Journal of Geosciences, Osaka City University
Vol. 45, Art. 5, p. 63-71, March, 2002

Active faults around Uchihata-cho in the southern margin of the Osaka Group Basin, southwest Japan*

Dicky MUSLIM**

**Department of Geosciences, Faculty of Science, Osaka City University, Osaka 558-8585, Japan.

*Part of this paper had been presented at the Annual Convention of the American Association of Petroleum Geologists 2000, New Orleans, USA

Abstract

The Sennan Formation, the Lowermost part of the Quaternary Osaka Group, is composed of intercalations of unconsolidated gravel, sand and silt, and is distributed in the southern margin of the basin. In this formation, faults are expressed as tectonic scarps and lineaments on the topographic map and are accompanied by fault breccia, gouge and minor faults. The active Koonoyama Fault, Koonoyama Flexure and Uchihata Fault cut this formation around Uchihata-cho. Minor faults in this area consist of single and conjugate pair types, which generally indicate direction of the axes of maximum compressive stress ($\sigma 1$) ranging from N-S to ENE-WSW.

Key-words : Active fault, stress direction, minor fault, neotectonics, Osaka Group

Introduction

The Quaternary Osaka Group, deposited in the Osaka sedimentary basin, is composed mainly of fluvio-lacustrine coarse sediments, with intercalations of fifteen marine clay beds and more than fifty volcanic ash layers (Yoshikawa, 1984). The Group had been intensively studied and the findings were summarized by Itihara (1993). Meanwhile, for the southern part of the Osaka basin, Itihara et al. (1975) and Itihara (1998) also explained in detail the geological conditions around Sennan-Senboku area.

After the destructive 1995 Hyogo-ken Nanbu Earthquake, geophysical surveys, drilling and geologic mapping have been applied for research of active faults in the middle to northern part of the basin (Geo-database Information Committee in Kansai, 1998; Yokokura et al., 1999; Iwabuchi et al., 2000). On the other hand, in the southern part of the basin, geological investigation on active faults has been less. Hence, the author attempts to study active faults in the southern margin of the Osaka Group basin in the Senboku area, close to the Izumi Mountains (Fig. 1).

The Research Group of Active Faults in Japan (1991) stated that the word 'active' might give the impression that a fault is actually in motion at the present time. However, no faults characterized by modern creeping are known in Japan. Therefore, the group defined an 'active' fault as one that has moved in the past 2 million years.

In this study, geomorphologic analysis was done using old topographic maps and aerial photographs for recognition of recent fault activity. The author has undertaken detailed geologic mapping in the study area. The texture and composition of clay, sand and gravel were examined visually in the field. The color of sediments was described, based on the rock color chart from the Geological Society of America. Particular attention was paid to the appearance of minor structures within a bed and the composition of sediments around the structures for later analysis.

The author attempts to clarify the behavior of lithostratigraphic units influenced by the presence of active faults, and also to analyze the appearance of evidence that remains preserved, especially in unconsolidated sediments.

Outline of Stratigraphy

The Osaka Group (Plio-Pleistocene) lies unconformably on Ryoke Granite (Mesozoic), the Kannabi Formation (Miocene) and Nabeyama Basalt (Miocene-Pliocene) in the southern part of Osaka basin (Fig. 2). The Osaka Group consists of the Sennan Formation as the Lowermost part, the Kokubu Formation as the Lower part and the Senpoku Formation as the Upper part (Itihara, 1998).

Around the study area, only the Sennan Formation, the lowest formation of the Osaka Group, is exposed and distributed from the east to southwest. The Sennan Formation consists of lacustrine and fluvial gravels, sand, silt, and clay intercalating with more than 12 tuff beds. No volcanic ash layers are found in the study area, though several volcanic ash layers (tuff beds) occur outside the study area.

The terrace deposits (Middle-Late Pleistocene) are distributed alongside each river and consist of weathered sand, pebbles, cobbles and boulders. Recent alluvium is made up of loose sand, gravel and boulder material, distributed along the floors of rivers.

Lithology of the Sennan Formation

The Sennan Formation consists of alternating beds of gravel, sand and silt. In the study area, the gravel deposit is predominant around the east and becomes finer toward west.

The gravel deposit is characterized by massive/non-stratified to crudely stratified beds. In this deposit, matrix supported is common although clast supported also occur. Clasts are predominantly sub angular to round pebbles and cobbles, and in some instances, half-round cobbles also occur. The maximum diameter of clasts range from 4 to 15 cm, though individual clast may reach diameter up to 40 cm. Moderately to poorly sorted gravel is common. Inverse graded bedding is observed especially at the bottom of a bed. Normal

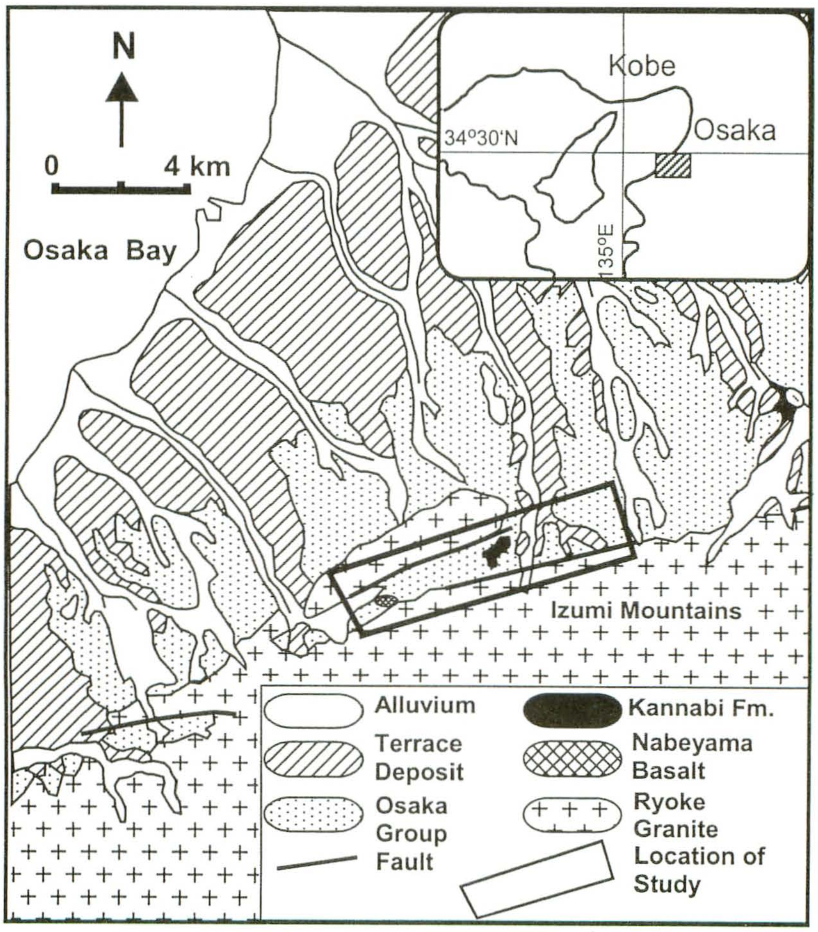

Fig. 1 Location of the study area (Modified after Itihara, 1998)

Geologic Age	Rock Unit	Lithology
Holocene	Alluvium	Loose gravel - sand
Middle- Late Pleistocene	Terrace deposit	Boulder, pebble, cobble, sand
Early Pleistocene - Late Pliocene	Sennan Fm. of the Osaka Group	Unconsolidated gravel, sand, silt, clay
Mio - Pliocene	Nabeyama Basalt	Basalt
Miocene	Kannabi Fm.	Conglomerate, breccia
Mesozoic	Ryoke Granite	Granite, Granodiorite.

Fig. 2 Stratigraphy of the study area (Simplified after Itihara, 1998)

grading, solitary planar cross stratification with average dip of set about 30o are common. Matrix is composed of sand and silt grain varying in fresh color from medium to dark gray (N5-N3). In some exposures, an array of clasts exhibits hard, dark brown color as a result of intensive oxidation and even the color of matrix also changes to grayish orange (10 YR 7/4).

Wedging out of gravel into sand bed, along with gradational contact, is common. Channeled bodies composed of gravel-sand beds and locally separated by planar cross-stratification occur in some exposures.

The finer deposits generally consist of fine to coarse grain sand and in most of the exposures exhibit pebbly facies. The color of these beds is from medium to dark gray (N5-N3) and also grayish orange (10YR 7/4) due to oxidation. Solitary planar cross-stratification is common, but parallel stratification composed of intercalation of sand and silt grain rarely occurs. These deposits are composed of quartz, feldspar, rock fragments and rarely mica.

The sand deposit is 1-2 meters thick and it generally occurs either as lenticular or stacked beds. This deposit changes gradually to the overlying bed, though underlying silt-clay beds are eroded and show an erosional contact with scour and fill structure in the bottom. In some exposures, pebbly sand bed contains plant remains and fossil wood is also observed.

Geologic Structure

The Osaka Group generally dips gently to the north at angles of 10° and gradually has steeper dips near to the basement rocks in the southern margin of the basin (Fig. 5). In the study area, faults are observed along the margin of the Osaka Group and the basement rock.

The Uchihata fault runs along E-W from southwest of Uchihata-cho to Kuki, outside the study area. At Uchihata-cho, the basement rocks thrust over the Osaka Group. Near the fault, the Osaka Group generally dips north at angles of 20° to 62°, as shown from Koonoyamacho area to the east (Fig. 3). This fault also marks the boundary between the Ryoke granite of the Izumi Ranges and the Lowermost part of Osaka Group in the southern side. Topographic discontinuity of height difference is observed along the Uchihata Fault.

The Koonoyama fault runs on the south side of the Koonoyama mountain-block, for as much as 4 km. It extends eastward from north of the Kotsumi area to west of Uchihata-cho village. This fault is also a thrust. The basement rocks on the northern side thrust over the Osaka Group. Fault scarp and fault exposures are observed along Koonoyama fault.

A syncline, with axis running NNE-SSW direction, can be traced up to 300 meters in the Kotsumi area (Fig. 4, E-E′). An overturned bed between this syncline and contact with basement rock Ryoke Granite of Koonoyama Mountain can be recognized from planar cross bedding. The overall thickness of the sedimentary deposit near Kotsumi area is about 200 m.

The Research Group of Active Faults in Japan (1991) designated these faults in the study area as active faults. The group also described the existence of the Koonoyama Flexure on the northern side, beyond the study area. According to this group, both of Uchihata and Koonoyama faults and Koonoyama flexure have degree of certainty I, based on the conclusive evidence that those structures have been active during the Quaternary period. Also both of those faults and the

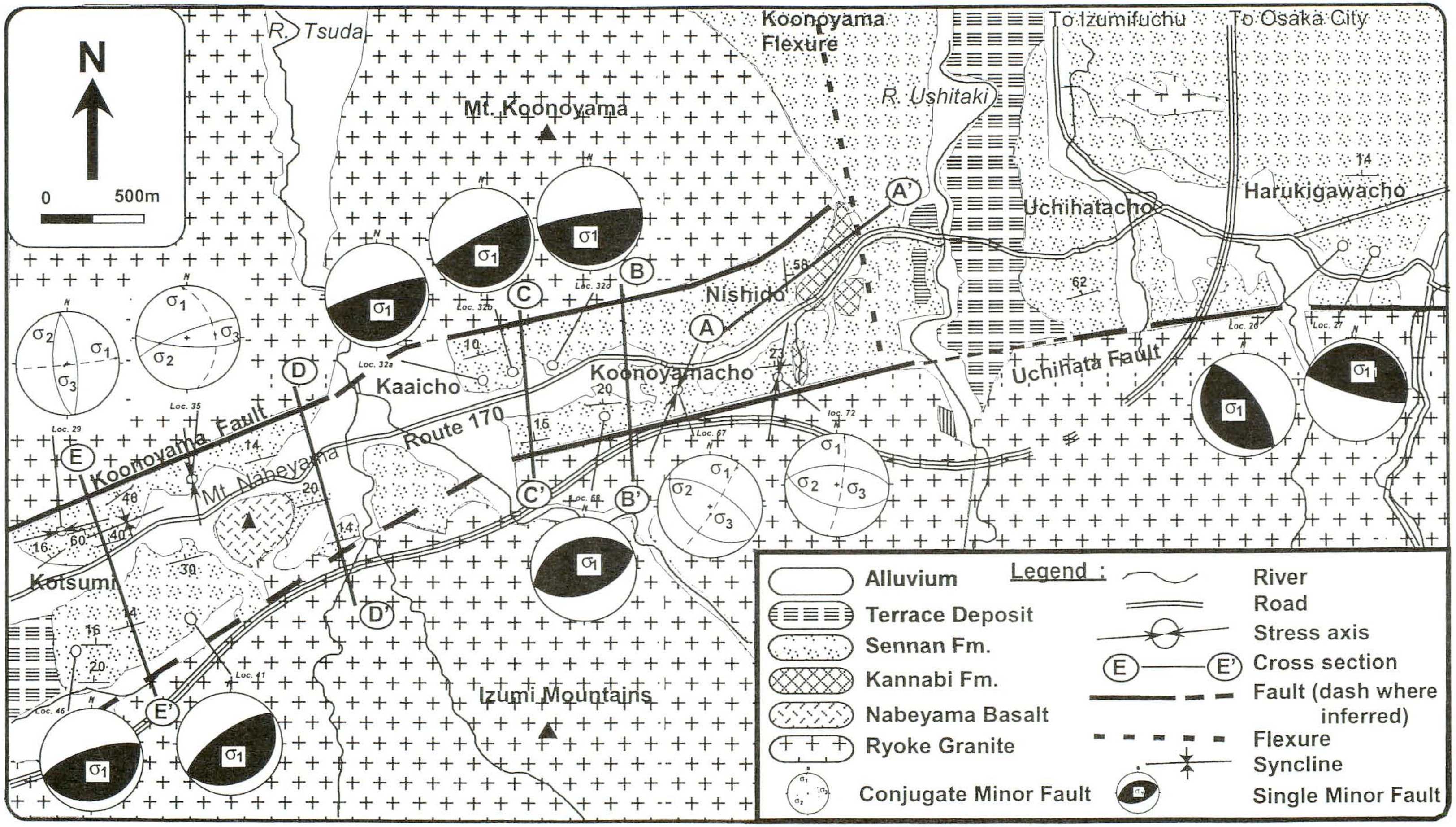

Fig. 3 Distribution of paleostress direction and orientation of minor faults through stereographic projections (lower hemisphere) and cross sections.

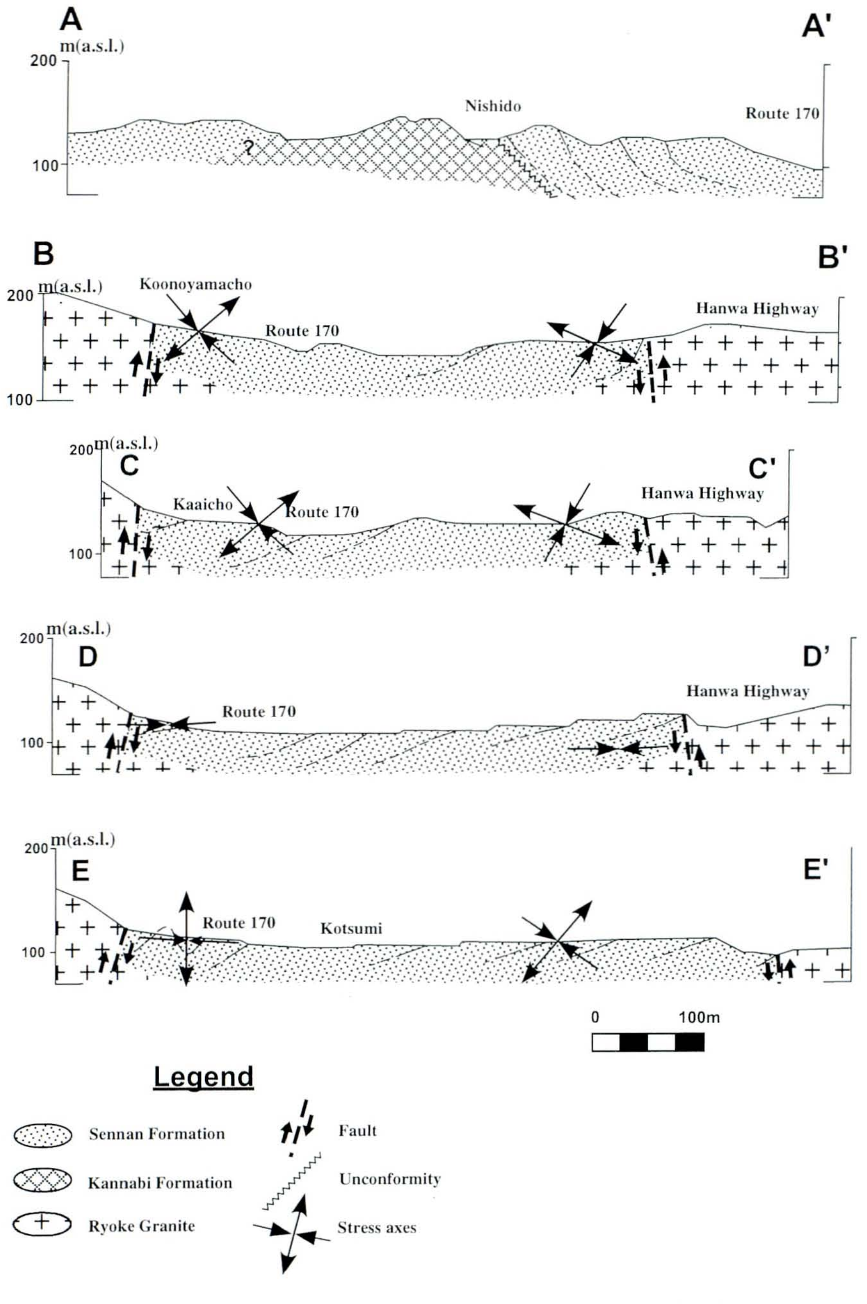

Fig. 4 Geological cross sections in the study area (see Fig. 3 for the location of sections)

flexure have degree of activity C, based on the long-term average slip rate of the active fault that is the amount of displacement of the Quaternary strata or topographic references divided by their age. The class C itself has an order of 0.01m/1000 years. When data for the calculation of fault activity are insufficient, the freshness of the topographic references is used.

Minor Faults Configuration

The study area around Uchihata-cho is a narrow path bounded by two parallel active faults running E-W. In this area, a lot of minor faults are found in the sedimentary deposits of the Osaka Group. The results of the stress field analysis through minor faults in this area are given below.

Following method by Leyshon and Lisle (1996) using the stereographic projection (lower hemisphere) technique, the author analyzed minor structures to estimate the nature of paleostresses which were responsible for the formation of the faults. The direction of principal stresses (axes of maximum ($\sigma 1$), intermediate

($\sigma 2$) and minimum ($\sigma 3$) compressive stress) can be estimated through plunge and plunge-direction of σ (axis of compressive stress) in the stereogram.

The fault plane that clearly displaces all strata within an exposure or at least, displaces the top and bottom boundary of a stratified bed in an exposure is considered in the study. Conjugate pairs of faults and single (individual) fault are identified in the outcrops (Fig. 5). Four sets of conjugate minor faults are found, which exhibit crosscutting relations, suggesting contemporaneity.

Conjugate minor faults are observed around

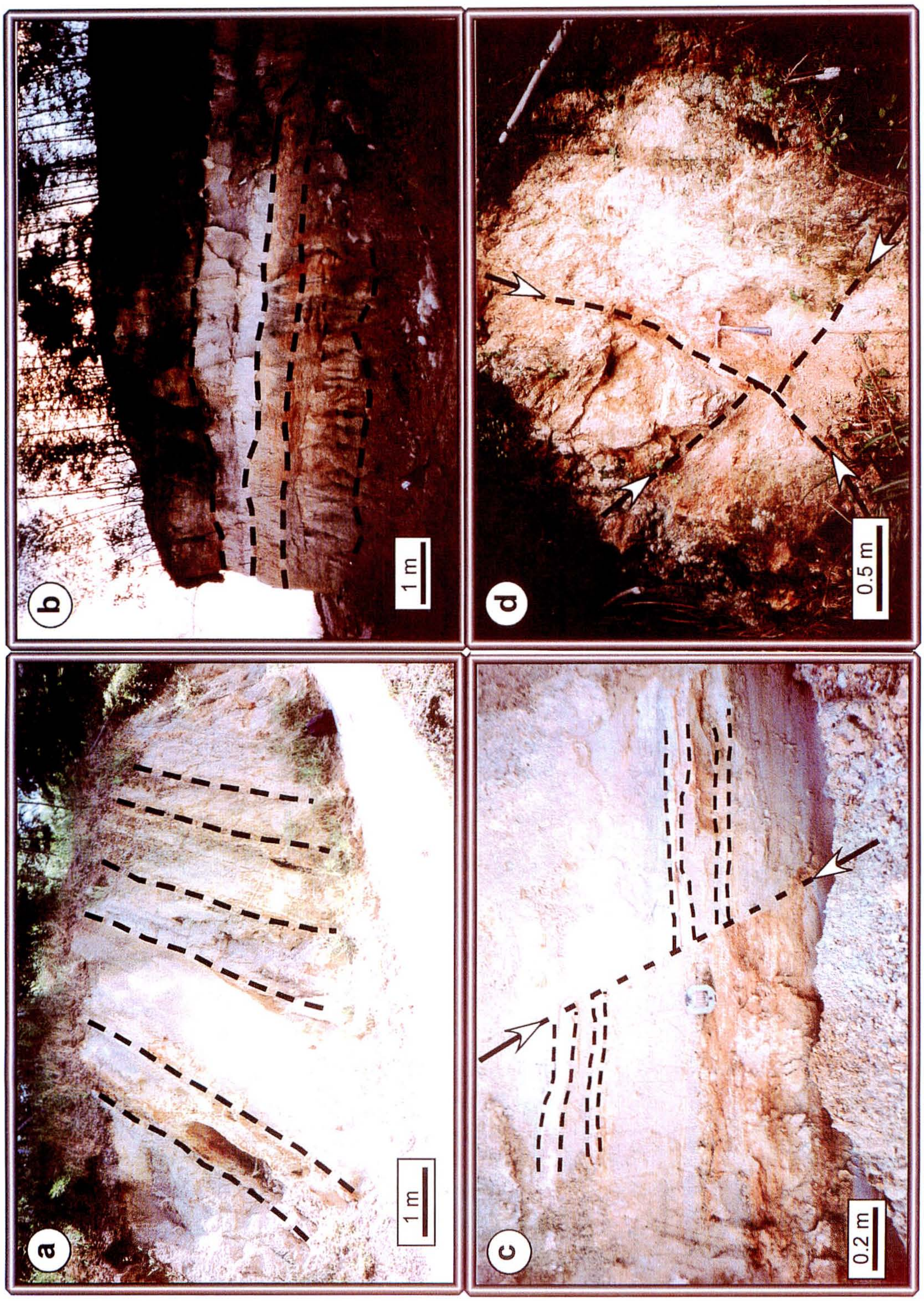

Fig. 5 Photographs of lithostratigraphy and minor faults in the Sennan Formation. (a) Steep dip layers near Nishido. (b) Gentle dip layers near Kaaicho . (c) Displacement of silt layer by single (individual) fault near Kotsumi (location no. 46). Vertical displacement of the layer is about 50 cm. (b) Displacement of gravel beds by conjugate pairs of fault near Koonoyamacho (location no 67). (see Fig. 3 for the locations).

Kotsumi (loc. No. 29) and Koonoyamacho (loc. No. 67) areas. Stereographic projections (lower hemisphere) that indicate plunge-direction of $\sigma 1$ are N86°E and N35°E (Table 1), which means that the axes of maximum compressive stress that responsible for the formation of those faults are in E-W and NE-SW directions respectively. Also other conjugate faults lie in Kotsumi near Mt. Nabeyama (loc. No. 35) and in Koonoyamacho near Nishido area (loc. No. 72), which show plunge-direction of $\sigma 1$ are N356°E and N8°E respectively (Table 1). They indicate that the axes of maximum compressive stress were in N-S direction.

The axis of minimum compressive stress ($\sigma 3$) is the least principal stress that is responsible for the formation of a fault. From conjugate minor fault analysis, these axes show high to very high angles of plunge (47° to 85°, Fig. 4). A thrust fault is formed when $\sigma 3$ is vertical (Davis, 1984 p. 314).

Orientation data from single (individual) faults allow only the broadest limits to be placed on the principal stress axes. The right dihedra method (Leyshon and Lisle, 1996 p. 58) is to estimate the stress direction from a single fault by plotting the fault plane with a second plane perpendicular to the fault and its slip direction (auxiliary plane) onto the stereogram. The auxiliary plane serves to divide all possible directions on a sphere into two pairs of quadrants. Depending on the fault's sense of movement, one pair of quadrants delimits the possible orientation of $\sigma 1$ and the other pair defines the possible $\sigma 3$ direction. Therefore, direction of the principal stress can only be approached through $\sigma 1$ orientation.

The result of the above method for individual fault characteristics in the stereogram generally shows E-W to ENE-WSW orientation of $\sigma 1$ (axis of maximum compressive stress) (Table 2). However, near Harukigawacho (loc. No. 26 and 27), there are minor faults that indicate the axes of maximum compressive stress ($\sigma 1$) to have NW-SE and WNW-ESE orientations (see also Fig. 3).

Kodama et al (1974) concluded that minor faults appear as steep normal or reverse faults during the vertical upheaval movement of basement blocks. These faults are designated as fractures of the first group in

Table 1 Data of conjugate minor faults in the study area. (see Fig. 3 for the locations)

Loc. No.	Plane of Minor Structures	Plane containing σ1 / σ3	Plunge → Plunge-direction of σ: σ1	σ2	σ3
29	N178E/68W - N355E/78E	N86E/86S	8 → N86E	2 → N356E	85 → N244E
35	N250E/80N - N095E/76S	N348E/45E	4 → N356E	45 → N262E	47 → N86E
67	N300E/65NE - N130E/43S	N35E/84SE	10 → N35E	6 → N305E	76 → N190E
72	N105E/56S - N270E/60N	N6E/78E	6 → N8E	12 → N188E	79 → N110E

Table 2 Data of single minor faults in the study area. (see Fig. 3 for the locations)

Loc. No.	Plane of Minor Structures	Orientation of σ 1
26	N325E/70NE	NW - SE
27	N106E/82SW	WNW - ESE
68	N253E/84NW	ENE - WSW
32a	N240E/81NW	ENE - WSW
32b	N243E/82NW	ENE - WSW
32c	N261E/85NW	ENE - WSW
41	N232E/70NW	E - W
46	N250E/72NW	NE - SW

their box-shaped fold experiment, using clay models.

Huzita and Okuda (1973) also Okada and Ikeda (1991) discussed the relationship between the Median Tectonic Line and many thrust faults adjacent to it. One of the conclusions is that during the Quaternary period, southwest Japan had been compressed strongly and resulted in the condition of compressive state. The result of minor fault analysis in the study area shows direction of axes of maximum compressive stress ranging from N-S to ENE-WSW, which means that the sediments in the study area were strongly influenced by fault activity during the Quaternary.

Previous reports concerning geological structures in the study area generally mentioned that thrust is the characteristics of faulting (the Research Group of Active Fault, 1991; Itihara 1993; Itihara 1998).

The stress direction from conjugate minor faults and stress orientation from single minor fault analyses may show variable results in the study area. One of the possibilities is that since some exposures are not in close proximity to the fault, they do not record the reaction of faulting properly. Another possibility is, as Maltman (1984) explained, that subaerial, unlithified sedimentary cover can deform in response to gravitational instabilities caused by tectonic movement below, therefore the stress axes in a minor fault do not fully reflect tectonic activity. Vita-Finzi (1986) also explained that gravitational adjustments could accompany active fault deformation, thus inducing various structures in poorly lithified sediments.

Conclusion

Minor fault analysis in the sedimentary deposits, in general, shows the direction of axes of maximum compressive stress ($\sigma 1$) ranging from N-S to ENE-WSW. Though the stress field may change according to the faulting process, it also shows that Quaternary sediments in the study area are strongly influenced by fault activity.

The occurrence and activity of faults and flexure in the study area are clarified through the appearance of tectonic scarps or scarplets, geomorphic lineaments, gouge and fault breccia, and the distribution of minor faults. The material composition of sedimentary rock is also useful as additional information for clarification.

Further investigation of the geologic structures in this area is suggested in order to analyze the relationship of the Koonoyama fault and flexure with the elongation of the Uemachi fault below the Osaka plain in the north.

Acknowledgement

The author would like to express his gratitude to Prof. Hisao Kumai for his patience and useful guidance. He also thanks Drs. M. Mitamura, S. Yoshikawa and Y. Suzuki for their constructive comments and direction. Supportive comments and discussion with Dr. Michael Ledet of the University of New Orleans is also appreciated.

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Manuscript received August 31, 2001.
Revised manuscript accepted January 18, 2002.