Appendix A5

Guidelines for geomorphological mapping in glacial hazard and risk assessment

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A5.1 Introduction

Geomorphological mapping involves the recording of surface form, near-surface materials and evidence of surface processes. Accurate geomorphological maps can provide valuable information about the ground conditions from which hazard and vulnerability assessments are made. As such, it is important that due consideration is given to the mapping approach before work begins to ensure that it is appropriate for the specific study. The flexibility of the geomorphological mapping method makes it a powerful tool in the hands of an operator experienced in the final application (e.g. glacial hazard and landslide assessments).

A5.2 Base maps

Many of the issues about base maps raised in Appendix A2 (engineering geological mapping) are valid for geomorphological mapping. Base maps should be as up to date as possible, unless the aim is to undertake a study of historical changes. Aerial photographs tend to be preferable in their clarity and detail, although satellite images with pixel resolutions of 1 m or less offer comparable detail. Satellite images have the benefit of often being more up to date in archives, and new images are easier and cheaper to commission than aerial photographs. They often have the added benefit of multiple spectral bands to aid interpretation. Topographic maps are less preferable, both on account of the level of detail represented, as the maps are already one step removed from the data upon which they are based, and because they tend to be dated for many mountainous regions. Positions of glacier margins, particularly for debris-covered glaciers, are especially unreliable on topographic maps.

A5.3 Issues of scale

The scale of mapping is dependent upon the final application, which in turn influences the choice of base map. Regional studies, for example those concerned with the distribution of glaciers and lakes throughout a catchment, will benefit from scales of 1:50,000 or 1:100,000. Corridor studies, such as along a potential flood runout route, where river terrace detail is required, will be better at scales of 1:10,000 to 1:20,000. Detailed studies of glacier margins and moraine dams will require the use of scales at 1:200 to 1:1,000. The scales of other datasets within the study will also have a bearing, e.g. engineering geological maps (Appendix A2), location of geophysical survey lines (Appendix A4) and/or plans for remedial works.

A5.4 Methods

The type of features to be mapped depends upon the nature of the study and the scale. For detailed large scale studies, for example an assessment of moraine dam stability, features such as breaks of slope and indicators of process (e.g. tension cracks) will be of greatest interest. For regional studies, where mapping at a smaller scale is required, one approach is to break up the landscape into different units. Known as *terrain systems mapping* (or land systems mapping), the study area is classified according to topography, soils and vegetation correlated with geology, geomorphology and climate (Phipps, 2001). The *terrain system* (e.g. glaciated valley) is sub-divided into defining *terrain facets* (or landform units, e.g. a moraine complex), which themselves can be sub-divided into *terrain elements* (e.g. ridge crest, meltwater channel, kettle hole). Representation of the different units on the map is subject to the mapping scale. Typically, terrain facets are the highest level of detail recorded at scales of 1:10,000 and smaller, whilst terrain elements are able to be recorded at scales of 1:10,000 and larger.

Several approaches to mapping can be employed (Table A5.1). Often, much of a map can be produced before leaving for the field if good quality remotely sensed images are available and the operator is familiar with the type of terrain. If precise measurements are needed, orthorectified aerial photographs or high resolution satellite images are the preferred base maps for desk studies. Major landform units (terrain facets) can normally be accurately recorded on the base maps by hand tracing or digitising their outlines. Other key features such as rivers and valley spurs can also be added at this time. Preparation of the map for fieldwork will depend upon the nature of other data sets to be collected and the proposed method of data management for the project. Registration of the base map and construction of subsequent field maps within a Geographical Information System can be a particularly effective way to manage multiple data sets.

Table A5.1: Merits of different approaches to geomorphological mapping.

MAPPING APPROACH	BENEFITS	DRAWBACKS	APPLICATIONS
Desk study (Aerial photographs / satellite images)	- Stereographic coverage (stereo pairs only) - Little distortion / accurate measurements (orthorectified images) - Rapid coverage - Coverage of inaccessible areas	- Fixed viewpoint - Lowest level of detail - 3-D data not always available - Shadows, cloud, steep slopes and vegetation obscure detail - Image resolution, wavelength and processing affects quality	- Reconnaissance studies - Regional / catchment studies (scales 1:10,000 or smaller) - Change detection (distances, areas, heights)
Desk study (Oblique aerial or ground photographs)	- More detail than vertical aerial photos and satellite images - Coverage of inaccessible areas - Imaging of steep slopes	- Fixed viewpoint - Perspective distortion - Precise ground control needed for measurements	- Change detection of glaciers, lakes and ground movements - Site specific studies (scales 1:1,000 to 1:10,000)
Field mapping (Using base maps or hand drawn maps)	- Highest level of detail - Inspection of material types possible - All round viewpoint aids interpretation	- Most time consuming method - Some areas may be inaccessible - Difficult to see the regional picture	- Large scale mapping of glacier snouts, moraine dams, individual landslides - Areas of steep terrain (e.g. gorges) - (Lightly) vegetated areas - Verification of maps based on photographs / satellite images

The reliability of maps produced from desk studies is strongly dependent upon the quality of remote sensing data used and physical conditions in the environment. Image resolution, wavelength and spectral characteristics, processing routines, cloud cover, shadow in mountainous terrain, thick vegetation, *etc*., all affect the level of detail that can be recorded. Snow cover is a particular problem in glacial environments as it often leads to strong contrast and image saturation problems. If remote sensing surveys are to be specified for geomorphological mapping purposes, care should be taken to ensure that data are collected at times of the year when snow and cloud conditions are favourable. In the Himalayas, for example, this coincides with the end of the melt season and post-monsoon period between late September and November.

Field mapping allows for the greatest detail and level of certainty in interpretation, but again its value varies according to the scale of the survey and the application. It is often the only way to record evidence of near-surface materials and processes. At a large scale (e.g. 1:200 to 1:10,000), for studies of moraine dams or sections of a potential runout route for example, a field-based approach is almost always necessary in order to obtain the required detail. In these instances it is preferable to map the basic landform units (terrain facets) from remote sensing imagery before leaving the field and to use the fieldwork to verify the map and add the fine detail.

There are no hard and fast rules for the production of the final map. The nature of the survey, type of terrain and personal preferences of the operator will influence the way in which information is recorded and presented. However, for the most commonly encountered features, such as breaks of slope, there are widely recognised symbols (Cooke and Doornkamp, 1990). The glacial geomorphological community also tend to use common symbols to record information about glacially derived features and materials. For recording information about glacier structures, symbols are often adapted from those used in structural geological studies. One of the strengths of geomorphological mapping is its flexibility, enabling a scheme to be devised to suit any area. A drawback to this user-orientated, site specific approach is that it can be difficult to interpret or compare maps from different areas or operators. It is common practice, therefore, to provide a summary map to clarify the key findings of the mapping exercise. These can take the form of a hazard map, or a distribution map of a particular feature or material type that is of interest to the end user (e.g. the extent of buried ice within a moraine as interpreted from surface features and processes).

A5.5 Applications

Geomorphological maps are a good way of displaying the spatial relationships between features and indicators of activity in a hazard context. Also, comparison of multi-temporal maps is a good way of identifying rates of change in the landscape, either on a relative scale or quantifiably where there is good base map or ground survey control. Specific applications to glacial hazards include:

- Catchment mapping to identify and record relative positions of glaciers, lakes, moraine dams and dead ice areas;
- Mapping areas of ground instability in moraine dams and around the margins of glacial lakes (Figure A5.1);
- Mapping glacier form and structure with respect to ice calving and avalanche events (Figure A5.2);
- Runout route mapping with respect to potential targets and secondary landslides.

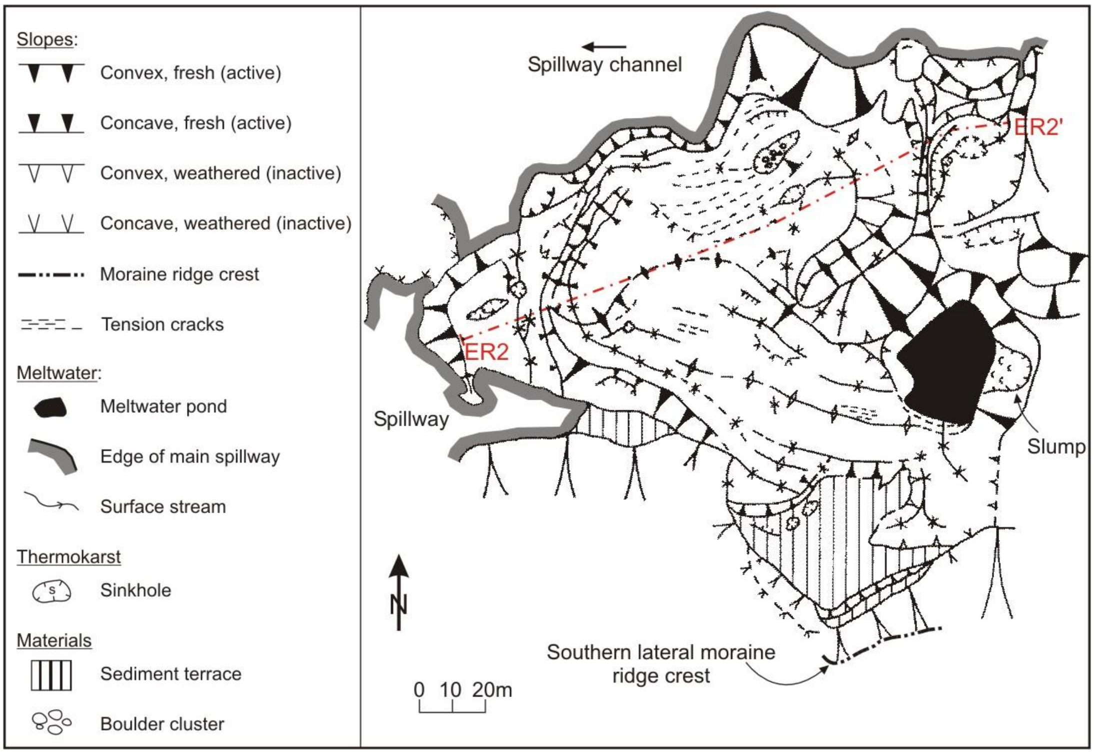

Fig. A5.1: Morphological-based maps of features related to melting buried ice in a moraine-dam, Imja Tsho, Nepal. Hand-drawn map, scale approximate (see Figure A4.3).

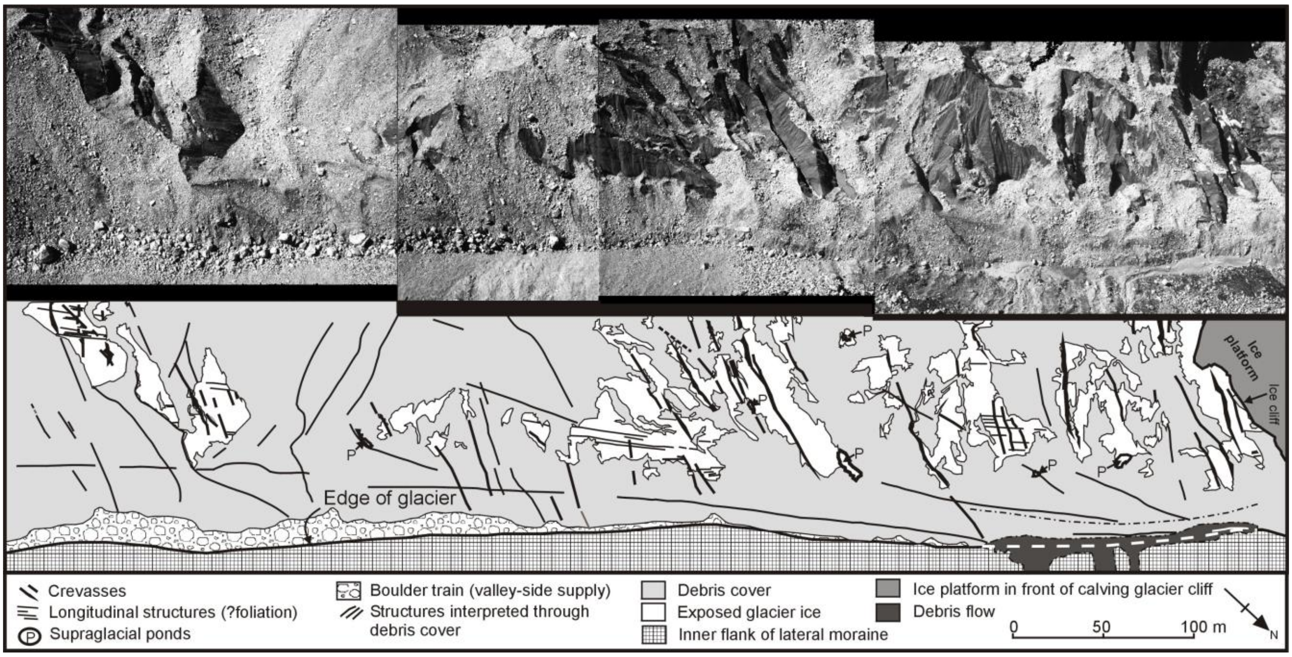

Fig. A5.2: Geomorphological plan (bottom) of near surface materials and ice structures, Trakarding Glacier, Nepal, based on near-vertical aerial photographs (top).

References

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