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Tectonic evolution of two paleo arc-trench systems in Hokkaido, northern Japan

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RESUMEN

Los paleo-sistemas de arco-trinchera del Japón y Kuriles que se desarrollaron del Cretácico Tardío al Paleoceno Temprano han sido estudiados usando trabajos paleomagnéticos y de petrología sedimentaria en la zona axial y en la parte occidental de Hokkaido en el noreste de Japón. Las rocas sedimentarias en la parte sur del Cinturón Hidaka definen tres petroprovincias (zonas I a III). Las características petrológicas de los sedimentos de la zona I son similares a aquellas de los depósitos de la cuenca antearco en la región del paleoarco de las Kuriles. La componente modal de las areniscas de la zona III es similar a la de los depósitos de antearco de la región de paleoarco del Japón. La zona II tiene propiedades intermedias entre la zona I y III. Los sedimentos del cinturón Hidaka fueron derivados entonces de dos sistemas de arco diferentes durante el Paleoceno. Los datos paleomagnéticos sugieren que una rotación de más de 70° en el sentido de las manecillas del reloj pudo haber ocurrido en Hokkaido oriental desde el Eoceno Tardío. En este trabajo se discuten posibles reconstrucciones de placas en relación con el esparcimiento en la Cuenca de las Kuriles.

PALABRAS CLAVE: Sistema paleo arco-trinchera, evolución tectónica, paleomagnetismo, petrología de areniscas, Japón.

ABSTRACT

The Paleo-Japan and Paleo-Kuril arc-trench systems that developed during late Cretaceous to early Paleocene have been studied by using paleomagnetics and sediment petrology in the axial zone and western part of Hokkaido, Northeast Japan. The sedimentary rocks in the southern part of the Hidaka Belt define three petroprovinces (zones I to III). The sediment petrologic characteristics of zone I are similar to those of forearc basin deposits in the Paleo-Kuril arc region. The modal component of sandstone from zone III is similar to the forearc deposits of the Paleo-Japan arc region. Zone II has properties intermediate between zone I and III. The sediments of the Hidaka Belt were thus derived from two different arc-trench systems during Paleocene. Paleomagnetic data suggests that more than 70° clockwise rotation may have occurred in Eastern Hokkaido since late Eocene. Possible plate tectonic reconstructions are discussed in relation to the spreading of the Kuril basin.

KEY WORDS: Paleo-arc-trench system, tectonic evolution, paleomagnetism, sandstone petrology, Japan.

INTRODUCTION

Two paleo-arc-trench systems, the Paleo-Japan arc-trench system (PJS) and the Paleo-Kuril arc-trench system (PKS) have been recognized in Hokkaido, northeast Japan, during late Cretaceous to early Paleocene representing a multi-phase collision complex. In this area, two arc-trench systems were active, one associated to a westward subduction beneath the marginal part of Eurasia, and the other to a northward subduction beneath the southern margin of the Okhotsk continental block during late Cretaceous to early Paleocene (Segawa and Oshima, 1975; Segawa and Furuta, 1978; Kimura and Tamaki, 1985a,b; Kimura, 1983). The eastern part of the axial zone of Hokkaido has been divided into several tectonic units: the Hidaka Belt, the Tokoro Belt and the Nemuro Belt, from west to east (Figure 1). The Hidaka belt is mainly composed of Paleocene turbidites with a small amount of hemipelagic melange facies deposits accumulated near the trench area. The main portion of Tokoro belt is an accreted seamount complex of the southern margin of the Okhotsk continental block (Nikoro Group), which formed as an accretionary prism of the PKS during late Cretaceous time (Sakakibara,1986). The slope basin deposits belonging to the PKS (Saroma Group) unconformably overlies the Nikoro Group (Research Group of the Tokoro Belt, 1984). The Nemuro Belt consists of forearc basin sediments of the PKS, formed along the southern margin of the Okhotsk continental block during late Cretaceous to middle Eocene (Kiminami, 1983; Kaiho, 1984).

In this paper, we present a synthesis on the basis of sedimentary petrologic analysis and paleomagnetic directions of each tectonic unit in Hokkaido. We discuss a tectonic setting and propose a new plate tectonic model of both PJK and PKS related to the back-arc spreading associated with plate motion.

SEDIMENTARY PETROLOGY OF THE HIDAKA BELT

(1) Modal component

The sandstone petrology of the southern part of Hidaka Belt was investigated in detail by one of the authors (F.T.), showing that three petroprovinces exist (zones I, II and III from south to north; Figure 2) (Nanayama ,1992a,b). The

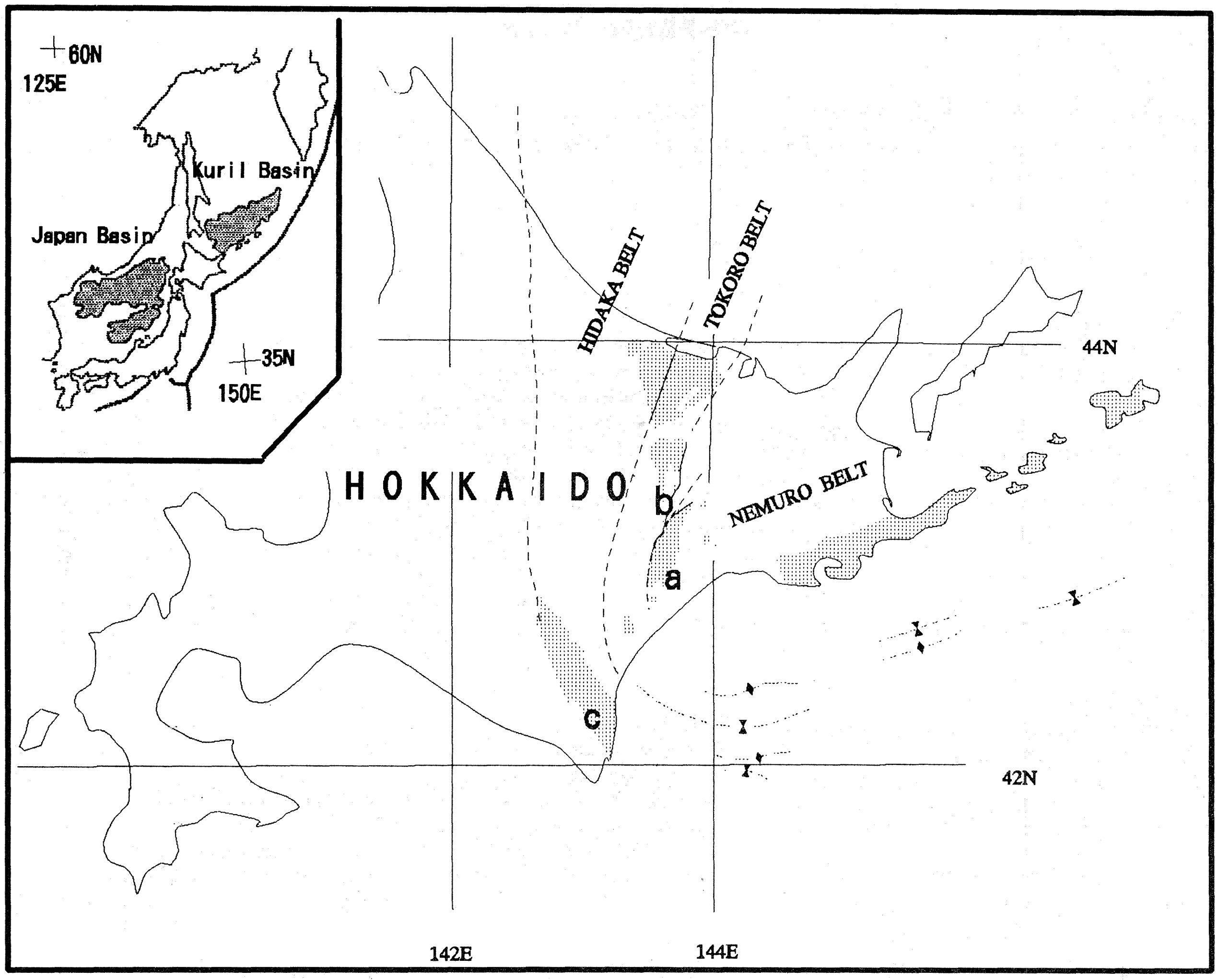

Fig. 1. The distribution of Mesozoic rocks around Eastern Hokkaido. Compiled from Kiminami ,1983 and Honza *et al.*, 1978.
a: Shiranuka Hill area, b: Yusenkyo Formation, c: Kamitoyoni Formation

modal component of sandstone from zone I is characterized by volcanic rock fragments of intermediate to basic composition, containing clinopyroxene and hornblende and poor in quartz and rock fragments. The sandstone compositions from Zone I are very similar to those from the Nemuro and Saroma Groups (Figure 3). Following Dickinson *et al.* (1983) these sandstone may have derived from an undissected and primitive arc region (Paleo-Kuril arc region). The modal composition of zone III sandstone consists predominantly of monocrystalline quartz and potassium feldspar, and is characterized by acidic volcanic and tectonite fragments. This strongly suggests that the source of sandstone of zone III is a dissected mature arc region or an active continental margin (Paleo-Japan arc region). The characteristics of zone II indicate that they are intermediate between zone I and III.

(2) Bulk chemistry

We have also carried out bulk chemical analysis of these sandstones (e.g. Figure 4). The compositional fields have been adopted from Bahatia (1983). The high content of FeO*+MgO wt%, Al_2O_3/ SiO_2 and TiO_2wt% are due to the high content of plagioclase and volcanic rock fragments. The fields defined by sandstones from zone III are included in the fields for Oceanic Island Arc, Continental Island Arc and Active Continental Margin sandstone (Bahatia, 1983). Clinopyroxene occurs as a detrital phase in zones I and II and the Nemuro and Saroma Groups. These detrital grains compare closely in composition with clinopyroxene from (1) non-alkalic, (2) orogenic, (3) calc-alkalic or tholeiitic basalt rocks, as summarized by Leterrier *et al.* (1982). These results strongly suggest that calcalkalic or tholeiitic volcanism existed near the sedimentary basins of the Paleo-Kuril arc.

(3) Detrital chromium spinel

Detrital high Al-chromium spinel grains are found in all rocks from zone I and II, and also in the forearc basin sediments of the Paleo-Kuril arc region (Nemuro and Saroma Groups) which was formed during latest Cretaceous to early Paleocene. The chromium spinels from zones I and II are characterized by low to high Al and low Fe^{3+} compo–

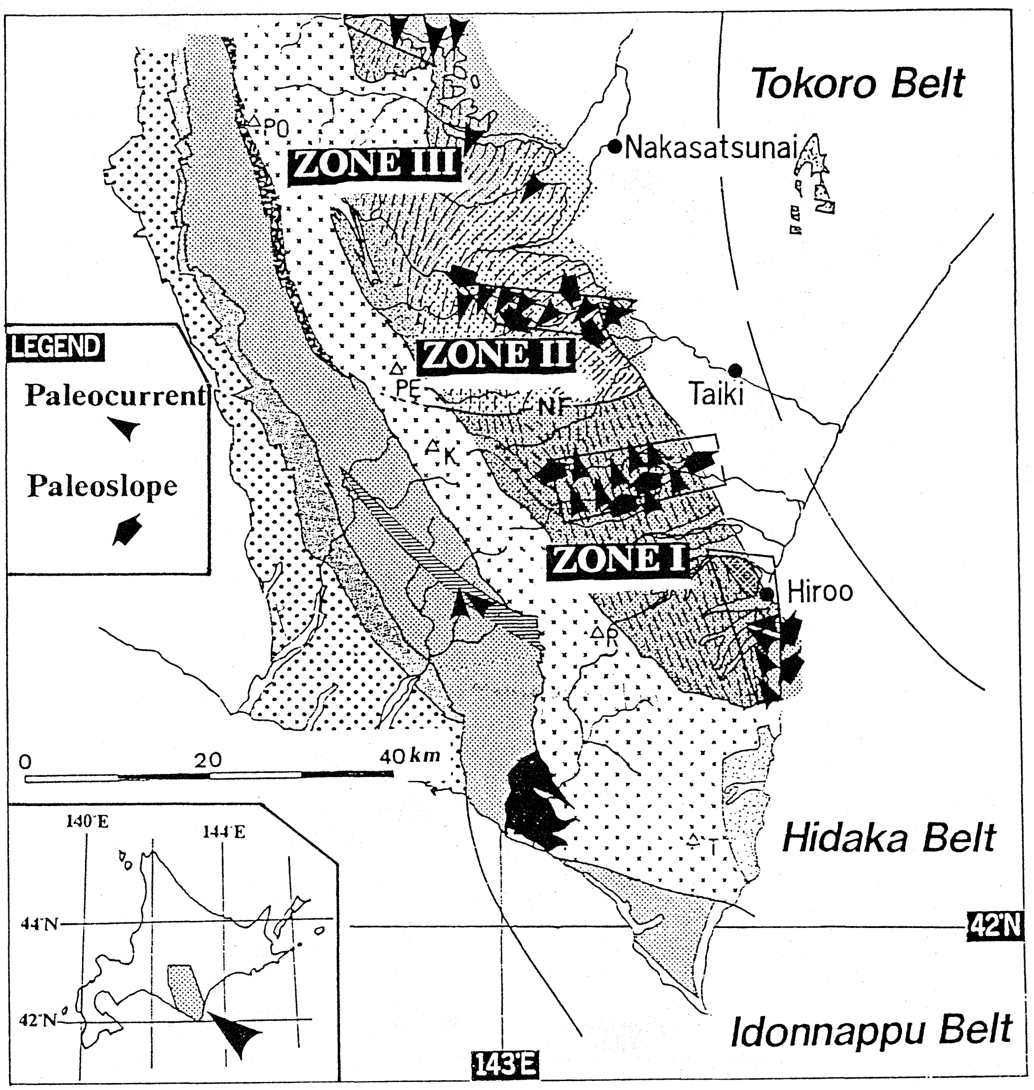

Fig. 2. Geologic map of the southern axial area of Hokkaido showing three petroprovinces of the Nakanogawa Group. NF: Nupinaigawa fault, HF: Hiroo fault, PO: Mt. Poroshiri, PE: Mt. Petegari, K: Mt. Kamui, R; Mt. Rakko, T: Mt. Toyoni.

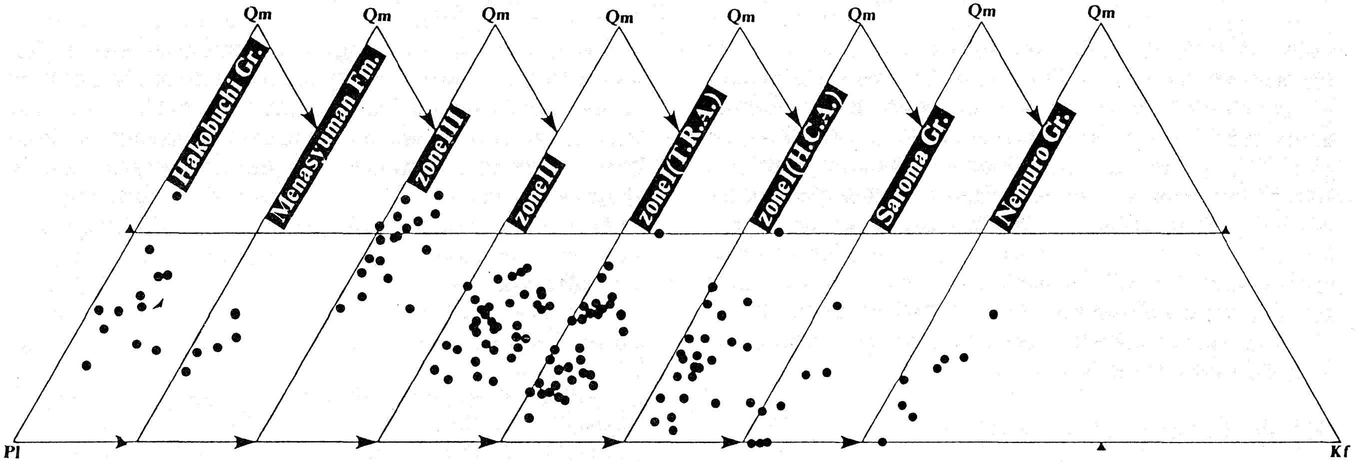

Fig. 3. Ternary Qm-Pl-Kf diagrams of sandstone compositions from Nakanogawa Group (Zone I, II and III) , Saroma Group and Nemuro Group in Eastern Hokkaido. Qm: monocrystaline quartz, Pl: plagioclase, Kf: potassium-feldspar.

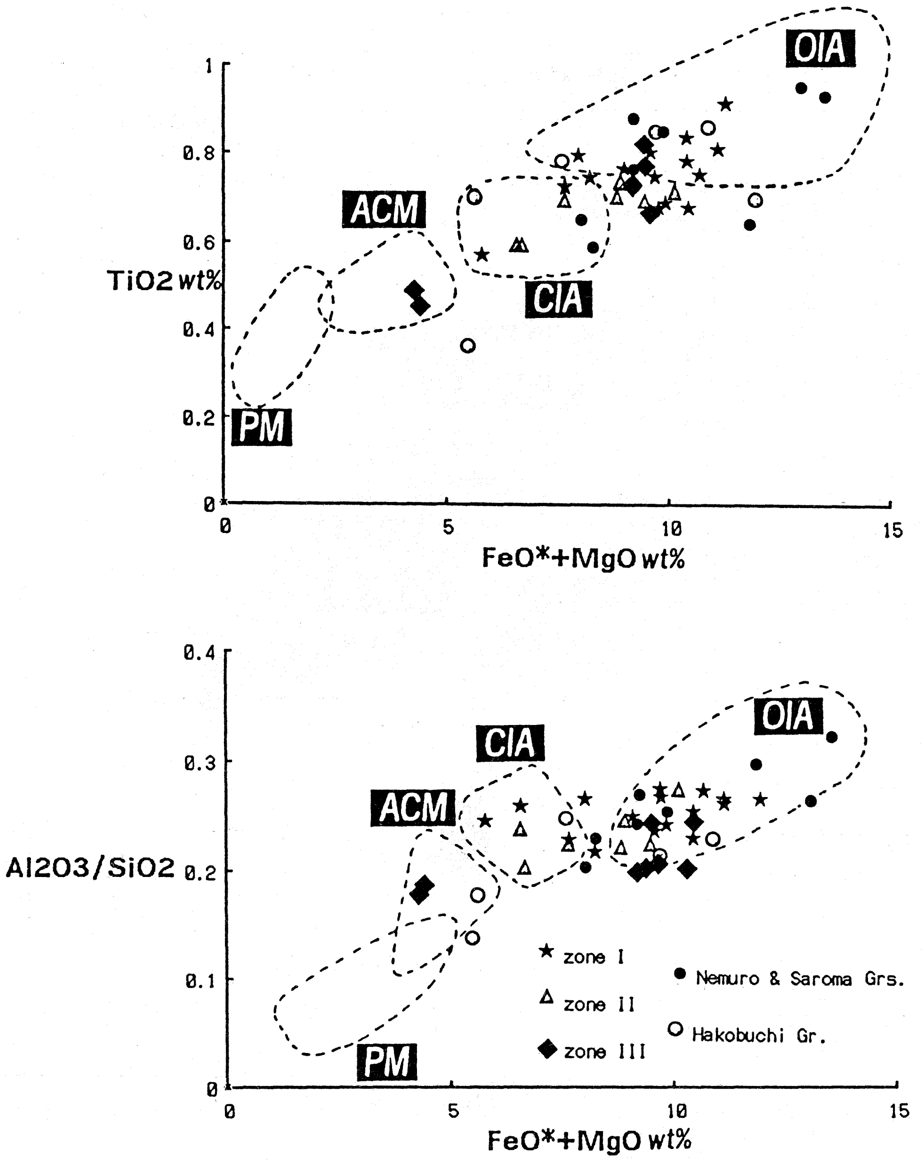

Fig. 4. Bulk chemical data of sandstone from the axial area of Hokkaido. The horizontal axis is FeO* (Total Fe as Fe_2O_3) + MgO wt%, and the vertical axis is Al_2O_3/SiO_2 and TiO_2 wt%. Fields from Bahatia (1983). PM: passive margin, ACM: active continental margin, CIA: continental island arc, OIA: oceanic island arc.

sitions. This characteristic is similar to that of the Nemuro and Saroma Group. However, we do not observe it in zone III, possibly due to lack of data. A large amount of these spinels undoubtedly derived from ultramafic rocks. However, this type of high Al chromium spinel has not been discovered in the Kamuikotan ultramafic belt which occupied a trench slope break of the Paleo-Japan arc-trench system (e.g. Arai, 1978, Okada, 1983; Maekawa, 1986; Katoh and Nakagawa, 1986; Watanabe *et al.*, 1986). We conclude that most of the chromium spinel grains of zone I and II derived from a serpentinite rock, probably an oceanic ophiolite of the Paleo-Kuril arc region.

PALEOMAGNETISM

Magnetic properties were determined with a computer-controlled Schonsted spinner magnetometer at the Department of Geology and Mineralogy of Hokkaido University. The alternating field demagnetization (AFD) was carried out by using a 400 Hz demagnetization device in fields of up to 60 mT. Thermal demagnetization (THD) was also carried out for some specimens in a non-magnetic shielded furnace. One pilot specimen from each site was studied by progressive AFD and THD to analyze the remanence components. AFD was effective to remove secondary components in most of our specimens. The paleomagnetic results are summarized in Table 1 and Figure 5. Antipodally distributed directions are clearly seen. They are fairly well clustered and significantly different from a recent field direction. The details of the experimental results will be described in a forthcoming paper (Kanamatsu and Fujiwara, in press).

1) The Hidaka belt

A total of 78 cores was collected from 6 sites representing the latest Cretaceous to Danian accretionary complex

Table 1

Paleomagnetic site mean directions from Eastern Hokkaido

	NRM						After Cleaning						
								Before tilt correction		After tilt correction			
	Loc.	N	D	I	k	Alpha95	Demag.	D	I	D	I	k	Alpha95
Nemuro Group	42.96, 143.66	3	33	-56	28	24	AFD(10)	41	-55	351	-57	26	24
(Shiranuka Hill area)	"	7	319	55	15	12	THD(520)	30	7	31	-7	7	25
	"	8	323	68	14	14	AFD(25)	323	58	52	65	13	20
	"	10	329	67	31	23	AFD(30)	323	65	55	71	16	13
	43.16 144.00	5	233	8	2	88	AFD(30)	240	-68	214	-71	20	18
	"	5	168	86	10	26	AFD(15)	93	62	75	65	14	21
	43.09, 143.81	5	84	24	6	34	THD(350)	106	-1	302	-83	42	19
	"	6	62	24	9	24	AFD(40)	91	-17	303	-66	147	10
	"	6	11	62	5	32	AFD(10)	326	11	34	45	28	24
	"	4	81	44	5	48	AFD(40)	115	-19	256	-64	89	10
	"	4	96	23	4	56	THD(470)	116	-14	254	-67	22	27
	"	12	6	45	7	18	THD(200)	246	62	129	13	85	6
	"	6	291	-22	14	34	AFD(30)	273	-46	273	68	139	11
	"	3	177	76	29	23	AFD(45)	67	-6	350	-58	1829	3
	"	3	127	-11	17	30	AFD(30)	124	-19	215	-63	615	5
	"	6	56	71	3	46	AFD45	122	-6	202	-71	728	5
	"	6	9	88	71	8	AFD(45)	127	-26	237	-54	136	10
	"	4	57	67	10	31	THD520	100	-1	89	-85	29	13
	"	7	17	83	146	5	AFD(25)	25	80	96	-1	74	8
	"	7	37	79	33	11	AFD(25)	30	71	84	-4	111	6
	"	5	314	44	8	29	THD(150)	359	29	45	17	6	35
	"	6	218	58	3	49	AFD(15)	177	55	136	-4	21	21
Mean		125 (22)								71	60	47	18
Urahoro Group	43.09, 143.81	6	353	42	3	30	THD(150)	312	44	52	38	9	24
(Rushin Formation)	"	7	297	52	6	26	THD(100)	298	37	90	61	24	13
	"	5	338	50	4	42	THD(100)	295	50	99	48	19	18
	42.86, 144.75	11	16	56	10	12	THD(300)	37	50	90	61	29	9
Mean		29 (4)								80	54	21	15
Ombetsu Group	43.09, 143.81	4	98	56	8	34	AFD(24)	159	19	178	-76	55	12
(Charo Formation)	"	3	137	-5	67	15	AFD(10)	163	-2	190	-28	387	13
	"	4	148	47	7	39	AFD(35)	118	14	138	-78	43	14
	"	4	80	39	7	30	AFD(45)	139	2	188	-64	22	18
	46.16, 143.81	6	120	-51	24	13	AFD(10)	116	-55	183	-63	23	14
	"	8	88	-35	12	17	THD150	170	-74	170	-14	29	10
Mean		29 (6)								1	65	17	17
Tokoro Belt	143.75, 43.15	10	105	47	25	15	AFD(35)	127	33	131	43	26	15
(Yusenkyo Formation)	"	3	310	8	5	41	THD(250)	349	-62	356	-56	485	4
	"	17	115	47	140	13	AFD(30)	125	40	129	51	41	9
	"	10	89	65	67	13	AFD(20)	113	53	142	51	31	14
	"	7	103	42	22	17	AFD(15)	108	22	121	28	91	8
	"	6	285	37	6	28	THD(250)	325	40	354	-11	62	2
	"	15	115	49	189	14	AFD(40)	121	33	127	41	21	14
	"	12	79	65	272	12	THD(200)	79	63	97	75	124	6
	"	9	116	66	26	19	AFD(30)	118	33	138	41	34	13
Mean		88 (9)								140	46	11	16
Hidaka Belt (Mean)	143.10, 42.04	52(4)	16	19	9	27	THD(320)	13	10	174	33	12	26
(Kamitoyni Formation)													

Loc.: latitude and longitude of sampling locality N: number of cores (number of sites) D: declination I: inclination k: Fisher's precision parameter Alpha95: radius of 95% confidence circle
Demag.: demagnetization treatment, AFD(mT), THD(C)

in zone I (Nanayama,1992b) along the south-eastern margin of the Hidaka Mountain belt. Results are given in Table 1. From 4 sites with 56 specimens the following paleodirection was calculated: declination D=174°, inclination I=33°, radius of confidence circle a_{95}= 26°.

4) The Tokoro belt

The pre-Tertiary Systems developed around the western side of the Shiranuka Hill area comprise three formations from north to south: middle Barremian to early Aptian melange (Rawanzawa Formation), late Jurassic hemipelagic deposits (Inaushi Formation), and late Campanian to early Maastrichtian terrigenous deposit (Yusenkyo Formation) (Kanamatsu *et al.* 1992). Paleomagnetic samples were collected from the Yusenkyo Formation at 10 sites. The mean direction from all 9 sites is D= 140°, I=46° with a_{95}= 16°.

5) The Nemuro belt

The late Cretaceous to early Oligocene marine deposits are well developed around Shiranuka Hill area. They are divided into three Groups: Nemuro Group, Urahoro Group and Ombetsu Group, in ascending order. Oriented cores were collected at 32 sites on the eastern side of Shiranuka Hill. Paleomagnetic results from these sedimentary rocks are also listed in Table 1. Of them, cores from 22 sites belong to the Nemuro Group, Paleocene to early Eocene in age. Site mean directions obtained from the Nemuro Group based on 125 cores from these 22 sites are D=71°, I=60° with a_{95}= 18°. The site mean direction of the Urahoro Group (late Eocene) based on 29 cores from 4 sites is D=80°, I=54° with a_{95}= 15°. However, the mean direction based on 29 cores from 6 sites belonging to the lower Ombetsu Group, late Eocene to early Oligocene in age, is D=1°, I=65° with a_{95}= 17°.

DISCUSSION

The Paleo-Kuril arc-trench system existed along the southern margin of the Okhotsk continental block since approximately 80 Ma, while the Paleo-Japan arc-trench system existed along the eastern margin of Eurasia since

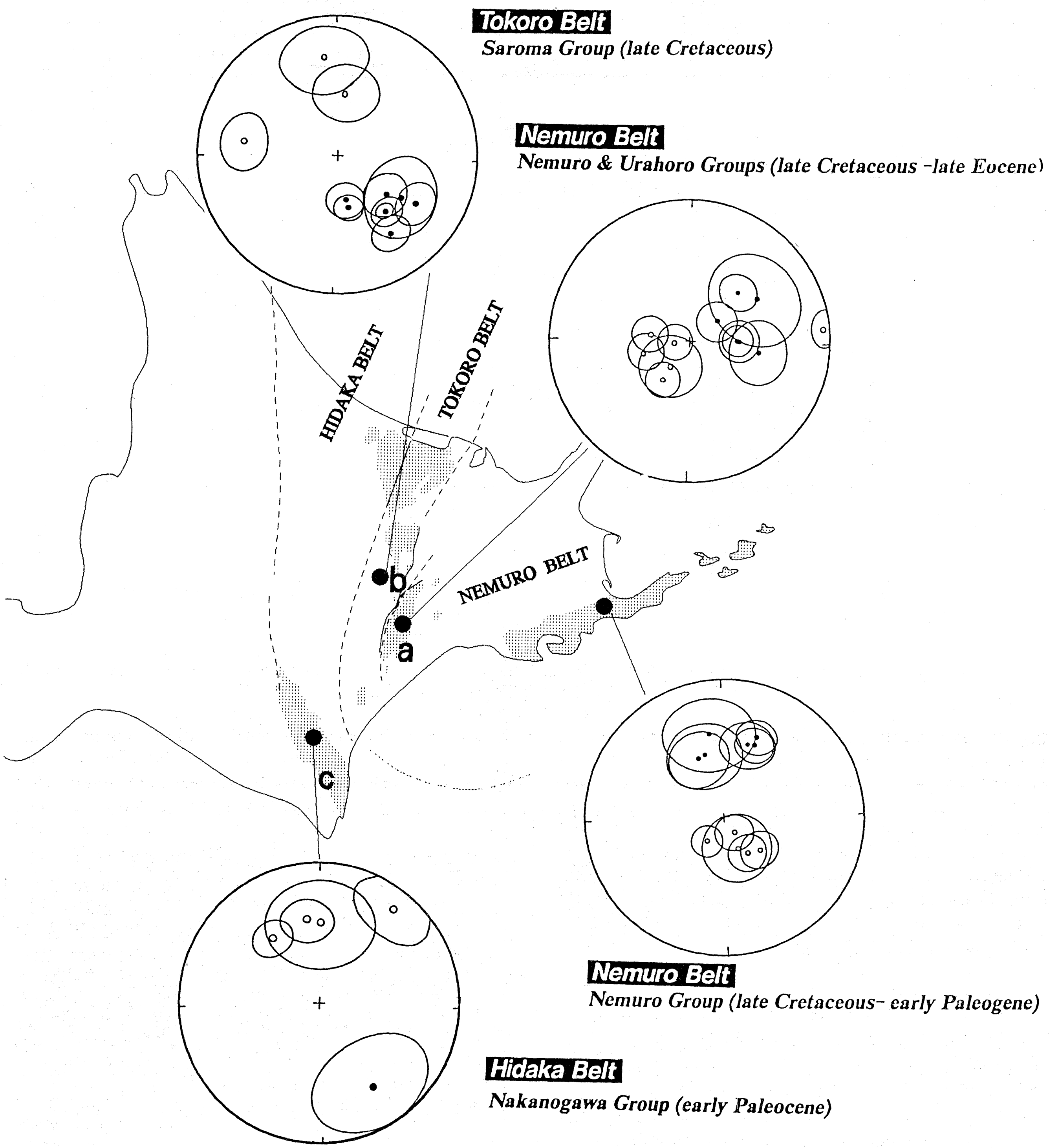

Fig.5. Paleomagnetic directions of the sandstone from Eastern Hokkaido. Site mean directions are plotted on equal-area projection. Data from the Nemuro Peninsula after Kanamatsu and Nanayama (1992).

ca. 140 Ma (Niida and Kito, 1986). During the early Paleocene, the Paleo-Japan arc-trench system was more mature than the Paleo-Kuril arc-trench system (Takahashi, 1983). Our earlier paleomagnetic data from the axial zone of Hokkaido indicate that two paleo-arc-trench systems existed (Kanamatsu and Nanayama, 1992). This is also strongly supported by analysis of aeromagnetic anomalies of eastern Hokkaido and adjacent area (Segawa and Oshima; 1975; Ogawa and Suyama,1976 ; Segawa and Furuta, 1978). The modal component of sandstone from zone II

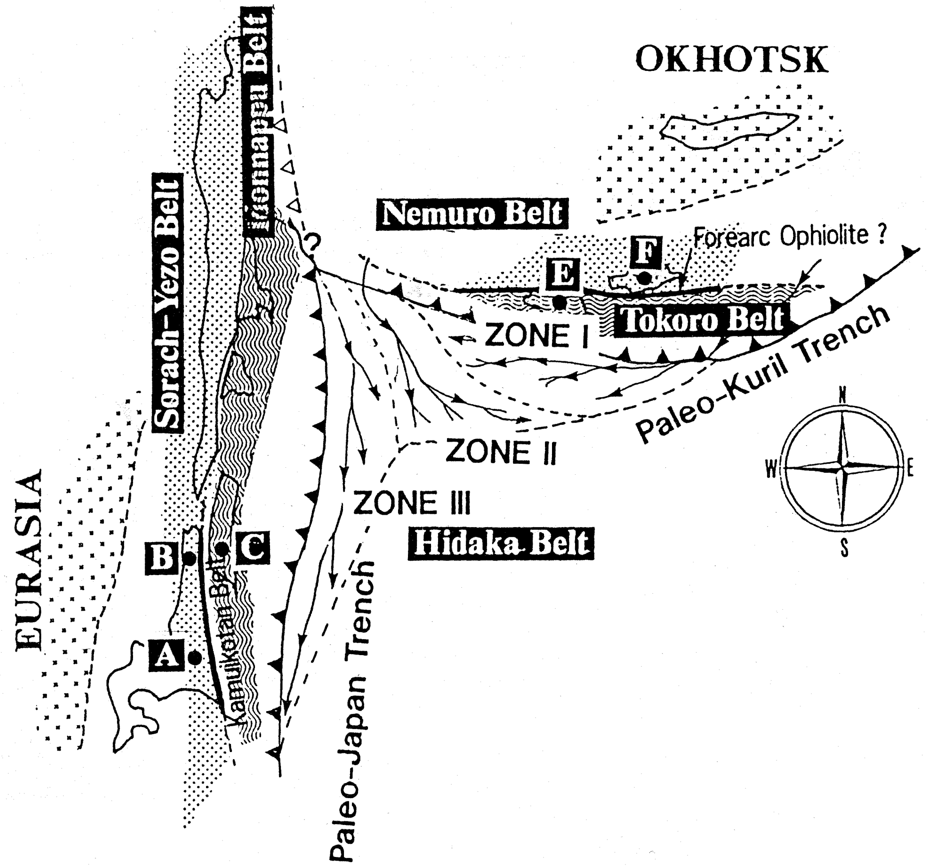

Fig.6. Paleogeographic reconstruction of the Hokkaido region and the distribution of the Nakanogawa Group sediments (Zone I, II and III) in the Hidaka Belt during Paleocene time.

suggests that they are intermediate between zones I and III. However, the chemical data of clinopyroxene and chromium spinel grains suggest that the sandstones of zones I and II were derived from the Paleo-Kuril arc region. Because of this evidence, we conclude that the turbidites of zones I and II were derived from the Paleo-Kuril arc region, but those of zone III were possibly derived from both Paleo-Japan arc (Eurasia) and Paleo-Kuril arcs. Topographic and aeromagnetic maps and photographs (Yamamoto and Moriya, 1989) do not indicate the presence of a prominent lineament which could point to a large tectonic structure such as a plate boundary between each petroprovince of the Hidaka Belt. Therefore, we believe that the deep sea fan sequences of the Hidaka Belt (e.g. Nakanogawa Group) have formed between the Paleo-Japan (Eurasia) and Pale-Kuril arc-trench systems during Paleocene time (Figure 6).

The Late Cretaceous up to Late Eocene paleodirections inferred from the sedimentary rocks of the Nemuro Group in the Nemuro Peninsula (Figure 5) do not show any remarkable deflection from the present geomagnetic field (Kanamatsu and Nanayama 1988). However, mean declination calculated from 22 site mean directions of the Nemuro Group is D=71° and 4 site mean directions from the lower Urahoro Group (Rushin Formation) is D=80°. These mean declinations are almost identical with the mean declination inferred form the uppermost horizons of the Nemuro Group (D=73°) as reported by Hamano *et al.* (1985). The mean declination calculated from 6 site mean directions from latest Eocene to Oligocene Ombetsu Group, however, is quite different: D=1°. This suggests that the Tokoro belt as well as the Hidaka belt probably rotated approximately 70° clockwise with respect to the Nemuro belt. This block rotation undoubtedly occurred in late Eocene and should be related to right lateral strike-slip faults that harmonized the westward migration of the Kuril arc. In a possible plate-tectonic reconstruction, taking into account the spreading of the Kuril basin, the Nemuro belt may have departed from the Okhotsk plate as a part of PKS with counter-clockwise rotation. Alternatively, the western part of PKS may have rotated clockwise. These different reconstructions might depend upon the plate geometry within the Kuril basin (Figure 7). The formation of a group of right lateral strike slip faults observed in the Hidaka belt suggests that the westward migration of the fore-arc sliver of the Kuril arc occurred after these rotational events.

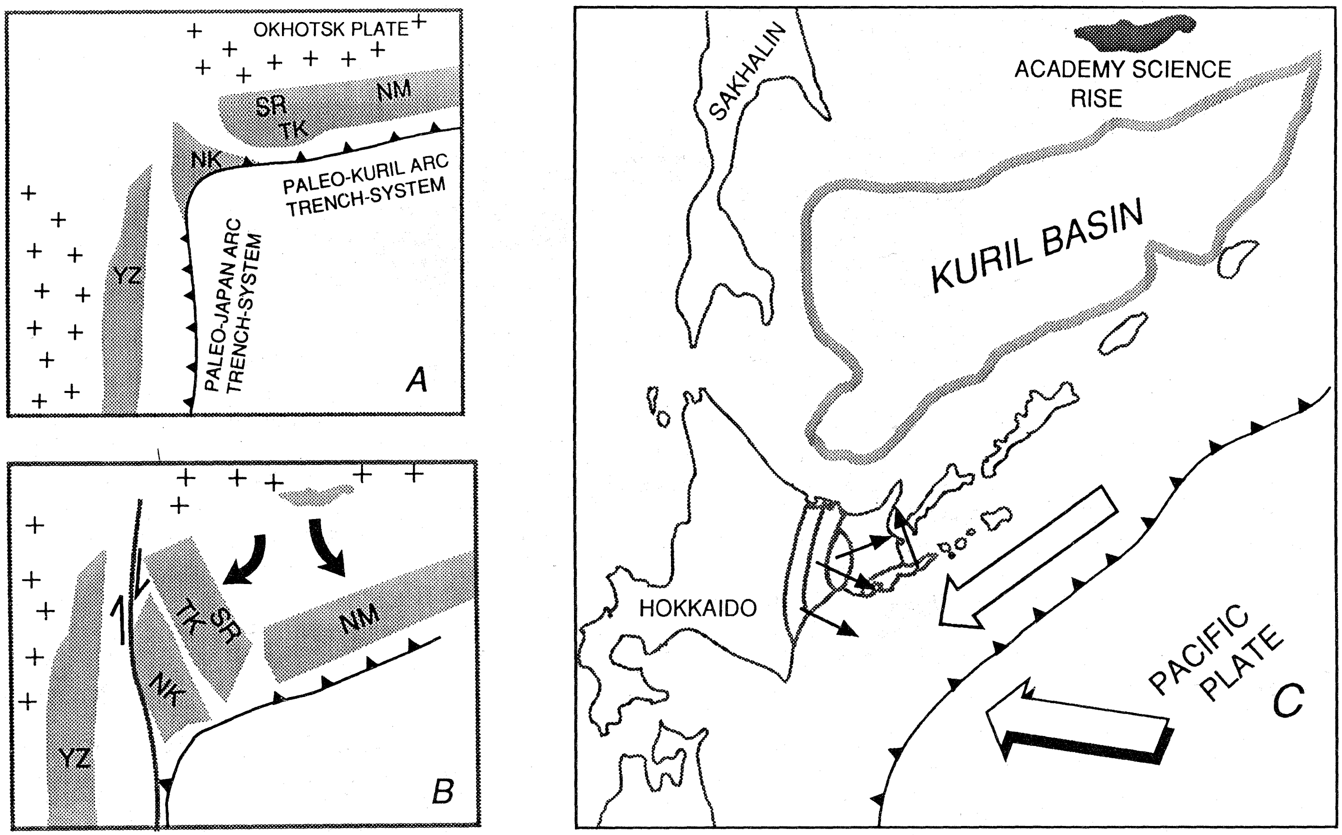

Fig. 7. Large scale tectonic evolution model around Hokkaido. NM: Nemuro Group in the Nemuro Peninsula, SR: Nemuro Group in the Shiranuka Hill area, TK: Tokoro Belt, NK: Nakanogawa Group, YZ: Yezo Group (forearc deposits of Paleo Japan arc), A: late Cretaceous, B: late-latest Eocene, arrows show expected strike slip of high angle fault, C: Recent. Large white arrows indicate the direction of plate motion, solid arrows show paleodirections based on the present study.

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