TXT-tool 1.081-2.2
Landslide Mapping Through the Interpretation of Aerial Photographs and Topographic Maps

Eisaku Hamasaki and Toyohiko Miyagi

Abstract

Processes of formation of topography and slopes are the result of a comprehensive combination of climatic change and crustal movement. When examining long time-scales, it is necessary to examine variations in internal and external stresses to understand the formative history of the topography. In this manual, the steps for understanding landslides will be described. The concept and frameworks for identifying unstable slopes (landslide topography) using aerial photos and topographic maps are introduced in details.

Keywords

Landslide topography · Aerial photo interpretation

Contents

E. Hamasaki (✉)
Advantechnology Co. Ltd, Aobaku, Sendai, Japan
e-mail: hamasaki@adovantechnology.co.jp

T. Miyagi
Department of Regional Management, Faculty of Arts, Tohoku-Gakuin University, 2-1-1, Tenjinsawa, Izumi, Sendai 981-3193, Japan
e-mail: miyagi@mail.tohoku-gakuin.ac.jp

1 Introduction

Many factors are related to both landform development and slope destabilization mechanisms (occurrence of landslides). When considering long time-scales, it is necessary to examine variations in

K. Sassa et al. (eds.), *Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools*, https://doi.org/10.1007/978-3-319-57774-6_3

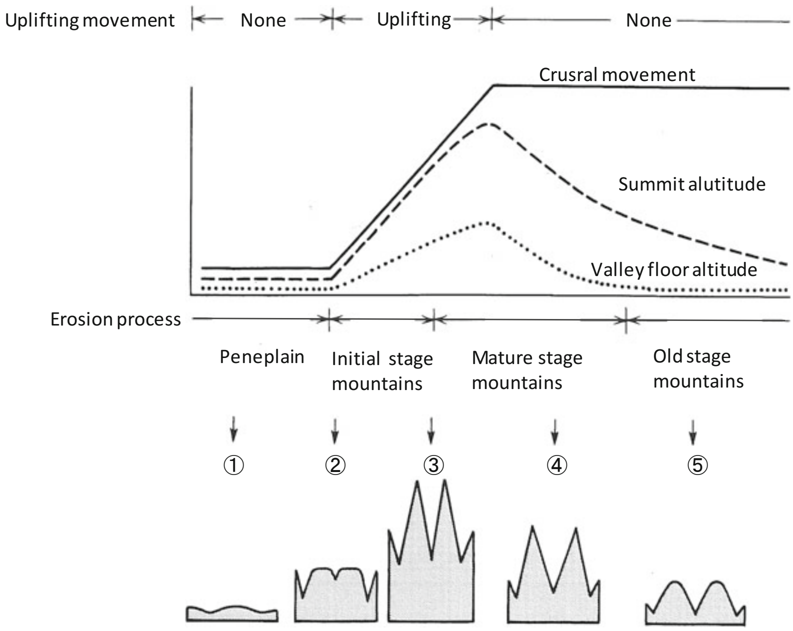


Fig. 1 Fluctuation of mountain topography due to uplift and erosion (Kaiduka 1977)

internal and external stresses to understand the formative history of the topography. Internal stress, including motions within the earth's interior, such as uplift (mountain formation) and submergence (basin formation), directly contribute to the formation of faults and folds (Fig. 1). On the other hand, external stress includes base-level changes (Fig. 2) caused by global climate change (glacial-interglacial) and by crustal movements (Fig. 1).

Processes of formation of topography and slope are the result of a comprehensive combination of climatic change and crustal movement (Fig. 3). From the view point of a short time scale, topography is essentially formed by a combination of rock strength, weathering processes, and erosion stress (Fig. 4). Only in extremely rare cases are erosion stresses kept constant. For example, temporary heavy rain may suddenly increase the strength of stream erosion. Or, if there are prolonged high temperatures and dry periods, erosion diminishes and weathering increases.

Under those conditions, the internal factors making slopes unstable (landslides) are physical changes—such as weathering, metamorphosis, and argillization—related to slip surface formation and inner stress fields. On the other hand, direct external factors are rainfall and snow melt (rise in pore water pressure), river channel erosion (impedance unloading), and seismic force (increased strain and decreased shearing strength). Of course, artificial changes can also be a contributing factor to landslides.

Given the above context, in this manual, the steps for understanding landslides will be described below.

2 Model of Landform Development

Steps in modelling landslides and landform development:

(1) Increase your understanding of the geomorphic development of the relevant slope: Consider the geomorphic development history in order to deepen understanding of landslides.
(2) Know the characteristic appearance and micro-topography of landslides:
Know the appearance and micro topography landslides possess when examined close up.
(3) Know the transitions of landslide topography, from outbreak to cessation:

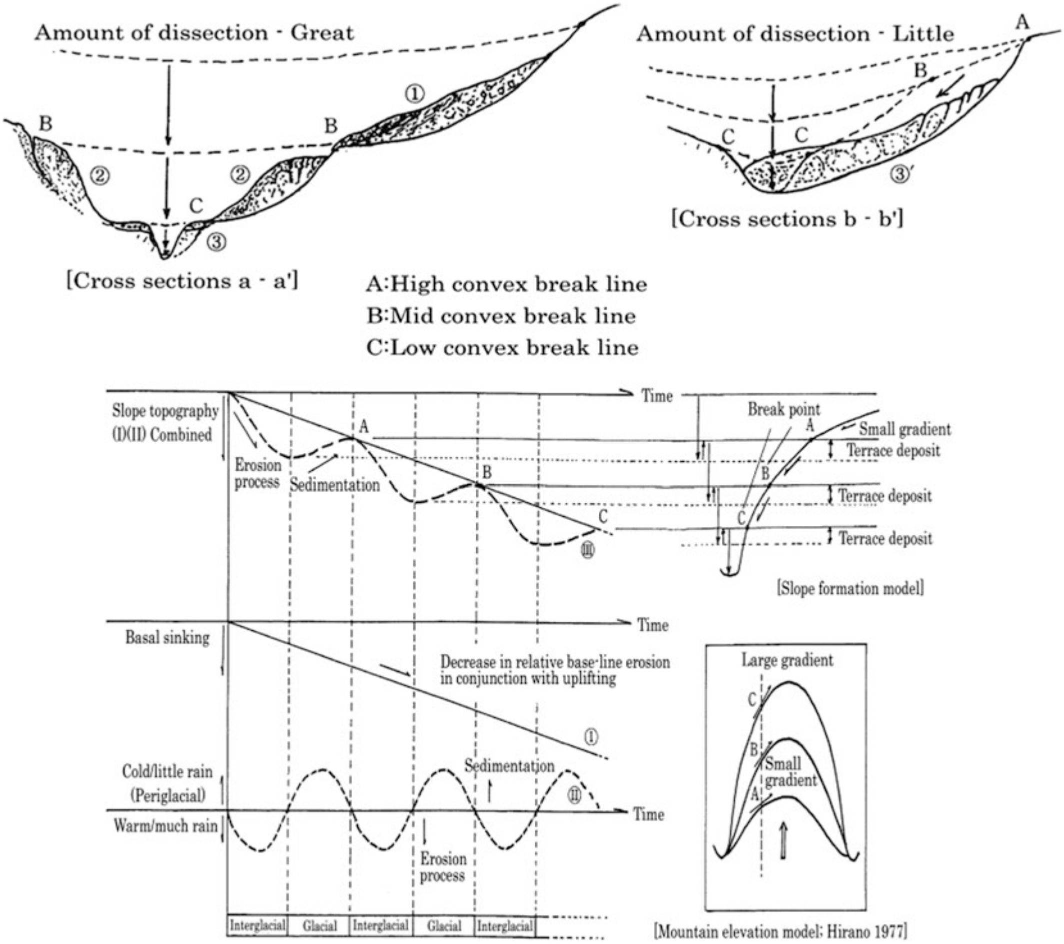
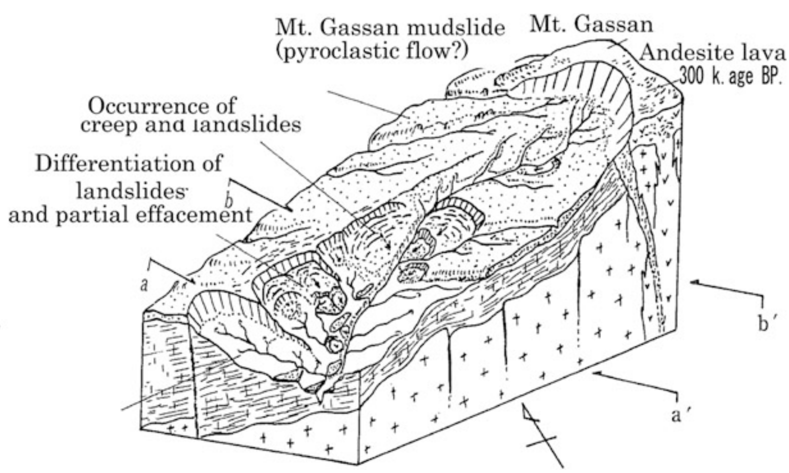


Fig. 2 Model of slope formation of uplifting mountainous areas (Kobayashi and Hamasaki 1988)

Fig. 3 Diagram of a landslide on the west slope of Mt. Gassan (Kobayashi and Hamasaki 1988)



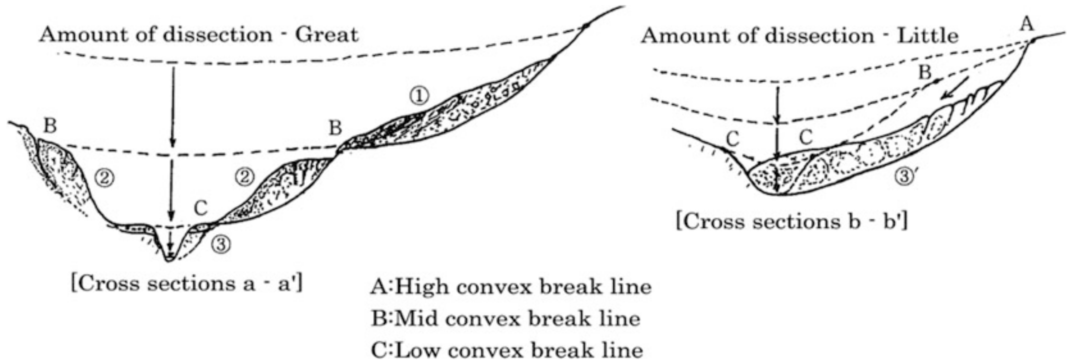


Fig. 4 Cross-section of a series of landslides. The landslides occurred in the numbered order: (*1*)–(*2*)–(*3*) (Kobayashi and Hamasaki 1988)

Understand the general topographical outline, from landslide outbreak to cessation.

(4) Landslide micro-topography definitions and interpretation.

(5) Method of topography boundary classification:
Learn topography classification methods, and then ideas and methods for understanding typical landslide topographies.

(6) Gain training in photographic interpretation to find landslide areas. Increase your amount of experience with landslide interpretation using real samples of aerial photographs.

Figures 5 and 6 illustrate these models.

In order to understand unstable slopes, such as landslides, it is important to deepen your understanding of the development of slope topography on location. Topography is essentially formed by a combination of rock strength, weathering processes, and erosion stress. Only in extremely rare cases is erosion always constant. i.e. over short periods. Temporary heavy rain may be followed by dry periods during which weathering processes make headway. Viewed over long timescales, base-level changes due to major global climatic change (glacial-interglacial) and crustal movements constantly alter erosion stress. Therefore, slopes form various topographies. The strength and weathering characteristics of bedrock can differ, depending on the type of rock, so in considering rock strength characteristics:

(1) When rock strength > erosion stress, there is little sediment runoff, and moderate slopes due to weathering are predominant.

(2) When rock strength < erosion stress, erosion topography progresses in stages, e.g., Stages 1–3.[1]

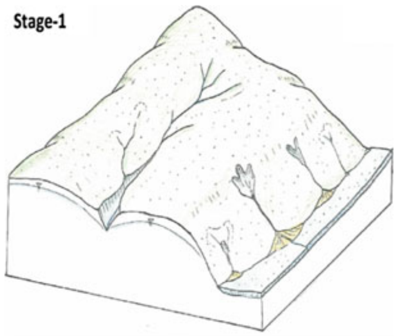
(3) When rock strength ≤ erosion stress, if an external force greatly exceeding the rock strength occurs during some kind of event (earthquake, sudden rainfall, snow melt), a high mass of the slope will become unstable (see Footnote 1).

3 Learning the Characteristic Appearance and Micro-Landforms of Landslides

Some characteristics are shown for interpretation of unstable slope such as landslides (Fig. 7). In order to understand an unstable slope (landslide), and learn about its internal structure and risk level, it is important to understand the characteristics of its exterior and micro-topography. Here we discuss the (1) interior of the landslide body, (2) head (3) side, and (4) toe.

[1]When erosion stress (from base-level sinking caused by bedrock rising and from precipitation), and geological conditions (strength of slope structure materials) are in dynamic balance, unstable slopes where large amounts of mass can move, i.e. landslides, are difficult to create.

Fig. 5 Gaining a deeper understanding of geomorphic development of the observed slopes



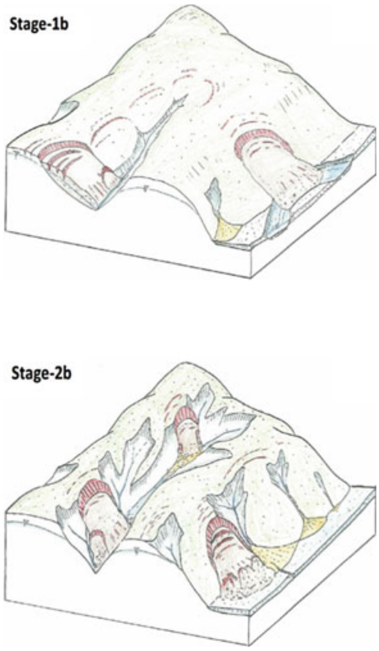
Original surfaces, which are found in places with higher than base-line erosion (e.g., formed from uplifted peneplains or pyroclastic flow surfaces from volcanic activity) are gradually eroded from the bottom (linear erosion from river water, etc.). Initially, they form small furrows such as rills and gullies.

The erosion area then spreads, with rills and gullies becoming v-shaped valleys. The eroded materials are swept downward, consequently they form depositional areas such as fans and alluvial cones with low gradients where flow energy is lost.

Moreover, when the base-level sinks, the original surface is lost, and steep topography, with predominant knife ridges and valley walls, is formed. From this stage, if basal level erosion does not fall temporarily, and becomes arrested, erosional forces weaken, moderate slopes develop due to weathering processes, and the topography will likely become rounded and hilly.

3.1 Interior of the Landslide Body

- Compared with its surroundings, the landslide body is not smooth, but will have distinct micro-relief features and be very rugged.
- In extremely newly formed landslides, there are clear fissures in the landslide body.
- Usually its slope will be gentle compared with its surroundings.
- In clayey landslides etc., the block has a high water retention potential; thus, there are often some lakes and bogs on the surface of the block.
- Within the landslide body, repeated small fluctuations lead to low channel density.
- Clay soils are easily utilized for rice paddies, etc.
- Many types of vegetation, such as reeds, cedar, and bamboo, are often overgrow the landslide. This is because the landslide includes soft soil and high groundwater levels that favour plant growth.
- Tongue fissures, flow mounds, and isolated mounds appear from time to time (Fig. 7).
- Volcanic mudflow and lava topography can also create tongue fissures, but they will not contain head scarp topography.



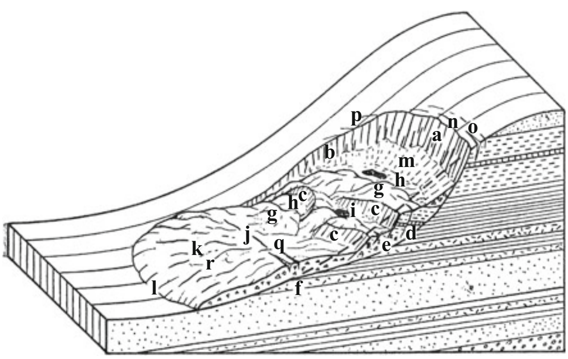
In places if bottom erosion has progressed slowly (Stage-1, 2), we may question the amount of sudden erosion that will occur due to sudden downpours and accelerated uplift of bedrock. We may also ask what effects sudden, large external forces, such as seismic movements, may have.

In such cases, dynamic equilibrium will be broken, and slope destabilization will suddenly increase. As a result, mass movements, such as landslides, are likely to occur over a wide area, including part of the erosion area.

Stage-1b shows some landslides occurring due to some large external forces or sudden downpours after the Stage-1 situation. On the other hand, **Stage-2b** shows more many landslides happen by similar external forces after Stage-2.

In this way, the landscape in landslide areas is established by the combination of linear erosion by fluvial processes and the processes of autonomous destruction by landslides.

Fig. 6 Deeper understanding of geomorphic development in the observed slope overall. *Stage b* is the development of a series of landslides



a.Main scarp, b.Lateral scarp, c.Secondary scarp,

d.Main slide surface, e.Secondary slide surface,

f.Toe part, g.Small prominence,h.Depression, i.pond (bog),

j.Uplifted area,k.Tongue, l.Tongue line, m.Talus, n.Crown,

o.Crown fissures,

p.Lateral (echelon) fissures,q.Fissures on uplifted area,

Notes

1) Not all of this micro topography forms with every landslide.
2) The shapes and sizes of elements of the micro-topography are extremely varied.

Fig. 7 Pattern diagram of landslide topography (Suzuki 1982)

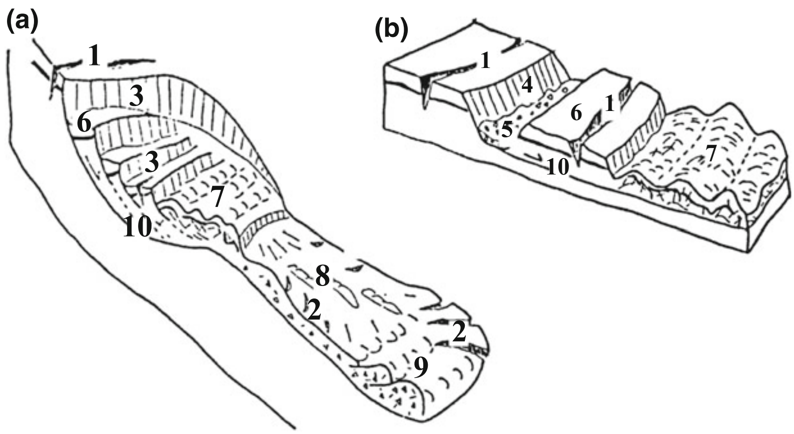


Fig. 8 Model of basic topographic units in landslide terrain (Kimata and Miyagi 1985)

3.2 Head Phenomena

The head part comprises a tension zone where scarps and detached scarps (depressions) form. Figure 8 shows a rotational landslide as A, a translational landslide.

A scarp may also appeared as a steep slope between the convex break line and the concave break line directly beneath it (Fig. 8—features 3 and 4). Consequently, if this scarp shape is found within a certain area, this scarp is the head part of landslide.

Rotational landslides typically have an arcuate scarp (Fig. 8—feature 3). On the other hand, translational landslides create a linear scarp and a depression zone in a separated head area. It is called a detached scarp (Fig. 8—feature 4, Fig. 12).

3.3 Lateral Sections

- Gullies and valley topography sometimes forms by erosion through cracks (Fig. 9—feature 7).
- Small failures may appear from the side to the toe (Fig. 9—feature 6).

3.4 Toe

- Small-scale landslides and slope failures often appear (Figs. 9 and 10).
- If the toe area pushes into a river, it can bury the river, creating a bend in the river channel.

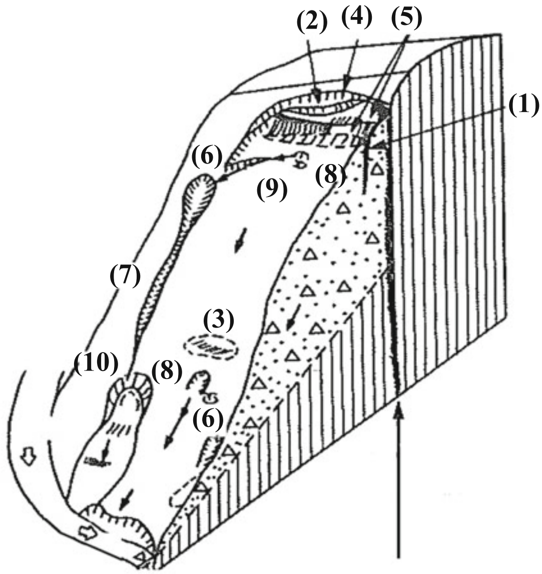
4 Transitions in Landslides from Beginning to Termination

To identify an unstable slope, it is important to understand how the topography changes, from the start of the landslide to its termination. Landslide development and termination processes are not limited to a single pattern. For example, landslide displacement often increase or change the initial micro-topography structure by causing continual expansion. Or, if the landslide remains stopped for a long time, its micro-topography features, such as scarps and fissures, become gentle terrain, and displacement features tend to disappear. Understanding the transitions in landslide topography, based on case studies, is important for recognizing landslides and performing stability evaluations.

4.1 Definition of the Internal Micro-topography of Landslide Bodies and Interpretation

4.1.1 Pressure Ridges

Definition: Pressure ridges are micro-relief features that occurs perpendicular to the direction of movement in a place of intense compression stress due to differences in relative movement speeds in the landslide body.



(1)Crack (fissure)
(2)Depression
(3)Shallow depression
(4)Eyebrow scarp - small but clear
(5)Erosional surface
(6)Slope failure - occurring above gully
(7)Gully - Extending upslope
(8)Groundwater channel topography
(9)Water system abnormality (gently curving gully)
(10)Small-scale landslide and crack topography
- surface landslide on bank at tip
of crack topography, small landslide,
and small crack topography.

Fig. 9 Example of micro-landform features (Suzuki 1982)

Interpretation: As they are formed by small-scale thrusting, they are recognised ripples.

4.1.2 Flow Traces/Flow Mounds or Flow Hills

Definition: Flow mounds are a micro-relief feature running parallel to the direction of movement, which occurs when a part of the landslide body turns to muddy or colluvial soil, and begins to move like a fluid. Flow hills are relatively high points on micro-relief features formed by this movement (so-called flow peaks).

Interpretation: They can often recognized as gentle micro-relief features in photographs that have no clear directionality. However, they usually exhibit fluid movement, have a very small sub-scarp forming the top edge of their area, and have a movement area that assumes a long, elliptical shape (Fig. 10).

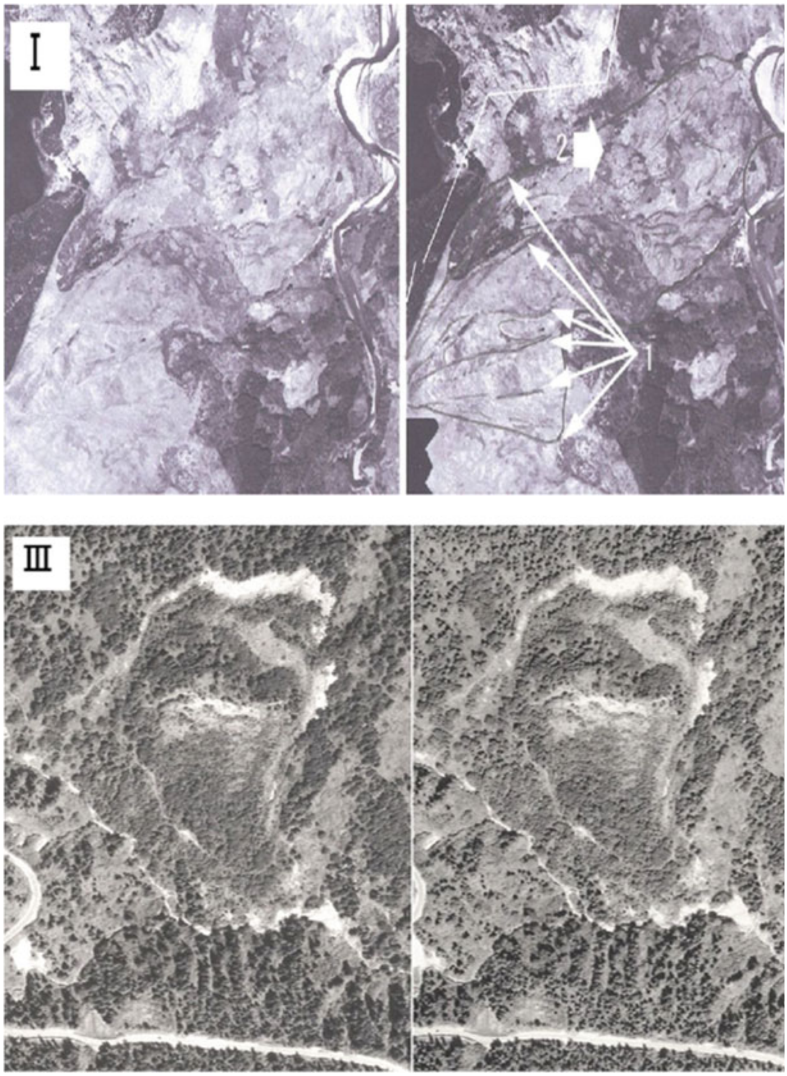


Fig. 10 Flow traces and pressure ridge (Miyagi et al. 2004) *Arrows 1* flow traces—the movement area assumes a long, narrow planar shape, and one part of it extends (obliquely) in the direction of movement, forming minute ridges and small talus topography. *Arrow 2* pressure ridge—protrusion topography that appears in the *lower part* of the movement area

4.1.3 Sub-scarp (Minor Scarp, Scarplet)

Definition: Scarp topography found in landslides in which fragmentation occurs.

Interpretation: After a small landslide occurs in the main landslide body, the sub-scarf exists there. Even though it has very similar shape to the main-scarp, it may not necessarily have a similar slip to the main-scarp (Figs. 11 and 12).

4.1.4 Detached Scarp/Fissured Depression

Definition: A steep scarp formed due to the movement caused by tension in the landslide body interior, and the relatively low-lying area interposed in that steep scarp. In such cases, the low-lying area is often an outcropping of the slip surface.

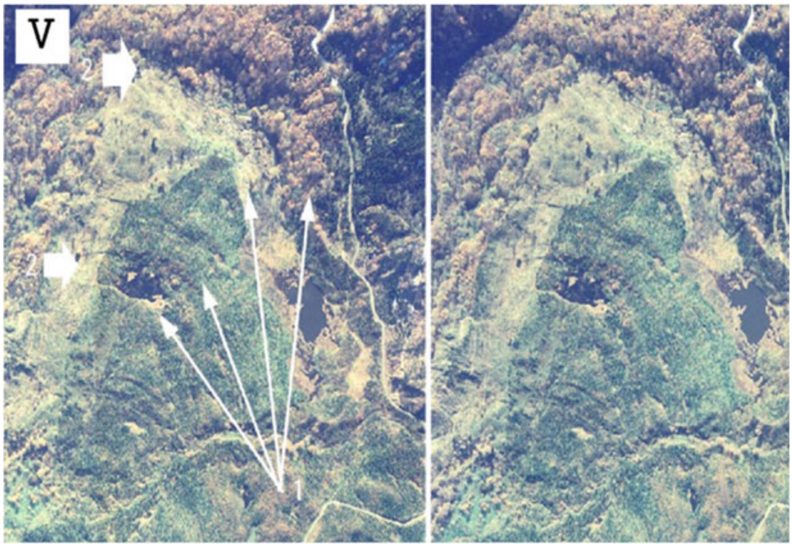


Fig. 11 Main scarp and sub-scarp. There is a large-scale sub-scarp in the central part of the landslide. Its *upper part* is formed of a large block, while in its *lower part* a characteristic colluvial landslide can be seen in low relief (Miyagi et al. 2004)

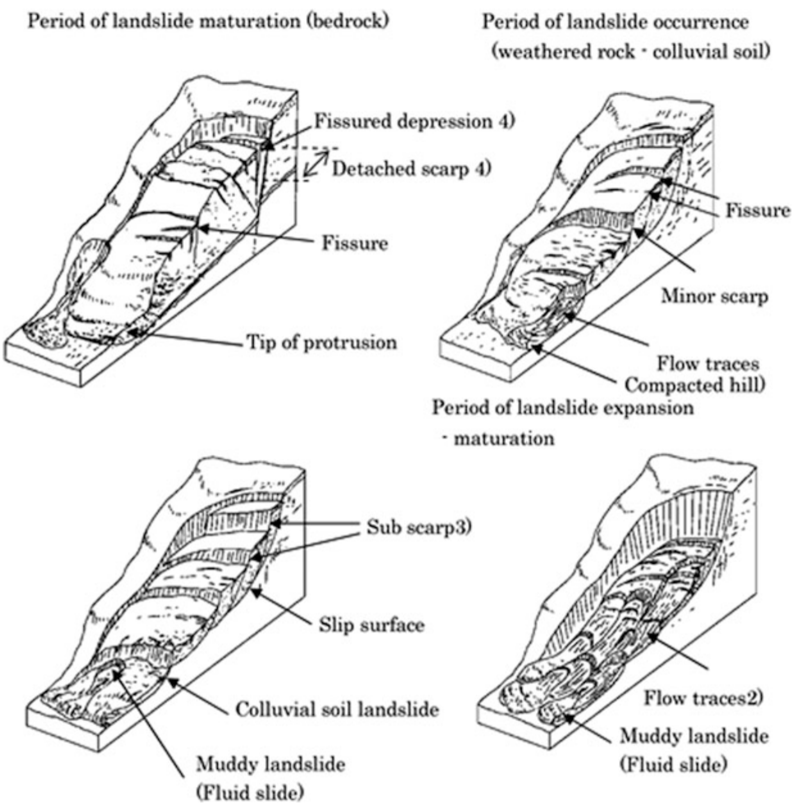


Fig. 12 Detached scarp and fissured depression. Detached scarps and fissured depressions frequently appear as dip slipping along the bedding plane of the stratum of sedimentary rocks. This shows the archetypal development of a detached scarp and fissured depression at the front of the main scarp and center of the landslide body. Ponds or bogs can be found in the depressions (Miyagi et al. 2004)

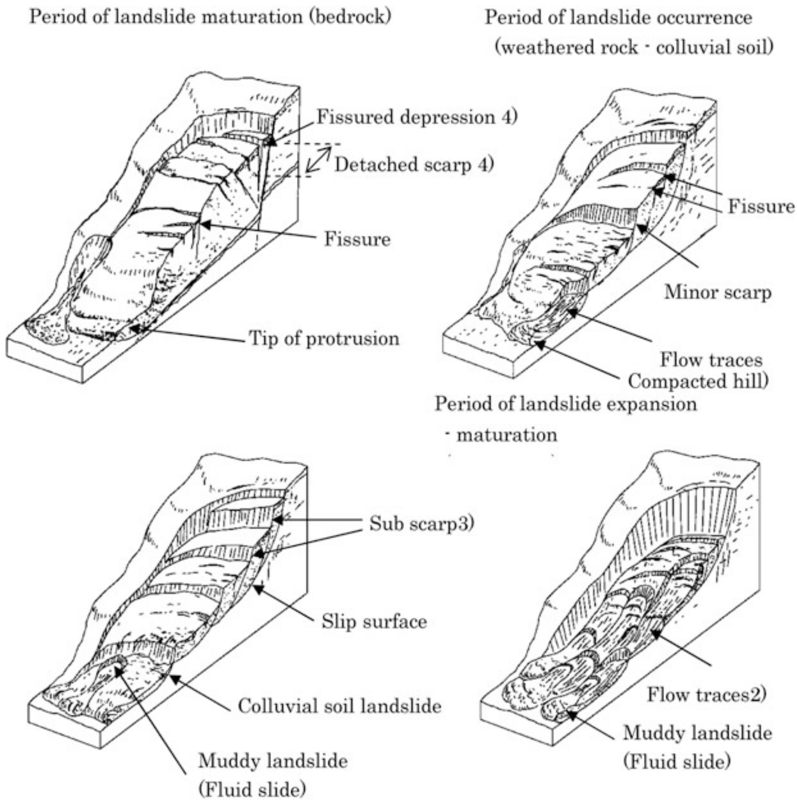


Fig. 13 Schematic diagram of landslide progress (Miyagi et al. 2004)

Interpretation: A steep scarp, similar to a sub-scarp, but clearly distinct from the main scarp in that it opposes a steep scarp.

With an understanding of the description so far, Fig. 13 shows a schematic diagram of landslide progress step by step.

4.2 How to Make Topographic and Classical Maps Step by Step, and Clarify Landslide Outlines

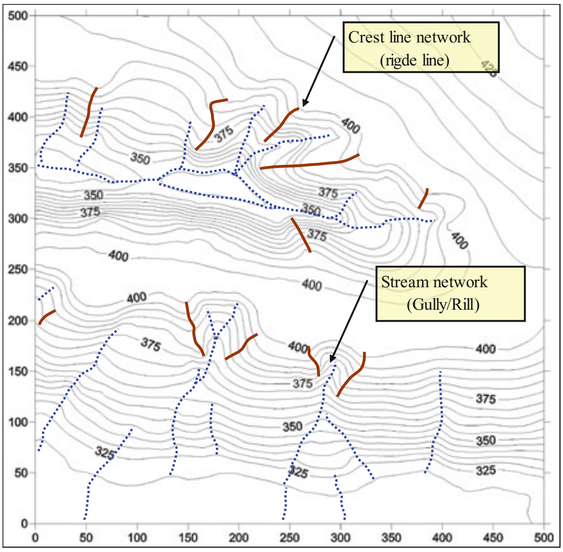
To clarify the landslide outlines on the topographic map, some techniques, such as drawing lines on the crest and stream network, are very useful. Figure 14a, b outline these techniques step by step.

5 Summary

(1) We need to understand that the processes of formation of topography and slope are the result of a comprehensive combination of climatic change and crustal movement. Furthermore it is important to consider the variations in internal and external stresses to understand the formative history of the topography, particularly when examining long time-scales.

(2) Especially, for landslides, it is important to consider the geomorphic development history as described above in order to understand the landslide mechanisms. Moreover, it is necessary to examine landslides and to know the mechanisms producing the micro topography on the landslides.

STEP ONE



First, draw the stream network (valleys, runoff, gullies, rills) on the figure.

Also, add the crest line network (ridge lines).

When doing this, it is useful to refer to both the aerial photograph and topography map.

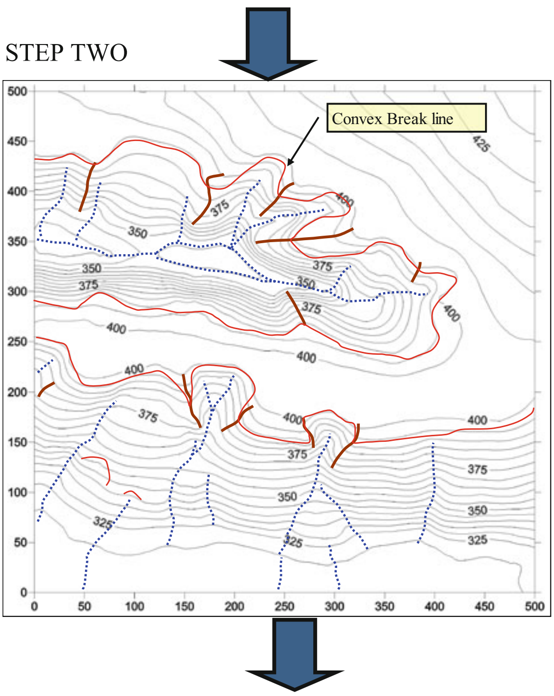
*This will make the catchment area for each area on the topography clear.

By outlining catchment areas, areas of active erosion will become clear.

*Channel density will reveal areas undergoing minute fluctuations.

*Suggest the existence of some weak lines, such as fault or lithological effects, in areas with broken ridges.

STEP TWO

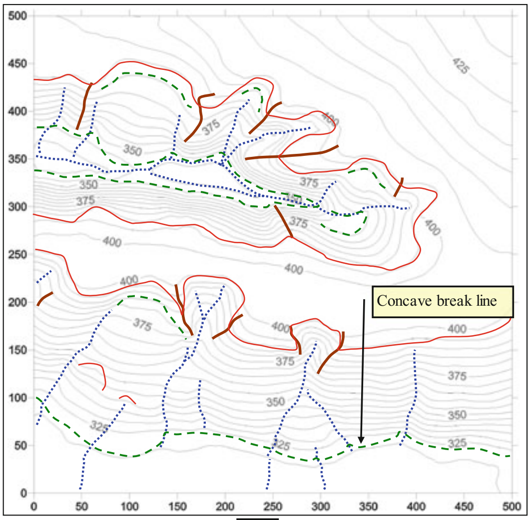


Next, add convex break lines.

*In general, the steep slope below the concave break line is often an area of active erosion, younger than the slope above it.

Fig. 14 Schematic diagram for landform mapping step by step

STEP THREE



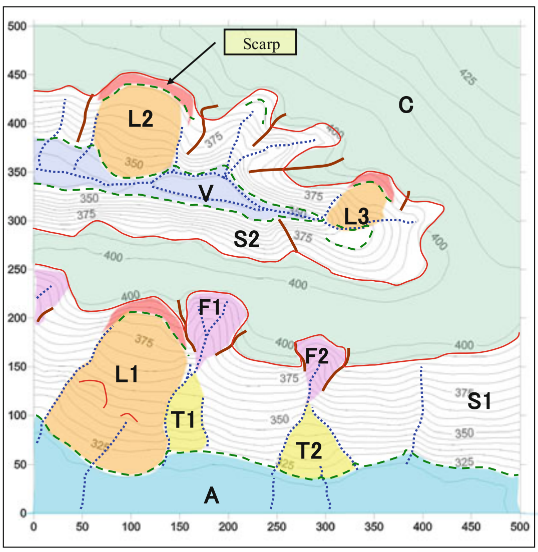
Then, add concave break lines.

In general, the gentle slope below the concave break line is often a depositional area, and younger than the above slope.

* Characteristics of landslides (unstable slopes)

- Distinct from surrounding topography.
- Covered in micro-relief.
- Have a tongue-shaped landform at the toe part.
- Low channel density.
- When there is an arced convex break line, and just beneath it the concave break line is almost parallel, there is a high probability of scarp due to land-sliding.

FINAL



Lastly, color in the landforms, referring to the boundaries of landform units, such as the convex break lines, concave break lines, and stream networks.

When doing this, in areas with similar geological formations (internal factors), and areas subject to identical external stresses, divide the surface with consideration to creating a basically continuous topography.

Also, consider *1 (Step 2) with regard to stable and unstable surfaces.

*Left figure: example of landform classification

Classified into: crest gentle slope (C), valley side slope (S), alluvial plain (A), valley bottom (V), slope failure (F), alluvial cone - talus (T) and landslide (L)

Final 3D image

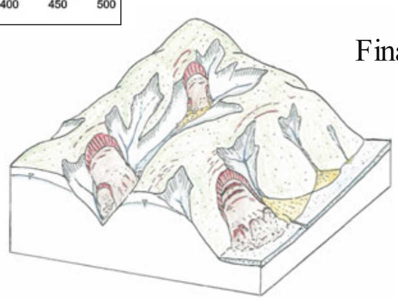


Fig. 14 (continued)

(3) This tool describes the several steps for understanding landslides using aerial photos and topographic maps.

Acknowledgments First of all, we would like to express Vietnam project leader and our supervisor, Prof. Kyoji Sassa, who give us some chances to study Vietnam Area, and many research experiences. And, we are grateful to Prof. Hiromitsu Yamagishi for helpful discussions. Finally, we wish to thank Haruna Ishikawa for the support in writing this tool.

References

Kaiduka S (1977) Japan of terrain—nature and origin, Iwanami Shoten, 215 p

Kimata R, Miyagi T (1985) The basic landform units composing of landslide area. J Jpn Landslide Soc 8:10–17

Kobayashi Y, Hamasaki E (1988) Landslide with transition of topography—case of west slope areas of Gassan Mt. Appl Geol Yamagata Jpn 8:10–17

Miyagi T, Prasada GB, Tanavud CI, Potichan A, Hamasaki E (2004) Landslide risk evaluation and mapping—manual of landslide topography and risk management. Report of the National Research Institute for Earth Science and Disaster Prevention No. 66, pp 75–137

Suzuki T (1982) Introduction of how to read of topographical map for construction engineers, vol 1–4. Kokonshoin