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Changing Tectonic Regime During the Plio-Pleistocene in the Kinki Region.

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Abstract

The location and continuity of active faults comprising a part of the Kinki region are clearly expressed in terms of topography. This area is the so-called Kinki Triangle; a region where many of Japan's active faults are concentrated within the triangle area. This study presents the results of seismic reflection surveys across active faults of the reverse fault systems (Yoro and Katata faults) and transcurrent fault system (Arima-Takatsuki Tectonic Line) forming the margins of the Kinki Triangle. The subsurface configurations of the active faults are interpreted in correlation with geomorphological, geological and geophysical information. On the basis of these seismic interpretations, the tectonic regime in the Kinki region is discussed.

The results of this study are summarized as follows; it is likely that the compressional axis has likely changed from NW-SE to E-W in 2.7 Ma to 0.6 Ma as inferred from the growth structure by movement of active faults in the Kinki region. A time lag of this axis change is identified; starting in the northeast and shifting to the northwest of the region.

1) Introduction

The location and continuity of active faults composing the margins of the so-called Kinki Triangle (Huzita, 1962) are in general clearly expressed in the large scale topography (Fig. 1). However, detailed locations of active faults are not easily determined because they are often covered by alluvial fans and delta deposits or eroded by natural agents as well as modified by human activity.

Thick sequences of Plio-Pleistocene unconsolidated sediments are distributed in the Kinki region. The volcanic ash layers lying between these layers are potentially good key beds for tracing time markers. Therefore, the Kinki region is an ideal location to conduct a study of seismic stratigraphy in Japan, because comparisons may be made of seismic sections and logged data from deep drillings in a number of those sections, and moreover many dates of key beds are available as a result of detailed geological investigations in this region. Slip rates of vertical displacement and changes of deformation mode can be determined by comparing partitions of seismic sections with the results of deep drilling.

The late Quaternary regional east-west compressional axis was estimated from focal mechanisms of small earthquakes and stress measurements in bore holes around southwest Japan (Tsukahara and Kobayashi, 1991; The Research Group for Crustal Stress in Western Japan, 1994). The 1995 Hyogo-ken Nanbu earthquake was caused by the displacement along a right-lateral strike-slip fault trending in the northeast-southwest direction. The focal mechanism is consistent with the east-west directed compressional regime (Kikuchi, 1995). Geodetic data also show east-west horizontal shortening (Geographical Survey Institute, 1994).

According to Huzita (1969), a change of the tectonic stress state since the Miocene took place in the inner zone of southwest Japan during the Plio-Pleistocene. This change of the compressional stress state from N-S to E-W was conspicuous. In fact, this change was established by the study of Miocene dyke swarms (Kobayashi, 1979) and studies of Plio-Pleistocene sedimentological analysis (Takemura, 1985). According to Takemura (1985), this change of stress field seems to be delayed to the west.

The seismic reflection survey is one of the most useful methods among common exploration prospects in terms of resolution and imaging capability of subsurface structures. Seismic reflection surveying can also provide information on the continuity and discontinuity of formation, flexure and fault. The detailed structural changes such as unconformity and lateral transformation of strata can be estimated with the history in the direction of the compressional axis and its geological time from the results of all of these surveys.

In this study, I present some results of seismic stratigraphy in the Kinki region. The reverse-type fault system is subdivided into high-angle and low-angle thrust, reverse fault and frontal thrust (Ouelette and Boucher, 1983), respectively. The frontal thrust is defined as the active fault which develops basinward several km distant from the inactive geological main boundary fault (MBF). This migration of the fault system and its accompanying deformations are known as thrust-front migration (Ikeda, 1983). The subsurface structure of active faults is interpreted from the results of these seismic surveys and is correlated with geomorphological evidence (such as stream offset and fault scarps identified from aerial photographs), geological information (obtained by field-work including hillside geology and analysis of deep drilling) and geophysical data (seismicity and geodetic measurement). It is important to understand the relationship between the subsurface structure and the associated surface deformation from the late Quaternary movement of active faults beneath the alluvial plain. I deal with the tectonic regime of the region based on the results of the seismic interpretations.

2) Geological Setting

The Kinki Triangle (Huzita, 1962) is a roughly triangular shaped region on map view in Central Japan defined by the Tsuruga, Ise, and Osaka bays and is a typical region for a study of Quaternary active tectonics (Fig. 1). It is generally believed that this region was formed under an east-west compressive geodynamic regime since the Middle Pleistocene (Huzita and Kasama, 1982). It is characterized by the presence of left-lateral faults along its northeast margin, right-lateral faults along its northwest margin, and north-south striking reverse

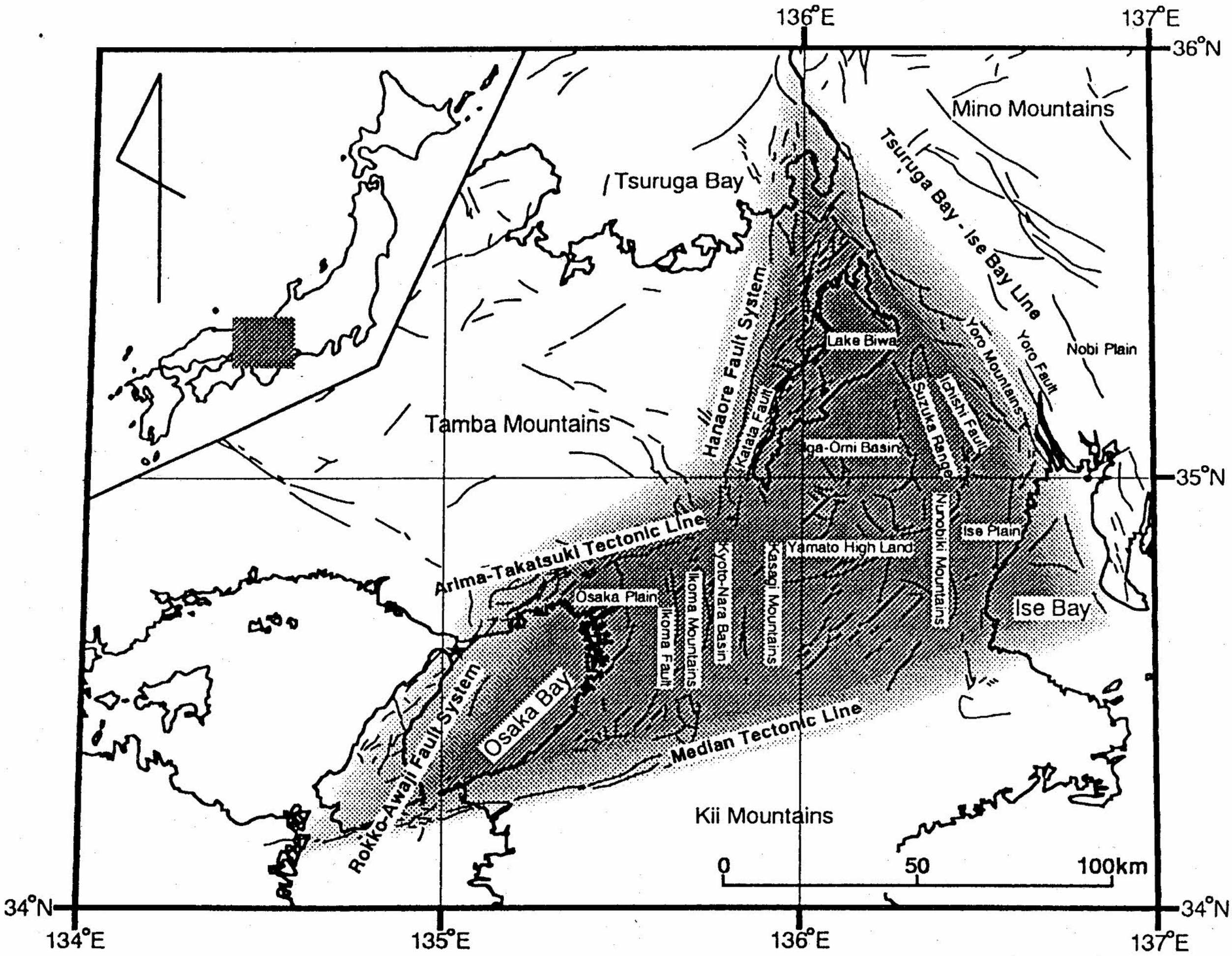

Fig. 1 Map showing active faults in the Kinki Region (after the Research Group for, Active Faults of Japan, 1991). The stippled area is the Kinki Triangle (after Huzita, 1962).

faults within this triangular region (Huzita, 1962).

Topographically high relief regions surrounding the Kinki Triangle include the Mino mountains on the northeast side, the Tamba mountains on the northwest side and the Kii mountains on the southern side. (Fig. 1).

The geology of the Kinki Triangle and surrounding mountains is composed of the following units: Mountainous regions are made up of the Tamba - Mino belt (Paleozoic-Mesozoic sedimentary rocks), Ryoke Granites and Late Mesozoic pyroclastic rocks (Arima Group, Sennan Group). Low relief basement rock mountains are covered by the Ichishi, Tsuduki and Nijo Groups belonging to the first Setouchi Super Group (Miocene). Non-marine sediments (late Pliocene - early Pleistocene) and non-marine - marine sediments (middle Pleistocene) belonging to the second Setouchi Super Group are distributed in and around the basins. They are named the Tokai Group, Kobiwako Group and Osaka Group from east to west respectively, and are found in the Nohbi - Ise basin, the Iga - Ohmi basin and the Osaka - Kyoto - Nara basin (Geological Survey of Japan, 1986) (Fig. 2).

The Yoro fault is located in the center of the northeast side of the Kinki Triangle and is known as a typical reverse fault (Geological Survey of Japan, 1994). The Katata fault is located at the western side of Lake Biwa between the Katata hills and the alluvial plain. The 1662 Kambun Earthquake, one of the largest Inland events (M ≒ 7.5), is estimated to have occurred around this area (Hagiwara, 1982). The Arima-Takatsuki Tectonic Line (ATL) clearly divides the Tamba mountains and the Osaka plain. The ATL consists of east-west trending right lateral faults. The epicenter of the 1995 Hyogo-ken Nanbu Earthquake was determined at the Akashi strait: southward of the western end of the ATL (Kikuchi, 1995).

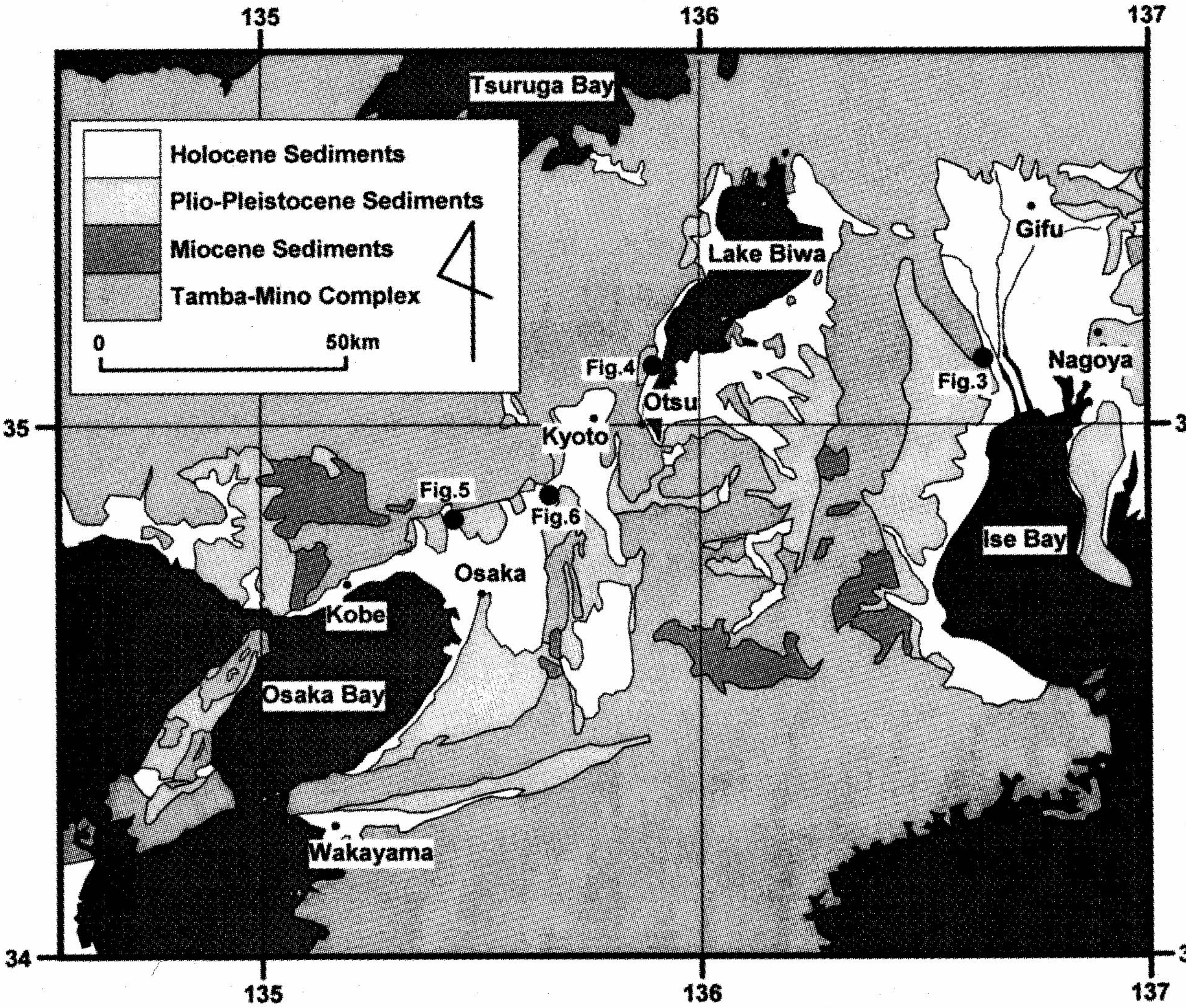

Fig. 2 Map showing geology in the Kinki Region (after Geological Survey of Japan, 1986). The solid circles correspond to Figs. 3-6.

3) Data Acquisition, Analysis and Seismic Sequence Division

I have made four seismic reflection surveys in the Kinki region. A 250 kg accelerating weight-drop source (BISON, EWG-3) and, a 24 channel seismic recording system (OYO, McSeis 16000) was used for these surveys. The spread of the source and receivers was usually the end-on-shooting type with the shot and receiver intervals being 10 m and 20 m, respectively. Maximum receiver-group offset was 480 m. Field data were analyzed by using a general CMP Stack Method.

Seismic sequences are first divided into some layers around a typical flat-layered structure, based on the typical traceable reflectors, features of reflectors and the interval velocities on the time section. More than 3,000 m/s P-wave velocity suggests the presence of basement rocks. The interval velocity less than 3,000 m/s are classified into Plio-Pleistocene and Holocene sediments by the previous seismic reflection studies (Yoshikawa, et. al., 1987).

On the depth section, seismic sequences are compared with the geological stratigraphic units of the close deep drilling cores, and the drilling cores of apart from the survey line which is inferred no large geological gaps between the drilling sites and the line according to the gravity anomalies.

4.1) Survey of the Yoro Fault

According to the Research Group for Active Faults of Japan (1991), the Yoro fault is a 30 km long structure, oriented NNW-SSE. The fault overlays the western portion of the Nohbi tilted block which is noted as tilting to the west, located on the central part of the northeast side of the Kinki Triangle along the Tsuruga - Ise bay Line (Fig. 1), and known as a systematic left-lateral fault (Geological Survey of Japan, 1994). It has a significant vertical component and the degree of activity is classified as class B (activity of class B has average slip rate in the order of 1 - 0.1mm per year).

It is known from deep drillings that the sediments under the Nohbi plain consist of five principal units; pre-Tokai Group, Kono, Kuragari and Oizumi formations of the Tokai Group, and middle Pleistocene to Holocene sediments. On the other hand, Mino sedimentary rocks, Biroku, Kono, Ichinohara, Kuragari, Oizumi and

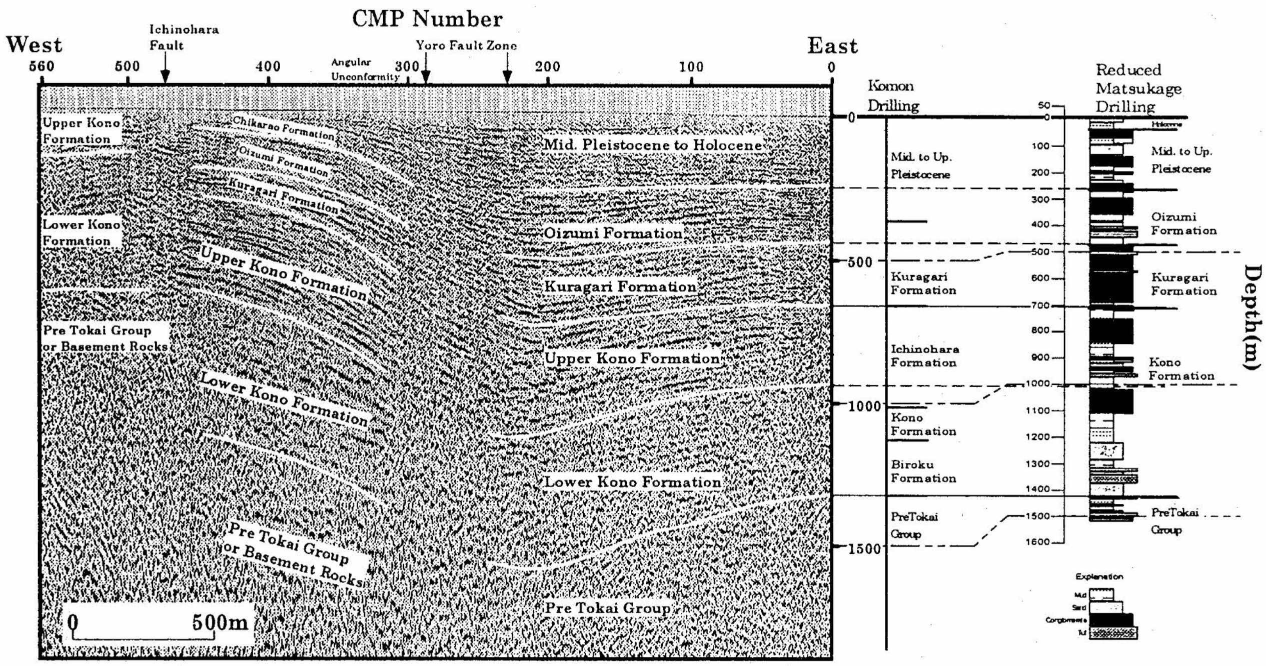

Fig. 3 Interpreted migrate depth section across the Yoro Fault. Vertical scale is in meters with no vertical exaggeration. Top of the section is adjusted to the sea level. The section begins in the Nohbi plain and extends to the Tado hill. The thin lines indicate reflector horizons. The seismic section was sub-divided into 6 layers based on the structure of reflector horizons, the interval P velocity after calculating the RMS velocity and comparing the deep drillings.

Chikarao formations and Alluvial deposits outcrop along hillsides at the Ise plain (Yoshida et al, 1991).

A seismic reflection survey was carried out on a non-paved agricultural road along the Hijie river. The length of the survey line was 2.8 km (Toda et al., 1997).

The eastern part of the section (Fig. 3) is divided into six layers, based on the features of reflectors and the interval velocities. The interval velocity rapidly increases from 3000 m/s up to 4000 m/s in the lower part, suggesting the presence of basement rocks with P-wave velocity more than 3000 m/s. Next, The seismic section is correlated to the stratigraphic column section by deep drillings (Fig. 3). The remarkable reflectors in the section at 650 m depth and 1,300 m depth were correlated with the bottoms of the Kuragari formation and the Tokai Group as the typical lithologic layers of the Komon drilling. The Matsukage drilling is located at the mouth of the Kiso river, about 10 km down stream from the Komon drilling. The drilling logs at Matsukage are reduced as the top of the Kono formation and the Tokai Group to fit with that of the Komon drilling logs (Fig. 3). The other strata are correlated with the reduced Matsukage drilling which is reclassified by the sedimentological studies.

The central and western parts of the section are correlated to the subsurface geology using the division of the eastern part of the section on the basis of surface geology, the P-wave interval velocities and the features of reflectors. The interpreted depth section shows about 500 m vertical displacement at the bottom horizon of the Tokai Group between both sides of the Yoro fault zone (Fig. 3). The thickness of the mutually correlated layers is compared between the eastern and central part of the section. The thickness of the Kono formation between both sides of the Yoro fault zone seems to be almost the same. But, some difference is recognized in the thickness of the Kuragari formation (2.7 Ma) between both sides. From this point of view it is presumed that the activity of the Yoro fault started to dislocate after the deposition of the Kono formation and during the deposition of the Kuragari formation. Thus, growth strata and pre-growth strata are correlated to the shallower Kuragari formation and the deeper Kono formation, respectively.

According to Takemura (1985), the Kuragari formation around the Ise plain includes many gravels of Cretaceous Nohi rhyolites, which originated in the central part of Honshu, showing the existence of paleo-current from the NE to the SW. The fact that the distantly originated gravels of the Nohi rhyolites are included only in the Kuragari formation suggests that the Nohbi tilted block activated during the time of deposition and that there was little topographical gap across the Yoro fault and a great amount of gravel was transported to the Ise plain from the high mountainous area to the northeast. After this time the Yoro fault is presumed to have started a rapid movement of faulting. This supposition is consistent with Takemura1s (1985) opinion.

4.2) Survey of the Katata Fault

Large-scale reverse faults (the Hira, Hiei and Katata faults) trending in the NNE-SSW direction are distributed at the western shore of Lake Biwa (The Research Group for Active Faults of Japan, 1991) (Fig. 1). The Hira-Hiei fault system is a main geological boundary between pre-Cenozoic basement rocks and Kobiwako Group late Pliocene - Pleistocene sediments. This system topographically is presumed to be located at the boundary between the Kobiwako Group, composed of furled hills, and the basement rock mountain (The Research Group for Active Faults of Japan, 1991), and the fault is partly unconformably covered by higher terrace deposits. This fault has not been active through the late Quaternary period (Hayashi, 1974).

The Katata fault is located at the eastern side of the Hira -Hiei fault system. According to the Research Group for Active Faults of Japan (1991), the Katata fault has a 30 km long arched trace oriented mostly in the N-S direction and is located on the central part of the northwest side of the Kinki Triangle. The Katata fault is an active fault separating the Katata hills from the alluvial plain west of Lake Biwa (Fig. 4). The fault has a vertical offset of displacement and its degree of activity is classified as class B as determined from the relative height of fault scarplets on the terrace.

The Katata formation, which is distributed on the Katata hills, is subdivided into seven units (Nijigaoka clays, Wani sands, Ogoto clays, Ogoto sands, Kamiogi clays, and Ryuge sand and gravel) (Fig. 4).

The profiles obtained by multi-channel seismic-reflection surveys (Fig. 4) on the Katata (1.6 km length) survey line around the southern part of Lake Biwa (Toda et al., 1996).

These surveys on both sides in the southern part of Lake Biwa reveal about 1,000m thick sediments under the lake. Three key seismic reflection horizons were observed in the Katata survey line (Fig. 4). A low angle thrust in the Quaternary sediments caused horizontal shortening as flexure is recognized in this section.

A geological column on Fig. 4 is inserted in the section on the hillside. The described three reflectors are compared to the top of the Kamiogi clays, Ogoto sands and the basement rocks, respectively (Fig. 4). The eastern side of the section is classified from the interval velocity and the features of reflectors.

As a result, the total amount of vertical offset across the Katata fault at the horizon of the basement rocks is estimated to be about 500 m, and the thickness of the corresponding formation differs on both sides of the fault. No apparent pre-growth strata are recognized on the profile. The age of the bottom of the Katata formation is determined as 0.9 Ma (Hayashi, et. al., 1976).

4.3.1) Survey of the Arima-Takatsuki Tectonic Line

According to the Research Group for Active Faults of Japan (1991), the ATL is an E-W striking, 44 km long, right-lateral fault located on the central part of the northwest side of the Kinki Triangle. The degree of fault activity is class B.

The ATL clearly divides the Hokusetsu mountains and the Osaka plain (Huzita and Okuda, 1973). The northeast-southwest trending Hanaori and the Rokko fault system exhibit right-lateral faulting formed by east-west compression. The ATL is also thought to be a right-lateral fault, because it is located between the Hanaori and the Rokko fault system. The ATL roughly coincides with the geological boundary between the Tamba Group (Tamba Belt) and the Ryoke Granites (Ryoke Belt). The NE-SW trending the Baba, the Minoh and the Satsukiyama faults which are branching from the ATL also show evidence of right-lateral faulting such as the bending of spurs and valleys (Geological Survey of Japan, 1986).

Thick unconsolidated late Neogene sediments deposited in the Osaka basin are divided into four strati-

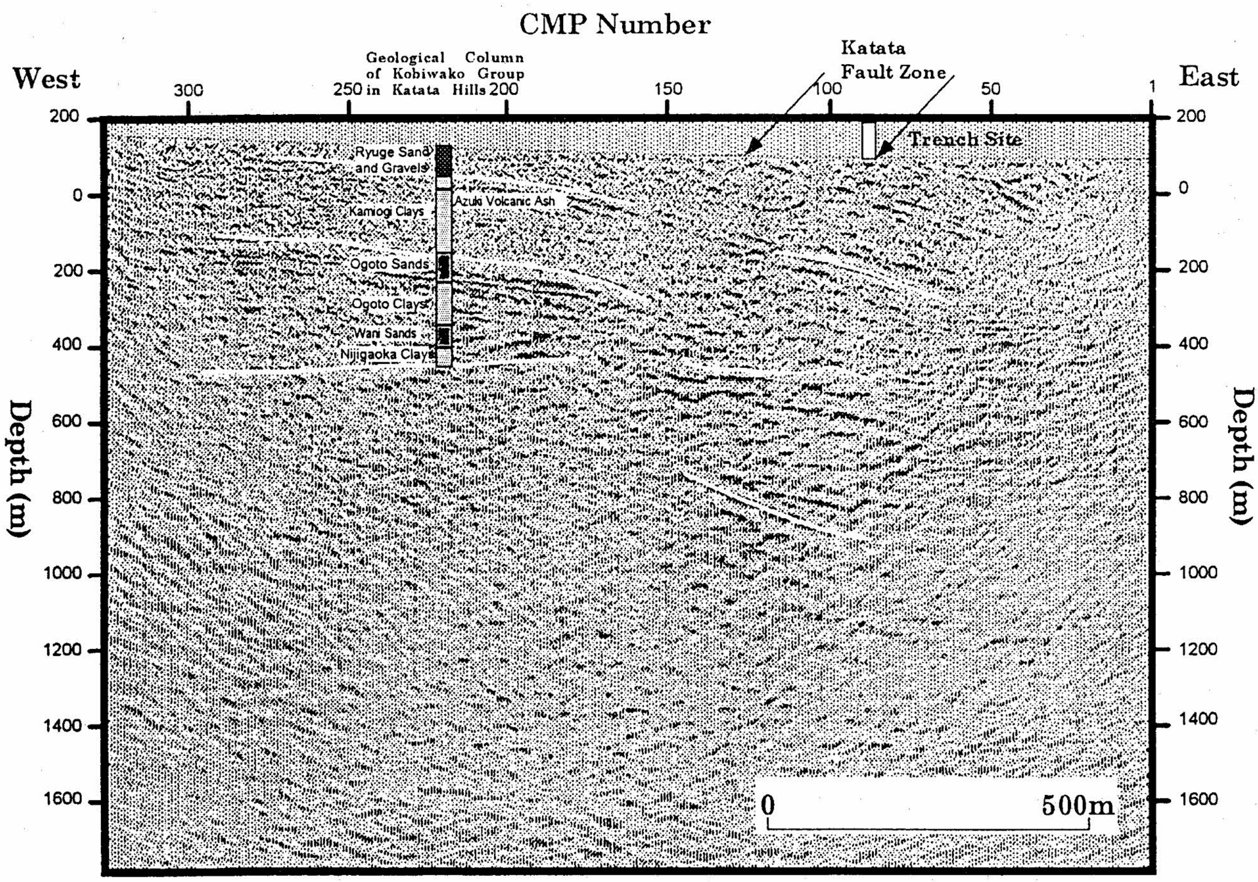

Fig. 4 Interpreted migrate depth section of the Katata survey line. Vertical scale is in meters with no vertical exaggeration. Top of the section is adjusted to the sea level. The section begins in the coast of Lake Biwa (right side) and extends to the Katata hills (left side). The thin lines indicate reflector horizons.

graphic units; 1) the Kobe Group, 2) the Osaka Group, 3) the terrace deposits, and 4) the alluvial deposits in ascending order. The Osaka Group is subdivided from the tectonic point of view into the Lower, Middle and Upper Subgroups. The Pliocene Lower Subgroup consists of non-marine sand and gravel, silt, and clay beds. The Middle and Upper Subgroups, Early to Middle Pleistocene in age, consist of alternating beds of non-marine sediments and marine clay. Many volcanic ash layers are also contained in the Osaka Group. The terraces in the Ina river survey area have been displaced by the Itami fault, the Koyaike graben, the Hanayashiki graben and the ATL. A syncline is found in the Otokoyama hill on the eastern side of the Yodo river survey line.

Two lines of seismic reflection survey with a total length of 8.7 km (Table 1) were carried out along the Ina and Yodo rivers across the ATL (Toda et al., 1995). The survey lines in Ina and Yodo river surveys are located in the northern part of the Osaka plain along the Ina and Yodo rivers and cross the central and eastern parts of the ATL, respectively.

Few clear reflectors appeared below the 1.0 sec. horizon on the time section, the interval velocities below the level are less reliable. At every picked CMP no., the interval velocity rapidly increases from 3000 m/s up to 4000 m/s in the lower part, suggesting the presence of basement rocks with P-wave velocity more than 3000 m/s. Interval velocity less than 3000 m/s are roughly classified into three group: around 1900 m/s, around 2200 m/s, and around 2500 m/s.

The depth section (Fig. 5) shows a similar feature as that obtained by the previous studies in the Osaka

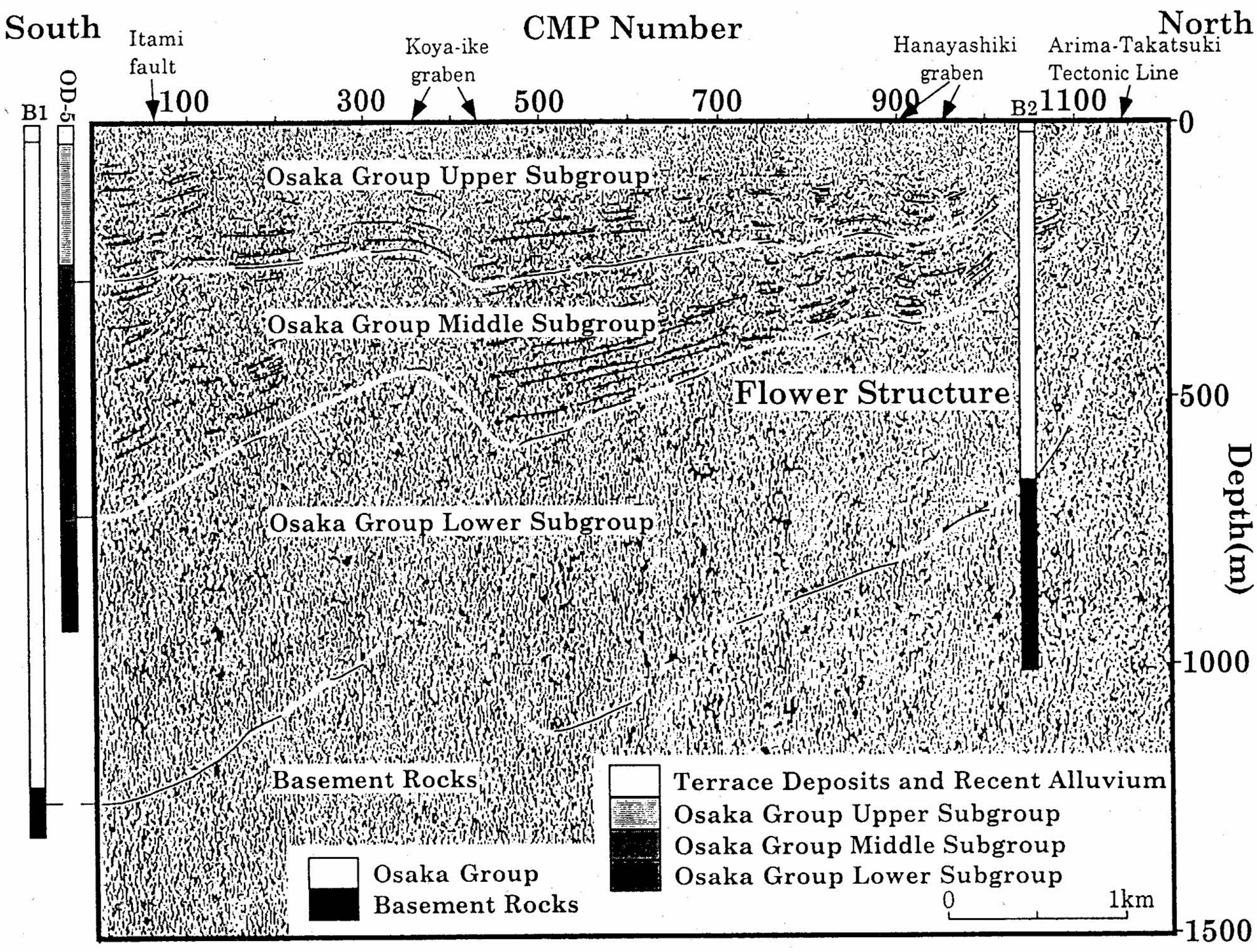

Fig. 5 Interpreted migrate depth section of the Ina river survey line compared with the stratigraphy of deep-drilling cores, OD-5, B1 and B2 (after Itihara 1991).
Vertical scale is in meters with no vertical exaggeration. Top of the section is adjusted to the sea level. The section extends from the Osaka plain (left side) to the Hokusetsu mountains (right side). The thin lines indicate reflector horizons. The seismic section was sub-divided into four layers (Upper, Middle and Lower Subgroup, and Basement Rocks) based on the structure of reflector horizons, the interval P velocity after calculating the RMS velocity and comparing with deep, drillings. Vertical displacement of the bottom of the Osaka Group Lower Subgroup across the Arima-Takatsuki Tectonic Line is about 1,000 m.

basin. The part above the 0.5 sec. horizon is characterized by many clear and laterally traceable reflectors, whereas the part from the 0.5 to 1.0 sec horizon shows several obscure reflectors. Below the 1.0 sec. horizon, few reflections are observable, suggesting the presence of basement rocks.

Since a flat-layered structure is clearest around CMP no.300 on the time section, the sediments are first divided into four layers, based on the features of reflectors and the interval velocities (Fig.5).

1) upper layer Around the 200 m horizon, a very clear reflector is traceable laterally on the entire section in Fig. 5. The A Layer is the part from the ground surface with interval velocity of 1,500 to 2,000 m/s. This layer is characterized by the lack of reflectors in the upper part and by the discontinuous but clear reflectors in the lower part.

2) middle layer The part from 200 to 500 m horizons corresponds to the B Layer with an interval velocity of 2000 to 2300 m/sec. This layer clear shows a series of cyclic and laterally traceable reflectors.

3) lower layer A weak reflector is recognized around the 1000 m horizon. The C layer extends from the 500 m horizon to the reflector, with an interval velocity of 2300 to 3000 m/s. This layer is characterized by fragmentary reflections with low frequency.

4) bottom layer The D layer is the deepest part below the reflector around the 1000 m horizon. This layer has the largest interval velocity, more than 3000 m/s, and shows very few reflectors.

This standard division is extended to the north and south from CMP no. 300 along the entire survey line. The four seismic layers are compared with the stratigraphic units of the three available deep drilling cores, OD-5, B1, and B2 after Itihara (1993) and Osaka City Office (1964) (Fig. 5). Although the sites of the OD-5 and B1 are apart from the survey line, no large geological gap in inferred between the sites and the survey line, according to the gravity studies of the Osaka basin (Huzita and Kasama, 1982; Gravity research group in Southwest Japan, 1994) and other seismic reflection studies (Yoshikawa et al., 1987; Yokota et al., 1996). Thus, it is thought to be possible to correlate the two cores with the seismic layers.

The boundary between the lower and bottom layers almost coincides with the interface between the basement rocks and the Osaka group recognized in the B1 and B2 cores. Compared with the stratigraphy of the OD-5 core sediments, the middle and lower layers roughly correspond with the Middle and Lower subgroups of the Osaka group, respectively. The upper layer is ascribed to the Osaka group Upper subgroup, the terrace deposits, and the Alluvium. The boundary between the upper and middle layers almost corresponds to the stratigraphic horizon between the Upper and Middle subgroup. Because this boundary is represented as a clear and laterally well traceable reflector on the seismic section.

4.3.2) Subsurface Structure of Yodo River Survey Line

The section along the Yodo river survey line was interpreted with consideration for surface geology, interval velocities, and feature of reflectors. Based on the correlation along Ina river survey line. At the Yodo river survey line, two flexures are discerned in the buried fault zone and they form a graben structure 0.5 km wide (Fig. 6). The graben structure at the horizon of the basement exhibits a subsidence at 200 m and 350 m on the northern and the southern sides respectively. Overlying the Osaka Group, the terraces and the alluvium are considered to have made flexure with faulting (Fig. 6).

The basement subsidence is considered to have been formed during the deposition of the Upper Subgroup. From this fact, the dips of the lower half of the Upper Subgroup and those of the Middle and Lower Subgroups are almost equal in the flexure on the southern edge of the subsidence. No difference in thickness of the Middle and Lower Subgroups is found on either side of the southern flexure. Thus, the shallower formation than the Upper subgroup of the Osaka group and the deeper formations than the Middle subgroup of the Osaka group are observed as growth and pre-growth strata, respectively.

The graben structures along the ATL have been active since 0.6 Ma, based on the age of the Upper Subgroup. The Yodo river survey line is arranged to cross the eastward extension of the Makami fault (Nishiyama Research Group and Earth Science Club of Katsura High School, Kyoto, 1970) and two buried faults, south and north sides upthrown, were detected in the section. From this result, the Makami fault was confirmed to connect to the syncline on the Otokoyama hill across the Yodo river. The fact that the Lower Subgroup is lacking in the northern side of the subsidence in the Yodo river section cannot be explained only by the accumulation of the vertical offset, but some horizontal offset must be assumed. This is consistent with the opinion that the ATL has a predominantly right-lateral slip movement (Sangawa, 1978).

5) Active Tectonics in the Kinki Region

In this section, I try to reconstruct the tectonics of the Kinki region. The Tsuruga bay-Ise bay line which occupies the northeast side of the Kinki Triangle has been active since 2.7 Ma, because there appears to be no change in the thickness of the Kono formation (2.7 - 3 Ma). This is probably the reason why the Yoro fault was a strike slip feature at that time, and it is also assumed that the direction of strike-slip faulting is similar to the left-lateral Yanagase fault, and the compressional axis was oriented NW-SE. Since 2.7 Ma, the sedimentary layers were probably displaced on one side through a combined west-side uplift accompanied by flexuring, thus transforming the Yoro fault into a reverse fault. This motion was most likely accompanied by tilting to the west of the Nohbi tilted Block since 2.7 Ma. At about that time, the compressional axis is assumed to have changed to a more E-W orientation.

Before and after deposition of the Katata formation (0.9 Ma), the Hanaori fault probably acted as a transcurrent fault judging from its length and linearity. Since at least 0.9 Ma, the deformation of the Katata formation suggests that displacement started as a frontal thrust. The compressional axis became E-W in orientation at about that time.

Before deposition of the Upper Subgroup in the Osaka Group (0.6 Ma), the ATL was a right-lateral fault and the Rokko mountains were uplifted along a reverse fault. Based on the linearity of the ATL and the uplift of the Rokko mountains on the northwest side of the Kinki Triangle, fault activity probably started by 3 Ma, about the same time as in the northeast side of the Kinki Triangle. The compressional axis was NW-SE around the ATL in 3 Ma - 0.6 Ma. The ATL became an oblique fault connecting the Hanaori fault and the Rokko fault

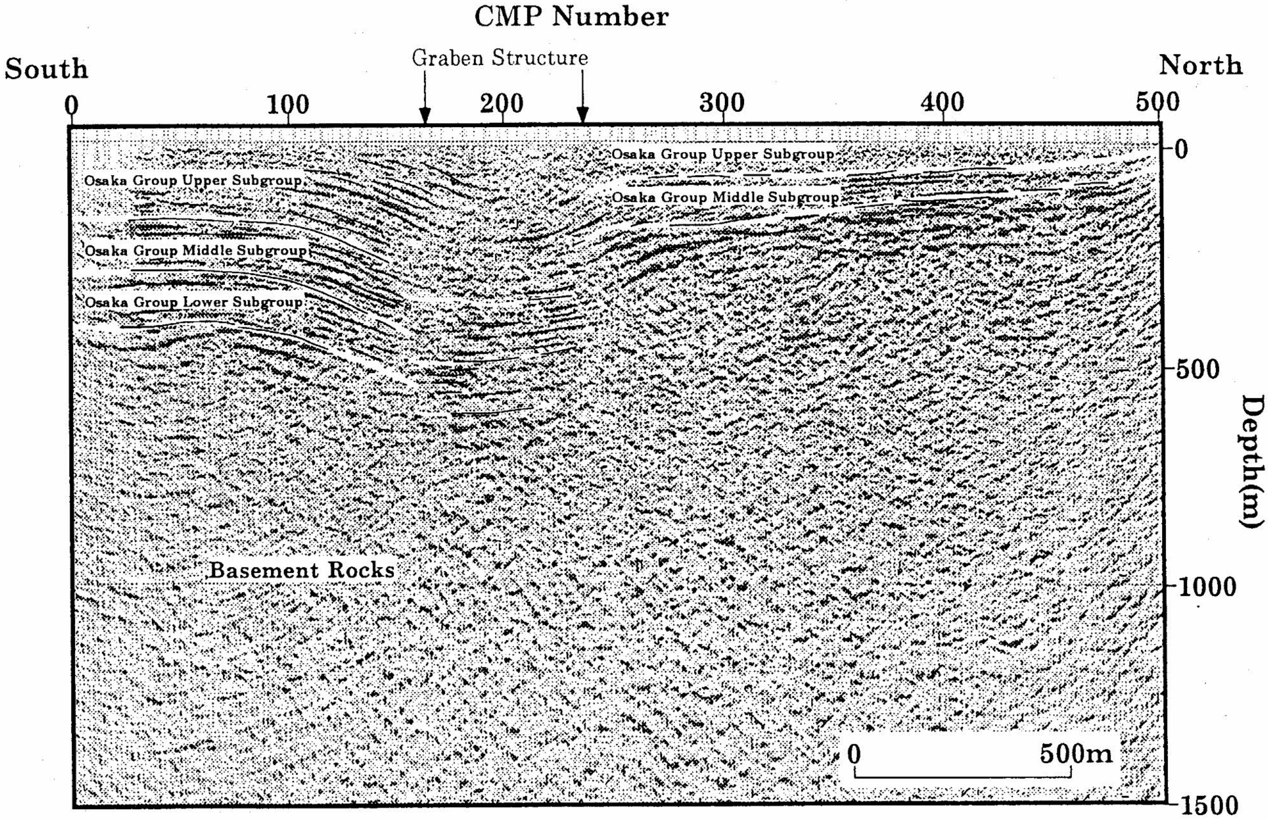

Fig. 6 Interpreted migrate depth section of the Yodo river survey line. Vertical scale is in meters, without vertical exaggeration. Top of the section is adjusted to the sea level. The thi lines indicate reflector horizons. The seismic section was sub-divided into 4 layers (Upper, Middle and Lower Sub-Group, and Basement Rocks) based on the structure of reflector horizons, the interval P velocity after calculating the RMS velocity and comparing the deep drinillings. A graben is observed at CMP 150 to 250, and is 500 m wide with the southern and northern sides measuring 200 and 350 m, respectively, top to basement rocks.

system since 0.6 Ma, because the graben structures have progressed since the formation of the Upper Subgroup. The compressional axis became almost E-W after 0.6 Ma, also around the ATL.

The tectonic history described above is summarized in Fig. 7. The compressional axis changed from NW-SE to E-W as inferred from the tectonics of active faults in the Kinki Triangle since 3.0 Ma. A time lag in the change in direction of the compressional axis is observed depending on the location in the Kinki Triangle. This time lag was presumably caused by the time taken by the leading wedge of the Philippines Sea Plate to reach beneath every location in the Kinki Triangle as a result of oblique subduction.

6) Summary

The configurations of subsurface structures of some active faults in the Kinki region were mainly revealed by seismic reflection surveys. The results are as follows;

1. The Yoro fault has moved since the deposition of the Kuragari formation (2.7 Ma). Growth strata and pre-growth strata were observed on the profile. The direction of the compressional axis around the Yoro fault has been E-W since 2.7 Ma.

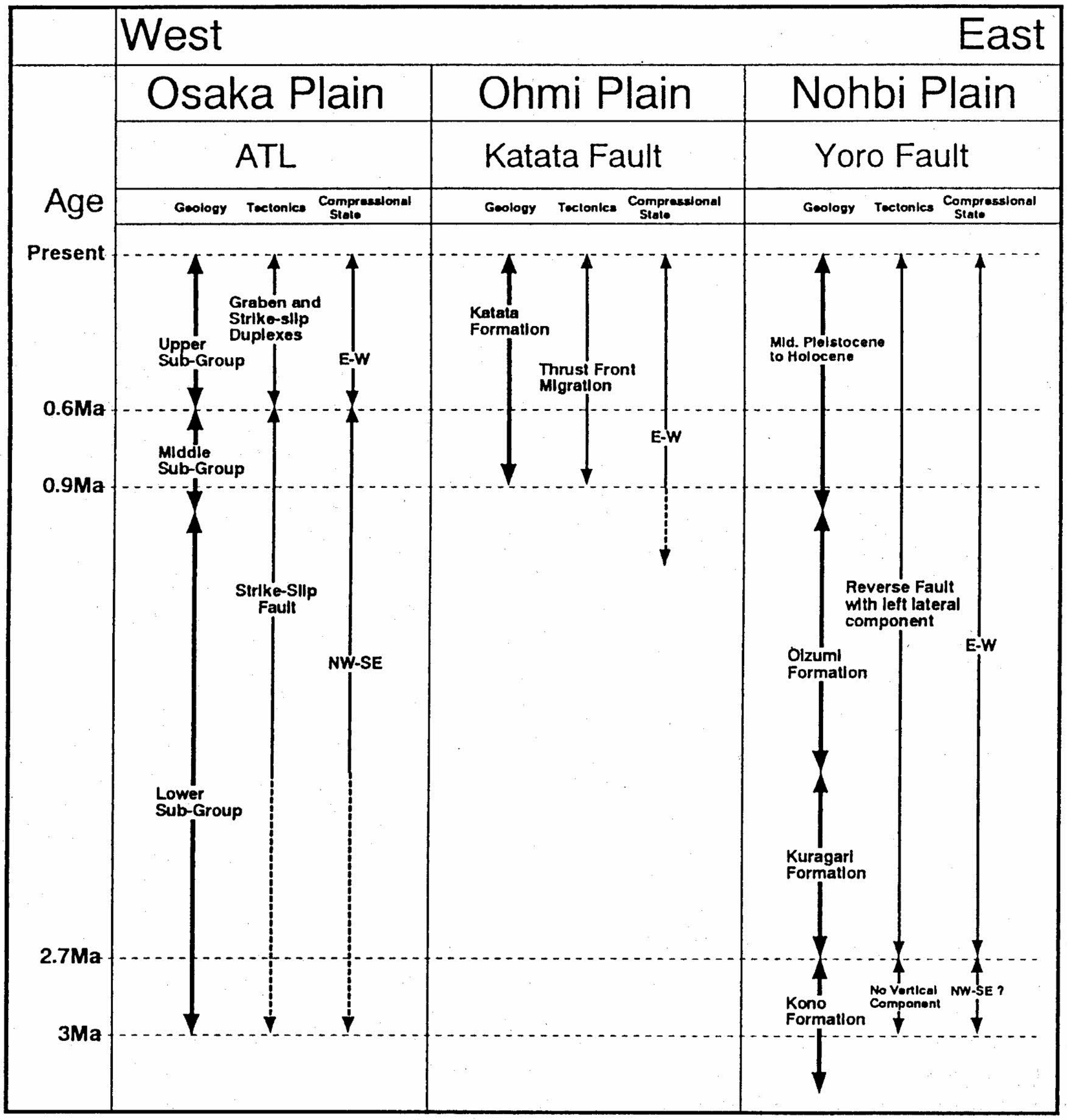

Fig. 7 Tectonic changes in the Kinki Region.

2. Pre-growth strata are not observed on the Katata profile. The Katata fault is a frontal thrust associated with a large flexure structure about 1.0 km wide by E-W compression since 0.9 Ma.
3. The Arima-Takatsuki Tectonic Line is an oblique fault connecting the northern Hanaori fault and the southern Rokko fault system. In the Osaka plain the graben structures have developed since the growth strata as the Upper Subgroup of the Osaka group. Thus, the E-W compressional regime has started about 0.6 Ma.
4. The compressional axis changed from NW-SE to E-W as inferred from the tectonics of the active faults in the Kinki region. A time lag in the change in orientation of the compressional axis is observed from the northeast to the northwest parts of the Kinki region.

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