

Prediction of tectonic stability in an island arc region for waste disposal

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ABSTRACT:

Disposal of high - level radioactive waste is due at the early 21st century in Japan. The territory of Japan is composed of a combination of arcuate islands along boundaries among four major plates: Eurasia, North America, Pacific and Philippine Sea plates. Interaction among plates dislocates faults and triggers earthquakes. Tectonic movements faster than 1 mm/year occur in restricted regions near the plate boundaries, volcanic fronts, or major active faults such as the Median Tectonic Line.

The density of active faults and that of volcanoes show drastic regional variation. Volcanic activity is absent in regions between the volcanic front and the subduction zone. Active faults are rare on the oceanic side of "active fault fronts." Relatively stable and rigid blocks lie between subduction zones and volcanic fronts. The great regional variation of the geologic environment in Japan will make forthcoming investigations for site selection important for safe disposal of radioactive waste.

Methods of prediction of tectonic disturbance are discussed with special references to the geologic setting of island arc region. The long - term prediction of tectonic stability and precise modeling of water - rock interaction are key issues for safety assessment of waste disposal.

Introduction

High level radioactive waste should be isolated longer than some 10,000 years from the human environment. One of the major questions on geologic disposal of high level radioactive waste is how we can confirm that the change of geologic environment

would not hurt the confinement of radioactive waste during some 10,000 years.

Japan is a country on a series of small islands between the Eurasia continent and the Pacific ocean(Fig.1). The Japanese Islands are composed of a combination of island arcs along bound aries among four major plates: Eurasia, North America, Pacific and Philippine Sea plates. Island arcs are tectonically mobile due to direct or indirect effects of plate interaction in comparison with continents. The confirmation of tectonic stability is necessary for construction of many important facilities in Japan. The high level radioactive waste disposal requires the confirmation of far longer tectonic stability than most of conventional facilities. However, we should note that the radioactive waste will become harmless in long but some limited future due to decay of radionuclides.

Japan generates nearly 10% of world's nuclear electricity using 39 nuclear reactors with a total capacity of 31 GWe. Japan has only poor reserves of conventional energy resources. The fear of global warming would limit the use of fossil fuels. By the year 2000, nuclear power generation in Japan is expected to reach 50 GWe, equivalent to 35% of the total electricity supply.

One of the current projects to achieve independence for Japan's energy supply is the construction of major nuclear fuel cycle facilities, such as a reprocessing plant, a uranium enrichment plant and a land burial facility for low-level radioactive waste (LLW) at Rokkasho-mura, Aomori Prefecture in north-eastern Japan. By the end of March 1989, the volume of LLW reached the equivalent of 760,000 drums of 200 liter capacity.

Japan's energy policy includes reprocessing of spent nuclear fuel and utilization of the plutonium and recovered uranium in atomic power plants. High-level radioactive waste(HLW) in liquid form, produced at reprocessing plants, is to be vitrified into a stable form, stored from 30 to 50 years for cooling, and finally disposed of in geologic formations deeper than several hundred meters. By the year 2030, the volume of vitrified HLW will be equivalent to 36,000 canisters of 110 liter capacity.

The Japan's current research on high level radioactive waste disposal emphasizes the generic validation of geologic disposal concept in the Japanese islands, analysis of multi-barrier systems, disposal technology, general survey of Japan's geologic environment and techniques for forthcoming site characterization (Koide,1991b).

Some kinds of intermediate level radioactive waste, too, should be isolated during some thousands of years, because they contain long-lived radionuclide. Some sorts heavy metals are eternally toxic. We should be aware in near future that many kinds of conventional waste should be isolated over so many years.

Geologic prediction

The long - term prediction of tectonic stability and water - rock interaction are key issues for performance assessment of waste disposal especially in the island arc region. Long - term geologic prediction is not necessarily more difficult than short - range prediction, because geologic prediction is usually hard to pinpoint exact time of occurrence but can suggest only broad range of possibility(Fig.2). For example, study of history of old earthquakes and analyses of active fault allow us the adequate long - term earthquake prediction of possible magnitude and source of future earthquakes. However, short - range earthquake prediction is still far to pinpoint the day of occurrence.

A systematic approach is necessary for geologic prediction of long - term tectonic stability, because the prediction by single method is not reliable enough to the safety assessment for waste disposal. Methods for geologic prediction are classified as follows(Koide,1990):

(1) Prediction by extrapolation: The most fundamental method for geologic prediction is effective especially in steady slow processes, but also applicable to periodic and cyclic phenomena. Research on the Quaternary geology is essential for this type of prediction. Tectonic movements such as fault displacements look as steady slow phenomena but often are periodic or cyclic in detail. The prediction should be made on the detailed observation over enough longer time span than the prediction period(Fig.3). Possibility of change of tendency should be checked up by other prediction methods.

(2) Prediction by analogy: Most of proposed earthquake prediction methods, such as "doughnut pattern" of precursory earthquake swarm, belong in this category. Natural analogues(Chapman and McKinley, 1987) and archaeological analogues are only reliable means of validating conceptual and numerical models for long-term prediction.

(3) Prediction by probability: Statistical research may be indispensable to the risk assessment of some catastrophic events. Most geologic events, however, are not random in the strict sense. Therefore, we should be careful to apply the evaluation by probability to geologic events.

(4) Prediction by experiment: Laboratory experiments and in - situ experiments are essential to exact understanding of deep geologic processes. We need more experiments about the mechanical and chemical behavior of rocks and fluids under

high temperature and high pressure. Experiments by scale models are often useful to understand some tectonic mechanisms. However, long experiments lasting hundreds or thousands of years are virtually impossible. Natural analogues may be used as "natural experiments."

(5) Prediction by conceptual model: The plate tectonic model is useful for prediction of tectonic movements in the island arc region such as the Japanese islands.

(6) Prediction by numerical simulation model: Great efforts have been made to develop reliable simulation models of groundwater flow around a repository. Faulting and fluid-rock interaction should be studied for development of numerical simulation model of tectonic processes.

(7) Prediction by safety assessment model: The simplified safety assessment model is useful to analyze the total performance of complex disposal system. The safety assessment of complex disposal systems requires the development of synthetic models, scenario analyses and consequence analyses.

Long-term geologic prediction for radioactive waste disposal should be performed and cross-checked by several different methods.

Long-term stability of geologic environment

Interaction of major terrestrial plates formed the complex geologic structures of the Japanese islands. Frequent earthquakes and numerous active faults clearly indicate severe deformation of the earth's crust in and around Japan. Volcanic eruptions and abundant hot springs suggest intensive underground geothermal and magmatic activity in some regions.

The speed of ordinary geologic process, however, is much slower than that of human activities. Tectonic movements faster than 1 mm/year occur in some restricted regions near the plate boundaries, volcanic fronts, or major active faults such as the Median Tectonic Line. Even most active faults move less than several meters after locked periods that can last as long as some thousands of years. Catastrophic events such as major earthquakes and gigantic volcanic eruptions are extremely rare in many regions.

Volcanic activities take place only on the continental side of the volcanic front (Fig.4, Sugimura and Uyeda, 1973). There are virtually no possibility of igneous intrusions between the subduction zone and volcanic front in the island arc. The volcanic activities are the most intensive near of the volcanic front on its continental side. Volcanoes become rarer towards the continent apart from the volcanic front.

High temperature hot springs are also rare on the oceanic side of the volcanic front indicating mild geothermal activities.

Kinugasa (1989) proposed "active fault fronts" similar to the volcanic front (Fig. 5). Active faults are rare on the oceanic side of active fault fronts. Shimamoto(1989) suggested that thickness of rigid upper crust with more strength than 100MPa is only about 20km due to high temperature of lower crust in the island arc on the continental side of volcanic front and active fault front(Fig.6). The tectonic deformations and active faultings are concentrated in the island arc area with thin rigid upper crust near the volcanic front(Fig.7). Active faults and big earthquakes are rare with no volcanic activity in the thick rigid "fore-arc wedge" (Shimamoto, 1989) between the subduction zone and volcanic front. There exist tectonically stable blocks in island arc between the subduction zones and volcanic front(Fig.8).

The underground repository should be designed using reliable knowledge of the possible maximum rate of tectonic movement, probability of catastrophic events, and consequences of the geologic events and processes. The high durability of underground facilities against earthquakes was demonstrated in the epicentral region during the 1976 Tang-Shan earthquake in China (Wang, 1985). The Tang-Shan earthquake brought great disaster to the Tang-Shan city, but resulted in relatively small damage to the underground Tang-Shan coal mine at a depth of 640m below the ground surface. Minimal damage occurred in spite of the presence of the earthquake-generating fault across the mine. However, Careful investigations are in progress to evaluate indirect effects of geologic events such as change of groundwater path by big earthquakes.

Rock bodies protect the underground repository from the direct effect of volcanic eruption. Extremely low probability is apparent for igneous intrusions to hit and break directly through the repository. However, underground structure of volcanoes and process of igneous intrusion should be investigated for regions in which igneous activity is possible.

Rock properties slowly change with consolidation, diagenesis, weathering and hydrothermal alteration. Hydrothermal processes are indirect effects of geothermal and igneous activity, and are widespread in Japan. Low-temperature hydrothermal processes are studied as analogues of water-rock and water-waste interaction following burial of radioactive waste. Altered clay materials and vein-filling precipitates from hydrothermal fluids often effectively prevent migration of groundwater and nuclides through faults and fractures in rocks.

Geologic setting of the Japanese island is investigated for the disposal of high level

radioactive waste(Koide,1991a). A systematic research for geologic prediction is planned for the safety assessment of radioactive waste disposal.

Conclusion

The great regional variation of the geologic environment in the island arc will make forthcoming investigations for site selection important for the safe disposal of radioactive waste. A systematic approach for geologic prediction of tectonic stability was proposed in this paper.

Tectonic deformation is intense near the plate boundary and near the volcanic front. However, some tectonically stable and volcano-free blocks are found in the island arc region between the subduction zone and the volcanic front. In other areas, more precise investigations are necessary to evaluate the effect of tectonic and igneous activities upon the waste repository.

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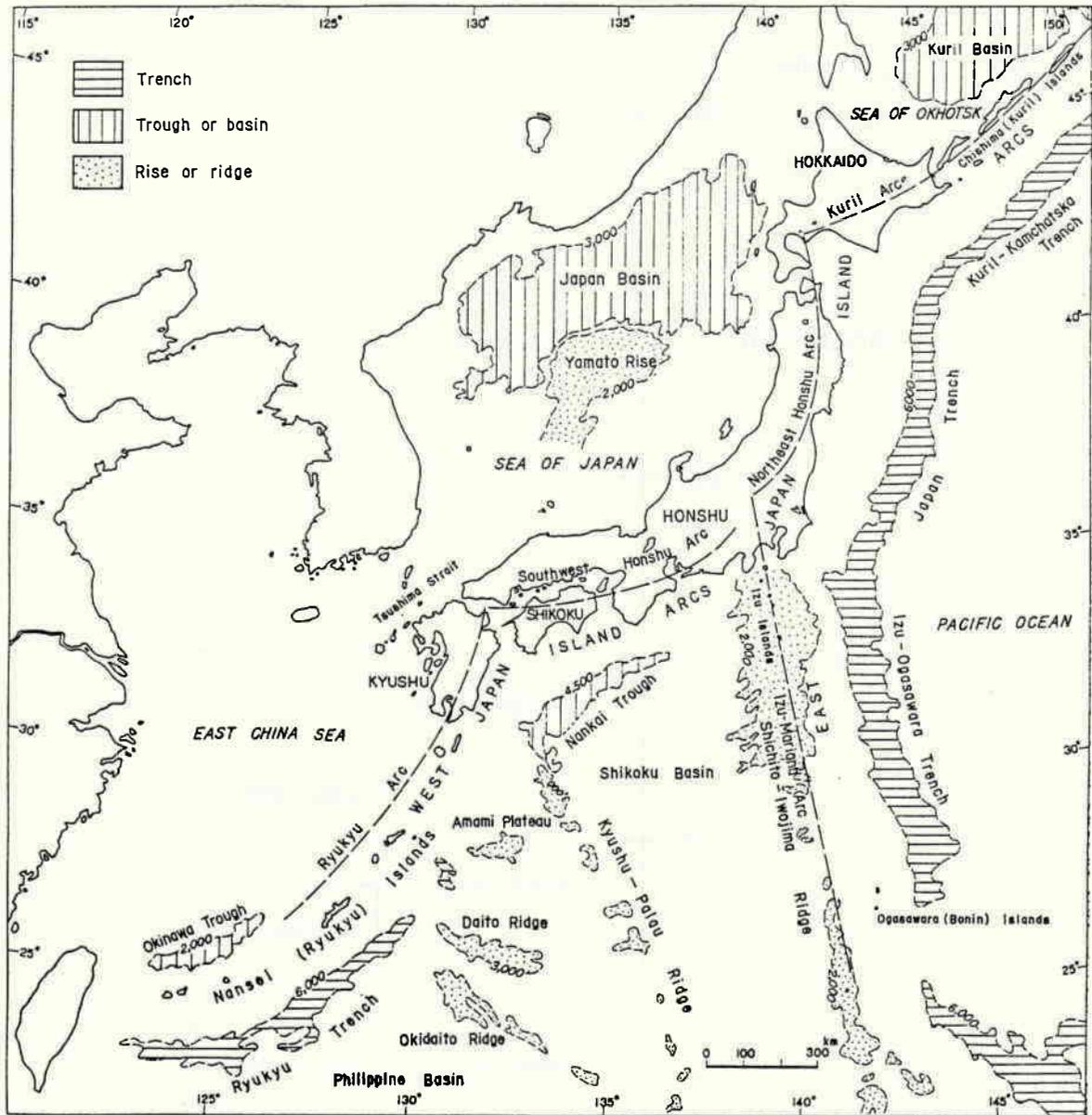


Fig.1 Major topography of Japan and its environs (Tanaka and Nozawa, 1977). Depth in meters.

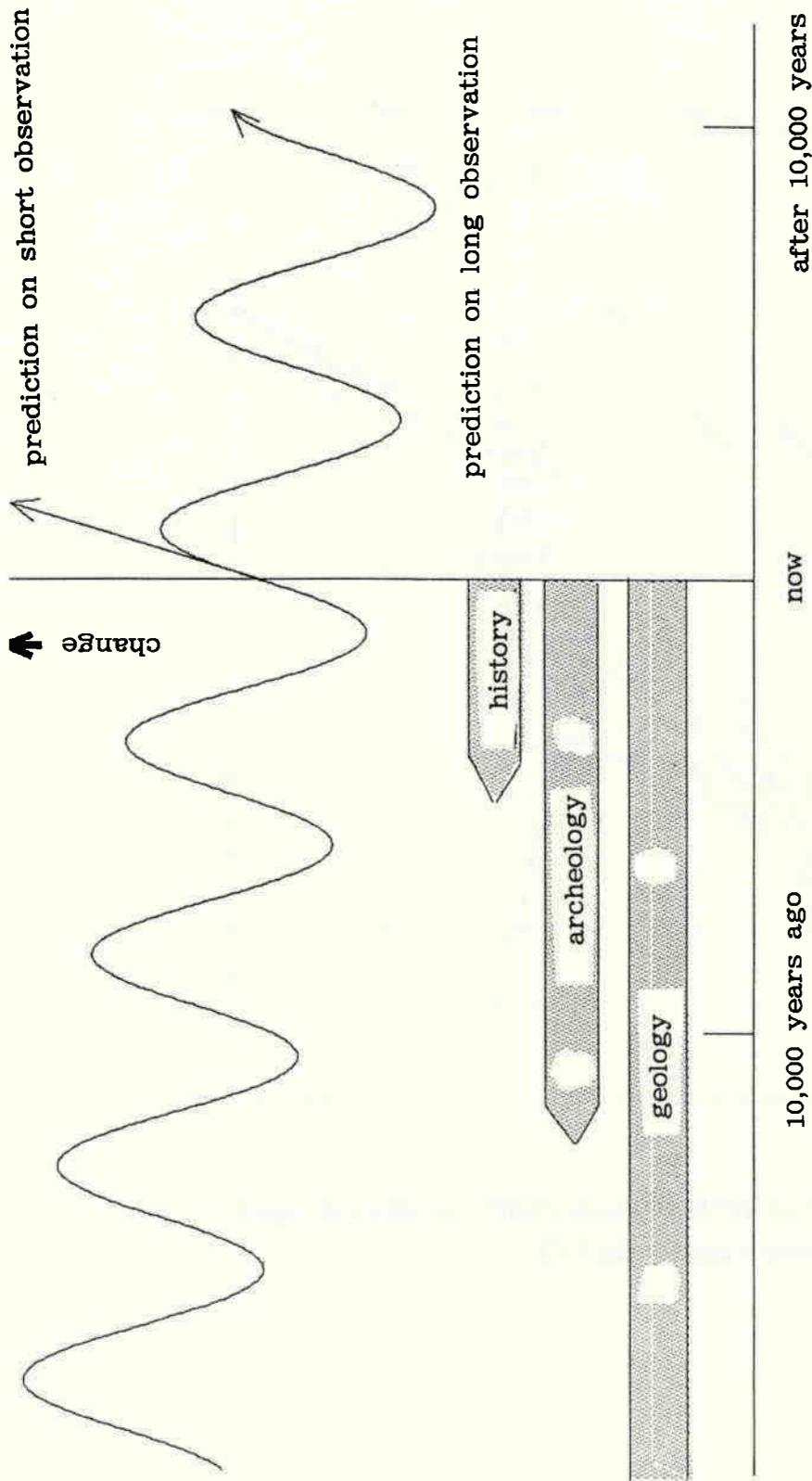


Fig.3 Prediction by extrapolation and observation period.

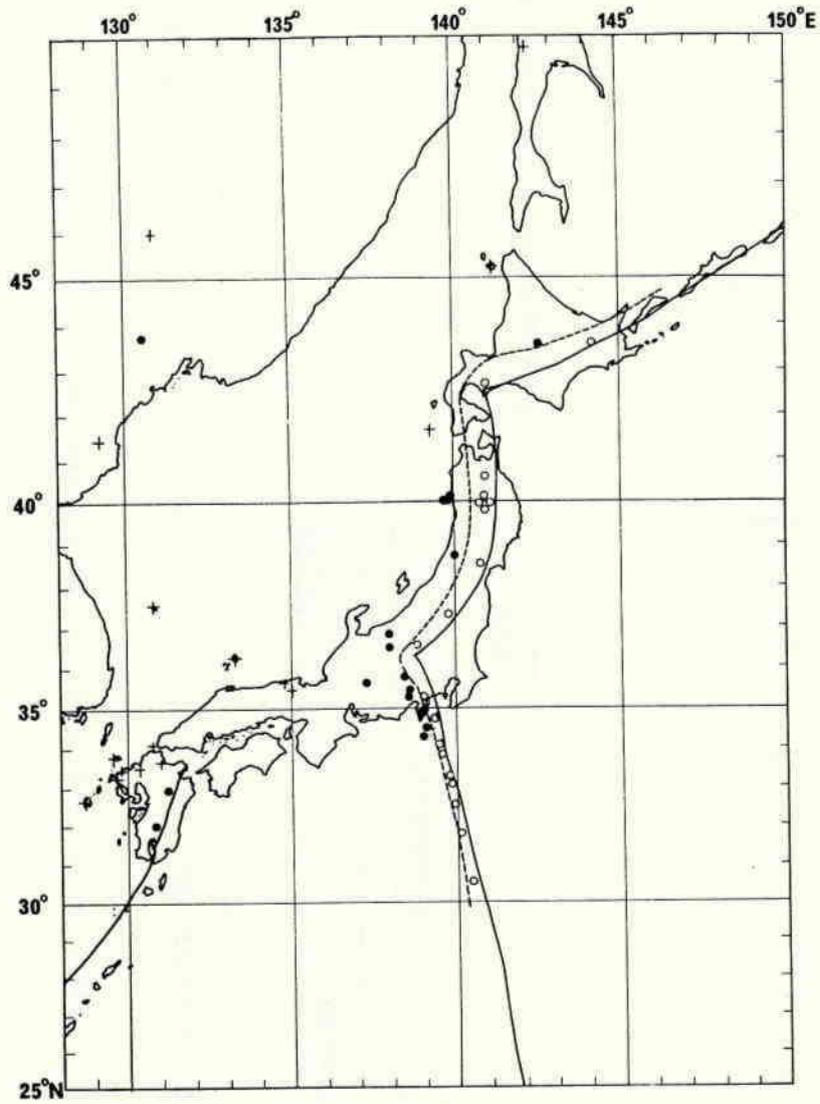


Fig.4 Volcanic fronts and Quaternary volcanoes in Japan
(Sugimura and Uyeda,1973)

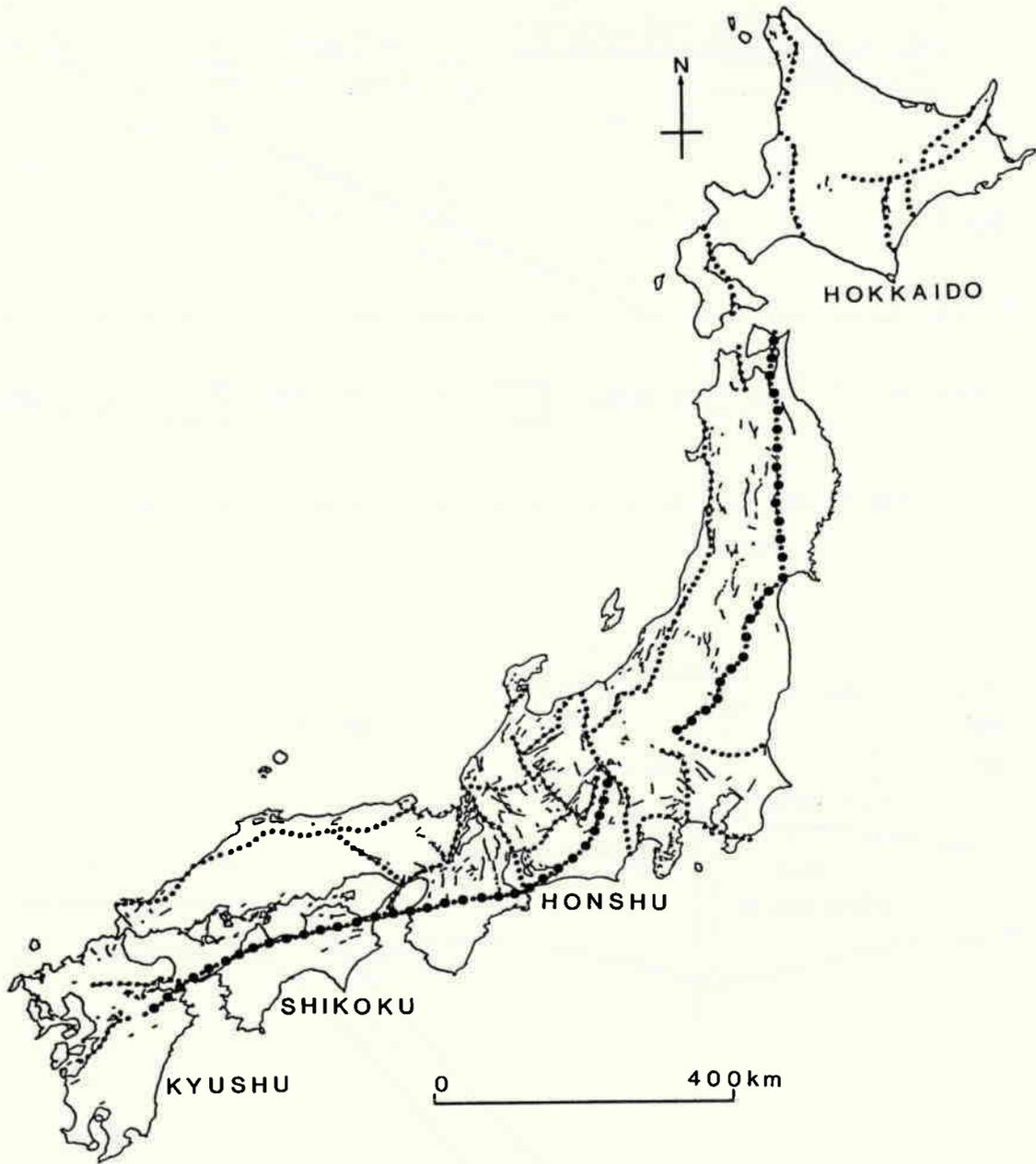
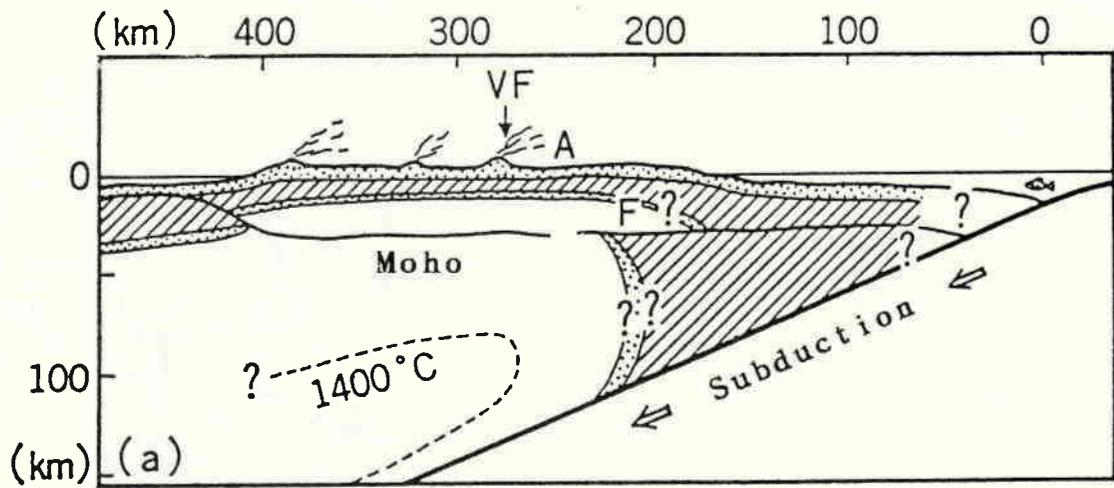


Fig.5 Seismotectonic provinces in Japan
 (Modified after Kinugasa, 1989).

Short solid lines, small dotted lines, and large dotted lines denote active faults, boundaries of provinces, and active fault fronts, respectively.



Strength : < 100 MPa 100~500 MPa > 500 MPa

Fig.6 Rock strength along a section of the north eastern Japan (Shimamoto, 1989)

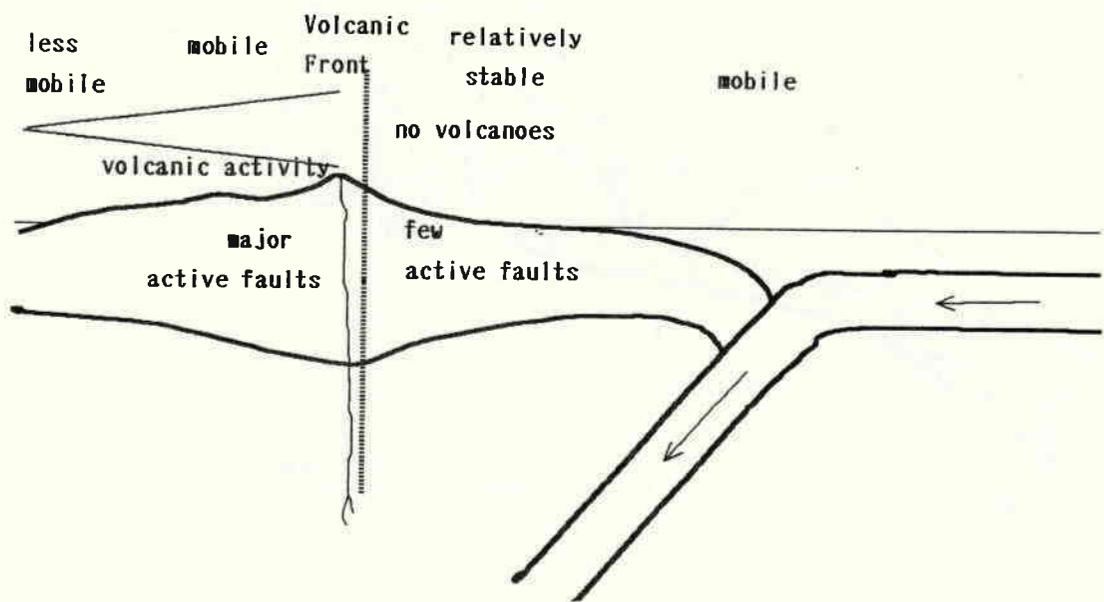


Fig.7 Tectonic stability section of island arc.

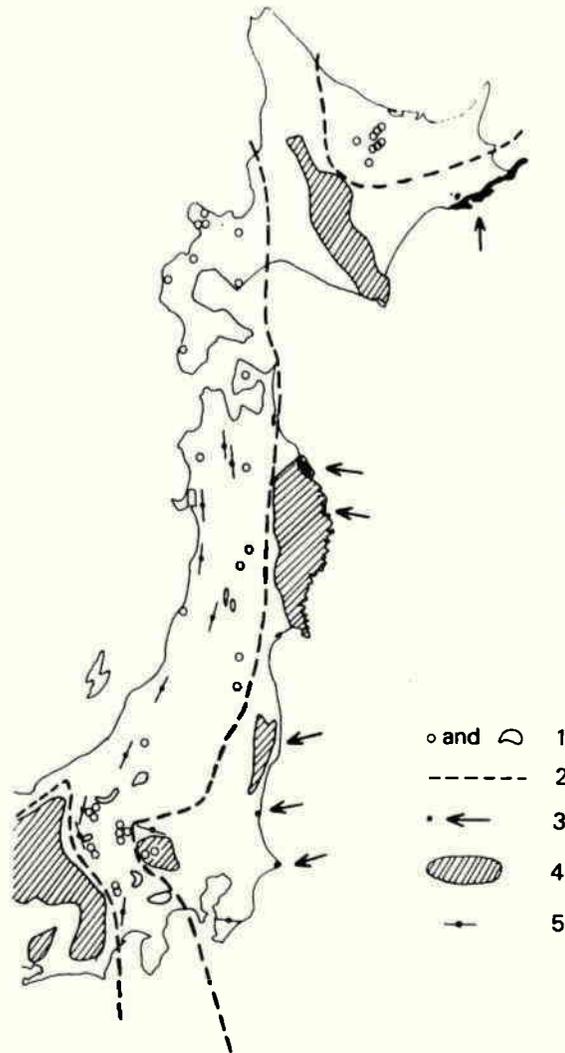


Fig.8 Zonal arrangement of geological features along the Northeast Honshu Arc(Sugimura and Uyeda, 1973)

- 1 = Middle Miocene acidic intrusive;
- 2 = Early Miocene volcanic belt ("Green Tuff" area);
- 3 = Late Cretaceous to Eocene formation not deformed;
- 4 = continuously emerged area since the Early Miocene; and
- 5 = direction of Quaternary fold axis.