SEDIMENTARY PATTERNS IN APPARENT BACK-ARC BASINS: A CASE STUDY OF THE NEOGENE SEQUENCE IN NORTHWESTERN HOKKAIDO, JAPAN

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In northwestern Hokkaido, where the Honshu and Kuril arcs intersect, an enormous pile of Neogene sediments (about 10 km thick) is developed in close relation to the Cenozoic orogenesis. The Kotanbetsu Formation, representing the lower to middle Miocene sequence of these sediments, exceeds 3 km in thickness and is characterized by gravity-flow deposits. The strata are divisible into three major facies: 1) chaotic deposits or olistostrome facies, 2) graded-bed or turbidite facies, and 3) ripple-bed or contourite facies.

The chaotic deposit facies, rather restricted in distribution in the proximal parts of the basin, is further subdivided into three sedimentary types: pebbly mudstone, chaotic breccia, and matrix-deficient conglomerate. The graded-bed and the ripple-bed facies are predominant in the relatively distal parts of the basin. The chaotic deposits were generated by intense tectonic movements of the 'Mesozoic' basement rocks thrust up to towards the west. The graded beds were deposited from turbidity currents, although their current directions are not clearly defined, whilst the ripple beds were formed by southward-flowing contour currents.

These characteristic sediments are comparable in their tectonic position of an apparent back-arc belt to the Onerahi Chaos-Breccia of Northland, New Zealand, related to the Miocene to Pliocene Kaikoura Orogeny. The Kotanbetsu and its equivalents, however, may have been the deposits in basins produced by collision of two continental blocks, known generally as the Hidaka Orogeny, but not in the ancient back-arc belt.

1. Introduction

The structural framework of arc systems and their tectonic development have been studied in some detail in terms of plate tectonics. However, the sediments, an important component of arc systems, are not so well understood. This paper presents an interesting example of the sedimentary features in tectonically active Neogene basins of the present back-arc area in northwestern Hokkaido.

Neogene sedimentary basins in northwestern Hokkaido, which are developed along the western margin of the Hidaka Mountain Range, apparently occupy the present back-arc position. Sediments in these basins attain a tremendous thickness, probably more than 10 km, far thicker than contemporaneous sediments in other areas of Hokkaido (Fig. 1). Neogene sediments in the west of the Hidaka Mountain Range have long been regarded as postorogenic sediments of the so-called Hidaka Orogeny which made the backbone of Hokkaido by the early Miocene (NAGAO, 1938; MINATO *et al.*, 1965), and in this context the Kawabata Formation in central Hokkaido and the Kotanbetsu Formation in the northwestern part are well known, both representing postorogenic sediments. It is interesting to note that serpentinite sandstones occur in the sequence of the Kawabata Formation (OKADA, 1964).

Fig. 1. Index map of Hokkaido showing major outcrops of Neogene sediments (dotted). Hatched are the exposures of the Kotanbetsu Formation, which are enlarged in Fig. 2. Columnar sections (A-E) showing generalized Neogene successions at some representative areas (Letters A-E correspond to those in the index map: A, Abashiri; B, Honbetsu; C, Haboro; D, western part of the Ishikari coal field; E, Setana; modified from MINATO *et al.*, 1965, pp. 262-263). a, unconformity; b, coarse clastics; c, pyroclastics; d, fine clastics.

This paper, aimed at presenting the sedimentary characteristics of apparent back-arc basins, describes the lithofacies of the Kotanbetsu Formation and discusses its tectonic significance.

2. Geologic Setting

Neogene strata, underlain by the Upper Cretaceous and locally by the Paleogene, are excellently exposed in northwestern Hokkaido. They are composed mostly of marine water deposits and partly of brackish to non-marine water ones. The general stratigraphy of the Neogene in the central part (Shosanbetsu and Haboro areas) is summarized in Table 1 according to MATSUNO and KINO (1958) and HATA (1961). The early Pliocene to late Miocene sequence of Table 1 was intensively studied by UJIMÉ *et al.* (1977) in order to establish a combined microfossil-paleomagnetic-sedimentologic stratigraphy. Their study indicates that Neogene marine sediments reveal evidence of active arc magmatism at the time of deposition related to active plate motion and a remarkably fast rate of sedimentation.

The early to middle Miocene Kotanbetsu Formation is very different in lithology and thickness from the rest of the Neogene (Fig. 1), as described in the following sections. This formation is most widely developed in northwestern Hokkaido, being accommodated

Table 1. General stratigraphy of the Neogene succession in the central part of northwestern Hokkaido.

Age	Stratigraphic unit*	Lithology	Environment	Thickness (m)
Pliocene	Mochikubetsu Formation	Fine-grained sandstone with pebbly sandstone near its top	Marine	260-350
	Embetsu Formation	Diatomaceous mudstone with a basal, strongly cross-bedded, coarse-grained sandstone	Marine	160-700
Miocene	Kinkomanai F./ Higashino F./ Chiebetsunai F.	Tuffaceous fine- to coarse-grained sandstone with andesitic agglomerate and breccia	Marine to the north and non-marine to the south	50-270
	Kotanbetsu Formation	Chaotic deposits and interbedded mudstone, graded sandstone and graded conglomerate	Marine	>3,000
	Chikubetsu Formation	Upper mudstone with shallow marine molluscs, lower sandstone with coaly shale and basal conglomerate	Shallow marine to brackish water	<450
	Sankebetsu Formation	Lower fine- to medium-grained sandstone and upper tuffaceous sandstone and shale alternation	Marine	<800
	Haboro Formation	Fine- to coarse-grained sandstone interbedded with mudstone, bentonitic tuff, coal and coaly shale	Non-marine	<240
	Pankezawa Formation	Upper banded andesitic crystal tuff and lower medium- to coarse-grained, massive sandstone	?	<115

* conformable, ~~~~~ unconformable.

Fig. 2. Geologic map showing the distribution and major structures of the Kotanbetsu Formation (adapted from GEOLOGICAL SURVEY OF JAPAN, 1962, 1965). a, post-Kotanbetsu sequence; b, Kotanbetsu Formation (the Miocene sequence underlying the Kotanbetsu Formation is included); c, Paleogene strata; d, Cretaceous sediments; e, serpentinite masses; f, thrusts; g, anticlinal axis; h, synclinal axis; S, Shosanbetsu; H, Haboro; K, Kotanbetsu; R, Rumoi.

in at least three depositional basins which are separated by major thrusts with an NW-SE trend (Fig. 2; MATSUNO, 1958). These thrusts are regarded as synsedimentary tectonic structures, along which Upper Cretaceous sedimentary rocks are narrowly exposed, sometimes forming dome structures. The Kotanbetsu Formation also forms large-scale fold structures with N-S axes plunging gently northwards. Two major synclines and one major anticline are recognized in the Shosanbetsu area (Fig. 2), the anticline indicating oil seepage at some places along the crest.

3. Sedimentology of the Kotanbetsu Formation

3.1 Lithofacies

The Kotanbetsu Formation, more than 3,000 m thick in the northern basin (Shosanbetsu area; see Fig. 2) is generally characterized by gravity-flow deposits. The formation is divisible fundamentally into three major facies: 1) chaotic deposit facies, 2) graded-bed facies, and 3) ripple-bed facies.

1) *Chaotic deposit facies.* This facies is rather restricted in distribution, mainly near the southern margin of the basin (Fig. 3). The facies may be further subdivided into three sedimentary types: 1a) pebbly mudstone, 1b) chaotic breccia, and 1c) matrix-deficient conglomerate.

1a) The pebbly mudstones are characterized by many pebbles, cobbles, and boulders randomly floating without clast contacts within non-stratified mudstones (Fig. 4). The clasts are generally fairly rounded. One of the pebbly mudstone sequences is about 200 m thick in the proximal part and traceable over 20 km, thinning out distally. The pebbly mudstones show the most extensive distribution of the chaotic deposits.

1b) The chaotic breccias are composed mostly of subangular to angular pebbles, cobbles, and boulders together with blocks of varying sizes from less than 1 cm to more than 20 m in diameter. The clasts show neither sorting effect nor preferred orientation.

Fig. 3. Columnar sections at some selected localities showing lithofacies changes in the Kotanbetsu Formation above the sequence of a tuff bed *tf3* exposed to the northeast of Shosanbetsu (Fig. 2). Note also that the thickness of *tf3* decreases northwards. a, claystone; b, ripple beds; c, graded sandstone beds; d, graded conglomerate beds; e, chaotic breccia; f, tuff.

Boulders and blocks consist generally of mudstone and thinly alternating sandstone and shale of 'cannibalistic' origin. Many of the stratified rock clasts show contorted or folded structures, formed during the sliding down of the chaotic breccias. Smaller clasts consist of extrabasinal older sedimentary rocks such as sandstone, slate, chert, marl and limestone, granite, porphyry, basalt, and so on. The matrix of the breccia is either coarse-grained sandstone or claystone, and this forms 10 to 50% of the rock. The chaotic breccias are mostly developed in the southeastern part of the basin, exceeding 50 m in thickness. The occurrence of the chaotic breccias is shown in Fig. 5.

1c) The matrix-deficient conglomerates are composed mainly of sorted, subangular to rounded pebbles and cobbles (Fig. 6). These consist of older (Mesozoic?) sedimentary rocks (mostly sandstone and slate), granite, basalt, rhyolite, porphyry, etc. This kind of deposit is from several meters to some tens of meters in thickness, sometimes reaching more than 100 m.

Fig. 4. An exposure of pebbly mudstones, about 16 km east of Haboro. Clasts of varying sizes are embedded in mudstones.

Fig. 5. Chaotic breccias, about 18 km east of Haboro, showing a large block of disrupted beds as large as at least 20 m.

2) *Graded-bed facies.* This facies is characterized by graded sandstone and/or conglomerate beds. It is predominant in more distal parts of the basin than the chaotic deposit facies. Graded sandstone beds are variable in thickness from a few centimeters to 5 m, whereas graded conglomerate beds are usually several meters thick. In many cases, graded conglomerate beds with gradually decreasing particle size change upwards into graded sandstones and finally into mudstones. Graded conglomerate beds almost always show reverse grading over several centimeters from their bases. In graded sandstone

Fig. 6. Matrix-deficient conglomerates in the river bed exposure in the upper course of the Sankebetsu River, about 17 km southeast of Kotanbetsu.

Fig. 7. A very thick graded bed with granule conglomerates at the basal part which are gradually changed upwards into very fine-grained sandstones, showing a clean-cut bottom surface.

beds, Ta, Tb, and Tb-c of the Bouma sequence (BOUMA, 1962) are common as internal structures. Usually the bottom surface of the graded beds is remarkably flat (Fig. 7).

3) *Ripple-bed facies*. This is represented by mudstones frequently intercalated by rippled thin beds of fine- to medium-grained sandstones (Fig. 8). These sandstone beds show some characteristic features: a) both upper and lower surfaces are sharply defined, b) small-scale ripple marks are developed on the surface, c) minor cross-lamination is common as internal structures, d) no graded-bedding is observed at all, e) the thickness of

Fig. 8. Typical exposure of the ripple-bed facies in the river bed of the Kotanbetsu River, about 6 km southeast of Kotanbetsu.

beds ranges from 0.5 to 3 cm, and f) the sandstones are deficient in matrix and well sorted in texture. Sometimes a type of ripple-bedding known as flaser-bedding is observed, which shows rippled sand lenses preserved within the mud, with mud streaks in the troughs and on the crests of ripples.

Horizontal and vertical distributions of the lithofacies described above are summarized as follows: the Kotanbetsu Formation as a whole shows that the chaotic breccia facies is developed in the most proximal or southeasternmost part of the basin, the pebbly mudstone and matrix-deficient conglomerate facies are more prominent in the proximal part, the graded bed facies is developed in more distal parts than the chaotic breccia facies, and the rippled bed facies is characteristic of the most distal part or the northernmost area of the basin (Fig. 3).

The vertical succession of the Kotanbetsu Formation generally shows a rhythmic stratigraphic pattern, which is distinguished by a unit sedimentary cycle (in ascending order): graded conglomerate-graded sandstone-mudstone with rippled or graded sandstone beds. The thickness of the unit sedimentary cycles ranges from 20 to 100 m. The mudstone sequence of unit cycles tends to predominate in the more distal areas.

As stated above, the general lithology of the Kotanbetsu Formation shows a gradual predominance of the fine-grained facies northwards or in distal areas. At the same time, not only single beds but also particular stratigraphic sequences decrease their thickness in the same direction (see a tuff bed tf3 in Fig. 3 and the sequence between tuff beds tf2 and 3 in Fig. 9).

3.2 *Paleocurrents*

Paleocurrent analysis was attempted, using sole markings such as flute marks, groove marks, etc. as well as ripple marks and cross-stratification. Sole markings indicate strong westward-flowing currents at the southwesternmost part of the Shosanbetsu basin, but are too poorly developed to show general current directions in the distal areas. On the

Fig. 9. Lithofacies changes of the Kotanbetsu Formation from south (Wuennai River section) to north (Chebotsunai River section) (15 km away) in the Kotanbetsu area in a sequence between Tuff 2 and Tuff 3.

Fig. 10. Map showing paleocurrent directions in the sequence above Tuff 3 in the northern basin of the Kotanbetsu deposits. Outer circle, ripple marks and cross-laminations; inner circle, sole marks.

contrary, ripple marks and cross-laminae show southward movements of bottom waters (Fig. 10).

3.3 Composition

For the conglomerates and breccias, the boulders and blocks are composed mostly of mudstone and stratified sedimentary rocks of 'cannibalistic' origin and partly of Mesozoic (?) sandstones and other sedimentary rocks, while granules, pebbles, and cobbles consist for the most part of Mesozoic (?) sandstone and slate (more than 80%) and partly of limestone, marl, chert (<5%), granite (<15%), porphyritic rocks, rhyolite, andesite, basalt, basic tuff, and others (<3%). Of these components, limestone and granite are relatively concentrated locally.

The sandstones are generally well-sorted, fine- to medium-grained and calcite-cemented. As Fig. 11 shows, major constituents of the sandstones are characterized by the overwhelming amount of lithic fragments derived from sedimentary rocks and igneous rocks as well as by a deficiency of quartz grains. Heavy minerals of the sandstones are characterized by rounded grains of zircon, tourmaline, rutile, and garnet and less worn

Fig. 11. Ternary diagram showing the composition of the Kotanbetsu sandstones, which are classified as the lithic arenite.

grains of augite, hornblende, epidote, anatase, etc. They suggest that sedimentary rocks and volcanic rocks were important as source rocks.

4. Discussion

During a short time span of the early to middle Miocene, an enormous pile of clastic sediments of the Kotanbetsu Formation was developed under the control of gravity in rapidly subsided basins along the western margin of the meridional Hidaka Mountain Range. The Kotanbetsu sedimentary basin seems originally to have been separated into some minor basins with an N-S direction (MATSUNO, 1958). These minor basins might have been formed through the development of the NW-SE trending faults, along which Mesozoic and Paleogene basement rocks were thrust up to form raised topographic features. Such active tectonic uplifts supplied detritus to the basins, and the cyclic stratigraphy of the Kotanbetsu Formation suggests rhythmic upheavals of these uplifts.

The lithology, geometry of the strata and the paleocurrent system suggest that the clastics of the Kotanbetsu Formation were supplied from the southeast. The sedimentary features summarized in the preceding section lead us to interpret the chaotic breccias as an olistostrome (in the sense of ELTER and TREVISAN, 1973) resulting from intense tectonic movements of the basement rocks thrust up to the west. The matrix-deficient conglomerates are assigned to grain-flow deposits defined by MIDDLETON and HAMPTON (1976). The graded-bed facies represents turbidity-current deposits or turbidites, and the ripple-bed facies implies contour-current deposits or contourites (see BOUMA, 1972). The

turbidity currents may have flowed in the proximal part mainly from the east to the west, but in the distal part it is rather difficult to define general current directions. However, the contourites were formed mainly by southward-flowing bottom currents.

The Kotanbetsu basin, characterized by thick gravity-flow deposits, extends southwards into the contemporaneous Kawabata basin filled up by similar sediments, and further southwards into the Neogene sedimentary basin called the Hidaka Trough (ISHIWADA and OGAWA, 1976) with more than 8 km of sediments. These depressions seem to represent the final stage of a collision of two continents, the western Hokkaido west of the Kamuikotan Belt and the Okhotsk Platform, which took place from the late Cretaceous to the early Miocene, as is advocated by GRAPES (1978). A series of the movements may correspond to the so-called Hidaka Orogeny, as was first argued by HORIKOSHI (1972). Westward upthrusting or overthrusting of basement rocks due to the southwestward movement of the Okhotsk Platform, depressing the eastern margin of the western Hokkaido block, developed these deep Neogene basins, which was most intense during Miocene time. In a sense that these basins apparently occupy the present back-arc belt in terms of arc tectonics (DICKINSON, 1974), the Kotanbetsu deposits are comparable to the Onerahi Chaos-Breccia (KEAR and WATERHOUSE, 1967) of Northland, New Zealand, which is related to the Miocene to Pliocene Kaikoura Orogeny (GRINDLEY, 1974). However, the Kotanbetsu and its related sediments cannot be regarded as representing the back-arc position, because they may have been deposited in basins developed by a collision of two continental blocks.

In addition, it is interesting that the Kotanbetsu and its equivalents are developed at the present arc-junction between the Honshu and Kuril arcs, where the folded seismic zone was recently discovered by MORIYA (1978) beneath the arc junction. In order to understand more fully the original tectonic setting of the present Neogene sedimentary basins, mutual relationships between these facts should be analyzed. It is also obvious that the Kotanbetsu and its equivalent sediments were deposited at a time of intense arc tectonism related to active plate movement in the North Pacific (HILDE *et al.*, 1977; NIITSUMA, 1978, among others).

5. *Summary and Conclusions*

This sedimentological study was carried out on the middle Miocene Kotanbetsu Formation which is a part of the very thick Neogene sediments in the west of the Hidaka Mountain Range, where the Honshu and Kuril arcs meet. The results of the study are summarized as follows:

The Kotanbetsu Formation, more than 3,000 m thick, was deposited in rapidly subsiding basins in a short time span within the early to middle Miocene, which seem originally to have been divided into some minor basins open to the northwest, arranged en echelon in an N-S direction. They were under active tectonic controls mainly due to thrust movements of basement rocks composed mainly of probably Mesozoic rocks, which provided such characteristic sediments as gravity-flow deposits.

The sediments of the Kotanbetsu Formation are divided into three major facies: 1) chaotic deposit or olistostrome facies, 2) graded-bed or turbidite facies, and 3) ripple-bed or contourite facies. The chaotic deposit facies is further subdivided into three sedimentary types: 1a) pebbly mudstone, 1b) chaotic breccia, and 1c) matrix-deficient conglomerate. The first type shows the most extensive distribution; the second one is

the most characteristic of the chaotic deposits, consisting of granules to boulders and blocks of varying sizes, of both intrabasinal and extrabasinal origins; the last one is characterized by sorted, subangular to rounded cobbles of extrabasinal origin. The chaotic breccias are mostly developed in the proximal (southern) parts of the basin. The graded-bed facies is predominant to the north of the chaotic breccia facies, and the ripple-bed facies is developed in the distal (northern) parts of the basin. The general lithology of the Kotanbetsu Formation shows a gradual predominance of the fine-grained facies northwards or in the distal areas.

The paleocurrent system and other sedimentary features suggest that the clastics were supplied from the southeast: the chaotic breccias were developed in the most proximal parts owing to intense tectonic movements of the basement rocks thrust up westwards. The graded beds were deposited from turbidity currents, though direction of these current flows is not clearly defined owing to a paucity of measurable sole markings. The ripple beds were developed in the mudstone facies by south-flowing contour currents.

The composition of the sediments is characterized by the predominance of clasts from both older and contemporaneous sedimentary rocks together with some igneous rocks.

Although the apparent tectonic position of the Kotanbetsu Formation in the present back-arc belt is similar to that of the Onerahi Chaos-Breccia of Northland, New Zealand, related to the Miocene to Pliocene Kaikoura Orogeny, the Kotanbetsu and its equivalents may have been deposited in basins developed by a collision of two continental blocks, which seems to correspond to the so-called Hidaka Orogeny. Therefore, the Kotanbetsu and its related sediments do not represent the ancient back-arc belt.

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