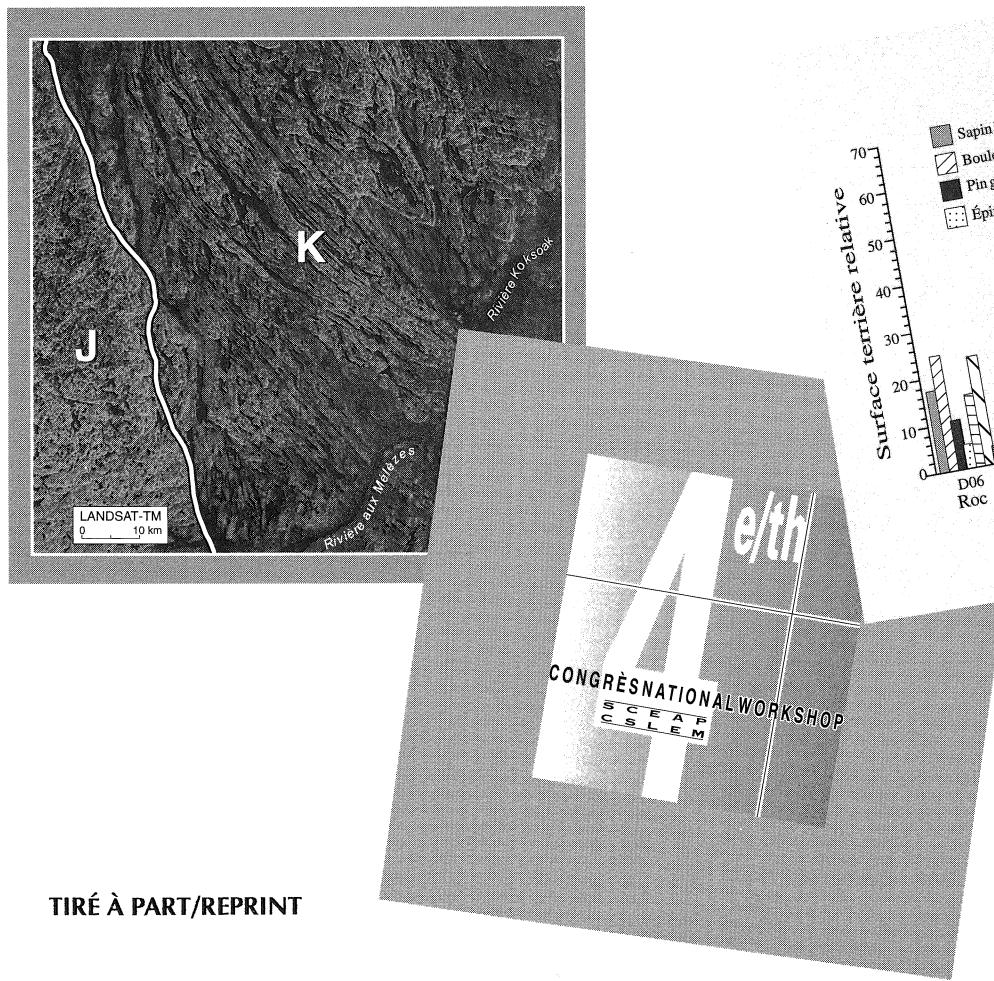


MÉTHODES ET RÉALISATIONS DE L'ÉCOLOGIE DU PAYSAGE POUR L'AMÉNAGEMENT DU TERRITOIRE

LANDSCAPE ECOLOGY IN LAND USE PLANNING METHODS AND PRACTICE

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SMALL-SCALE ECOLOGICAL MAPPING OF QUÉBEC: NATURAL PROVINCES AND REGIONS (CARTOGRAPHIC DELINEATION)

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ABSTRACT

In recent years, the Québec government has frequently expressed the will to manage the territory of Québec with greater ecological knowledge (ecosystem-based management), to use the land according to its capability (sustainable land and resource use, environmental assessments, state of the environment reporting) and to develop a coherent conservation policy (parks, ecological reserves, biodiversity). In order to carry this out, the Québec environment department, the Ministère de l'Environnement (MENVIQ), decided to develop an ecological reference framework for the province in 1992. Intended as a continuation of ecological mapping begun in the late 1960s, this ecological reference framework is based on a segregation approach which proposes a hierarchical system for mapping natural structures. Cartographic polygons are delineated based on an analysis of remote sensing data, sometimes correlated with geomatic data (GIS, DTM); the geological and geomorphological history of Québec and North America; aerial surveys; and terrestrial transects.

To date, 13 natural provinces and 81 natural regions have been mapped using this approach. These provinces and regions correspond to large-scale spatial structures associated with continental and regional tectonic phenomena. Natural provinces and natural regions are the two primary levels of perception of the ecological reference framework for Québec.

Keywords : Ecological mapping, level of perception, hierarchical system, segregation, spatial structures.

RÉSUMÉ

Dans les dernières années, le gouvernement du Québec a maintes fois réitéré sa volonté de gérer son territoire en intégrant une meilleure connaissance écologique (gestion écosystémique), d'utiliser son territoire selon ses capacités (utilisation durable des ressources et du milieu, évaluations environnementales, bilans de l'état de l'environnement) et de développer une politique cohérente de conservation (réseau de parcs, de réserves écologiques, biodiversité). Pour mettre ses politiques et ses actions en application, le ministère de l'Environnement du Québec a décidé, en 1992, de dresser un cadre écologique de référence pour l'ensemble du Québec. Inscrit dans le prolongement des travaux de cartographie écologique entrepris au Québec dès la fin des années 60, ce cadre écologique de référence s'appuie sur une approche de ségrégation qui s'inscrit dans un système hiérarchique et cartographie des structures naturelles. Pour le découpage des polygones cartographiques, nous avons eu recours à l'analyse d'images satellites parfois couplées à des éléments géomatiques (système d'information géographique, modèle numérique d'élévation), à l'histoire géologique et géomorphologique du Québec et de l'Amérique du Nord, à des survols aériens et à des transects terrestres.

Dans un premier temps, nous avons distingué 13 provinces naturelles et 81 régions naturelles qui correspondent à des ensembles spatiaux de grande taille respectivement révélés par des phénomènes tectoniques d'envergure continentale et régionale; ils constituent les deux premiers niveaux de perception supérieur du cadre écologique de référence du Québec.

Mots clés : Cartographie écologique, niveaux de perception, système hiérarchique, ségrégation, structures spatiales.

INTRODUCTION

In 1992, the Québec environment department, the Ministère de l'Environnement (MENVIQ),¹ decided to develop a small-scale ecological reference framework for the territory of Québec. The departmental authorities thereby hoped to obtain a generalized ecological planning tool that could be used to:

- establish the provincial network of ecological reserves;
- draft state of the environment reports for Québec;
- propose an ecological reference framework for assessing the environmental impact of major development projects; and
- ensure ecosystem-based, sustainable land management.

Development of this ecological reference framework was initially intended to be a continuation of the ecological mapping of Québec begun in the late 1960s (Jurdant, 1968; Jurdant *et al.*, 1972 and 1977); however, the need to adapt and fine-tune the conceptual framework and methodology arose along the way. The two main reasons for this were: 1) the normal evolution of any dynamic methodology (Gerardin and Ducruc, 1990; Ducruc, 1991; Bélanger *et al.*, 1992) and; 2) the levels of perception used in the project.

The conceptual framework for ecological mapping will be explained, followed by a brief discussion of the method used to delineate the natural provinces and regions. A preliminary map of these regions is also included.

CONCEPTUAL FRAMEWORK

Hierarchical system

Ecological mapping is based on a hierarchical system comprising nested levels of spatial perception (Hills, 1960; Lacate, 1969; Isachenko, 1973; Walter and Box, 1976; Jurdant *et al.*, 1977; Mateo, 1984; Richard, 1989). This nested hierarchy (Bailey, 1985; O'Neill *et al.*, 1986; Urban *et al.*, 1987; Klijn and Udo de Haes, 1994) is built on a top to bottom approach: knowledge of the higher level is needed to understand the composition, organization, interaction and function of lower-level units (Weiss, 1971).

Segregation approach

Segregation takes a holistic approach to the territory to be mapped. Regardless of the level, the territory is considered first as a whole and then delineated into relatively homogeneous spatial entities that nonetheless contrast significantly with adjacent parts of the territory since delineation is normally carried out with an eye on differences (Rowe, 1991).

¹ Now the environment and wildlife department, Ministère de l'Environnement et de la Faune (MEF).

² Land satellite - Multispectral-scanner.

Mapping of functional natural structures

Each level of perception corresponds to a specific spatial organization of the natural environment defined by one or more dominant ecological variables mapped to an appropriate scale. This spatial organization translates to a territorial structure that controls the numerous exchanges of energy and materials, thereby creating functional ecological units (Blandin and Lamotte, 1988; Zonneveld, 1988).

Geology, inherent to spatial organization

These functional units must be defined by boundaries; however, to do so, they must not be considered in their present state alone, since they are the result of a long evolution which has produced a relatively complex pattern of landforms depending on the level of perception (Wiens *et al.*, 1985). These landforms have been modified by geological history, beginning with their genesis, through cycles of erosion and sedimentation, climatic variations and subsequent tectonic phenomena. Geology is the backbone of the territory's ecological organization and becomes more significant as the level of perception gets higher.

Climate, the driving variable of ecosystems

Climate is also essential to increasing our ecological knowledge, since it determines the distribution of living populations on the planet. Latitude, altitude and continentality are major variables in climate characterization. All climatic boundaries are approximate and statistical in nature, and serve only to indicate major transitional zones (Trewartha and Horn, 1980).

Furthermore, regardless of the level of perception or scale, the relief shapes and redistributes climatic influence (Rowe, 1988), while landforms dictate the nature of energy exchanges (gas, liquid, solid), i.e., the very bases of the ecosystem function. The climatic regime therefore plays a predominant role in this function since it directly affects the intensity of energy exchanges but is not instrumental in cartographic delineation.

MATERIAL AND METHOD

We required documents that provided an overall view of Québec, if possible, and would help us identify and differentiate specific spatial structures.

Landsat-MSS² mosaic

Only one document meeting all of these criteria exists in Québec. Despite its age, the poor resolution of the images, and the fact that they were taken in a variety of weather conditions, the Landsat-MSS mosaic (scale 1:1 000 000) was the key document used in our cartographic delineation. It helps effectively locate large-scale spatial units

characterized by a specific geological structure (pattern, form and density of major tectonic elements) often associated with the nature, morphology, density and orientation of the drainage network. The Landsat-MSS mosaic was used in correlation with other data appearing below, although not necessarily in the order listed. In fact, several sources of data were often used simultaneously to delineate certain spatial entities more precisely.

Other remote sensing products

Bissonnette et al. (1994) provide a detailed description of most of the complementary tools used in this study: Landsat-TM³ imagery using separate images or images mounted in small mosaics, Landsat-TM imagery combined with a digital terrain model (DTM) and a digital elevation model (DEM) and ERS-1⁴ radar images.

In general, the Landsat-TM imagery provided the best support for the proposed delineation on the Landsat-MSS mosaic, largely due to better definition and technical quality which made the images much easier to examine visually.

Geological documents

Geology, in the broad sense of the term, is the chief genetic factor in the natural environment's spatial organization at these levels of perception. Geological documents were used early on in the study to confirm the proposed delineation. We worked primarily with the geological map of Québec (Avramtchev, 1985), the geological history of Québec (Gauthier, 1992) and the geology of North America (Hoffman, 1989; Rast, 1989; Rivers et al., 1989).

Topographical maps

Base maps on a scale of 1:250 000 were occasionally used, this being the smallest scale showing contour lines that enable a general relief characterization. Using these maps, we were able to define more precisely and justify in whole or in part the proposed boundaries between two natural regions.

Aerial surveys

Several systematic aerial surveys were conducted in southern Québec in collaboration with conservation groups that monitor forest fires. The surveys were used primarily to describe and characterize the natural regions surveyed, providing a better understanding of the reality of the different regions and confirming certain boundaries, particularly in the Southern Laurentian Mountains natural province (Figure 1).

Land surveys

A large part of southern Québec was also explored by land, using the local road network wherever possible. The main objective of the land surveys, even more than with the aerial surveys, was to describe the natural regions. In the

³ Land satellite - Thematic mapper.

⁴ European Radar Satellite-1.

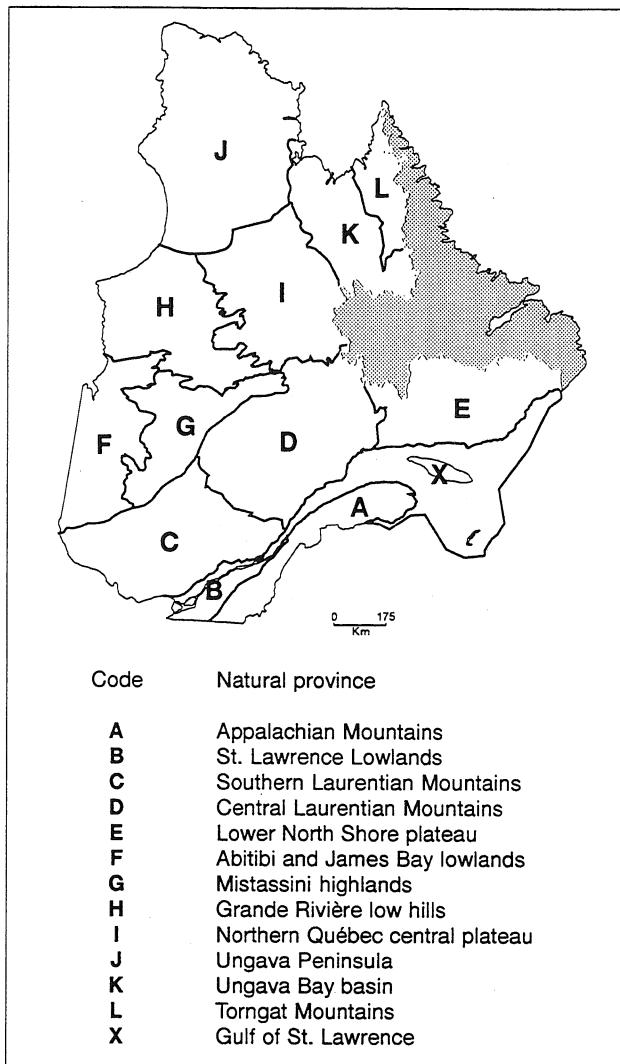


Figure 1. *The natural provinces of Québec**.

Appalachian Mountains (Figure 1), in particular, they helped justify and define precisely the proposed boundaries of the different natural regions.

PRELIMINARY RESULTS

Natural provinces

Natural provinces are territorial units created by major continental or subcontinental tectonic events. The territory of Québec has been divided into 13 natural provinces (Figure 1). A natural province is therefore a large-scale spatial entity (approx. 10^5 km^2) associated with major tectonic phenomena that cause different and sometimes highly contrasting territorial structures.

A satellite image (Figure 2) highlights the contrast between the spatial structures characterizing two natural provinces, which was confirmed by a closer oblique aerial photo (Figure 3).

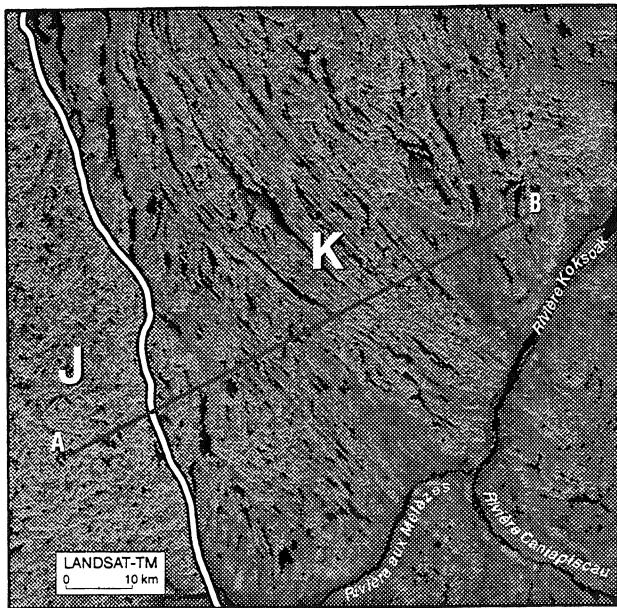


FIGURE 2 . Limit between natural provinces J and K(J: Ungava Peninsula; K: Ungava Bay basin).

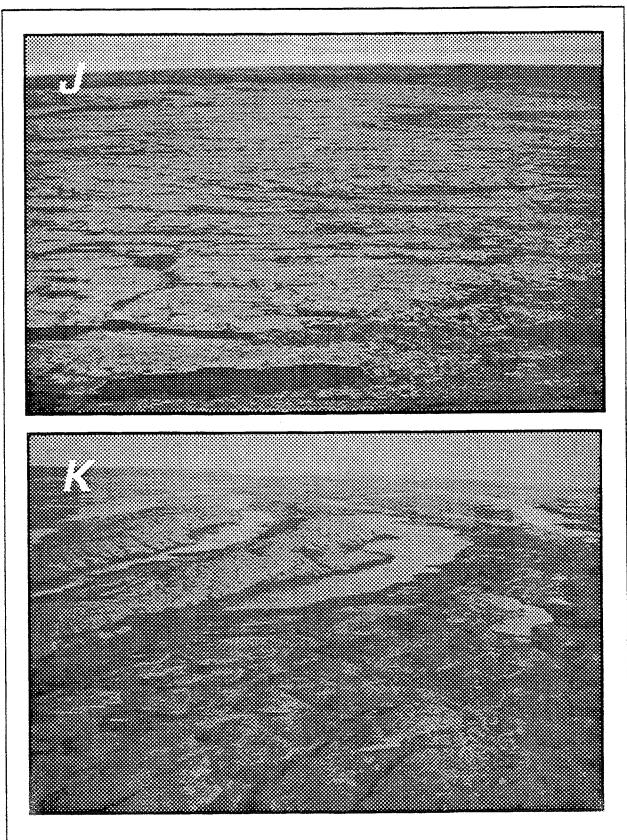


FIGURE 3 . Partial oblique aerial view of natural provinces J and K (J: Ungava Peninsula; K: Ungava Bay basin).

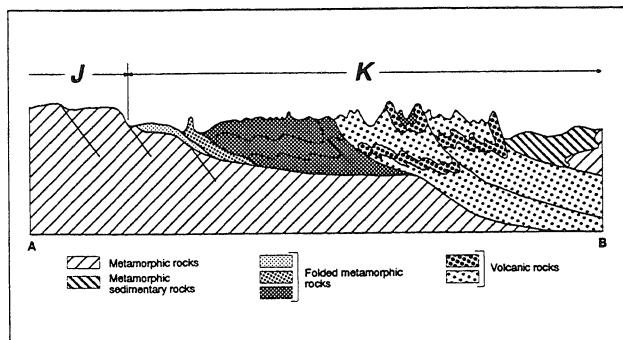


FIGURE 4 . Simplified geological cross-section of natural provinces J and K (J: Ungava Peninsula; K: Ungava Bay basin).

TABLE 1 . Basic characteristics of natural provinces J and K.

Basic characteristics	Ungava Peninsula	Ungava Bay basin
Geological period Age (in billions of years)	Archean ≈ 2.7	Proterozoic ≈ 1.8
Structural domain Tectonics	Basement Broken	Chain of folds Folded
Petrography Metamorphism	Metamorphic rocks High-grade	Volcanic and sedimentary rocks Low-grade
Relief Drainage Climate Vegetation cover	Relatively flat plateau Orthogonal Homogenous Tundra	Parallel low hills Parallel Variable (contrast. microclimates) Tundra/forest
Water quality Soil productivity Overall productivity Ecological diversity	Acid Low Low Low	Neutral Low to moderate Low to moderate High

A simplified geologic cross-section (Figure 4) of the two natural provinces shows why they represent two very different spatial organizations. The boundary between natural province J and natural province K corresponds to the boundary between the Superior province and the Churchill province. Natural province J has an Archean basement (2.7 billion years old) composed primarily of severely metamorphised intrusive rocks, while natural province K constitutes the remains of a Proterozoic mountain range (1.8 billion years old), initially much higher, composed of severely folded sedimentary and volcanic rocks. The main features characterizing each of these two provinces are listed in Table 1.

Natural regions

A natural region is a territorial unit within a natural province that is generally associated with regional tectonics and lithology.

The territory of Québec is divided into 81 natural regions (Figure 5 and Table 2).

Like natural provinces, natural regions are also large-scale spatial entities (approx. 10^4 km^2).

The satellite image in Figure 6 highlights the phenomena that help differentiate the natural regions.

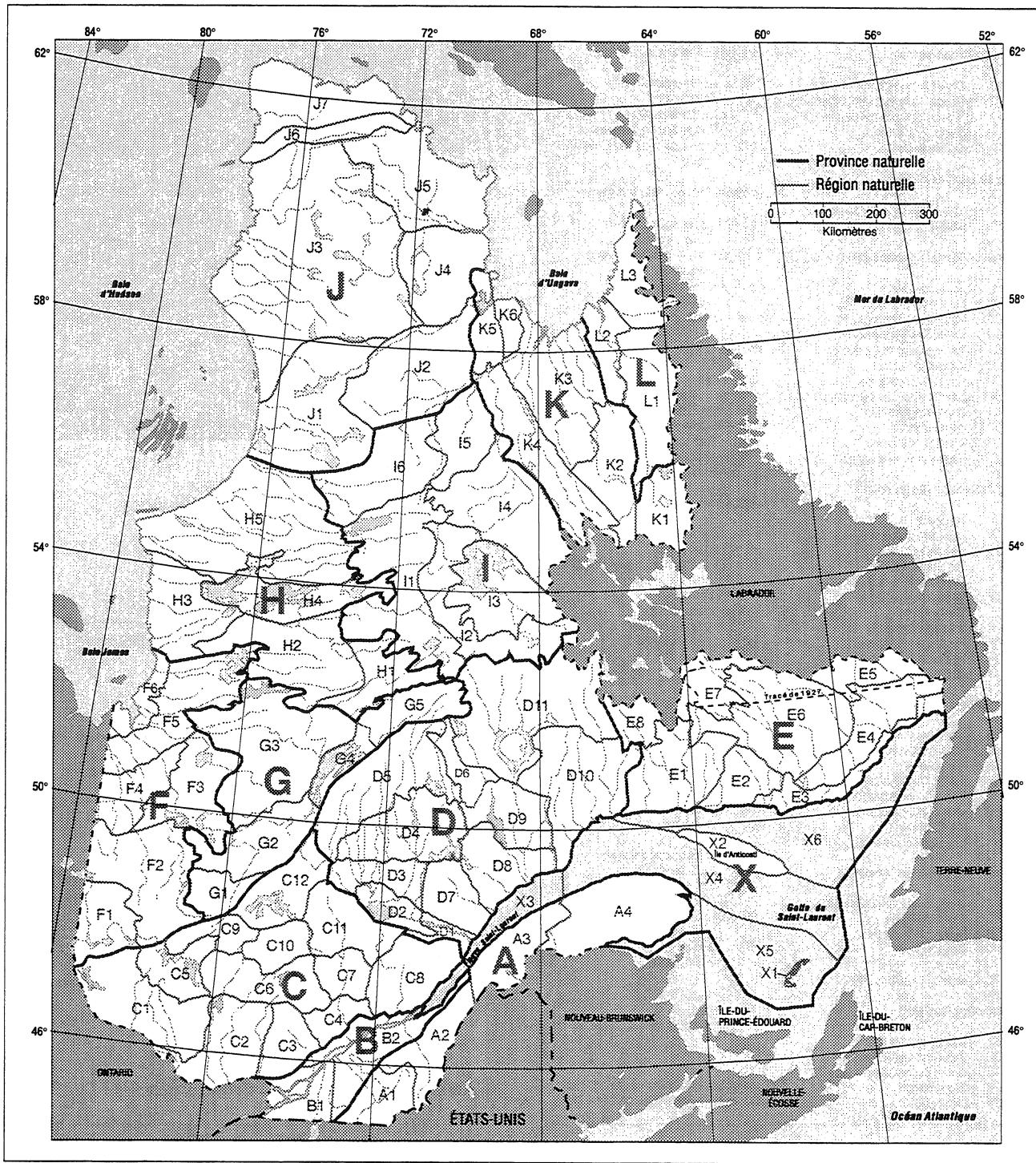


FIGURE 5 . *The natural provinces and regions of Québec.*

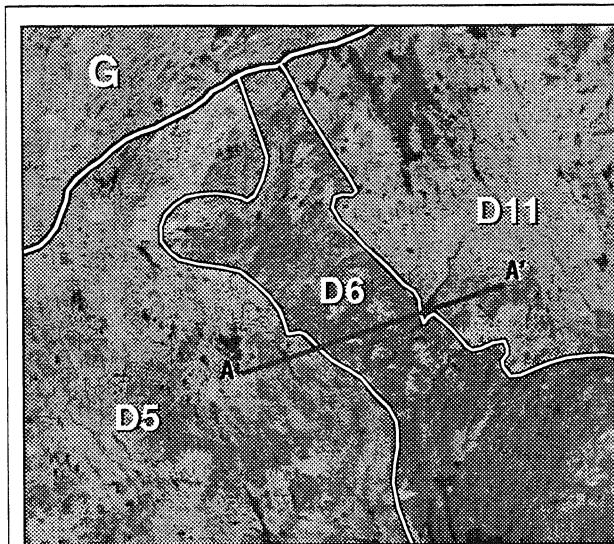
A simplified geologic cross-section can again be used (Figure 7) to understand the origins of the three natural regions whose individual features are the result of regional geological events related to the Grenville orogeny. Natural region D6 (Manouanis highlands) corresponds to an anorthosite intrusion (hard igneous rocks) within gneiss (softer metamorphised rocks) comprising the basement of

natural regions D11 (Réservoir Manicouagan basin) and D5 (Lac Manouane depression). The effects of erosion have highlighted this difference, more visible during the Quaternary period, through the distribution of unconsolidated material left by glaciers in keeping with the pre-existing relief. This phenomenon has clearly resulted in distinctive regional characteristics (Table 3).

TABLE 2 . The natural provinces and regions of Québec*.

A Appalachian Mountains	H Grande Rivière low hills
A1 Appalachian complex of Estrie	H1 Upper Eastmain hills
A2 Appalachian complex of Beauce	H2 Opinaca hills
A3 Appalachian complex of the Lower St. Lawrence	H3 Lac Duncan plain
A4 Gaspé peninsula	H4 Grande Rivière depression
	H5 Grande rivière de la Baleine plateau
B St. Lawrence Lowlands	
B1 Upper St. Lawrence plain	I Northern Québec central plateau
B2 Middle St. Lawrence plain	I1 Lac Bienville plateau
C Southern Laurentian Mountains	I2 Lac Oiscotéo hills
C1 Dumoine plateau	I3 Reservoir de Caniapiscau depression
C2 Mont-Laurier depression	I4 Caniapiscau plateau
C3 Mont Tremblant highlands	I5 Lac Châteaugay plateau
C4 Lower Saint-Maurice hills	I6 Lac D'Iberville hills
C5 La Vérendrye depression	
C6 Lac Kempt terrace	J Ungava Peninsula
C7 La Tuque depression	J1 Lac à l'Eau Claire plateau
C8 Lac Jacques-Cartier highlands	J2 Lac Nedlouc plateau
C9 Chochocouane hills	J3 Lac Couture hills
C10 Parent plateau	J4 Lac Faribault plateau
C11 Windigo highlands	J5 Vachon plateau
C12 Réservoir Gouin depression	J6 Monts de Puvirnituq
	J7 Salluit plateau
D Central Laurentian Mountains	
D1 Saguenay Fjord	K Ungava Bay basin
D2 Lac Saint-Jean plain	K1 Lac aux Goélands depression
D3 Girardville hills	K2 Lac Champdoré depression
D4 Lac Péribonka hills	K3 Rivière à la Baleine lowlands
D5 Lac Manouane depression	K4 Labrador hills
D6 Manouanis highlands	K5 Lac aux Feuilles hills
D7 Monts Valin	K6 Lac Diana plateau
D8 Betsiamites plateau	
D9 Manicouagan plateau	
D10 Sainte-Marguerite plateau	
D11 Réservoir Manicouagan basin	
E Lower North Shore plateau	L Torngat Mountains
E1 Lac Magpie highlands	L1 George River upper plateau
E2 Lac Watshishou hills	L2 George River lower plateau
E3 Mécatina hills	L3 Torngat Mountains
E4 Middle Saint-Augustin hills	
E5 Upper Saint-Augustin plateau	X Gulf of St. Lawrence
E6 Petit Mécatina plateau	X1 Magdalen Islands
E7 Lac Brûlé plain	X2 Anticosti Island
E8 Lac Fournier plateau	
F Abitibi and James Bay lowlands	
F1 Lac Témiscamingue lowlands	X3 St. Lawrence River
F2 Abitibi plain	X4 Golf of St. Lawrence (Honguedo Strait)
F3 Matagami depression	X5 Golf of St. Lawrence (Magdalen Islands)
F4 Turgeon plain	X6 Golf of St. Lawrence (north shore)
F5 Lower Rupert plain	
F6 James Bay littoral plain	
G Mistassini highlands	
G1 Lac Mégiscane hills	
G2 Chibougamau depression	
G3 Upper Rupert plateau	
G4 Lac Mistassini	
G5 Monts Otish	

* The French toponyms have been approved by the Québec Commission de toponymie.



The natural provinces

- G: Mistassini highlands
- D: Central Laurentian Mountains

The natural regions

- D5 Lac Manouane depression
- D6 Manouanis highlands
- D11 Réservoir Manicouagan basin

FIGURE 6 . Limits among natural regions D5, D6 and D11.

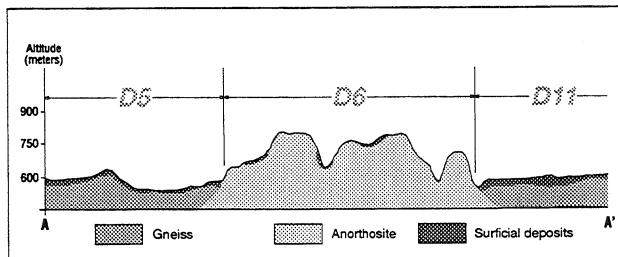


FIGURE 7 . Simplified geological cross-section of natural regions D5, D6 and D11. (D5 Lac Manouane depression, D6 Manouanis highlands, D11 Réservoir Manicouagan basin).

TABLE 3 . Basic characteristics of natural regions D5, D6 and D11.

Basic characteristics	Lac Manouane depression	Manouanis highlands	Réservoir Manicouagan basin
Petrography	Gneiss	Anorthosite	Gneiss
Relief	Low hills + plain	High hills	Low hills
Regional climate	Large valleys	Embedded valleys	Large valleys
River level	Homogeneous	Variable	Homogeneous
Lake density	Level 2	Level 1	Level 2
	High	Low	Average
Dominant deposit	Glacial and glacioluvial	Glacial	Glacial and glacioluvial
Deposit thickness	Thick	Veneer	Thick
Drainage	Moderate to poor	Excessive to rapid	Moderate

The general definition of natural regions applies to all but a few cases. In the natural lowland provinces (St. Lawrence Lowlands and Abitibi and James Bay Lowlands), the Quaternary can be key to understanding large-scale regional spatial structures. This is the case, for instance, in the differentiation of natural regions F5 (Lower Rupert plain) and F6 (James Bay littoral plain). Satellite imagery (Figure 8), vertical aerial photographs (Figure 9) and a simplified profile section show the differences in the spatial organization of these two natural regions, which also boast their own distinctive features (Table 4).

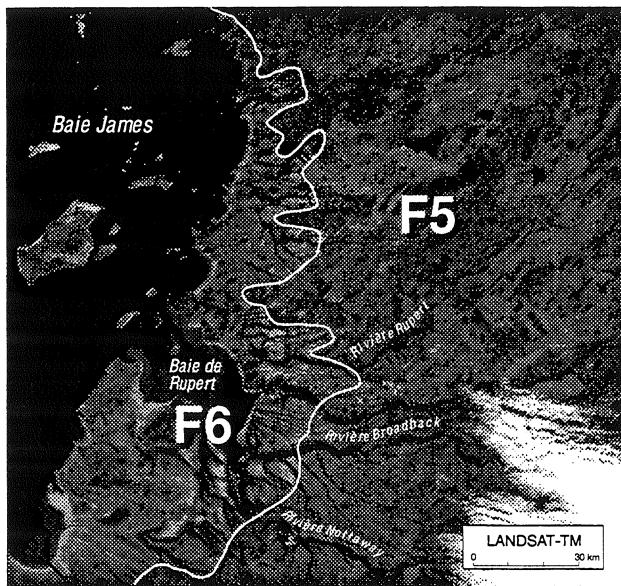


FIGURE 8 . Limit between natural regions F5 and F6. (F5 Lower Rupert plain, F6 James Bay littoral plain).

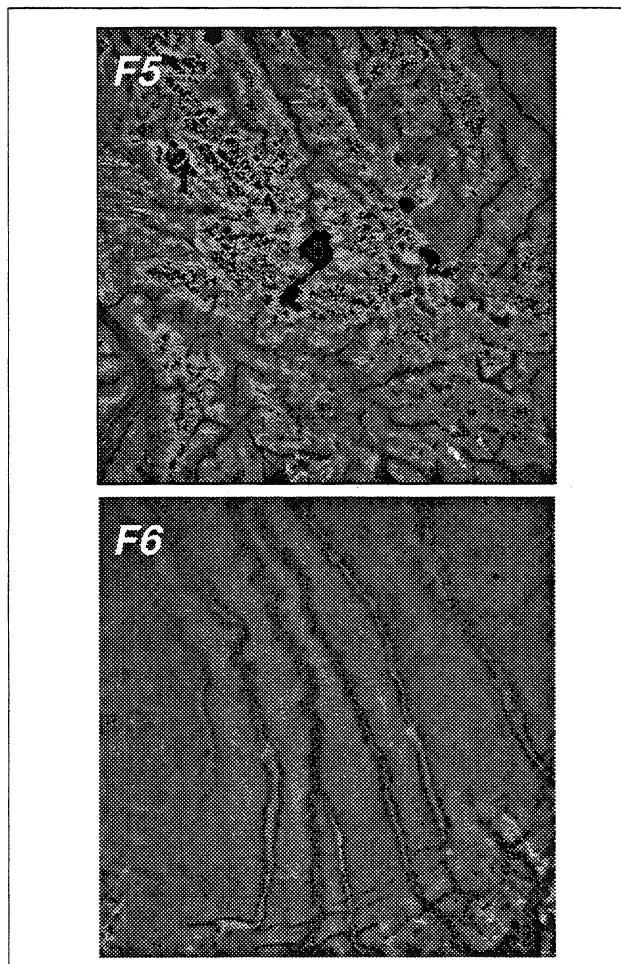


FIGURE 9 . Vertical aerial photography of natural regions F5 and F6. (F5 Lower Rupert plain, F6 James Bay littoral plain).

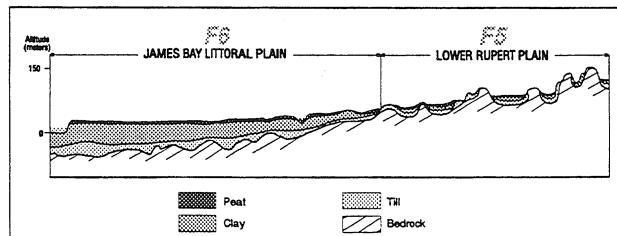


FIGURE 10 . Simplified topographic profile of natural regions F5 and F6. (F5 Lower Rupert plain, F6 James Bay littoral plain).

TABLE 4 . Basic characteristics of natural regions F5 and F6.

Natural Region	James Bay littoral plain	Lower Rupert plain
Drainage pattern	Parallel	Dendritic
Relief	Flat	Rolling
Surficial deposit	Peat-clay	Peat-clay-till
Vegetation cover	Peat bog-marsh	Peat bog-forest
% peat bog cover	70%	50%
Dominant type of peat bog	Rich	Poor
Diversity of peat bogs	High	Low
Potential for waterfowl	High	Low
Conservation potential	High	Average

CONCLUSION

Natural provinces and natural regions are higher-level, concrete spatial entities. Geology plays a key role in their identification, being the genetic ecological variable that determines the small-scale spatial organization of the landscape. The map of natural provinces and regions is by no means a geological map, since geology serves primarily to help us understand the spatial structures, relief, hydrography, climatic variations, and soil distribution which combine to create a unique vegetation and wildlife pattern and, consequently, determine the ecosystem's function. Based on this knowledge, it is possible to establish the land capability and potential and environmental sensitivity of each spatial unit, as well as an ecological diversity index.

In future, natural regions should become the preferred spatial reference framework for environmental data bases in Québec. The level of perception for natural provinces has already been correlated with the federal project on terrestrial ecozones and ecoregions of Canada (Ecological Stratification Working Group, 1993), serving as the spatial reference framework for Québec.

Delineation of natural regions is being finalized, although no significant changes in the continental portion are planned.

However, the natural regions of the St. Lawrence gulf and estuary natural province will be revised during 1994-1995 based on the work carried out by the federal/provincial working group under the biodiversity component of the St. Lawrence Vision 2000 agreement. The group's mandate is to propose small-scale regionalization of the St. Lawrence.

At the same time, we will be putting in place a process enabling systematic description of the natural provinces and regions.

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