EFFECTS OF RELIEF ON THE SELECTION OF RADARSAT-1 INCIDENCE ANGLE FOR GEOLOGICAL APPLICATIONS

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ABSTRACT

Our research presents some guidelines for the selection of the various RADARSAT-1 incidence angles for geological applications. The study areas were selected to represent different terrain types and surfaces both in Canada and around the world. The terrain types represented include: high relief, rugged, forested, mountainous environments (Hope, BC; China), moderate to high relief environments (Cape Breton Highlands, N.S.), moderate relief environments, glaciated, forested Precambrian Shield terrains (Geraldton, ON; Sudbury, ON; Whitecourt, AB), and low relief environments, partly vegetated, flat to rolling prairie landscapes (Morden, MN; Jordan).

Our results show that the selection of the most useful RADARSAT-1 viewing geometry is application and site specific. Significant difference exists in the interpretability of geological structure, lithological units, landform and terrain types depending on the incidence angle chosen for image acquisition. In low relief environments, small incidence angles (10 to 25 degrees from vertical) will produce the maximum relief enhancement, but larger incidence angles (25 to 59 degrees) will also result in acceptable terrain rendition by increasing the terrain textural contrasts. In moderate relief environments, small to intermediate incidence angles (20 to 35 degrees) are suitable since they produce a good topographical enhancement. In high relief environments, intermediate to large incidence angles (35 to 59 degrees) are recommended to reduce geometric distortion and minimise shadow effects.

Keywords: ADRO 510, RADARSAT-1 beam selection, surface morphology, geological structure, geology

1. Introduction

One of the main advantages of radar as a remote sensing technique is that it permits control of illumination, unlike passive methods that depend, for example on sunlight. The incidence angle, polarization, frequency, and usually the illumination azimuth can be chosen for optimum effectiveness in various applications. In the paper, we discuss the effects of incidence angle on geologic mapping of orbital radar, using examples from RADARSAT-1.

Incidence angle as used here refers to the angle from the vertical to the radar beam. The effect of incidence angle on radar backscatter cannot be discussed without including the effect of target roughness. Ford *et al*. (1989) and others has shown that the effect of incidence angle on backscatter decreases with target roughness. We will present examples of this behaviour, although our discussion will concentrate on incidence angle effects.

The effects of SAR viewing geometry for geological mapping are significant, because the effects of terrain and surface roughness on RADARSAT-1 backscatter vary with different viewing geometry. Geologists identify structures and landforms from changes in topography and textural patterns. In barren environments, surficial materials and rock types are identified by their surface roughness characteristics

(Budkewitsch *et al*., 1997). The different ways the SAR views the terrain naturally affects the geological interpretation in terms of the delineation of geological structures, surficial materials, rock units and landforms.

Recently, the Canada Centre for Remote Sensing (CCRS) has investigated the use of airborne and spaceborne Synthetic Aperture Radar (SAR) images for structural, lithological and geomorphologic mapping in various terrains in Canada and abroad (Lowman, 1994; Rivard *et al*., 1994; Saint-Jean *et al*., 1995; Saint-Jean and Singhroy, 1997; Singhroy, 1996; Singhroy *et al*., 1992, 1993; Warner *et al*., 1996). These studies have focused on evaluating the relative benefits of the viewing geometry of CCRS airborne SAR, ERS-1, JERS-1 and RADARSAT-1 for geologic mapping. Results have shown that the SAR viewing geometry and surface cover affect the delineation of geological structures, surficial materials, lithological units and landforms. In addition, Ahern and Raney (1993) have shown that the effects of terrain slope on SAR backscatter are significant with different viewing geometry.

RADARSAT-1 offers 35 different beam-mode combinations, with incidence angles ranging from 10 to 59 degrees, and spatial resolution varying from 10 to 100 m. In order to maximize its use, it is necessary to evaluate the various "beam-mode" combinations and determine their suitability for geological and geomorphological mapping. This investigation provides some general guidelines for the selection of the optimal configuration of RADARSAT-1's products for representative geological terrains.

2. *Study Areas*

The study areas were selected to represent different terrain types and surfaces around the world (Fig. 1). The terrain types represent high, moderate and low relief in forested to arid environments. They are:

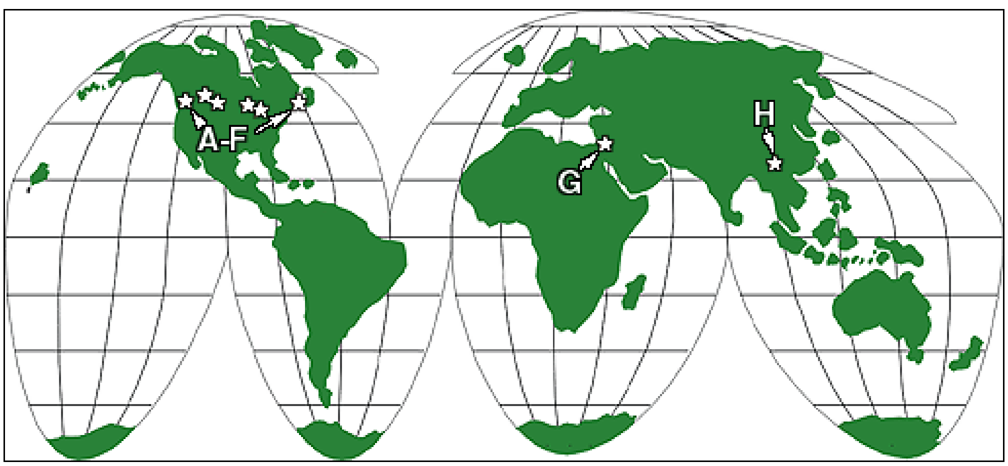

Figure 1. Location of the test sites: Hope, BC (A); Whitecourt, AB (B); Morden, MB (C); Geraldton, ON (D); Sudbury, ON (E); Cape Breton Island, NS (F); Azraq, Jordan (G) and; Jin Shajiang river, China (H).

- The rugged mountainous forested terrains in the Fraser valley, north of the city of Hope, BC. in the Canadian Cordillera and of the Jin Shajiang river area in China;
- The moderate-high topography forested terrains of the Cape Breton Highlands, NS. where Precambrian crystalline rocks are overlain by Palaeozoic sedimentary rocks;
- The variable glaciated forested and moderate relief of the Canadian Shield in the Geraldton – Beardmore greenstone belt and the Sudbury mining area, both sites located in Ontario and

having a surficial morphology typical of the Canadian Shield. The forested, rolling topography environment of Whitecourt, Alberta, in the foothills of the Canadian Rockies;

- The low terrain rolling relief of the Morden area of SW Manitoba and the flat arid environment of the Azraq area in eastern Jordan.

The Fraser Valley in the Canadian Cordillera is one of the most strategically important transportation corridors in Canada. The significance of selecting this area is the occurrence of active landslides, and the increasing need to develop remote sensing techniques for improved geological hazard mapping in mountainous terrains. The purpose of the study was to select the most suitable RADARSAT-1 image to characterize landslide features and fracture systems on the steep mountain slopes. The Jin Shajiang river area in Southern China comprises rocks of Precambrian age but this area is subject to important slope instability. The interest of this study site lies in the use of RADARSAT-1 imagery for the mapping of landslide features in the vicinity of the large Three Gorges hydroelectric project in China.

The Cape Breton Highlands contain one of the largest segments of crystalline Protaerozoic and Palaeozoic rocks in the Atlantic Canadian section of the Appalachian Mountain belt. The RADARSAT-1 images were used to support geological mapping done by the Geological Survey of Canada.

The Geraldton area in northern Ontario is a greenstone belt hosting several mineral deposits of economic importance. RADARSAT-1 data were acquired in this area to support ongoing detailed geological mapping and mining exploration programs. The Sudbury area is a well-known base metal mining area in Canada. These forested terrains are highly representative of the Canadian Shield and represent good test sites for geological mapping as described by Lowman, 1994; Singhroy *et al*., 1993; Mustard, 1994; Harris *et al*., 1994. The morphology of the sites consists of old rocky rolling surfaces where structures and lithologies are well exposed. Depressions are covered by glacial and periglacial deposits. RADARSAT-1 was used to assist in the mapping of glacial landforms, surficial deposits and geological structures. Whitecourt is located in the foothills of the Canadian Rockies. This site was selected for its characteristic morphology of rolling topography that is locally dissected by drainage.

The Morden area is located within the Lake Agassiz plain in Manitoba. The area is flat and gently rises to the Pembina hills, west of Morden. The area is typically agricultural, with a forest cover on the slopes of the streams, which flows from Pembina hills to the Agassiz Lake plain. This site was selected to support current surficial geological mapping in the region. Finally, the Azraq area in eastern Jordan where the test site is located in an arid environment. The vegetation is scarce and rock exposure is good. Geology consists of young volcanic flows, dolomitic cherty limestone and silty limestone covered by recent alluvial deposits.

3. Discussion

Several RADARSAT-1 images with different viewing geometry were evaluated. An interpretation of the RADARSAT-1 image in relation to viewing geometry is briefly described for each test site. Figure 2 shows a simplistic model that can be used to guide the selection of RADARSAT-1 beam and modes for geological mapping. For the most part the RADARSAT-1 images were interpreted for surficial geological mapping. From this figure, it is clear that orthogonal viewing, which is determined by the local slope, is the most suitable for geological mapping.

Mountainous terrains

Figure 3 shows a comparison of Standard beam mode, S1 (20-27º), and an Extended high beam mode, EH6 (57-59º). It is clear that the landslide features and faults on the steep slopes of the Fraser valley are more easily recognized on the EH6 images than from the S1 image. The eastern slopes where most of the slides are occurring have a local slope which vary from 40-60º, and as such are suitable for RADARSAT-

1 viewing at the higher angles between 40 and 60 degrees. From the EH6 image, block slide scarps and transverse ridges, associated with rock slumps and faults were identified. On the image, block slides (1) are characterized by a number of parallel fault blocks, and steps. The rock slumps are characterized by numerous closely spaced arcuate and transverse ridges (2) with considerable rock exposure and sparse vegetation. Slide scarp (3) appear as light tone areas on steep convex slopes. Faults associated with slides appear as arrows and show linear depressions on the image. The advantage of identifying the characteristic landslide features is that they provide clues on the nature of motion and therefore identify potential hazards along transportation routes and can indicate where protective measures should be made.

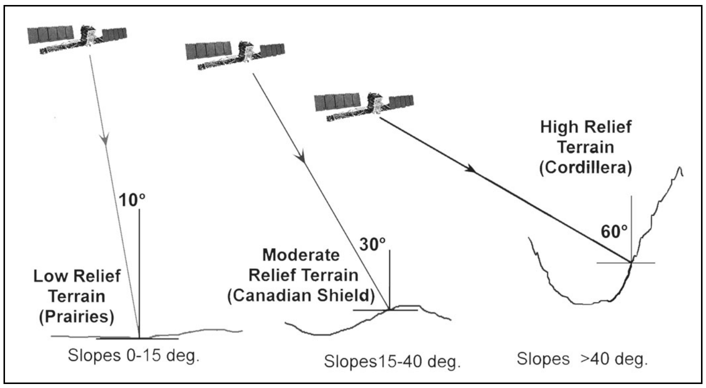

Figure 2. General model for RADARSAT-1 preferred incidence angle for geological applications.

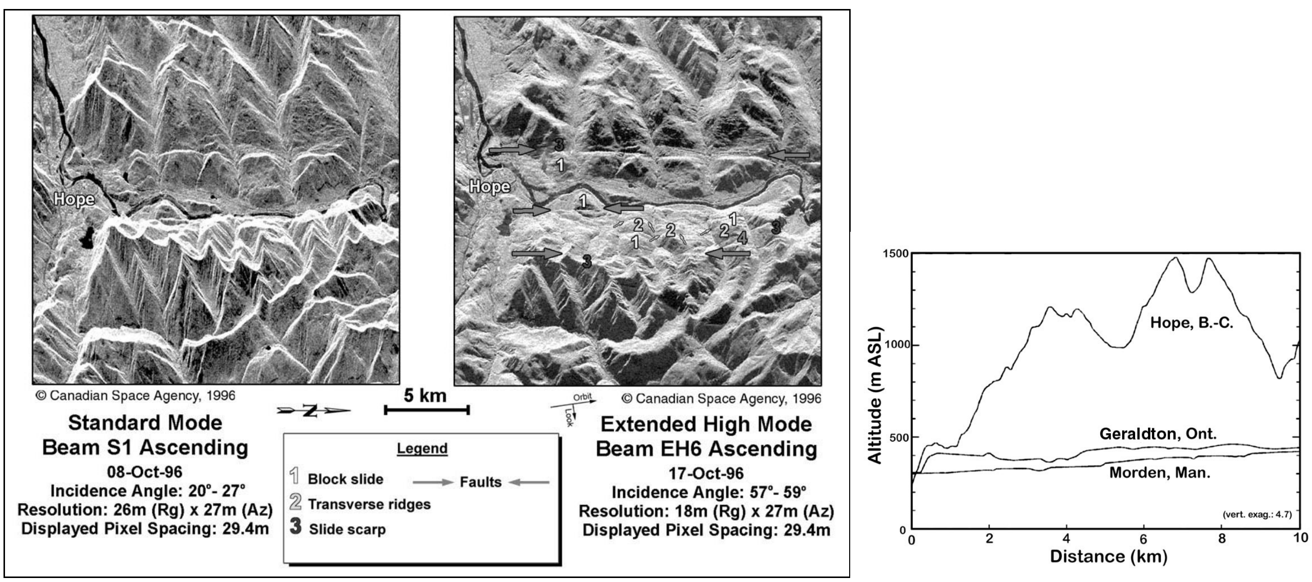

Figure 3. The Fraser valley test site and topographic comparison with the other test sites.

In comparison, the S1 image with its steep viewing geometry resulted in considerable layover, which restricts interpretation of landslide features. Figure 4 shows a RADARSAT-1 Fine mode beam 3 image of the high relief of the Jin Shajiang river area in southern China, where many landslides were mapped. The image shows several landslides, rockslides and debris flows in the area. In this mountainous environment, an incidence angle of 41 to 44 degrees provides information on slope morphology and suitable spatial resolution while minimizing shadowing effects.

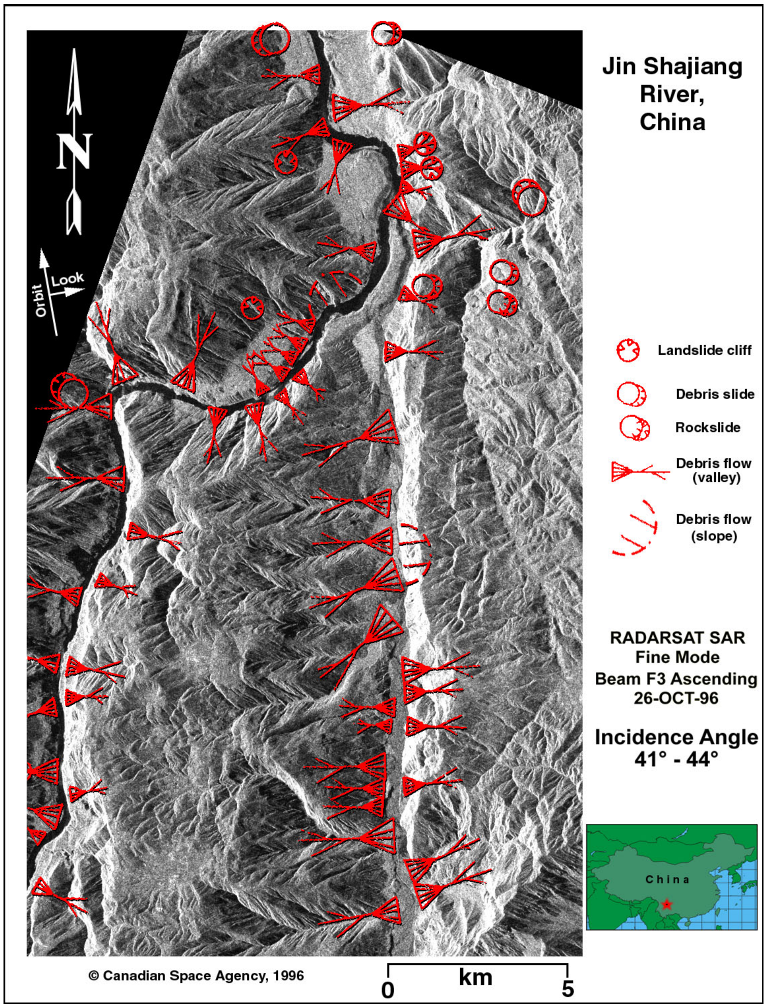

Figure 4. Jin Shajiang test site in China

Moderate-high relief terrains

Figure 5 shows a part of Cape Breton Highlands where the steeper incidence angles (20-27º) S1 image is more suitable for delineating structural and geomorphic features than the shallow incidence angles (45-49º) S7 image. The terrain slope varies from 25-35 degrees, and so the steeper incidence angles are more suitable. For instance, fold systems associated with sedimentary sequences, drainage patterns, the major NE - SW trending Aspy fault and other similar fault systems are more easily recognized on the S1 image than on the S7 RADARSAT-1 image. Using this information, we produced a series of integrated image map at 1:250 000 of the Cape Breton Highlands (Hetu and Singhroy, 1998).

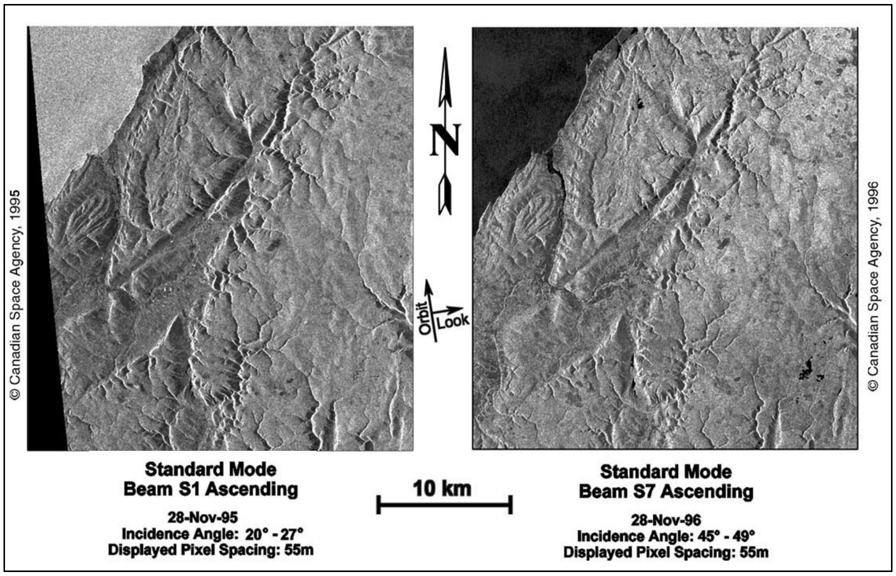

Figure 5. The Cape Breton Island test site in Nova Scotia

Moderate relief terrains

The Geraldton area (fig. 6) has a local slope that varies from 10 to 35 degrees with sharp breaks in the terrain produced by differential erosion. If acquired with the appropriate illumination geometry, imaging radar can provide exceptionally good renditions of topographic variations over large areas, hence its usefulness in the delineation of topographically expressed structures and regional glacial features. In vegetated environments, the SAR backscatter is primarily from the canopy of the boreal forest cover. Topographic variations are enhanced by the large number of steep but small breaks in the terrain. These breaks are very significant from a geological standpoint. They represent the slopes of glacial and linear features and edges of outcrops. RADARSAT-1 Standard mode beams 1 or 2 (incidence angle varying between 20-31º) are the most suitable to recognize geological features in most Canadian Shield terrains. It is clear that more linears and glacial features are recognised from the S2 image than from the S6. Although the S6 provides useful geological information, the S1 and S2 beams (20-31º), provide a better enhancement of surface morphology.

The Sudbury area (fig. 7) in the Canadian Shield, has a topography relatively similar to the Geraldton-Beardmore greenstone belt described above. The RADARSAT-1 S1 and S7 images presented here again demonstrate the greater topographical enhancement provided by a steeper incidence angle. In the same area shown on these images, Saint-Jean and Singhroy (1997) found that RADARSAT-1 Fine resolution mode, beams 1 and 5, provides a considerable amount of geomorphologic and structural information but there is little difference in geological information between F1 (37-40º) or F5 (45-48º).

The Whitecourt S1 imagery (figure 8, left side) shows a good morphological enhancement providing information for mapping surficial geology. The S7 image (right side) shows less morphological enhancement. However, the S7 imagery shows good contrast between forested and clear cut areas and is therefore more suitable for forestry applications.

Low relief terrains

In the Morden area in SW Manitoba, mapping for aggregate resources is ongoing by federal and provincial geological agencies (surficial geology is described in Elson, 1952). As shown in figure 9, both the RADARSAT-1 S2 (24-31 degrees) and the S7 (45-49 degrees) images are useful in the mapping of drainage patterns, strandlines of lake Agassiz and flow slides as seen on the slopes of the Pembina hills.

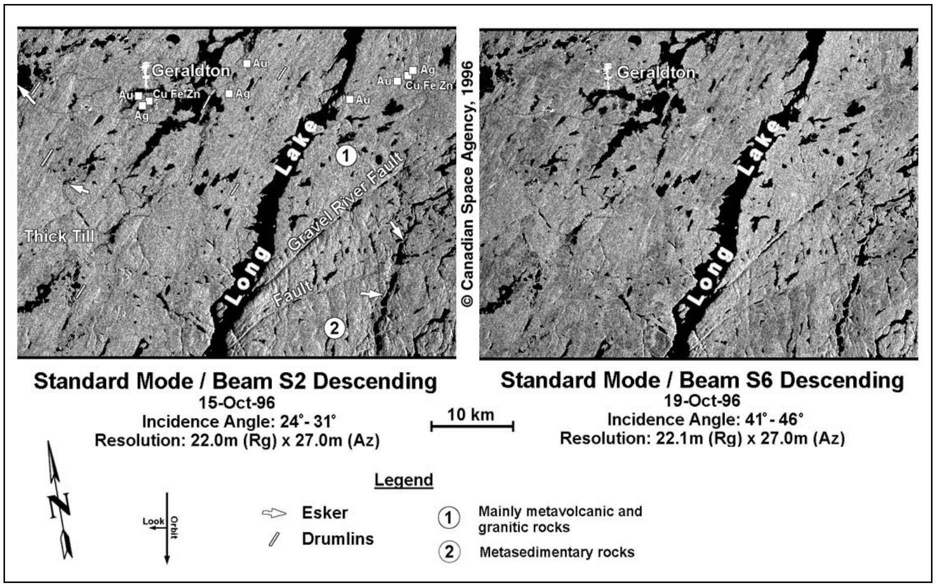

Figure 6. The Geraldton test site in Ontario

In this area, the local slope varies from 5 to 30 degrees, but unlike the Canadian Shield the topographic breaks are less abrupt and are enhanced by local landuse patterns. For this reason, differentRADARSAT-1 viewing geometries are useful for surficial geologic mapping. For example the S1 or S2 is suitable for the subtle topographic breaks and the S7 is suitable for surface roughness mapping in this case related to landuse. Because the geomorphology is related to landuse (vegetation associated with stream patterns and agriculture),

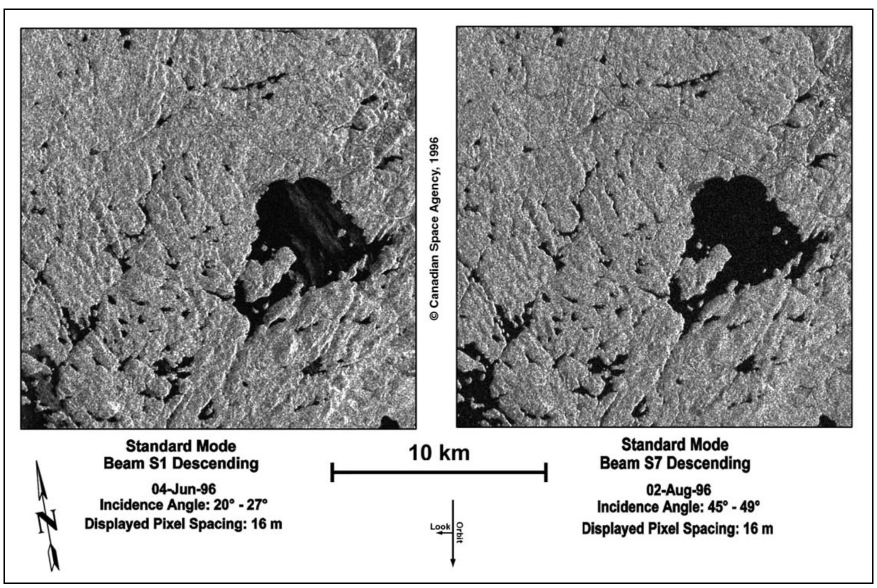

Figure 7. The Sudbury test site in Ontario

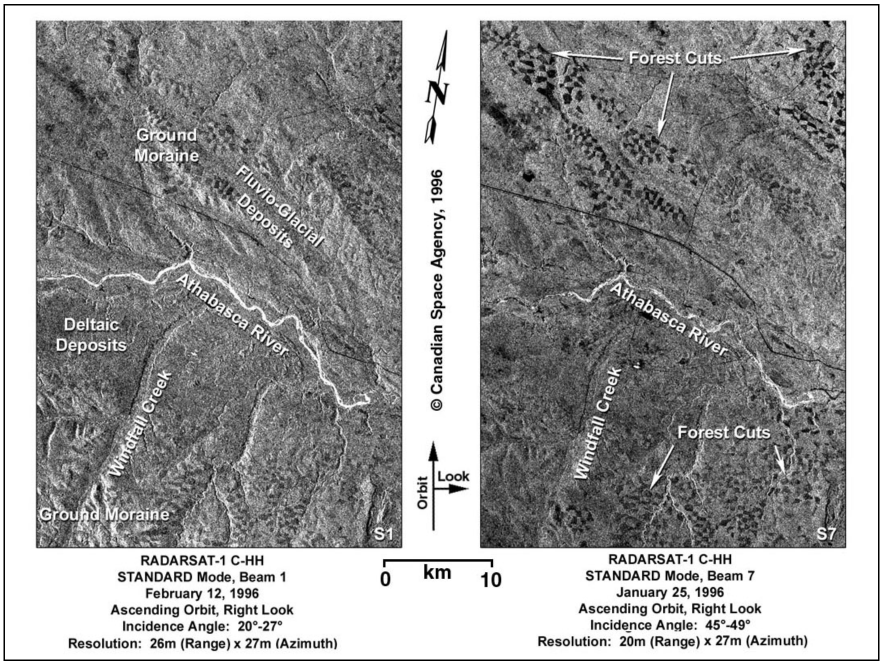

Figure 8. The Whitecourt test site in Alberta

the S7 appears to be a more useful image. Therefore in such low relief terrains the fine modes with higher resolutions as well as the wide modes will also be suitable for surficial geological mapping.

The S1 and S7 RADARSAT-1 imagery of eastern Jordan (fig. 10) are representative of a relatively flat area located in an arid environment. The S1 imagery gives a better enhancement of topographical features. In this area, since vegetation cover is relatively scarce, the surface roughness information provided by the S7 imagery is more useful for geological interpretation. The S7 imagery provides valuable information on drainage patterns that are controlled by underlying structural features.

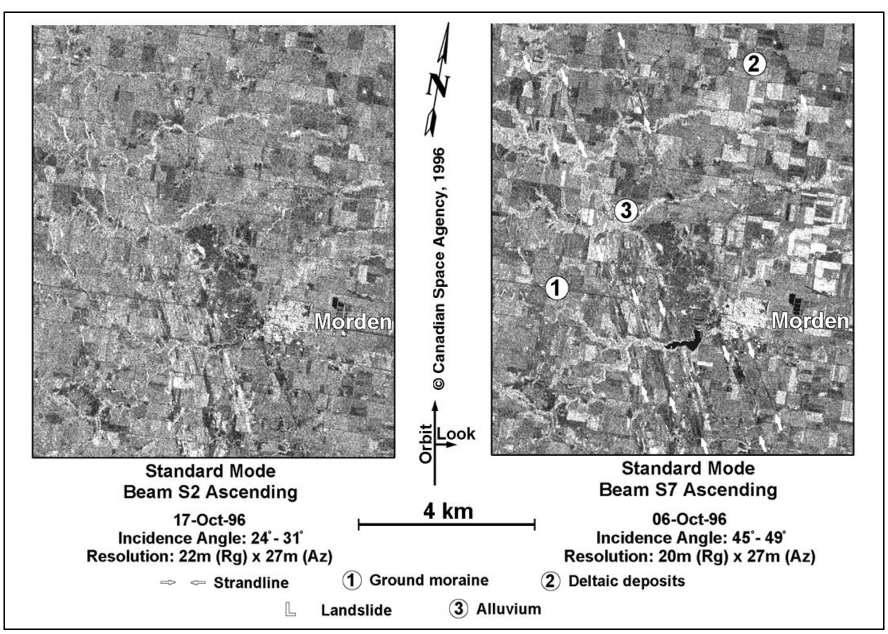

Figure 9. Morden test site in Manitoba

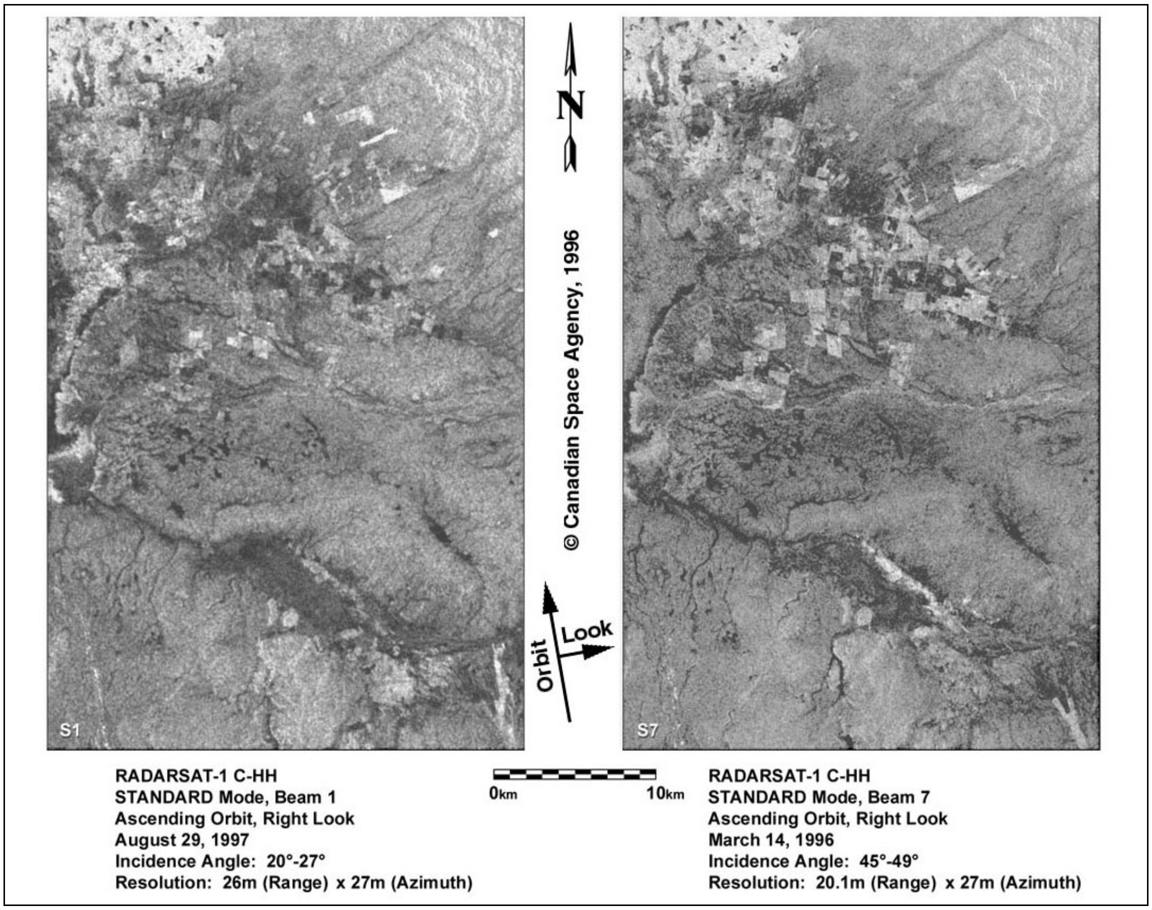

Figure 10. Azraq test site in Jordan

Stereo viewing

With the exception of stereo viewing, there are no strict guidelines for the use of ascending and descending mode for geological mapping. Their use is based on the direction of the structures and landforms needed to be interpreted. The maximum information is obtained only when the feature is perpendicular to the SAR viewing geometry. However, stereo viewing is a technique, which provides a better rendition of the geologic features than monoscopic (single) image interpretation. Depending on the nature of the application, the additional image needed for the stereo radar interpretation can be costly. D'Iorio *et al*., (1997) showed that the best results are obtained from same-side stereo (ascending / ascending or descending / descending) with large overlaps and stereo intersection angles (e.g. S1/S6 or S2/S7).

These recommended guidelines are based on variance in local topography. Therefore from an economic and practical stand point the three wide modes RADARSAT-1 images which provides a large range of incidence angles and a larger area coverage will be useful for geological mapping in both the low and moderate relief areas. Using the examples described above for the Standard modes the W1 (20-31 degrees) is suitable for shield terrains and all the wide modes W1, (20-31 degrees) W2 (31-39 degrees) and W3 (39-45 degrees) are useful for low prairie terrains.

4. Conclusion

The guidelines developed from this study can be of use in similar terrains outside Canada (see figure 11). The interpretation of several RADARSAT-1 beam modes and their uses to surficial geological mapping, and geohazard assessment in different Canadian terrains has shown the following.

- The delineation of geological structures, lithological units, landforms and terrain types are facilitated by using selected RADARSAT-1 incidence angles.
- In mountainous terrains, incidence angles varying from 40-59 degrees are suitable for structural and geomorphic mapping.
- Steep incidence angles, varying from 20-35 degrees, are suitable for moderate relief and the Precambrian Shield terrains.
- A wide range of incidence angles, varying from 25-45 degrees, is suitable for the flat and rolling prairies.

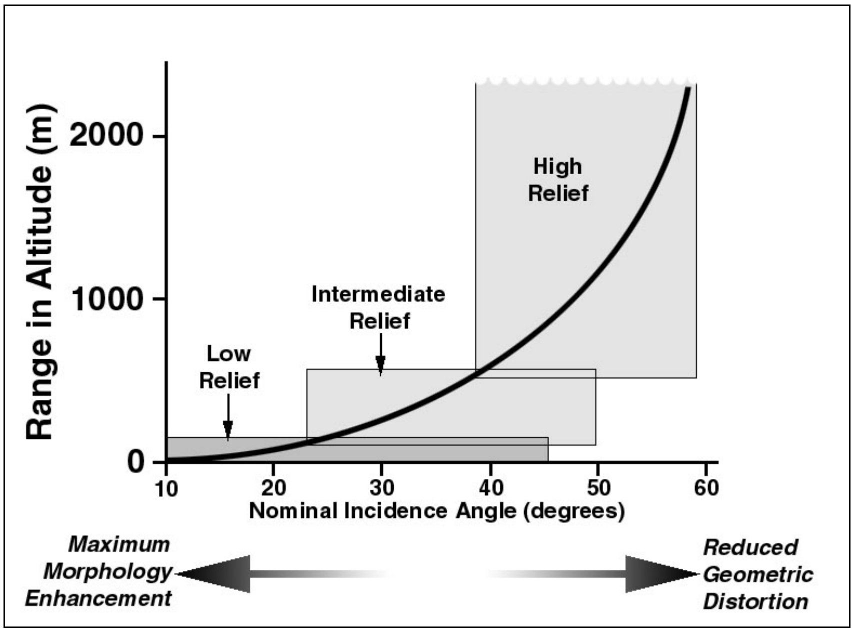

Figure 11. Guidelines for the selection of RADARSAT-1 imagery.

5. Acknowledgements

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