Exploration applications of RADARSAT imagery in the Foothills and the Western Canada Basin

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ABSTRACT

A series examples from the tropics and the heavily vegetated areas of the Western Canada Basin are being used to illustrate the surface mapping capabilities of RADARSAT and its potential for exploration applications. Result show that the RADARSAT image products, in all modes evaluated to date, provide significant geological information and appear to overcome the series limitations associated with shadowing (airborne systems) and layover affects (ERS-1 satellite systems).

Some of the key advantages of RADARSAT as compare to other available remote-sensing data includes the availability of : 1) ascending and descending scenes which allow the interpretation of geological structures from two look directions 2) variable incident angles that can be used to create stereo as well as enhance the topographic expressions of subtle structures and 3) variable resolutions that can be used to “zoom” on key geological structures with higher resolution images.

In fold belt regions, the analysis of RADARSAT images can improve the mapping of exposed complex structural features, detect the presence of cross trending faults, assist in the evaluation of the geometry of prospective structures. In foreland regions, the analysis of RADARSAT data can lead to the recognition of buried and obscured structures that are often too subtle to be fully recognized with conventional exploration tools. The recognition of these features can improve the understanding of the trends, style of deformation and availability of prospects in these low relief areas.

Figure 1a
Landsat TM image of Sumapaz Area of the Magdalena Basin in Colunbia.
(Image courtesy of Chevron Overseas Petroleum)

Figure 1b
RADARSAT S7 descending image of Sumapaz Area of the Magdalena Basin in Columbia.
(Image courtesy of CSA ©1996)

Figure 1c
Landsat TM image of the Inga Field in the West Canada Basin
(Image courtesy of IIT)

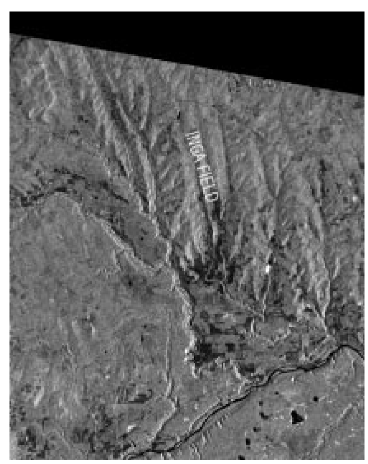


Figure 1d
RADARSAT W2 image of the Inga Field in the West Canada Basin
(Image courtesy of CSA ©1996)

INTRODUCTION

For the past two decades or so, remote-sensing satellite imaging technology has been widely used by the petroleum industry to support exploration in both frontier and mature areas. The application of this technology covers a wide range of geological and logistical aspects of the petroleum sector including: reconnaissance geological mapping of large areas, detailed mapping of prospective structures, delineation of fractured related reservoir trends, direct detection of surface alterations and vegetation changes related to oil seeps , logistical application associated with the collection and planning of seismic data, and environmental monitoring of petroleum related activities (e.g. Sabins 1983, Drury 1987, Berger 1994, Frost 1994) . To date, most of the remote-sensing studies are conducted with images that are obtained from passive satellite imaging systems such as the US Landsat and the French SPOT. However, because these systems relay on short way length energy which is omitted from the sun, their imaging capabilities are quite limited in the tropics and other humid regions which are frequently covered by clouds and the surface expressions of their structures are usually obscured by thick vegetative cover.

For these areas, radar has emerged as the preferred remote sensing tool for four main reasons. First, because radar used much longer wavelengths, images of the earth's surface can be obtained through the heavy cloud cover prevalent in the tropics and other humid areas. Second, radar imaging systems have proven to be excellent surface mapping tools in tropical and temperate areas because they are sensitive to variations in topography and surface roughness and thus are capable of imaging the topographic expression of structures which are completely obscured by vegetation and other surfical material. Third, the shadow effect which results from the radar's active nature greatly enhances the surface expression of structures on the image. This effect can be maximized by carefully selecting the beam alignment to coincide with preferred structural orientations. Fourth, images over the same area with different incidence angles and same or opposite look directions can be used to obtain a stereo image which also improves the structural mapping capabilities of radar (e.g. Ford et al 1980, Harris 1991, Ellis et al 1994, Valenti et al 1996)

The advantages of radar systems as compared to passive imaging technology (such as the sensors on Landsat and SPOT satellites) can be seen in Chevron's exploration attempts in the Sumapaz Area of the Magdalena Basin in Colombia (Figure 1a & 1b). Landsat images of the area without significant cloud-cover were very difficult to find. The best of these images is shown in Figure 1a and the corresponding RADARSAT image is shown in Figure 1b. Not only does the radar image defeat the cloud-cover problem, it captures, in much greater detail, the topographic expression of the structures . The advantages of radar systems in areas with more subtle structures is illustrated in Figures 1a & 1b. which show a comparison between Landsat (TM) and RADARSAT images over the mildly-deformed region of the Canadian fore-foothills. Note that the LANDSAT (TM) in this area is very flat, showing no topographic relief whereas the shadowing effect of radar enhances the topographic expression of subtle elongated anticlines which form significant hydrocarbon traps in the area (i.e., the Inga field).

Successful application of radar imaging systems for geological exploration has been achieved so far with airborne SAR surveys. However, airborne surveys suffered from two main shortfalls. First, the surveys can become prohibitively expensive when used as regional reconnaissance tools. Second, airplane access to remote or politically unstable areas is problematic. Recent space borne radar systems which were designed for inexpensive, reliable reconnaissance scale mapping include the ERS-1, the JERS-1, ALMAZ and RADARSAT satellites. The capabilities of these satellites have steadily improved with time. RADARSAT (the most recent) is considered to be the most advanced space-borne radar system available today for geological mapping.

The objective of this paper is two fold: first, to introduce the reader to the type of imagery data that can be obtained from RADARSAT. And second, to illustrate, with examples from the Canadian Fold and thrust belt and the Western Canada Basin, the potential application of RADARSAT for petroleum exploration.

The RADARSAT System and related image products.

RADARSAT is an advanced earth observation satellite developed by the Canadian government and is Canada's first remote sensing system. The satellite was launched in November, 1995 and is designed for a five-year lifetime. RADARSAT is equipped with a C-band, horizontally polarized Synthetic Aperture Radar (SAR) system. The CSA is responsible for the program management, design and operation of RADARSAT while CCRS oversees the operation of the ground receiving stations and SAR processor as well as being actively involved in radar research and applications development. RADARSAT orbits the earth at 798 km in a near-polar, sun-synchronous (dawn-dusk) orbit. A dawn-dusk orbit of the satellite implies that is crosses the equator at dawn and dusk such that the solar-powered satellite is rarely in eclipse and is able to acquire data at any time (RADARSAT International, 1993). RADARSAT is an active sensor, thus it provides its own energy source allowing it to operate both day and night. The satellite orbits the earth 14 times per day and the repeat cycle for imagery acquired with exactly the same specifications of the same point on the earth is 24 days.

The RADARSAT was designed to provide the user with a variety of modes that can be selected on the basis of the type of mapping required (Table 1) . The polar RADARSAT orbit implies that the satellite's direction as it crosses the equator may be ascending or descending and due to the earth's rotation about its axis. RADARSAT images are therefore collected in two look-directions: west-look descending pass (north-to-south) and east-look ascending pass (south-to-north). Resolutions of 10m, 25m, 30m, 50m & 100m are available with incidence angles ranging from approximately 10 to 60 degrees and aerial coverage's from 50km by 50km to 500km by 500km. In general, smaller aerial coverage indicate higher resolution imagery which is useful for large scale mapping. The choice in incidence angles is a huge bonus since one may request shallower angles for high relief terrain in order to reduce layover and foreshortening artifacts and yet not result in large areas lost in shadows. The variable incident angle also provides stereo coverage.

Compression with other radar data

Prior to the selection of RADARSAT data as the preferred surface mapping tool of the tropics and subtropics, it is necessary to compare its surface mapping capabilities with other available radar sensors. Figure 2 shows three different radar images of the Butler Ridge Area having the following attributes : (1)airborne radar with 6m spatial resolution and app 70 degrees incidence angle(2) 30m ERS-1 satellite radar data with 23 degrees incident angle and (3) RADARSAT Standard Mode image with 30 meter spatial resolution and app 47 degrees incidence angle.

All of the images nicely illustrate the general structural and topographical setting of this area with the typical expression of narrow anticlinorial ridges and broad intervening synclines, as well as, the surface manifestation of flat irons and fault line scarps. The high resolution airborne image (Figure 2a) provides detailed structural and topographic features and shows no evidence of lay-over effects despite the high topographic relief because of the relatively shallow incidence angles used , however, the shadowing effect significantly reduces the information content availability. In comparison, the ERS-1 satellite image (Figure 2b) shows general structural and topographic features of the area but the structures are extremely distorted by foreshortening and layover due to the relatively steep incidence angles used . A significant improvement to both of the previous problems may be seen in the RADARSAT image (Figure 2c) which does not have shadowing effects or severe foreshortening in this scene.

The standard RADARSAT mode image provides a lower resolution than the airborne data which limits its capabilities for detailed analysis of geological features as well as for logistical applications (i.e. identifying seismic cut line, assessing environmental impacts of exploration activities etc.). However, this advantage can be reduced by using RADARSAT's fine mode images.

Exploration applications in the Western Canada Basin.

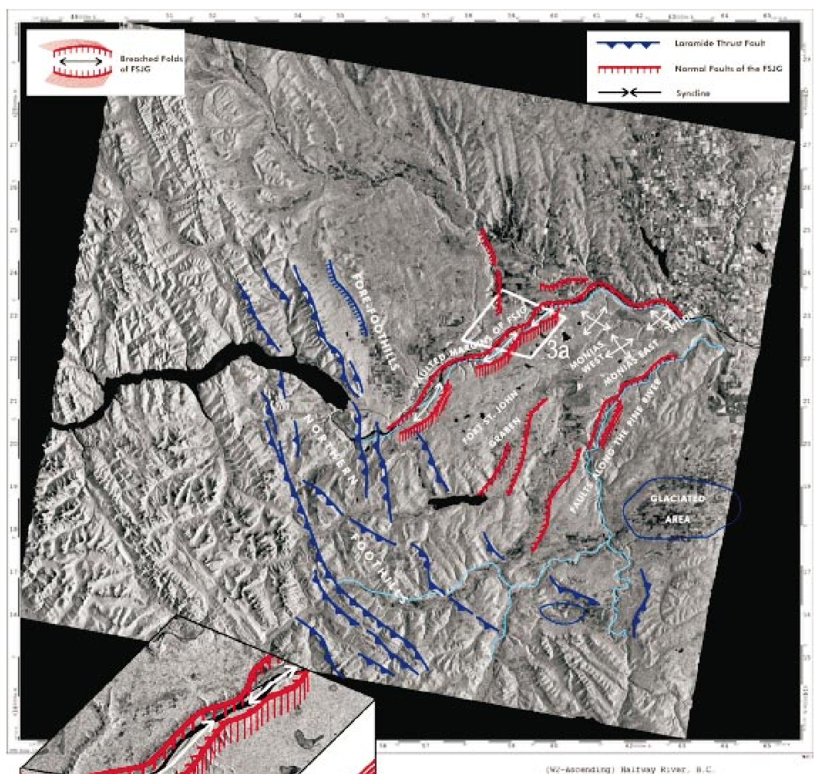
Shortly after the first RADARSAT images became available to the oil industry, they became a popular tool for geological mapping in frontier and mature areas of the tropics and other humid regions. For example, in the past year or so, Image Interpretation Technologies Ltd has acquired RADARSAT coverage (W2 ascending and ScanSar descending) of the entire Western Canada Basin and the Canadian Foothills. This data is being incorporate into several regional studies which are conducted in several active areas of exploration such as : the Canadian Foothills, the Peace River Arch, the Rainbow Zama Area, and large portion of NE British Columbia.

An outstanding example of the surface/structural mapping capabilities of RADARSAT is illustrated with a wide mode image that covers the Forth St. John Graben (FSJG) and Canadian Foothills of N.E. British Colombia (figure 3). The shadowing effect of the RADARSAT enhances the subtle topographic expressions of buried and obscured structures of this region providing an excellent reconnaissance prospecting tool. The faulted margins of the (FSJG) graben manifest at the surface the typical expressions of high angle, normal faults. That is, the fault line traces are made up of short segments of individual ,multidirectional faults that intersect at oblique angles to form zigzag pattern. Distinct topographic features can be observed at the intersection of the blocks which form dogleg edges patterns and positive structural features known as trap-door.

In the foothills region, thrust faults are well expressed on the imagery as a series of positive, sinuous, and asymmetric surface features where the topographically high blocks reflect the upper overriding plates. In some places, however, the actual location of the thrust faults is difficult to detect on imagery data because they occur along parallel bedding plains. In this cases, the interpretation of the thrust faults is inferred by the alignment of preexisting structures such as truncated folds, faults and bedding surfaces.

The elongated anticlines which are formed along the reactivated faults of the graben systems also manifest clear expressions on RADARSAT data. These structures are breached by erosions and their exposed limb produce profound expressions of circular patterns of inclined bedrock strata that are particularly enhanced by the shadowing effect of the side looking radar. The internal folds of the known producing fields are expressed as subtle topographic highs which are outlined by radial drainage patterns and other structurally related stream patterns.

The block diagram in figure 3a , illustrate how the interpretation of surface data may be used to constrain the analysis of seismic data and lead to the development of new prospective structures in the area. Here, RADARSAT data was used , together with a key seismic line, to delineate prospective fold that developed along the reactivated and inverted margin of the graben. Mapping these structures across the deep valley with seismic data alone is quite expensive and the processing of the data can be quite problematic. Note also that the geometry of the structure was reconstructed by using dip and strike measurements which were obtained from stereo RADARSAT data , which was obtained by using another image with the same look direction but different incidence angle. The precise reconstruction of the size and geometry of the surface structure play a significant role in the analysis of the seismic data as well as the evaluation of the exploration potential (i.e. size of the potential hydrocarbon traps) of the prospective structure.



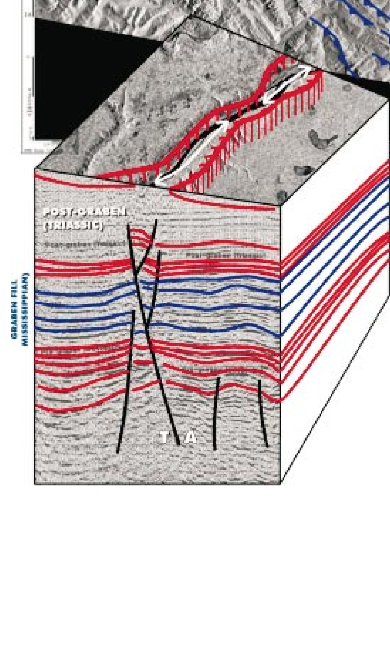


Figure 2
RADARSAT W2 ascending image of Halfway River, B.C. - FSJG and Canadian Foothills. (Image courtesy of IIT ©1996)

Figure 2a
The block diagram illustrates the relationship between surface and subsurface structures along the deep valley of the Peace River. Seismic data after Berger, 1994. The location of seismic lines was modified for illustrative purposes as well as for proprietary reasons.

Closing remarks

Our experience with RADARSAT data has been quite positive so far. The RADARSAT products, in all modes, provide significant geological information and seems to overcome some of the limitations of the previous available radar images. We have found that the key to successful application of RADARSAT data lies on three main factors: 1) Careful selection of RADARSAT mode so that they can provide the appropriate data for the task at hand 2) The use of experiences remote-sensing geologists that have been trained to work with this unique data set. And 3) The integration of RADARSAT images (or any other remote-sensing data) with other available surface and subsurface data.

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