

Records of major and minor transgression and regression events in the Paleo-Sea of Japan during late Cenozoic

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ABSTRACT

Late Cenozoic strata distributed along the coastal region of the Sea of Japan are a good recorder of transgression and regression events in the Paleo-Sea of Japan. The main events are recognized from many stratigraphical horizons of Niigata late Cenozoic formations. They are 1) early/middle Miocene transgression; 2) latest Miocene / early Pliocene events; 3) late Pliocene to early Pleistocene transgressions and regressions; 4) middle to late Pleistocene transgressions and regressions; and 5) Holocene transgression. It is thought that the events were related to global sea-level changes, crustal movements and local landform changes.

Keywords: transgression, regression, late Cenozoic, Niigata, Sea of Japan.

RESUMEN

Estratos del Cenozoico tardío distribuidos a los largo de la región costera del Mar de Japón son buenos registros de eventos de transgresión y regresión en el Paleo Mar de Japón. Los principales eventos se reconocen en muchos horizontes estratigráficos de las formaciones del Cenozoico tardío de Niigata. Estos eventos son: 1) trasgresión en el Mioceno temprano/medio; 2) eventos del Mioceno tardío / Plioceno temprano; 3) transgresiones y regresiones del Plioceno tardío al Pleistoceno temprano; 4) transgresiones y regresiones del Pleistoceno medio a tardío; y 5) trasgresión del Holoceno. Se considera que estos eventos se relacionan con cambios globales del nivel del mar, movimientos corticales y cambios locales del relieve.

Palabras clave: transgresión, regresión, Cenozoico tardío, Niigata, Mar de Japón.

INTRODUCTION

Field and seismic examinations revealed transgression and regression events in the Paleo-Sea of Japan during late Cenozoic. These events were recorded in late Cenozoic strata widely distributed along the coastal area of the Sea of Japan and have been related distinctly to marine faunal and floral changes. In this short article, the records in Niigata district, central Japan (Figure 1), are

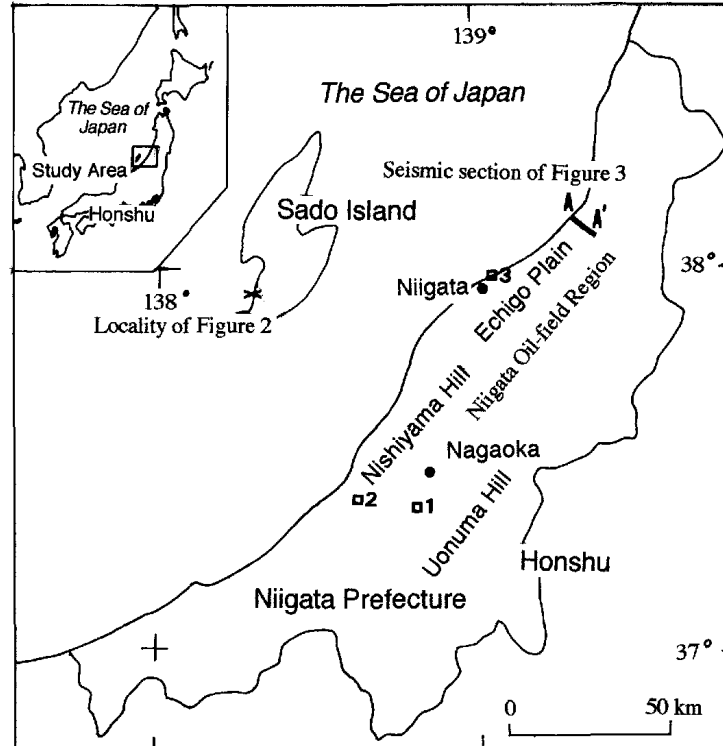
presented. It is thought that the events were related to global sea-level changes, crustal movements and local landform changes. The Niigata late Cenozoic sedimentary basin contains a very thick sequence of clastic sediments; they are about 6,500 m in thickness. Numerous gas and oil fields are characteristically formed in the basin. Table 1 shows the outline of geologic history in the late Cenozoic Sea of Japan basin. Evidences of transgressions and regressions are recognized from many

stratigraphical horizons of Niigata late Cenozoic formations. The main events recorded in this basin are 1) early / middle Miocene transgression, 2) late Miocene / early Pliocene events, 3) late Pliocene to early Pleistocene transgressions and regressions, 4) middle to late Pleistocene transgressions and regressions, and 5) Holocene transgression.

EARLY MIDDLE MIOCENE TRANSGRESSION

The clino-unconformity between the early Miocene and middle Miocene strata and the overlying shallow marine sediments, as evidence of transgression, are widely recognized in early / middle Miocene strata in Niigata, and also in Japanese Islands. Early Miocene pyroclastic sediments, the Aikawa Group in Sado Island and the Mikawa Formation in Niigata, were unconformably covered by shallow marine sediments, the Orito Formation in Sado Island and the Tsugawa Formation in Niigata (Kobayashi and Tateishi, 1992). The early Miocene formations are composed mainly of lavas and pyroclastics of rhyolite, dacite, andesite and basalt. The rocks were erupted from terrestrial volcanos which were distributed along the continental margin. Just before the

beginning of middle Miocene non-marine and main marine deposition, the underlying early Miocene strata underwent strong crustal movements and were eroded widely in Sado Island. At some exposures, the underlying pyroclastic sediments were strongly fractured (Ogi Collaborative Research Group, 1986). These volcanic rocks were unconformably covered by shallow marine sediments. The marine sediments were not deformed, lacking faults and joints. The lower part of marine clastic sediment is composed of delta deposits at some places. The upper part consists mainly of sand and gravel deposits with brackish to shallow marine molluscan fossils, and with tropical and subtropical marine animal fossils. This vertical facies change clearly indicates a transgression. The geologic section of this transgressive phenomenon is well recorded in the early middle Miocene strata at the Hiranezaki Point of Sado Island (Kimura and Kobayashi, 1977). Figure 2 shows one exposure of the unconformity and overlying marine clastic sediments with marine fossils indicating a transgressive facies. The lower half of this outcrop is the Aikawa Group which consists of fractured andesitic lavas, and the upper half is the Orito Formation composed by marine conglomerates. The transgression began in earliest middle Miocene at Blow's N8 Zone. The overlying shallow marine deposits



1. Minaminagaoka - Katagai gas field
2. Kashiwazaki - Yoshii gas field
3. Higashiniigata gas field

Figure 1. Index map.

Table 1. The outline of geologic history in the late Cenozoic of the paleo-Sea of Japan.

Age		Division of Geologic History		Sado Island	Niigata oil-field
Quaternary		MARGINAL SEA II	PRESENT MARGINAL SEA AGE		
				Katsuta F.	Uonuma F. Hz F.
Pliocene		MARGINAL SEA II	PRESENT MARGINAL SEA AGE	Kawauchi F.	Si F. Nishiyama F.
Miocene	Late	MARGINAL SEA I	Uplift and subsidence of sea floor Uplift of Japanese Islands		Shiiba F.
	Middle		DEEP SEA AGE	Nakayama F.	Teradomari F.
			DEEPENING and WIDENING SEA AGE	Tsurushi F.	Nanatani F.
			GREAT TRANSGRESSION AGE <i>Birth of Marginal Sea</i>	Orito F.	Tsugawa F.
	Early		CONTINENTAL MARGIN AGE	Aikawa G.	Mikawa F.

Hz F.: Haizume Formation; Si F.: Shirowaa Formation

contain many kinds of marine fossils such as the large foraminifers *Operculina* and *Myogipsina*, and molluscan fossils named the Kadonosawa fauna (Kobayashi and Ueda, 1991). This transgression during early middle Miocene is widely known in the Japanese Island. Fractured early Miocene pyroclastic rocks in Sado Island suggest that there was a large crustal movement related to rifting under a tensional stress field before the transgression with warm currents.



Figure 2. Unconformity between the underlying Aikawa Group and the overlying Orito Formation. A white arrow points the position of unconformity.

LATEST MIOCENE / EARLY PLIOCENE EVENT

On Sado Island and in the marginal area of the Niigata oil-field region, there is a large unconformity between late Miocene and early Pliocene strata, or early Pliocene and late Pliocene strata. Many localities of unconformity during early Pliocene are known (Kobayashi and Tateishi, 1992). They are especially distributed in the marginal area of the Niigata oil-field region and Sado Inland. The unconformity is a clino-unconformity, sometimes with basal conglomerates. In contrast, in the center of the basin, Miocene marine strata were conformably covered by early Pliocene strata without unconformity. All strata are composed of diatomite or diatomaceous mudstone of a deep sea origin. The late Miocene sedimentary basin was deeper than the Pliocene basin according to microfossil data (Kobayashi and Tateishi, 1992). There was a land area along the backbone region of Honshu during Pliocene. The plane of unconformity is not clear in some outcrops, but it is sometimes recognized by diatom analysis (Kobayashi and Watanabe, 1985; Hiramatsu and Miwa, 1998). Diatom zones of Miocene strata are continuously found from the *Denticulopsis hyalina* zone to the *Neodenticula kamschatrica* zone in Sado Island (Akiba, 1987; Nakahara *et al.*, 1987). The overlying Pliocene strata yield species derived from the underlying Miocene strata. It is thought that the unconformities were formed at sea bottom, judging from the condition of strata. The overlying Pliocene basal beds distributed along the marginal

area of the Pliocene Niigata sedimentary basin consist of basal conglomerate which are composed of poorly sorted boulder to pebble gravels and sands derived from the Miocene strata. Thick marine sandy siltstone and mudstone beds conformably accumulated on the basal conglomerate beds. They are marine beds with diatoms, planktonic and benthic foraminifers, and molluscs (Kobayashi and Watanabe, 1987; Akimoto *et al.*, 1998). Diatom fossils indicate the *Neodenticula kamtschatica* zone to *Neodenticula koizumii* zone, and planktonic foraminifers indicate the *Neoglobobadrina pachyderma* (dextral) / the *Globorotalia orientalis* zone (Maiya, 1978). The No.3 *Globorotalia inflata* bed, indicating an age of 3.6 Ma - 2.6 Ma, is detected from these deep marine mudstone strata. This bed indicates an influx of warm currents into the Sea of Japan. These results indicate a regression and transgression event. Moreover, a seismic profile (Figure 3), crossing the northern area of Pliocene sedimentary basin in the Niigata oil-field region shows that the underlying strata, mainly Miocene strata, are covered by the overlying strata with erosional truncation (Takano, 1998). Overlying muddy sediments accumulated with onlaps in a deep-sea environment with warm-water planktonic foraminifers such as *Globorotalia inflata*. The evidence indicates one large scaled regression and transgression event during the latest late Miocene and early Pliocene times. It is recognized that the early Pliocene transgression occurred widely in the Paleo-Sea of Japan (Kobayashi and Tateishi, 1992).

LATE PLIOCENE TO EARLY PLEISTOCENE TRANSGRESSION AND REGRESSION

The latest Pliocene to early Pleistocene sediments, the Uonuma Formation and its correlative strata, are widely distributed in the Niigata District (Uonuma Hills Collaborative Research Group, 1983). They consist of shallow marine facies, coastal facies and terrestrial-fluvial facies, indicating shallow marine to coastal plain depositional systems. The total thickness of the Uonuma Formation is more than 2,000 m. It is thought that a great subsidence occurred mainly during early Pleistocene in the Niigata District. Beds of the Uonuma Formation mostly show alternating and laterally changing facies from terrestrial to shallow marine beds. Marine mud beds of inner bay facies are inserted at more than fifteen horizons shown in Figure 4 (Kobayashi *et al.*, 1986; Kazaoka *et al.*, 1986; Kazaoka, 1988). They sometimes yield fossils of the continental coast molluscan fauna which is composed of warm-water and shallow marine to tidal flat species (Uonuma Hills Collaborative Research Group, 1983). One of marine bed is shown in Figure 5 (Research Group for Depositional Environments of the Uonuma Formation, 1996). Beds in this exposure consist of shallow marine to terrestrial facies in one sequence. The sequence consists of fluvial gravel deposits, lagoonal poorly sorted silt deposits, thick massive mud deposits with poorly sorted basal conglomerate, alternating beds of silt and very fine sand, coarse sand and

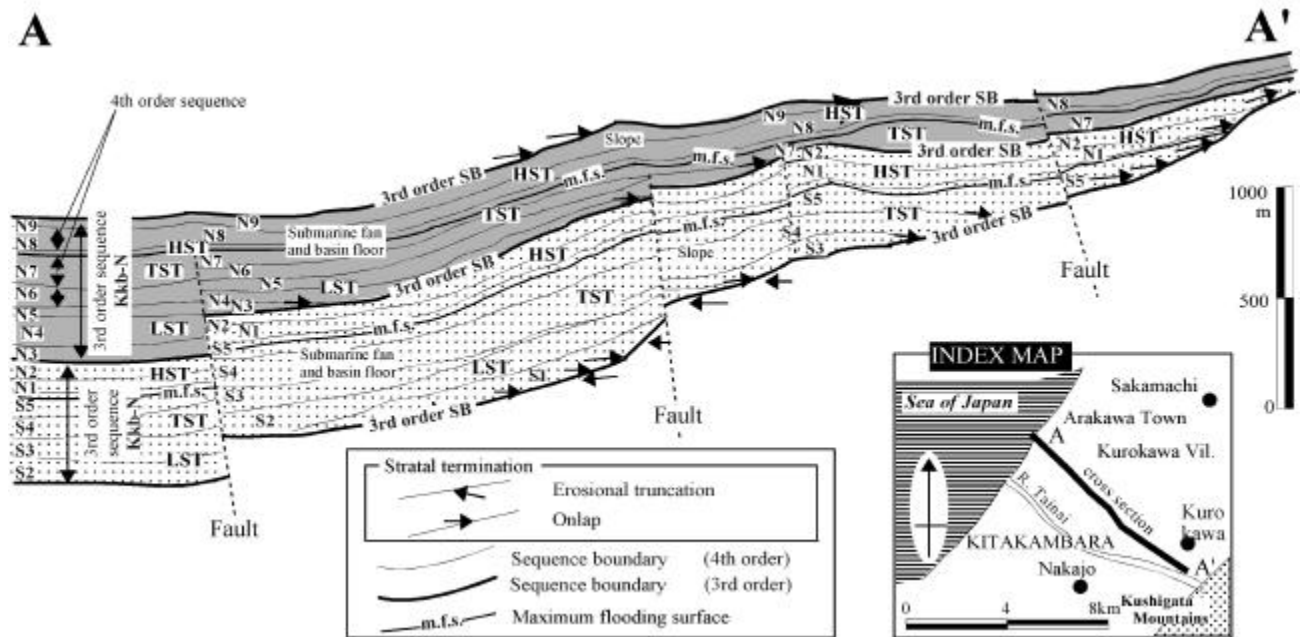


Figure 3. Interpreted cross-section of seismic data in Kita-Kanbara area (Takano, 1998). The sequence stratigraphic division was determined using reflection termination patterns such as onlap and erosional truncation on the seismic section, well-log patterns, occurrence patterns of foraminifers, and lithologic data from cuttings and cores at wells on the seismic section. The methods of sequence determination were based on Mitchum *et al.* (1977) for reflection termination analysis, and Vail and Wornardt (1991) for well log and foraminifer analyses. The terminology of sequence stratigraphy used in this study is after Posamentier *et al.* (1988) and Van Wagoner *et al.* (1988).

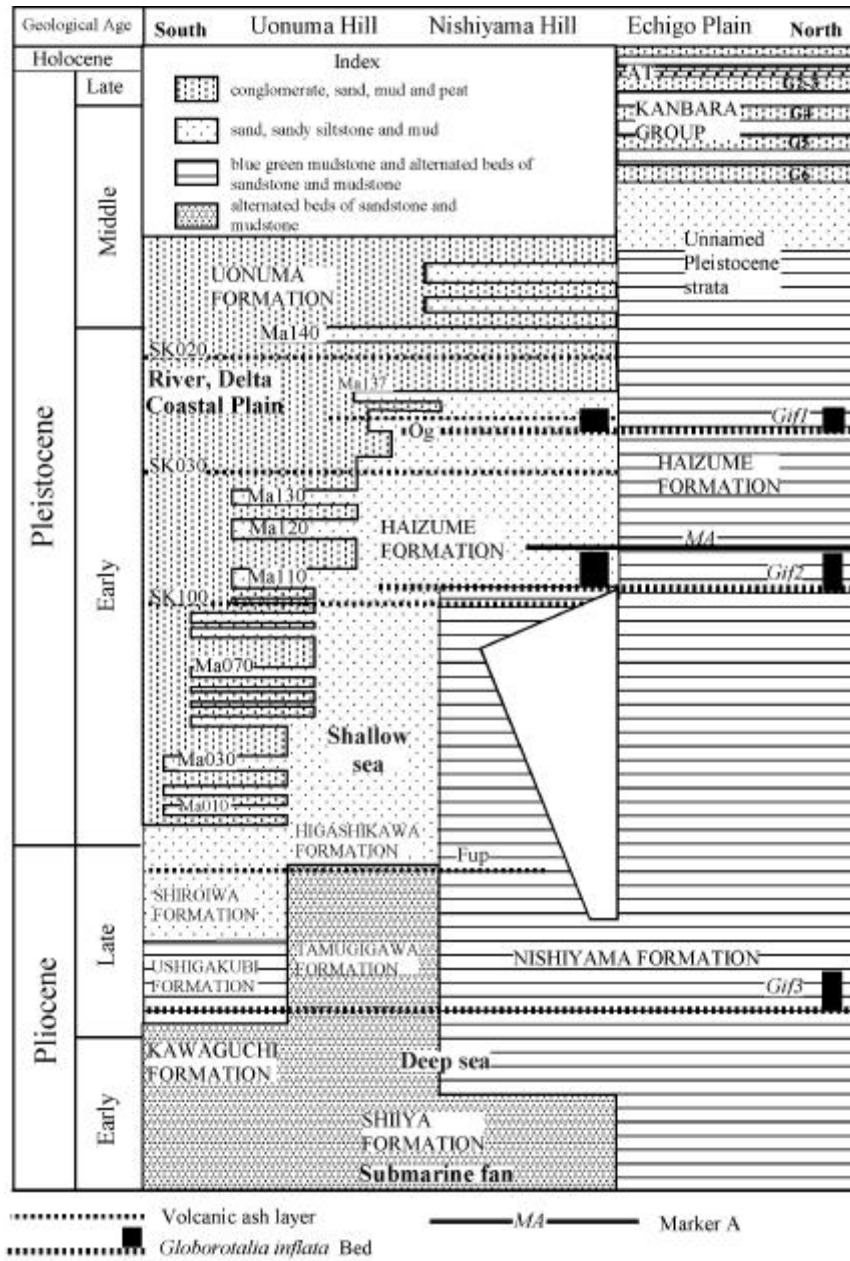


Figure 4. Transgressions and regressions recognized in the Uonuma Formation (Kobayashi, 1996).

cross-laminated sand deposits, and lagoonal massive silt in ascending order. A poorly sorted basal conglomerate bed (4A subunit) yields abundantly fresh-water diatoms such as fresh-water *Cymbella*, *Epithemia*, *Navicula*, *Pinnularia* and *Synedra* with some brackish-water species. And also, a silty mud bed (4B) yield bivalvian *Barnea dilatata*, *Anadara subcrenata*, *Macome tokyoensis*, *Raeta rostralis*, *Fulvia mutica* which lived on and in mud and sandy mud bottom sediments of upper shallow sea in an inner bay. They indicate one cycle from transgressive shallow marine to regressive fluvial facies. More than fifteen marine beds were found in the

Uonuma Formation and named from Ma010 to Ma015. Most of them were formed under continuous crustal subsidence with climatic sea-level changes (Kobayashi *et al.*, 1986; Urabe *et al.*, 1995). The records of sea-level change in the early Pleistocene Omma Formation were recognized on the basis of rock facies and molluscan fossils (Kitamura and Kondo, 1990). The other record is in the late Pliocene Tsunozu Formation of the Sanin district. Most of these records may be correlated to the marine beds of the Uonuma Formation. Since late Pliocene, the formation of strata in shallow marine and coastal areas has strongly been affected by global

climatic sea-level changes with continuous subsidence in the Sea of Japan.

MIDDLE TO LATE PLEISTOCENE TRANSGRESSIONS AND REGRESSIONS

Under the Niigata plain, there are thick middle to late Pleistocene sediments, named the Kanbara Group (Makiyama, 1963). They are composed of alternating beds of thick fluvial or deltaic conglomerates and shallow marine muds. Makiyama (1963) pointed out an

unconformity at the base of conglomerates strata bearing the G5 gas bed (Figure 6). Industrial water-resolved natural gases are included in these conglomerate beds. Mud strata with warm-water faunal fossils were deposited at the transgressive time, while conglomerate strata were at the regressive time. Figure 6 shows the stratigraphy of the Kanbara Group (Makiyama, 1963) distributed under Niigata City. The total thickness of the group is 500 m to 700m (Kobayashi, 1996). The age of this group may be from middle to late Pleistocene times. There are natural gas reservoirs named G1 to G5 gas beds in Kanbara Group. The G6 gas bed belongs to the

UNIT / SUBUNIT	THICKNESS	SECTION	LITHOLOGY	INTERPRETATION
9	60 (m)		Conglomerate Massive pebbly sand	Fluvial
8			Massive Silt	Lagoon
7	50		Cross Laminated Sand Conglomerate	Foreshore Upper Shoreface
6			Massive Silt	Lagoon
5	40		Cross Laminated Sand Conglomerate	Foreshore Upper Shoreface
4D			HCS Sand	Bay
			Sand/silt Alternation	
4C			Laminated Silt	
4B	30		Barnea Bearing Silt	
4A			Sandy Silt Poorly Sorted Cgl.	
3	20		Poorly Sorted Silt	Lagoon
2	10		Current Ripple Cross Laminated Sand	Fluvial
1B			Sand/silt Alternation	Backshore
			Bioturbated Silt	
1A	0		Cross Laminated Sand Massive Silt	Foreshore

Figure 5. One sequence of marine to terrestrial facies in the Uonuma Formation (Research Group for Depositional Environments of the Uonuma Formation, 1996).

underlying strata. They consist of sand and gravel with ground water. The water is salty, probably originated from ancient seawater. The volume of salt component gradually increases according to depth. The mud strata yield shallow marine molluscan fossils such as *Olivella japonica*, *Ringicula doliaris*, *Fulvia mutica*, *Nitidotellina nitidulla* and *Placamen tiara* (Kobayashi and Matsuda, 1991). The gravel and sand strata containing natural gas do not yield any fossil. It is thought that the mud strata are a shallow marine or an inner bay facies, on the other hand, the gravel and sand strata are deltaic and fluvial plain facies. These strata were accumulated under the condition of continuous subsidence in the Niigata sedimentary basin. Large-scale alternating beds of gravel and sand, and mud indicate several times of transgression and regression phenomena. These thick alternating beds were formed under the condition of climatic sea-level

change and crustal subsiding during middle and late Pleistocene times.

HOLOCENE TRANSGRESSION

This global transgression occurred after the last glacial age. The record is well preserved in deposits underlying all Japanese coastal plains. The sediments in the Echigo Plain are very thick, more than 150 m in thickness (Minato *et al.*, 1967). They overlie the last glacial age deposits with parallel and clino-unconformities and are composed of deltaic and coastal facies, shallow inlet facies, brackish lagoonal facies, and marsh and fluvial facies upwards (Niigata Diatom Research Group, 1976; Kobayashi, 1996). The unconformity was formed when the alluvial deposition started at late glacial and

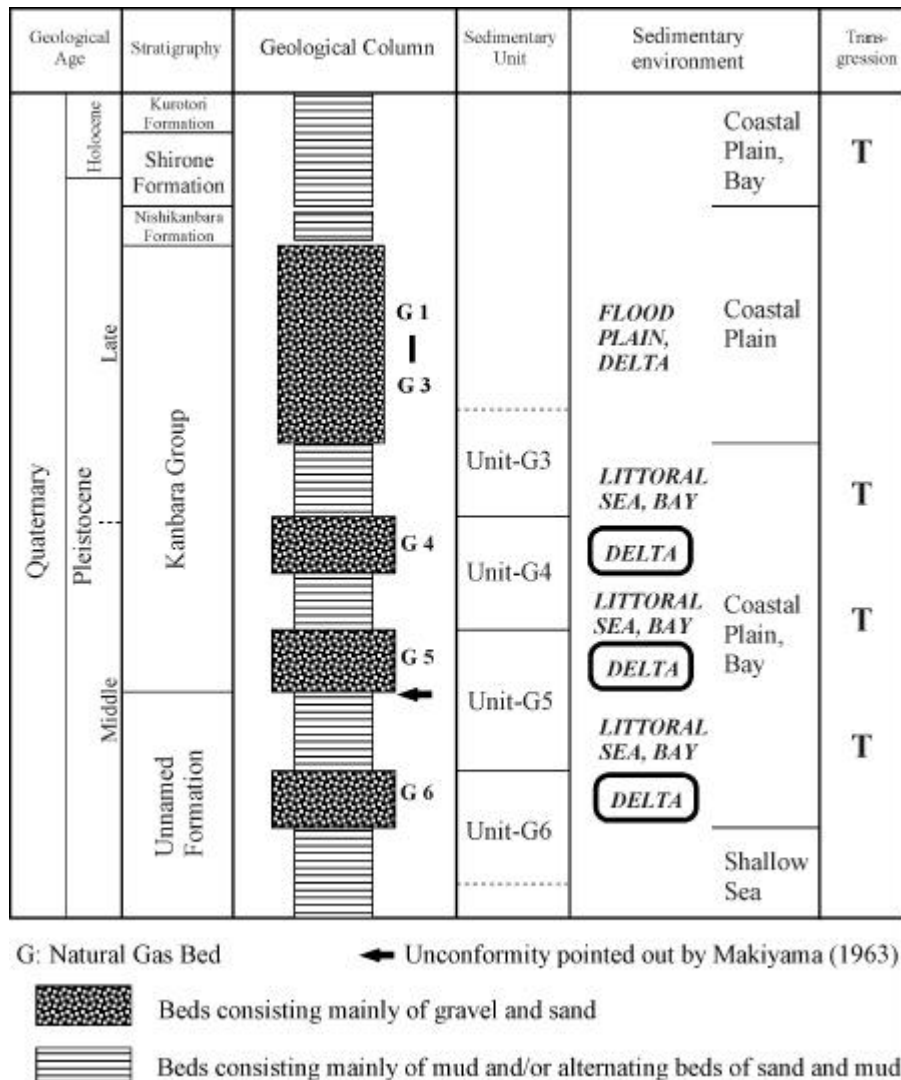


Figure 6. Alternating beds of the Kanbara Group related to climatic sea-level change (Kobayashi, 1996).

postglacial substages. Generally, the latest Pleistocene and lower Holocene beds are composed of gravel and alternating beds of sand and mud with fresh-water to brackish-water diatom fossils. They indicate the commencement of transgression. The overlying beds consist of soft marine clay and silty mud with several kinds of marine animal and plant fossils. They indicate transgressive facies. According to Yasui *et al.* (2000), the marine transgression occurred 9,000 to 8,000 years ago in Echigo Plain. The appearance of lagoonal environment with sand barriers may have taken place about 7,000 years ago. The time with the highest sea level was inferred 6,500 to 6,000 years ago. After that, numerous sand dune rows nearly parallel to the recent coastline were well developed towards the seaside (Niigata Ancient Dune Research Group, 1974). And also, the coastal flooding plain gradually was expanding over the lagoon area which was gradually diminished. This transgression was the result of the latest climatic sea-level change (Nguyen *et al.*, 1999; Yasui *et al.*, 2000).

CONCLUSIONS

The marginal sea, the Paleo-Sea of Japan, has existed since the latest early Miocene. The main phenomena of transgression and regression in the shallow marine beds of late Cenozoic Niigata sedimentary basin were found in the field as follows. 1) The great transgression during early/middle Miocene time: this event was recorded not only in the Niigata District, but also around the Paleo-Sea of Japan, and may be global. 2) Regression and transgression occurred during upper Miocene to early Pliocene times: this event is also seen in the Hokuriku District. 3) Small and large-scaled regressions and transgressions has occurred since late Pliocene time mainly due to the glacio-eustatic sea-level changes: these events are recorded in the Sanin and Hokuriku Districts, probably in the Tohoku District as well. Especially, these events are very well recorded in Pliocene to Quaternary strata distributed in the coastal and shallow sea areas of the Paleo-Sea of Japan.

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