PALEOSEISMIC ACTIVE FAULT STUDY IN KINKI TRIANGLE

Ehsanullah* **Supervisor: Harutaka SAKAI****
MEE08160

ABSTRACT

Kohistan-Chilas area in northern Pakistan has experienced few damaging earthquakes for recent few decades that showed the current active crustal movement.

This study is mainly aimed to understand the relation of tectonic stress field and active faults in Kinki Triangle and to compare it with those of Kohistan-Chilas area. It is also aimed to confirm the relationship between geomorphologic evidence detected by the interpretation of aerial photographs and structural behavior of the geological units surveyed in the field.

Throughout the study of eleven active faults in Kinki-Triangle this relationship has been confirmed. It is revealed also that the active faults there are grouped into three: those along Median Tectonic Line (MTL), those of left lateral motion having NW(NNW)-SE(SSE) strike and those of right lateral having NE(NNE)-SW(SSW) strike. The latter two can be summarized by the tectonic stress of E-W compression. Namely they are conjugate shear faults. It has been said for long time that this regional stress might be caused by subducting Pacific Plate. The recent studies, however, show a possible alternative cause, i.e., the irregularly shaped subducting Philippine Sea Plate.

These two areas show a similarity in the tectonic frame work of the compressive regional tectonic stress and the accompanying conjugate shear faults systems. The existence of other tectonic units, however, makes them different each other.

Therefore, it is necessary to conduct systematic studies of active faults in Kohistan, northern Pakistan not only by the conventional geological survey but also by the geomorphologic interpretation of aerial photographs combined with field survey including trench observation.

Keywords: Paleoseismology, Active Fault, Aerial Photograph, Kohistan Island Arc, Kinki Triangle

1. INTRODUCTION

Pakistan is located mainly along the active boundary between Eurasian plate and Indian plate except the coastal area along the Arabian Sea. Kohistan-Chilas area in the northern Pakistan is the ancient Island Arc in Ceno-Tethys and today located among these plates. Today a big dam in Chilas along Indus River is in planning stage. Moreover, the damaging earthquakes that took place in recent few decades in Kohistan show that the crustal movement in this area is still active and that it is necessary to take the earthquake hazard in this area into account for the safety of the dam. This is the reason why it is necessary to conduct studies on the current crustal activities there.

My overall goal in future is a clear understanding of the tectonic framework and crustal activities of Kohistan-Chilas area and surroundings for estimation of earthquake hazard. This study is the first step for this overall goal and mainly aimed to understand the relation of tectonic stress field and active faults in Kinki Triangle and to compare it with those of Kohistan-Chilas area. It is also aimed to confirm the

* Water and Power Development Authority (WAPDA), Pakistan
** Professor, Department of Geology and Mineralogy, Kyoto University

relationship between geomorphological evidence detected by the interpretation of aerial photographs and structural behavior of the geological units surveyed in the field.

2. Method

In order to confirm the relationship between geomorphologic evidence detected by the interpretation of aerial photographs and structural behavior of the geological units surveyed in the field. I selected eleven major active faults from the Kinki Triangle.

+ Okamura, Hatano, Ikeda faults (MTL in Shikoku area, right-lateral)
+ Neo-dani, Yamasaki, Yoro-Kuwana faults (NW(NNW)-SE(SSE) strike, left-lateral)
+ Hanaore, Katata, Aibano, Rokko, Ikoma faults (NE(NNE)-SW(SSW) strike, right-lateral)

Then I tried to detect displaced landform and identify active faults on aerial photographs of 1:20,000 by means of stereoscope. After finding of offset of topographic references, I interpreted the sense of displacement and drew lines of active faults on the topographic maps of 1:25,000 published by Geographical Survey Japan. Total number of aerial photographs which I interpreted was about 360 photos.

After recognition of active faults on the aerial photographs, I conducted literature survey for each fault and compiled the information about the selected active faults.

Lastly, I visited the areas where active landform and fault exposures can be observed in order to confirm, in the field, the reliability of geomorphological evidences for identification of active faults.

3. STUDY ON ACTIVE FAULTS IN KINKI TRIANGLE, JAPAN

Kinki district is located in the central part of Japan, and Kyoto and Nara of ancient capital of Japan and modern mega-city, Osaka and Kobe, are main cities in this district. Those cities are developed in basins surrounded by narrow mountain ranges (e.g., Huzita, 1974; Research Group for Active Faults of Japan, 1991). The basins and ranges are bounded by thrust faults or strike-slip faults, many of which are active at present and occasionally cause earthquakes.

Central part of the Kinki district is characterized by young basins and ranges structure formed by folding of basement rocks accompanied by many thrusts that initiated their activity in Quaternary. The area characterized by such topography and geologic structure forms a triangular shape connecting the Bays of Wakasa, Osaka and Ise. Huzita (1962) proposed to name this area as “Kinki Triangle”.

From the view points of active fault tectonics, the Kinki Triangle is bordered by three tectonic lines: the bottom of triangle is MTL, the eastern side is the Tsuruga Bay-Ise Bay Tectonic Line (TITL), the western side is the Niigata-Kobe tectonic zone (NKTZ). This neotectonic province is characterized by dense concentration of active faults running three directions: NW(NNW) - SE(SSE) trending left-lateral and thrust faults, NE(NNE) - SW(SSW) trending right-lateral and thrust faults and E-W trending right-lateral faults of the MTL.

4. MAJOR ACTIVE FAULTS SYSTEMS

Median Tectonic Line (MTL) in Central Shikoku

MTL is the first class fault that divides Southwest Japan into the Inner Zone and the Outer Zone. The present movement of the MTL in Central Shikoku is predominantly arc-parallel right-lateral strike-slip fault, which is related to subduction of the Philippine Sea plate beneath the Eurasian plate along the Nankai Trough. Its slip rate during the Quaternary is 5~10 mm/yr in Shikoku (Okada, 1973). The vertical displacement during the Quaternary was estimated to be more than 1500 m in Central Shikoku, and form

Figure 1 Left) Aerial photographs of the Hatano fault, Doi area, MTL. Right) The Road constructed on the scarp of the Hatano fault which shows prominent offset of ridge and valley. Topography is artificially changed and a substation was constructed.

the Ishizuchi fault scarp though its average displacement rate is one digit smaller than that of lateral-slip (Okada, 1980).

I selected three faults from the MTL fault system: Okamura fault in Niihama area; Hatano fault in Doi area (Figure 1), Ikeda fault in Awa-Ikeda area. In Niihama and Doi, I could convince Quaternary right-lateral movement from offset of ridge and stream, fault scarp, vertical displacement of terrace surface. The maximum lateral displacement is more than 230 m after 29,000 yr BP, and its displacement rate is estimated to be 7~8 mm/yr (Okada, 1973; 1980). In Awa-Ikeda town, I could confirm that the river terrace of ancient Yoshino River was tilted and cut by active faults. Okada (1968) estimated vertical slip rate of 1mm/yr based on 14 C dating of wood fragments contained in the terrace gravels, and reported ~200m right-lateral displacement.

NW (NNW) – SE (SSE) left-lateral faults

One of the prominent topographic features of active faults in the Kinki Triangle and its neighboring area is a set of NW(NNW)-SE(SSE) trending left-lateral faults and NE(ENE)-SW(WSW) trending right-lateral faults, both of which are considered to be a set of conjugate shear faults. They were recognized as very sharp lineaments in satellite images and aerial photographs, and historical earthquake occurred in some faults.

Among them, most famous left-lateral fault is the Neo-dani fault, which caused the Nobi earthquake of M8.0 in 1891 (Matsuda, 1974). I have studied its fault topography both in the aerial photographs and in the field. Especially in the field, I could convince about 6 to 7 m vertical displacement along the earthquake fault in 1891, both in the field and the Museum (Figure 2).

I selected the Yamasaki fault, because its fault topography as a strike-slip fault is prominent, though it is located 50km to the west of the western margin of the Kinki Triangle. I detected many offset ridge and offset stream and valley, misfit river, shutter ridge and pond along the linear valley. All indicators of displacement show right-lateral movement and its maximum offset attains 400 m and vertical displacement reaches 200 m. After 14 C dating and discovery of tephra layers from several trenches

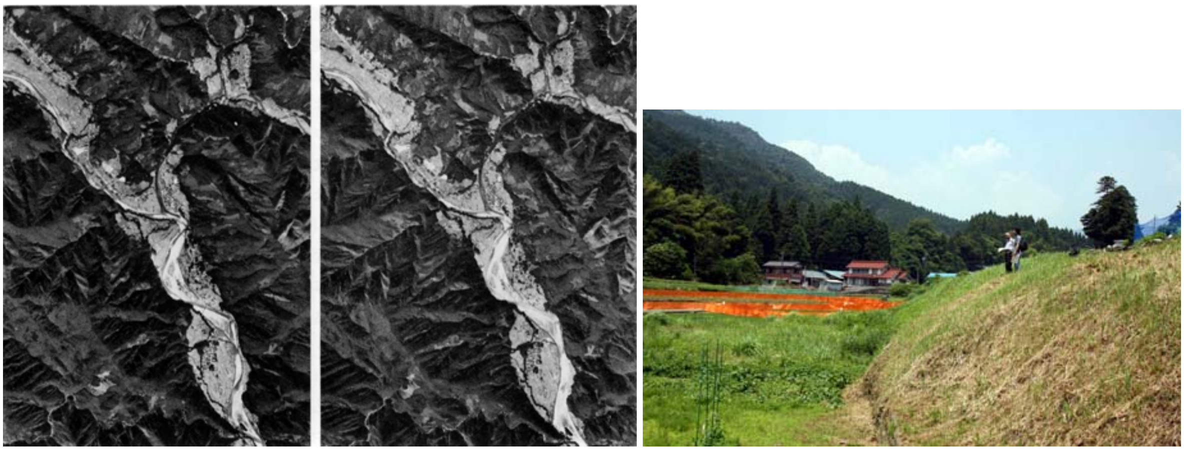

Figure 2 Left) Aerial photograph of the Neo-dani fault around Midori village. Right) A scene of the fault scarp of the Neo-dani fault formed by Nobi Earthquake, 1891.

crossing the fault, the lateral displacement rate was estimated to be 7 mm/yr and vertical one to be more than 1mm/yr (Okada et al., 1987).

In the southeastern part of the Kinki Triangle, NNW-SSE trending faults are thrust faults rather than strike-slip faults (Ota and Sangawa, 1984; Awata and Yoshida, 1991). The Kuwana fault is located in the frontal deformation zone in the Suzuka Mountain marginal fault system. On the aerial photograph, I could recognize various kinds of fault topography: tilting, flexure and folding of terrace surfaces, depression zone bounded by linear fault scarps. The vertical displacement of the Kuwana fault is 5 to 25 m, and generally increasing from S to N. The average displacement rate is estimated to be 0.1~0.3 mm/yr (Suzuki et al., 1996).

NE(NNE) - SW(SSW) right-lateral faults

Another fault of conjugate shear set is NE(NNE) - SW(SSW) trending right-lateral fault. One of the fault running in the western part of the Awaji Island called Nojima fault, caused Hyogoken-Nanbu earthquake in 1995. Its maximum net slip was 2.5 m, and the right-lateral displacement was 2.0~2.1 m, whereas vertical displacement was 1.1~1.4 m. The NE trending Nojima fault has fault scarps higher than 250m for about 10km. The total right-lateral displacement is greater than 300m, almost equal to total vertical displacement.

The northeast continuation of the Nojima fault in mainland Honshu is the Rokko fault system, which is composed of a series of right-lateral fault for about 30 km. At the surface, the fault system appears as the high-angle thrust faults. The Rokko Mountains north of the Kobe-Nishinomiya area is interpreted to have been uplifted by neotectonic movement, called the "Rokko Movements" (Huzita, 1962; Huzita et al. 1971; Huzita and Kasama, 1982; 1983). The average vertical slip rate is greater than 0.5 mm/yr based on the elevation difference of the first marine bed called Ma 1 in the Osaka Group, whereas the right-lateral slip rate is not well defined by the filed data.

Another big right-lateral strike-slip active fault is the Hanaore fault, which is traceable for 48 km from the northeastern margin of Kyoto basin to Kutsuki to the north of the Hira Mountain. It shows NNE-SSW trending very sharp lineament with a narrow valley bottom in mountain area, but has a thrust component of east-side up. Offset of ridge and stream indicates maximum lateral displacement of 120 m, but its slip rate is not well defined. The middle Pleistocene terrace surface shows ~30m vertical displacement along the fault, and its slip rate is estimated about 0.3 mm/yr.

To the east of the Hanaore fault beyond the Hira Mountain, the Biwako-seigan (west coast) fault system is running along the western margin of the Lake Biwa (Sangawa and Tsukuda, 1987). They are

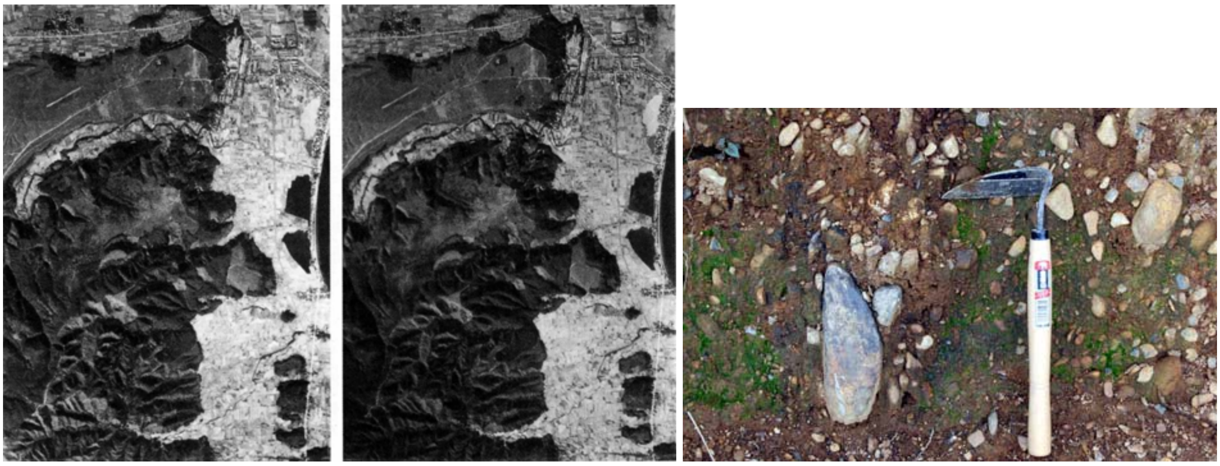

Figure 3 Left) Aerial photographs of the Aibano fault around Oomi-Imazu station of JR. Right) Terrace gravels change their attitude to perpendicular after drag by faulting. The digging tool is about 15-20 cm long.

thrust faults, along which the Hira Mountain thrusts onto the Oomi sedimentary basin including the Lake Biwa. I selected two faults for my study: one is the Katata fault and another is the Aibano fault (Figure 3). The Pleistocene beds of the Kobiwako Group are uplifted about 800 m along the Katata fault during the last 0.85 m/yr, and its vertical slip rate is estimated about 1 mm/yr. The Ikoma fault is also NNE-SSW trending thrust fault running along the margin of the Osaka plain, and the Ikoma Mountain thrusts onto the Osaka plain. Based on the elevation difference of basement rocks and the base of the Osaka Group on the seismic profile, total vertical displacement of 600m is estimated.

3. CONCLUSION & RECOMENDATIONS

Active faults in northern Pakistan are mainly grouped into two: one is left-lateral strike-slip fault along the western margin of northward drifting Indian subcontinent and another is thrust fault caused by collision of Indian plate. There are several right-lateral strike-slip faults that form a set of conjugate shear fault with left-lateral one. The fault which caused a big earthquake (Mw 7.6) of October 8, 2005 in Pakistan, called the Balakot-Garhi fault or Muzaffarabad fault, is one of the right-lateral faults. Around northern Pakistan, a typical pattern of the conjugate shear faults is shown by a big scale active fault systems. These also are caused by N-S compressional tectonic stress field due to the collision of Indian plate to Eurasian plate.

The study in Kinki-Triangle confirms the relationship between geomorphological evidence detected by the interpretation of aerial photographs and structural behavior of the geological units surveyed in the field and reveals that the active faults there are grouped into three: those along MTL, those of left lateral motion having NW-SE strike and those of right lateral one having NE-SW strike. The latter two can be summarized by the tectonic stress (E-W compression). Namely they are conjugate shear faults. It has been said for long time that this regional stress might be caused by subducting Pacific plate. The recent studies, however, show a possible alternative cause, i.e., the irregularly shaped subducting Philippine Sea plate.

These two regions show a similarity in the framework of the compressive regional tectonic stress and the accompanying conjugate shear faults systems. The existence of other tectonic unit, however, makes them different each other. That is Philippine Sea plate with irregular shape for Kinki Triangle that makes Osaka Basin and Lake Biwa subsiding. For northern Pakistan, uplifting Nanga-Parbat Syntaxis and Hazara

Syntaxis may be caused by the collision of two continental plates and also disturb it with Kohistan Island Arc that lies between them.

Based on the above summarized tectonics, seismicity, active faults and recent damaging earthquakes in Kinki Triangle, it is necessary to conduct systematic studies of active fault in Pakistan not only by the conventional geological survey but also by the topographical interpretation of aerial photographs combined with field survey including trench observation. In addition, systematic dating of carbonaceous material contained in sediments and establishment of tephra stratigraphy in Pakistan are important to evaluate activity of the active faults and earthquake hazard estimation.

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REFERENCES

Awata, Y. and Yoshida, S., 1991, Active Fault Res., 9, 61-68.

Huzita, K., 1962, Jour. of Geosciences, Osaka City Univ., 6, 103-144.

Huzita, K. and Kasama, T., 1971, Geology in and around Rokko Mountain Range, Kobe City Office.

Huzita, K. (ed.), 1974, Neotectonic Map “Kinki”, Geol. Surv. Japan.

Huzita, K. and Kasama, T.,1982, Geology of Osaka-Seihokubu district, Quadrangle series, 1:50,000.

Huzita, K. and Kasama, T., 1983, Geology of Kobe district, Quadrangle series, 1:50,000.

Ikebe, N., 1969, Jour. Geosciences, Osaka City Univ., 12, 45-51.

Matsuda, T., 1974, Special Bull. Earthq. Res. Inst., University of Tokyo, 13, 85-126.

Okada, T., 1968, Quat, Res., 7, 15-26.

Okada, A., 1973, in R. Sugiyama (ed.), the Median Tectonic Line, Univ. Tokai Press.

Okada, A., 1980, Mem, Geol. Soc. Jpn., 18, 79-108.

Okada, A., Ando, M. and Tsukuda, T., 1987, Jour. Geography, 96, 81-97

Ota, Y. and Sangawa, A., 1984, Geogr. Rev. Jpn., 57, 237-262 (in Japanese with English abstract).

Research Group for Active Faults of Japan, 1991, University of Tokyo Press.

Sangawa, A. and Tsukuda, E., 1987, Chishitsu News, 390, 6-12 (in Japanese)

Suzuki, K., et al., 1996, Active Fault Map in Urban Area 1：25,000 Kuwana, Geograph. Surv. Of Japan.