

# Miocene subsurface half-grabens in the Kanto Plain, central Japan

Masaki Takahashi<sup>1</sup>, Yukio Yanagisawa<sup>1</sup>, Hiiroki Hayashi<sup>2</sup>,  
Keiji Kasahara<sup>2</sup>, Takeshi Ikawa<sup>3</sup>, Taku Kawanaka<sup>3</sup> and Shigeyuki Suda<sup>3</sup>

<sup>1</sup> Integrated Bio- and Chronostratigraphy Group, Institute of Geology and Geoinformation,  
Geological Survey of Japan, AIST, Tsukuba, Ibaraki 305-8567, Japan

<sup>2</sup> Solid Earth Science Division, National Research Institute for Earth Science and Disaster Prevention,  
Tsukuba, Ibaraki 305-0006, Japan

<sup>3</sup> JGI Co., Ltd., Tokyo 112-0012, Japan

## Summary

A new general model for the deep subsurface geology of the Kanto Plain is established, integrating high quality geological data obtained by thorough investigation of the surface sedimentary sequences and previously published geophysical data sets. The sedimentary sequences in the Kanto Plain are composed of three distinct units of the “N.8 deposits”, “post N.8 deposits” and the Kazusa-Shimosa Groups, which are separated by regional unconformities. The “N.8 deposits” are half-graben-fill deposits characterized by very thick, extreme-deformation, high sedimentation rate, abrupt change in thickness, and poorly sorted angular gravel (talus breccia) along the basin margins. The “post N.8 deposits” overlies the “N.8 deposits” with a remarkable angular unconformity called “Niwaya Unconformity”(15.3-15.2 Ma), and show almost constant thickness, low sedimentation rate and weak deformation. The “post N.8 deposits” are covered by the Kazusa-Shimosa Groups with “Kurotaki Unconformity” (ca. 3 Ma). To test this model, we examined a seismic profile (KAN-94) along the western margin of the Kanto Plain was examined, and confirmed that this model well explains the subsurface structures in this area. This model will contribute for constructing a seismic velocity structure model and estimating possible strong motion caused by earthquakes. Especially, the distribution of concealed subsurface “N.8 deposits” and the location of the boundary normal faults of each “N.8 half graben” may be the most important for strong motion estimation.

## 1. Introduction

The Kanto Plain is the largest plain in Japan, where Tokyo metropolitan area is located and one third of population in Japan lives (Fig. 1). This area has been repeatedly suffered heavy damages from large inter-plate or intra-plate earthquakes. For mitigating earthquake disasters, it is important to understanding the basic geological structures of the plain. Suzuki (2002) first presented a deep subsurface geological model compiling data of deep cores and geophysical investigation. However, the Kanto Plain was accumulated by more than 3,000-5,000 meters thick sedimentary rocks, and therefore detailed geological structure underneath of the plain remains still not clear. Moreover, the Kanto Plain has been subjected to intricate tectonics of the back-arc spreading of the Japan Sea (ca.15 Ma; Otofujii et al., 1985) and collision of the Izu-Ogasawara Arc to central Japan since 15 Ma (Takahashi and Saito, 1997).

The purpose of this study is to establish a general model for the deep subsurface geology of the Kanto Plain, integrating high quality geological data and previously published geophysical data set. This model will contribute for estimating strong motion caused by large earthquakes.

## 2. Methods

As stated above, the Kanto Plain has a very complicated geo-history, and resultant highly complex geologic structures. Nevertheless, very few data of deep drilling (more than 1,000 meters) are available to study the geology and stratigraphy of this basin (Suzuki, 2000). Moreover, published seismic data are also very scarce compared to the other sedimentary basins in Japan. Thus it is very difficult to clarify the detail of deep subsurface geology of the Kanto Plain at present.

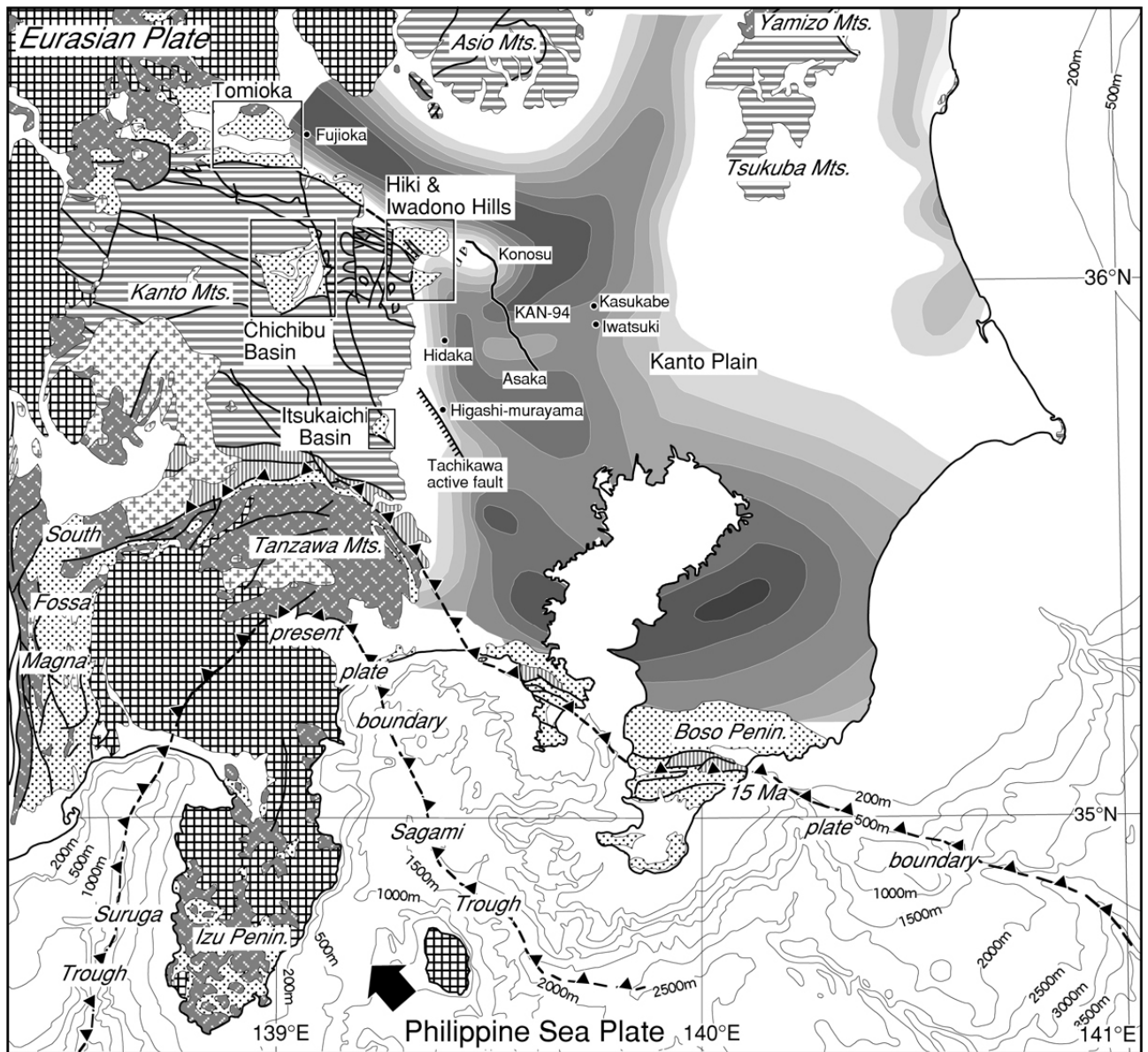


Figure 1. Depth contour map of pre-Miocene basement rocks in the Kanto Plain (Suzuki, 2002) on the geological map of central Japan (Geological Survey of Japan, 2002). The route of the Asaka-Konosu seismic reflection survey (KAN-94) and some Miocene sedimentary basins cropped out in and around the Kanto Mountains are also indicated.

To overcome this difficulty, we adopted a following strategy. Fortunately, sedimentary sequences of late Cenozoic, which are equivalent to sequences distributed in subsurface, cropped out in the

mountains and hills surrounding the Kanto Plain. The both sedimentary sequences are presumed to have the same tectonic and accumulation history before 3 million years ago (Ma), when the sediments near the

Kanto Mountains began to uplift. Therefore, we can understand the subsurface geology by investigating the sedimentary sequences exposed in the surface.

First, we conducted a thorough investigation on the geology, biostratigraphy and numerical dating for the surface sedimentary sequences. Especially, a high resolution biochronological dating method using the evolution of microfossils (fossils of micron-scale organisms) such as radiolarians, diatoms, calcareous nanofossils and planktonic foraminifers (Fig. 2) is a powerful tool for constructing a firm geo-chronological frame works.

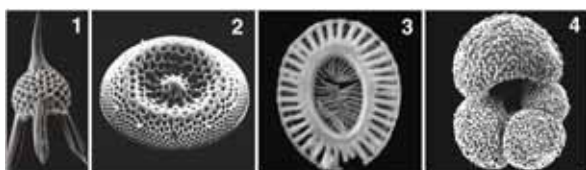


Figure 2. Scanning electron photomicrographs of microfossils. 1: radiolaria, 2: diatom, 3: calcareous nanofossil, 4: planktonic foraminifer.

Second, on the basis of these investigations, we established a new geologic model to fully explain the stratigraphy and tectonic development of the Kanto Plain. As shown in the next chapter, the sedimentary sequences of the late Cenozoic in the Kanto Plain are composed of three distinct units which are separated by regional unconformities.

Third, we collected previously cored deep drilling core data as far as possible, and re-interpreted sedimentary facies, microfossil data, logging data and others of these cores, using our new geologic model. In addition, biostratigraphic analyses of microfossils as well as radiometric dating were conducted for some well-preserved cores.

Finally, we developed a general model for the deep subsurface geology of the Kanto Plain, integrating a newly established geological model and previously published geophysical data sets such as seismic profiles and gravity data.

### 3. Geologic model of surface Geology

The sedimentary rocks, correlative to the sedimentary covers distributed in the subsurface of the Kanto Plain, are cropped out in and adjacent areas of the Kanto Mountains, west of the Kanto Plain (Fig. 1).

As a result of thorough investigation of geology, biostratigraphy and numerical dating, these sediments can be divided into three sedimentary units, i.e., “N.8 deposits”, “post N.8 deposits” and the Kazusa-Shimosa Groups (Fig. 3).

The “N.8 deposits” is characterized by very thick, extreme-deformation, high sedimentation rate, abrupt change in thickness, and poorly-sorted angular gravel (talus breccia) along the basin margin (Fig. 4). In contrast, the “post N.8 deposits” show almost constant thickness, low sedimentation rate and weak deformation. The Kazusa-Shimosa Groups are also relatively thin deposits, except in the Boso Peninsula where the groups have a maximum thickness of more than 3,000 meters.

The “post N.8 deposits” covered the “N.8 deposits”, unconformably. This stratigraphic discontinuity is named the Niwaya Unconformity, and dated at 15.3 to 15.2 million years ago (Ma) by microfossil biochronology. The Niwaya Unconformity is the most important geologic event in central Japan, because it was formed by the initiation of the subduction of Philippine Sea Plate under Southwest Japan and collision of the Izu-Ogasawara arc with the Kanto Mountains.

The typical “N.8 deposits” of the very thick marine sediments in the Chichibu (>6,000m in thickness) and Itsukaichi Basins (>2,000m), were accumulated during a very short interval from 16.5 to 15.3 Ma (Figs. 3, 4). About a lower half of these sequences was composed of turbidite succession deposited in deep basin bottom and formed large submarine fans. The upper half of these sequences are characterized by non-sorted talus breccia (angular stone) interbedded with shallow marine fine sediments. This talus breccia may have been supplied by the collapse of the steep cliff surrounding the sedimentary basin. More than 1,000 meter-thick marine sediments with breccia were deposited in a shallow environment, and the breccia developed along the fault between the sedimentary basin and basement rocks. This indicates that the Chichibu and Itsukaichi Basins were typical half-grabens in the earliest Middle Miocene (ca. 15 Ma). The minor fault analysis indicates that the Chichibu Basin was formed by the southeastward tilting faulted-basement under E-W to NW-SE extension stress field (Fig. 5). This extension tectonics is the response of the back arc spreading of the Japan Sea, which occurred during 16-15 Ma (Otofuji et al, 1985).

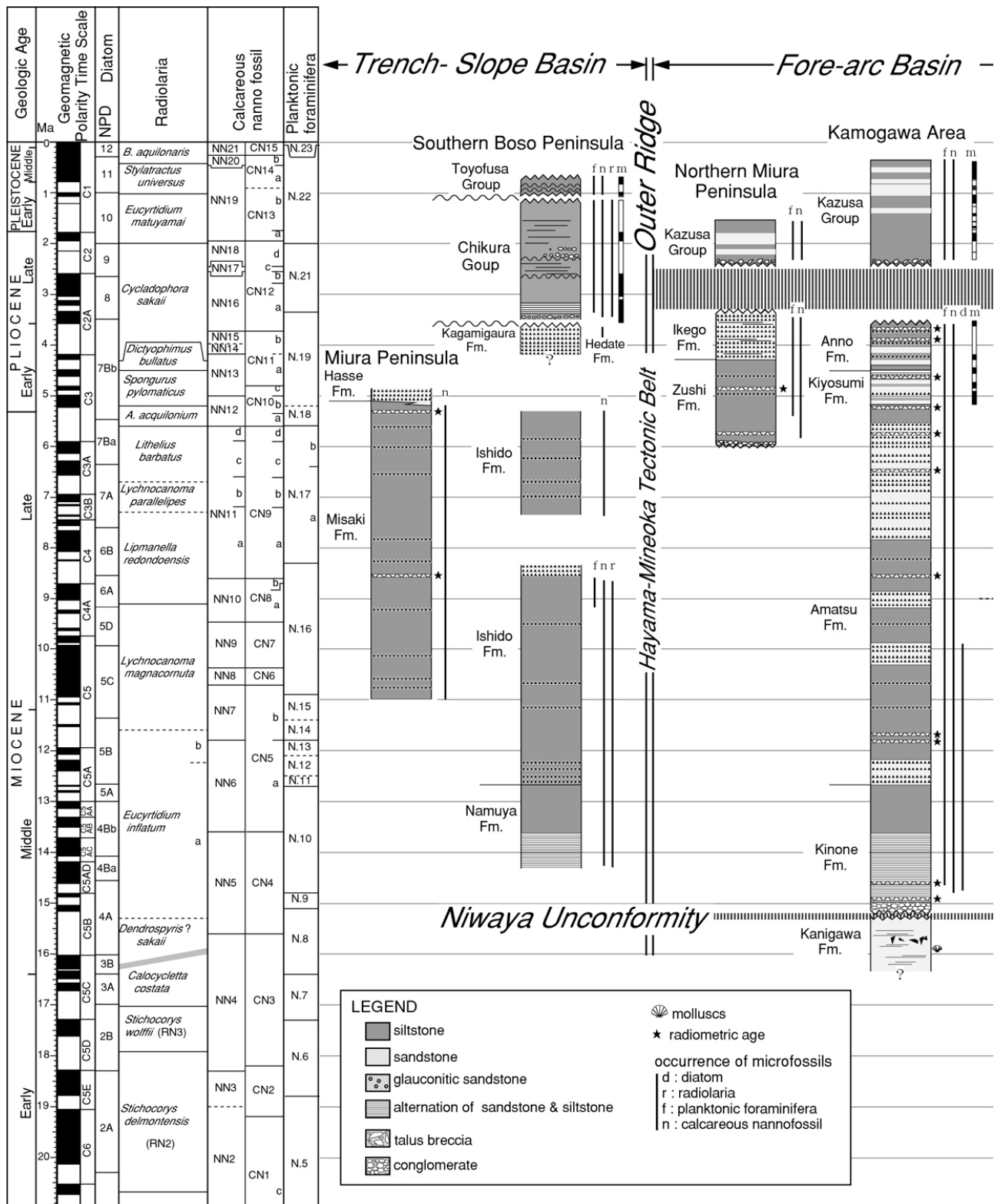


Figure 3. Correlation of the sedimentary sequences in the Kanto Plain (modified from Takahashi et al., 2003). Geologic age: Berggren et al. (1995), Geomagnetic polarity time scale: Cande and Kent (1995); Diatom zones: Yanagisawa and Akiba (1998), Watanabe and Yanagisawa (2003); Radiolarian zones: Motoyama (1996) and Kamikuri et al. (2004); Nannofossil zones: Martini (1971) and Okada and Bukry (1980); Planktonic foraminiferal zones: Blow (1969).

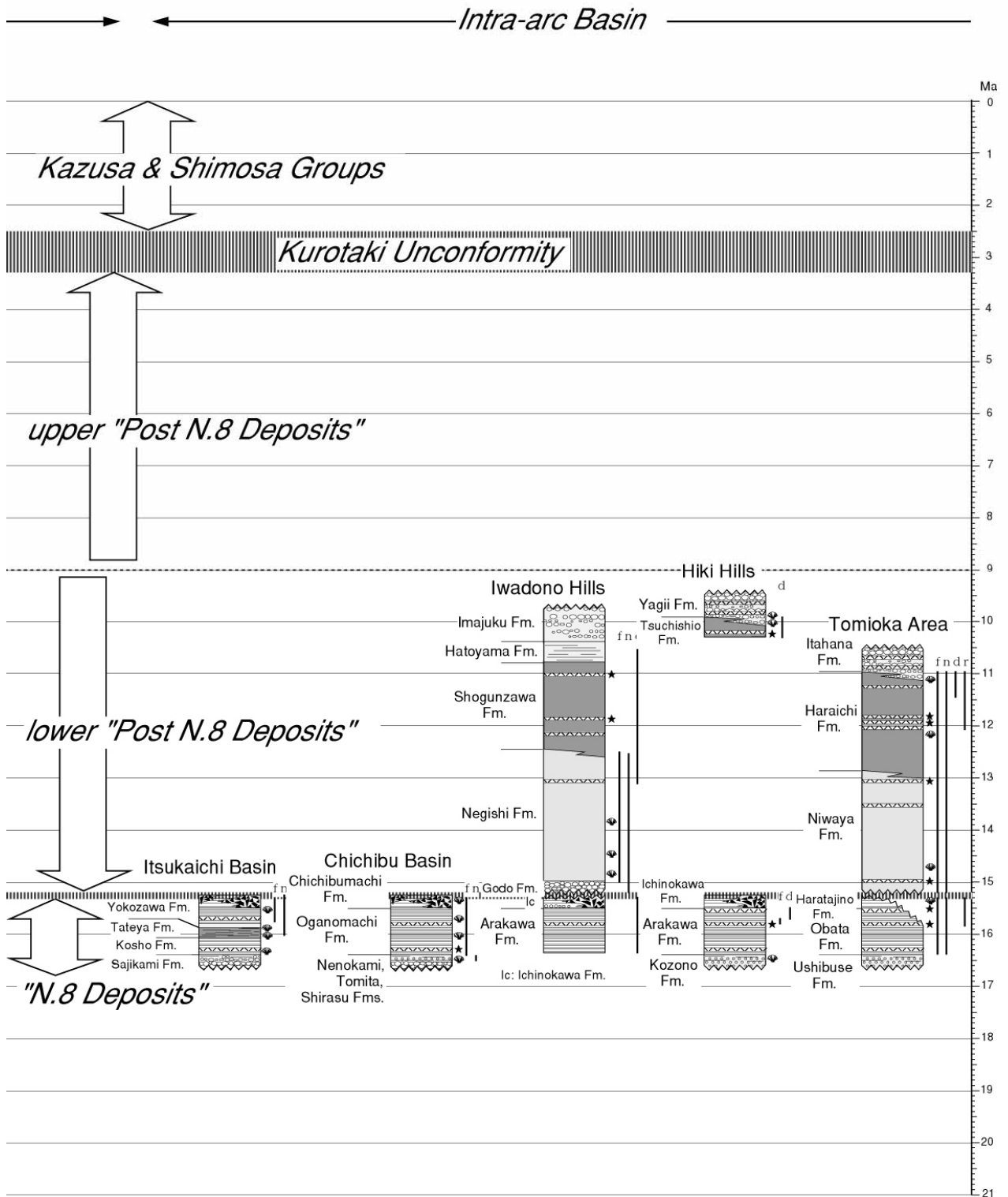


Figure 3. Continued.

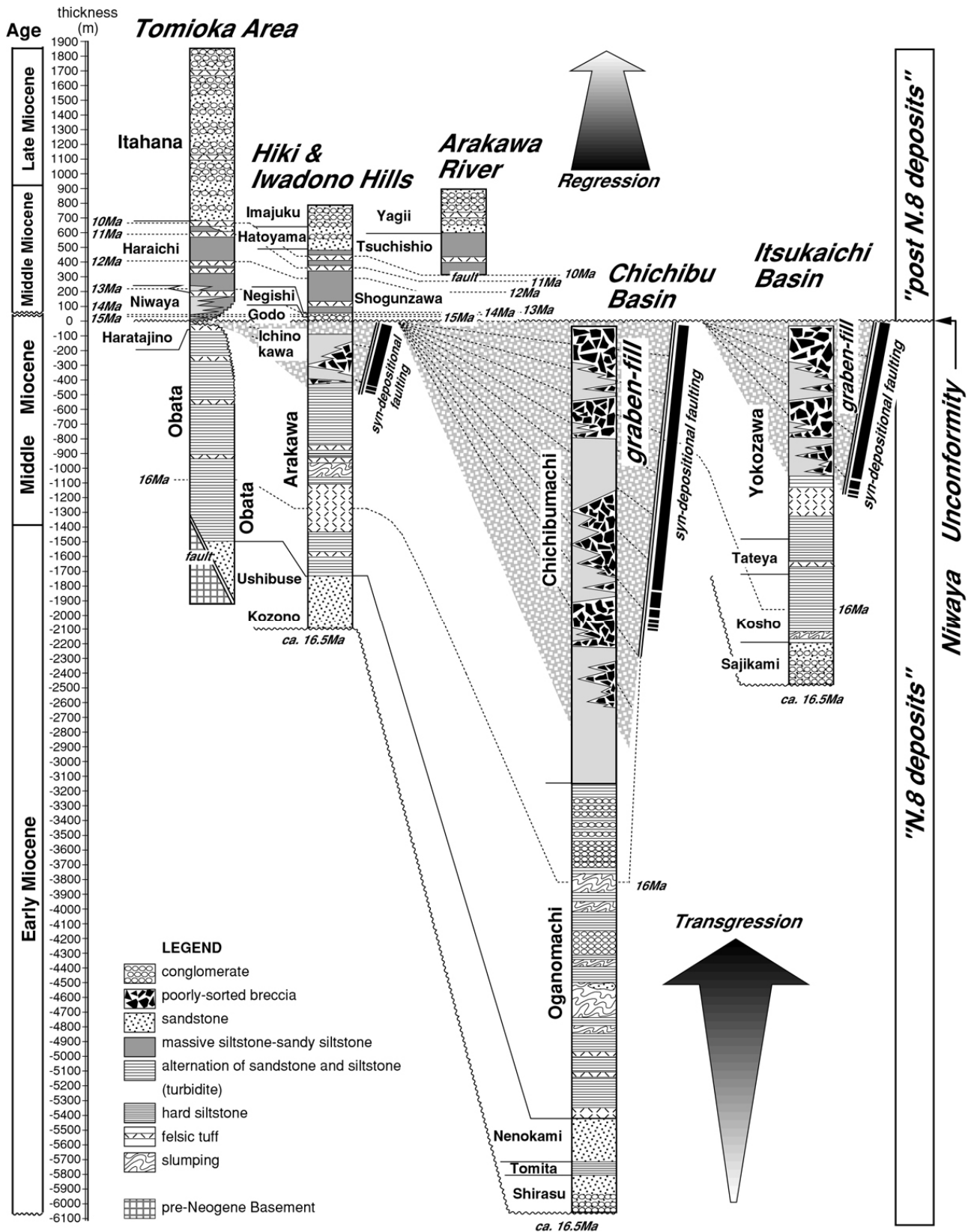


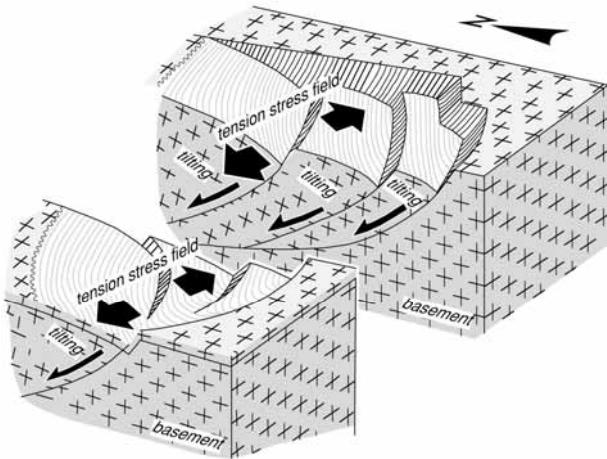
Figure 4. Stratigraphic correlation of some typical Miocene sequences in and around the Kanto Mountains (Takahashi and Yanagisawa, 2004). The “N.8 deposits” of each sedimentary basin are characterized by very thick graben-fills deposited during a geologically very short interval (only 1 million years). However, overlying “post N.8 deposits” show much lower sedimentation rate.

Compression deformation occurred during a very short interval (15.3-15.2 Ma), resulted in the inversion of reverse faulting of pre-existing normal faults surrounding each half-graben (Takahashi, 1992). The “N.8 deposits” were faulted and folded, and anticlinal uplifting portion was eroded (Niwaya Unconformity; Oishi and Takahashi, 1990).

After the Niwaya Unconformity (<15.2 Ma), the Kanto region was subsided gently (Takahashi and Hayashi, 2004), and very fine clastics were accumulated widely and slowly (“post N.8 deposits”). No major tectonic change occurred after the Niwaya Unconformity (15.2 Ma) until the Kurotaki Unconformity (ca. 3 Ma).

Latest 3 million years are characterized by compression tectonics. The Kanto Mountains uplifted while the Kanto Plain subsided. During this interval, thick sediments (Kazusa and Shimosa Groups) covered and concealed both the “N.8 deposits” and “post N.8 deposits” (Fig. 6).

#### Development of half-graben



#### Syn-depositional tectonics

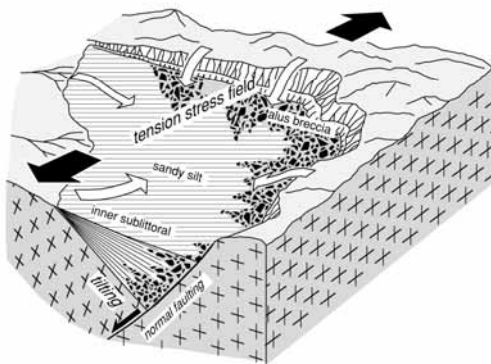


Figure 5. Schematic diagrams of the tilting of basement and filled up of the Miocene Chichibu Basin. Listric normal faulting occurred under extension stress field (A), and this half-graben was accumulated by thick sediments. Along the boundary normal faults, talus breccia was supplied from surrounding basement.

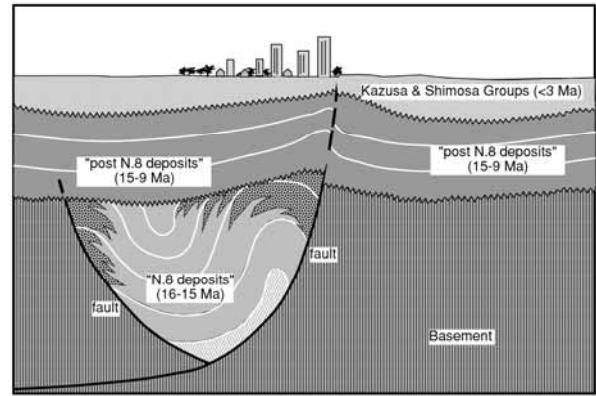


Figure 6. Schematic model for the geology in the Kanto Plain established by thorough geological survey of sedimentary sequences exposed in hilly area around Kanto Mountains. Very thick “N.8 half graben fill deposits” are confined in narrow area bounded by faults. In contrast, unconformably overlying “post N.8 deposits” are distributed widely. Kazusa and Shimosa Groups (< 3 Ma) cover the underlying sediments, unconformably.

#### 4. Model of subsurface Geology

As described above, the subsurface geological character of sedimentary rocks, concealed by the Kazusa and Shimosa Groups, may be the same as the surface geology, and therefore, the subsurface geology in the Kanto Plain is expected to consist of “N.8 deposits” and overlying “post N.8 deposits”. To test this hypothesis, we examined a typical seismic profile (KAN-94) along the western margin of the Kanto Plain (Fig. 1), using a deep borehole data for a reference section to interpret the profile.

As shown in Fig. 7, the seismic profile of KAN-94 exhibits complicated structure with a number of abrupt up-and-down reflectors below the almost horizontal reflections.

The most prominent deep reflector can be safely interpreted as the boundary between the Pre-Neogene basement and Neogene sedimentary sequences. The sedimentary strata above this boundary can be divided into three distinct units, which are separated by clearly recognized discontinuities. The surface geological model developed in this paper indicates that these three units are “N.8 deposits”, “post N.8 deposits” and overlying Kazusa and Shimosa Groups, in ascending order. This interpretation is supported by microfossil chrono-logical data obtained at a nearby borehole. The stratigraphic relationships of the lower and upper boundaries are Niwaya (15.3-15.2 Ma) and Kurotaki (ca. 3 Ma) Unconformities, respectively.

Two fan-shaped structures of the “N.8 deposits” recognized in the KAN-94 profile can be interpreted as half-grabens, as illustrated in Fig. 7. Therefore, we can conclude that two concealed subsurface half-grabens lie underneath of the western Kanto Plain.

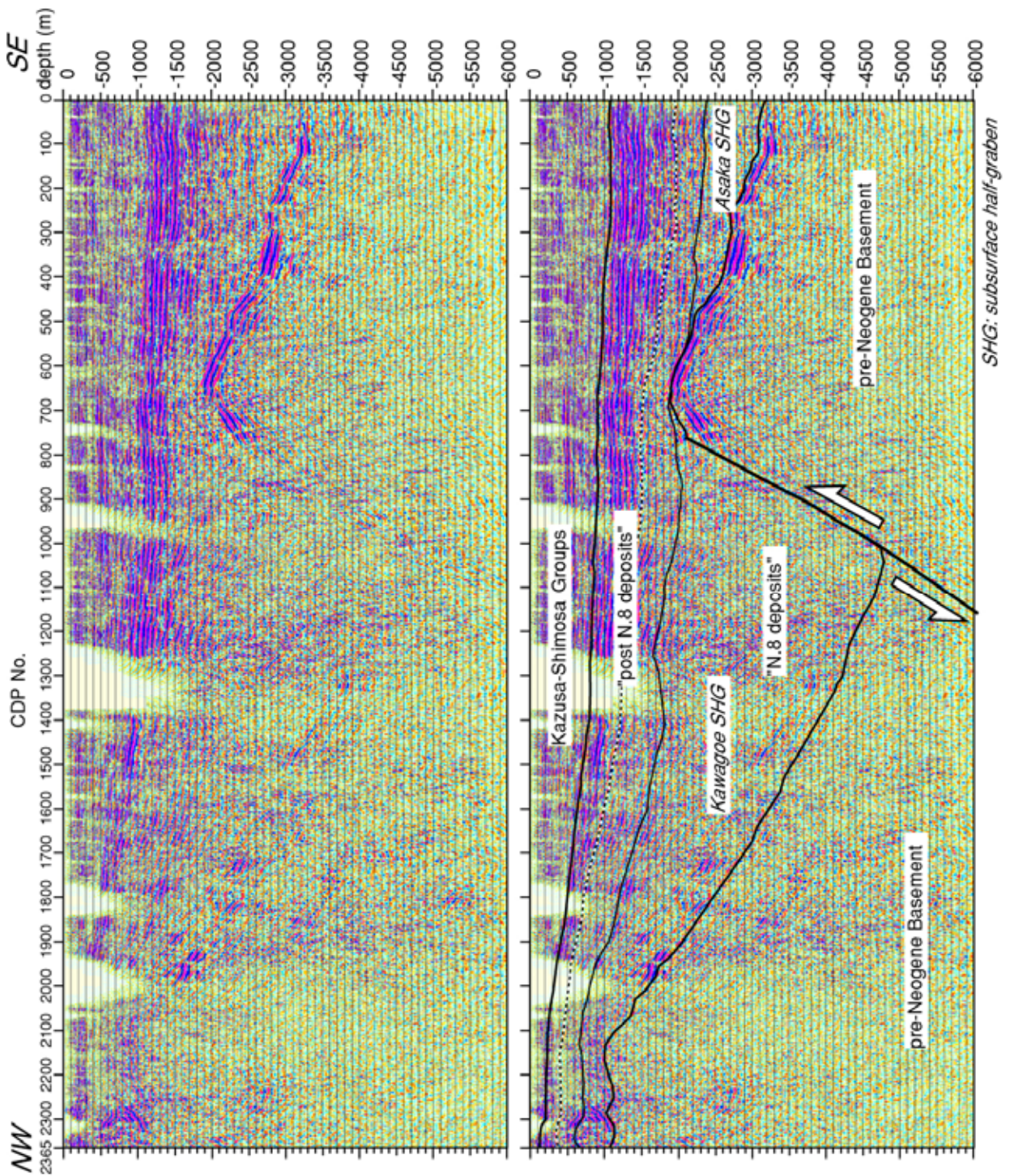


Figure 7. Seismic reflection profile along the Asaka-Konosu Line (KAN-94), and its geological interpretation.

A number of such subsurface half-grabens filled with thick “N.8 deposits” may be present underneath the Kanto Plain, although their location and size are not known at present due to the scarcity of reliable borehole data and seismic profiles.

The surface geological model (Fig. 6) suggests the presence of a large normal fault in front of each tilting half-graben (Fig 8). The depth of pre-Miocene basement rocks along these boundary normal faults abruptly changes. These normal faults such as Tachikawa Fault (Fig. 1) would be re-activated as reverse fault under recent compression stress field. Therefore, it is crucial to clarify the distribution of concealed subsurface “N.8 deposits” and the location of the boundary normal faults of each “N.8 half graben” for estimation of strong motion caused by large earthquakes.

## 5. Conclusion

This study established a general model for the deep subsurface geology of the Kanto Plain, integrating geological and geophysical data sets. The sedimentary sequences in the Kanto Plain are composed of three distinct units of “N.8 deposits”, “post N.8 deposits” and the Kazusa-Shimosa Groups, which are separated by regional unconformities. In particular, the distribution pattern of subsurface “N.8 deposits” and the location of the boundary normal faults of each “N.8 half graben” are the most important. Our model will contribute for constructing a seismic velocity model and estimating possible strong motion caused by large earthquakes.

*A: Kazusa & Shimosa Groups (<3 Ma)*  
*B: "post N.8 deposits" (15-9 Ma)*  
*C: "N.8 deposits" (16-15 Ma)*

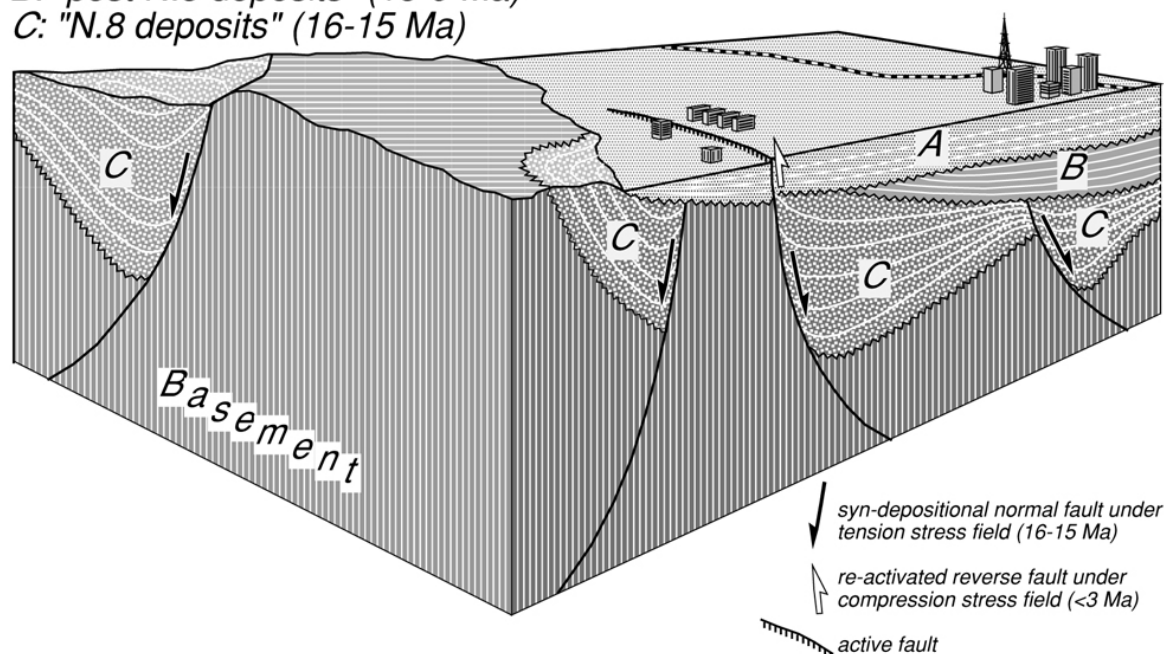


Figure 8. Three-dimensional model of the “N.8 half graben fills” and unconformably overlying “post N.8 deposits”. Kazusa and Shimosa Groups cover the underlying sediments, unconformably. Under present compression stress field, pre-existing boundary normal faults of the “N.8 half-grabens” would be re-activated. The Tachikawa Active Fault may be one of these re-activated faults.

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