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

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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
	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- Feature name

Moraine

2- Hierarchy

Landforms – glacial – glacial debris – landform – moraine

3- Definition

According to CTI (2002 or 2004), accumulated glacial debris, generally till, thick enough to create relief, such as mounds or ridges; or a mound, ridge, or accumulated glacial debris deposited by direct glacial action.

In geomorphology, a moraine is a ridge of till or other juxtaglacial materials pushed ahead of or deposited along the sides of a glacier.

According to Landry and Mercier (1992) and Mollard and James (1985), there are two types of moraine on the Canadian landmass, whether current or old forms. CTI maps only those moraines currently being formed by contact with a valley glacier or ice cap, specifically:

- push (in front of the glacier);
- lateral (deposited by a glacier at its sides along valley walls);
- medial (between two glacier tongues).

Recessional moraines no longer in contact with the glacier are not represented, but are considered glacial debris if still in proximity with the glacier.

4- Summary table of identification elements

Table 2: Summary of elements identifying moraines

Form	Plan view: linear or arced Cross-section: triangular ridge
Dimensions	Length: hundreds of metres to kilometres Width: decametres to a few hundreds of metres Height: decametres to a few hundreds of metres
Topographic position	Valley, slope, or interfluvial
Drainage	Excellent
Vegetation	Bare or herbaceous vegetation
Means of formation	Loose materials in contact with a glacier
Status	Being formed
Spatiotemporal variations	Relatively stable A push moraine may appear or disappear within a few decades
Environment	Glacial in elevation or latitude
Identification in the image	Bands 5-4-3 Position evident along the glacier edge
Identification in B/W aerial photo	Form evident in stereoscopy Position evident along the glacier edge
Elements of confusion	Developing esker, glacial debris

5- Characteristics

5.1- Specific to feature

5.1.1- Form

A moraine is linear in form or bowed in the case of a push moraine. The typical cross-sectional view is a triangular-shaped ridge with a slightly rounded ridge (Figures 1 to 3).

5.1.2- Dimensions

Length: a few hundreds of metres to several kilometres (in the case of lateral and medial moraines).

Width: a few tens of metres to a few hundreds of metres.

Height: a few metres to a few hundreds of metres.

5.1.3- Topographic position

Moraines can be found in all topographic positions: valley, slope, or interfluvial.

5.1.4- Drainage

Drainage is excellent because of the steep slopes of the moraine crest.

5.1.5- Vegetation

Moraines that are currently being formed by active glaciers are usually bare or support sparse herbaceous vegetation. The older the formation, the greater the vegetation cover, progressing from herbaceous vegetation to shrubs.

5.2- Related to feature dynamics

5.2.1- Means of formation

Moraines are deposited directly by or from the ice or pushed ahead of the glacier.

5.2.2- Status

While many moraines on the Canadian landmass are paleolandforms (Figures 1 to 3), only active features near current glaciers are represented on topographic maps. The *National Atlas of Canada* (<http://atlas.goc.ac>) provides maps for locating the main glacier areas within the country.

5.2.3- Spatiotemporal variations

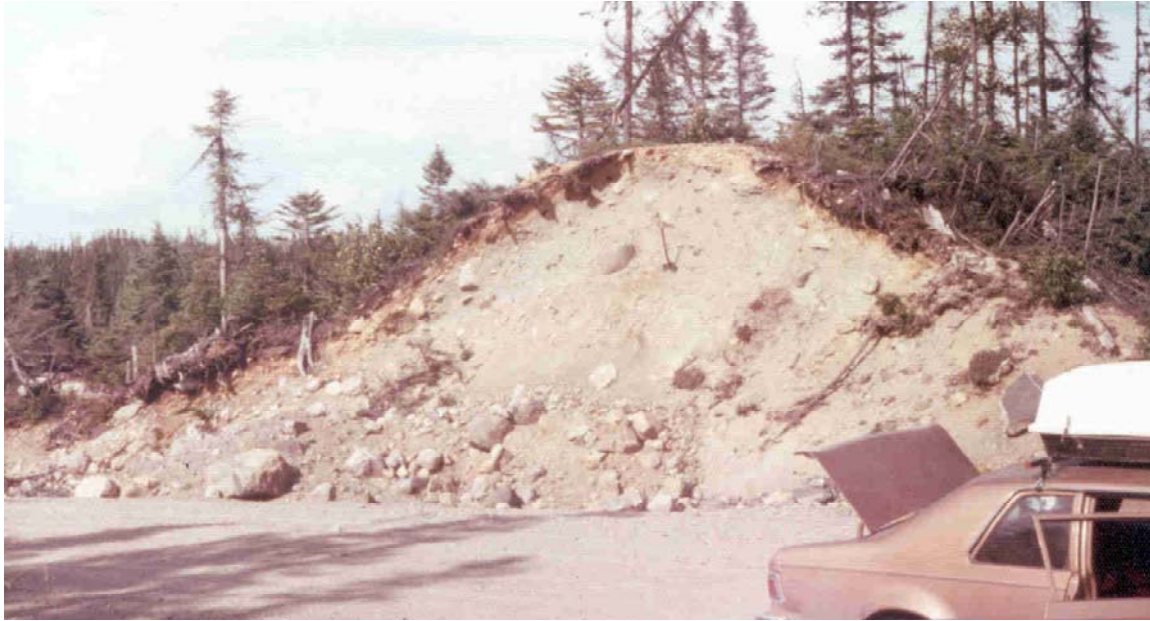
Developing moraines are relatively stable on the human scale. Nevertheless, certain push moraines formed by valley glaciers in the Rockies or Northern Canada can be deposited by a retreating glacier tongue over several decades (Figure 5). In contrast, certain valley glaciers can also advance, which is much less common, and incorporate their push moraine.

5.3- Related to the environment

Developing push, lateral, and medial moraines can only be deposited in a current glacial environment at altitude (mountainous setting) or latitude (arctic setting).

6- Optimal conditions for identification

Given their position along glacier edges and their topographic expression, moraines are best distinguished with the combination of bands 5-4-3, for which colors are less saturated. Moreover, identification is easier with oblique lighting and when the landform's shadow is apparent. For the same reasons, there are no identification issues with



aerial photographs, especially when stereoscopy is used for smaller forms.

7- Examples

Source : photo J.-M. Dubois n° 76-16-29, Côte-Nord du Saint-Laurent (Québec)

Figure 1 : Example of a cut in a moraine crest



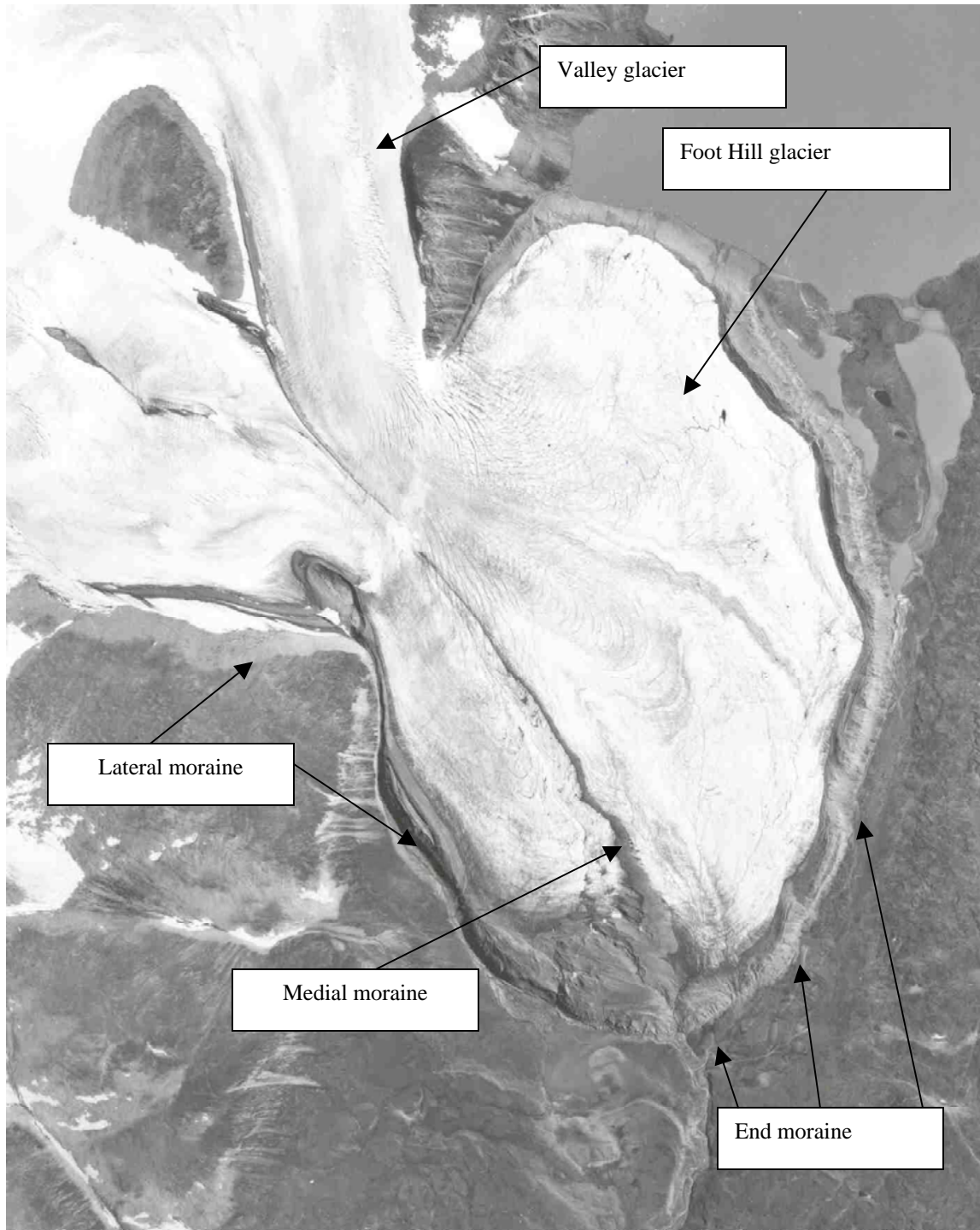
Source : photo J.-M. Dubois n° 75-10-3, and GSC. n° 202880-Q, ST-Lawrence River. Côte-Nord area (Québec)

Figure 2 : Example of a vegetated moraine crest



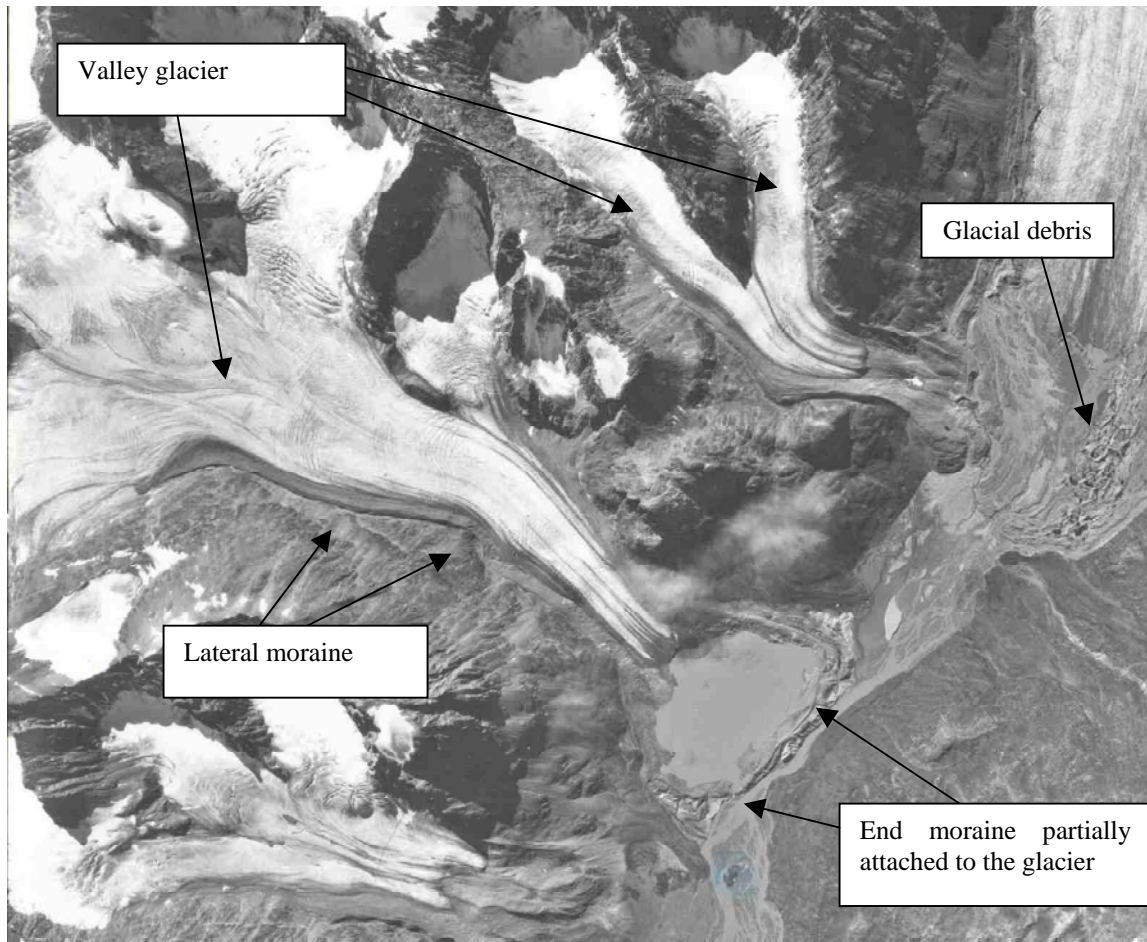
Source : photo Dubois et Dionne (1985), Côte-Nord area moraine (Québec)

Figure 3 : Aerial view of a moraine crest



Source : photo A15420 (66), T.S.C.A.P. n° 135-2B, Original scale 1 : 60 000, carte 26I, 66° 55' N – 65° 50' O, **Pangnirtung** Area (Nunavut.)

Figure 4 : Example of an end moraine attached to a glacier tongue



Source : photo A15467 (43), T.S.C.A.P. n° 166-2B, Original scale 1 : 60 000, map 16L, 66° 43' N – 62° 20' O, **Cape Dyer** area (Nunavut)

Figure 5: Example of lateral and end moraines separating from a glacial tongue; note the similarity between these shape and position with the moraine in figure 4

8- Interpretation

8.1- Critical path

The critical path comprises two phases: discrimination and delimitation of the form as well as its identification.

8.1.1- Discrimination and delimitation

The elongated or arced shape of developing moraines and their position along the edge of glaciers are prime factors in discrimination and delimitation, especially with stereoscopy. The combination of bands 4-3-2 is required with ETM+ images, although very narrow moraines may not be captured.

On the other hand, some eskers may be interpreted as medial moraines if near a retreating valley glacier since these

two features have similar shapes and are perpendicular to the glacier front. Medial moraines, however, coincide with the visible shape on the glacier (Figure 4), which is not the case with eskers, which extend from the glacier.

Sometimes, areas of glacial debris are juxtaposed to moraines, especially push moraines. Shape usually makes it easy to accurately delimit moraines, even if the average grey tone is the same.

8.1.2- Identification

The process for identifying moraines requires the analyst to deal with different elements of confusion and discrimination (Table 2). Discrimination accuracy is directly proportional to the analyst's knowledge and experience.

8.2- Verification with complementary sources of information

No complementary sources of information are needed to identify developing moraines.

9- Elements of confusion

Table 3: Elements of confusion and discrimination between moraines and other features or forms

Feature or Form	Elements of Confusion	Elements of Discrimination	Examples
Esker	- Linear - Position parallel to lateral and medial moraines	- Alignment with its visible shape on the glacier - Perpendicular to the glacier front	Figure 4
Glacial debris	- Positioned along the glacier edge - Medium grey tone	- Linear or arced	Figure 5

10- Bibliography

Dubois, J.-M.M. and Dionne, J.-C. (1985) The Québec North Shore Moraine System : A Major feature of Late Wisconsin deglaciation. *in* H.W. Borns Jr., P. La Salle and W.B. Thompson (ed.). Late Pleistocene History of Northeastern New England and Adjacent Quebec. The Geological Society of America, Special Paper 197, p. 125-138.

Landry, B. et Mercier, M. (1992) Notions de géologie. 3^e édition, Modulo, Mont-Royal, 565 p.

Mollard, J.D. et Robert James, J. (1985) La photo-interprétation et le territoire canadien. Approvisionnements et services Canada, Ottawa, 424 p.

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.