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Interpretation guide of natural geographic features from ETM+ Landsat imagery and aerial photography: Permanent snow and ice

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Table of contents

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- Feature name

Permanent snow and ice

2- Hierarchy

Landforms – glacial – glacier and ice cap and ice platform – permanent snow and ice – permanent snow and ice.

3- Definition

Permanent snow and ice such as a glacier, ice cap, snowfield, ice field, and ice shelf.

A **glacier** (or **glacier tongue**) is a body of slow-moving perennial snow and ice resulting from an accumulation of snow from a higher elevation (**Figure 1**).

An **ice cap** is a dome-shaped body of perennial snow and ice that spreads out from a center and covers a large area.

A **snowfield** is an area of permanent snow cover. It becomes an **ice field** when enough snow accumulates, turns into ice, and begins feeding glaciers (**Figure 2**).

An **ice shelf** is a thick body of ice floating in the sea, a fjord, or flooded valley along a glacier or ice sheet (**Figure 1**). An ice shelf can be partially anchored to islands, islets, or shoals.

A snow-drift is a small snow field perpendicular to taluses or slopes but is generally too small to be mapped (**Figure 1**).

4- Summary table of identification elements

Table 2: Summary of elements identifying permanent snow and ice

Form	Surfaces of various forms that may be convex and extend into valleys
Dimensions	Diameter or length and width: a few hundreds of metres to kilometres
Topographic position	Mountains, high plateaus, or valleys At sea level in the case of ice shelves
Drainage	Not applicable.
Vegetation	None
Means of formation	Accumulation of permanent snow and ice
Status	Stable on the human scale
Spatiotemporal variations	Decadal increase or decrease
Environment	Glacial or periglacial at high elevation or latitude
Identification in the image	Combination of bands 5-4-3 If shade: combination of bands 3-2-1
Identification in B/W aerial photo	Very white shade or "salt-and-pepper" effect Smooth texture
Elements of confusion	Glacial debris, shadows, adjacent rock deposits or bedrock covered with fresh snow

5- Characteristics

5.1- Specific to feature

5.1.1- Form

A **valley glacier** is an elongated surface, with a slightly crowned center, parallel to the valley in which it lies (**Figure 1**). Valley glaciers are slow-moving. Valley glaciers are often the product of a number of glacier tongues coming together (moraine sheet, **Figure 4**).

Ice caps and **ice fields** are dome-shaped bodies of glacier ice that spread out in all directions, sometimes with multiple extensions depending on the relief, with slow-flowing glacial tongues along the edges in valleys (**Figure 1**). Ice caps are regional in scope; ice fields are local.

A **snowfield** is an uncrowned area of variable shape that closely follows the surrounding topography.

An **ice shelf** is a flat area of ice of variable shape in a waterbody. Its surface may be rough if the shelf is made of a number of icebergs that have coalesced (**Figure 1**). An ice shelf is a slow-flowing structure since it is the extension of a glacier, ice field, or ice cap into water.

5.1.2- Dimensions

Ice caps, ice fields and ice shelves: a few hundreds of metres to several tens of kilometres in diameter.

Valley glaciers:
- Length: a few hundreds of metres to several kilometres.
- Width: a few hundreds of metres to kilometres.

5.1.3- Topographic position

On mountains or highland plateaus in the case of ice caps, ice fields, and snowfields. In mountain valleys or highland plateaux in the case of valley glaciers. At sea level in the case of ice shelves.

5.1.4- Drainage

Not applicable.

5.1.5- Vegetation

None

5.2- Related to feature dynamics

5.2.1- Means of formation

Accumulation of snow or snow turned into ice by transformation or pressure, and characterized by a slow down-slope flow, except in the case of a snowfield.

5.2.2- Status

Mapped occurrences of permanent snow and ice are stable on the human scale. The *National Atlas of Canada*

(http://atlas.gc.ca) provides maps for locating the main glacier areas within the country.

5.2.3- Spatiotemporal variations

Areas of permanent snow and ice undergo little change on the human scale, although they can advance (accumulation) or retreat (ablation) over several decades.

5.3- Related to the environment

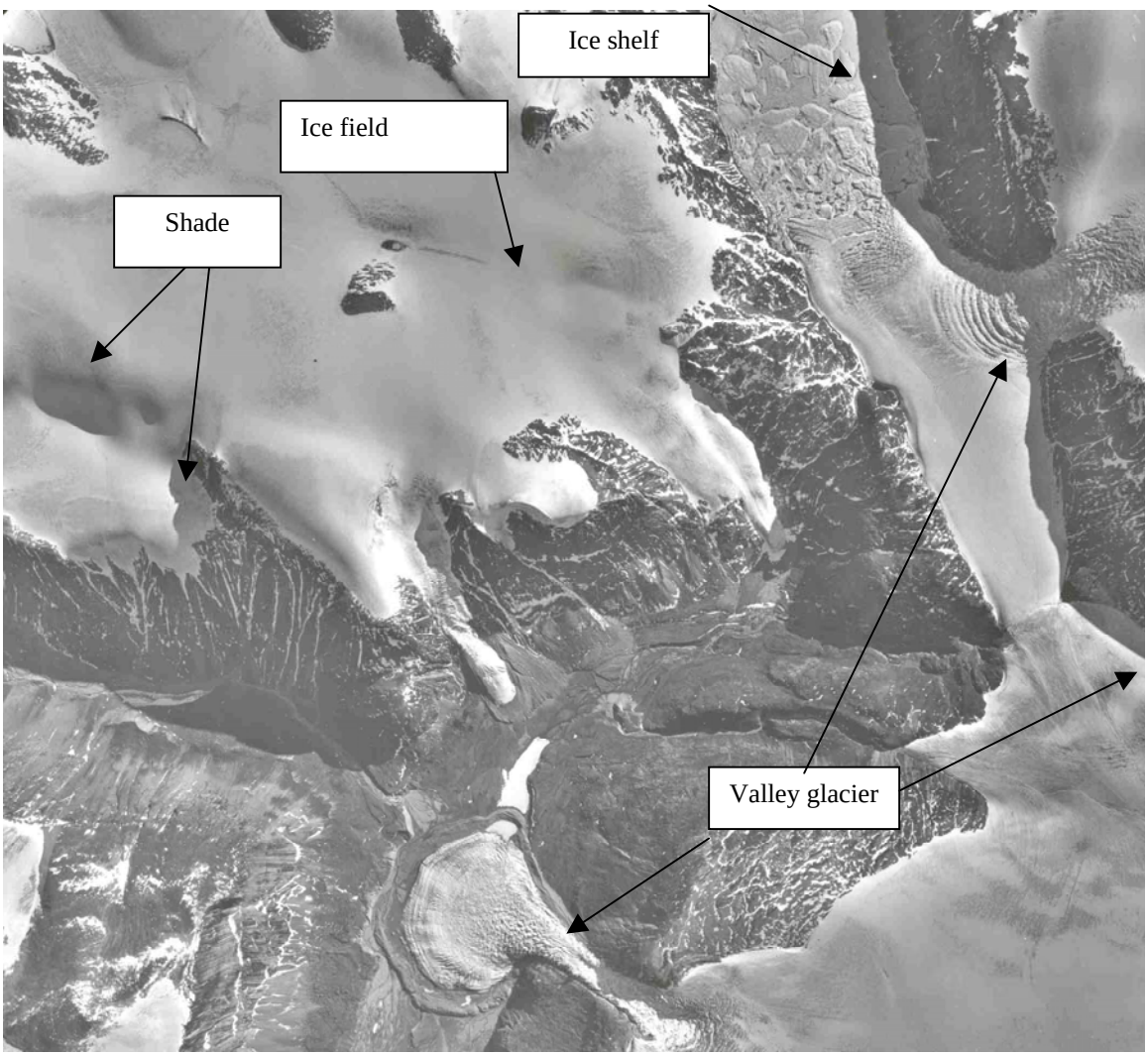
Areas of permanent snow and ice are found in glacial and periglacial environments on mountains, highland plateaus, and valleys at high altitude or high latitude.

6- Optimal conditions for identification

Areas of permanent snow and ice are evident on aerial photographs, due to their generally very whitish appearance.

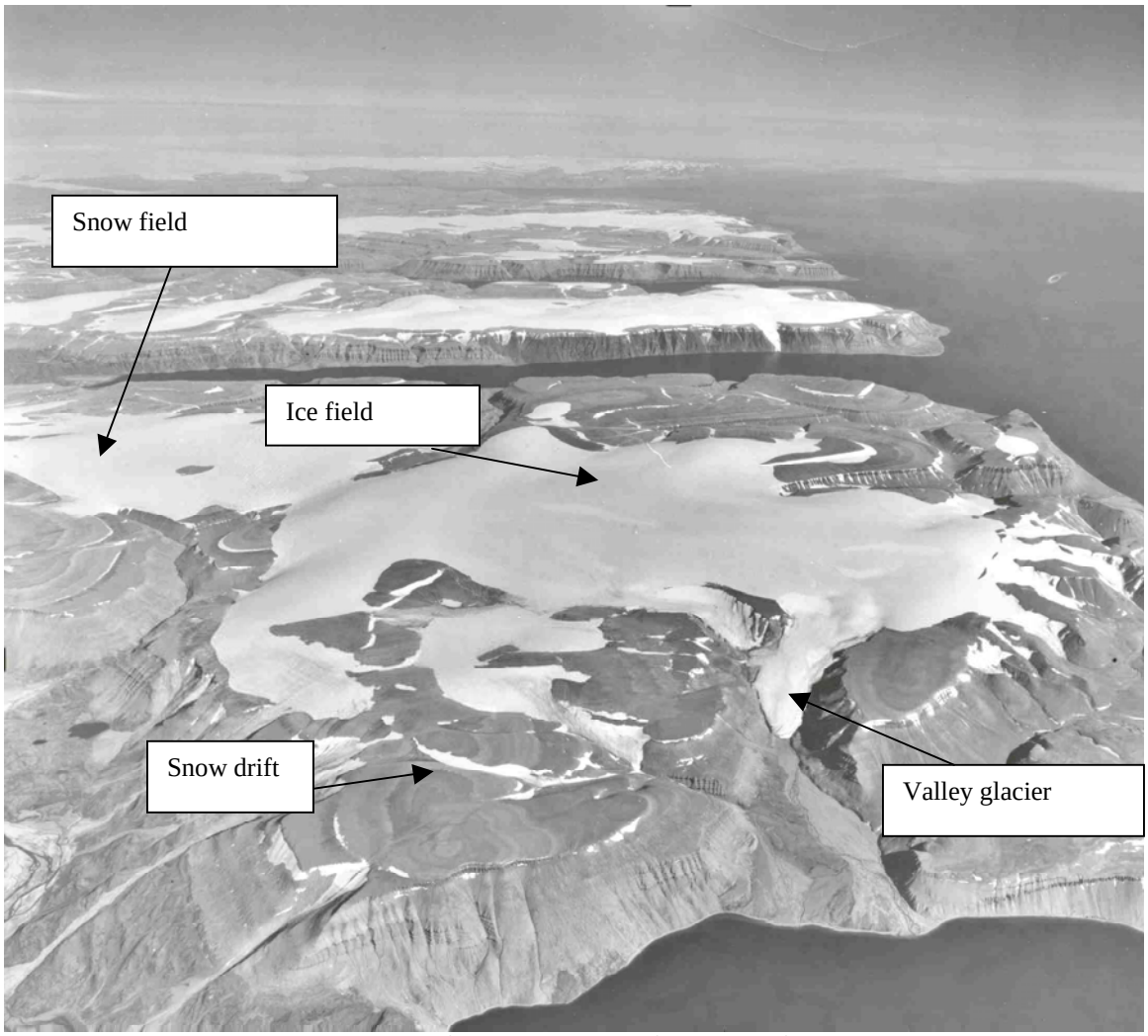
In the case of ETM+ imagery, the most common combination of bands is 5-4-3, since it provides clear delimitation of the feature. The combination of bands 3-2-1 coupled with good enhancement (linear and a high percentage values ignored) brings out the feature, even when significant shadows are present, especially in the case of valley glaciers. As a result of the lack of snow cover in summer images, glaciers are pale in color in bands 1, 2, 3, 4, and 8 (high reflectance) and dark on bands 5 and 7 (high absorption). In band 6, glaciers appear darker than surfaces not covered with ice (surface temperature differential).

7- Examples



Source : photo A16101(14), T.S.C.A.P. n^{o} 221, original scale 1 : 60 000, map 37E, 70^{o} 51' N – 72^{o} 55' O , **Baffin Island**

Figure 1 : Example of a valley glacier and ice field with a floating ice shelf made up of welded icegbergs



Source : photo T4412(208), T.S.C.A.P. n° 248, map 48F, 74° 35' N – 86° 05' O, **Devon Island** (Nunavut)

Figure 2 : Oblique aerial photography of an ice field with snow fields and snow drifts

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 very whitish tone of snow and ice in aerial photographs makes it possible to clearly identify and delimit areas of permanent snow and ice. The main problems are related to loess, the percentage of debris on the ice, shadows, and fresh snow.

The first problem is to discriminate zones of loess, which is comprised of fine glacial particles that have been transported and deposited by wind action with respect to areas of glacial debris. Indeed, unlike glacial debris, loess just dirties up the surface of the snow or ice. The distinguishing feature of loess is that it is deposited as a fine wavy

layer, without modifying microtopography (**Figure 3**). Loess shows up as a light to medium grey tone, but has a fine texture through which the whitish tone of underlying snow or ice appears.

The second problem lies with discriminating areas of glacial debris in the ablation zone (lower part of the glacier) based on the area that they cover. The surface should be mapped as permanent snow and ice (whitish tone) if less than 80% of the surface showing a salt-and-pepper effect is covered with debris (average grey tone). In this instance, the texture is smoother and the topography less hummocked than the area of debris, making it easy to identify when viewed stereoscopically.

The third problem relates to very heavy shadows that mask shapes and surfaces (dark grey tone) in the photographs (**Figure 1**). Nevertheless, stereoscopy clearly reveals areas of permanent snow and ice based on their smooth texture and geomorphological context.

Similarly, fresh snow fallen before the photographs are taken can cover adjacent deposits or bedrock (**Figure 4**). Smoother texture, the absence of variegated texture (alternance of snow and bare ground), taking geomorphological context into account, and stereoscopy combine to make it easy to discriminate areas of permanent snow and ice from these entities.

The feature is readily identifiable in ETM+ images with combination of bands 5-4-3, if the surface is not covered with snow or debris. Snow cover attenuates spectral response and discrimination is more difficult if relief is not taken into consideration. Feature delimitation is vaguer if the surface is lightly covered with debris. A thick layer of debris could lead to confusion with areas of glacial debris along the glacier's edge.

8.1.2- Identification

The process for identifying permanent snow and ice requires the analyst to deal with various 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

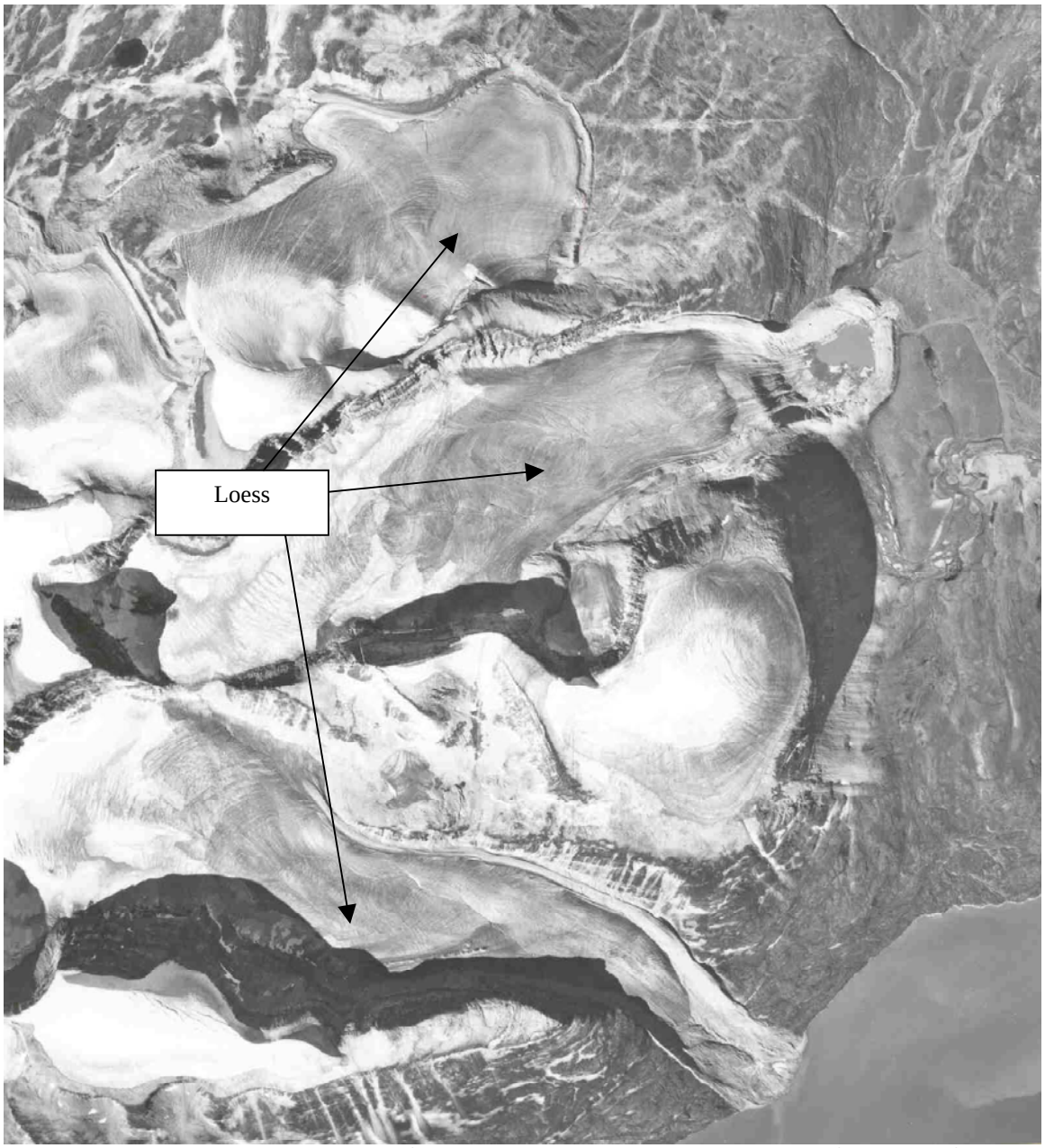
No complementary sources of information are needed. Landry and Mercier (1992) provide a good summary of the current glacier environment.

9- Elements of confusion

Table 3: Elements of confusion and discrimination between permanent snow and ice and other features or forms

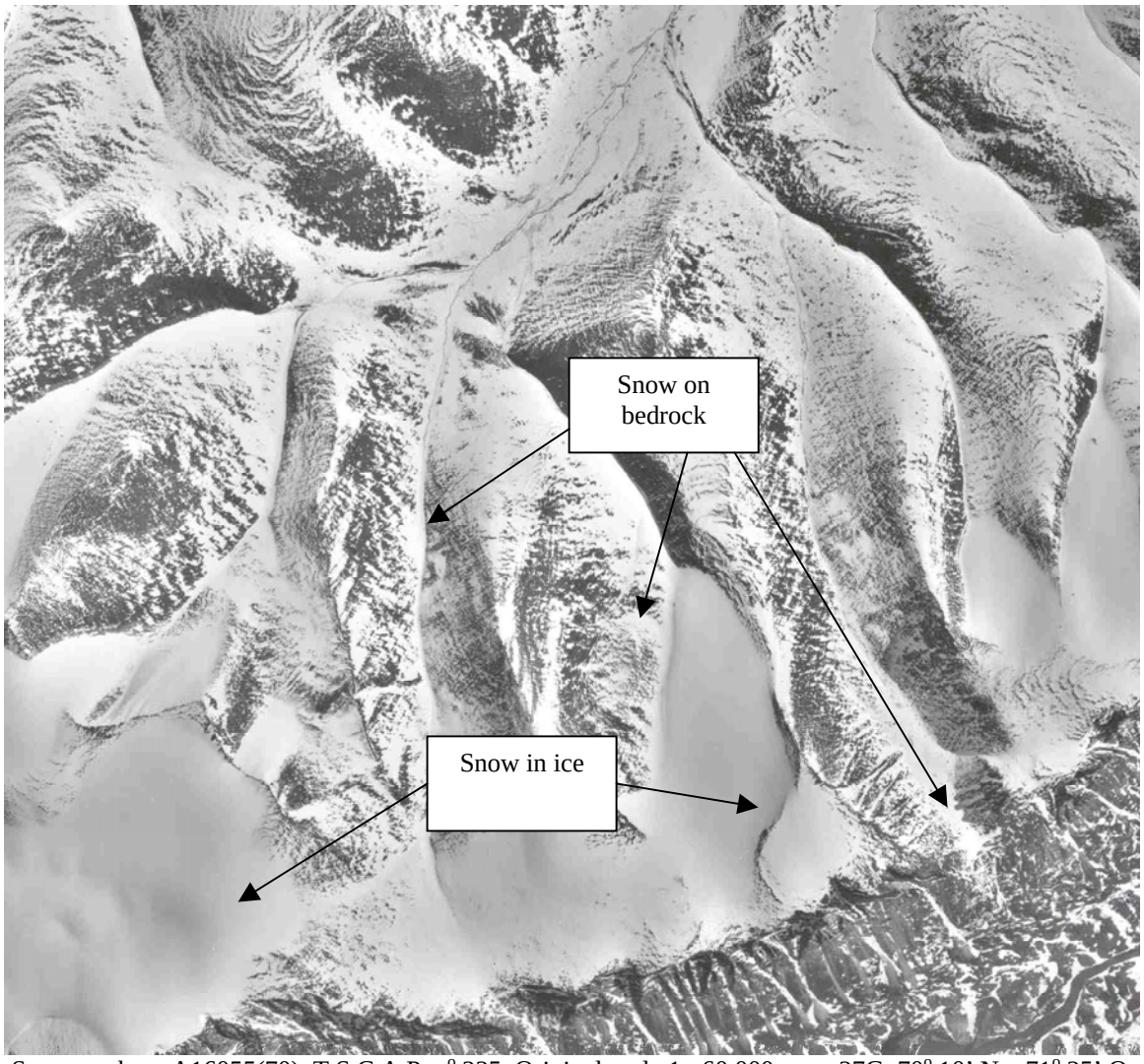
Feature or Form	Elements of Confusion	Elements of Discrimination	Examples
Loess	- Light to medium grey tone (debris on ice)	- Smooth texture that allows underlying snow or ice to show through	**Figure 3**
Glacial debris	- Debris on the ice	- Whitish tone	

	- Salt-and-pepper effect	- Smoother texture - Surface not as hummocked - Geomorphological context	
Shadows	- Dark and medium grey tone of deposits and bedrock	- Smooth texture - Geomorphological context - Stereoscopy - Combination of bands 3-2-1	**Figure 1**
Deposits or bedrock covered with fresh snow	- Very whitish tone	- Smooth texture and unvariegated (snow, bare ground) - Geomorphological context - Stereoscopy	**Figure 4**



Source : photo A15420(42), T.S.C.A.P. n^{o} 158,Original scale 1 : 60 000, map 16E, 65^{o} 53’ N – 63^{o} 34’ O, **Hoare Bay** (Nunavut.), 1956-08-31

Figure 3 : Example of loess coverage on glaciers



Source : photo A16055(70), T.S.C.A.P. n^{o} 225, Original scale 1 : 60 000, map 27G, 70^{o} 10’ N – 71^{o} 25’ O, **Scott Inlet** (Nunavut), 1958-07-22

Figure 4 : Example of a mountain glacier area covered with fresh snow when picture was taken

10- Bibliography

Landry, B. et Mercier, M. (1992) Notions de géologie. 3e édition, Modulo, Mont-Royal, 565 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 Landset7 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 on 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.