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**Interpretation guide of natural geographic features from ETM+
Landsat imagery and aerial photography: Glacial debris**

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Introduction

The purpose of this project is to create a visual interpretative guide to the natural geographical entities in the geospatial database (GDB) using Landsat7 ETM+ imagery and aerial photography. The methodology and information fact sheet were developed by Provencher and Dubois (2004a), and the application of this procedure to a test case has already garnered a consensus among the staff of CTI at Sherbrooke (Provencher and Dubois (2004b). The meanings of the sections of the fact sheets are explained in the appendix.

The eight natural entities in the GDB (Centre for Topographic Information, 2004) fall under eight themes that are grouped into three domains: hydrography, landforms, and vegetation (**Table 1**). In practice, for interpretive purposes they are often subdivided further and represented by 17 fact sheets.

N.B.: Elaboration of the illustrative examples and potential elements of confusion was constrained by the limited time allocated to this guide. It is recommended that they be supplemented as other cases are documented, especially from Landsat ETM+ imagery.

Table 1: Hierarchy of natural geographical entities

Domain	Theme	Sub-theme	GDB entity	Fact sheet
Hydrography	Watercourse	Perennial watercourse	Permanent water	Permanent water
		Alluvium	Intermittent water	Intermittent water
		Waterfall	Water disturbance	Waterfalls and rapids
		Rapids	Water disturbance	Waterfalls and rapids
	Waterbody	Perennial freshwater body	Permanent water	Permanent water
		Alluvium, rocky surface	Intermittent water	Intermittent water
		Saltwater	Permanent water	Permanent water
		Alluvium, rocky surface (tidal flat)	Intermittent water	Intermittent water
		Reef	Water disturbance	Reef
	Wetland	Tundra pond	Saturated soil	Tundra ponds
		Palsa bog	Saturated soil	Palsa bog
		Marsh, swamp, and uniform peat bog (wetland)	Saturated soil	Wetlands (marshes and swamps, peat bogs)
		String bog	Saturated soil	Wetlands (string bog)
Landforms	Glacial landform	Glacial debris	Landform	Glacial debris
		Esker	Landform	Esker
		Moraine	Landform	Moraine
		Glacier, glacial ice cap, and ice shelf	Permanent snow and ice	Permanent snow and ice
	Periglacial landform	Polygonal soil	Landform	Tundra polygon
		Pingo	Landform	Pingo
	Littoral landform	Barrier beach and spit	Landform (sand)	Barrier beach and spit
	Eolian landform	Dunes	Landform (sand)	Dunes
Vegetation	Wooded region		Wooded region	Wooded region

1- Name of entity

Glacial debris

2- Hierarchy

Landforms – glaciers – glacial debris – relief feature – glacial debris

3- Definition

A heterogeneous mix of rocks, boulders, and sand that is transported by glaciers or deposited within, on top of, or beside glaciers or permanent snow, irrespective of the specific formation (terminal, lateral, or medial moraines). Glacial debris also includes ice covered with debris.

Glacial debris is only indicated on maps when it forms a significant topographic feature.

4- Summary table of elements of identification

Table 2: Summary of identifying elements of glacial debris

Shape	Hummocky surface that is generally elongated along a valley
Dimensions	Diameter: a few hundred metres to kilometres Height: metres to decametres
Topographic position	Valley bottom or below a glacier
Drainage	Mixed: excellent and poor
Vegetation	None or sparse
Emplacement process	Unconsolidated materials deposited by a glacier and touching a glacier
State	In the process of formation
Spatio-temporal variations	Relatively stable May grow, sometimes being incorporated into an advancing glacier or reshaped by meltwater
Environment	Current alpine or arctic glacier
Identification on imagery	Location next to glacier Bands 5-4-3
Identification with B/W aerial photography	Location next to glacier Hue medium grey Hummocky surface dotted with small zones of shade Ice sometimes visible through the debris
Elements of confusion	Moraine, bedrock, permanent snow and ice

5- Characteristics

5.1- Specific to the entity

5.1.1- Shape

The surface may assume varying sizes and shapes. It is generally elongated along a valley bottom, characterized by a random scattering of hummocks, and frequently gouged by channels of meltwater and dotted with ponds. Often ice can be seen on the rims of the depressions.

5.1.2- Dimensions

Diameter: a few hundred metres to several kilometres

Height: metres to decametres.

5.1.3- Topographic position

Glacial debris is usually found in the bottoms of glacial valleys or below alpine glaciers.

5.1.4- Drainage

Drainage is mixed: excellent on the hummocks and poor between them.

5.1.5- Vegetation

Vegetation is usually absent or sparse on glacial debris.

5.2- Relative to the entity's dynamics

5.2.1- Emplacement process

Glacial debris usually accumulates next to a glacier, either as materials deposited by ice that has melted or carried by ice that is melting.

5.2.2- State

Many paleolandforms of glacial debris are found in Canada and their main constituent, till, is distributed throughout the country. However, only accumulations of glacial debris that are currently being formed, and are thus in direct contact with glaciers, are mapped. The Atlas of Canada (<http://atlas.gc.ca>) contains a map of the principal zones of glaciation in Canada.

5.2.3- Spatio-temporal variations

Glacial debris fields that are in the process of formation are relatively stable in the human timeframe. However, some zones of glacial debris beside valley glaciers in the Rockies or the North may exhibit considerable growth in a few decades. Conversely, a few valley glaciers may expand and reincorporate glacial debris, though this situation is much less common. Furthermore, accumulations of glacial debris lying below glaciers may be reshaped by watercourses or covered with meltwater deposits within a few decades.

5.3- Relative to the environment

Zones of glacial debris that are forming today can do so at current alpine (mountain environment) or arctic (northern

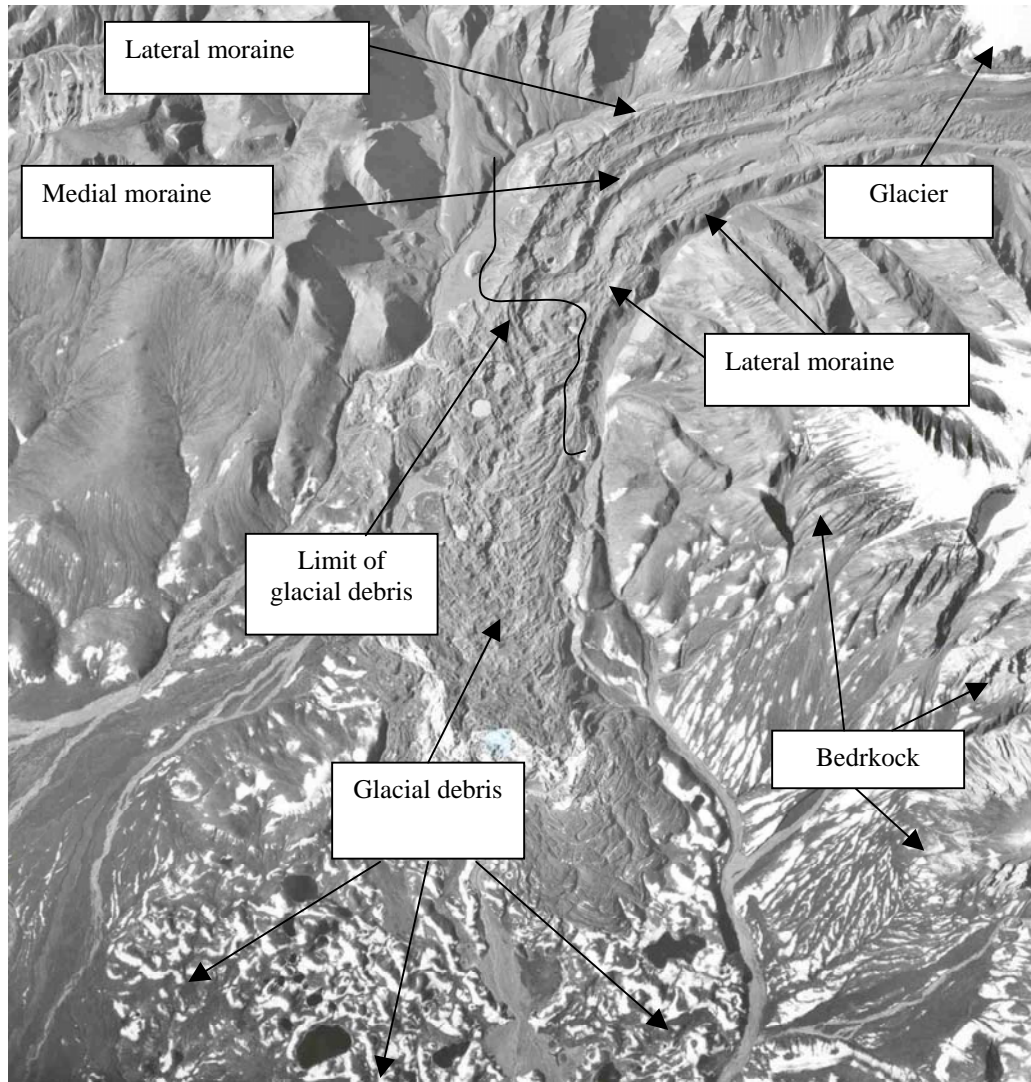
environment) glaciers.

6- Optimal conditions for identification

In light of their location on the edge of glaciers and their topographic characteristics, glacial debris fields stand out on imagery taken with a combination of bands 5-4-3 because of their paler hue.

They are readily distinguished with aerial photography, especially using stereoscopy, primarily by their position next to glaciers, but also owing to their hummocky relief (Figure 1).

7- Examples



Source : photo A15728 (76), T.S.C.A.P. n° 369, Original scale 1 : 70 000, Map 115F-G, 61° 35' N – 140° 47' O, **Kluane Lake** area (Yukon)

Figure 1: Surface of a former valley glacier that has become a rough and hummocky stretch of glacial debris after completely or partially thawing. Two lateral moraines and one medial moraine that remain attached to the glacier can be observed on the far right. The ice buried below the debris is still visible on the rim of the depression formed by the merging glaciers.

8- Interpretation

8.1- Critical path

The critical path encompasses two phases: distinguishing and delimiting the form, and identifying it.

8.1.1- Distinction and delimitation

Glacial debris fields are primarily distinguished by their shapeless, hummocky configuration beside or on top of glaciers.

Using aerial photography, especially stereoscopy, these zones are easy to identify and delimit unless they are on top of glaciers, in which case it becomes necessary to assess what proportion of the ice surface (whitish hue) is to be mapped as a zone of debris (medium-greyish hue). We recommend approximately 80 per cent, since this is the percentage at which the salt-and-pepper zone clearly stands out using ETM+ imagery. However, debris fields have the same greyish hue as moraines and, frequently, as the barren bedrock that surrounds them.

With ETM+ imagery, glacial debris can readily be identified using the combination of bands 5-4-3.

The problem of differentiating bedrock is easily resolved with stereoscopy when using aerial photography, since, unlike glacial debris, the substrate is generally found on mountainsides. Use the DEM in conjunction with ETM+ imagery.

8.1.2- Identification

The identification process for glacial debris requires that the analyst address the various elements of confusion and distinction (Table 2). The greater the analyst's knowledge and experience, the more accurate the outcome of this labour of discrimination will be.

8.2- Cross-checking with complementary sources of information

No supplementary sources of information are required for identifying glacial debris fields that are in the process of formation. Nonetheless, if maps of the surficial formations in the region under study are available, it is easy to verify whether the delimitation between the deposits and the substrate is accurate.

9- Elements of confusion

Table 3: Elements of confusion and recognition between glacial debris and other entities or forms

Entity or form	Elements of confusion	Elements of recognition	Examples
Moraine	- Location next to glacier - Hue medium grey	- Absence of elongated or bowed shape - Hummocky surface	Figure 1
Bedrock	- Hue medium grey - Sometimes absence of vegetation	- Location on slope - Use of stereoscopy or a DEM	Figure 1
Permanent snow and ice	- Presence of debris on the ice - Salt-and-pepper appearance	- Hue medium grey - Less than 20% of surface is ice	Figure 1

10- Bibliography

None

Appendix: the meanings of the sections

1. Name of entity

The name of the entity as it appears in the GDB and in Topolan7.

2. Position in hierarchy

The position of the entity in the hierarchical structure of entities in the GDB.

3. Definition

A brief description based on the entity's principal characteristics and allowing it to be distinguished from any other natural or manmade entity in the GDB.

Only the core features are part of the definition. A detailed description of the characteristics necessary for identification is given in Section 4.

4. Summary table of elements of identification

Presentation of a table summarizing the entity's characteristics (Section 5), of the optimal conditions for identification on ETM+ imagery and black and white (B/W) aerial photography (Section 6), and of the elements of confusion (Section 9).

5. Characteristics

Categorization and description of the characteristics useful for visual identification of the entity.

5.1. Specific to the entity

Characteristics unique to the entity that allow all aspects useful for its identification to be grasped.

5.1.1. Shape

Distinction between linear, point, and areal shapes, three-dimensional pattern of the entity.

5.1.2. Dimensions

Expanse (length, width, diameter) and height of the entity: minima, maxima, and means.

5.1.3. Topographic position

Location of the entity relative to major landforms: drainage basin, mountain, plateau, plain, valley, slope, etc.

5.1.4. Drainage

Surface moisture, outside of saturated zones, in connection with the texture of the materials in the entity.

5.1.5. Vegetation

Presence of vegetation typical of the entity or patterns of plant associations making it possible to distinguish the entity.

5.2. Relative to the entity's dynamics

Characteristics pertaining to the origin and the state of the entity.

5.2.1. Emplacement process

The agent or set of agents responsible for the entity's emplacement and evolution.

5.2.2. State

Dynamic state of the entity: inherited or current. In the case of inherited features, we speak of paleolandforms; in the case of current landforms, we speak of their ongoing formation.

5.2.3. Spatio-temporal variations

Variations in the entity or its appearance that are functions of cyclical conditions (seasonal, multi-year, etc.) or event driven.

5.3. Relative to the environment

Characteristic of the conditions in the entity's milieu and its relationship with other entities or forms present in this milieu.

6. Optimal conditions for identification

Drawing on documentary sources and the experience of the participants, establishment of the optimal conditions for visual identification of the entity. Using satellite imagery, determine the capability of Landsat7 ETM+ to capture the characteristics of the entity and identify the band or combination of bands best for visually distinguishing and identifying the entity. Using B/W aerial photography, identify the hues and textures that are most representative of the entity. In cases in which the relief may be significant, recommend the use of stereoscopy.

7. Examples

Illustrating the entity with examples reflecting several of its aspects:

7.3. Land-based photography

Photographs of the landscape that present one or several examples of the entity's aspects, as they might be seen from the ground.

7.3. Aerial photography

Oblique or vertical aerial photographs that present one or several examples of the entity's aspects, as they might be seen from the air.

7.3. Satellite imagery

Satellite images (from Landsat7 ETM+) that present one or several examples of the entity's aspects, as they might be seen from space.

8. Interpretation

Identification of the entity proceeds from interpreting the information in the imagery or aerial photography and complementary sources of information. The quality of the outcome of this interpretive activity will depend upon the knowledge and the experience of the analyst.

8.1. Critical path

Establishing a unique critical path of interpretation for each entity from the imagery or aerial photography on the basis of its characteristics.

8.1.1. Distinction and delimitation

The possibility of distinguishing and delimiting the shape on the image or aerial photograph has been established and the criteria for success have been described.

8.1.2. Identification

Contrasting the various elements of confusion and recognition with other entities or forms for purposes of identification.

8.2. Use of complementary sources of information

Complementing or cross-checking the interpretation with additional sources of information that are easily accessible, such as those on known Internet sites.

9. Elements of confusion

Identifying the entities and forms with which the entity in question can be confused in a table, along with the differentiating features.

10. Bibliography

A list of useful documents quoted in the previous sections.