Geological Mapping in the Canadian Shield: Implications for RADARSAT-2

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Abstract

Recent results have shown that RADARSAT-1 images have provided geologists with useful information in mapping structure and geomorphology and rock units in vegetated and non-vegetated terrains. In this paper, we evaluate the role of the additional capabilities planned for RADARSAT-2 for geological mapping in a typical Precambrian Shield terrain. Specifically, this involves the role of high resolution and polarimetric data for mapping outcrops and other geological features. For this evaluation, we have acquired two airborne high-resolution polarimetric SAR data set in the Madawaska Highlands area of Ontario. The areas are typical "Canadian Shield terrains" and consist of 10-30% Precambrian outcrops, variable thickness of drift cover and a dense to sparse forest cover. The imagery was acquired to simulate RADARSAT-2 Ultra Fine modes using the Environment Canada CV-580 C-band SAR system originally developed by CCRS. Our initial results show that in vegetated areas, the improved spatial resolution of RADARSAT-2 will be more useful for geological mapping than the polarization capability. However, we are finding that the polarimetric composites are providing additional details in lineament definition in some areas. The reason for this is not clearly understood.

Introduction

Current civilian satellite radar such as ERS-2 and RADARSAT-1 are single band, single polarization Synthetic Aperture Radar (SAR). The next generation of spaceborne SAR sensors (ENVISAT, RADARSAT-2) currently planned will carry multi-resolution, multi-incidence, multi-polarization and possibly multi-bands systems. The latest SIR-C mission (Jordan *et al*., 1995) and several airborne studies have demonstrated the enhanced capabilities of these sensors for geological studies. RADARSAT-2 currently being engineered is to be launched by the end of 2002. In addition to the current RADARSAT-1 acquisition beams and modes, RADARSAT-2, will propose greater flexibility through several innovations such as high-resolution modes, polarimetric capabilities, right or left of orbit track acquisition and a faster response time.
Assuming that the airborne data can properly simulate the resolution, polarization capabilities and incidence angle that will be available from RADARSAT-2, this paper present a preview of what the user might be expecting from RADARSAT-2 for geological applications in the environment of the forested Canadian Shield.

Much studies have been done for geological mapping in arid environment (Evans, D.L., et al., 1986) or for forestry applications (Ahern, F.J., *et al*., 1996). Rheault *et al*. (1998), presented some preliminary results concerning the evaluation of airborne polarimetric SAR data for lithological mapping and noted that although not clearly explained, the cross-polarized imagery showed a significant difference with the like polarized imagery. Saint-Jean *et al*., (1999a) again partly addressed the problem for the Lac Volant area and found that the crosspolarized image show an enhancement of certain lineaments directions attributed to a combined effect of land form and vegetation depolarisation. Until now, no extensive reference has been found on the usefulness of polarimetric imagery for geological applications or geo-morphological mapping in boreal forested environments.

Objectives
The objectives of the work are as follow:

- To document the differences between SAR images from RADARSAT-1 and RADARSAT-2 for geological applications,
- To conduct an initial evaluation of polarimetric SAR for geological applications in forested terrain in the Canadian Shield,
- To propose preliminary recommendations as to which polarizations has the most valuable information content for geological applications in PreCambrian vegetaed terrains.

Study areas

Two airborne C-band SAR and two RADARSAT-1 images were obtained from two areas of the Canadian Shield (figure 1). The first area is located in the Madawaska Highlands, an area located approximately 80 km W of Ottawa, to the S of Algonquin provincial park. For this test site, we used a 7.0 km by 8.6 km airborne polarimetric C-SAR sub-image and a Wide mode beam 1 RADARSAT-1 image.
The second area is located in the Lac Volant area, approximately 60 km NE of Sept-Îles, Quebec. For this test site, we used a 5.0 km by 5.0 km airborne polarimetric C-SAR sub-image and a Standard mode beam 6 RADARSAT-1 image.

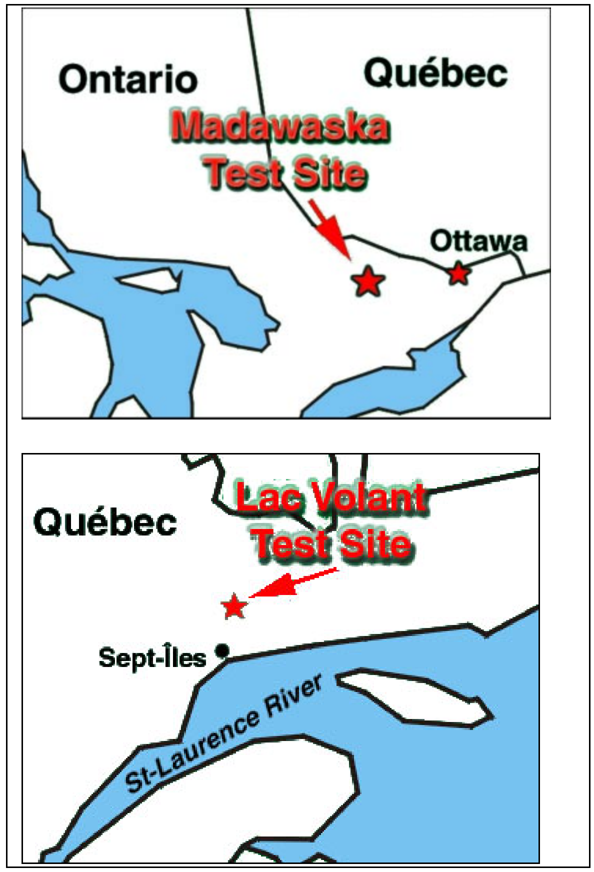

Figure 1. Location of the two test sites

Both sites were selected for their typical morphology representative of the Canadian Shield, for their relatively good rock exposure and for their uniform forested cover (both sites show very little human activities). The Madawaska Highlands site consist of an old dissected hilly plateau with an average altitude of 300 m and morphological features in the range of 100 - 150 m. The area is covered by a mixed forest. The Lac Volant area consists of a highly dissected plateau at an average altitude of 730 m and with morphological contrast in the range of 150 m. The area is covered by a relatively uniform vegetation cover, the main species being Black spruce (*Picea mariana*), Balsam fir (*Abies balsamea*) and Jack pine (*Pinus banksiana*). Outcrop exposure is important (10%).

The rocks of the Madawaska highlands surrounding the test site belong to the Hastings group of the Grenville geological province. The rocks consist mostly of pink and white leuco-granite; granite and alaskite interspersed with gabbros and hornblendite and overlaying the amphibolite, hornblende-plagioclase gneiss of the paragneiss-amphibolite group of the Grenville Series (Hewitt, 1953). The rocks often show a high intensity metamorphism to the facies of the amphibolite and granulite (Douglas and Tremblay, 1972). Some old mining activity is reported in the northern sector of the test site where several pits were dug for molybdenum mineralisations. Glacial sediment cover is thin leading to important outcrops surfaces.

The rocks of the Lac Volant area belong to the allochtonous polycyclic belt of the Grenville geological province. The rocks consist of fine grained gabbronorite, mangerite, monzonite and granite of the Matamec Igneous Complex underlain by gneiss and granitic gneiss of the Manitou Gneiss complex (Perrault *et al*., 1997). The area was highlighted by the discovery in 1996 of a Ni mineralized showing just SE of Lac Volant.

Data

Table 1 summarizes the acquisition parameters for both the airborne flights and the RADARSAT-1 images. Table 2 presents a brief overview of the new acquisition modes that will be available with RADARSAT-2 (CCRS, 1998; MDA, 1999).

The airborne C-SAR multipolarized data is used as a basis for this study. Figure 2 and 3 show the Airborne C-SAR and RADARSAT-1 imagery covering both test sites.

Table 1. Acquisition parameters for SAR imagery

	RADARSAT-1	**Airborne C-SAR**
Frequency / Wavelength / Band	5.30 GHz, 5.66 cm, C-Band	5.30 GHz, 5.66 cm, C-Band
Polarization	HH	HH, HV, VH, VV
Number of looks (nominal)	4	7
Sensor elevation	796 km	6.5 km
MADAWASKA, On.		
Acquisition date	August 14, 1997	June 30, 1999
Trajectory, Illumination	N352°, N82° (ascending)	N106°, N16°
Incidence angle (near, far range)	20°, 31°	45°, 76°
Mode, Resolution	W1, 30 m	Narrow, 6 m
Simulated RADARSAT-2 mode	W1	Ultra Fine
LAC VOLANT, Qc.		
Acquisition date	August 3, 1996	February 25, 1997
Trajectory, Illumination	N352°, N82° (ascending)	N62°, N152°
Incidence angle (near, far range)	30°, 37°	45°, 76°
Mode, Resolution	S6, 25 m	Narrow, 6 m
Simulated RADARSAT-2 mode	S6	Ultra Fine

Table 2. Acquisition parameters for RADARSAT-2

Parameters	**RADARSAT-2**
Orbital characteristics	Similar to RADARSAT-1
Imaging modes	Similar to RADARSAT-1 **plus** Fine mode, 3 looks Ultra Fine Large mode, 1 look, 3 m resolution, 20 km swath Ultra Fine Narrow mode, 1 look, 3 m resolution, 10 km swath
Look direction	Similar to RADARSAT-1 (right of orbit) **or** left of orbit
Polarization	Similar to RADARSAT-1 (HH) **plus** HV, VH and VV (Selective single polarization transmit H or V receive H or V) for all modes. Dual polarization transmit H and V on alternate pulses, receive H and V on any pulse (fully polarimetric dataset) available for Standard and Fine modes.

Notes:

- The RADARSAT-1 and the airborne C-SAR data do not have the same illumination direction. This particularity can explain some selective feature enhancement observed on the images.
- The resolution indicated for the airborne C-SAR (6 m) data approximates the resolution that will be available for RADARSAT-2 Ultra Fine modes (4 m). This difference can somewhat be compensated by the higher number of looks of the airborne C-SAR (7 looks) compared to RADARSAT-2 Ultra Fine modes (1 look).
- The VH and HV polarizations are usually considered reciprocal (almost identical). Therefore, we use indifferently one or the other.
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Discussion

For each of the two test sites, we will look at the resolution and polarization images and analyse each dataset to establish the relevance of the intrinsic information content.

Resolution

Resolution is probably the most important improvement to the data. In geology, the synoptic view available to the user through large swath modes is very useful to regional mapping survey but often, geologist need to focus on a specific area. The Ultra Fine (Narrow and Large) modes, with its 3 m resolution at 1 look will provide a tool suitable to depict morphological features which can be of interest to the mapping geologist. It is clear that a large number of fine lineaments can be mapped on the high resolution image that cannot be seen on the RADARSAT-1 image with the only drawback that the high resolution image cannot give the synoptic view.

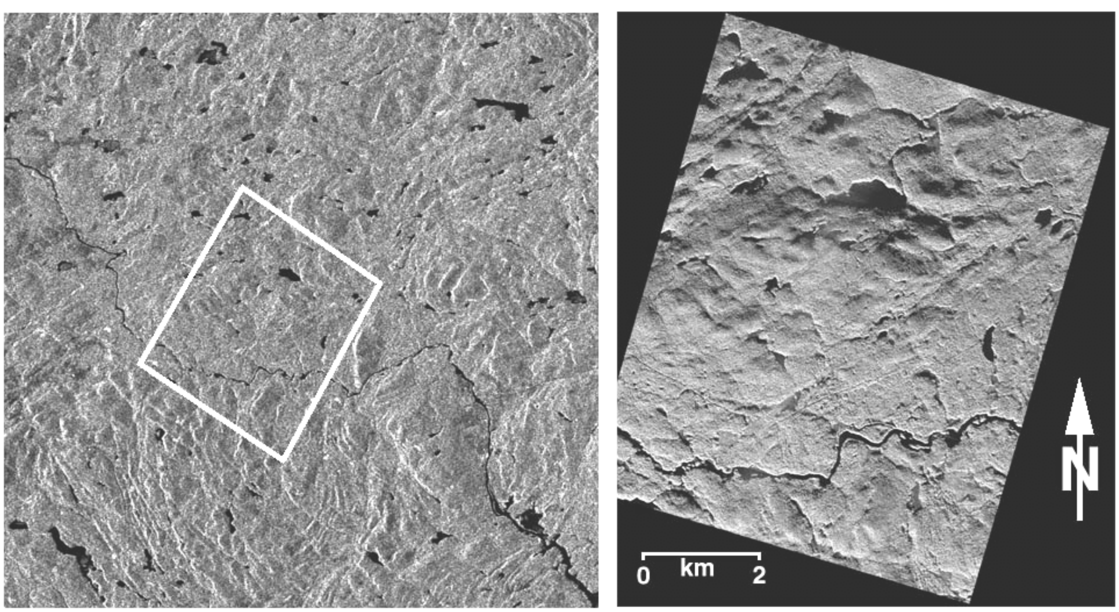

Figure 2. Left: RADARSAT-1 W1 of the Madawaska Highlands area. The white square indicates the area show at right. Right: Airborne C-SAR. RADARSAT-1 imagery is © Canadian Space Agency, 1997.

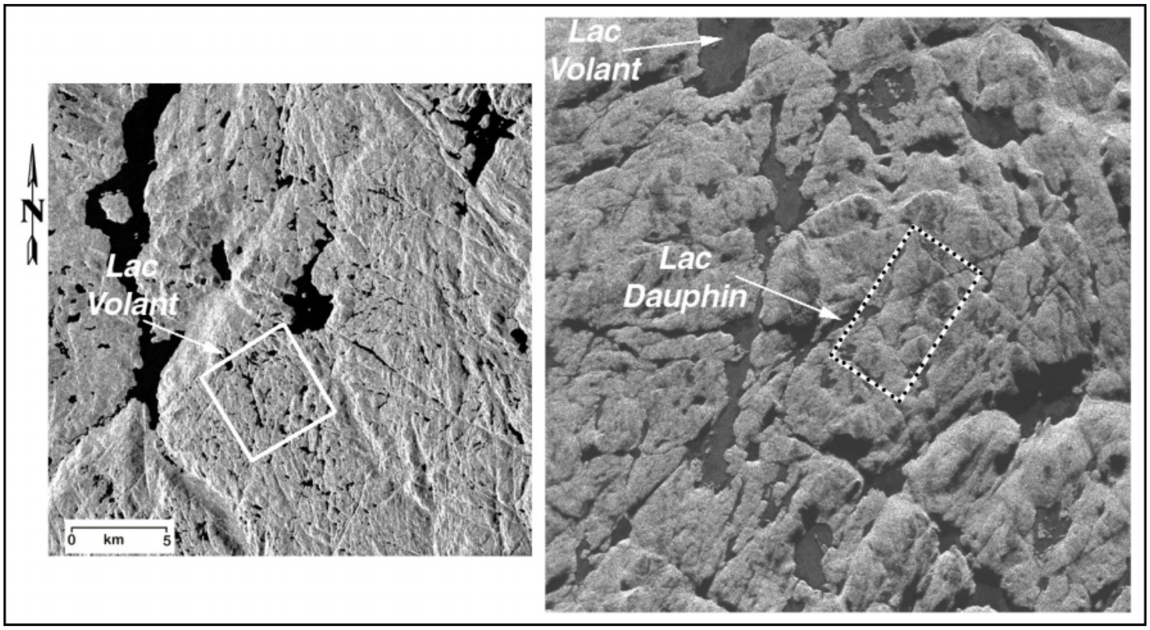

Figure 3. Left: RADARSAT-1 S6 of the Lac Volant area.The white square indicates the area show at right. Right: Airborne C-SAR. RADARSAT-1 imagery is © Canadian Space Agency, 1996.

Figure 4 shows the three polarizations full resolution images and the corresponding RADARSAT-1 image of the Madawaska test site. Several short lineaments can easily be mapped along the NNW trend. The lack of synoptic view does not permit to see very clearly the main lineament of the area, the Madawaska fault that crosses the area in an E-W direction in the lower part of the image although this fault is almost perpendicular to the illumination direction. Although several lineaments can be mapped, it is difficult to classify them according to their importance. Because of its coarser resolution, the RADARSAT-1 image shows only the major features. Although vegetation cover is uniform over the area, the image texture is rich indicating that a meaningful lithotextural information is available.

Figure 5 presents the three polarizations full resolution images and the corresponding RADARSAT-1 image of the Lac Volant area. On the high resolution imagery, lineaments oriented NE and NNW are the most obvious. The RADARSAT-1 image shows only some sections of the NNW lineaments (perpendicular to illumination direction) while the other direction can only be guessed.

Polarization

On the Madawaska multipolarization airborne images (figures 4a, b and c), the difference in the various polarisation images are very subtle. In fact, polarisation differences are mostly noticeable in swampy areas where they outline variations in vegetation type. No lineaments or lithological features are preferably enhanced by any specific polarisation.

On the Lac Volant quad-pol images, the crosspolarized image show a distinct enhancement of lineaments oriented NNW and E-SE. This enhancement was interpreted to be resulting from a combined effect of land form and vegetation depolarisation effect (Saint-Jean *et al*., 1999a). We were expecting a directional enhancement of lineaments on the Madawaska quad-pol images. Several reasons may explain the differences on the Lac Volant crosspolarized images and its absence on the Madawaska images. First, the terrain morphology is different, slopes

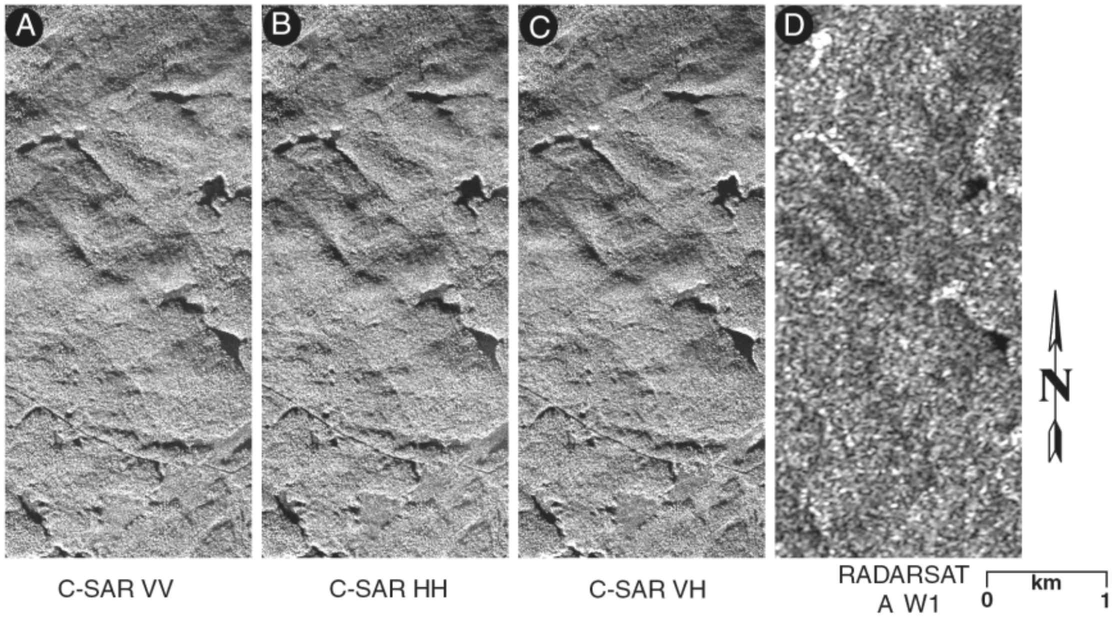

Figure 4. (a, b, c) Airborne polarimetric C-SAR image and (d) RADARSAT image of the Madawaska Highlands. RADARSAT-1 imagery is © Canadian Space Agency, 1997.

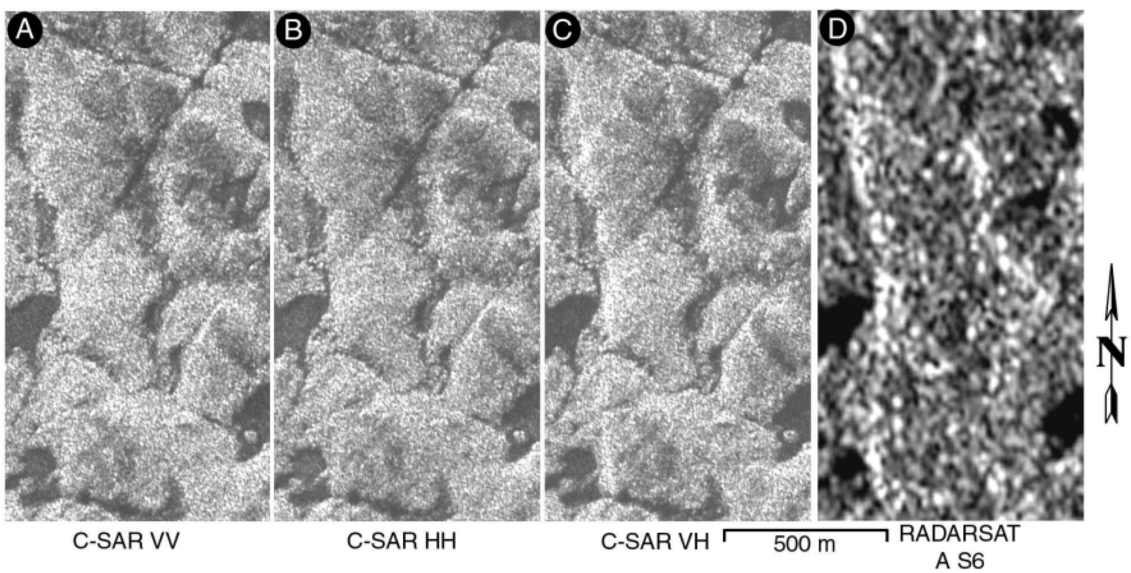

Figure 5. (a, b, c) Airborne polarimetric C-SAR image and (d) RADARSAT image of the Lac Volant area. RADARSAT-1 imagery is © Canadian Space Agency, 1996.

being more abrupt in the Lac Volant area, may product a more effective corner reflector. Second differences in vegetation architecture may produce a depolarization of the signal that is significantly different on either site. Third, the Lac Volant image was acquired during the winter while the dielectric properties of the vegetation are significantly different from those that prevail in summer conditions.

Conclusion

This initial evaluation has shown the following:

- The spatial resolution of the new sensor will improve the interpretability of RADARSAT-2 for geological mapping, particularly in the delineation of detailed lineaments in some areas, and in the definition of lithotextural units.
- No significant differences are observed on the HH and VV polarization images. The crosspolarized VH (and HV) polarization images show details in lineament enhancement on the Lac Volant image but no such enhancement has been observed on the Madawaska images
- The new Ultra Fine modes will provide an excellent mapping tool at a more local scale but the larger swaths imaging modes will still provide a more synoptic view that is useful to provide a more regional understanding of the geology.
- We have demonstrated here that the simulation of RADARSAT-2 Ultra Fine modes will permit a detailed mapping of lineaments.

These results clearly demonstrate that more research is needed to explore the capabilities of high resolution and polarimetric SAR for geological mapping in these environments.

Acknowledgements

The authors wish to thank MIR Télédétection Inc, who provided the airborne C-SAR imagery of the Lac Volant test site.

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