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# Landslides in weathered granitic rocks in Japan and Malaysia

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**Abstract:** Landslides in weathered granitic rocks are strongly affected by the types of weathering, which is site specific and quite different between temperate Japan and tropical Malaysia. Major landslide hazards induced by rainstorms in Japan and Malaysia are compared in terms of weathering scheme and landslide mechanisms. Many landslides have been induced in weathered granitic rock areas by rainstorms in Japan, killing nearly 1500 people since 1938. Some major landslides in Malaysia are also associated with weathered granitic terrain and these have killed more than 200 people.

**Keywords:** landslide, granite, weathering, Malaysia, Japan

## INTRODUCTION

Granitic rocks are commonly weathered to as deep as 10-30 meters, and innumerable slides in weathered granites have been documented in tropical and humid regions, resulting in great numbers of casualties. For example, Japan has sustained many recurring disasters in granitic areas following heavy rains, resulting in a total of nearly 1500 casualties over the last 70 years, including 20 in Hiroshima in 1999 and 11 in Yamaguchi in 2009 (Figure 1). Similar phenomena have occurred in Malaysia but the causalities are not substantial. Major types of failures are shallow and deep sliding, debris flow and erosional failure. These occur mainly along major highways and residential areas such as Bukit Antarabangsa and Genting Sempah (Figure 2).

In the granite and gneiss areas of Rio de Janeiro in 1966 and 1967, severe rainstorms resulted in tens of thousands of landslides and about 1000 casualties (Durgin, 1977). Southern Italy has also suffered from landslides in weathered granite (Calcatera *et al*., 1996). In 2002, a rainstorm of typhoon Rusa hit Korea and many landslides occurred in the granitic areas of Gangneung and Muju.

Granitic rocks are known to be very sensitive to weathering and are vulnerable to landsliding; exceptions are the granites of North America and north Europe. These granites are not generally associated with landslides because most of the weathered granites on these continents have been eroded by glaciation.

## CHARACTERISTICS OF WEATHERED GRANITE PROFILE

A typical weathering profile of granite in subtropical climate consists of decomposed granite with core stones in the lower part and saprolite in the upper part (Ruxton & Berry, 1957). The core stones are formed by spheroidal weathering (Figure 3, Ollier, 1967). If decomposed granite is removed from core stones, tors are left (Linton, 1955). Another type of weathering profile, which is not as commonly

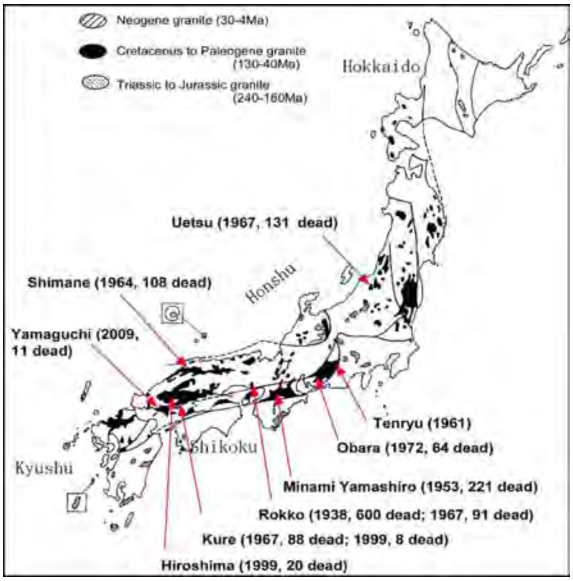

**Figure 1:** Landslides in areas underlain by granitic rocks in Japan.

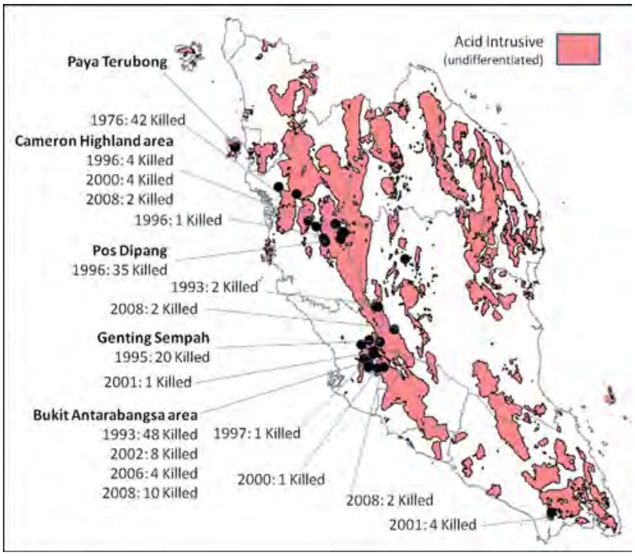

**Figure 2:** Landslides in areas underlain by granitic rocks in Peninsular Malaysia.

seen as that above, consists of saprolite in the upper part and a zone of micro-sheeting in the lower part (Figure 4, Hashikawa & Miyahara, 1977; Hashikawa, 1978; Folk & Patton, 1982; Chigira, 2001). Micro-sheets, previously called laminations (Twidale, 1971), are thought to be made by buttressed expansion due to unloading or a number of other factors (Folk & Patton, 1982). Weathering intensity has been classified from A to D (A, B, Ch, Cm, Cl, D) Japan and from I to VI in United Kingdom and Malaysia. Weathering grades D corresponds to IV and V and the weathered granite in these grades and soil are the materials to slide during rainstorms. Weathering grade VI is for soil.

**Figure 3:** Spheroidal weathering of granite. Yagyu in Japan. The scale is 1 m.

**Figure 4:** Micro-sheeting of granite. Hiroshima in Japan.

In a wet tropical region like Malaysia, deep weathering profile can have a thickness of up to 100 m. Even though the characteristics of weathering profiles differ from place to place, two most common types of profiles are with and without core-stones (Komoo, 1985, 1989, 1998). Type A (without core-stones) profile is characterized by a very thick layer of residual soil (grade VI) and completely weathered material (grade V). The soil material overlay slightly weathered (grade II) and fresh (grade I) rocks making the soil-rock boundary very sharp. Type B (with core-stones) is characterized by a more complete profile consisting of material from grades VI to I. Grade V profile is thick and often with weathered core stones. Highly to moderately weathered (grades IV and III) materials contain core stones of various sizes (from few cm to few m in diameter). Both types of profiles are prone to rainstorm-induced landslides.

Several studies on rainstorm-related disasters have indicated that shallow landslides in granitic areas are closely related to weakly weathered (altered) decomposed granite, rather than to heavily weathered saprolite. Thus Oyagi (1968) reported that numerous shallow landslides occurred in areas of weakly weathered granite after a rainstorm in Shimane Prefecture (western Japan) in 1964. Durgin (1977) also discussed the relationship between the weathering stages of granite and the occurrence of landslides, and pointed out that shallow landslides or debris avalanches occur preferentially in decomposed, weakly weathered granitic areas. Iida & Okunishi (1979) and later Onda (1992) studied weathering profiles of granite underlying Obara Village, Aichi Prefecture, and central Japan, where innumerable disastrous landslides occurred following a heavy rainstorm in 1972. They found that the weathering front of the granite was abrupt and that water could collect among the loose surface rock, and they attributed the landslide generation to these particular structural and hydrological features. Chigira & Ito (1999) and Suzuki et al. (2002) studied re-weathering of weathered granite on artificial cut slopes and found that, after artificial cutting, some decomposed granite could be re-weathered quickly (i.e., over approximately 12 years) to a depth of as much as 1 m with a clearly-defined front due primarily to physical disintegration. Although the above studies on the weathering profiles of granite did not find distinct micro-sheeting, the landslides occurring in Hiroshima Prefecture in June 1999 were closely related to micro-sheeting.

Micro-sheeting generally dips 10 to 30 degrees downslope to form an overdip cataclinal slope, as described by Cruden (1989), which is a favorable structure for the rock mass to creep, as is frequently observed in densely foliated schists or laminite (Chigira, 1992). In addition, cracks in micro-sheeting and other related microcracks widen and increase in number due to stress release, temperature change, changes in water content near the ground surface, and creep movement. Alteration and expansion of biotite may also accelerate this disintegration process (Wahrhaftig, 1965; Isherwood & Street, 1976; Tassell & Grant, 1980; Hill, 1996).

Although the precise factors affecting this disintegration process are not well understood, field observations indicate that this process extends to a depth of a few meters from the ground surface when a slope inclines some 40 degrees. The extent of disintegration seems to abruptly change at the base of a loosened zone, probably due to the fact that creep and widening, as well as neoformation of microcracks, occurs interconnectedly. In other words, the increase of microcracks accelerates creep movement and vice versa, both resulting in disintegration of micro-sheets. Thus, loosened granite increases in thickness and partly changes into debris, which finally slides as a result of heavy rainfall, exposing the micro-sheeted tight granite at the base of landslide scars. Weathering profiles made through micro-sheeting or not through micro-sheeting, and with or without core stones are expected to behave in different ways against infiltrating water, and this difference could be used for the hazard assessment in granitic rock areas.

## EXAMPLES FROM JAPAN

### The 1972 Nishimikawa Disaster, Central Japan — Granite versus Granodiorite

Figure 5 shows the distribution of landslides during the heavy rain of 1972 Nishimikawa disaster, when rain fall reached more than 200 mm during 5 hours (Tobe *et al*., 2008). Similar amounts of rainfall were observed over both granite and granodiorite areas, and the resultant landslides occurred preferentially in the granite area (Yairi *et al*., 1973). This difference is attributed to the difference in weathering profiles. The weathering profile of granite has an abrupt weathering front as stated before, whereas the weathering extent of granodiorite decreases gradually downward without a well-defined front. The abrupt front in weathered granite profile is due to the loosening of grain contacts in decomposed granite (Tobe *et al*., 2007). The loosening proceeds with time (Suzuki *et al*., 2002).

### The 1999 Hiroshima and 2009 Yamaguchi Disasters, Western Japan — Micro-sheeting

Rainstorms induced many shallow landslides in weathered granite areas in Hiroshima in 1999 and in Yamaguchi in 2009. Precipitations of these were 250 mm and 300 mm per day (Figure 6), respectively. Landslides in Hiroshima took place in dense patterns within an elongate zone with a long axis trending NE-SW, which coincided with the zone of heavy rain of 50-70 mm/hr (Kaibori *et al*., 1999). The individual landslides were relatively small, with lengths and widths of about 10-50 m and depths of only a few meters. The landslide density reached about 24 in an area of 1 km$^2$. Debris generated by a shallow landslide rushed down streams for a distance of as much as 1 km and struck residential houses in many locations. There were several types of landslides, and the most prevailing one was landslide of decomposed granite or debris on micro-sheeted granite. Micro-sheeting results in slopes of unstable structure, which, combined with mechanical disintegration of micro-sheets, leads to landsliding, as shown schematically in Figure 7. Landslides in Yamaguchi in 2009 occurred only in weathered granite areas and not in the surrounding metamorphic rocks. The granite is very similar to that in Hiroshima and is micro-sheeted.

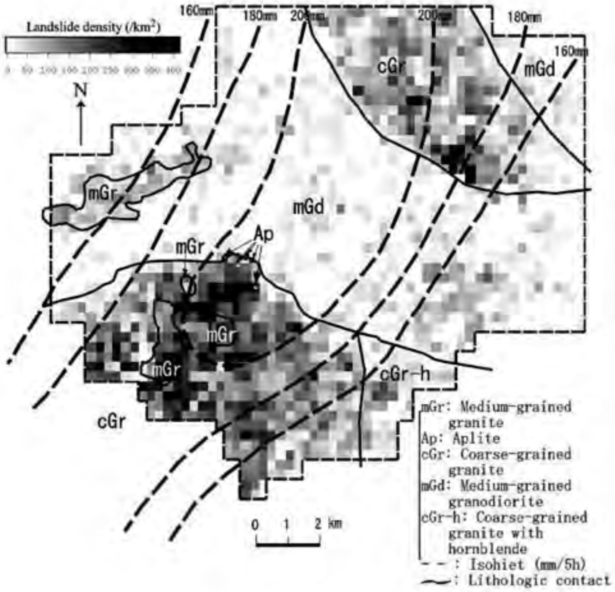

**Figure 5:** Landslide distribution during the heavy rain of the 1972 Nishimikawa disaster (Yairi *et al*., 1973).

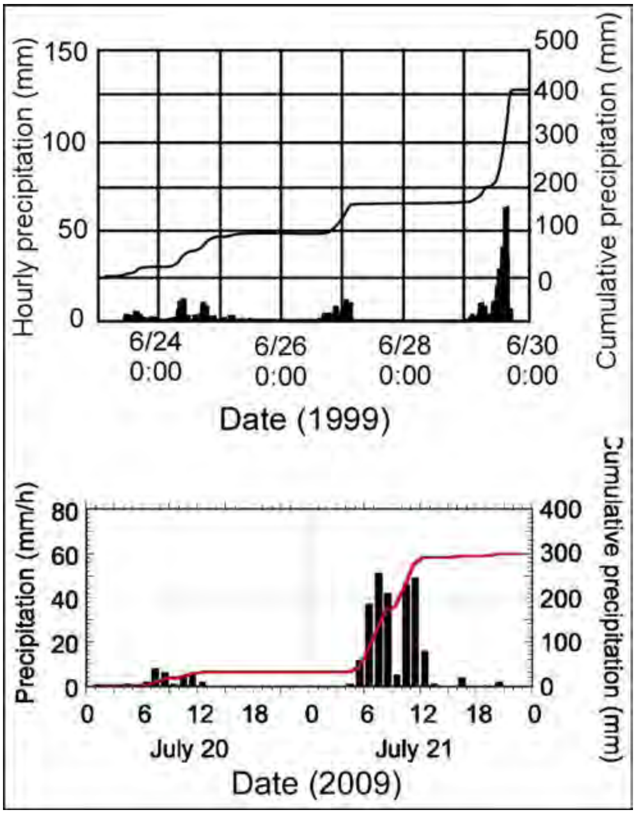

**Figure 6:** Precipitation during the rainstorm in Hiroshima in 1999 (upper) and in Yamaguchi in 20009 (lower).

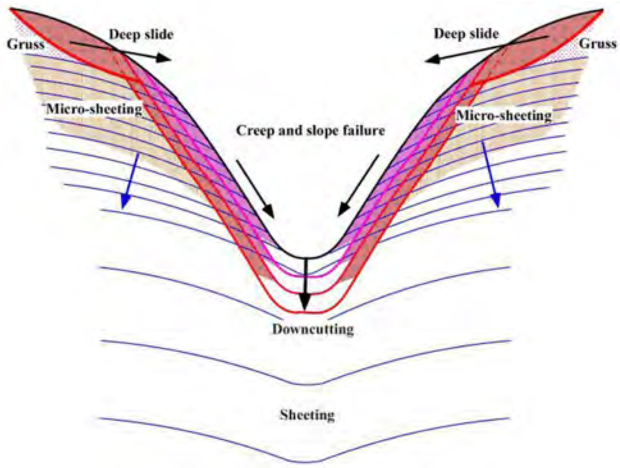

**Figure 7:** Schematic sketch showing the development of micro-sheeting and landslide.

### The 1953 Minami-Yamashiro Disaster

The 1953 Minami-Yamashiro rainstorm induced many landslides, devastating the village of Tarao and killing 40 people. This occurred in a weathered granite area with a landslide density of 82/km$^2$. Airborne laser scanner detected much more previous landslides, which had a density of 108/km$^2$. This area has terraces made by debris flow and riverbed deposits of debris flows. Carbon 14 dating of these deposits indicate that there were 6 large sediment yielding events over 700 years. The granite in this area has scarce micro-sheeting.

## EXAMPLES FROM MALAYSIA

### Bukit Antarabangsa

Six major landslides have occurred in Bukit Antarabangsa since 1993, which mark significant milestones in the history of landslide disasters in Malaysia (Figure 8). Bukit Antarabangsa, located north of Kuala Lumpur forms a narrow ridge that extends in the northeast-southwest direction with a maximum elevation of 230 m. The hill is underlain by granite which is grey, course grained and slightly porphyritic. Extensive weathering has transformed the granite into residual soil (grade VI) and completely weathered material (grade V). The average thickness of the weathered profile is approximately 30 m. The weathered material is sandy and rapidly looses its consistency with increasing amounts of water. Landslide which occurred on 11th December 1993 is responsible for triggering the collapse of the 12-storey Highland Tower condominium, killing 48 of its occupants. The main scarp of the slide was vertical with a drop of up to 3 m and three slip heads were observed in the field indicating the multiple nature of the sliding mechanism. Weathered granitic material contributed to this landslide; it is porous, friable and inherits relict planes of weakness from the parent rock (Komoo, 1997). Another significant landslide occurred on 20th November 2002, approximately 100 m south of the 1993 landslide. This landslide destroyed a bungalow house killing 8 people. The mechanism of landslide was rather complex, i.e. a combination of rotational at the head and sliding in the middle, which was followed by a flow occurrence at the toe. Continuous heavy rain triggered the sliding, however, other contributing factors were weathered granitic materials prone to failure, geological lineament facilitating the sliding, and old landslide landforms that aided the accumulation of groundwater (Komoo & Lim, 2003).

### Genting Sempah, Pahang

More than 80 landslides occurred along the road from the main highway to Genting Sempah, a mountainous area located approximately 45 km northwest of Kuala Lumpur. Most of the landslides occurred within a few hours on 30th June 1995 after continuous rain for more than 72 hours. A majority of the landslides are of small to medium size (sliding materials of less than 500 m$^3$), however, two of them are of large size. Types of failure include shallow and deep sliding, rock block or boulder sliding, and debris flow. This region is part of the Main Range that was formed by granite batholiths. The granite has undergone intensive tropical weathering creating weathered profiles of various characteristics and thickness. Most of the landslides are associated with such weathered materials. Intense and heavy rain saturated the residual soil, triggering at least two major landslides upstream of a tributary of Sungai Gombak. The

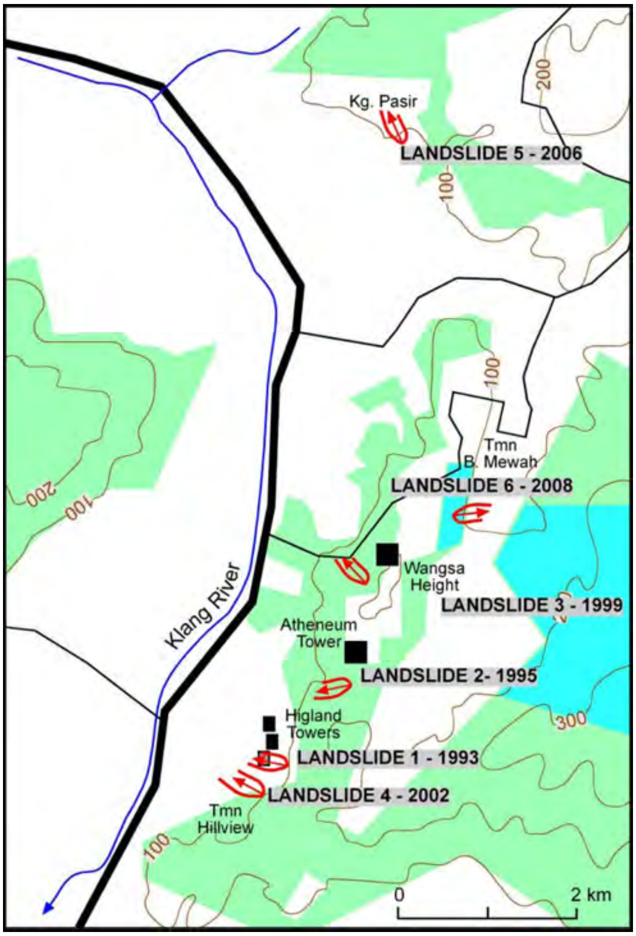

**Figure 8:** Location of major landslides in Bukit Antarabangsa.

landslide material entered the stream forming a debris flow that subsequently uprooted trees and excavated top soil and boulders in its path downstream. Gravity increased the momentum of the debris flow thereby increasing the power of scouring. The debris flowed from 800 m elevation to 570 m, over a distance of approximately one kilometer. The estimated amount of debris moved was 3,000 $m^3$. One of the landslides was a massive debris flow originating from the Genting Sempah catchment area, which swept over the Genting Highland slip road killing 20 people, injuring 22 others and damaging vehicles.

### Paya Terubong, Penang Island

A major part of Penang Island is underlain by granite bedrock. Numerous small to medium-sized landslides have occurred in granitic terrains and this has been a major issue in the development of Penang Island, especially with respect to high-rise and residential buildings. Paya Terubong is located at the southeastern half of the Penang Island where the terrain is composed of medium-grained to coarse-grained biotite granite with microcline. (Ahmad *et al.*, 2006). The Paya Terubong landslide, which occurred in the 28th November 1998, is an example of the landslides that have occurred here (Figure 9). Fortunately there was no casualty, only 16 vehicles were buried and badly damaged. The average thickness of the highly to completely weathered granitic soil was found to be about 30 m. The sampled residual soil consisted of about 14% gravel, 55% sand, 18% silt and 13% clay; representing coarse-grained residual soil with high permeability that is susceptible to landslides.

## CONCLUDING REMARKS

The fact that weathered granite is liable to slide is well known for many years. However, its landslide mechanism has not been understood enough, mainly because weathering profile, which is essential for the understanding of landslide mechanism, is site specific and different among different climate schemes and has not been studied enough. Some granite is weathered deeply in geological time scale in both Japan and Malaysia, and weathered granite has been prone to landslide.

In Japan, the most frequently occurred landslides are of moderately weathered decomposed granite. It is loosened rapidly if it is exposed to the ground surface to form loosened layers to slide. Another type of granite is weathered to form micro-sheeting, which also forms loosened surface layers to slide. Soil erosion has not been a serious problem in comparison to shallow landslides in Japan. In Malaysia, the mechanisms of failure in deep weathering profiles are highly controlled by the nature of the weathered material and its mass structure. The dynamics of weathered material under saturated conditions, the high erodability of grade V material, the existence of relict discontinuities, the sharp soil-rock boundary and the inhomogenity of weathering structures are all important factors, which lead to frequent slope failure events in wet tropics.

**Figure 9:** Landslide in Paya Terubong, Penang Island occurred in highly weathered to completely weathered granitic rock.

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