International Symposium on Active Faulting*

The 1995 Kobe (Hanshin-Awaji) earthquake devastated a rich populated area in Japan. This was quoted as an example to argue that even a technologically advanced society was not able to foresee disasters and take necessary precautionary measures. However, each earthquake provides the scientists an opportunity to test the hypotheses with real data, enabling them to push the frontiers of knowledge. By studying the Kobe earthquake we gained a lot of understanding of the earthquake processes. The occurrences of earthquakes like that at Kobe also reemphasize the need to pursue more vigorous earthquake geology researches on a global level so that potential active faults can be identified. Additionally, this event gave fresh impetus to the study of earthquakes in Japan. Besides the traditional seismology, a major thrust of studies was in the field of earthquake geology. A recently developed discipline, it aims to characterize the earthquake source from geologic and geomorphic evidences and evaluate temporal and spatial pattern of past earthquakes. From an academic point of view, these studies have contributed much to the understanding of the fault behaviour in different parts of the world providing much insight into the recurrence of earthquakes. From a practical point of view, these data happen to be the key input in seismic hazard assessment. These concerns must have motivated the organizers to hold a meeting on active faulting in Japan. The meeting brought together over 100 leading researchers from various parts of the world and through oral, poster and discussion sessions, they addressed the phenomenon of earthquake and various approaches to understand this problem. The venue of the meeting itself was affected by the 1995 earthquake and the causative structure, *Nojima* fault had ruptured the ground surface in the Hokudan Town of the Awaji Island; the rupture is now preserved in the Hokudan earthquake museum (see Figure 1).

The major objectives of the symposium were to highlight the recent worldwide efforts in active fault research and applications to seismic hazard assessment. The topics of the presentations centred around fundamental ideas on active faulting and earthquakes, studies of active faults in Japan, application and knowledge transfer on active faulting and hazard mitigation, large earthquakes in 1990s, and active faulting under various tectonic conditions, which included some parts of the Himalaya also. Detailed discussions were held on earthquake mechanics and stress change analyses, recurrence models, recent progress in dating techniques, palaeoseismology of subduction zones, and geophysical aspects of active faulting.

Leading researchers including Kerry Sieh, David Schwartz, Steven Wesnounsky, David Jackson, Tom Rockwell, Ross Stein, Takashi Nakata, Paul Somerville, Kunihiko Shimazaki, Michael Machette, Koji Okumura, Robert Yeats and many others participated in the conference. The meeting opened with the remarks of Takashi Nakata of the Hiroshima University, Director of the Organizing Committee. This was followed by a lecture on the geological and geomorphological studies of large earthquakes in and around Japan by Nobuyuki Yonekura who narrated the efforts to classify faults on the basis of long-term activity. The highlight of the first day was the lecture by David Schwartz of the US Geological Survey. The major thrust of his talk was about raising the standard of palaeoseismological research. This, he said, can be achieved only by avoiding subjectivity in interpretation, thereby facilitating reproducibility of the results. He further stated that besides characterizing active faults, the challenge for the researchers will be to identify nucleation points of the earthquakes. The talk by Steven Wesnousky focused on the importance of geological observations in preparing the seismic hazard maps. He discussed how the geological data question the applicability of the Gutenberg–Richter frequency relationship to individual faults and why the extrapolation of the historical data underestimates the expected recurrence time of large events defined by the length of the fault and slip rate (characteristic earthquakes). However, David Jackson in his lecture contended that the length of the fault or slip distribution does not provide a reliable measure of the largest possible earthquake in a given region. This model suggests that large earthquakes not limited by the inferred length can occur, and the earthquakes need not be confined to existing faults. The debate on the characteristic earthquake model recurred many times during the course of the conference.

One entire session was devoted to the discussion on large earthquakes in the 1990s, e.g. Landers (USA), Kobe (Japan), Izmit (Turkey), Chi-chi (Taiwan) and Duzce (Turkey). Presentations on Kutch, New Madrid and SCR sites elsewhere in North America and Australia suggested that the common yardsticks to evaluate seismicity along plate boundaries cannot be applied in these sites. The style of crustal deformation and seismicity pattern in these sites are unique. Another important presentation was on palaeoseismology of subduction zones. Kerry Sieh provided the details about how he and his colleagues used coral reefs to constrain the timing of large subduction zone earthquakes for measuring interseismic vertical deformation along the Sumatran coast. A large number of papers were devoted to the study of the Kobe earthquake, the largest hazard faced by Japan since the Second World War. One of the interesting papers presented in this category was that of Dapeng Zhao of the Ehime University, Japan. He presented results from seismic tomography to establish the causes of the 1995 Kobe earthquake and suggested that the fluid-filled, fractured rock matrix contributed to the initiation of the Kobe earthquake. The existence of fluids beneath the seismogenic layer may affect the long-term structural and compositional evolution of the fault zone. The presenta

*A report on the International Symposium and School on Active Faulting held at the Awaji Island, Hokudan, Japan during 17–26 January 2000, also marking the fifth anniversary of the Kobe earthquake. The symposium was mainly organized by Hokudan Town, Hokudan Board of Education, International Lithosphere Program Task Groups II-5 and II-2, Geological Survey of Japan and Science Council of Japan.

Figure 1. Rupture generated by the 1995 Great Hanshin–Awaji (Kobe) earthquake. About 150 m of this rupture with an elevation of ~1 m, which cut through the Hokudan Town is now preserved and an earthquake memorial park is built around this feature. What is shown in the foreground is the fault offset visible on a vertical section.

tion by Hisao Ito and others on drilling of the *Nojima* fault was particularly interesting to understand the nature of work being done as a part of post-earthquake studies. The Geological Survey of Japan drilled a 747-m-deep borehole penetrating the *Nojima* fault. Apart from conventional logging, fault zone at depth was studied for changes of the P and S wave velocities, which were determined by Dipole Shear Zone Images. Permeability structure and width of the fault zone were estimated from the surface trapped wave observations. The demonstration of a soil sample named geoslicer developed by T. Nataka and K. Shimazaki showed a new method to extract undisturbed slices of unconsolidated Quaternary sediments. This is an important development in sampling techniques for active faulting research as it enables us to carry out high resolution analyses of samples most effectively.

On the field trip, participants examined the effect of recent deformation and evidences of palaeoseismicity. On 23 January an open house was held where some of the victims and those who live in the neighbourhood of the *Nojima* fault shared their experiences of the Kobe earthquake with the seminar participants. Many of the scientists, especially those from California who live near the active faults shared their concerns with Awaji residents not as scientists but as ordinary citizens who too are compelled to deal with earthquakes in their daily life. We could sense the strong bond that was built between the people and the scientists over the meeting that lasted for about two hours. This is an excellent example of an outreach programme to assure the people of the efforts that are being initiated to understand the problems regarding the seismic hazard. The meeting ended with field trip to Median Tectonic Line (MTL). This structure which cuts across Japan forms an important area of tectonic studies in Japan.

The impression we carried from this meeting is that earthquake science has advanced much further and the Hokudan Symposium has set the stage for major advances in active faulting research. One major development in the recent years has been in the field of imaging the fault structure at depth through tomographic studies. The second significant advance is in the field of predicting ground motions. The third is the rapid growth of earthquake geology and its application in characterizing the active faults. Drilling into a fault that caused a large earthquake provided data useful for future studies as it helped validate many assumptions. There was a general consensus that some of the large earthquakes do not strike anywhere, but only in anomalous areas that can be detected with geophysical and geological methods. Even though we are quite far from earthquake prediction per se, combining seismological studies with geological, geochemical and geophysical investigations would certainly provide us with better understanding of the earthquake process and contribute to the mitigation of earthquake hazards.

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RESEARCH NEWS

Some recent investigations about dynamics of mantle upwelling

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Ever since earth took shape 4.5 billion years ago, its interior has been cooling essentially through volcanic upwellings and these have progressively led to changes in its physical and chemical makeup[1]. According to the plate tectonic concepts, fresh crust such as the extensively studied mid-ocean ridge basalts (MORB), developing at the ocean bottoms along divergent plate boundaries are products of thermal upwelling while hotspots[2–5], superplumes