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Folding Mechanism in the Central Niigata Oil Field, Central Japan and Its Origin

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新潟油田中央部における褶曲メカニズムとその起源

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Abstract

In backarc fold-belts of island arcs, thick Late Cenozoic sediments accumulated and folded, possessing hydrocarbon productivity. The folding mechanism of the belts is an issue important not only to petroleum exploration, but also to the tectonics of arc-trench genesis. The central Niigata oil field is on the backarc side of the southern end of the Northeast Japan arc. Folds in the oil field are grouped into bending folds at the edges of tilted basement blocks and disharmonic folds detached in the middle Miocene undercompacted mudstone. They were formed through the northwestward tilting of the basement blocks bounded by antithetic (s. l.) faults and through the gravity gliding of sedimentary cover on the tilting basement blocks, respectively. The essential fold mechanisms in the central Niigata oil field are thus the basement tilting toward the Japan Sea and antithetic faulting.

The fold mechanisms are attributed to the asymmetric arching of the Northeast Japan arc with a Pacific-ward vergence, which arching has formed the major relief of the arc-trench system in Northeast Japan since the Pliocene. Slant upwelling of a thermal plume in the wedge mantle under the arc appears to have driven the asymmetric arching. The folding mechanism is thus originated ultimately from the slant upwelling.

A basement block in the southwestern part of the central Niigata oil field tilted southeastward, so that rather rigid volcanic rocks on the undercompacted mudstone glided opposite to the general gliding direction. Conjugate shear zones consequently appeared along both sides of

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the volcanics, forming the crook of fold axes and wrench faults with drag folds. Since such southeastward tilting is common in the triple junction of island arcs on the south of the oil field, it may be concerned with the complicated interference of the island arcs.

Key words : folding mechanism, Niigata oil field, arc-trench genesis

Introduction

The backarc belts of Japanese Islands are called "the Green Tuff region", accumulating thick, late Cenozoic volcanic and normal sediments (Fig. 1). They attain to several thousand meters thick in the western coastal zones, where they are moderately folded to form backarc fold belts. The Niigata oil field, a biggest one in Japan, occupies the southern end of the backarc fold belt of the Northeast Japan arc, and is adjacent to "Fossa Magna" on the south (Fig. 1), through which the Green Tuff region protrudes to the Izu-Ogasawara arc across the Honshu arc.

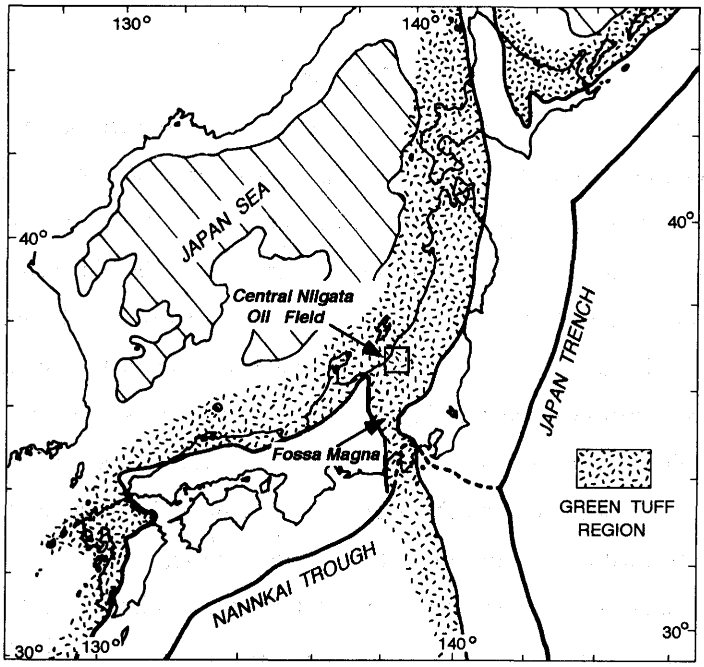

Fig. 1. Distribution of the "Green Tuff region" and the location of the central Niigata oil field.

The deformational mechanism in the Niigata oil filed has been an issue important to the structural geology of backarc fold belts, and to exploration of hydrocarbon deposits (Kimura, 1968 ; Komatsu and Watanabe, 1968 ; Suzuki *et al.*, 1971 ; Uemura and Shimohata, 1972 ; Uemura and Takahashi, 1974 ; Kodama *et al.*, 1974 ; Suzuki and Mitsunashi, 1974 ; Collaborative Research Group for the Niitsu Anticline, 1977 ; Aiba, 1982 ; Nakamura, 1982 ; Komatsu, 1990 ; Uemura, 1990 ; Nakamura, 1992 ; Yamada *et al.*, 1992 ; etc.). Besides, it has a prime importance to elucidate the tectonics of arc-trench genesis in Northeast Japan.

On the basis of morphology, arrangement and deformational phase of folds in the Niigata oil field, Uemura (1976) proposed to distinguish two fold domains, the Hokuetsu and the Nan'etsu fold domains (Fig. 2). They are bounded by the Kashiwazaki-Choshi Tectonic Line (Yamashita, 1970) buried with the sedimentary cover of the oil field. The deformational characters of the domains are summarized as follows (Uemura, 1976). The Hokuetsu domain is characterized by the anticline-dominant folds with long axes and short widths, sometimes with overturned

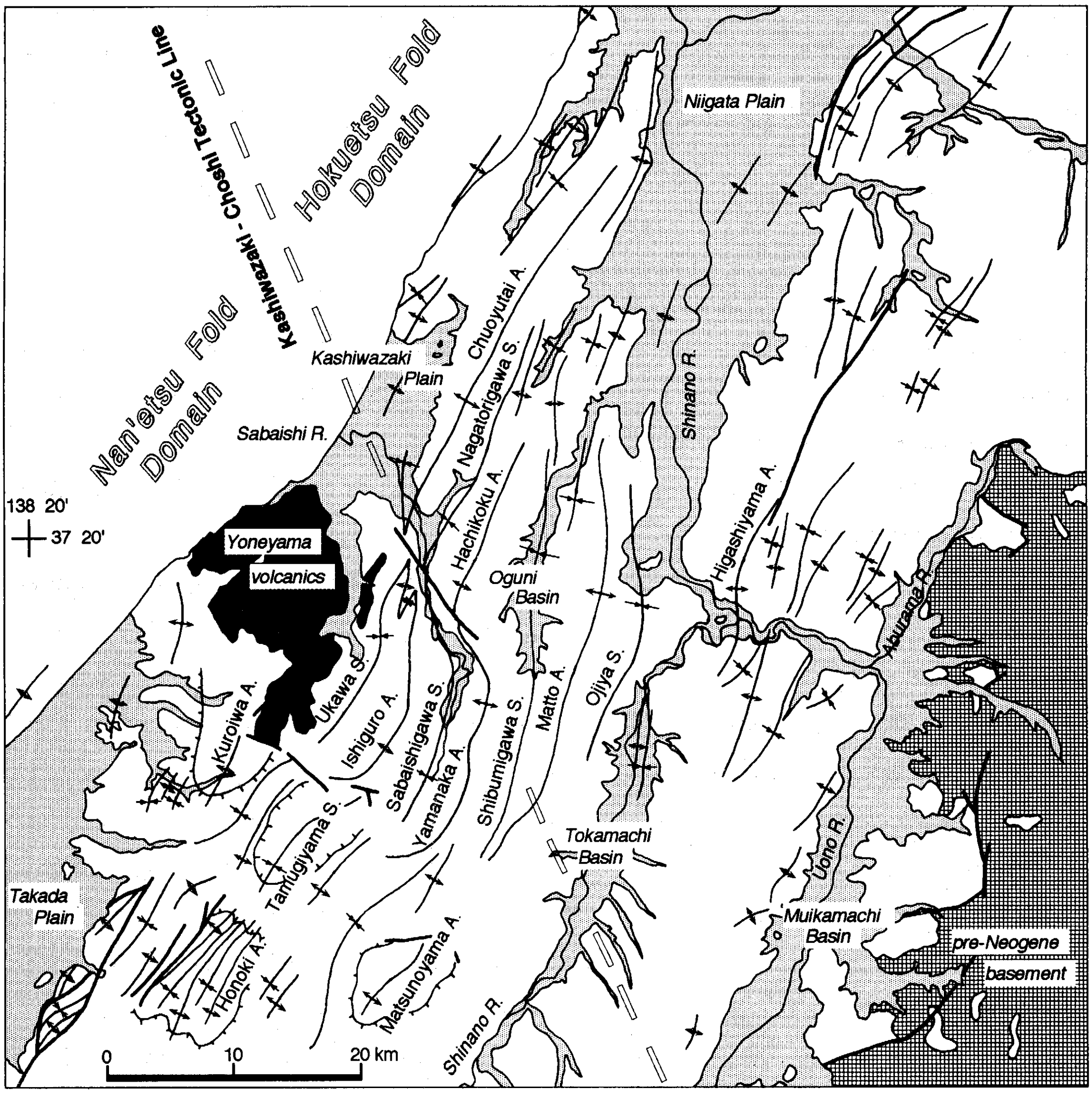

Fig. 2. Structural map of the central Niigata oil field (simplified and modified from Niigata Prefectural Government, 1989).

and thrust limbs. In contrast, broad and flat-bottomed asymmetric, curvilinear-bottomed synclines and chevron anticlines, sometimes with axial-surface thrusts are dominant in the Nan'etsu domain. The northeastern margin of the Nan'etsu domain, named 'the Borderland', consists of brachy-anticlines and -synclines (the Matsunoyama, Honoki and Kuroiwa Anticlines and the Tamugiyama Syncline, shown in Fig. 2). As to deformational phase, folding in the Hokuetsu domain seems later than that in the Nan'etsu domain.

The structural discontinuity along the boundary between the fold domains may provide an important clue to clarify the folding mechanism, because the mechanical difference between the domains comes out most conspicuously along the domain boundary. Hence, this paper describes the geologic structure around the boundary first, and then elucidates the folding mechanism on the basis of the three-dimensional structure of the central Niigata oil field. Lastly, the origin of the folding will be interpreted from a view point of the tectonics of arc-trench genesis in Northeast Japan.

Geologic structure around the domain boundary

The authors surveyed the midstream of the Sabaishi River (Fig. 2), because the structural discontinuity between the Hokuetsu and Nan'etsu fold domains appeared to be most distinct there. Marine sediments of the middle to late Pliocene age (4 to 2 Ma ; Kobayashi *et al.*, 1989) are distributed in the surveyed area and moderately folded in NNE-SSW or N-S trend (**Fig. 3**).

Outline of stratigraphy

The Pliocene sediments form a conformable sequence composed of the Hachikokusan, Suganuma and Hachioji Formations and the Uonuma Group in ascending order. The Hachikokusan Formation, more than 500 m thick, is divisible into two facies, the Hachikokusan pyroclastic and the Hachikokusan mudstone Members. The former consists of pyroclastics and autobrecciated lavas of two-pyroxene and hornblende two-pyroxene andesites. The latter is massive mudstone with thin layers of sandstone and fine-grained pyroclastics. The top of this formation is marked with the Hachikokusan pumiceous tephra group [Hap] (Sawaguri and Kurokawa, 1986). The Suganuma Formation is massive mudstone, 200 to 420 m thick, intercalating the Fudodaki pumiceous tephra [Fup] (Kurokawa *et al.*, 1989) at the middle horizon. The Hachioji Formation, 150 to 500 m thick, consists of siltstone and thinly-bedded alternation of mudstone and sandstone. The Uonuma Group is a thick sequence more than 2,500 m. Distributed in the surveyed area is the lower 240 to 900 m, consisting of the lower massive sandstone and the upper alternation of sandstone, siltstone and conglomerate. Glassy or pumiceous tephra layers, named SK130 and SK120 (Niigata Plain Collaborative Research Group, 1970), are traced.

Geologic structure in the midstream of the Sabaishi River

Geologic structure in the surveyed area is constructed of two major folds, an oblique fault, and echelon folds (Figs. 3 and 4).

Of the major folds, the eastern Yamanaka-Hachikoku Anticline has hitherto been regarded as diagonally positioned, two independent anticlines called the Yamanaka and the Hachikoku Anticlines. The attitude and distribution of strata, however, show that these two anticlines are continuous, though the axial trace is crooked in between and displaced by the oblique fault (Figs. 3 and 4). Toward the crooked part the anticlinal axis becomes strongly depressed and the interlimb angle decreases. The western Sabaishigawa-Nagatorigawa Syncline has also been described as the two independent Sabaishigawa and Nagatorigawa Synclines. However they form a continuous syncline, of which axial trace curves subparallel with that of the Yamanaka-Hachikoku Anticline and is shifted by the oblique fault. The syncline axis weakly culminates on the north of the axial crook. Both the major folds are thus ca. 40 km long, being biggest folds in the Niigata oil field, and crook in a left-hand manner at the fold domain boundary as shown in Fig. 2.

The oblique fault, named the Morichika Fault, strikes in the NNW to NW direction subparallel with the fold domain boundary (Fig. 2) and shifts the formation boundaries and the axial traces of the major folds. If the fault surface was vertical, the slip vector between the projections of displaced axes of the Yamanaka-Hachikoku Anticline plunges to 130° at an angle of 45° and is 710 m long (Fig. 5). Thus the Morichika Fault is an oblique slip fault with sinistral and southwestward-throwing components.

The echelon folds are the Ukawa Syncline, the Kano Anticline, the Miyanotaira Syncline and the Ishiguro Anticline. The former two and the latter two respectively converge to each other northeastward, resulting in disappearance of fold structure on the southwestern wall of the Morichika Fault. The echelon folds are arranged in a left-hand manner to the Morichika Fault. The Ukawa Syncline and the Ishiguro Anticline continue southward 15 km long (Fig. 2), and the latter becomes overturned southeastward, as well as the southern part of the Sabaishigawa Syncline.

Conjugate sets of minor faults observed in the surveyed area, though only thirteen sets, are grouped into two types. The A type is a reverse fault system showing a compressive stress in the N-S direction. Since this type of minor faults show a regular stress trajectory after the tilt correction of bedding, it may have formed in a time before the folding. The B type is a reverse fault system showing a compressive stress in the E-W direction, and may have been associated with the folding. The maximum compressive principal stresses restored from this type of minor faults plunge up to 40°, probably due to their rotation during the folding, as pointed out by

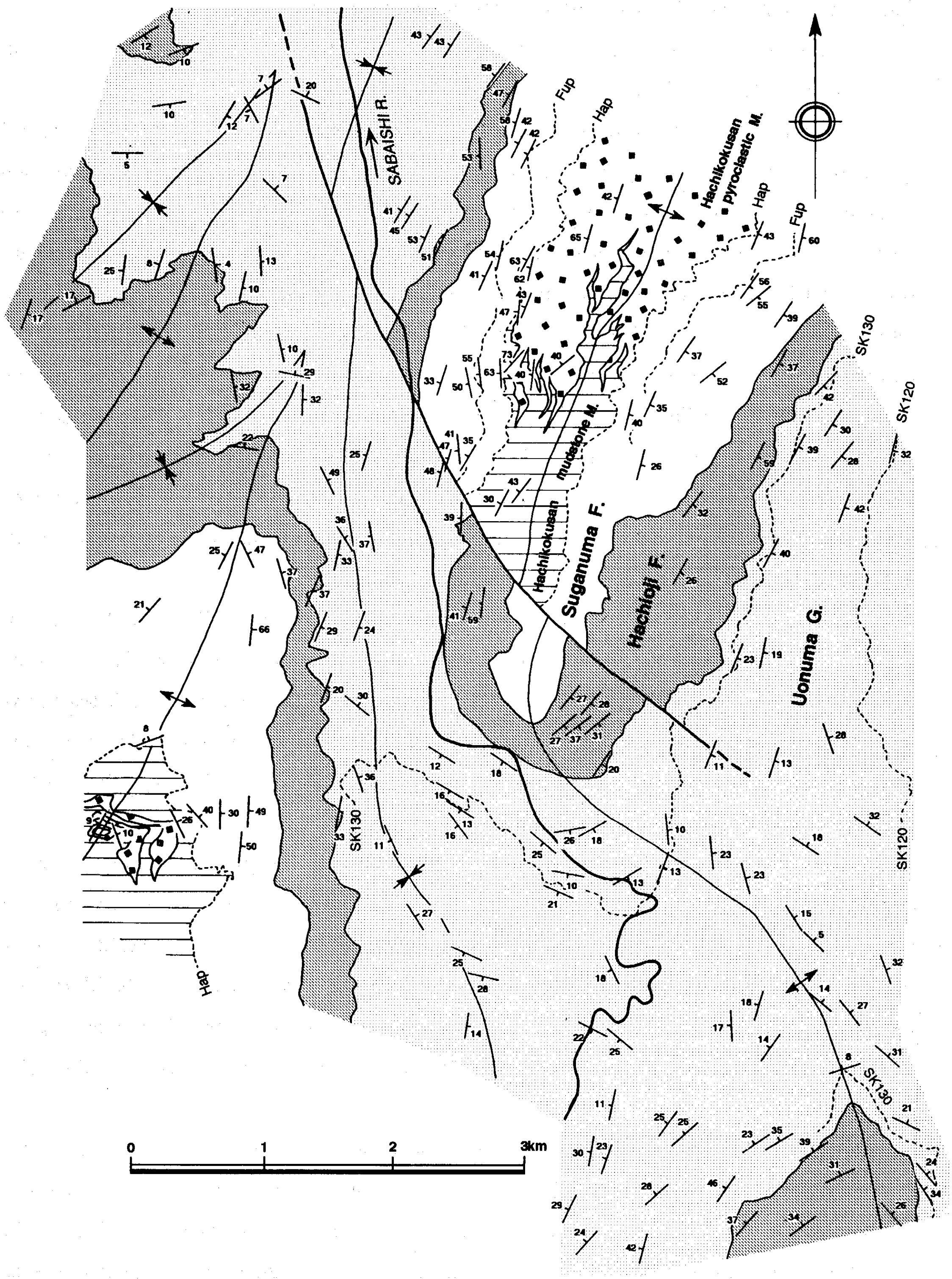

Fig. 3. Geologic map in the midstream of the Sabaishi River.

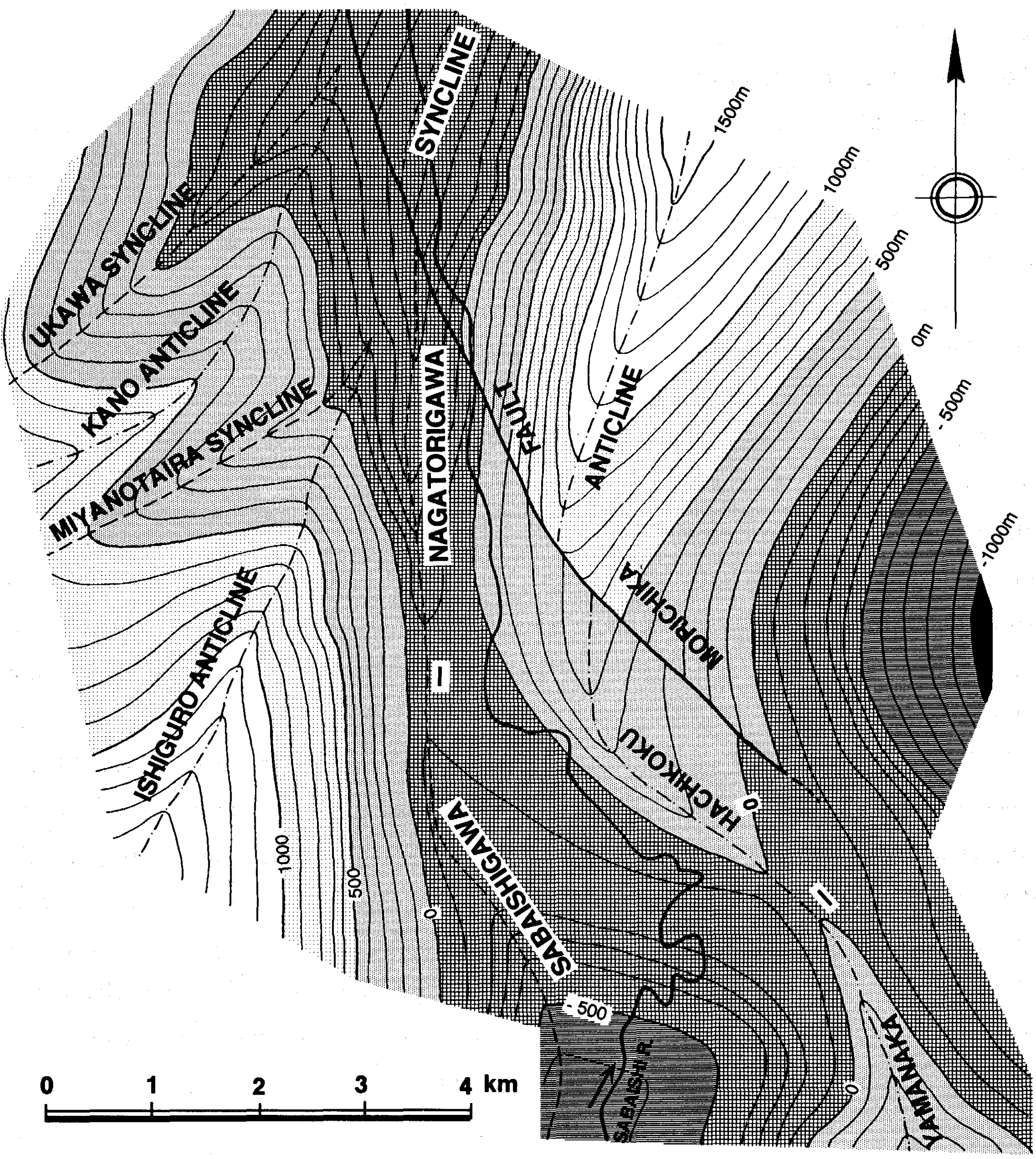

Fig. 4. Structural contour map of the base of the Uonuma Group in the midstream of the Sabaishi River.

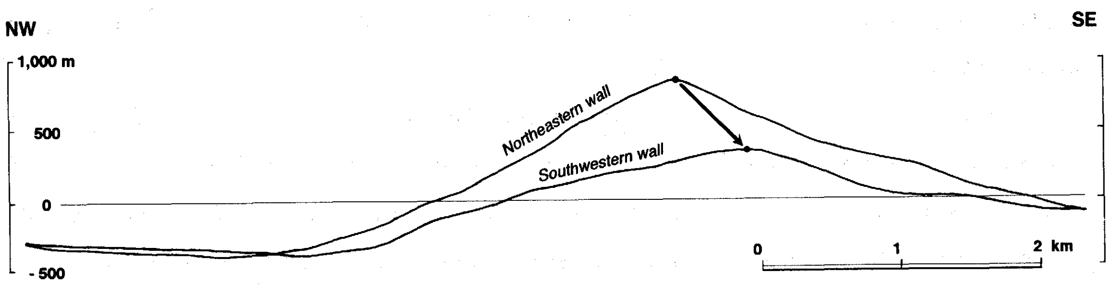

Fig. 5. Displacement of the base of the Uonuma Group by the Morichika Fault.

Uemura (1990).

Geologic structure around the domain boundary

The crooking axes of major folds, the oblique slip fault and the echelon folds in the midstream of the Sabaishi River (Figs. 3 and 4) indicate that the northwestern part of domain boundary is a sinistral shear zone (Fig. 2). The shift of this shear zone amounts up to 5 km and seems to decrease southeastward. The alluvial surface of the Oguni Basin terminates at the southeastward elongation of the shear zone, and the Shibumigawa Syncline becomes more closed in the southwestern side of the elongation. Hence the shear zone appears to affect so far as the area of the Shibumigawa Syncline (Fig. 2).

On the other hand, the northwestward elongation of the shear zone coincides approximately with the northeastern margin of the Yoneyama volcanic rocks, which is correlative to the Hachikokusan Formation in the midstream of the Sabaishi River. The volcanic rocks consist of andesitic pyroclastics, 1,000 to 2,000 m thick, and clino-unconformably overlies the Miocene strata (Yoneyama Research Group, 1973). On the southeastward elongation of the southwestern margin of the Yoneyama volcanic rocks, the bending of several fold axes indicates the presence of a possible dextral shear zone of WNW-ESE trend.

The northwestern segment of the domain boundary along the Kashiwazaki-Choshi Tectonic Line shows a marked sinistral wrench deformation, but the southeastern one was not subjected to any distinctive deformation. Hence the northwestern segment and the possible dextral shear zone mentioned above appear to form a conjugate shear zone along both margins of the Yoneyama volcanic rocks. The volcanic rocks form a homocline dipping southeastward at angles from 40° to 20°, without marked folds (Yoneyama Research Group, 1973). Hence it is inferred that the Yoneyama volcanic rocks behaved as a rigid body during the folding, and consequently generated the conjugate shear zones on the both sides.

Three-dimensional structure of the central Niigata oil field

In this section, the geologic structure of the central Niigata oil field is described with block diagrams (**Fig. 6**). The diagrams are cut off in WNW-ESE direction and cover the major part of the central Niigata oil field (Fig. 2).

According to Niigata Prefectural Government (1989), the lithology of the oil field succession is summarized as follows. The basement of the oil field consists of the Permo-Triassic and partly Jurassic sedimentary mēlange and the Cretaceous granitoid. The Late Cenozoic sediments, overlying the basement with a marked unconformity, are composed of the Middle to Upper Miocene and the Pliocene to lower Pleistocene. The Miocene sequence is subdivided into the Jonai, Nanatani, Teradomari, Shiiya Formations in ascending order. The Jonai Formation consists of conglomerate and andesitic pyroclastics. The Nanatani Formation is composed of rhyolitic pyroclastics, perlite lava and shale. The Teradomari Formation is a muddy alternation of mudstone and sandstone, and its lower part predominates in mudstone. The Shiiya Formation is composed of western sandy flysch facies and eastern mudstone facies. The Pliocene to lower Pleistocene is subdivided into the Nishiyama, Haizume Formations and the Uonuma Group. The Nishiyama Formation is massive mudstone with local but thick andesitic volcanics represented by the Yoneyama volcanic rocks. The Haizume Formation is sandy siltstone with sandstone intercalations. The Uonuma Group is composed of the lower marine sandstone and the middle to upper fluvial alternation of gravel, sand and mud. Although the greater part of the group is contemporaneous with the Haizume Formation and the upper part of the Nishiyama Formation, the stratigraphic division in the block diagrams represents the lithologic units.

The Yoneyama volcanic rocks (designated as Yv) forms a gentle homocline dipping southeastward, and southeastward of the homocline the Ishiguro Anticline develops with an eastward vergence (Figs. 6-C and -D). A sinistral shear zone on the northeastern margin of the Yoneyama volcanic rocks bends the axial traces of the Yamanaka-Hachikoku Anticline and the Sabaishigawa-Nagatorigawa Syncline, which were torn by the Morichika Fault (Fig. 6-C). Except for such a deformational area related to the Yoneyama volcanic rocks, the geologic structure of the central Niigata oil field is dominated by homoclinal structure gently dipping northwestward (Fig. 6). Furthermore, the homoclinal structure is modified with many folds, and displaced by some antithetic faults with frictional drag.

Komatsu (1990) classified the fold structure in the Niigata oil field into two types, i.e., 'detached' and 'basement involved' according to Harding and James (1979). His classification is adequate to the central Niigata oil field. Although the deep structure of the central Niigata oil field is obscure, deep drillings and seismic profiling (Japan Natural Gas Association and Japan Offshore Petroleum Development Association, 1982; Komatsu, 1990; Inooka, 1991; Yamada *et al.*, 1992) clarified that some major anticlines are disharmonic (Fig. 6). Komatsu (1990) explained the character and origin of the disharmonic folds as follows. The Shiiya Formation and its overlying strata are folded rather strongly, whereas the deformation of the Nanatani Formation is gentle. Hence the Teradomari Formation sandwiched between them consequently seems to have played a role of lubricant, detaching the shallow structure from the deep one. The smaller shear strength of the Teradomari Formation is evidenced by the fact that under-compacted mudstone commonly develops in the formation, particularly in its muddy lower part.

On the other hand, the basement-involved folds are formed as broad anticlines above the uplifting edges of tilted basement blocks. The blocks dip gently northwestward, and are

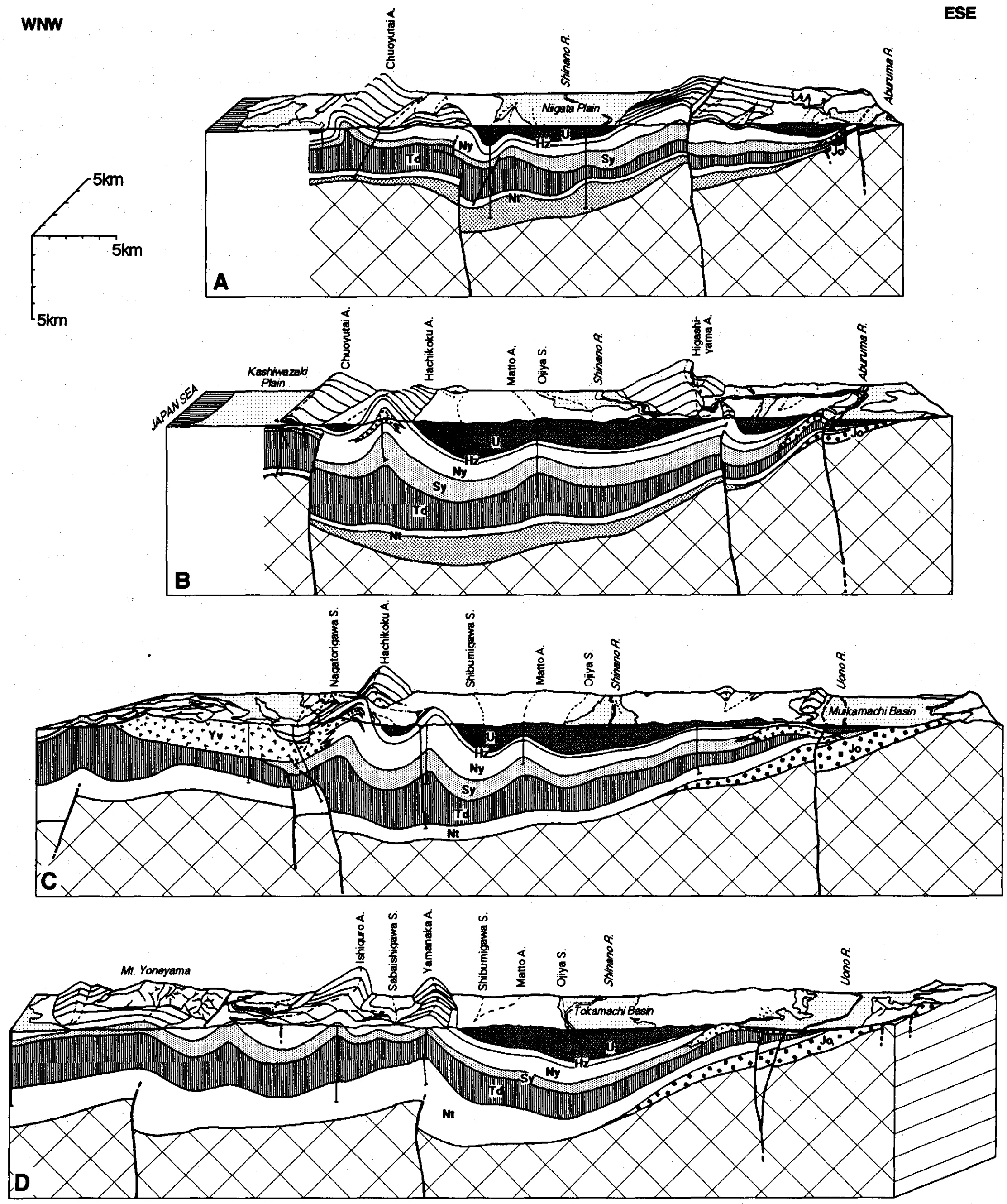

Fig. 6. Block diagrams in the central Niigata oil field (compiled mainly from Yoneyama Research Group, 1973 ; Niigata Prefectural Government, 1977 ; Japan Natural Gas Association and Japan Offshore Petroleum Development Association, 1982 ; Yanagisawa *et al.*, 1985, 1986 ; Niigata University Research Group of Geology in Higashikubiki District, 1987 ; Kobayashi *et al.*, 1989, 1991).

U : Uonuma Group, Hz : Haizume Formation, Ny : Nishiyama Formation, Sy : Shiiya Formation, Td : Teradomari Formation, Nt : Nanatani Formation (the lower shaded parts in the block diagrams A and B are abundant in volcanics), Jo : Jonai Formation, Yv : Yoneyama volcanic rocks.

bounded by antithetic faults. The term "antithetic" in this paper is taken in the wide sense redefined by Mackin (1960) as 'regardless of the direction of the dip of the faults, their throws tend to be opposite to, and counteract the effect of, the dip of the faulted strata'. The dip angles of the antithetic faults decrease toward the earth's surface and change into reverse faults, probably due to gravity spreading of the upheaving walls. The basement-involved folds may have been formed by the northwestward tilting and antithetic faulting of the basement blocks and by the derivative gravity spreading and frictional drag, as pointed by Komatsu (1990).

Thus, the three-dimensional structure of the central Niigata oil field is characterized with the combination of the disharmonic folds formed by detaching mainly in the Teradomari Formation and the bending folds formed by northwestward tilting and antithetic faulting of the basement (Fig. 6). In addition, the conjugate shear zones along both margins of the Yoneyama volcanic rocks modify the structure through wrench deformation.

Folding mechanism in the central Niigata oil field

From the three-dimensional structure of the central Niigata oil field, the folding mechanism is depicted as a model in **Fig. 7**. To simplify environmental conditions, the model is imagined as a double-layered system composed of basement and sedimentary cover with uniform thicknesses. The slip surface supposed between the layers acts for the Teradomari Formation as lubricant. The folding mechanism is explained separately into the following three steps.

At the first step (Fig. 7-1) the distributional area of the Yoneyama volcanic rocks began to uplift before regional folding, as indicated by the fact that the cobbles and boulders from the Yoneyama volcanics were supplied into the Asojima Formation (Yoneyama Research Group, 1973), correlative to the Hachioji Formation in the midstream of the Sabaishi River (Kobayashi *et al*., 1989). The uplift probably caused the northward gliding of the sedimentary cover, and produced a horizontal compressive stress field of the N-S trend recorded as the A type of conjugate faults.

Then (Fig. 7-2), regional northwestward tilting of the basement blocks bounded by antithetic faults took place, and consequently the sedimentary cover initiated to glide and to form disharmonic folds. However, only the basement block under the Yoneyama volcanic rocks (the Yoneyama block, for short) tilted southeastward. Along the boundary of the opposite directional tilting movements a sinistral shear zone appeared to shift the axial trace of the embryonic Yamanaka-Hachikoku Anticline.

With progress of the tilting movements (Fig. 7-3), the disharmonic folds and the antithetic faults continued to grow. The sediment cover on the Yoneyama block glided southeastward,

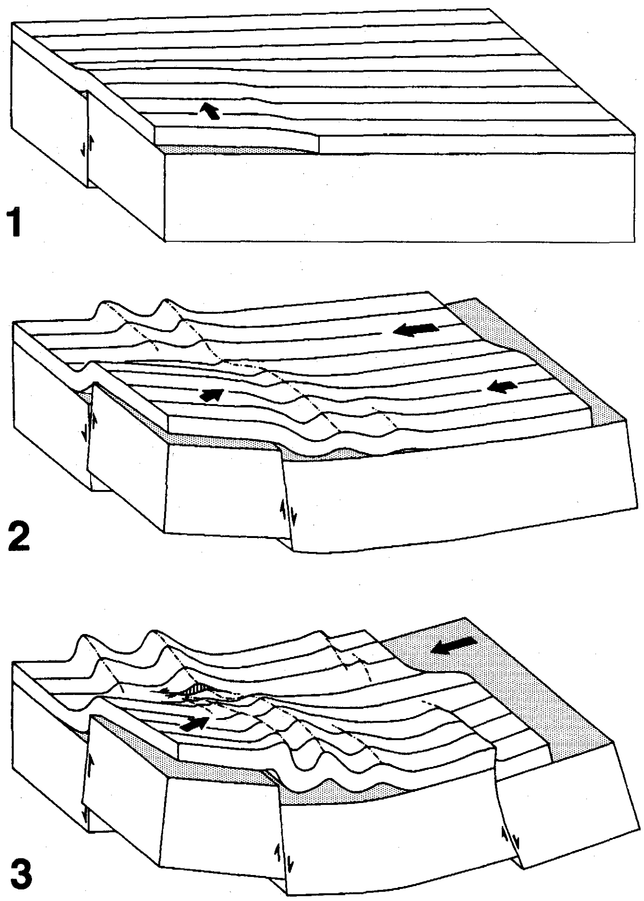

Fig. 7. Folding model in the central Niigata oil field

without marked folding due to the rigidity of the Yoneyama volcanic rocks, and compressed the sedimentary cover on the southeast, resulting in the formation of the partly overturned Ishiguro Anticline. The displacement of the sinistral shear zone increased through the opposite directional gliding movements of the sedimentary cover. Finally the sedimentary cover was torn to form the Morichika Fault with the echelon folds of left hand. If the axial trace of the embryonic Yamanaka-Hachikoku Anticline had been straight, the displacement of the shear zone amounted to ca. 5 km. The dextral shear zone along the southwestern margin of the Yoneyama volcanic rocks may have appeared contemporaneously.

The essential mechanism of folding in the central Niigata oil field is, thus, the northwestward tilting of the basement blocks bounded by antithetic faults. It is modified regionally by the derivative gravity gliding of the sedimentary cover, and locally by the southeastward tilting of the Yoneyama block.

Origin of the folding

It became clear that the folding in the central Niigata oil field was caused by the northwestward tilting of basement blocks bounded by antithetic faults. The origin of the folding is lastly interpreted from a view point of the tectonics of arc-trench genesis, with which the northwestward tilting and the antithetic faulting seem to be concerned.

The tectonic movement that had formed arc-trench systems since the Pliocene was named 'the Island Arc Movement' (Fujita, 1970). The kinematic picture of the Island Arc Movement in Northeast Japan can be reconstructed on the basis of the strain picture of the arc-trench system (Yano, submitted). To interpret the dynamic picture the velocity structure of the wedge mantle under the arc-trench system provides an important clue.

Strain picture of the arc-trench system

The Northeast Japan arc-trench system consists of the Northeast Japan arc and the Japan trench. The term "island arc" is defined as a tectono-geomorphic high ranging from the foot of the backarc continental slope to the trench axis, beyond islands. Synthesis of local structures in the Northeast Japan arc-trench system clarified that its strain picture is framed of the following five constituents (Fig. 8-3).

asymmetric arch: The asymmetric arch is the largest structure of the arc-trench system, represented by geomorphic and geologic profiles across the island arc. It is 500 to 600 km wide and shows a slight oceanward vergence. The "backarc" and "forearc" in this paper are bounded by the arch axis.

longitudinal faults : The longitudinal faults are a fault system producing the basin and range structure over the island arc except its landward trench slope. They are normal or reverse, and mostly antithetic to the arch. Their displacements are larger in the backarc and crest of the arch than in the forearc.

forearc undulation : The forearc undulation is a gentle fold in the area ranging from the lower half of the forearc continental slope to the upper margin of the landward trench slope. Its synclinal portion forms a forearc basin, of which depoaxis has migrated landward (Nasu *et al.*, 1980). Its anticline axis corresponds to the trench slope break.

arcfront overthrust : The arcfront overthrust, dipping gently landward at an angle from 10° to 20° bounds the arcfront and the underlying oceanic crust. It is actually a complex fault zone forming an imbricate or decollement structure beneath the lower landward trench slope.

flexure of oceanic crust : The flexure of oceanic crust bends down the oceanic crust of the Northwest Pacific, forming the Japan trench in the front of the island arc. It is embellished by the trench outer swell at its upward end and by normal faults on the seaward trench slope.

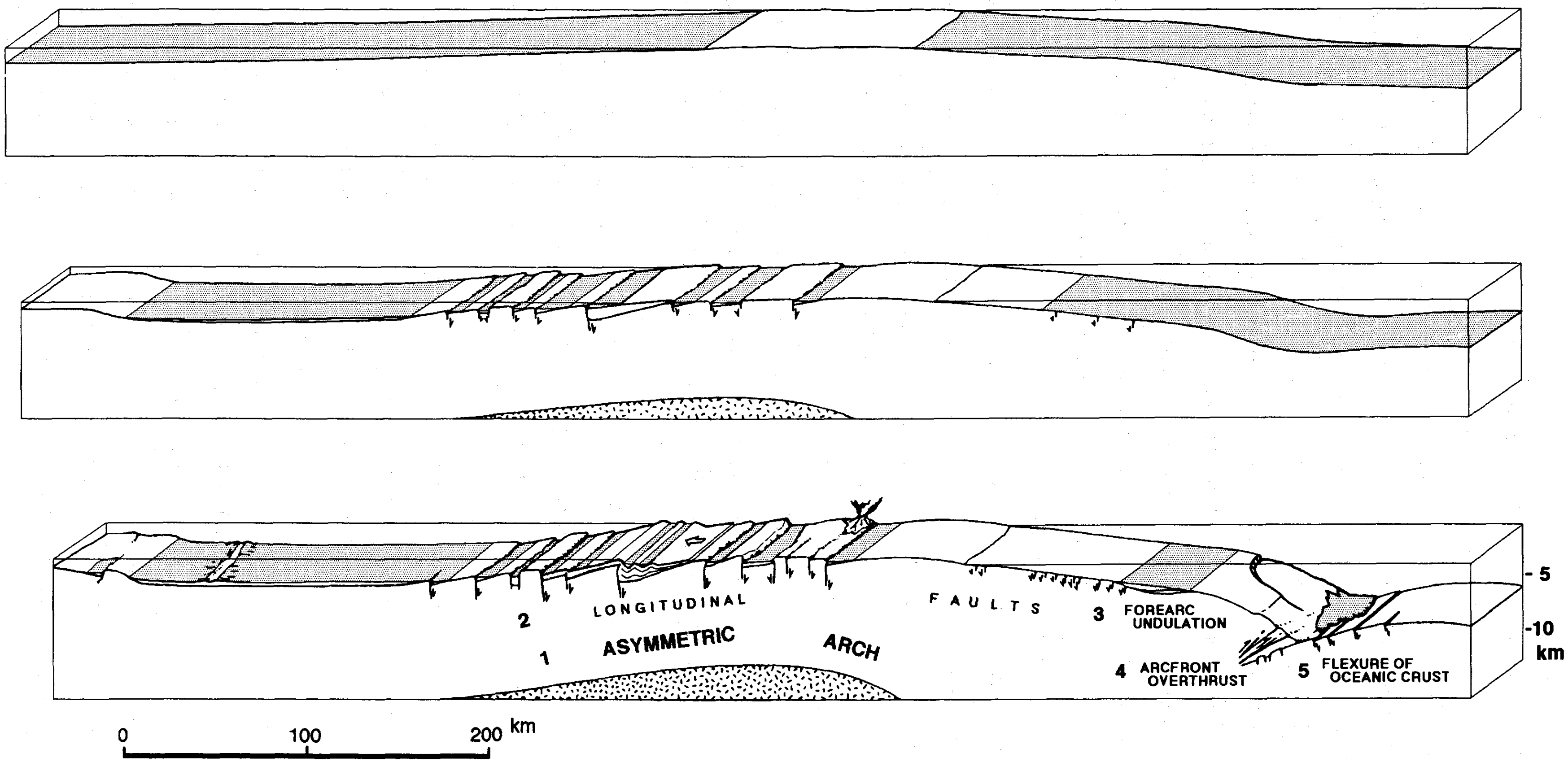

Fig. 8. Strain and kinematic pictures of arc-trench genesis in Northeast Japan (modified from Yano, submitted).

Kinematic picture of arc-trench genesis

The kinematics of arc-trench genesis, as a matter of course, should explain the generative processes of all the above constituents, in a unified manner. It appears that the asymmetric arching of the island arc can drive the whole generative processes (Fig. 8).

With the initiation of the asymmetric arching (Fig. 8-2), the greater part of the island arc became to be occupied by a stress field of horizontal extension. Longitudinal normal faults, mostly antithetic, consequently generated over the island arc except its frontal part. Their displacements were larger on the backslope and crest of the island arc than the foreslope, because of the asymmetry of arching. Through the progress of the asymmetric arching (Fig. 8-3), the longitudinal faults continued to grow in an intensified stress field of horizontal extension, and produced a marked basin and range structure on the backslope and the crest. Longitudinal faults with large displacements were likely to change reverse faults near the earth's surface, due to gravity spreading. On the other hand, the frontal part of the island arc was occupied by an intensified stress field of horizontal compression, resulting in the generation of the forearc undulation and the arcfront overthrust. The lower part of landward trench slope was steepened by frictional drag of the arcfront overthrust (Nagumo, 1980). Gravity loading of the overthrusting arcfront (Nagumo, 1982) and of the huge amount of sediments collapsed from the landward trench slope flexed down the underlying oceanic crust, and consequently generated the Japan trench in front of the island arc. The trench outer swell appeared as an elastic response of the oceanic crust to the flexuring, and the normal faults embellished the seaward trench slope in an extensional stress field.

Thus, the essential kinematics of arc-trench genesis is the eastward-facing asymmetric arching of the island arc. Because, through interaction with gravity it can form all the five constituents, i.e., the whole strain picture of the arc-trench system.

The above kinematic picture of the arc-trench system seems incompatible with the recent compressional state revealed seismologically and geodetically. As to this incompatibility, the stress character of an arch should be noticed. Once an arch was formed, its stress state hangs in a sensitive balance between extension and compression. The presence of five regional fracturing phases over the Northeast Japan arc during the Pliocene and Quaternary (Fujita, 1982) indicates that the asymmetric arch has grown in an unsteady, pulsatile state. In activated stages of the asymmetric arching, a horizontally extensional state may occupy the grater part of the arc except the arcfront. In relaxed stages, in contrast, a horizontally compressional one may occupy the whole arch, as in the recent several decades. The above kinematic picture of arc-trench genesis is, hence, not incompatible with the recent compressional state. Incidentally, such a reciprocal stress change was already pointed out by Chen (1965) in the case of Mesozoic

Diwa basins in southeastern China.

With abundant geochronological and paleoenvironmental data, a more realistic kinematic picture of the arc-trench genesis is depicted in the surface parts of the block diagrams in **Fig. 9**. Described in another paper (Yano, submitted), its details are omitted here.

Dynamic picture of arc-trench genesis

Hasemi *et al.* (1984) and Obara *et al.* (1986) clarified the three dimensional velocity structure of the wedge mantle under the arc-trench system, in terms of an inversion of seismic-wave arrival times. It is characterized by the presence of diapiric slowness, which has a concentric internal structure and inclines westward at angles from 30° to 40° nearly parallel with the Wadati-Benioff zone (Fig. 9, the bottom diagram). The diapiric slowness ranges from just under the most active volcanic chain on the volcanic front, to the depth about 100 km or more. The aerial projection of the slowness magnitude coincides with the volcanic and geothermal activeness on the island arc, so that the low velocity anomaly was interpreted to indicate high temperature and high partial-melting degree. The diapiric slowness may be derived from an extensive low-velocity anomaly in the upper mantle under the East Asian continental margin observed by Fukao *et al.* (1992).

The inclined attitude of the diapiric slowness may indicates its slant rising toward the Pacific. If so, the slant upwelling of the diapric thermal plume appears necessary and sufficient as the dynamics of arc-trench genesis (Fig. 9). Because, it causes the asymmetric arching of the overlying crust, inevitably resulting in formation of the present arc-trench system through the kinematics reconstructed above. The pulsatile growth of the asymmetric arch may indicate that the thermal plume has upwelled in an unsteady state. The dynamic picture driven by the slant upwelling of the thermal plume is similar to that by mantle diapirism or mantle tectonic flow (e. g., Scheinman, 1970 ; Nagumo, 1976 ; Meyerhoff and Meyerhoff, 1977 ; Fujita, 1982, 1990 ; Nishmura, 1985, 1986 ; Tian, 1987 ; Rodnikov, 1988 ; Meyerhoff *et al.*, 1992).

Origin of the folding in the central Niigata oil field

The folding in the central Niigata oil field was caused by the northwestward tilting and antithetic faulting of the basement. These structural movements represent a backarc part of the kinematic picture of arc-trench genesis. The former is no more than the rotation of the backarc limb of the growing asymmetric arch, and the latter is an adjustment of the asymmetric arching to gravity field. Thus, the folding in the central Niigata oil field was produced by the asymmetric arching of the Northeast Japan arc and its interaction with gravity, and was originated from the slant upwelling of the thermal plume in the wedge mantle (Figs. 8 and 9).

Concluding remarks

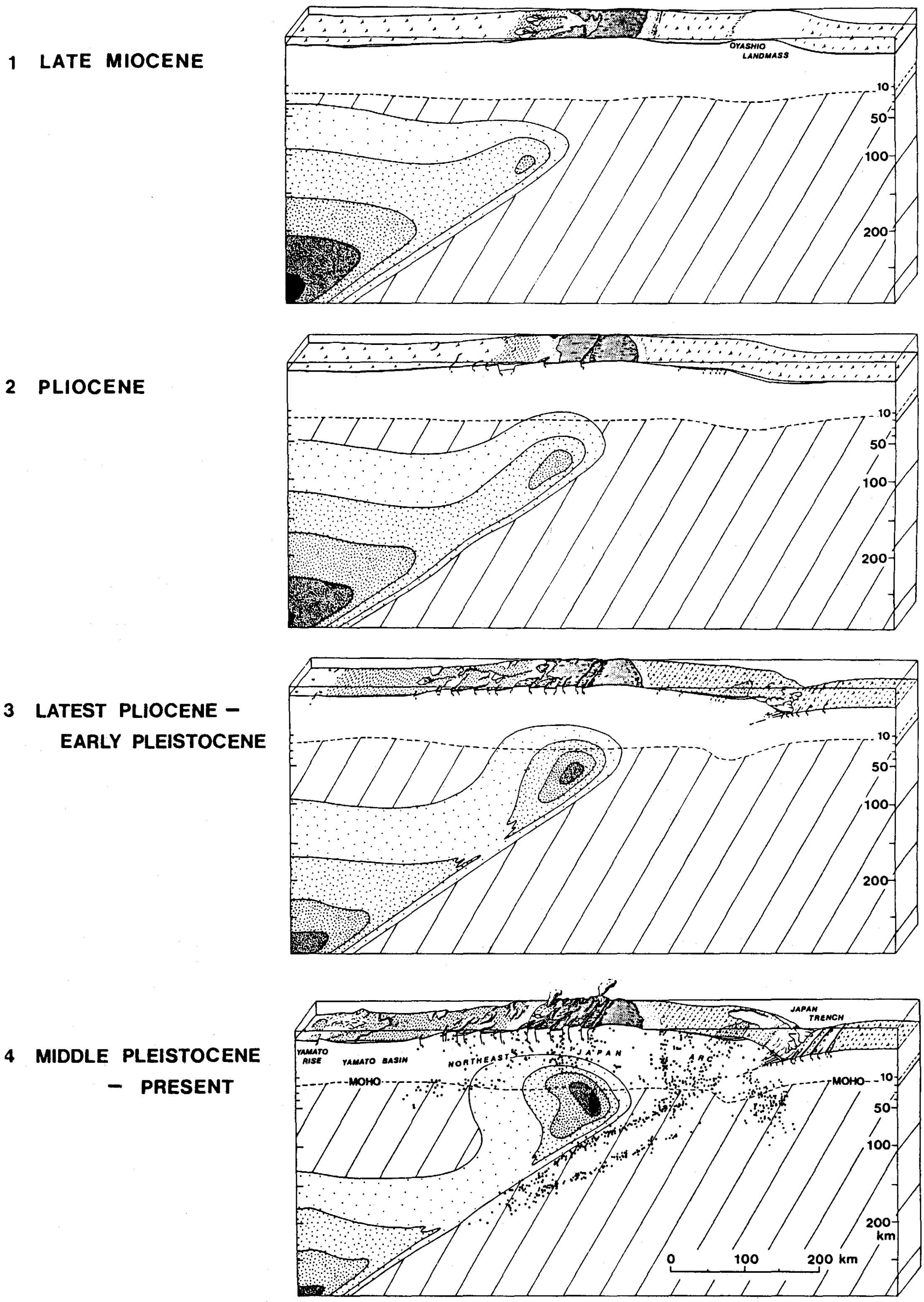

Fig. 9. Dynamic picture of arc-trench genesis in Northeast Japan (Yano, submitted). The present velocity structure under the island arc was taken from Obara *et al.* (1986). The focal depth distribution of microearthquakes shown as large stipples was compiled from Takagi (1985).

On the basis of the geologic structure of the central Niigata oil field, particularly in the midstream of the Sabaishi River, the folding mechanism of the oil field sequence was elucidated with a simplified double layered model, and its origin was interpreted from a view point of arc-trench genesis in Northeast Japan.

The actual folding process must be much complex, because the northwestward tilting of the basement began contemporaneously with the sedimentation of the Nishiyama Formation (Komatsu, 1990) and the sediment cover and the basement are considerably heterogeneous. Hence the simplified folding model (Fig. 7) should be improved to represent more detailed folding process since the beginning of the Pliocene.

The southeastward tilting of the Yoneyama block, which is opposite to the general tilting direction in the oil field, does not seem accidental, because tilting movements in the similar direction are commonly observed on the northwestern part of the Nan'etsu fold domain and the northern Fossa Magna (Nakamura, 1982 ; Mining Society of Natural Gas and Japanese Association for Petroleum Exploitation on Continental Shelf, 1982 ; Acoustic Research Subgroup for Nojiri-ko Excavation, 1987 ; Yano, 1990). In contrast to the northwestward, unidirectional tilting in the Hokuetsu domain, bilateral (face to face) tilting movements, i. e., a regional synclinal deformation of the basement could be the essential folding mechanism of the Nan'etsu domain and the northern Fossa Magna. The bilateral tilting movement appear to be connected with the complex tectonic movement in central Japan where three island arcs—the Northeast Japan, Southwest Japan and Izu-Ogasawara arcs encounter to each other. The complex movement in the triple junction of the arcs is to be discussed in another paper.

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** in Japanese

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Place names

Aburuma	破間	Nagatorigawa	長鳥川
Asojima	阿相島	Nanatani	七谷
Choshi	銚子	Nan'etsu	南越
Chuoyutai	中央油帯	Niigata	新潟
Fudodaki	不動滝	Nishiyama	西山
Hachikoku	八石	Oguni	小国
Hachikokusan	八石山	Ojiya	小千谷
Hachioji	八王子	Sabaishi	鯖石
Haizume	灰爪	Sabaishigawa	鯖石川
Higashiyama	東山	Shibumigawa	渋海川
Hokuetsu	北越	Shiiya	椎屋
Honoki	朴木	Shinano	信濃
Ishiguro	石黒	Suganuma	菅沼
Jonai	城内	Takada	高田
Kano	加納	Tokamachi	十日町
Kashiwazaki	柏崎	Tamugiyama	田麦山
Kuroiwa	黒岩	Teradomari	寺泊
Matsunoyama	松之山	Ukawa	鵜川
Matto	真人	Uono	魚野
Miyanotaira	宮平	Uonuma	魚沼
Morichika	森近	Yamanaka	山中
Muikamachi	六日町	Yoneyama	米山

（要　旨）

Yano, T. and Kunisue, S., 1993, Folding mechanism in the central Niigata oil field, central Japan and its origin. Hokuriku Geology Institute Report, no. 3, 71－94.（矢野孝雄・国末彰司，1993，新潟油田中央部における褶曲メカニズムとその起源．北陸地質研究所報告，no. 3，71－94.）

島弧の背後側に発達する後期新生代の褶曲帯（背弧褶曲帯）における褶曲メカニズムは，石油探査のみならず，島弧－海溝系形成のテクトニクスにとっても重要な研究課題である．新潟油田中央部には，傾動地塊の縁に形成された横曲げ褶曲と中部中新統の高圧泥岩をdetachment layerとする非調和褶曲が発達する．それらは，アンティセティック（広義）な断層に境された基盤ブロックの北西への傾動と，それから派生する被覆層の重力滑動によって形成された．

このような傾動運動とアンティセティックな断層運動は，東北日本弧の非対称arching（太平洋側フェルゲンツ）と、それにともなう重力断層運動に由来する．島弧の非対称archingは，島弧下のウェッジマントル内にみられる熱プリュームの斜め湧昇運動に起因するものと考えられ，背弧褶曲帯における褶曲作用はこの湧昇運動に起源をもつ．