the NE Japan arc, in and around the Akita-Yamagata oil field (AYOF) (Figure 1). This area is underlain by Tertiary volcanic rocks and clastic sediments. Tertiary volcanism in this area continued from late Oligocene to Middle Miocene (Figure 2). It is subdivided into the unimodal (andesitic) volcanism of the Monzen Stage and the bimodal (acidic and basaltic) volcanism of the Daijima and Nishikurosawa stages; the latter taking place concurrently with similar bimodal (rhyolite-dacite) volcanism occurring elsewhere in the NE Japan arc at this time (Konda, 1974). The absolute ages of the units defined in this area are as follows: 17-21 Ma for the Daijima stage (Usuda and Okamoto, 1986); 13-16.5 Ma for the Nishikurosawa stage (Ogasawara *et al.*, 1986); 9 to 13.5 Ma for the sediments of the Onnagawa stage (Ogasawara *et al.*, 1986); 1 to 9 Ma for the sediments of the Funakawa to Sasaoka stages (Ogasawara *et al.*, 1986).

2.1 Middle Miocene formations of the AYOF

The formations of the Nishikurosawa stage include molluscs and foraminifera which indicate that the study area was submerged to bathyal depths (500-2500 m) after early Middle Miocene time (Kitazato, 1983; Sato, 1986).

In the AYOF, the Nishikurosawa stage consists mainly of thick piles of subaqueous lavas and volcaniclastic rocks of basalt interbedded with black mudstone. A number of basalt feeder dikes intrude the basalts and volcaniclastic rocks. The mudstone yields benthic foraminiferal fossils of deep marine type (upper to middle bathyal zone). The Onnagawa stage consists mainly of siliceous hard mudstone intercalated locally with basalt lava and volcaniclastic rocks. Dolerite sills were intruded mainly in the mudstone of the Nishikurosawa and Onnagawa stages. The dolerite sills were dated about 10 Ma and may have been intruded at the time of the Onnagawa stage (Kurasawa and Konda, 1980).

2.2 Middle Miocene formations of the surrounding area

In the surrounding areas of the AYOF, the Nishikurosawa stage consists mainly of voluminous acidic volcaniclastic rocks, basalt, sandstone and mudstone. The sandstones contain shallow water molluscan fossils, while the basalt contains oxidized scoria and pillow lava. The lithofacies and biofacies of this stage indicate that the bimodal volcanism occurred in a shallow water environment during the early Middle Miocene (Konda, 1974; Tsuchiya *et al.*, 1989).

Basaltic dikes and grabens oriented NNE-SSW to NE-SW are found in the surrounding areas; for example, in the Shiragami and Uetsu mountains (Ozawa *et al.*, 1983; Yamaji, 1990). The grabens formed until early Middle Miocene and were rapidly filled with volcanic rocks and thick Middle Miocene sediments. The basaltic dikes and grabens formed in a WNW-ESE to NW-SE extensional environment during the early Middle Miocene.

The Onnagawa stage consists mainly of siliceous mudstones intruded by dolerite sills. The mudstone of this stage contain some bathyal foraminiferal fossils and therefore may have been deposited in a deep-water environment (Sato, 1986). From the lithofacies and fossil evidence, bimodal volcanism declined and basaltic magma formed dolerite sills in the mudstone. The change in lithofacies and fossils from the Nishikurosawa stage to the Onnagawa stage suggests a regional subsidence in this area during the Middle Miocene (Sato and Amano, 1991; Yamaji, 1990).

3. DATA AND METHODS

The lithofacies/isopach map (Figure 3) and the cross section of the submarine volcano of the Nishikurosawa stage are constructed from data obtained from industry wells and other field samples (Figure 4), such as the southwestern Shirakami Mts. (Ozawa *et al.*,1984), Gojome district (Tsuchiya, 1986), Aosawa district (Tsuchiya, 1989), Tachiyazawa district (Ozawa *et al.*, 1986) and the northern Uetsu Mts. (Tsuchiya *et al.*, 1984).

Petrochemical analysis of Middle Miocene basaltic rocks was made by X-ray fluorescence (XRF) and instrumental neutron activation analysis (INAA). Major-element and trace element (Rb, Sr, Y, Zr and Nb) compositions were determined with XRF (Tsuchiya, 1988; Ujike and Tsuchiya, 1993) Other trace element conpositions were determined with INAA (Tsuchiya, 1988).

4. RESULTS

4.1 Distribution of basaltic rocks in the AYRZ

The lithofacies/isopach map of the Nishikurosawa stage (Figure 3) indicates that within the AYRZ a widely distributed, thick pile of basaltic rocks covers an area approximately 200 km long (N-S) and 30 to 40 km wide (E-W). The exact thickness of these volcanics is indeterminable since few wells traversed the entire volcanic section. However, the thickness of the pile is estimated to be between 1,000 m and 1,500 m, and the estimated volume around 6,000 km^3; much larger than the 1, 500 km^3 of

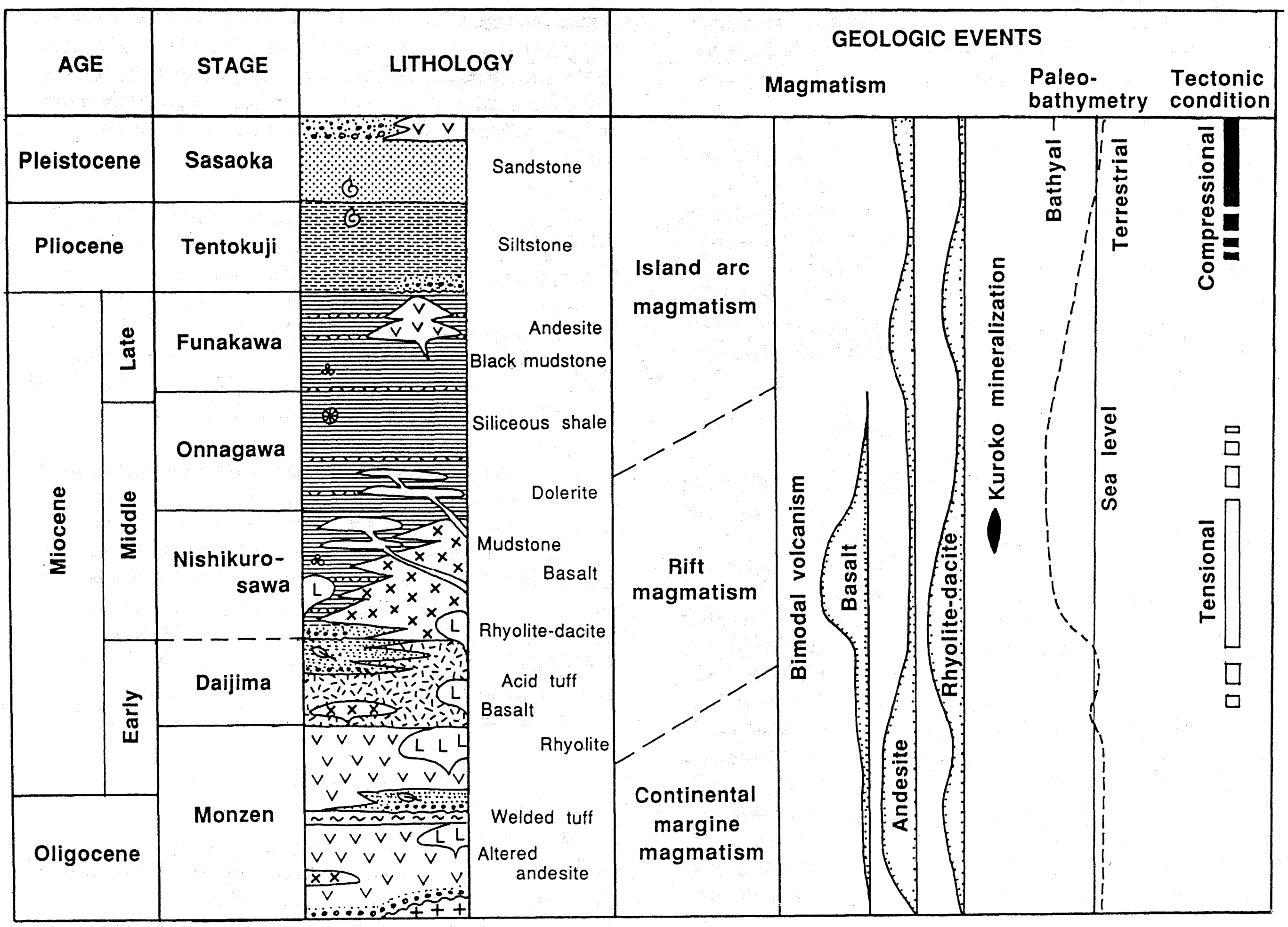

Fig. 2. Stratigraphic division of Tertiary system and geologic events in the Akita Yamagata oil field.

Quaternary volcanics in the NE Japan arc (Aramaki and Ui, 1978). In contrast, volcanic rocks of the Nishikurosawa stage in the surrounding area consist of acid volcaniclastic and basaltic rocks whose thickness is generally less than 500 m. Further, the volume of Nishikurosawa volcanics is far greater than that produced during the Onnagawa stage which consisted mainly of intrusive bodies confined to the rift zone. The lithofacies/isopach map also indicates a thick deposit of Middle Miocene sediments within the rift zone, suggesting that volcanism occurred together with rapid subsidence.

The analysis of field and well data helps us to understand the nature of the volcanism which occurred during the Nishikurosawa and Onnagawa stages. During the Nishikurosawa stage the magmatism was primarily extrusive, producing numerous submarine volcanoes within the AYRZ. A schematic cross section of the Gojome district (Figure 4) illustrates one such volcano. The upper part of the volcano contains mostly vesicular subaqueous volcaniclastic rocks with oxidized scoria; the flanks consist of basaltic volcaniclastic rocks interbedded with, and covered by, deep marine foraminiferous mudstone. The mudstone is well stratified and is gently tilted. It is cut by minor normal faults which strike mainly NNE-SSW to NE-SW. The basaltic feeder dikes of this volcano are also oriented NNE-SSW to NE-SW, and have clearly been intruded into pre-existing cracks and void spaces. Thus, the area appears to have been subjected to WNW-ESE to NW-SE oriented extension as the volcano formed.

The basaltic rocks of the Nishikurosawa stage in other districts are similar to those of the Gojome district, or the Aosawa and Tachiyazawa districts (Tsuchiya, 1989; Ozawa *et al.*, 1986). Nishikurosawa volcanism in these districts also produced submarine volcanoes exceeding 1,000 m in elevation (Tsuchiya, 1989). The deep-seated basaltic rocks of the Nishikurosawa stage in the boreholes also have similar occurrence to that in the Gojome districts (Sato and Annaka, 1986; Ozawa *et al.*, 1989; Tsuchiya *et al.*, 1989).

During the Onnagawa stage, unlike the Nishikurosawa stage, magmatism was primarily intrusive and formed numerous dolerite sills. For example, in the Gojome district (Figure 4), dolerite sills formed mainly within the mudstone of the Onnagawa stage and the underlying Nishikurosawa stage. The dolerite was intruded exten–

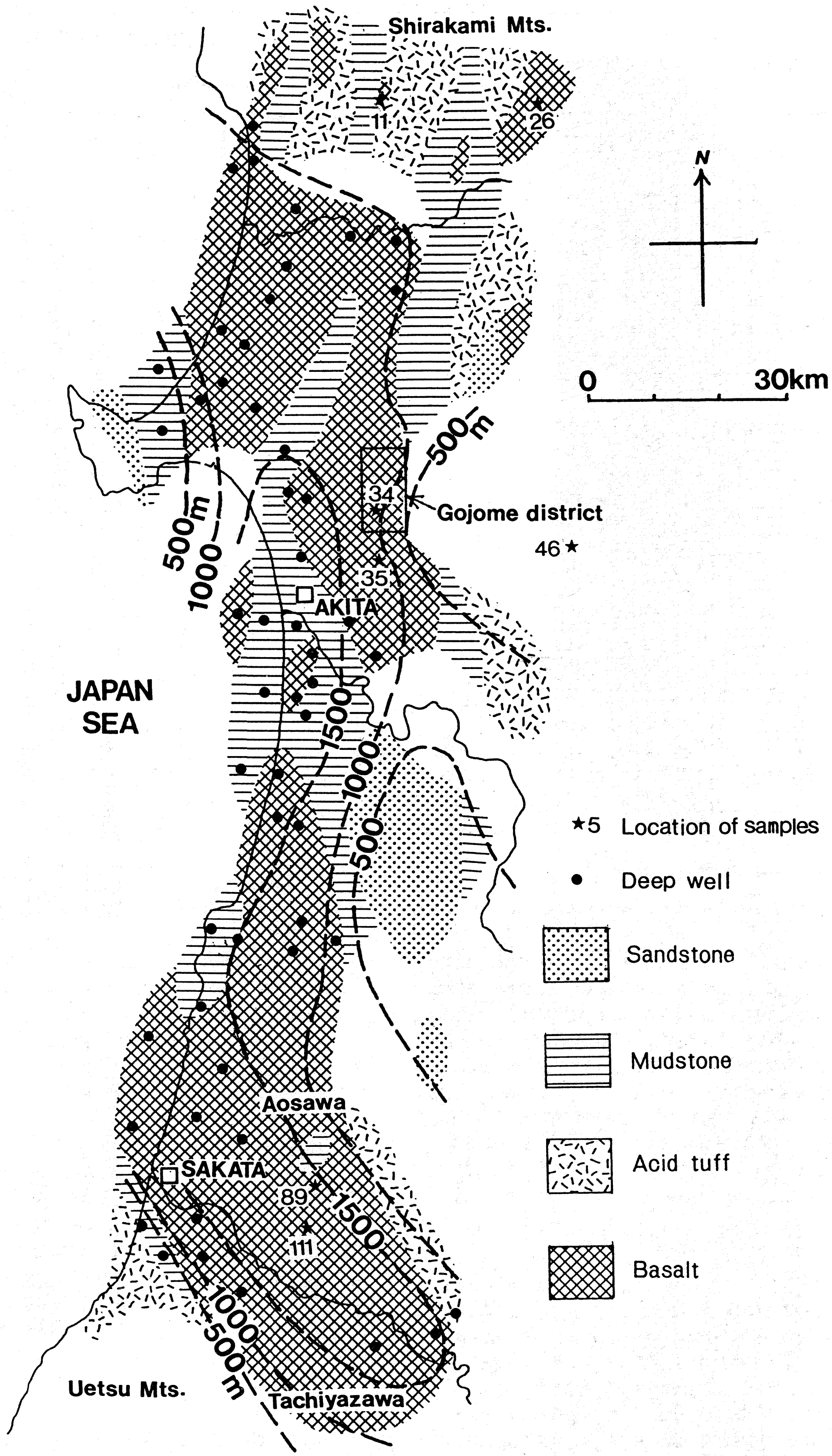

Fig. 3. Lithofacies and isopack map of the Nishikurosawa stage (Early Middle Miocene) in the Akita-Yamagata oil field and surrounding areas.

sively along the bedding planes: it commonly exhibits vesicular chilled margins. In places the dolerite disturbed the bedding plane near the contact and inclusions of irregular-shaped mudstone fragments can be observed within the

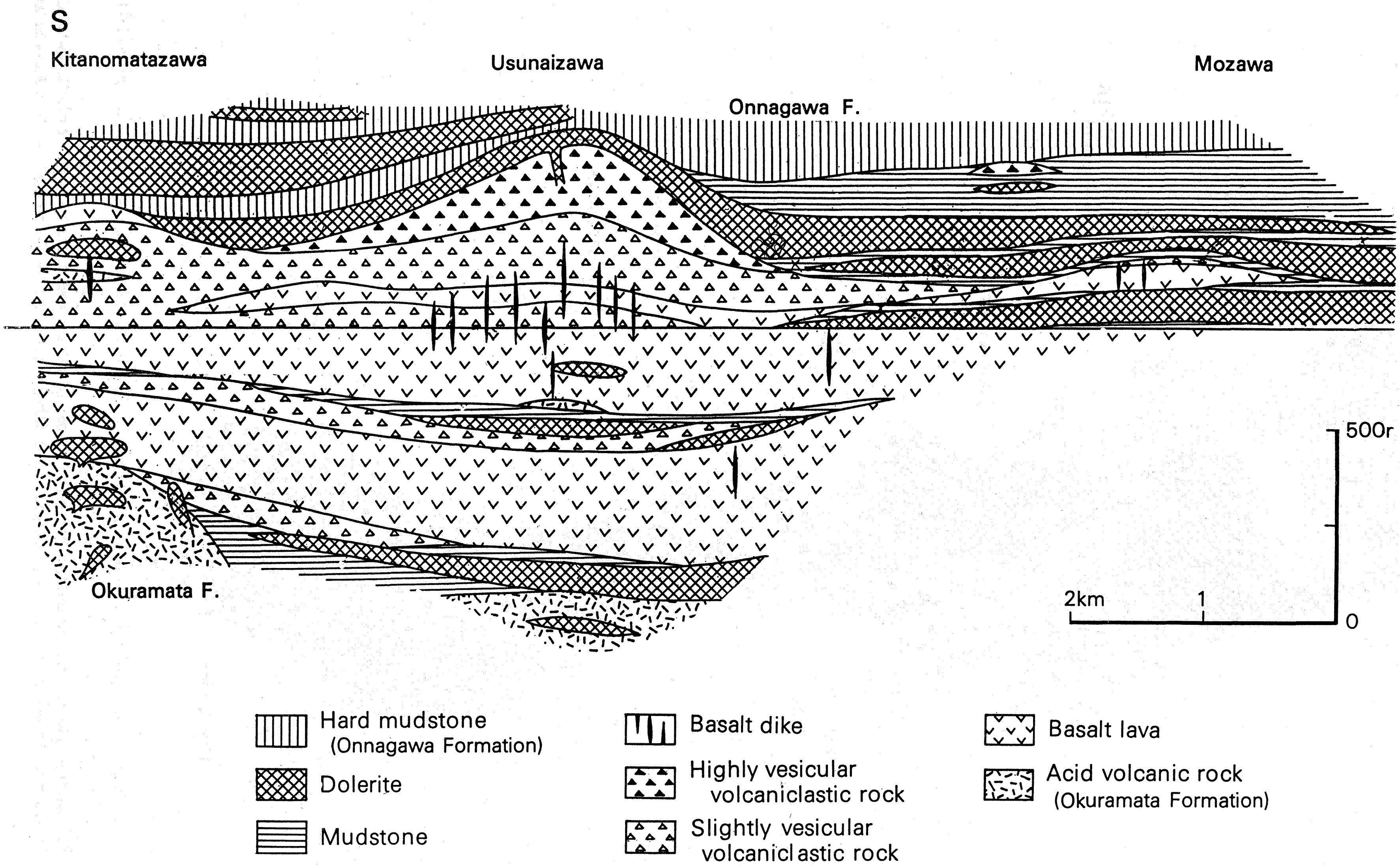

Fig. 4. A schematic cross section of a basalt volcano in the Gojome district (Tsuchiya, 1986).

dolerite. The occurrence of the dolerite suggests that the basaltic magma intruded the soft sediments.

4.2 Petrology of early Miocene basaltic rocks in the AYRZ.

4.2.1. Petrographic description

Chemical analysis of the basaltic rocks of the Nishikurosawa stage suggests that they consist mainly of olivine and augite- olivine basalt. The rocks belong to the pigeonite rock series of Kuno (1950) but contain alteration minerals such as chlorite, zeolite, carbonates, etc. However, the basaltic rocks used in the analysis preserve their original texture and show little alteration, even when their olivine and volcanic glass are altered.

4.2.2. Major and trace element chemistry

The results of the major and trace element analysis for several representative samples are shown in Table 1. The basaltic rocks exhibit a SiO_2 range of 50-54 wt%, a FeO/MgO ratio of 1.0-1.8 (Figure 6), and are less differentiated than the Quaternary volcanic rocks of the NE Japan arc (Katsui *et al.*, 1978; Aoki, 1983; Yoshida and Aoki, 1984). Further, these rocks (1) exhibit mostly tholeiitic composition and have tholeiitic trends in various differentiation diagrams (Tsuchiya, 1988), (2) mostly plot in the field of the Low-K and Medium-K series of Gill (1981) (Figure 6), (3) are generally rich in Cr content (20-320 ppm) and (4) have a wide range of Ba content (60-360 ppm).

5. COMPARISON OF BASALTS

The early Middle-Miocene basaltic rocks have different features from island-arc volcanics such as the Quaternary volcanic rocks of the NE Japan arc. The basaltic rocks are products of bimodal volcanism (Konda, 1974) and have no systematic increment of alkali and K_2O contents toward the back-arc side. Bimodal volcanism commonly has occurred in continental rift and back-arc spreading regions, such as the Basin and Range and Río Grande rifts, western United States (Lipman, 1969; Lipman and Mehnart, 1979).

To clarify the origin and tectonic setting of the basaltic magmatism, the geochemistry of the early Middle Miocene basaltic is compared with that of tholeiitic basalts from island arcs, mid-oceanic ridges, back-arc basins, and continental rifts. Tholeiitic basalts of island arcs (e.g. those of the Nasu volcanic zone of the NE Japan arc) have a higher range of tFeO/MgO ratios than midoceanic ridge basalt (MORB), back-arc basin basalt (BABB) and continental rift basalt. Tholeiitic basalt of island arcs is generally poor in TiO_2 and rich in K_2O compared with MORB, BABB and tholeiitic basalt of continental rifts (e.g. Pearce and Cann, 1973), while BABB tends to be slightly poorer in TiO_2 and richer in K_2O than MORB (e.g. Hawkins, 1977; Hawkins and Melchior, 1985). Tholeiitic basalts of the Río Grande Rift (Aoki, 1967; Lipman, 1969) and of the Great Basin (Hart *et al.*, 1984) erupted at the time of rifting and are similar to BABB in petrochemistry.

Table 1

Representative chemical composition of early Middle Miocene basaltic rocks in the Akita-Yamagata oil field

no	11	26	34	35	46	89	111
SiO_2 wt%	51.07	47.02	49.73	48.64	48.36	48.53	48.05
TiO_2	0.77	1.13	0.86	0.94	0.83	1.00	0.94
Al_2O_3	16.67	16.21	17.26	16.96	15.89	17.93	15.77
tFe_2O_3	7.81	11.68	8.41	9.17	8.36	10.54	9.41
MnO	0.13	0.17	0.14	0.13	0.12	0.15	0.15
MgO	6.66	5.99	6.28	6.88	8.17	6.70	8.67
CaO	9.01	10.05	9.77	6.34	9.31	11.02	10.18
Na_2O	2.40	1.62	2.82	1.91	1.92	2.21	2.14
K_2O	1.07	0.07	0.42	0.17	0.69	0.19	0.55
P_2O_5	0.16	0.09	0.14	0.11	0.16	0.10	0.16
I.L.	3.76	5.81	3.40	5.57	5.34	2.31	3.66
Sc ppm	32.0	40.0	34.5	35.4	32.7	37.2	34.4
Cr	199	19	172	158	405	207	448
Zn	43	70	55	63	56	69	61
Rb	30	2	13	4	15	4	13
Sr	365	312	372	268	336	298	330
Y	19	22	23	20	20	25	23
Zr	70	51	75	71	65	75	76
Nb	5	4	3	3	7	5	5
Ba	228	60	119	75	168	67	90
La	9.1	4.6	7.8	5.8	7.8	6.3	6.7
Ce	22.3	11.9	19.4	14.5	18.5	16.8	16.9
Nd	12	8	9	8	13	12	8
Sm	3.04	2.34	2.95	2.77	2.66	2.93	2.73
Eu	1.03	0.87	1.02	1.01	0.95	1.08	1.05
Yb	2.07	1.71	2.11	2.03	1.86	2.36	1.96
Lu	0.27	0.26	0.30	0.29	0.29	0.36	0.30
Hf	1.76	0.97	1.77	1.73	1.46	1.82	1.57
Th	2.35	0.70	1.47	0.50	1.47	0.77	1.07
U	0.6		0.3		0.4	0.3	

In the SiO_2 vs. K_2O and TiO_2 vs. tFeO/MgO diagrams (Figure 6), the Middle Miocene basaltic rocks exhibit a similar range of SiO_2 content and tFeO/MgO ratio to the basalts from the Mariana trough. The Middle Miocene basaltic rocks are slightly higher in TiO_2 with increasing tFeO/MgO, and show a similar trend to that of the Mariana trough basalt. These characteristics are similar to those of BABB rather than island arc basalts.

In the n-MORB normalized pattern of incompatible elements (Figure 7), island-arc basalts are mostly richer in large ion lithophile (LIL) elements such as K, Sr, Ba and Th, and poorer in high field strength (HFS) elements such as Ti, Nb, and Hf compared to MORB (Pearce, 1982). The source mantle of island-arc basalt is enriched in LIL elements which may have been derived from a subduction zone. Figure 7 also illustrates that island arc basalts are characteristically depleted in Nb compared with LIL elements. In contrast, transitional MORB and intra-plate basalts do not show depletion of Nb in the normalized pattern and both basalts are commonly observed in continental rifts and back-arc basins (Pearce, 1983; Wilson, 1989).

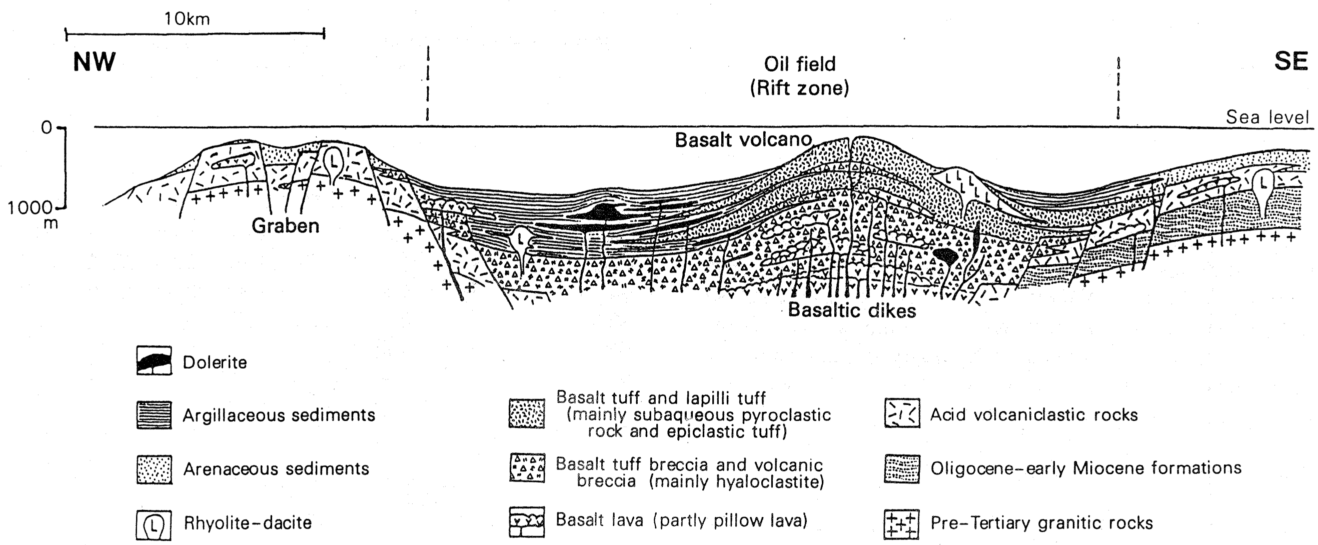

Fig. 5. A schematic cross section showing the mode of magmatism in the Akita-Yamagata oil field and surrounding areas in middle Miocene time.

The early Middle Miocene basaltic rocks are rich in incompatible elements compared with MORB, and mostly show smooth slopes from Ba to Yb in the n-MORB normalized patterns (Figure 7). The basaltic rocks exhibit a slight depletion of Nb, and also exhibit intermediate patterns between transitional MORB and island arc basalt of the NE Japan arc. The patterns of the basaltic rocks are, however, clearly distinct from island arc basalts of the NE Japan arc.

6. DISCUSSION

On the basis of the results of the present study (Figures 5 and 8) and previous paleogeographic studies of the NE Japan arc (Sato and Amano, 1991), the geotectonic features of the early Middle Miocene in the central part of the NE Japan arc, including the AYOF, are illustrated in a schematic block diagram (Figure 9). During early Middle Miocene time, a volcanic front was most likely located along the western margin of the Kitakami Mountains, 30 km east of the Quaternary volcanic front (Figure 1) (Togashi, 1983; Ohguchi *et al*., 1989). The central part of the basaltic magmatism of the AYOF was located 100 km west of the Middle Miocene volcanic front.

At this time intense, unimodal, extensive, basaltic magmatism occurred concurrently with intense local subsidence with the AYRZ. This magmatism extruded from NNE- SSW to NE-SW oriented dike swarms forming numerous submarine volcanoes along the rift axes. These volcanics are intercalated with bathyal mudstones. These basaltic rocks are akin to back-arc basin basalts in major and trace element chemistry; however, they exhibit a slight petrochemical affinity to island arc basalts which suggests a slight metasomatism of LIL elements from a subduction zone. Further, this composition is distinct from those of Quaternary volcanic rocks of the NE Japan arc.

Based on isotopic studies of Tertiary volcanic rocks of the NE Japan arc (Kurasawa and Konda, 1986), the mantle source must have been located beneath the back-arc region of the NE Japan arc until the early Middle Miocene. Ujike and Tsuchiya (1993) also showed that the basaltic rocks suddenly decreased in $^{87}Sr/^{86}Sr$ and increased in $^{143}Nd/^{144}Nd$ since 16 Ma, and they suggest that the lithosphere beneath the AYOF has been disrupted or thinned since 16 Ma.

In the area surrounding the AYRZ, extensive bimodal volcanism occurred producing acidic and basaltic volcanic rocks. Concurrently with this volcanism, narrow grabens and normal faults, oriented NNE-SSW to NE-SW, formed. In the Ou backbone ranges, east of the AYOF (Figure 1), Middle Miocene acidic volcanism occurred producing thick piles of lava and volcaniclastic rocks, normal faulting and tilting (Figure 9) (Amano, 1983). This volcanism was followed by late Middle Miocene doleritic intrusive magmatism and regional subsidence.

These geotectonic and geochemical results are similar to those observed in continental rifts, such as the Río Grande rift of western North America (Lipman, 1969; Stuwart, 1978), strongly suggesting that the AYRZ was a continental rift during the middle Miocene and that extensive basaltic magmatism occurred in response to this rifting.

The axes of the early Middle Miocene rift are most likely delineated by the location of the ancient submarine volcanoes. Ozawa *et al.* (1989) demonstrated that topographic ridges are associated with these volcanoes, using many cross sections in the AYOF. Thus, the topographic ridges can be used to infer the location and orientation of the Middle Miocene rift axes. Figure 8 illustrates the distribution and orientation of these topographic ridges, and

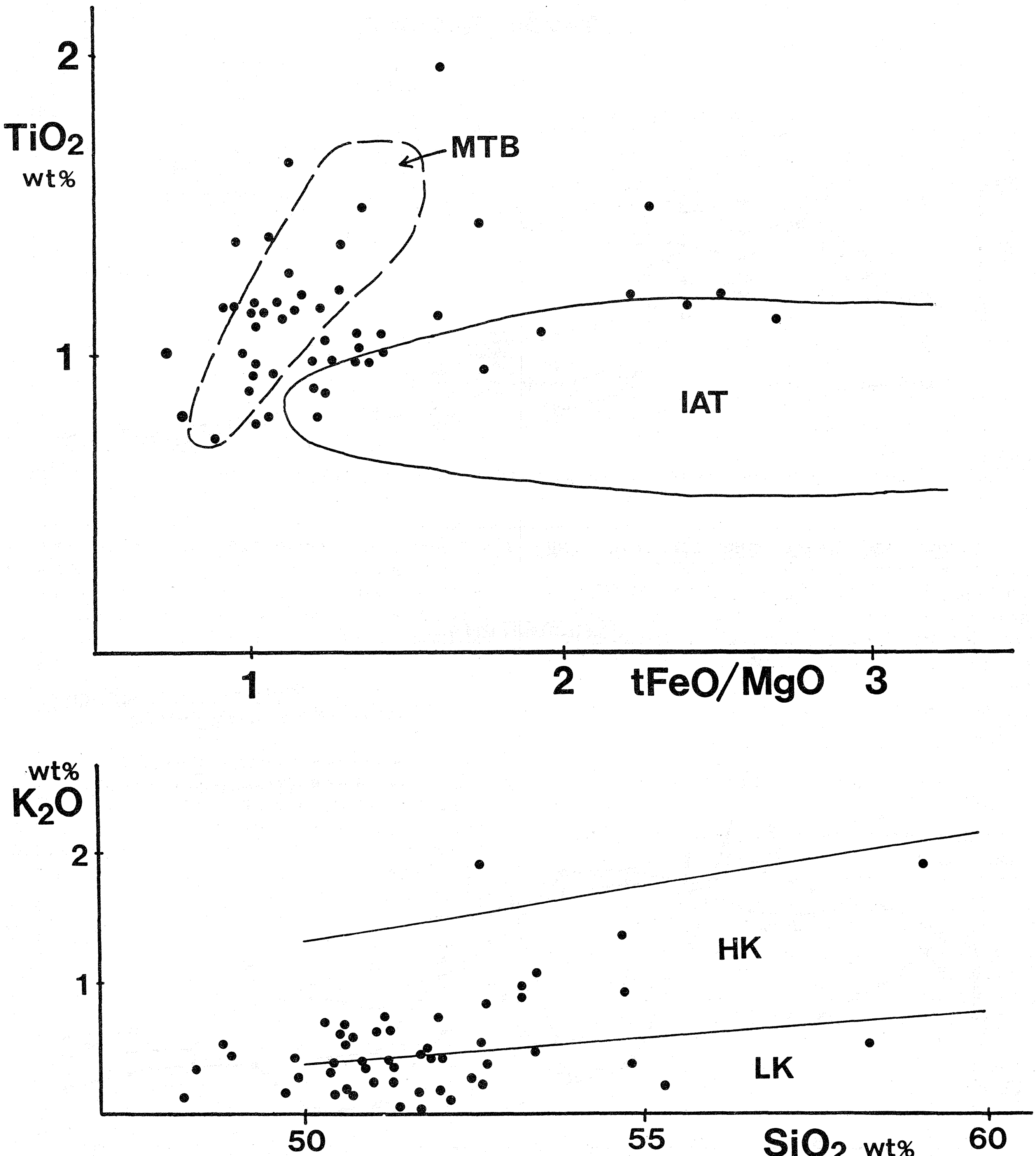

Fig. 6. TiO_2 vs. total FeO/MgO and K_2O vs. SiO_2 diagrams for the early Middle Miocene basaltic rocks in the Akita-Yamagata oil field. MTB and IAT show the compositional fields of Mariana trough basalt (Hawkins and Melchior, 1985) and Island arc tholeiite of the NE Japan arc, respectively. LK and MK show the fields of Low K_2O and medium K_2O series of Gill (1981).

hence, the rift axes. The axes trend mainly NNE-SSW to NE-SW oblique to the overall N-S trend of the AYRZ, as observed in other continental rifts such as the Gulf of California (e. g. Lonsdale and Lawver, 1980). Thus, extension was directed NNW-ESE to NW-SE.

The rifting event of the AYRZ may have occurred contemporaneously with the spreading of the Japan Sea. Paleomagnetic studies suggest that the Japan Sea started to spread rapidly in early to Middle Miocene time (Otofuji *et al.*, 1985; Jolivet and Tamaki, 1992). In the Japan Sea, two

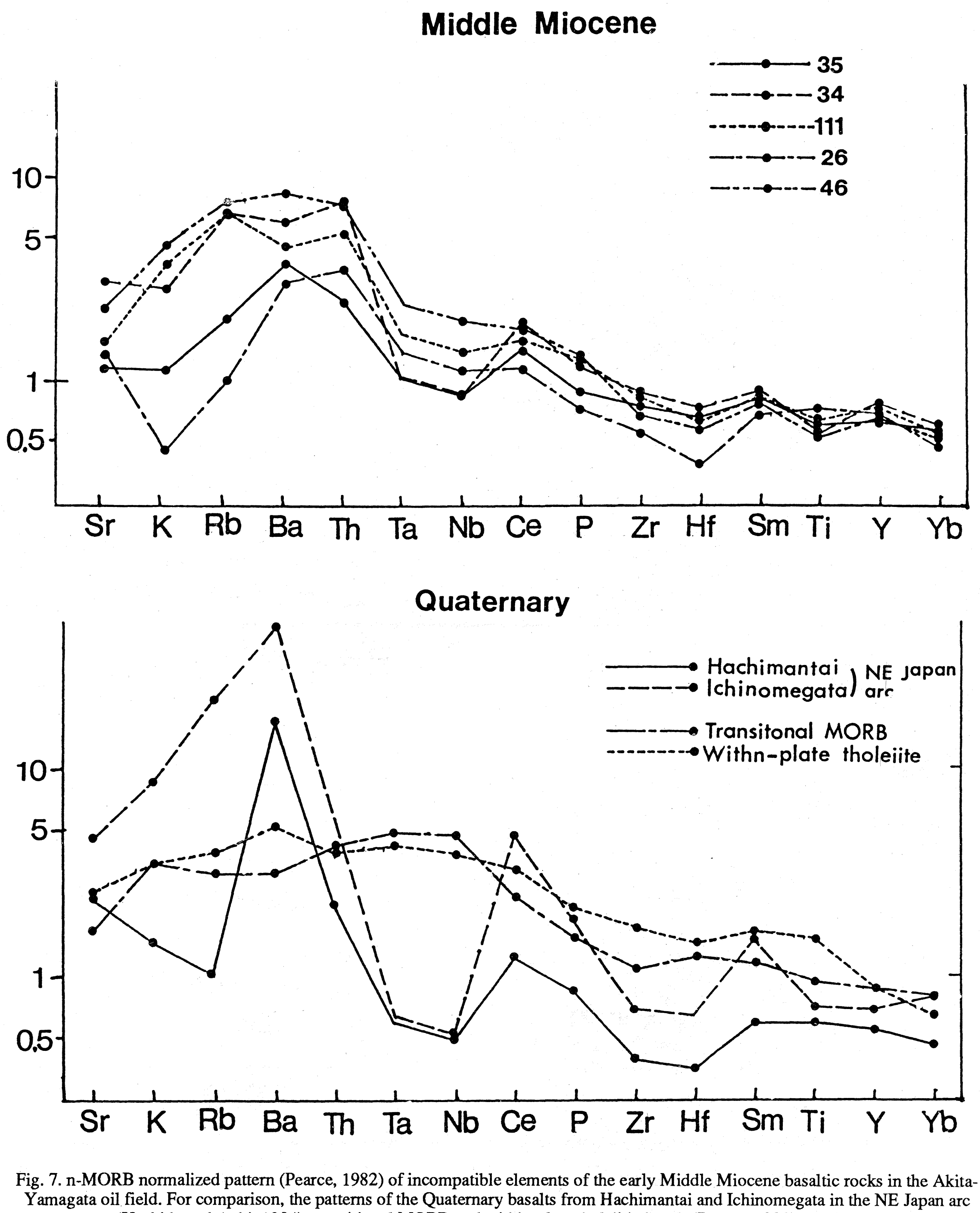

Fig. 7. n-MORB normalized pattern (Pearce, 1982) of incompatible elements of the early Middle Miocene basaltic rocks in the Akita-Yamagata oil field. For comparison, the patterns of the Quaternary basalts from Hachimantai and Ichinomegata in the NE Japan arc (Yoshida and Aoki, 1984), transitional MORB and within-plate tholeiitic basalt (Pearce, 1982) are shown.

main spreading basins (the Japan and Yamato basins) and several failed rifts have been recognized (Tamaki, 1988). The failed rifts are about 40 km wide and occur in the peripheral part of the Japan Sea. Since the size and nature of the Middle Miocene basalts, and the location of the AYRZ, are comparable to those of other failed rifts along the margins of the Japan Sea, the AYRZ is most likely a failed rift formed during the opening of the Japan Sea (Figure 10).

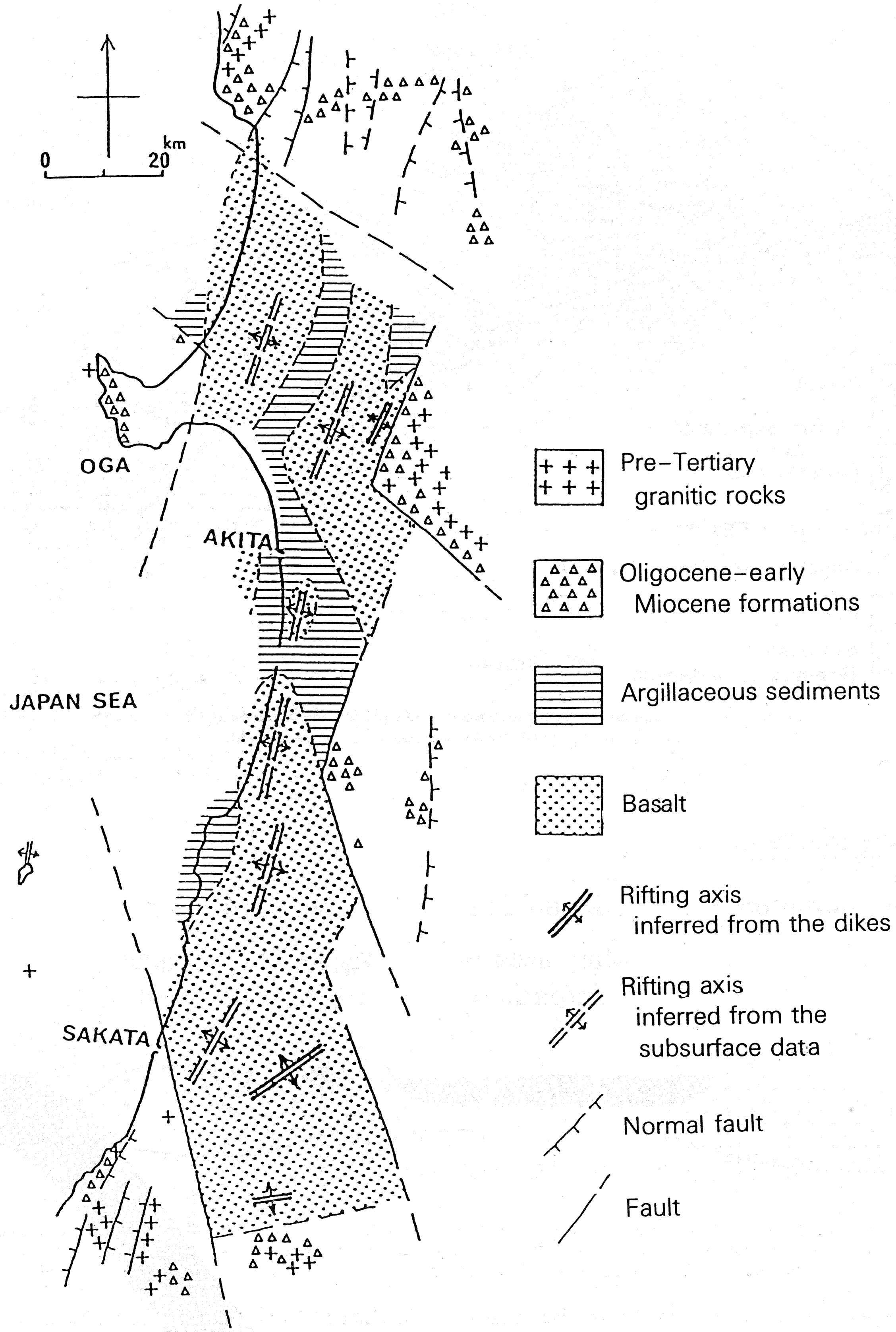

Fig. 8. Distribution of thick basaltic rocks and regional tectonic features in early middle Miocene age in the Akita-Yamagata oil field and surrounding areas.

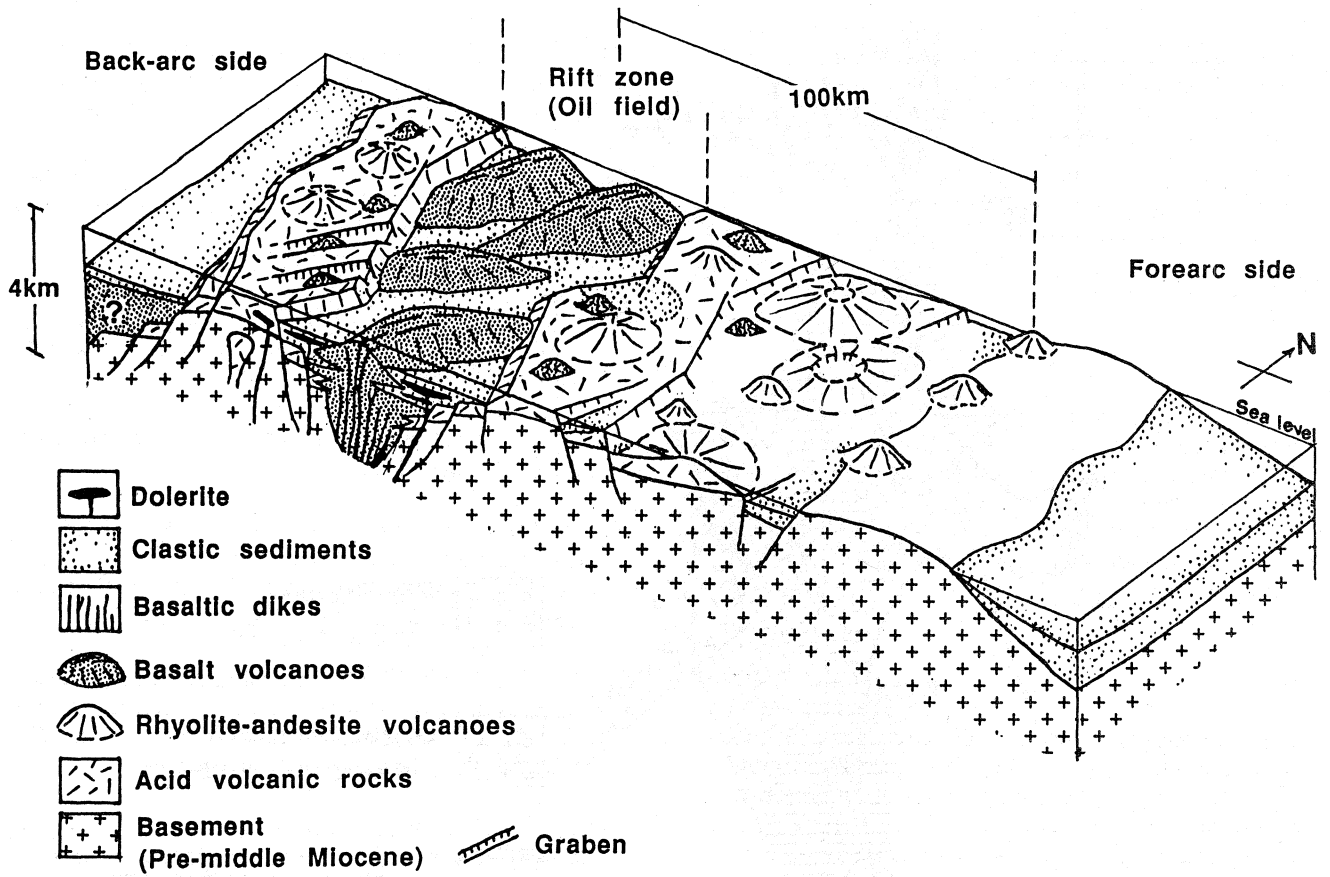

Fig. 9. A block diagram showing the magmatism and tectonic features in early Middle Miocene age in the central part of the NE Japan arc including the rift zone of the Akita-Yamagata oil field.

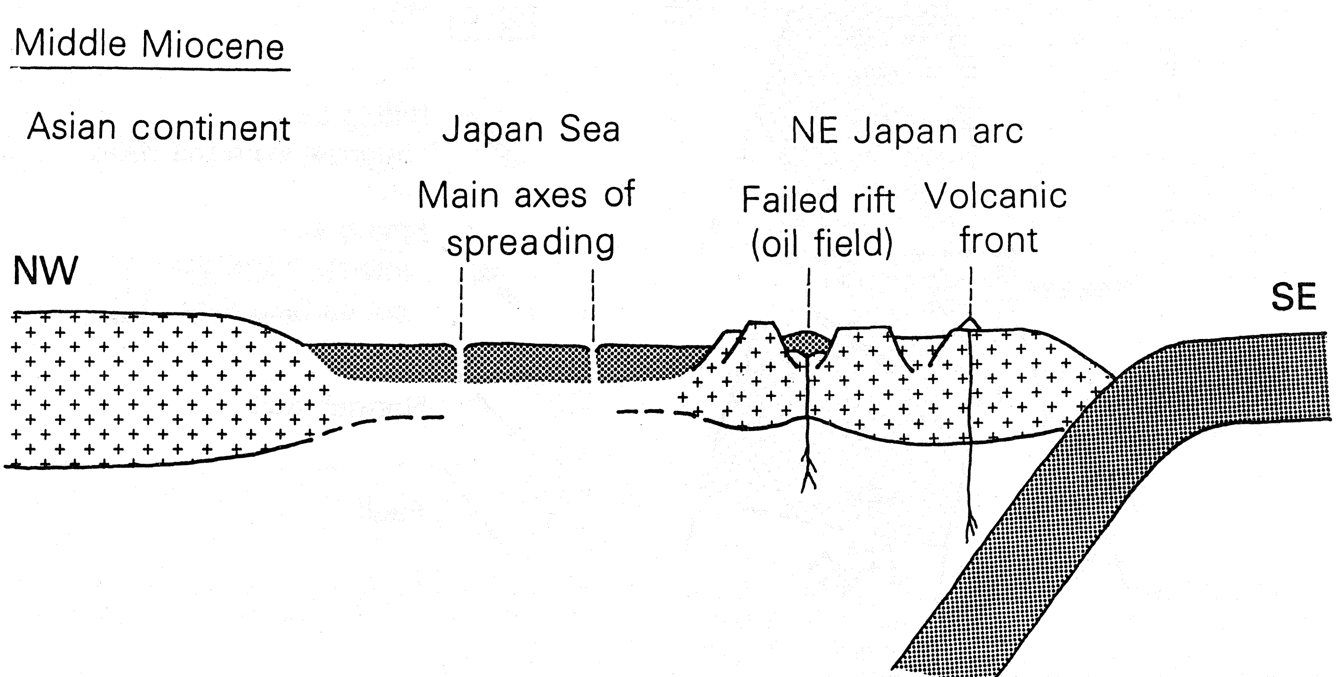

Fig. 10. A model of the rifting of the Akita-Yamagata oil field related to spreading of the Japan Sea.

7. CONCLUSION

Extensive Middle Miocene basaltic magmatism took place in the Akita-Yamagata oil field and surrounding areas which were subsiding due to rifting within a tensional tectonic environment. The basaltic magmatism yielded a large amount of submarine extrusive rocks (6,000 Km^3) in the rift zone containing the Akita-Yamagata oil field, whereas bimodal magmatism produced acidic extrusive rocks and basalt in the surrounding areas. Major geotectonic features of the oil field and surrounding areas are similar to those of continental rifts and back-arc basins. The major features are summarized as follows.

(1) In the rift zone, early Middle Miocene basaltic rocks erupted from NNE-SSW to NE-SW-trending feeder dikes forming numerous submarine volcanoes; the magma of these volcanoes being intercalated with deep marine argillaceous sediments. The feeder dikes and normal faults indicate tensional tectonics. The inferred rifting axes trend NNE-SSW to NE-SW, oblique to the N-S elongation of the rift zone.

The basaltic magmatism declined in late Middle Miocene and the volcanics were subsequently overlain by thick deposits of marine sediments. Next, the mode of basaltic magmatism shifted from extrusive to intrusive, resulting in the emplacement of dolerite sills within the sediments. Until late Middle Miocene time the basaltic magmatism and sedimentation formed a complex unit of basaltic extrusive rock, intrusive rock and marine sediments.

(2) In the surrounding areas, bimodal volcanism of early Middle Miocene age yielded acid volcaniclastic rocks and basaltic lavas. 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 in the rift zone have affinities to back-arc basins in terms of major and trace element chemistry. The basaltic magma may have derived from a mantle source of back-arc basin type with slight metasomatism by subduction components.

(4) The rift zone most likely represents a failed, middle Miocene rift which developed on the periphery of the then spreading Japan Sea.

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