新潟背弧堆積盆地のシーケンス層序学的堆積相モデル：特に第4オーダー堆積シーケンスについて

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Sequence stratigraphic facies models in the back-arc Niigata Sedimentary Basin, Central Japan, with special reference to the fourth-order depositional sequences.
Sequence stratigraphic facies models in the back-arc Niigata Sedimentary Basin, Central Japan, with special reference to the fourth-order depositional sequences

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ABSTRACT

A relatively universal facies model cannot only act as a standard of evaluation and comparison for new geologic information, a guide and framework for future observations, and a basis of logical predictions under unknown or new geological situations, but also support comprehensive understandings of relationship between basin-fill processes and their geologic controlling factors. This study is intended to construct such facies models for active margin sedimentary basins in the Niigata Sedimentary Basin as a Japanese representative back-arc sedimentary basin with introduction of the concept of sequence stratigraphy which is widely diffused in the world in recent years.

In the Niigata Sedimentary Basin, which was filled mainly by the Neogene and Quaternary clastic sediments, petroleum geological information was piled up by the petroleum exploration during the last several tens years. Based on the interpretation of this information by the concepts and methods of sequence stratigraphy, it was clarified that the hierarchial cyclicities were encountered within the sediments by which the Niigata Sedimentary Basin was filled. This suggests that the depositional processes in the Niigata Sedimentary Basin, which were previously interpreted to be controlled mainly by the sediment influx and subsidence, are actually controlled also by eustatic cycles. The hierarchial cyclicities were compiled as a sequence stratigraphic framework of the Niigata Sedimentary Basin. On the basis of the sequence stratigraphic framework, the stratigraphic correlations and the morphological characteristics of the systems tracts are studied, and then the component depositional systems of the systems tracts are estimated. Moreover, the sequence stratigraphic facies models of the progradational fourth-order depositional sequences are constructed as a result of the interpretation of the building sedimentary facies of the depositional systems on the basis of the wireline logs and the cuttings records of the exploratory wells. Those facies models indicate that the deposits of the final filling stage of the Niigata Sedimentary Basin consist of a third-order highstand delta complex, and that the delta complex are formed by the fourth-order cycles of the prograding coast depositional systems such as forced-regressive strandplain systems, braidplain delta systems, filled-estuary systems and fluvial-dominated delta systems. Those models may provide an example of allocyclic formational
process of a delta and hierarchial sedimentary processes of a delta.

The method for the construction of the facies models are standing on the combination of the concept of depositional sequences and the concepts of depositional systems and sedimentary facies which were independently proposed. This method can utilize the petroleum geological information at its maximum, and can be applied to the other type of sedimentary basins to study facies models. Furthermore, the application of such facies models leads the improvement of predictabilities for unknown reservoir distributions, and the establishment of facies models with high universal validity may be supported by the stockpiling of such examples of the applications.
I. INTRODUCTION

To generalize sedimentary facies distribution, depositional patterns and depositional mechanisms as *facies models* is one of the most significant tools for studying natures of clastic deposits and their depositional settings. Because a depositional model with high universal validity provides i) a standard of evaluation and comparison for new geologic information, ii) a guide and framework for future observations, iii) logical predictions under unknown or new geological situations, and iv) comprehensive understandings of relationship between basin-fill processes and their geologic controlling factors (Walker, 1992). Universal facies models can be constructed by elimination of "local irregularities" and by selection of general characteristics within a number of individual examples. Walker (1992) called this process "distillation." The "distillation" of local examples and its repetitive feedback may produce a generalized facies model with universal validity from less universal particular facies models.

From a point of view of petroleum geology, the demands for facies models are increasing in recent years for the following two reasons. Firstly, as un-explored concessions or sparsely explored areas are decreased recently, a major trend for play-types of petroleum exploration is being shifted from simple structural traps such as anticline or horst structures to stratigraphic traps depending upon thinning-out of reservoirs toward updip onto structures. In case of the exploration for the stratigraphic traps, the more accurate prediction of the reservoir distributions are required besides the subsurface structures. Thus, the facies model will be applied to a minimum geological database for a certain area to predict detailed distributions of reservoirs logically with high precision. Secondly, facies models are occasionally applied to understand three-dimensional distribution of reservoir characteristics especially in oil and gas fields within a development stage. Because authigenic non-homogeneity of reservoir properties is considered to be controlled by sedimentary environments, the application of an appropriate facies model will make it possible to predict three-dimensional distributions of reservoirs with potential properties.

Lastly, with rapid diffusion of sequence stratigraphy in the world a number of facies models is proposed on the basis of sequence stratigraphic framework. In the sequence stratigraphic
concept, *depositional sequences* (Mitchum et al., 1977b) are treated as fundamental stratigraphic units, which are created with response to relative sea-level cycles (Vail, 1987; Posamentier et al., 1988).

Because relative sea-level cycles are given as the sum of eustatic cycles and subsidence, morphological characteristics and building sedimentary facies distributions of depositional sequences must be controlled by certain rule related to relative sea-level movements, which may be the genetics of strata. In addition to relative sea-level cycles, controlling factors of sedimentation include changes in sediment influx (Galloway, 1989), transportation or redistribution of clastic material within a basin (Swift and Thorne, 1991) and others, and those additional factors affect the variability of stratal stacking patterns or sedimentary facies distributions, which are spatial-temporal distributions of *systems tracts* (Brown and Fisher, 1977) within the fundamental sequence stratigraphic framework controlled mainly by relative sea-level cycles.

The "Exxon model" (Vail, 1987; Posamentier et al., 1988), which is the precursor of sequence stratigraphic facies models, provides the interpretations systematically and genetically for the building sedimentary facies distribution of depositional sequences by using several important fundamental concepts for sequence stratigraphy. The direct prediction of the sedimentary facies distributions is difficult, in general, based on petroleum geological information such as seismic profiles, cuttings or wireline logs but cores (Arato and Takano, 1995). However, the application of the "Exxon model" as facies models against the result of seismic and well-log sequence analyses makes it possible to predict sedimentary facies distributions systematically and genetically, even though it is indirect. Because of the powerfulness and convenience of the sequence stratigraphy in petroleum exploration, the "Exxon model" is propagated rapidly while the sequence stratigraphic concepts were widely accepted in the world, and is tested its applicability to the various types of the sedimentary basin in the world. However, this model was constructed originally on the presumptions that i) the subject basins subside inclinedly basinward with gentle and stable rates, ii) the hinge points are located within subaerial exposed areas, iii) geomorphologic features such as shelf, slope and basin floor are identified clearly and easily, and iv) the sediment influx is approximately constant (Posamentier et al., 1988). The "Exxon model," therefore, is the conceptual facies models extracted from a number of examples.
in passive margin basins by "distillation," and might not be applied to other types of basins characterized by different scale, rate of subsidence, sediment influx, or tectonic controls from those of passive margin basins without any careful tests or checks.

Recently, facies models for foredeep basins (Embry, 1988; Nummedal, 1992; Posamentier and Allen, 1993; etc.) and for rift basins (Nummedal, 1994; Howell et al., 1994; etc.) are newly proposed as the models which are equivalent to the "Exxon model" for passive margin basins.

Within the such worldwide tendencies for the sequence stratigraphical researches, this study deals with the Niigata Sedimentary Basin (Figs. 1 and 2) as a Japanese representative back-arc sedimentary basin. The characteristics and distributions of sedimentary facies in the Upper Cenozoic succession (Fig. 4) are analyzed on the basis of petroleum geological data in the Kanbara area (Fig. 3) occupying the central part of the Niigata Sedimentary Basin, and facies distributions in each depositional sequence are tried to be identified in a back-arc sedimentary basin in this study. Furthermore, the first step of "distillation" was carried out against to the "progradational fourth-order depositional sequences" (Arato and Hoyanagi, 1995) using the sequence stratigraphic framework interpreted formerly (Arato et al., 1994a; Arato et al., 1994b; Arato and Hoyanagi, 1995). And then, the formation mechanisms of the progradational 4th-order depositional sequences and their depositional patterns of the final stage of the back-arc sedimentary basin fill will be discussed on the basis of the extracted features for facies distributions, and the applicable facies models to the Niigata sedimentary basins will be proposed.

The depositional sequence for which the facies models are proposed in this study is one of the three types of fourth-order depositional sequence observed in the Kanbara area: the fan-delta fourth-order depositional sequence, the retrogradational and aggradational fourth-order depositional sequence, and the progradational fourth-order depositional sequence (Arato and Hoyanagi, 1995). In other words, some other 4th-order depositional sequences consisting of the different depositional systems and their building sedimentary facies from those of the proposed models also exist in the Niigata Sedimentary Basin. Therefore, the accurate prediction of the facies distributions for the depositional sequences in the Niigata Sedimentary Basin must be impossible only based on the proposed facies models in this study. However, several facies models for the different types of depositional sequence will provide a next step of "distillation" for a new facies model with higher generalities in the Niigata Sedimentary Basin. Furthermore,
Fig. 1. Index map showing the locations of Japan-arcs, the Niigata Sedimentary Basin, and global tectonic settings around Japan.
NIIGATA SEDIMENTARY BASIN

- Southern part
- Northern part

Kanbara area (middle part: study area)

Fig. 2. Index map showing the locations of the Northern Fossa Magna Region, the Niigata Sedimentary Basin, the Kanbara area, and their bounding major tectonic lines.
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a model applicable to all the back-arc basin deposits might be extracted on the basis of comparison with facies models for the other back-arc sedimentary basins. A facies model with this status may be comparable to the "Exxon model" for the deposits in the passive margin basins.

In general, the construction of facies models based on the observation for surface outcrops is accomplished by an estimation of depositional systems from combinations of sedimentary facies seized by lithofacies and sedimentary structures of the strata, and then by a positioning them within a chronostratigraphic framework. However, this study stands on the different starting point from the above mentioned generalized method of sedimentary geology, because it employs mainly subsurface geological information acquired during petroleum exploration. This study starts from an identification of geomorphological characteristics for the chronostratigraphically contemporaneous packages, goes through a subdivision of the depositional sequences and systems tracts into component depositional systems, and reaches an estimation of building sedimentary facies of the depositional systems on the basis of well-geologic information eventually. In other words, the subsurface method aims at the construction of the facies models on the basis of the chronostratigraphic units and investigates the distributions of the subject sedimentary facies by a result of sedimentary basin analyses. In contrast to this, the surface outcrop method based on descriptions of lithostratigraphic units researches the development processes and filling mechanisms of sedimentary basins. Therefore, even the objectives are common for both methods, the starting point and the paths of the researches must vary depending upon a type of employing data.

The differences of employing data is reflected not only to the method of the research but also to the resolution of proposed facies models. For instance in this study based mainly on the seismic profiles and well-geologic information, the three dimensional morphological characteristics of the strata are understood successfully basin-wide at several thousands of meters below the surface, however, it is not possible to discuss directly the detailed stratigraphic correlations beyond the resolution of seismic records which is said approximately several tens meters in minimum, and the sedimentary facies beyond the resolution of wireline logs which is approximately several meters in minimum. Therefore, the resolution of the facies models proposed in this study must be improved by the repetitive verifications based on the sedimentary geological analysis for the cores and high-resolution wireline logs and on the detailed sedimentological
observations for the surface outcrops.

From the point of view of petroleum exploration, the facies models for the progradational fourth-order depositional sequence in this study should be tried to apply to depositional sequences in sedimentary basins with similar geologic settings. Such an effort of a case study for the improvement of resolution and universality of the models must lead a discovery of general rule for basin-filling and an excavation of new exploration plays for development of oil and gas fields.
II. METHOD AND DATABASE

1. Method of study

The Kanbara plain area (Figs. 1 and 2) was selected as the study area because it satisfy the following condition:

(1) Long seismic profiles have been recorded systematically with favorable quality in recent years.

(2) Many exploratory wells, having the basic wireline logs such as gamma-ray log, spontaneous-potential log and resistivity log with cuttings records at least, were drilled on or nearby the above mentioned seismic lines.

(3) There was less tectonic disturbance encountered after Late Miocene time.

The author demarcated the procedure of the study into the following six stages to discuss the depositional processes of the final stage in the Niigata Sedimentary Basin and to construct the facies models for the progradational fourth-order depositional sequences on the basis of petroleum geological information in the Kanbara area.

The sequence stratigraphic subdivision of the clastic deposits in the Kanbara area and its related filling processes of the basin were clarified as the first step of this study (Arato et al., 1994b). The sequence stratigraphic framework was illuminated with reference to the procedure of the sequence analysis (Vail and Mitchum, 1977; Vail, 1987) proposed by Vail et al. (1991), that is, the detection of stratal termination patterns, consecutive designation of discontinuities on the seismic profiles, and subdivision of depositional sequences (Mitchum et al., 1977; Van Wagoner et al., 1987) or systems tracts (Brown and Fisher, 1977; Van Wagoner et al., 1987) by the bounding discontinuities on the top and base. Then stratal stacking patterns within the depositional sequences and systems tracts were analyzed on the basis of the seismic profiles and well-geologic information, and then the filling history of the basin was discussed (see Chapter IV-1: Arato et al., 1994b).

As the second step of this study, the classification of the depositional sequences was carried out, and then the sequence stratigraphic framework of the Niigata Sedimentary Basin was demonstrated (Arato et al., 1994b; Arato and Hoyaaagi, 1995). The depositional sequences
in the subject study area were classified into three types based on the association of the systems tracts and their stacking pattern within the depositional sequences and on the stratal stacking patterns within the systems tracts. The results of the classification for the depositional sequences were explained genetically by the application of the concept of "matrix trend" (Arato and Hoyanagi, 1995), and then sequence stratigraphic framework was constructed (see Chapter IV-1).

The first and second steps of the study were already published by Arato et al. (1994b) and Arato and Hoyanagi (1995), respectively.

As the third step of this study, the chronostratigraphic positions are clarified for the depositional sequences distributed in the subsurface of the Kanbara plain, and they are correlated stratigraphically to the Uonuma Group and its correlative strata cropping out in the Higashikubiki-Uonuma area on the south of the Kanbara area based on the applications of the stratigraphic relationship uncovered by Sato et al. (1987) (see Chapter V-1).

Calcareous nannofossil datums of Plio-Pleistocene age in the Northwestern Atlantic ODP cores (Takayama and Sato, 1986) are adopted as a reference scale for this study.

As the fourth step of this study, the morphological characteristics (external forms, stratal termination patterns, and stratal stacking patterns) of the systems tracts were described on the seismic profiles (see Chapter IV-2), and then the component depositional systems of the systems tracts were interpreted on the basis of the descriptions of the morphological characteristics (see Chapter V-3). Systems tracts show individual morphological features depending upon depositional settings, so the morphological characteristics were described by every geomorphological division. Furthermore, the sedimentary facies building the depositional systems were interpreted on the basis of the estimated lithofacies by the wireline logs and the cuttings records and of the stratal stacking patterns (see Chapters IV-3 and V-4).

Then as the fifth step of this study, a benthic foraminiferal standard was designed for the paleo-bathymetric analysis of the Kanbara area, and the temporal-spatial distributions of the paleo-environments since the Pleistocene were discussed with the application of the standard to the benthic foraminiferal faunal assemblages occurred in the exploratory wells in the Kanbara area (Arato and Kudo, in preparation: see Chapters IV-4 and V-2). The high-resolution sequence stratigraphic framework constructed in the first and second steps and the detailed sequence
stratigraphic correlations discussed in the third step were both accepted as the chronostratigraphic controls for the paleo-environmental discussions.

As the final step of this study, the facies models for the progradational fourth-order depositional sequences in the final filling stage of the Niigata Sedimentary Basin were constructed on the basis of the sedimentary facies distributions within the individual depositional systems (see Chapter V-5). In general, a depositional sequence can be subdivided into plural systems tracts by the bounding discontinuities at their bases and tops, which are composed of the individual sedimentary facies and stratal stacking patterns (Van Wagoner et al., 1988; Posamentier et al., 1988). Because a systems tract is defined as "a linkage of the contemporaneous depositional systems" (Brown and Fisher, 1977), it can be subdivided into horizontally adjoining plural depositional systems. A depositional system is defined as "the three-dimensional association of genetically related sedimentary facies" (Fisher and McGowen, 1967), such as the examples of fluvial systems or deltaic systems. As the final step of this study, the component depositional systems of the systems tracts were interpreted by the combination of the distributional and morphological features clarified by the descriptions in the fourth step and the paleo-environments estimated from the benthic foraminiferal faunal assemblages elucidated in the fifth step of this study. Then the building sedimentary facies of the depositional systems are estimated from the wireline log responses and the cuttings records, and the facies models for the progradational fourth-order depositional sequences were constructed under the discussions of their formation mechanisms and the depositional patterns.
2. Database

Though the clastic deposits filling the Niigata Sedimentary Basin cannot be observed on the surface outcrops because the elevation is approximately less than ten meters and there are few outcrops in the Kanbara area, three-dimensional stratigraphic and sedimentological studies are available on the basis of the subsurface geological information such as the seismic profiles and well-geologic data acquired with petroleum exploration. In the Kanbara area, the systematic seismic records were acquired with slightly irregular grids in approximately 2 to 5 kilometers (Fig. 3). Those seismic profiles were recorded in 1983 to 1985, and reprocessed in 1991 and 1992 by Teikoku Oil Co., Ltd. Those seismic lines, which have enough length and relatively favorable quality, cover the widespread plain area through the northern region of Niigata City to around Nagaoka City with the 30 east-west and 18 north-south trended lines, total 48 lines which have the total length of 678.08 kilometers. For the sequence stratigraphic interpretation such as the subdivision of stratigraphic units, the construction of the sequence stratigraphic framework, identification of the depositional sequences, and subdivision of the systems tracts and depositional systems, the five north-south trended lines (83024N, 84022, 84036, 84018 and 84016) and the six east-west trended lines (83020, 84010, 85063, 83021, 83023, 83025/84025B) were used associated with the wireline logs, cuttings records, a result of the biostratigraphic and paleontological analyses and sedimentological core analysis of 16 exploratory wells drilled by Teikoku Oil Co., Ltd. and Japan Petroleum Exploration Co., Ltd. and the Ministry of International Trade and Industry (MITI) since 1956 (Table 1). Some old seismic record sections with relatively poor quality were also used as the support information.

For paleo-environmental analysis by the benthic foraminiferal faunal assemblages, the exploratory wells satisfying the following conditions were selected and used:
(1) The wells might have been drilled on or near the seismic lines used for the seismic sequence analysis (Fig. 3).
(2) The wells must have a minimum logging data such as a gamma ray log, a spontaneous potential log, a resistivity log, and cuttings records at least.
(3) The wells must have a result of paleontological analysis with the modern methods.
| well code | well name      | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 | 無言地 |
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The following fourteen exploratory wells are selected: MITI "Shimoigarashi," MITI "Masugata," MITI "Niigata-heiya," Shinminamiaga-1, Ogikawa-1, Nishiakatsuka-1, Kitashirone TS-1, Shoze-1, Masugata-1, Nakanokuchi SK-1, Kanbara GS-1, Yoroigata-1, Nishitsubame-1, and Takaki R-4 (Fig. 3; Table 1).

For the identification of the stratal stacking patterns and the sedimentary facies of the strata, the Akatsuka R-1 and Maigata R-1 wells are added to the above mentioned fourteen wells, having minimum logging information.
III. STUDY AREA AND GEOLOGICAL SETTING OF THE NIIGATA SEDIMENTARY BASIN

1. Tectonic setting and study area

The area, bounded by the Itoigawa-Shizuoka Tectonic Line (Editorial Committee of CHUBU I, 1988) at the western limit, by the Shibata-Koide Tectonic Line and the southern part of the Kashiwazaki-Choshi Line (Yamashita, 1970) at the eastern limit, and by the boundary of Nagano and Yamanashi Prefectures at the southern limit, is named the "Northern Fossa Magna Region" (Editorial Committee of CHUBU I, 1988). The Northern Fossa Magna Region is also called the Northern Fossa Magna Neogene-Quaternary Sedimentary Basin (Takano, 1995). The sedimentary basins in the Northern Fossa Magna Region had been formed by the rifting under the extensional conditions (Tateishi, 1988; Shiki and Tateishi, 1991) associated with the opening of the Japan Sea (Otofuji et al., 1985; Tamaki, 1988) since the early Middle Miocene (approximately 15 million years before present), and the area belonged to a part of the paleo-Japan Sea (Tateishi, 1989). Some tectonic barriers, such as the unsubsided basement blocks, the submarine volcanic bodies and boundary faults of the rifting, divided the Northern Fossa Magna Region into plural sedimentary basins since the initial stage of rifting (Suzuki, 1989a; Kimura et al., 1993; etc.).

The Niigata Sedimentary Basin is defined by its southwestern boundary as the northern part of the Kashiwazaki-Choshi Tectonic Line and by its southeastern boundary as the Shibata-Koide Tectonic Line (Fig. 2: Niigata Prefectural Government, 1982; Suzuki, 1989a, 1989b; etc.). This basin is approximately equivalent to the Niigata Oil and Gas Field area (Editorial Committee of CHUBU I, 1988) or the Hokuetsu District (Uemura, 1976). The Niigata Sedimentary Basin is subdivided into three subbasins; the northern part, the southern part, and the central part including the Kanbara area, based on their stratigraphical and sedimentary geological characteristics and the tectonic relationship with the surrounding areas. Those subbasins are characterized by narrow shelves, high gradient of slopes, and large bathymetries at the basin floor.

The Kanbara area as the objectives of this study, bounded the eastern border by the Niitsu
Hills and the western border by the Kakuda-Yahiko Mountains, spreads from the north of the Agano River to Nagaoka City. It has the east-west width of approximately twenty kilometers and the north-south length of approximately fifty kilometers, and occupies the central part of the Niigata Sedimentary Basin (Figs. 2 and 3).

The Niitsu Hills at the eastern border and the Kakuda-Yahiko Mountains at the western border of the Kanbara area and the Nishiyama-Chuo Oil Belt and Yoneyama area as their southern extension were uplifted and became land areas associated with deformations by folding and over-thrusting (Komatsu, 1990) under the east-west compressional stress field exerted in northeastern Japan since the Late Miocene time (Sato and Amano, 1991; etc.). As a result of this uplifting, the Kanbara and Higashikubiki-Uonuma areas remained as a bathyal ocean, making an embayment opened to the paleo-Japan Sea at its northern end (Kobayashi and Tateishi, 1992). Since then, the embayment had been filled up by marine and non-marine sediments, and changed into the subaerial depositional area with the fluvial floodplain, lagoonal and coastal dune deposits since approximately 20,000 year before present (Nakagawa, 1987). This study names the embayment left at the Kanbara area at the final stage of deposition of the Uonuma Group, the "paleo-Niigata sea." Thus, the deposits filling up the "paleo-Niigata sea" are called the "paleo-Niigata sea deposits," and the depositional time of the "paleo-Niigata sea deposits" as the "paleo-Niigata sea period," respectively. The "paleo-Niigata sea" was situated at the center of the Niigata Sedimentary Basin, being demarcated by the Kakuda-Yahiko Mountains, Nishiyama-Chuo oil field belt on its western border and by the Niitsu Hills and Higashiyama Mountains on its eastern border. It was located on the north of the depositional area of the Uonuma Group. The "paleo-Niigata sea" was connected with the paleo-Japan Sea at the northern limit initially. Then the "paleo-Niigata sea" was filled gradually by marine clastic sediments and was finally changed to a depositional area of non-marine sediments. The "paleo-Niigata sea deposits" nearly correspond to the uppermost third-order depositional sequence (Sequence F through N: Arato et al., 1994a) of the Niigata Sedimentary Basin (Arato, in preparation). The "paleo-Niigata sea period," therefore, almost represents the time span since the Middle Pleistocene time.
2. Stratigraphic setting

The Niigata Sedimentary Basin was filled by the Upper Neogene and Quaternary clastic sediments with more than five thousands meters in the maximum thickness (Fig. 4). The lower Middle Miocene mudstones of the Nanatani Formation, occupying the lowermost part of the clastic succession in this study area, overlies and interfingers in part the submarine volcanic rocks of the Nanatani stage, which erupted with the rifting of Japan Sea (Komatsu et al., 1983; Sato and Sato, 1992). It clarified that the Nanatani Formation in the Kanbara area and in the southern part of the Niigata Sedimentary Basin consisted of the bathyal deposits and pinched out northward (Kato et al., 1992). The mudstones of the Nanatani Formation and the volcanic rocks of the Nanatani stage are overlain by the Teradomari, Shiiya, Nishiyama Formations, and the Haizume Formation or its correlative Uonuma Group in ascending order. The Teradomari Formation consists mainly of the alternating beds of sandstones and mudstones deposited in abyssal to bathyal environments and partly intercalates tuffs and volcanioclastic beds. The Shiiya Formation is composed of the alternating beds of sandstones and mudstones of bathyal or submarine fan environments. The Nishiyama Formation consists largely of silty mudstones of submarine fans and slopes. The Uonuma Group and its correlative Haizume Formation are composed largely of conglomerates, sandstones, siltstones and mudstones deposited on shelf, nearshore or fluvial environment (Editorial Committee of CHUBU I, 1988; etc.). Therefore, the Upper Neogene and Quaternary clastic deposits filling the Niigata Sedimentary Basin show an upward-shallowing trend in general.
IV. RESULTS OF SEQUENCE STRATIGRAPHIC ANALYSIS

1. Sequence stratigraphic framework

Many reflection terminations, discontinuities and reflection stacking patterns are recognized within the Upper Neogene and Quaternary clastic deposits buried under the plain of the Kanbara area on the basis of seismic sequence analysis. As a result of those recognitions, a sequence stratigraphic framework with hierarchical structure was clarified as the following detailed reviews (Arata et al., 1994b; Arata and Hoyanagi, 1995). The stratigraphic position of the deposits is made clear based on the nannofossil and planktic foraminiferal datums in the well-geologic data (Japan National Oil Corporation, 1991).

1-1. Second-order tectonosequence

The Upper Neogene and Quaternary clastic deposits filling the Niigata Sedimentary Basin overlie the early Middle Miocene or older volcaniclastic rocks, which are so called "Green Tuff." Those volcaniclastic rocks are interpreted to be the products of subaqueous volcanic eruptions (Komatsu et al., 1983; Sato et al., 1984; Sato and Sato, 1992) associated with the massive tectonic subsidence during the formation of the Niigata Sedimentary Basin (Shuto and Chihara, 1987; Arata and Shuto, 1990; etc.). The "Green Tuff," therefore, can be considered as the strata deposited during a rising phase of relative sea-level related to the spreading of Japan Sea. The clastic deposits underlain by the "Green Tuff" form a large upward-coarsening succession in general. Even in the area where the Nanatani Formation and a large part of the Teradomari Formation are absent (Sato and Sato, 1992; etc.), the lowermost part of the clastic succession consists of the middle to lower bathyal deposits, and the upper strata consist of the shallower water deposits (e.g. Japan National Oil Corporation, 1991). Based on those facts, the early Middle Miocene and older volcaniclastics and their overlying clastic succession are interpreted as a transgressive systems tract formed during a rising phase of relative sea-level and a highstand systems tract formed during a highstand stable phase of relative sea-level, respectively. Because the younger volcanic rocks are distributed between the early Middle Miocene
volcaniclastics and their overlying clastic rocks in a part of the Kanbara area (Sato and Sato, 1992), the bottom surface of the clastic deposits are not necessarily contemporaneous, however, the top surface of the early Middle Miocene volcaniclastics at least are interpreted as a maximum flooding surface (Arato and Hoyanagi, 1995). The entire sediments of the Niigata Sedimentary Basin including the volcaniclastic strata had been deposited during approximately fifteen to twenty-three million years at least, and filled the sedimentary basin which had been formed under influence of the tectonics of the back-arc spreading. Therefore, the early Middle Miocene and older volcaniclastics and their overlying clastic deposits including some younger volcaniclastic rocks can be considered as a transgressive and a highstand systems tracts included within a tectonosequence (Vail et al., 1991) which was formed with correspondence to a second-order tectonic event (Arato and Hoyanagi, 1995; Figs. 5 and 6).

1-2. Third-order depositional sequences

The Upper Neogene and Quaternary clastic deposits, the highstand systems tract of the second-order tectonosequence, are subdivided into three cycles of third-order depositional sequences; Sequences A, B and C-N in ascending order (Figs. 5 and 6: Arato et al., 1994a). Depending upon the stratigraphic correlation based on the identifications of volcanic ash layers and datum plains for planktic foraminiferal and nannofossil zonations (Sato et al., 1987; Uonuma Hills Collaborative Research Group, 1983; Japan National Oil Corporation, 1991; etc.), the Sequences A and B are correlative to the Hachioji Formation (Yasui et al., 1983) and the Lowermost to Lower Formations of the Uonuma Group (Uonuma Hills Collaborative Research Group, 1983; Kazaoka, 1988) in the Higashikubiki-Uonuma area, respectively (Arato, in preparation). The Hachioji Formation consists mainly of the shelf muddy deposits, and the Uonuma Group consists of the fluvial to lacustrine deposits intercalating some inner sublittoral deposits. In contrast to this, the Sequences A and B in the Kanbara area are composed of the hemipelagic mudstones and the alternating beds of turbidite sandstones and mudstones (Arato et al., 1994a; 1994b; 1994c), and include the middle to lower bathyal benthic foraminiferal faunas (Japan National Oil Corporation, 1991). The lowstand systems tract of the Sequence C-N, consisting of the clastics deposited since approximately one million and four hundred thousand
Fig. 5. Sequence stratigraphic framework of the Kanbara area and hierarchy of the sequences (from Arato and Hovanagi, 1995; summarized after Arato et al., 1994a).
Fig. 6. Schematic diagram showing the relationship among depositional settings, 3rd-order depositional sequences and 4th-order sequence models (from Arata and Hoyanagi, 1995).
years before present (Arato et al., 1994b), is correlative to the Middle and Upper Formations of the Uonuma Group (Uonuma Hills Collaborative Research Group, 1983) in the Higashikubiki-Uonuma area. Furthermore, a part of the transgressive systems tract of the Sequence C-N can be correlated with the uppermost part of the Upper Formation in the Uonuma Group or the Usagidani Sands in the western flank of the Niitsu Hills (Arato, in preparation). However, the most part of the transgressive systems tract and the highstand systems tract or their correlative strata were not discovered at the surface outcrops yet, and they are not defined and named formally as lithostratigraphic units, except dealt as the "un-named Middle Pleistocene" by Kobayashi (1996).

1-3. Fourth-order depositional sequences

The Sequence C-N, the youngest third-order depositional sequence in the Kanbara area, is subdivided into twelve higher-order depositional sequences (Sequences C, D, E1, E2, F, G1, G2, H, J+K, L, M and N in ascending order) on the basis of the seismic sequence analysis (Arato et al., 1994b). In accordance with the geologic ages for the nannofossil datums recognized in the MITI "Niigata-heiya" well (Japan National Oil Corporation, 1991), those depositional sequences are all fourth-order depositional sequences with durations of approximately several tens thousand to four hundred thousand years (Figs. 7 and 8: Arato et al., 1994a, 1994b). Those fourth-order depositional sequences are classified into three types based on their morphological characteristics, distributions and stacking pattern, that is, Fan-delta depositional sequences (Fig. 9: the Sequences C, D, E1 and E2), Retrogradational and aggradational depositional sequences (Fig. 10: the Sequences F, G1, G2 and H), or Progradational depositional sequences (Fig. 11: the Sequences J+K, L, M and N). The respective types of the fourth-order depositional sequences are interpreted to compose the lowstand, transgressive and highstand systems tracts of a third-order depositional sequence by the introduction of a concept of "matrix trend" as will be described later in the Section IV-1-5 (Arato and Hoyanagi, 1995). The repetitions of the sand-dominated and mud-dominated alternating beds within the third-order Sequences A and B are also interpreted to correspond to fourth-order cycles (Arato et al., 1994b). This study deals with the four cycles of the progradational fourth-order depositional sequences, that is, the Sequences J+K, L, M and N (Fig. 12).
Fig. 7. Stratigraphic summary for the MITI "Niigata-heiya" well. After Arato et al. (1994a).
Fig. 8. The relationship between the rate of deposition and the sequences in the MITI "Niigata-heiya" well. The third-order Sequence A and B are characterized by approximately 50 cm/1,000 yr as their rate of deposition. In contrast to this, overlying fourth-order depositional sequences show faster deposition. (after Arato et al., 1994b).
Fig. 9. The diagrams for a fan-delta fourth-order depositional sequence showing a typical stratal stacking pattern and its systems tracts (A), a typical stratigraphic columnar section (B), and its fourth-order relative sea-level cycle (C) (Modified from Arato and Hoyanagi, 1995).
Fig. 10. The diagrams for a retrogradational and aggradational fourth-order depositional sequence showing a typical stratigraphic columnar stacking pattern and its systems tracts (A), typical stratigraphic columnar sections (B), and its fourth-order relative sea-level cycle (C) (Modified from Arato and Hoyanagi, 1995).
Fig. 11. The diagrams for a progradational fourth-order depositional sequence showing a typical stratigraphic stacking pattern and its systems tracts (A), a typical stratigraphic columnar section (B), and its fourth-order relative sea-level cycle (C) (Modified from Arato and Hoyanagi, 1995).
Sequences C, D, E1 and E2

Sequences F, G1, G2 and H

Sequences J+K, L, M and N

Fig. 12. Relative sea-level cycles and the three types of sequence model in the back-arc Niigata Sedimentary Basin (after Arata and Hoyanagi, 1995).
1.4. Systems tracts within progradational fourth-order depositional sequences

Every progradational fourth-order depositional sequence is subdivided into a **Regressive Progradational Wedge (RPW)**, a **Lowstand stable Progradational Wedge (LPW)**, a **Transgressive Aggradational Sheet (TAS)**, and a **Highstand stable Progradational Wedge (HPW)** systems tracts based on the internal morphological feature of the depositional sequences such as stratal termination patterns, discontinuities and stratal stacking patterns (Fig. 11: Arato and Hoyanagi, 1995). Arato and Hoyanagi (1995) calls the regressive progradational wedge systems tracts of the Sequences J+K, L and M as **Systems tracts Ja, La and Ma**, the lowstand stable progradational wedge systems tracts of those sequences as **Systems tracts Jb, Lb and Mb**, the transgressive aggradational sheet systems tracts as **Systems tracts Jc, Lc and Mc**, and the highstand progradational wedge systems as **Systems tracts K, Ld and Md**, respectively. Furthermore, they call the bounding discontinuities at the base of the Sequence J+K, L, M and N as **Discontinuities (dc) 11, 13, 14 and 15**, those of the Systems tracts Jb, Lb and Mb as **dc 11.1, 13.1 and 14.1**, those of the Systems tracts Jc, Lc and Mc as **dc 11.2, 13.2 and 14.2**, and those of the Systems tracts K, Ld and Md as **dc 12, 13.3 and 14.3**, respectively (Fig. 5, Table 2). The Sequence N was not subdivided into systems tracts and bounding discontinuities were not named because only the non-marine deposits are observed in the transgressive aggradational sheet or highstand stable progradational wedge systems tracts, even though this depositional sequence is widely distributed in this study area.

1.5. Concept of "matrix trend"

In general, a relative sea-level cycle at a certain location is believed to be a composite of several cycles characterized by individual frequency, amplitude and wave form. For instance, each fourth-order relative sea-level cycle in the Niigata Basin in the Late Neogene to Quaternary time is divisible into the following three elements: (1) fourth-order eustatic cycle, (2) fifth- or higher order eustatic cycles, and (3) a part of third- and lower order eustatic cycles and subsidence. Arato and Hoyanagi (1995) discussed the relationship between (1) and (3) for the simplicity.
Table 2. List for the depth of the discontinuities in the studied exploratory wells.
The curve (A) and (B) on the Fig. 13 represents the cycles of the group (1) and (3), respectively. Assuming that the influences of the cycle (2) can be negligible, the effective relative sea-level cycle (C) is assigned as the sum of the curves (A) and (B). Here, ① to ② on the curve (C) illustrate the wave forms of some representative fourth-order cycles on the actual relative sea-level curve. For instance, the fourth-order cycle ①, located upon the falling phase of the third-order relative sea-level cycle, is characterized by the lowering general trend of the sea-level movement with the right-side down curve-shape. On the contrary, the fourth-order cycle ③, situated on the rising phase of the third-order relative sea-level cycle, is characterized by the going-up general trend of the sea-level movement with the right-side up curve-shape. The fourth-order cycles ② and ④, on the other hand, located on the lowstand or highstand stable phase of the third-order relative sea-level cycle, show the almost original curve-shapes on the curve (A). Those relationships indicate that the actual curve-shapes of the fourth-order cycles are controlled by the third-order phases where the fourth-order cycles are located. Arato and Hoyanagi (1995) named the general trend of movement in the third-order phase, that is, the relative sea-level changes shown as the group (3) tentatively "matrix trend" for the cycles of the group (1).

The difference of the matrix trend in the fourth-order relative sea-level cycles brings the individual internal combinations of the relative sea-level phases. For example, the curves (1) to (5) on the Fig. 14 demonstrate the fourth-order relative sea-level cycles with the rapid-rising, gentle-rising, stillstand, gentle-falling and rapid-falling matrix trends, respectively. Here, the curve (3) consists of the falling, lowstand stable, rising and highstand stable phases with isometric time spans. In contrast to this, the curves (1) and (2) having the rising matrix trend are characterized by the longer rising phase, and the curves (4) and (5) with the falling matrix trend are characterized by the longer falling phase. Furthermore, the curves (1) and (5) do not include the falling phase and the rising phase respectively as the extreme cases. Those effects suggest that the difference of a matrix trend is displayed as a different phase assemblage of the cycles. Arato and Hoyanagi (1995) insisted that the difference in the assemblage of the phases for the fourth-order relative sea-level cycle caused by the different matrix trends produces the three types of the fourth-order depositional sequence with the individual combinations of the systems tracts in the Niigata Sedimentary Basin (Fig. 15).
Fig. 13. Schematic diagram showing the relationship between fourth-order cycles (A) and superimposed third-order phases (B). The curve (C) indicates effective movement as the sum of fourth- and third-order cycles. ①: fourth-order cycle on third-order falling phase, ②: fourth-order cycle on third-order lowstand stable phase, ③: fourth-order cycle on third-order rising phase, ④: fourth-order cycle on third-order highstand stable phase (from Arato and Hoyanagi, 1995).
Fig. 14. Phase variation diagram showing phase combination within 4th-order cycles superimposed by different 3rd-order phases. (1): The 4th-order cycle on 3rd-order rapid rising phase, (2): the 4th-order cycle on 3rd-order slow rising phase, (3): the 4th-order cycle on 3rd-order stillstand phase, (4): the 4th-order cycle on 3rd-order slow falling phase, and (5): the 4th-order cycle on 3rd-order rapid falling phase. The 4th-order cycle (1) consists mainly of rising and stillstand phases. In contrast to this, the 4th-order cycle (5) consists mainly of falling and stillstand phases. (from Arato and Hoyaanagi, 1995).
Fig. 15. Variations of 4th-order relative sea-level cycles and derived sequence models (from Arato and Hoyanagi, 1995).
1-6. Chronostratigraphic controls in the Kanbara area

The biostratigraphic analyses were carried out for the cuttings and sidewall core samples from the MITI "Niigata-heiya" well by Japan National Oil Corporation (1991), and the following biostratigraphic datums were identified.

(1) The planktic foraminifers *Globorotalia inflata* are abundantly recognized at 3,700 - 3,820 meters, 2,540 - 2,840 meters and 2,040 - 2,200 meters in drilling depth. Each of these depth intervals is interpreted to correspond to the No. 3, No. 2 and No. 1 *Globorotalia inflata* Bed (Kudo, 1967) in ascending order.

(2) The calcareous nannofossil datums, discovered by Takayama and Sato (1986), are recognized at the following depths: i) datums No. 11 (extinction of *Gephyrocapsa caribbeanica*) and No. 10 (extinction of *Calcidiscus macintyrei* and the first appearance of *Gephyrocapsa oceanica*) at 3,161 meters, ii) datum No. 9 (first appearance of *Gephyrocapsa* spp. (large form)) at 2,878 meters, iii) datum No. 8 (extinction of *Hellicosphaera sellii*) at 2,693 meters, iv) datum No. 7 (extinction of *Gephyrocapsa* spp. (large form)) at 2,442 meters, v) datum No. 6 (first appearance of *Gephyrocapsa paralela*) at 2,326 meters, and vi) datum No. 5 (top acme zone of *Reticulofenstra* sp.) at 2,227 meters.

The above mentioned biostratigraphic datums (Japan National Oil Corporation, 1991) show the following relationship with the sequence stratigraphic framework (Arato et al., 1994b; Fig. 16(D)).

(1) The No. 3 *Globorotalia inflata* Bed corresponds nearly to the bounding discontinuity between Sequences A and B.

(2) The No. 2 *Globorotalia inflata* Bed is correlated to Sequence C except for the uppermost and the lowermost parts.

(3) The No. 1 *Globorotalia inflata* Bed is recognized at the lowermost part of Sequence E1.

(4) The calcareous nannofossil datums No. 10 and 11 are included within the upper part of Sequence B.

(5) The calcareous nannofossil datum No. 9, which is included within the No. 2 *Globorotalia inflata* Bed, is recognized at the lower part of Sequence C.
Fig. 16. Stratigraphic correlation chart showing A: calcareous nannofossil datum planes and their geological ages in the ODP Leg 94 reference section of the northeastern Atlantic (Takayama and Sato, 1986), B: stratigraphic column comprising selected calcareous nannofossil datum planes, planktic foraminiferal zones, and volcanic ash key layers (SKs) on the Aida route in the Izumozaki Town (Sato et al., 1987), C: stratigraphic subdivisions of the Uonuma Group and their relationship to main volcanic ash key layers (SKs) (Kazama, 1988; Kobayashi et al., 1988; Urabe et al., 1995; etc.), and D: sequence stratigraphic subdivisions and their relationship to selected calcareous nannofossil datum planes and planktic foraminiferal zones (Japan National Oil Corporation, 1990; Arato et al., 1994a).
(6) The calcareous nannofossil datum No. 8, which is also included within the No. 2 *Globorotalia inflata* Bed, is recognized at the upper part of Sequence C.

(7) The calcareous nannofossil datum No. 7 is contained within the lower part of Sequence D.

(8) The calcareous nannofossil datum No. 6 is recognized at the upper part of Sequence D.

(9) The calcareous nannofossil datum 5, which is recognized beneath the No. 1 *Globorotalia inflata* Bed, corresponds to the bounding discontinuity between sequences D and E1.
2. Morphological and distributional characteristics of systems tracts and depositional systems

2-1. Criteria for morphological features of depositional systems

The depositional settings of each progradational fourth-order depositional sequence (Sequences J+K, L, M and N) are classified into higher flat planes, their margins, tilted planes, and lower flat planes, based on the geomorphological characteristics observed on the seismic profiles. For convenience, this study names tentatively those geomorphological units as (1) platform, (2) platform margin, (3) flank and (4) bottom, respectively (Fig. 17). The platforms are relatively proximal higher flat planes occupying mainly the southern portion and eastern and western marginal parts of the "paleo-Niigata sea." In contrast to this, the bottoms are relatively distal lower flat planes occupying the northern central part of the "paleo-Niigata sea." The platform area and the bottom area are bounded by the area of flank between them. Moreover, the marginal area of the platform contiguous to the flank would be distinguished as a platform margin from the platform itself, because the sedimentary facies and their controlling processes in the platform margin are expected to be different from those in the platform.

Those geomorphological characteristics, even slightly valuable, can generally be applicable to the every systems tract building the progradational fourth-order depositional sequences. Such a geomorphological framework is widely identified on the seismic profiles in the study area, even it was slightly deformed by subsidence related to differential compaction of the underlying strata or local tectonic activities after the deposition of the subject strata.

The systems tracts of the progradational fourth-order depositional sequences are distributed and demonstrate individual morphological characters such as external forms, stratal termination patterns and stratal stacking patterns in response to the geomorphological features of their depositional locations. The external forms of the systems tracts are classified into I) sheet, II) wedge, III) bank, IV) sigmoid, V) mound, or VI) "channel" (Fig. 18-(1)). The stratal termination patterns are classified into a) toplap, b) truncation, or c) apparent truncation at the upper bounding discontinuities, and into x) onlap or y) downlap at the lower bounding discontinuities of the systems tracts. Moreover, the upper and lower bounding discontinuities with rare stratal
Fig. 17. Schematic diagrams showing geomorphological subdivision of the Kanbara area.
Fig. 18. Criteria for morphological classification of depositional systems.
(1) External forms of strata are subdivided into I. sheet, II. wedge, III. bank, IV. sigmoid, V. mound, and VI. "channel." (2) Upper stratal termination patterns are subdivided into a. toplap, b. truncation, and c. apparent truncation, and lower stratal termination patterns are subdivided into x. onlap and y. downlap. Discontinuities without distinct termination patterns are classified into p. parallel. (3) Stratal stacking patterns are subdivided into 1. aggradation, 2. retrogradation, 3. progradation, and 4. mound. For instance, IV-ay-3 indicates sigmoidal strata with progradational stratal stacking pattern associated on the upper bounding discontinuity with toplap and on the lower bounding discontinuity with downlap as stratal termination patterns.
terminations are distinguished as p) parallel, respectively (Fig. 18-(2)). The stacking patterns of the strata building the systems tracts are classified into 1) aggradation, 2) retrogradation (backstep) and 3) progradation (offlap) (Fig. 18-(3)).

2-2. Subdivision to depositional systems based on the morphological criteria (Table 3)

2-2-1. Morphological features of depositional systems in Sequence J+K
2-2-1-1. Systems tract Ja

The systems tract Ja is distributed in the relatively limited area. This systems tract thins out southward drastically at the south of the Kanbara GS-1 and Nakanokuchi SK-1 wells, at the area between the Yoroigata-1 and Nishitsubame-1 wells, and near to the block 1 on the Seismic profile 84018 on the platform margin, and is not distributed on the platform (Figs. 19, 20 and 21). The thin Systems tract Ja is distributed at the bottom and pinches out basinward gradually at the area between the MITI "Shimoigarashi" and MITI "Masugata" or Masugate-1 wells (Figs. 19, 20 and 21). To the east and west this systems tract thins gradually toward updip on the flanks at the wings of the tectonically uplifted belts such as the Kakuda-Yahiko Mountains and Niitsu Hills (Figs. 26, 27, 28 and 29).

The Systems tract Ja shows the wedge-like external form accompanied with the abrupt pinching-out southward on the platform margin (Fig. 22). The Discontinuity 11.1 is a flat surface bounding the top of the Systems tract Ja, which is characterized by the distinct southward truncation (Fig. 18-(2)-b). There are no obvious stratal terminations recognized on the Discontinuity 11 bounding the base of the systems tract at the platform margin. The progradational stratal stacking pattern (Fig. 18-(3)-3) is observed within the wedge. Those occurrences of the Systems tract Ja are observed at the block 1 on the Seismic line 83024N, at the block 1 on the line 84036, or at the block 1 on the line 84018 (Figs. 19, 20, 21 and 22).

The depocenter of the Systems tract Ja, located on the flank at the southern "paleo-Niigata sea," has a sigmoidal external form (Fig. 18-(1)-IV). The northward downlaps (Fig. 18-(2)-y) are observed on the Discontinuity 11 bounding the base, and no obvious stratal terminations are observed on the Discontinuity 11.1 bounding the top of the systems tract. The sigmoid, characterized by the internal distinct progradational stratal stacking patterns (Fig. 18-(3)-3), is
Fig. 19. Line drawing section of the north-south trended seismic profile 83024N showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 20. Line drawing section of the north-south trended seismic profile 84022 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 21. Line drawing section of the north-south trended seismic profile 84036 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 22. Line drawing section of the north-south trended seismic profile 84018 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 23. Line drawing section of the north-south trended seismic profile 84016 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 24. Line drawing section of the east-west trended seismic profile 83020 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 25. Line drawing section of the east-west trended seismic profile 84010 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 26. Line drawing section of the east-west trended seismic profile 85063 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 27. Line drawing section of the east-west trended seismic profile 83021 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 28. Line drawing section of the east-west trended seismic profile 83023 showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Fig. 29. Line drawing section of the east-west trended seismic profile 83025/84025B showing stratal terminations with small arrows, discontinuities with thicker lines and italic numbers, and stratal stacking patterns with thinner lines.
Table 3. Morphological characteristics of the depositional systems and systems tracts.
observed at the block 2 on the Seismic lines 84022 and 83024N (Figs. 19 and 20).

The Systems tract Ja at the bottom is distributed mainly in the central axial area of the "paleo-Niigata sea" with the sheet-like external form (Fig. 18-(1)-I), where the MITI "Masugata," Masugata-1 and Nakanokuchi SK-1 had been drilled. No obvious stratal terminations are observed beneath the Discontinuity 11.1 bounding the top of the systems tract. The northward low-angle downlaps are observed on the Discontinuity 11 bounding the base of the systems tract, and the thin Systems tract Ja pinches out northward gradually associated with the downlaps. The Systems tract Ja distributed at the bottom is characterized by indistinct stratal stacking patterns or unclear aggradation (Fig. 18-(3)-1). Moreover, the systems tract at the flank and bottom includes mound-like stratal stacking patterns (Fig. 18-(3)-4) occasionally (Figs. 20 and 21).

2-2-1-2. Systems tract Jb

The Systems tract Jb, having similar external form to the Systems tract Ja, is also distributed in the relatively limited area. The thickness of this systems tract decreases at the platform margin around the locations of the Nishitsubame-1 and Kanbara GS-1, and thins out gradually southward to the platform near the Yoroigata-1 and Nishitsubame-1 wells (Figs. 19, 20 and 21). The thin Systems tract Jb is distributed at the central axial area of the bottom, and thins out basinward gradually at the area between the MITI "Shimoigarashi" and MITI "Masugata" or Masugata-1 wells (Figs. 20, 21 and 22). Moreover, this systems tract thins out to the east and west gently to the updip at the flanks of the uplifted belts (Figs. 26, 27, 28 and 29).

The Systems tract Jb is thinly distributed with the sheet-like external form (Fig. 18-(1)-I) on the platform margin, and pinches out southward at the north of the Yoroigata-1 or Nishitsubame-1 wells. The Discontinuity 11.1 bounding the base of the Systems tract Jb is characterized by the unclear onlaps (Fig. 18-(2)-x). This systems tract is estimated to consist of the strata with the aggradational stacking pattern (Fig. 18-(3)-1), and no obvious stratal terminations are noticed beneath the Discontinuity 11.2 by which this systems tract is bounded at the top. The characteristics of the Systems tract Jb are observed at the block 2 on the Seismic profile 83024N or the blocks 1 and 2 on the Seismic profile 84022 (Figs. 19 and 20).

The systems tract Jb at the platform margin is characterized by the external form of the wedge-shape (Fig. 18-(1)-IV), the distinct toplaps beneath the Discontinuity 11.2 at the top of this systems tract and the progradational stratal stacking patterns (Fig. 18-(3)-3). Those features
of the systems tract on the platform margin are typically observed at the blocks 2 and 3 on the Seismic lines 83024N and 84022 (Figs. 20 and 21).

The systems tract Jb at the flank is marked by the sigmoidal external form (Fig. 18-(1)-IV), and consists of the strata stacked progradationally (Fig. 18-(3)-3). The typical occurrences of this systems tract at the flank are seen at the blocks 3 and 4 on the Seismic profile 83024N, at the block 3 on the Seismic profile 84022, and at the block 3 on the Seismic profile 84036 (Figs. 19, 20 and 21). No distinct stratal terminations are identified on or beneath the discontinuities at the base and top of the systems tract at the flank, except for the minor and unclear downlaps (Fig. 18-(2)-y) on its basal discontinuity. The mound-like stratal stacking patterns (Fig. 18-(3)-4), moreover, are included within this systems tract at the flank occasionally.

The systems tract Jb at the bottom is characterized by the limited distribution at the central axial area of the "paleo-Niigata sea" with the thin, sheet-like external form, the low-angle northward downlaps (Fig. 18-(2)-y) associated with the pinching out, and the unclear aggradation (Fig. 18-(3)-1). The occurrences of this systems tract at the bottom are observed at the blocks 4, 5 and 6 on the Seismic profile 84022 (Fig. 20).

2-2-1-3. Systems tract Jc

The systems tract Jc is widely distributed and can be seen everywhere in the study area. The thin Systems tract Jc is distributed at the central and northern part of the "paleo-Niigata sea" and thins northward at the area between the Kanbara GS-1 and MITI "Masugata" or at the north to the Nakanokuchi SK-1 wells on the platform margin or flank, contrasting to the distribution of the thicker Systems tract Jc on the platform occupying the southern portion of the "paleo-Niigata sea" (Figs. 20 and 21). The Systems tract Jc on the platform has a sheet-like external form (Fig. 18-(1)-1), and is characterized by the low-angle southward onlaps (Fig. 18-(2)-x) on the Discontinuity 11.2 bounding its base, the unclear apparent truncations (Fig. 18-(2)-c) beneath the Discontinuity 12 at its top, and the distinct aggradation (Fig. 18-(3)-1). Such occurrences of the Systems tract Jc on the platform is observed at the blocks 1 and 2 on the Seismic profile 84022, the blocks 1, 2 and 3 on the profile 83024N, and the blocks 1 and 2 of the profile 84036 (Figs. 19, 20 and 21).

The Systems tract Jc on the platform margin has a bank-like external form (Fig. 18-(1)-III) with thinning northward slightly, and is characterized by the apparent truncations (Fig. 18-(2)-c)
beneath the Discontinuity 12 at its top and the backstepping (Fig. 18-(3)-2). This occurrence of
the Systems tract Jc is observed at the block 3 on the Seismic profile 84022, the block 3 on the
profile 84036, or block 3 on the profile 84018 (Fig. 20, 21 and 22).

The Systems tract Jc on the flank also has a bank-like external form (Fig. 18-(1)-III) with
thinning northward slightly, and is characterized by the unclear apparent truncations (Fig. 18-
(2)-c) at its top and the unclear aggradation (Fig. 18-(3)-1). Such a external form, stratal
termination pattern, or stratal stacking pattern is observed at the blocks 3 and 4 on the Seismic
profile 84022 (Fig. 20) or on some other profiles.

The Systems tract Jc at the bottom is distributed widely with the sheet-like external form
(Fig. 18-(1)-I) in the central and northern portions of the "paleo-Niigata sea" where the Masugata-
1 and MITI "Shimoigarashi" well are located. Less distinct stratal termination is identified at its
top and base and the irregular aggradation (Fig. 18-(3)-1) is recognized in it. The typical
occurrence of the Systems tract Jc at the bottom can be seen at the blocks 4, 5 and 6 on the
Seismic profile 84022, or the blocks 4, 5 and 6 on the profile 84036 (Figs. 20 and 21).

2-2-1-4. Systems tract K

The Systems tract K is also distributed widely and is observed within the entire study
area. On the platform at the south to the Kanbara GS-1 or Nakanokuchi SK-1 well, the thin
Systems tract K is distributed... The thickness of the systems tract increases northward on the
platform margin between the Kanbara GS-1 and Masugata-1 wells, or at the blocks 3, 4, 5 and 6
of the Seismic profile 84036, and reaches the maximum value on the flank. The systems tract
thins abruptly on the lower flank and the bottom, and the thin Systems tract K is distributed on
the bottom in the northern "paleo-Niigata sea" (Figs. 20, 21 and etc.).

The Systems tract K on the platform, showing the thin sheet-like external form (Fig. 18-
(1)-I) and thinning gradually, is characterized by the low-angle southward onlaps (Fig. 18-(3)-
I) and by the minor aggradation (Fig. 18-(3)-1). Such an external form, stratal termination
pattern, or stratal stacking pattern is well observed on the southern portion of the Seismic profile
84022 from the Kanbara GS-1 well, and the southern portion of the profile 84036 from the tie-
point with the Line 83023 (Figs. 20 and 21).

The Systems tract K on the platform margin shows the wedge-shape external form (Fig.
18-(1)-II) with thickening basinward. The systems tract is characterized by the toplaps (Fig. 18-
(2)-a) beneath the discontinuity bounding its top and the typical basinward progradation (Fig. 18-(3)-3) as a stratal stacking pattern. The typical Systems tract K on the platform margin is observed at the blocks 3, 4 and 5 on the Seismic profile 84022, the blocks 4 and 5 on the profile 84036, and the blocks 4 and 5 on the profile 84018 (Figs. 20, 21 and 22).

The Systems tract K on the flank is characterized by the typical sigmoidal external form (Fig. 18-(1)-IV) and the distinct progradation (Fig. 18-(3)-3). The typical occurrences of the systems tract on the flank are observed at the blocks 3, 4, 5 and 6 on the Seismic profile 84022, or at the blocks 3, 4, 5 and 6 on the profile 84036 (Figs. 20 and 21).

The Systems tract K on the bottom, distributed in the northern "paleo-Niigata sea" with the sheet-like external form (Fig. 18-(1)-I), is characterized by the low-angle northward downlaps (Fig. 18-(2)-y) on the Discontinuity 12 bounding the base of this systems tract, and by the unclear and minor aggradation (Fig. 18-(3)-1). The typical occurrences of the Systems tract K are recognized at the limited area around the MITI "Shimoigarashi" well in the study area (Figs. 19 and 24).

2-2-2. Morphological features of depositional systems in Sequence L

2-2-2-1. Systems tract La

The Systems tract La is identified only on the Seismic profiles 83020, 84010 and 85063, and is considered to be distributed limitedly at the northern axial area of the "paleo-Niigata sea" (Figs. 20, 24, 25 and 26). This systems tract thins out drastically southward near the block 5 on the Seismic profile 84022, and is not distributed on the platform in the central and southern "paleo-Niigata sea." To the north, the thickness of the systems tract reaches maximum at the flank near the block 6 on the Seismic profile 84022. However, the scale of this depocenter is minor and this systems tract pinches out northward at the block 7 (Fig. 20). Such morphological features of the Systems tract La can also be recognized at the blocks 1 and 2 on the east-west trended Seismic profile 84010 (Fig. 25).

The Systems tract La on the platform margin, observed on the Seismic profiles 84022 and 85063 (Figs. 20 and 26), is characterized by the wedge-like external form (Fig. 18-(1)-II), the obvious truncations (Fig. 18-(2)-b) beneath the Discontinuity 13.1 bounding the top of this systems tract, and the small-scale but clear progradation (Fig. 18-(3)-3).
The Systems tract La on the flank is characterized by the sigmoidal external form (Fig. 18-(1)-IV) and the relatively unclear progradation (Fig. 18-(3)-3). Some mound-like stratal stacking patterns (Fig. 18-(3)-4) and the associated onlaps (Fig. 18-(2)-x) and downlaps (Fig. 18-(2)-y) are identified within the Systems tract La on the east-west trended Seismic profiles 84010 and 85063 (Figs. 25 and 26).

The Systems tract La on the bottom, distributed in the northern axial "paleo-Niigata sea" with the sheet-like external form (Fig. 18-(1)-I), thins out basinward (Figs. 20 and 25). Based on the limited recognition on the Seismic profiles 84022 and 84010, this systems tract on the bottom is characterized by the unclear downlaps (Fig. 18-(2)-y) on the Discontinuity 13 bounding the base of this systems tract and the small scale aggradation (Fig. 18-(3)-1).

2-2-2-2. Systems tract Lb

The Systems tract Lb, identified on the Seismic profiles 84022, 83020, 84010 and 85063, is distributed at the limited area of the northern axial "paleo-Niigata sea" (Figs. 20, 24, 25 and 26). The systems tract thins southward abruptly on the platform margin at the block 6 on the Seismic profile 84022, and pinches out at the north of the Masugata-1 well on the platform occupying the central and southern portions of the "paleo-Niigata sea." To the north the thickness of the systems tract reaches maximum at the block 6 on the profile 84022 on the flank, however, the scale of the depocenter is small and it thins northward at the block 7 on the bottom (Fig. 20). The comparable characteristics are also recognized on the east-west Seismic profile 85063, but on the western portion of the profile 84010 this systems tract thins out abruptly on the platform margin (Figs. 24 and 25).

The Systems tract Lb, recognized only on the Seismic profiles 84022 and 85063, is characterized by the landward onlaps (Fig. 18-(2)-x) and associated thinning, the sheet-like external form (Fig. 18-(1)-I), and the small scale aggradation (Figs. 20 and 26).

The Systems tract Lb on the platform margin is not developed well in the study area. This systems tract is estimated to be characterized by the toplaps and the progradation because it shows the similar wedge-like external forms to the Systems tract Jb at the platform margin, though this is not confirmed on the seismic profiles.

The Systems tract Lb on the flank and bottom is confirmed to show the sigmoidal (Fig. 18-(1)-IV) and sheet-like (Fig. 18-(1)-1) external forms respectively, but the stratal termination
patterns and stratal stacking patterns are not recognized clearly within them because the systems tract is not developed well in the study area (Figs. 20 and 25).

2-2-2-3. Systems tract Lc

The Systems tract Lc is distributed widely in the entire study area. At the platform on the central and southern "paleo-Niigata sea" except the northern axial area, the relatively thicker Systems tract Lc is distributed. The systems tract tends to decrease gradually in thickness to the north on the platform margin, flank and bottom. Moreover, this systems tract also tends to thin toward the tectonically uplifted areas of the Niitsu Hills at the eastern margin and the Kakuda-Yahiko Mountains at the western margin of the "paleo-Niigata sea."

The Systems tract Lc on the platform, showing the sheet-like external form (Fig. 18-(1)-I), is characterized by the landward low-angle onlaps (Fig. 18-(2)-x) and the distinct aggradation (Fig. 18-(3)-1). There is less stratal termination observed beneath the Discontinuity 13.3 at the top of the systems tract.

The Systems tract Lc on the platform margin, marked by the bank-like external form (Fig. 18-(1)-III), the apparent truncations (Fig. 18-(2)-c) beneath the Discontinuity 13.3 at the top, and the backstepping (Fig. 18-(2)-c), decreases in thickness toward the flank (Figs. 20 and 25). The Systems tract Lc on the flank, characterized by the bank-like external form (Fig. 18-(1)-III) extended from the platform margin, the apparent truncations (Fig. 18-(2)-c) beneath the Discontinuity 13.3 at the top, and the unclear aggradation (Fig. 18-(3)-1), decreases in thickness toward the bottom at the northern axial "paleo-Niigata sea" (Figs. 20 and 25). Occasionally the onlaps are identified on the discontinuity at the base of the systems tract (Figs. 25 and etc.).

The Systems tract Lc, recognized slightly on the Seismic profiles 84022 and 84010, shows the sheet-like external form (Fig. 18-(1)-I), however, the stratal terminations and stratal stacking pattern are not identified clearly within it.

2-2-2-4. Systems tract Ld

The Systems tract Ld is distributed in the northern and central axial "paleo-Niigata sea" except the southern portion of the platform, the western flank of the Niitsu Hills and the eastern flank of the Kakuda-Yahiko Mountains. This systems tract thins out southward at the south of the Yoroigata-1 well on the Seismic profile 84022 and the south of the MITI "Niigata-heiya" well on the profile 84018 (Figs. 20 and 22). The systems tract also thins out westward at the east
to the Nishiakatsuka-1 well on the Seismic profile 84010, and eastward at the east to the Kitashirone TS-1 well on the profile 85063 and the MITI "Niigata-heiya" well on the profile 83021, respectively (Figs. 25, 26 and 27). The thickness of the Systems tract Ld increases drastically on the platform margin in the northern "paleo-Niigata sea," reaches maximum on the flank, and decreases gradually on the bottom. The Systems tract Ld on the bottom is rarely observed at the block 3 on the Seismic profile 83020 in the study area.

The systems tract on the platform, showing the sheet-like external form (Fig. 18-(1)-1), is characterized by the landward low-angle onlaps (Fig. 18-(2)-x) on the Discontinuity 13.3 at the base and the small-scale aggradation (Figs. 18-(3)-1, 21 and etc.). The landward low-angle onlaps (Fig. 18-(2)-a) are also identified beneath the Discontinuity 14 of the top at the block 2 on the Seismic profile 83024N and the block 5 on the profile 84022.

The Systems tract Ld on the platform margin is characterized by the wedge-like external form (Fig. 18-(1)-II) thickening basinward, the unclear toplap (Fig. 18-(2)-a) beneath the Discontinuity 14 at the top, and the basinward-progradation (Figs. 18-(3)-3 and 20). Such morphological features are also recognized on the east-west trended seismic profiles in the northern "paleo-Niigata sea" (Figs. 24 and 25).

The Systems tract Ld on the flank is characterized by the sigmoidal external form (Fig. 18-(1)-IV) and the progradation (Figs. 18-(3)-3, 20 and 24).

The Systems tract Ld on the bottom is observed only at the block 3 on the Seismic profile 83020 (Fig. 24). The systems tract is characterized by the sheet-like external form (Fig. 18-(1)-I) and the basinward downlaps (Fig. 18-(2)-y) on the discontinuity at the base.

2-2-3. Morphological features of depositional systems in Sequence M

2-2-3-1. Systems tract Ma

The Systems tract Ma, recognized only on the Seismic profile 86020, is characterized by the wedge-shape external form (Fig. 18-(1)-II) on the platform and the sigmoidal external form (Fig. 18-(1)-IV) on the flank, but the stratal terminations and the stratal stacking pattern are not identified. The systems tract thins out both landward and basinward, and is not distributed on the platform and the distal part of the bottom (Fig. 24).

2-2-3-2. Systems tract Mb
The Systems tract Mb, recognized only on the Seismic profile 83020 like the Systems tract Ma, is distributed thinly on the platform and the bottom, and thickly on the platform and the flank. This systems tract thins out landward gradually (Fig. 24).

The Systems tract Mb on the platform, showing the sheet-like external form (Fig. 18-(1)-I) with thinning out landward gradually, is characterized by the onlaps (Fig. 18-(2)-x) on the discontinuity at its base and the small-scale aggradation (Fig. 18-(3)-1).

The Systems tract Mb on the platform margin is characterized by the unclear wedge-shape external form (Fig. 18-(1)-II), the toplaps (Fig. 18-(2)-a) beneath its upper bounding discontinuity and the progradation (Fig. 18-(3)-3).

The systems tract on the flank and bottom show the unclear sigmoidal (Fig. 18-(1)-IV) and sheet-like (Fig. 18-(1)-I) external forms respectively, but the stratal terminations and stratal stacking patterns are not identified.

2-2-3-3. Systems tract Mc

The Systems tract Mc, distributed in the extremely wide area, is recognized within the entire study area.

The relatively stable thicker Systems tract Mc is deposited on the platform occupying almost all the portions of the "paleo-Niigata sea," but the thickness of the systems tract decreases on the platform margin in the northern axial area. The Systems tract Mc on the flank or bottom is not distributed in this study area.

The systems tract on the platform, showing the thick, sheet-like external form (Fig. 18-(1)-I), is characterized by the low-angle southward onlaps (Fig. 18-(2)-x) on the Discontinuity 14.3 at its base and the distinct aggradation (Fig. 18-(3)-1).

The Systems tract Mc on the platform margin, recognized limitedly in the northern axial area of the "paleo-Niigata sea," shows the bank-like external form (Fig. 18-(1)-III) with the gradual northward thinning, but the stratal terminations at its top or base and its internal stratal stacking patterns are not identified (Figs. 20, 21 and 24).

2-2-3-4. Systems tract Md

The Systems tract Md has a relatively wide distribution in this study area, except the eastern flank of the Kakuda-Yahiko Mountains and at the southeastern "paleo-Niigata sea" where it pinches out and is absent (Figs. 22, 23, 28 and 29). The thickness of this systems tract increases
toward the platform margin and flank at the northern axial portion of the "paleo-Niigata sea" (Figs. 20 and 24).

The Systems tract Md on the platform, showing the sheet-like external form (Fig. 18-(1)-1) and thinning out landward gradually, is characterized by the low-angle southward onlaps (Fig. 18-(2)-x) on the Discontinuity 14.3 at its base, the low-angle southward toplaps (Fig. 18-(2)-a) beneath the discontinuity 15 at its top, and the aggradation (Fig. 18-(3)-1).

The Systems tract Md on the platform margin is characterized by the wedge-shape external form (Fig. 18-(1)-II), and no stratal terminations on its base or top and no internal stratal stacking patterns are identified. Though a part of the Systems tract Md on the flank is found at the block 3 on the Seismic profile 83020, its morphological characteristics are not identified (Fig. 24). The Systems tract Md on the bottom is not found in this study area.
3. Lithofacies and stratal stacking patterns based on well-log responses

3-1. Criteria of well-log responses for lithofacies identifications

For the sedimentary facies analysis of the subsurface strata, generally core samples can provide the most significant information, even though cuttings records, wireline logs and a result of micropaleontological analysis can also be applicable (Arato and Takano, 1995; etc.). However, the lithofacies of the strata within the progradational fourth-order depositional sequences in the subsurface of the Kanbara plain were interpreted on the basis of the cuttings records and the wireline log responses of the exploratory wells, because no core samples were taken from the objective horizon in the studied wells.

The sequence stratigraphic interpretation of the wireline log responses, as seen on the examples by Van Wagoner et al. (1988), Galloway (1989), Van Wagoner et al. (1990), Mitchum et al. (1991), Coleman and Galloway (1991), or Wornardt (1993), is performed by the recognition of cyclicities and their repetitive patterns. In this study the following standard for the cuttings records and wireline log responses is prepared for the classification of the lithofacies, in order to describe the cyclicities, to clarify the sedimentary facies building the systems tracts and depositional systems, and to discuss the mechanisms for deposition of them. At first, the patterns of the vertical lithofacies variations are classified into the following five types; i) upward-coarsening type, ii) upward-fining type, iii) massive type, iv) crescent type, and v) irregular type. And then, each type of lithofacies is subdivided into four groups as 1 to 4 respectively on the basis of the tendency of grain size (Fig. 30). The classified lithofacies and their interpreted sedimentary facies will be described in every systems tract of the progradational fourth-order depositional sequences as following sections.

3-2. Interpreted lithofacies and stratal stacking patterns of progradational fourth-order depositional sequences

3-2-1. Lithofacies and stratal stacking patterns of regressive progradational wedge
Fig. 30. Criteria of well-log responses for lithofacies identifications.
systems tracts

The regressive progradational wedge systems tracts (RPW) are not distributed on the platforms (Figs. 19, 20 and 21).

This type of systems tract on the platform margins is observed only in the upper portion of the Systems tract Ja in the Kanbara GS-1 well. The strata of this systems tract, distributed at the most distal location below the truncational surface tilted basinward (Fig. 20), consists mainly of the upward-coarsening silt/sand alternations overlain by the massive sand beds (Fig. 31).

The regressive progradational wedge systems tracts on the flanks are observed as the lower portion of the Systems tract Ja in the Kanbara GS-1 and the Systems tract Ja in the Nakanokuchi SK-1 wells. The strata of those systems tracts occupy the upper part of the flank (Fig. 20). The lower portion of the Systems tract Ja in the Kanbara GS-1 well consists of the crescent type silt/sand alternations, and especially the lowermost two cycles of the crescent type alternations are relatively sandy, as compared to their overlying alternations. The Systems tract Ja in the Nakanokuchi SK-1 well, on the other hand, consists also of a pile of the crescent type silt/sand alternations, and the cycles in the middle part of the systems tract are relatively sandy, as compared to the remaining cycles (Figs. 31 and 32).

The regressive progradational wedge systems tracts on the bottoms are observed as the Systems tract Ja in the MITI "Masugata" and Masugata-1 wells. The systems tract in both wells, occupying the marginal area of the basin floor near to the lower slope (Fig. 20), is composed of a pile of the crescent type mud/silt alternations (Figs. 31 and 32).

3-2-2. Lithofacies and stratal stacking patterns of lowstand stable progradational wedge systems tracts

The lowstand stable progradational wedge systems tracts (LPW) on the platforms are rarely observed except the Systems tract Jb in the Kanbara GS-1 (Fig. 20), and is supposed to consist of the irregular type sand/mud alternation (Fig. 31).

The lowstand stable progradational wedge systems tract on the platform margins, observed only as the upper portion of the Systems tract Jb in the Nakanokuchi SK-1 well (Fig. 21), is composed of the unclear and relatively thin upward-coarsening sand/silt alternations overlain
Fig. 31. Well correlation cross section A-A' showing the sequence stratigraphic framework, the interpreted paleo-environments, and cuttings records and wireline log responses.
Fig. 32. Well correlation cross section B-B' showing the sequence stratigraphic framework, the interpreted paleo-environments, and cuttings records and wireline log responses.
by the thick massive sand beds (Fig. 32).

The systems tracts on the flank are observed as the lower portion of the Systems tract Jb in the Nakanokuchi SK-I, as the Systems tract Jb in the Shoze-1, as the Systems tract Lb in the Maigata R-1, and as the Systems tract Mb in the MITI "Shimoigarashi" (Figs. 21, 22, 24 and 28). This type of the systems tracts on the flanks located on the upper slope consists of the upward-coarsening mud/sand alternations at the lower portion of the Systems tract Jb in the Nakanokuchi SK-1, the massive sand beds overlain by the massive silt beds at the Systems tract Jb in the Shoze-1, and the massive silt beds and their overlying crescent type silt/sand alternations at the Systems tract Mb in the MITI "Shimoigarashi" wells (Figs. 32 and 33). Those systems tracts on the flanks located on the middle of the slope are composed of the crescent type mud/silt alternations at the Systems tract Jb in the MITI "Niigata-heiya" and at the Systems tract Lb in the Maigata R-1 wells (Fig. 33).

The lowstand stable progradational systems tracts on the bottoms are observed as the Systems tract Jb in the MITI "Masugata," Masugata-1 and Kitashirone TS-1, and as the Systems tract Lb in the MITI "Shimoigarashi" wells (Figs. 20, 24 and 26). The Systems tract Jb in the Kitashirone TS-1, located in the marginal basin floor near the slope, consists of the massive mud beds containing the crescent type gravel/sand/silt alternations in their middle part (Fig. 33). The Systems tract Jb in the MITI "Masugata" and Masugata-1 are composed largely of the upward-coarsening mud/sand alternations, and the Systems tract Lb in the MITI "Shimoigarashi" consists of the crescent type mud/silt alternations (Figs. 31 and 32).

3-2-3. Lithofacies and stratal stacking patterns of transgressive aggradational sheet systems tracts

The transgressive aggradational sheet systems tracts (TAS) on the platforms are observed as the Systems tracts Jc, Lc and Mc in the Shoze-1, Nishitsubame-1, Nakanokuchi SK-1, Yoroigata-1, Kanbara GS-1, Takaki R-4 and Shinminamiaga-1 as the Systems tracts Lc and Mc in the Nishiakatsuka-1, MITI "Niigata-heiya," Kitashirone TS-1 and Ogikawa-1, and as the Systems tract Mc in the Maigata R-1 and Akatsuka R-1 wells (Figs. 20, 21, 22, 23, 25, 26 and 27). The lithofacies of those systems tracts, consisting basically of the upward-coarsening sand/silt/mud alternations, upward-fining mud/silt/sand alternations, irregular gravel/sand/silt
Fig. 33. Well correlation cross section C-C' showing the sequence stratigraphic framework, the interpreted paleo-environments, and cuttings records and wireline log responses.
alternations, and massive mud beds, are classified into the following three groups. The first group, observed as the Systems tracts Jc and Lc in the Takaki R-4, Nishitsubame-1 and Nishiakatsuka-1, or the Systems tract Mc in the Ogikawa-1 and Shoze-1, or others, includes the systems tracts consisting mainly of a pile of the upward-coarsening alternations (Figs. 31, 32, 33 and 34). The transgressive aggradational sheet systems tracts in this group, in many cases, intercalate the irregular type alternations, massive mud beds or upward-finining alternations. Especially, the Systems tract Jc in the Kanbara GS-1, Nakanokuchi SK-1 and Yoroigata-1 and the Systems tract Mc in the Ogikawa-1 wells are formed characteristically of an upward-finining stacking trend of several upward-coarsening alternations (Figs. 31, 32 and 34). The Systems tracts of the second group, recognized as the Systems tract Lc in the Shoze-1, Shinminamiagata-1 or Kitashirone TS-1 wells, contains mainly the upward-finining alternations. Those systems tracts in this group include occasionally the irregular type alternations, massive mud beds or upward-coarsening alternations (Figs. 33 and 34). The systems tracts in the third group, observed as the Systems tract Jc in the Takaki R-4 and Nishitsubame-1, or as the Systems tract Mc in the Nakanokuchi SK-1 wells, are composed of various types of alternations or massive beds. The transgressive aggradational sheet systems tracts in the third group, consisting mainly of the irregular type alternations and massive mud beds, intercalate the upward-coarsening and upward-finining alternations and then demonstrate the complicated wireline log responses (Figs. 31 and 32).

The transgressive aggradational sheet systems tracts on the platform margins are observed as the Systems tract Jc in the Ogikawa-1 and the Systems tract Lc in the Maigata R-1 and Akatsuka R-1 wells (Figs. 22, 23 and 27). The Systems tract Jc in the Ogikawa-1 well consists of the crescent type silt/sand alternation overlain by the upward-coarsening silt/sand alternation and their overlying massive gravel/sand beds. The systems tract Lc in the Maigata R-1 well is made up of a pile of the relatively distinct upward-coarsening silt/sand/gravel alternations overlain by the crescent type silt/sand alternation. The Akatsuka R-1 well, which reached the total depth within the uppermost part of the Systems tract Lc, was drilled into the massive mud beds slightly.

The transgressive aggradational sheet systems tracts on the flanks are observed as the Systems tracts Jc, Lc and Mc in the MITI "Masugata," as the Systems tracts Lc and Mc in the Masugata-1, and as the Systems tract Jc in the Nishiakatsuka-1 and Kitashirone TS-1 wells
Fig. 34. Well correlation cross section D-D' showing the sequence stratigraphic framework, the interpreted paleo-environments, and cuttings records and wireline log responses.
The Systems tract Jc in the MITI "Masugata" well consists of the massive mud beds (Fig. 32). The Systems tract Lc in the MITI "Masugata" and Masugata-1 wells, on the other hand, is composed of the typical upward-coarsening mud/silt/sand alternations. Moreover, the Systems tract Mc in these two wells are made up of the typical upward-coarsening mud/silt/sand alternations and the overlying irregular type mud/silt/sand alternations (Fig. 34). The Systems tract Jc in the MITI "Niigata-heiya" is composed of the upward-fining mud/silt alternations and the overlying upward-coarsening mud/silt/sand alternations (Fig. 33). The Systems tract Jc in the Nishiakatsuka-1 and Kitashirone TS-1 wells and the Systems tract Mc in the MITI "Shimoigarashi" are composed of the crescent type mud/silt or mud/silt/sand alternations intercalating the various types of the alternations and the massive mud beds (Figs. 33 and 34).

The transgressive aggradational sheet systems tracts on the bottoms are observed as the Systems tracts Jc and Lc in the MITI "Shimoigarashi" and as the Systems tract Jc in the Masugata-1 wells (Figs. 20 and 24). The Systems tract Jc in the Masugata-1 consists of the massive mud beds. The Systems tracts Jc and Lc in the MITI "Shimoigarashi" are composed of the massive mud beds intercalating the crescent type or irregular type alternations (Fig. 31).

3-2-4. Lithofacies and stratal stacking patterns of highstand stable progradational wedge systems tracts

The highstand stable progradational wedge systems tracts (HPW) on the platforms are observed as the Systems tract K in the Yoroigata-1, Nishitsubame-1, Takaki R-4, Nakanokuchi SK-1, Ogikawa-1 and Shoze-1, as the Systems tract Ld in the Kitashirone TS-1, and as the Systems tract Md in the Kanbara GS-1, Yoroigata-1, Nakanokuchi SK-1, Nishitsubame-1, MITI Niigata-heiya," Ogikawa-1, Kitashirone TS-1, Takaki R-4, Masugata-1, MITI "Masugata," Maigata R-1, MITI "Shimoigarashi," Akatsuka R-1 and Nishiakatsuka-1 wells. Those systems tracts are classified into the following three groups on the basis of their lithofacies. The systems tracts in the first group, observed as the Systems tract K in the Nishitsubame-1, Takaki R-4, Yoroigata-1 and Shoze-1, or as the Systems tract Md in the Yoroigata-1, Nakanokuchi SK-1, Nishitsubame-1, Masugata-1 and MITI "Masugata," consist of the massive mud or silt beds. Especially, the massive mud beds forming the Systems tract K in the Takaki R-4, Nishitsubame-1 and Yoroigata-1 is characterized by the remarkably stable low-resistivity and high-gamma ray
or spontaneous potential (Figs. 31, 32 and 33). The systems tracts in the second group, observed as the Systems tract Md in the MITI "Niigata-heiya," Ogikawa-1, Maigata R-1, Akatsuka R-1 and Nishiakatsuka-1, as the Systems tract K in the Ogikawa-1, and as the Systems tract Ld in the Kitashirone TS-1 wells, are made up mainly of a pile of the upward-coarsening alternations (Figs. 33 and 34). The systems tracts in the third group, observed as the Systems tract Ld in the Takaki R-4 or the Systems tract Md in the Kitashirone TS-1, consist of the irregular type alternations (Fig. 33).

The highstand stable progradational wedge systems tracts on the platform margins are observed as the Systems tract K in the Shinminamiaga-1, as the upper part of the Systems tract K in the MITI "Niigata-heiya" and Kitashirone TS-1, as the uppermost part of the MITI "Masugata" and Masugata-1, as the Systems tract Ld in the Nakanokuchi SK-1 and Takaki R-4, as the upper part of the Systems tract Ld in the Maigata R-1, Masugata-1 and Akatsuka R-1, and as the upper part of the Systems tract Md in the MITI "Shimoagarashi" wells (Figs. 20, 21, 22, 24, 25 and 27). In many cases, those systems tracts are composed of the upward-coarsening or irregular type alternations and the overlying irregular type alternations or massive silt beds (Figs. 31, 32 and 34).

The highstand stable progradational wedge systems tracts on the flanks are observed as the upper part of the Systems tract K in the Nishiakatsuka-1, as the middle part of the Systems tract K in the MITI "Masugata" and Masugata-1, as the lower part of the Systems tract K in the MITI "Niigata-heiya" and Kitashirone TS-1, as the lower part of the Systems tract Ld in the Maigata R-1, Masugata-1 and Akatsuka R-1, and as the lower part of the Systems tract Md in the MITI "Shimoagarashi" wells. Those systems tracts are made up of a single cycle or a pile of the upward-coarsening alternations, or the upward-coarsening stacking of the massive mud, silt and sand beds (Figs. 31, 32 and 34).

The highstand stable progradational wedge systems tracts on the bottoms are observed as the Systems tracts K and Ld in the MITI "Shimoagarashi" and as the lowermost part of the Systems tract K in the MITI "Masugata" and Masugata-1 wells (Figs. 20 and 24). The Systems tract K in the MITI "Shimoagarashi" well consists of the crescent type alternations. The lowermost part of the Systems tract K in the MITI "Masugata" and Masugata-1 and the Systems tract Ld in the MITI "Shimoagarashi" wells are composed of the massive mud beds (Figs. 31 and 32).
4. Environmental analysis based on benthic foraminiferal fauna

4.1. Principle of paleo-environmental analysis

Distribution of benthic foraminifer is controlled by hydrographical properties such as water depth, temperature, salinity, dissolved oxygen contents and nutrients of water masses. Actually, Recent benthic foraminifers show distinct habitat segregations as regards water depth (Pflum and Trerichs, 1976; Ingle, 1980; Matoba and Honma, 1986). Bathymetric distributions of Recent species could be applicable to same species and their affinities, which occurred in ancient deposits as fossils. Therefore, distributional environments of extinct species could be restored on the basis of their coexistence with Recent species under clear habitat environments. Especially, paleo-environmental analysis with relatively higher resolution would be expected by using Late Neogene and Quaternary benthic foraminifers.

In the offshore areas of the Japanese Islands, paleo-environments have been studied for many years by the application of bathymetric distribution of Recent species. Akimoto and Hasegawa (1989) re-analyzed those data and defined bathymetric zones of Recent foraminiferal fauna. Hasegawa et al. (1989) discussed paleo-ecology of Late Cenozoic extinct species, and defined the "Shallow Bathymetric Zone" by some index species based on the bathymetric zones by Akimoto and Hasegawa (1989).

Kudo and Sasaki (1995) and Kudo (1995) applied the "Shallow Bathymetric Zone" by Hasegawa et al. (1989) to benthic foraminiferal faunas from some exploratory wells in the northern Niitsu Hills. As a result, it was revealed that a reference model proposed by Hasegawa et al. (1989) is generally applicable to the northern Niitsu Hills, though occurrence of several index species does not correspond exactly to the model. Kudo and Sasaki (1995) and Kudo (1995), furthermore, estimated bathymetric distributions of species, which are not included in the reference model by Hasegawa et al. (1989). They discussed, moreover, changes of paleo-bathymetry in the area based on their local reference.

4.2. Establishment of a paleo-bathymetric standard for the "paleo-Niigata sea"
Fourteen wells were selected for benthic foraminiferal analysis for the following reasons. 

(I) Wells drilled on or near the seismic lines used for seismic sequence analysis by Arato et al. (1994a) and Arato and Hoyanagi (1995) (Fig. 3).

(2) Wells provided with wireline logs and mud logs such as gamma-ray log or spontaneous-potential log, resistivity log, and cuttings log.

(3) Wells surveyed and analyzed micropaleontologically by an up-to-date modern method and standard.

The exploratory wells selected, as described above, are Kanbara GS-J, Kitashirone TS-1, Masugata-1, MITI "Masugata", MITI "Niigata-heiya", MITI "Shimoigarashi", Nakanokuchi SK-1, Nishiakatsuka-1, Nishitsubame-1, Ogikawa-1, Shinminamiaga-1, Shoze-1, Takaki-4, and Yoroigata-1 (Fig. 3).

Foraminiferal faunas found in samples from the wells are classified into several assemblages on the basis of their abundance and occurrences of index species. An paleo-bathymetric standard applicable to the "paleo-Niigata sea" has been established, according to the "Shallow Bathymetric Zones" and the method introduced by Kudo and Sasaki (1995) and Kudo (1995) as follow (Table 4).

**Inner sublittoral zone (0-30m).**- Foraminiferal assemblage in this zone is rich in *Ammonia beccarii, Ammonia japonica* and *Pseudorotaria gaimardii*. The occurrence of these species is restricted to this zone.

**Inner-middle sublittoral zone (0-100m).**- Foraminiferal assemblage of this zone is characterized either by one of *Siphogenerina raphanus*, and *Quinqueloculina* spp. or faunal elements of the inner sublittoral zone, and/or it is associated with *Buccella* sp., *Elphidium* sp. and *Cribrnonion clavatum*. Though most of these species and genera belong to the inner sublittoral zone, some are not restricted to the inner sublittoral zone.

**Middle sublittoral zone (30-200m).**- This zone is characterized by an assemblage comprising only *Buccella* spp. and *Cribrnonion clavatum*.

**Middle-outer sublittoral zone (30-200m).**- This zone is characterized by the occurrence of one of the following three assemblages: (1) an assemblage composed chiefly of *Cribrnonion clavatum* or *Epistominella pulchella*, (2) an assemblage abundant in *Cribrnonion clavatum* and *Epistominella pulchella* accompanied by *Cassidulina norcrossi, Buccella* sp. or...
### Table 4. Benthic foraminiferal standard for paleo-bathymetric analysis (after Arato and Kudo, in preparation).

<table>
<thead>
<tr>
<th>Bathymetric Zone</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INNER SUBLITTORAL ZONE (0-30m)</strong></td>
<td>Ammonia spp.</td>
</tr>
<tr>
<td></td>
<td>Pseudorotalia gainardii</td>
</tr>
<tr>
<td><strong>MIDDLE SUBLITTORAL ZONE (30-100m)</strong></td>
<td>Cribrinion Clavatum</td>
</tr>
<tr>
<td></td>
<td>Buccella spp.</td>
</tr>
<tr>
<td></td>
<td>Cribrinion Clavatum</td>
</tr>
<tr>
<td><strong>OUTER SUBLITTORAL ZONE (100-200m)</strong></td>
<td>Cassidulina norcrossi</td>
</tr>
<tr>
<td></td>
<td>Islandiella japonica</td>
</tr>
<tr>
<td></td>
<td>Cassidulina norcrossi + Epistominella pulchella</td>
</tr>
<tr>
<td><strong>UPPER BATHYAL ZONE (200-500m)</strong></td>
<td>Trifarina kokozuraensis</td>
</tr>
<tr>
<td></td>
<td>Trifarina kokozuraensis + Uvigerina akitaensis</td>
</tr>
<tr>
<td></td>
<td>Trifarina kokozuraensis + Uvigerina akitaensis + Epistominella pulchella</td>
</tr>
<tr>
<td><strong>UPPER BATHYAL - UPPER MIDDLE BATHYAL ZONE (500-1,000m)</strong></td>
<td>Uvigerina akitaensis</td>
</tr>
<tr>
<td></td>
<td>Globulimina spp. + Cribrostomoides spp.</td>
</tr>
<tr>
<td></td>
<td>Uvigerina akitaensis</td>
</tr>
<tr>
<td></td>
<td>Globulimina spp. + Cribrostomoides spp. + Epistominella pulchella</td>
</tr>
<tr>
<td></td>
<td>Uvigerina akitaensis</td>
</tr>
<tr>
<td></td>
<td>Cribrostomoides cf. evoluta</td>
</tr>
<tr>
<td></td>
<td>Uvigerina akitaensis &gt; 25</td>
</tr>
<tr>
<td></td>
<td>Epistominella pulchella</td>
</tr>
<tr>
<td></td>
<td>Globobulimina spp. + Cribrostomoides spp.</td>
</tr>
</tbody>
</table>

**INNER - MIDDLE SUBLITTORAL ZONE (0-100m)**

- Ammonia spp.
- Siphogenerina raphanus
- Buccella spp.
- Quinqueloculina spp.
- Cribrinion clavatum
- Siphogenerina raphanus
- Ammonia spp.
- Quinqueloculina spp.
- Quinqueloculina spp.
- Cribrinion clavatum

**MIDDLE - OUTER SUBLITTORAL ZONE (30-200m)**

- Cribrinion clavatum
- Cassidulina norcrossi
- Epistominella pulchella
- Cassidulina norcrossi + Trifarina kokozuraensis
- Buccella spp. + Cassidulina norcrossi
- Epistominella pulchella
- Cribrinion clavatum + Cassidulina norcrossi + Quinqueloculina spp.
- Cassidulina norcrossi
- Cribrinion clavatum

**OUTER SUBLITTORAL - UPPER BATHYAL ZONE (100-500m)**

- Epistominella pulchella > 25
- Cassidulina norcrossi
- Epistominella pulchella > 25
- Uvigerina akitaensis
- Cassidulina norcrossi + Islandiella japonica + Epistominella pulchella

- Epistominella pulchella > 50
Quinqueloculina sp., and (3) an assemblage consisting of Cassidulina norvangi and Cribrnonion clavatum.

**Outer sublittoral zone (100-200m).**- This zone is characterized by an assemblage rich in Cassidulina norvangi or Islandiella japonica associated with Cassidulina norcrossi and Epistominella pulchella.

**Outer sublittoral - upper bathyal zone (100-500m).**- This zone is characterized by one of the following three assemblages: (1) an assemblage composed mainly of Cassidulina norvangi associated with Cassidulina norcrossi, (2) an assemblage of Epistominella pulchella, which occupies 25 percent of the population and is accompanied by Cassidulina norcrossi or Uvigerina akitaensis, and (3) an assemblage of Epistominella pulchella over 50 percent. The foraminiferal assemblages of this zone, in many cases, include Epistominella pulchella or Islandiella japonica, and occupy the area between outer sublittoral and upper bathyal areas.

**Upper bathyal zone (200-500m).**- An assemblage of this zone is characterized by Trifarina kokozuraensis, or by the abundance in Trifarina kokozuraensis accompanied by Uvigerina akitaensis or Epistominella pulchella.

**Upper bathyal - upper part of middle bathyal zone (200-1,000m).**- This zone is characterized by one of the following three assemblages: (1) an assemblage consisting of Uvigerina akitaensis, Globobulimina sp., Cribrstomoides (Haplophragmoides of Hasegawa et al., 1989) sp. or Epistominella pulchella, (2) the above described assemblage associated with Cribrstomoides cf. evoluta, and (3) an assemblage of Uvigerina akitaensis over 25 percent in population. Globobulimina sp., Cribrstomoides sp. and Cribrstomoides cf. evoluta were not designated as index species or genera since Late Pliocene time by Hasegawa et al. (1989). Those foraminifers, however, are interpreted to show the deeper shallow bathymetric zone than the upper bathyal zone for the following two reasons: (1) Globobulimina sp. and Cribrstomoides sp. are assigned to index of the middle bathyal zone from Late Miocene to Early Pliocene time, and (2) Thalmannammina parkerae, which is a Recent species with similar morphological features to Cribrstomoides cf. evoluta, occurs at deeper bathymetry than 120 meters in the present offshore Nishitsugaru area (Matoba and Honma, 1986).
4.3. Application of the paleo-bathymetric standard to the "paleo-Niigata sea"

Though *Islandiella japonica* and *Epistominella pulchella* are designated as the index species of the upper to middle bathyal zones according to Hasegawa et al. (1989), they possibly indicate the shallower "Shallow Bathymetric Zone" in the northern Niitsu Hills. Based on the occurrence, these species are considered as the index for the outer sublittoral to upper bathyal zones in the "paleo-Niigata sea" (Kudo and Sasaki, 1995; Kudo, 1995).

*Cassidulina* (equal to *Islandiella* of Hasegawa et al., 1989) *norcrossi*, index species for the upper bathyal zone in the standard by Hasegawa (1989), would not indicate any distinct shallow bathymetric zones in the northern Niitsu Hills (Kudo and Sasaki, 1995; Kudo, 1995). The similar results are suggested by the foraminiferal analysis in the "paleo-Niigata sea."

*Siphogenerina* (equal to *Rectobolirina* by Hasegawa et al., 1989) *raphanus* shows the outer sublittoral zone, according to the "Shallow Bathymetric Zone" by Hasegawa et al. (1989). In the "paleo-Niigata sea," however, this species is interpreted as an index of the inner to middle sublittoral zones rather than the outer sublittoral because of its coexistence with *Ammonia beccarii*, *Ammonia japonica*, and *Pseudorotalia gaimardii* associated with extremely few planktic foraminifer.

*Epistominella pulchella* probably indicates the middle to outer sublittoral zones, based on coexistence with *Cribrononion clavatum* or *Trifarina kokozuraensis*. This species occupies more than 25 percent of the assemblage in total population in many cases, and attains 50 - 90 percent in some cases. The assemblage consisting of this species more than 50 percent in population is mainly distributed in the northern axial area of the "paleo-Niigata sea." A water mass containing such a benthic foraminiferal fauna should have some special characteristics (Kudo and Sasaki, 1996), which would be described in detail in the near future.

It is suggested that a different foraminiferal distribution from the standard for open ocean may be observed in a strongly restricted ocean such as the Bay of Toyama under an influence of complex water mass distribution (Hasegawa, 1986). Therefore, it may not be out of the question to apply the paleo-bathymetric standard by Hasegawa et al. (1989) directly to the "paleo-Niigata sea," because it is interpreted as an almost closed embayment. In contrast to this, assemblages,
which have a similar composition to that of open ocean, are reported in an area of embayment (Inoue, 1986). As discussed above, it is not easy to interpret paleo-bathymetry of embayments from assemblages of benthic foraminiferal fauna. However, the standard by Hasegawa et al. (1989) seems to be applicable to the "paleo-Niigata sea" as an indicator of relative paleobathymetric relationship.

### 4-4. Paleo-bathymetric analysis in the Yoroigata-1 well

The author will take Yoroigata-1 well as an example to illustrate a result of paleobathymetric analysis of benthic foraminiferal assemblages, based on the standard (Table 4) for the "paleo-Niigata sea." Figure 35 demonstrates the abundance of the significant species or genera and the results of their paleo-bathymetric analysis in Yoroigata-1.

**0 - 470m.**- The deposits of this drilling interval are interpreted as non-marine, because neither planktic nor benthic foraminifer is encountered.

**470 - 490m.**- The assemblage of this interval is abundant in *Ammonia japonica*, *Ammonia beccarii* or *Ammonia* sp. accompanied by *Buccella* sp. and *Cribrononion clavatum*. It also includes a small number of planktic species. This is, therefore, the assemblage of the inner sublittoral zone.

**490 - 800m.**- Neither benthic nor planktic foraminifer occurs. This suggests that the deposits of this interval are non-marine.

**800 - 840m.**- The assemblage of this interval is composed chiefly of *Ammonia japonica*, *Pseudorotalia gaimardii* or *Siphogenerina raphanus*, and is associated with *Buccella* sp., *Cribrononion clavatum*, and *Rectobolivina subangularis*. This is, therefore, the assemblage of the inner to middle sublittoral zone. A few planktic foraminifers also occur.

**840 - 900m.**- The deposits of this interval are interpreted to be sediments in non-marine area, because neither benthic nor planktic foraminifer occurs.

**900 - 960m.**- The assemblage of this interval indicates the inner sublittoral environment, because *Ammonia japonica* occupies more than 80 percent of this assemblage in foraminiferal population. A few planktic foraminifers are associated with this assemblage.

**960 - 1,160m.**- The most deposits of this interval are interpreted as non-marine sediments,
Fig. 35. Benthic foraminiferal assemblage chart of selected species for the Yoroigata-1 well (after Arato and Kudo, in preparation).
because no foraminifers are encountered. However, a small number of the inner sublittoral foraminifers are recognized within a few parts of this interval exceptionally.

1,160 - 1,180m.- *Ammonia japonica* or *Ammonia* spp. occupies 40 to 50 percent of the assemblage, which is associated with *Quinqueloculina* sp. in this interval. This assemblage, therefore, indicates the inner sublittoral zone. Planktic foraminifers are rarely found in this interval.

1,180 - 1,270m.- An assemblage from this interval contains abundant fauna of *Cribraronion clavatum* and *Buccella* spp. accompanied by *Ammonia japonica*, *Ammonia takanabensis* or *Pseudorotalia gaimardi*. This is, therefore, the assemblage of the middle sublittoral zone. Planktic species occupy 10 to 30 percent of the whole foraminifers.

1,270 - 1,430m.- The deposits of this interval are interpreted as non-marine because neither benthic nor planktic foraminifer occurs.

1,430 - 1,460m.- *Epistominella pulchella* occupies 50 to 80 percent of the assemblage from this interval, which is associated with a small number of *Cribraronion clavatum* and *Siphogenerina raphanus*. This is therefore the assemblage of the outer sublittoral to upper bathyal zones. Planktic species occupy 20 to 50 percent in population of bulk foraminiferal number.

4.5. **Paleo-bathymetries of the progradational fourth-order depositional sequences by benthic foraminiferal assemblages**

4.5-1. Paleo-bathymetries in the regressive progradation wedge systems tracts (RPW)

The regressive progradational wedge systems tract on the platform, observed as the upper portion of the Systems tract Ja in the Kanbara GS-1, is characterized by the discontinuous occurrences of the inner - middle sublittoral benthic foraminiferal faunal assemblages intercalating with barren zones (Fig. 36).

The middle - outer sublittoral benthic foraminiferal assemblages occur in the upper part of the Systems tract Ja of the Kanbara GS-1 and Nakanokuchi SK-1 wells deposited on the flanks, respectively (Figs. 36 and 37).
Fig. 36. Well correlation cross section A-A' showing the sequence stratigraphic framework, the results of benthic foraminiferal paleo-bathymetric analysis and interpretations for paleo-environments (from Arata and Kudo, in preparation)(must be modified).
Fig. 37. Well correlation cross section B-B' showing the sequence stratigraphic framework, the results of benthic foraminiferal paleo-bathymetric analysis and interpretations for paleo-environments (from Arato and Kudo, in preparation).
The middle - outer sublittoral benthic foraminiferal assemblages, on the other hand, are recognized in the lower part of the Systems tract Ja of the Nakanokuchi SK-1, and the middle sublittoral - upper bathyal assemblages are recognized in the Systems tract Ja of the MITI "Masugata," Kitashirone TS-1, MITI "Niigata-heiya," and Shoze-1 wells.

4-5-2. Paleo-bathymetries in the lowstand stable progradational wedge systems tracts (LPW)

The Systems tract Jb in the Kanbara GS-1, occupying the platform of the lowstand stable progradational wedge systems tract, does not contain any marine microfossils (Fig. 36).

The uppermost part of the Systems tract Jb in the Nakanokuchi SK-1 deposited on the platform margin is characterized by the occurrence of the inner sublittoral benthic foraminiferal fauna or barren zone.

The inner - middle sublittoral faunal assemblages occur in the lower part of the Systems tract Jb in the Nakanokuchi SK-1 deposited on the flank (Fig. 37).

The middle sublittoral - upper bathyal benthic foraminiferal faunas, on the other hand, are identified within the Systems tract Jb on the bottom in the MITI "Masugata" and Masugata-1 located to the north of the Kanbara GS-1 or Nakanokuchi SK-1, and in the Kitashirone TS-1, MITI "Niigata-heiya" and Shoze-1 located to the east of the Kanbara GS-1 or Nakanokuchi SK-1 wells (Figs. 36, 37, 38 and 39). In the MITI "Shimoigarashi" well located in the northern axial area of the "paleo-Niigata sea," the middle sublittoral - upper bathyal faunas in the Systems tract Jb on the bottom and the middle - outer sublittoral faunas in the Systems tract Mb on the bottom are recognized respectively (Fig. 38).

4-5-3. Paleo-bathymetries in the transgressive aggradational sheet systems tracts (TAS)

The occurrence of the inner sublittoral benthic foraminiferal faunas intercalating the barren zones is confirmed in the Systems tract Jc of the Yoroigata-1 and Takaki R-4 wells located on the platform in the southern "paleo-Niigata sea" (Fig. 36). The analogous occurrence on the platforms is observed in the Systems tract Lc in the Takaki R-1, and in the Systems tracts Lc and Mc in the Yoroigata-1 and Nakanokuchi SK-1 wells (Figs. 36 and 37). In the eastern and western margins of the platform in the "paleo-Niigata sea," the inner - middle sublittoral faunas
Fig. 38. Well correlation cross section C-C' showing the sequence stratigraphic framework, the results of benthic foraminiferal paleo-bathymetric analysis and interpretations for paleo-environments (from Arato and Kudo, in preparation).
Fig. 39. Well correlation cross section D-D’ showing the sequence stratigraphic framework, the results of benthic foraminiferal paleo-bathymetric analysis and interpretations for paleo-environments (from Arato and Kudo, in preparation).
mainly occur in the Systems tract Jc of the Shoze-1, in the Systems tract Lc of the MITI "Niigata-heiya" and Kitashirone TS-1, and in the Systems tracts Lc and Mc of the Nishiaikatsuka-1 wells (Figs. 38 and 39). The non-marine deposits on the platform, on the other hand, are generally observed in the relatively landward remote areas from the platform margins such as in the Systems tracts Lc and Mc of the Shoze-1, in the Systems tract Mc of the MITI "Niigata-heiya" and Kitashirone TS-1, and in the Systems tract Lc of the Ogikawa-1 wells, though they are rarely identified in the Systems tracts Jc, Lc and Mc of the Kanbara GS-1 and in the Systems tract Lc of the MITI "Niigata-heiya" wells (Figs. 36, 38 and 39).

No marine microfossils are contained in the Systems tract Jc of the Ogikawa-1 well drilled in its platform margin (Fig. 38). The paleo-environments of the platform margin are unknown, because the paleontological analyses were not carried out in the Systems tract Jc of the Maigata R-1 and Akatsuka R-1. (Figs. 38 and 39). In the MITI "Shimoigarashi," drilled on the platform margin of the Systems tract Mc, the middle - outer sublittoral faunas are recognized in the lower portion of the systems tract (Figs. 36 and 37).

The paleo-environments on the flank of the transgressive aggradational sheet systems tract are estimated from the benthic foraminiferal faunal assemblages contained in the Systems tract Jc of the MITI "Masugata," Nishiaikatsuka-1, or Kitashirone TS-1 wells. The middle sublittoral - upper bathyal, the outer sublittoral - upper bathyal, and the outer sublittoral assemblages are recognized in the Systems tract Jc of the MITI "Masugata," Nishiaikatsuka-1, and Kitashirone TS-1 wells respectively (Figs. 37, 38 and 39).

The Systems tracts Jc and Lc of the MITI "Shimoigarashi," located on the bottom in the northern axial "paleo-Niigata sea," contain the outer sublittoral - upper bathyal benthic foraminiferal faunal assemblages (Figs. 36, 37 and 38).

4-5-4. Paleo-bathymetries in the highstand stable progradational wedge systems tracts (HPW)

The Systems tract K on the platform consists of the alternating beds of the deposits containing the inner sublittoral or the inner - middle sublittoral faunas and the barren zones in the Yoroigata-1 and Nakanokuchi SK-1 wells located in the southern "paleo-Niigata sea" (Figs. 36 and 37). In the Systems tract Md of the Nishiaikatsuka-1 well, the deposits containing the
inner sublittoral faunas intercalates with the barren zones (Fig. 39). The non-marine deposits on
the platform, on the other hand, are observed in the Systems tract K of the Shoze-1 and Ogikawa-
1, in the Systems tract Ld of the Kitashirone TS-1, and in the Systems tract Md of the MITI
"Niigata-heiya" wells located on the eastern portion of the "paleo-Niigata sea" (Figs. 38 and 39).
In addition to this, the non-marine deposits on the platform are identified also in the upper part
of the Systems tract K of the Nishiakatsuka-1 located in the western "paleo-Niigata sea," in the
Systems tract Ld of the Kanbara GS-1 and Yoroigata-1, and in the Systems tract Md of the
Kanbara GS-1, Yoroigata-1 and Nakanokuchi SK-1 located in the southern "paleo-Niigata sea"
(Figs. 36 and 37).

The upper part of the Systems tract K in the MITI "Niigata-heiya" and Kitashirone TS-1,
which is the deposits on the platform margin, consists of the alternating beds of the non-marine
deposits without marine fossils and the inner-middle sublittoral deposits (Fig. 38). The occurrence
of the marine microfossils is not recognized in the upper part of the Systems tract K
of the Nishiakatsuka-1 well located on the platform margin in the western "paleo-Niigata sea"
(Figs. 39).

The highstand stable progradational wedge systems tract on the flanks is observed in the
Systems tract K in the Kitashirone TS-1, MITI "Masugata," and Nishiakatsuka-1 wells. The
middle-outer sublittoral benthic foraminiferal faunas occur in the lower part of the Systems
tract K of the Kitashirone TS-1 and the lowermost part of the Systems tract K of the MITI
"Niigata-heiya" wells (Figs. 37 and 38). The middle sublittoral-upper bathyal faunas occur in
the lower part of the Systems tract K of the Nishiakatsuka-1 well (Fig. 39).

The highstand stable progradational wedge systems tract on the bottoms is observed as the
Systems tracts K and Ld in the MITI "Shimoigarashi" well. The outer sublittoral-upper bathyal
faunas occur in those systems tracts.