Georisks along active faults of Median Tectonic Line in Shikoku, Southwest Japan

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Abstract

The Median Tectonic Line (MTL) is one of the most predominant and active faults in Japan. The MTL marks striking contrast in topography between the mountains and alluvial plains in Shikoku, Southwest Japan. The active faults of the MTL are inferred to cause magnitude 7 to 8 class earthquakes on the basis of the fault lengths and the amount of displacement. These topographic contrast and nearby strong earthquakes are the primary cause of landslides along the MTL. Geological investigations have revealed that large-scale landslides have occurred since Early Pleistocene along the fault scarps of the MTL in Shikoku. Recently, many small landslides have occurred due to slope cutting and ground excavation for tunneling during the construction of the expressways. Geotechnical investigations on these landslides have revealed that smectite-bearing clay-rich zones are the origin of sliding surfaces. The smectite is inferred to be formed by hydrothermal alteration which is originated from Middle Miocene volcanism. This hydrothermal alteration also yield fine-grained pyrites which are the main cause of acid soil after slope cutting. The rockmass types of tunnels composed of the Cretaceous Izumi Group is divided into four types from view-points of landslide and hydrothermal alteration. Experience from the Median Tectonic Line in Shikoku provides us typical georisks along major active faults.

Keywords: Median Tectonic Line, active fault, hydrothermal alteration, landslide, georisk

1. Introduction

Japan is located in the Circum-Pacific “Ring of fire" where seismic and volcanic activities occur constantly. Japan has suffered great damages from the massive inter-plate earthquakes produced by plate subduction (such as the 2011 Tohoku Earthquake) and the inland crustal earthquakes caused by active faulting (such as the1995 Kobe Earthquake).

In southwest Japan, Nankai Trough earthquakes whose magnitudes are measuring 8 to 9 have occurred every 100 to 150 years along the Nankai trough on the boundary megathrust between Eurasia and the Philippine Sea plate (Fig. 1). The Median Tectonic Line (MTL) is one of the most predominant and active faults in Japan. It forms an active fault system with predominantly right-lateral displacement in the Quaternary in Shikoku and western Kii, southwest Japan, owning to oblique subduction of the Philippine Sea plate. The active fault planes of the MTL are usually steep and north dipping. Thus, the MTL have marks a topographical boundary between the mountains and the alluvial plains in Shikoku. This topographic contrast is the primary cause of landslides along the MTL.

The georisks associated with the MTL are active faulting and source of big earthquakes, large-scale unstable fault scarps, fracture and hydrothermal alteration zones, and large-scale landslides. The Median Tectonic Line in Shikoku provides us typical georisks along major active faults.

2. Geological setting

2. 1 Median Tectonic Line (MTL)

The Median Tectonic Line (MTL) is the main topographical boundary in north Shikoku, and it runs from Naruto city on the north of Tokushima city to Matsuyama city, trending N75° E. The MTL is marked by remarkable contrast in topography between the mountains and plains. The active faults of the MTL run along the foot of the Sanuki Range in eastern Shikoku and along the foot of Shikoku Range in central and western Shikoku. The fault scarps reach up to 1000 meters in height in central Shikoku.

The MTL forms a boundary between the Upper Cretaceous Izumi Group on the north and the Sambagawa metamorphic rocks on the south (Fig. 1). The distinct fracture zone of the MTL reaches 80 meters into the bedrock, and hydrothermal alteration zones are widely distributed in the bedrock (Hasegawa et al., 2001).

2. 2 Bedrocks

The Sanuki Range in eastern Shikoku and hills to the north of the MTL in central and eastern Shikoku are underlain by the Upper Cretaceous Izumi Group). The Izumi Group consists mostly of interbedded sandstone and shale, with subordinate felsic tuffs and conglomerates. The Sambagawa metamorphic rocks are widely distributed in the southern Shikoku Range and are mainly composed of pelitic schists and greenschists.

In Shikoku, not only are the intrusive rocks of rhyolite of the middle Miocene distributed along the MTL. These rocks indicate K-Ar dating of about 13 to 15Ma, with many of them concentrated around 14Ma (Shinjoe and Sumii, 2000 etc.).

3. Active faulting of the MTL

The rate of right-lateral slip of the fault during the late Quaternary is estimated to be several meters per 1000years in Shikoku (Okada, 1980).

The MTL active faults were previously thought to be unruptured at least in the past 1000 years based on the absence of historical evidence for destructive earthquakes. However, trench excavations show that part of the MTL ruptured most recently during or after the 16th century A.D. with at least 6.9 ± 0.7 m of slip along the main fault trace (Tsutsumi and Okada, 1996).

The MTL probably does not rupture along its entire length in a single earthquake but instead consists of multiple "earthquake segments" that rupture independently of one another. The recurrence interval and surficial offset for surface-rupturing earthquakes at four individual sites on the MTL in Shikoku Island are 1000–3000 years and 5–8 m, respectively (Tsutsumi et al., 1996).

The active faults of the MTL are inferred to cause magnitude 7 to 8 class earthquakes on the basis of the fault lengths and the amount of displacement. Fault segmentation models have been developed by using various types of information about faults, including both geological and geophysical data, in order to estimate the size of future cascade earthquakes (Okada, 1992; Ikeda et al., 2009).

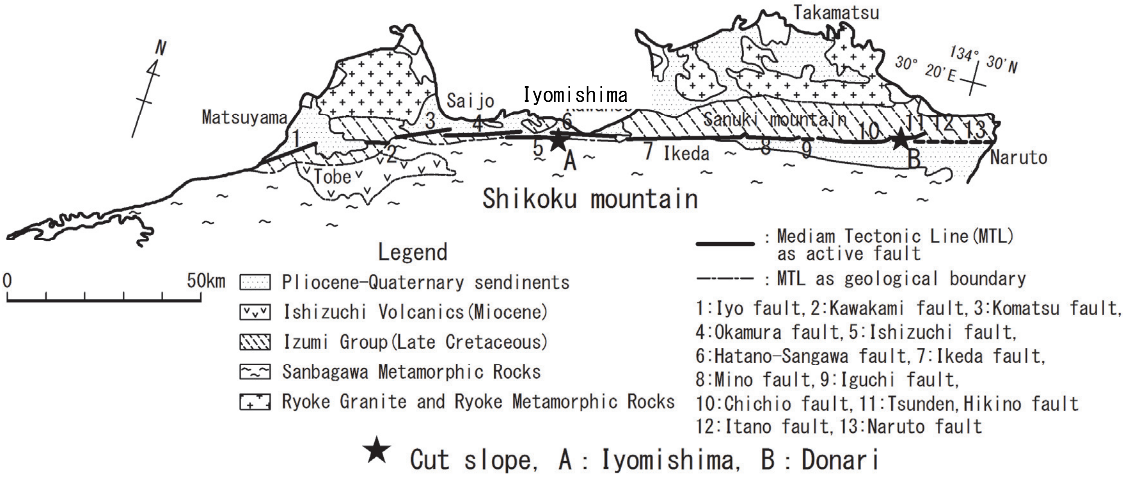


Fig.1 Geology and active faults along the median Tectonic Line in Shikoku

4. Hydrothermal alteration along the MTL

4.1 Hydrothermal alteration of fault gouge along the MTL

Hasegawa et al. (2001) reported that the fault gouge along the intrusive rock of the MTL contains tridymite, dolomite and magnesite, as well as smectite and illite-smectite mixed-layer mineral and reported that those mineral composition had been produced by hydrothermal alteration. This hydrothermal alteration also yield fine-grained pyrites which are the main cause of acid soil after slope cutting.

4.2 Landslides due to hydrothermal alteration on cut slopes

Tamura et al. (2007) have reported bedrock deterioration by hydrothermal alteration on the cut ground slope along the MTL (Fig.1). The bedrocks of the cut slope at Iyomishima is composed mainly of pelitic schist of the Sanbagawa belt. Rhyolite with a width of about 2 m, belonging to the Ishizuchi group of the middle Miocene intrudes into the lowest part of cut slope (Fig. 2).

On this cut slope, an altered clay zone is observed around the rhyolite intrusive. X-ray diffraction reveals that greenschists or rhyolites is characterized by containing more swelling clay mineral of smectite and a chlorite-smectite mixed-layer mineral. Smectite and chlorite-smectite mixed-layer mineral are located mainly near the rhyolite which have provided slip surface of landslide (Fig.3).

In the east region of Shikoku (Loc. B at Donari in Fig.1) intrusive rhyolite is not observed along the MTL, however, hydrothermal alteration occur similarly as observed in the west and central regions of Shikoku. Unexpected landslides occurred on a cut slope 5 years earlier. The occurrence of such an unexpected landslide is considered to be caused by the smectite-bearing altered sandstone, which is an expansive clay mineral with weak strength due to hydrothermal alteration, and the presence of fissure dipping towards the face of the slope (Tamura et al., 2007).

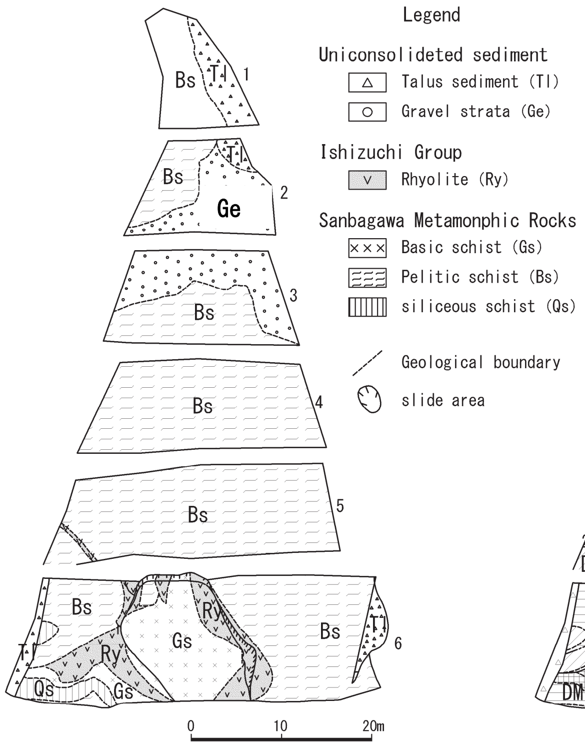


Fig.2 Geology of cut slope at Iyomishima, Ehime prefecture (modified after Tamura et al., 2007a)

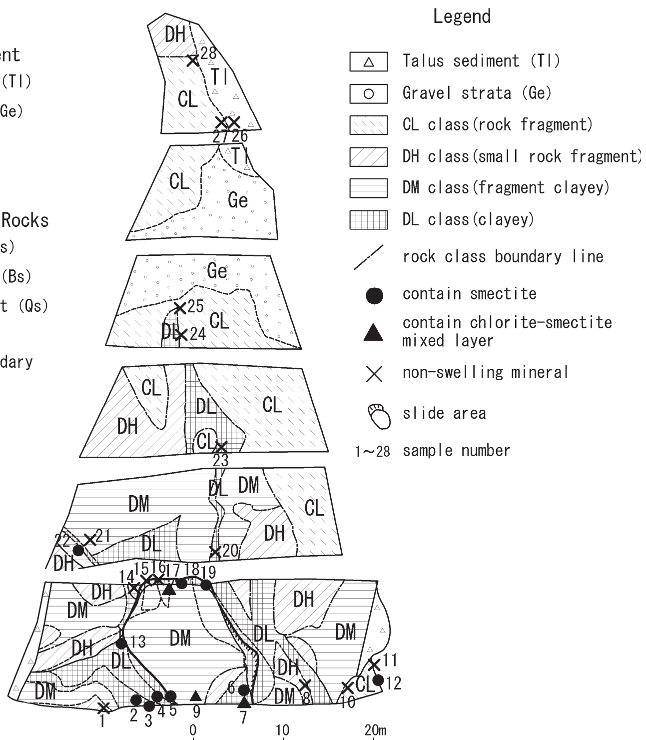


Fig.3 Rock mass classification and distribution clay minerals of cut slope at Iyomishima (modified after Tamura et al., 2007a)

5. Large-scale landslides along the MTL

Geological investigations have revealed that large-scale landslides along the fault scarps of the MTL have been occurring since early Pleistocene in Shikoku (Hasegawa, 1991, Hasegawa, 1992, Hasegawa & Sawada, 1999, 2001). Typical examples of the Early Pleistocene rock mass slide in Sanuki Range is the Kirihata Hill rock mass slide situated along the Chichio fault (Fig.1, Fig. 4, Fig. 5). It is inferred that big earthquakes due to the fault activity caused the rock mass slides is the fault scarps in the past and slid on/in the Quaternary sediments. Their findings are as follows:

i) Large-scale rock mass slides along active faults of the MTL have occurred from Early Pleistocene (about 1Ma) to Holocene. The masses are highly dissected by erosion in case of older formative ages are older.

ii) The masses have been displaced right-laterally by active fault of the MTL. More the masses are dissected, more are the displacements by the active fault. The average displacement rate attains 5-10m/kiloyears at the Ikeda faultand 2-3m/kiloyears at the Chichio fault (Hasegawa and Sawada, 1999).

iii) The rock slide masses of the Izumi Group are extremely loose and possess abundant open cracks with lost cohesion. They have preserved original stratifications, but some of them resemble debris.

iv) This sliding zone material composed of "clay-matrix brecciated layer (CBL)" indicates that the rock mass slid rapidly on this clay-rich brecciated layer as lubricant layer. This clay-matrix layers can be inferred to be caused by the hydraulic fracturing

v) The Middle Miocene hydrothermal alteration along the MTL has produced smectite and smectite bearing mixed-layer minerals in bedrocks as fault gouges or clay veins and might have become a geological factor to cause the landslides.

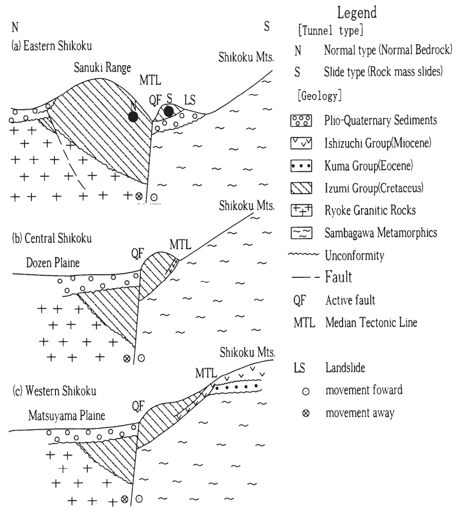


Fig. 4 Geological profile along the Median Tectonic Line in Shikoku (Hasegawa et al., 2006)

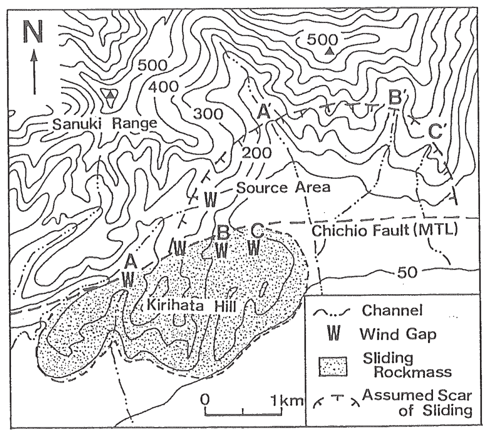


Fig. 5 Kirihata hill as an ancient mega-landslide occurred at 1 Ma along the Chichio fault of the Median Tectonic Line in Shikoku (Hasegawa, 1991).

Fig. 6 Sliding zone material composed of "clay-matrix brecciated layer (CBL)" (Hasegawa and Sawada, 2001)

6. Rockmass characterization of expressway tunnels along the MTL

As national highways which connect Tokushima, Takamatsu and Matsuyama are usually crowded, new expressways have been constructed by Japan Highway Public Corporation since 1985. Three expressways have been constructed in North Shikoku. They are Tokushima, Takamatsu and Matsuyama expressways (Fig.7).

Most of three tunnels of three expressways are constructed in the sedimentary rocks of the Cretaceous Izumi Group. Moreover, Tokushima and Matsuyama Expressways has been constructed along active faults of the Median Tectonic Line (MTL). These tunnel constructions have revealed the difficulty in predicting the ground condition before and during tunnelling, because the convergences during tunnelling do not correspond to lithology or face observation. Hasegawa et al. (2006) and Yoshida et al. (2006) have re-examined the tunnelling data and have clarified the rock mass characteristics of the Izumi Group near the MTL. These papers proposes the rock mass characterization of the Izumi Group for the tunnel construction on the base of the damage history of both rock mass sliding and hydrothermal alteration (Table 1).

This classification was confirmed by the rock mass grades and convergences during tunnelling (Fig. 8, Fig.9, Fig10). The first N-type ground is composed of sound rock mass and shows very small convergence during tunnelling. The second S-type ground is composed of cracked rock mass, but shows small convergence during tunnelling. The third H-type ground is composed of altered rock mass and shows very large convergence during tunnelling even if rock mass at face seems to be sound. The fourth HS-type ground is composed of altered and cracked rock mass and shows very large convergence during tunnelling.

These four types of tunnel show distinct characteristics during tunnelling. Especially, it is clear that the large convergence tends to appear in H-type and HS-type tunnel ground. X-ray diffraction analysis suggests that smectite-bearing clay veins originated from hydrothermal alteration and have caused large convergence during tunnelling. Therefore, it is very important to confirm the presence of the swelling clay mineral (smectite etc.) before and during tunnel construction.

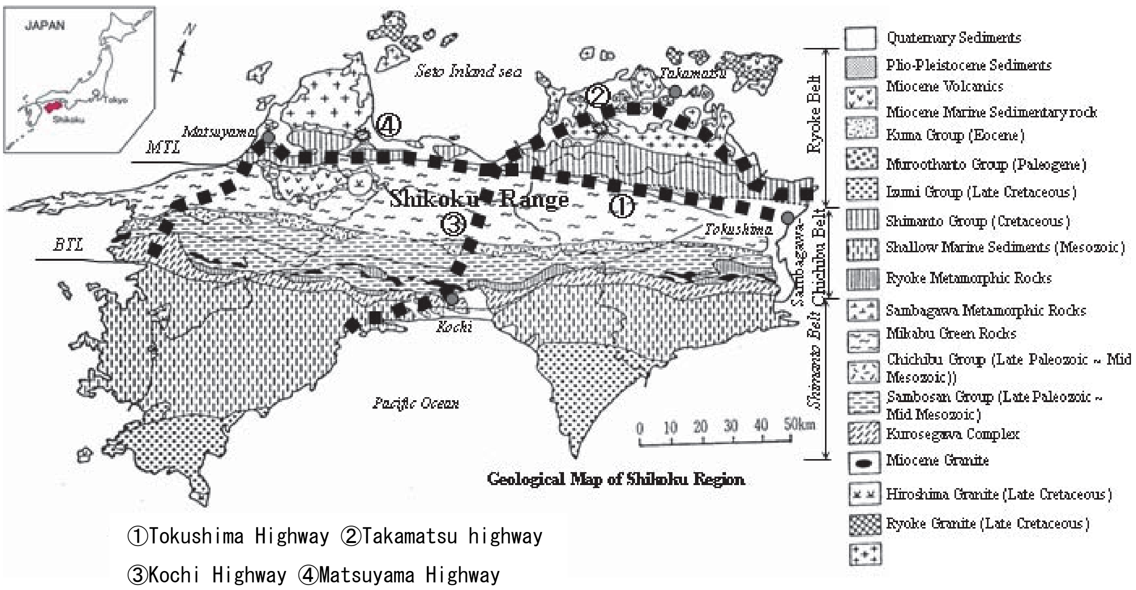


Fig.7 Geological map and expressway of Shikoku region (Hasegawa et al., 2006)

Table 1 Classification of tunnel ground in the Izumi Group from rock mass slide and hydrothermal alteration (Hasegawa et al., 2006).

Landslide \ Hydrothermal alteration	×	○
×	N-type	H-type
○	S-type	HS-type

○: affected, ×: unaffected

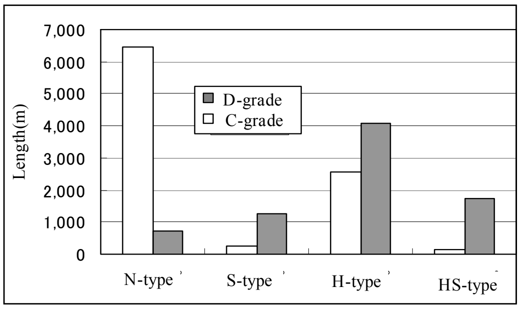


Fig. 8 Length of rock mass grades in each ground types in tunnels of Tokushima, Takamatsu and Matsuyama expressways (Hasegawa et al., 2006).

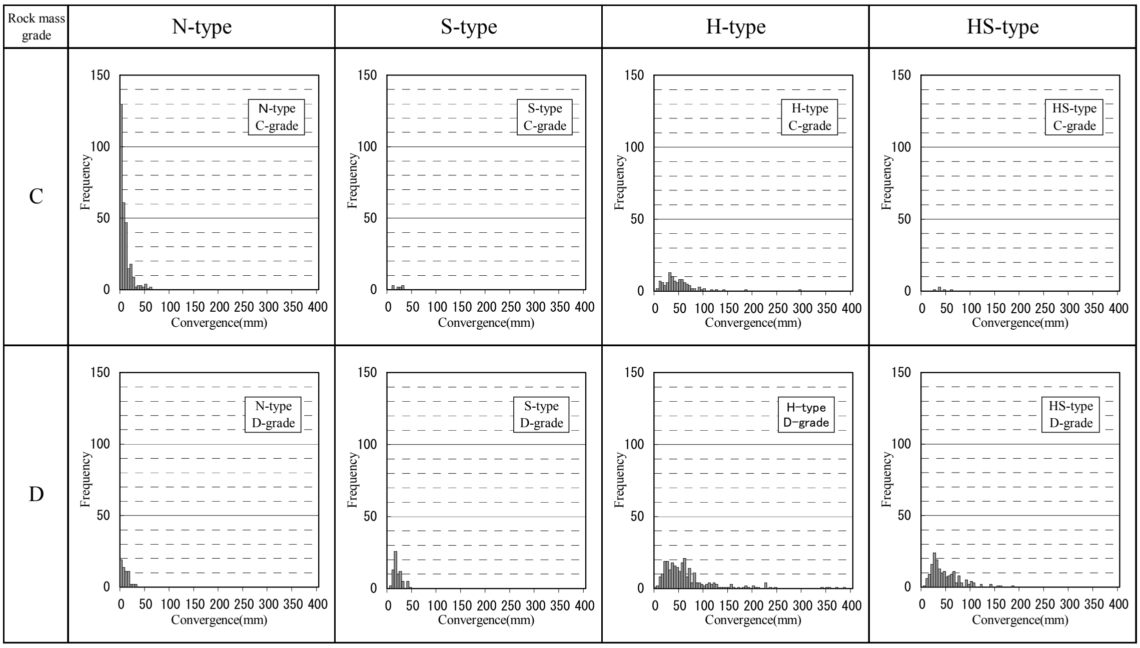


Fig.9 Convergence of four types of tunnel ground in tunnels of Tokushima, Takamatsu and Matsuyama expressways (Hasegawa et al., 2006).

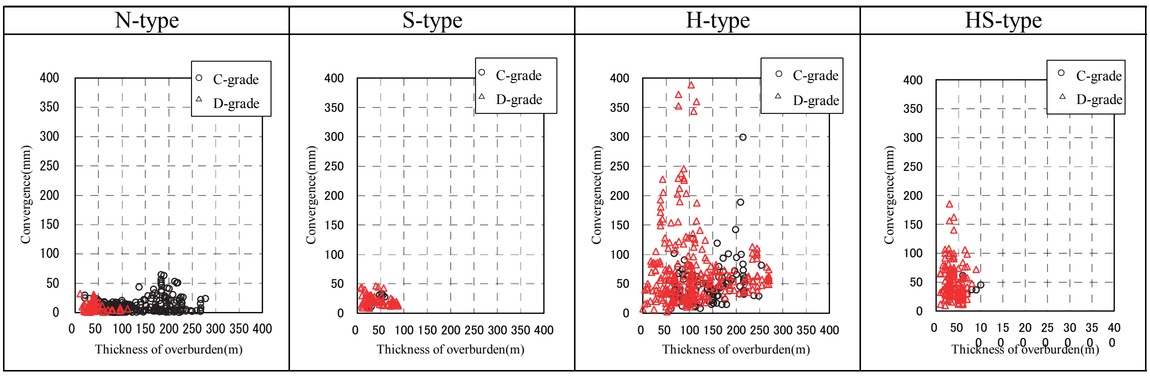
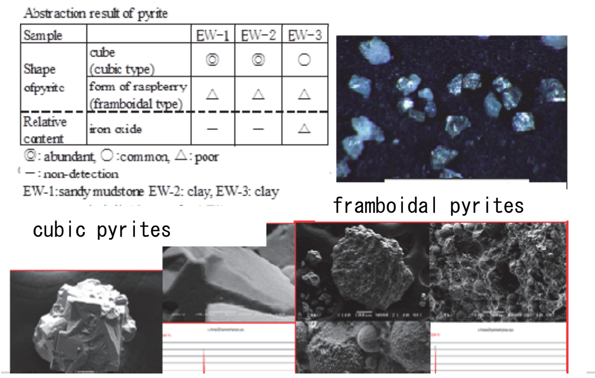


Fig. 10 Convergences of four types of tunnel ground to thickness of overburden in tunnels of Tokushima, Takamatsu and Matsuyama expressways (Hasegawa et al., 2006).

7. Acid soils on cut slops

Acid soils on cut slopes were rare in Shikoku, but after the construction of expressway along the MTL, poor vegetation on cut slopes have occurred. Typical acid soil are observed on cut slope along the Mino fault where about half of hydrothermally altered soil of interbedded sandstone and shale are less than 4 in pH. Surface of soil are covered by fine-grained gypsum which suggests sulfuric acid.

The altered soil contains smectites and pyrites. Observation by SEM have confirmed abundant cubic pyrites which suggest the origin of hydrothermal alteration (Fig.11). Although shale of the Izumi Group contains framboidal pyrites, hydrothermally originated cubic pyrites are inferred to have acted as source material of acid soils.



Sample		EW-1	EW-2	EW-3
Shape ofpyrite	cube (cubic type)	◎	◎	○
	form of raspberry (framboidal type)	△	△	△
Relative content	iron oxide	—	—	△

Fig.11 Pyrite in altrated rock and altrated fault clay along MTL

8. Conclusions

This paper reviewed Georisks along active faults of Median Tectonic Line in Shikoku, Southwest Japan.

The Median Tectonic Line (MTL) is one of the most predominant and active faults in Japan. The MTL marks striking contrast in topography between the mountains and alluvial plains in Shikoku, Southwest Japan. The active faults of the MTL are inferred to cause magnitude 7 to 8 class earthquakes on the basis of the fault lengths and the amount of displacement.

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