HOW USEFUL ARE AIRSAR DATA FOR REGOLITH-LANDFORM AND GEOLOGICAL MAPPING IN AUSTRALIA – AND WHAT ARE THE LIMITATIONS?

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Introduction

AIRSAR datasets were recorded in 1993 and 1996 over selected sites in Australia to examine the strengths and weaknesses of radar remote sensing for geomorphological and geological mapping at contrasting sites representing typical Australian exploration environments. Several industry-funded research projects were established to assess the data for their ability to provide information about the terrain and its processes that are otherwise unobtainable from optical remotely sensed and other geophysical datasets. Whereas optical datasets, such as Landsat Thematic Mapper, provide information about the chemistry of earth surface materials, radar signals are sensitive to their texture (roughness) and dielectric properties, and have the ability to penetrate vegetation canopies and thin sand veneers that obscure surface and near-surface geological features. The importance of understanding the distribution of regolith cover and its relationship to the underlying bedrock is well recognized by the gold exploration industry which faces the difficult task of exploration in complex and deeply weathered terrains often masked by a discontinuous blanket of calcrete, colluvium and aeolian sands. Understanding the nature and distribution of regolith materials is critical to a range of geological and geochemical exploration methods. The regolith can generally hinder mineral exploration by concealing the bedrock and preventing easy sampling, mapping and photo-interpretation of structure. Exploration in Australia must, therefore, rely on geochemistry, geophysics and remote sensing. The following paper summarizes the main findings emanating from an examination of AIRSAR data over terrains considered important for mineral exploration.

Subsurface mapping

A major benefit of imaging radar is the ability of long wavelength signals (λ>60 cm) to penetrate loose overburden and map subsurface structures, provided that the volumetric soil moisture is <1% and the soils have fine to medium textures. This is a major advantage over reflectance remote sensing. In the Great Sandy Desert of Western Australia for example, where sandplains, dunefields and shrub-steppe vegetation obscure much of the subtle topography and underlying Proterozoic sedimentary rocks, enhancements of AIRSAR data have demonstrated the benefits of polarimetric radar for revealing more information about the composition of the terrain than enhancements of either SPOT-PAN or Landsat TM data (Tapley and Craig, 1995). Figure 1 compares a Landsat TM image of bands 2:4:7 (left) with a composite image of the vertical polarization response for AIRSAR bands C:L:P (right). The TM scene highlights the ubiquitous nature of the dunefields and a composite history of fireburns, whereas the radar image "sees through" much of this cover and confusion to reveal significant geological detail. Some of the more significant observations in the image include:

- The identification of the closure of a previously unmapped syncline [Location 1];
- Regional extensions of alignments of truncated sedimentary sequences, much of which is subsurface, within the sandplains and pronounced expression of the geometric alignment of individual stratigraphic units [Location 2]; and
- Morphological evidence of a complex fluvial history under a former climatic regime that permits the construction of a sequence of palaeo-environmental events that produced the landforms associated with the palaeodrainage networks [Locations 3 and 4].

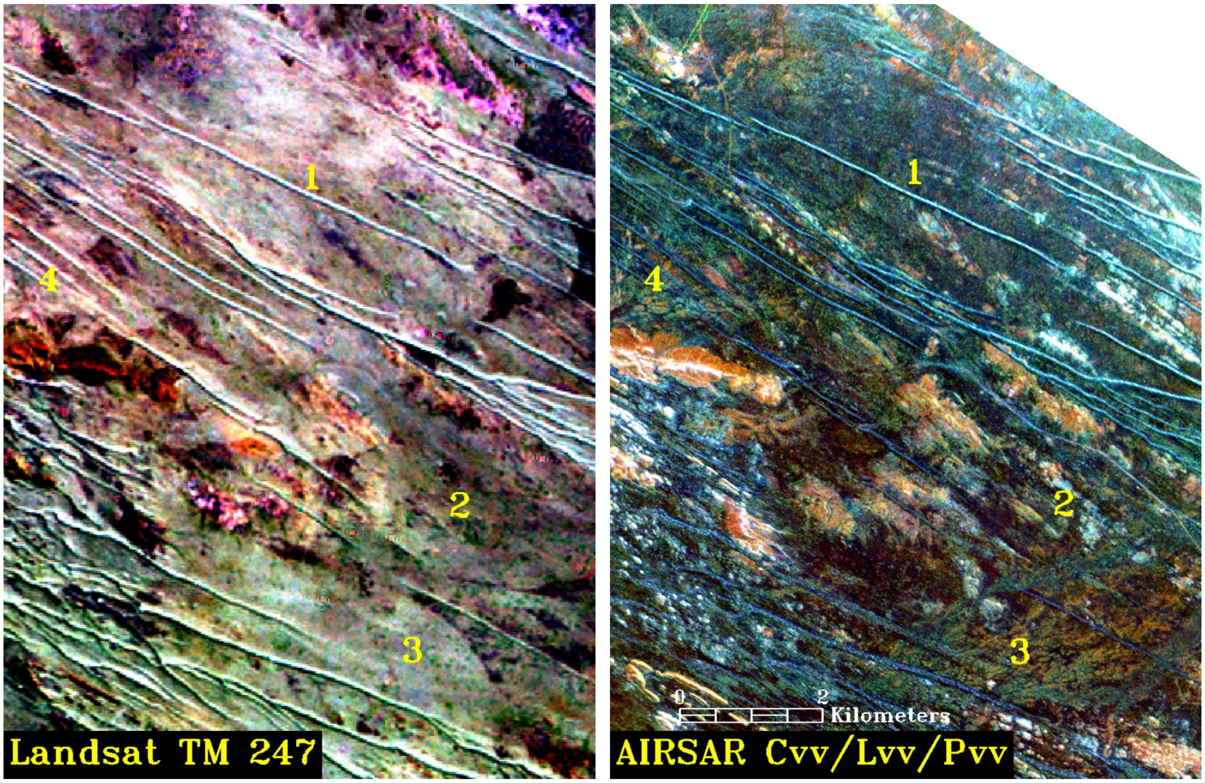


Figure 1: Images of Landsat TM and AIRSAR polarimetric data compare surface and sub-surface textural information from radar with surface mineralogy and vegetation from TM.

Regolith and landform mapping

The benefits of radar for mapping landforms and discriminating between regolith materials in deeply weathered terrains are well described by reference to an examination of AIRSAR polarimetric data in the Lake Barry region of the Gawler Craton, South Australia. Importantly, the fundamental attributes of this deeply weathered terrain, namely erosional and depositional regimes, can be recognized. The most distinctive radar responses occur from prominent outcrop and associated debris of Precambrian volcanics [Figure 2, Location 1] and irregular surfaces of dissected silcrete tablelands (Location 2). These contrast strongly with a blanket of alluvial, colluvial and aeolian sediments (Location 3) with a ~10% vegetative cover of chenopod-shrubland communities, which have low-to-medium backscatter. Specific observations include:

- The mapping of regolith-landform units is primarily a function of multi-frequency rather than multi-polarization, with the greatest sensitivity to roughness being observed in the VV-polarized data for each frequency. Regolith-landform units of the erosional regime can be delineated from those in other regimes by the increased surface roughness resulting from the accumulation of coarser lag gravels and exposure of bedrock during active erosion of the landscape. Outcrops of igneous rocks at Locations 1, 4 and 5 produce the strongest returns in co-polarized signals from all three frequencies and appear as white to bright yellow in the composite image.
- Best discrimination between the landforms developed in erosional terrains is obtained from enhancements of L- and P- band data. C-band data generally do not discriminate between these landforms because their surface materials are "radar rough" at this wavelength. For example, in C band outcropping rhyodacite at Location 1 are confused with the medium to coarse lags of silcrete gravels and calcrete nodules developed over granite saprolite [Location 2], whereas clear distinction is made in L band. L- and, to a lesser extent, P-band signals highlight the topographic alignments of breakaway slopes that define the extent of these tablelands. Incision of the tableland by ephemeral streams has resulted in exposure and accumulations of massive to nodular calcrete and silcrete gibber that strongly backscatter the radar signals. In addition, in an area of increased dissection at Location 2, L band has clearly delineated a semi-radial pattern of isolated topographic highs of weathered granite overlain by a lag of silcrete gravels and cobbles.

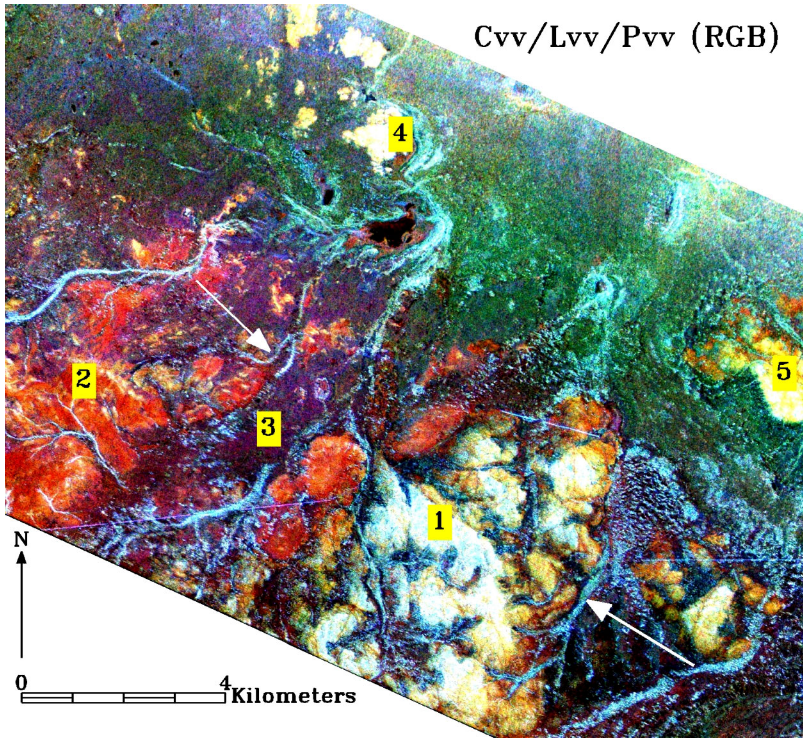


Figure 2: Variation in vertically polarized radar backscatter with changing surface roughness according to AIRSAR C, L and P band wavelengths.

- C band provides clear discrimination between erosional and depositional terrains owing to the relative smoothness, at the scale of the L-and P-band wavelength, of regolith-landforms located in depositional terrains.

Terrain analysis

An interpretation of radar images can often permit a fuller comprehension of the morphology of the landforms and the nature of the materials that form those landforms when compared with optical datasets. This interpretation is driven by a relationship between surface morphology and composition of particular landform units. For example, in the Ophthalmia Range region of the Hamersley Basin in Western Australia, a series of landscape evolution processes can be deduced from enhancements of AIRSAR imagery (Tapley, 1996). These processes were active under former climatic regimes and led to the construction of a sequence of palaeo-environmental events to produce the landforms associated with the colluvial and alluvial units. In Figure 3 two broad morphological regimes can be recognized. Extensive bedrock outcrops of the Ophthalmia Range have been, and are still part of, an erosional regime capable of supplying large volumes of material. This material has been transported and deposited in the depositional regime by both colluvial and alluvial processes to form marginal colluvial fans [Location 1], alluvial fans [Location 2] and sheetwash plains [Location 3].

The colluvial fans form a series of interconnecting, laterally coalescing, landforms. Each displays a distinctive yellow or red hue depending on the mean grain size and/or angularity of the surface lags, and the cover ratio of lag:soil:vegetation. The "yellow" fans are considered to have formed initially in the piedmont zone at the foot of the strike ridges as debris flows of locally derived coarse materials. The "red" fans are younger debris flows of slurry material formed by landslide action following deposition of the "yellow" fans. These flowed out over the "yellow" fans. During subsequent wet climatic phases, generations of alluvial fans developed as a series of discrete and topographically prominent, alluvial fan lobes over the marginal fans. Creeks since formed have developed as well-formed flow lines

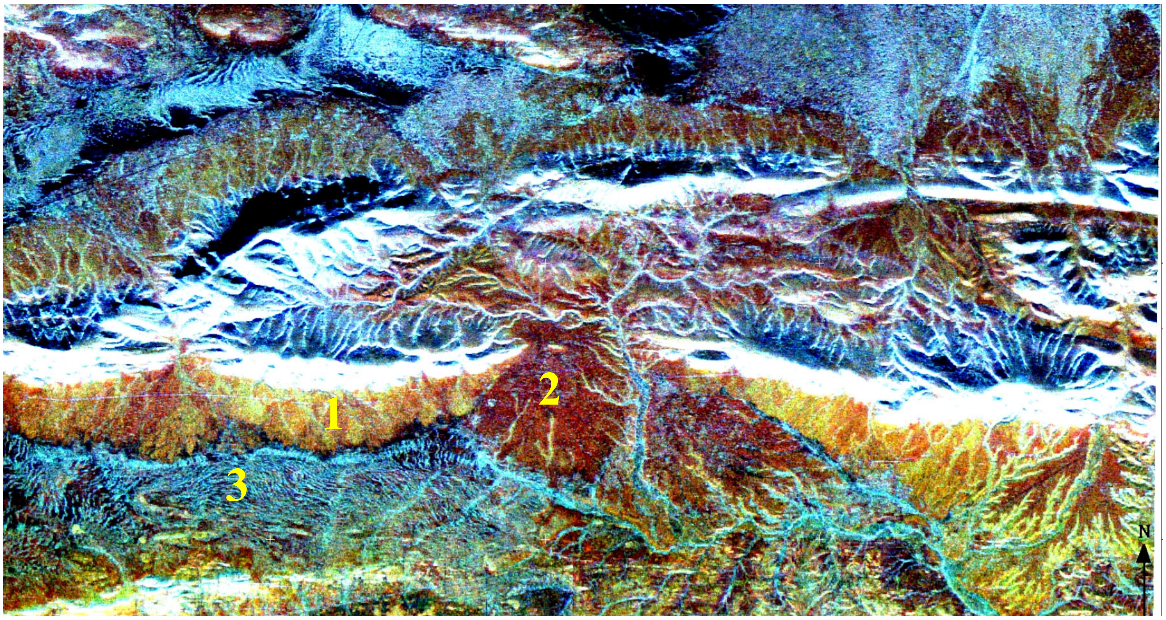
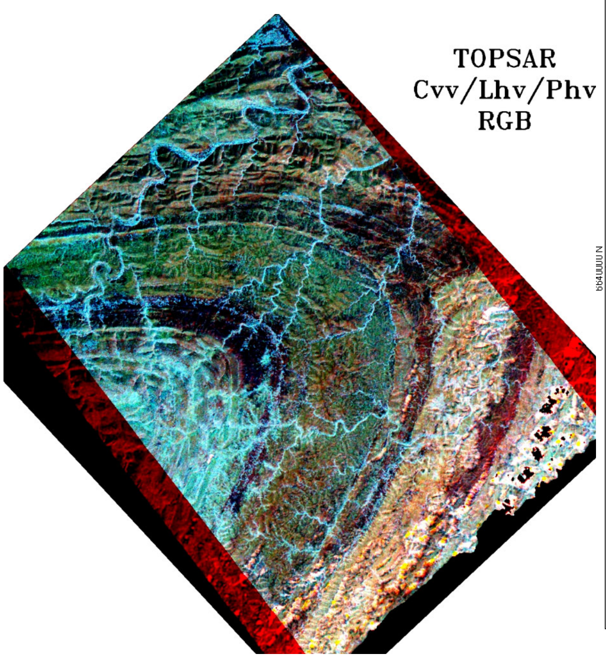


Figure 3: Landforms in vicinity of Ophthalmia Range, Hamersley Basin – a composite image of AIRSAR bands Cvv/Lvv/Pvv as RGB. Site dimensions - 16x8 km; north direction to top of image.

Geological mapping

Enhancements of multi-parameter radar data are excellent for delineating rock units based on variations in surface roughness and dielectric properties when vegetative cover is minimal (Tapley, 2000). For example, rock units within the closure of Arkaroola syncline, Flinders Ranges, South Australia, have distinct roughness properties according to their lithology, weathering and erosional characteristics. A subset of three bands Cvv/Lhv/Phv displayed as an RGB image in Figure 4 provides an accurate representation of the distribution of the rock units in the accompanying geological map. The technique is more appropriate for sedimentary sequences rather than metamorphic complexes where results have shown a poor correlation between roughness and radar backscatter.



TOPSAR
Cvv/Lhv/Phv
RGB

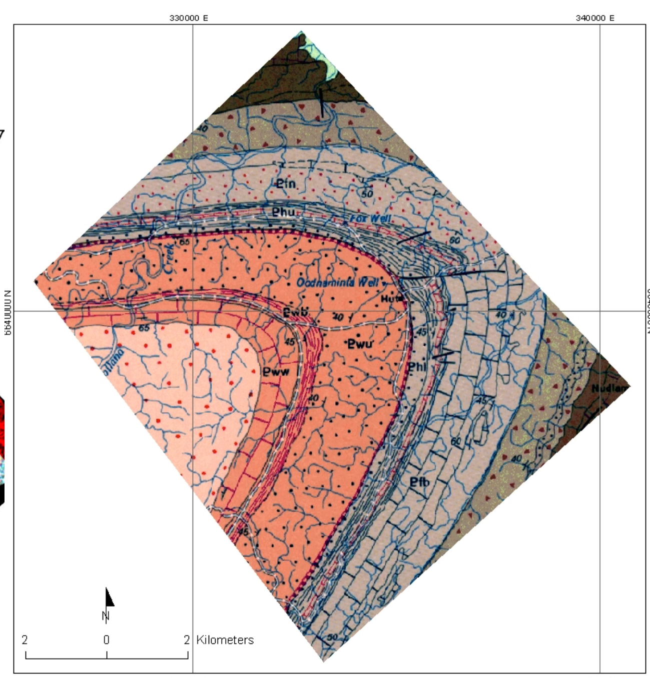


Figure 4: AIRSAR C-, L- and P-band multi-polarization composite image of stratigraphic sequence comprising Arkaroola syncline, Flinders ranges, South Australia, shows a strong relationship with the mapped geology.

A canonical variate analysis of training classes representative of each rock unit demonstrates the polarimetric uniqueness of each unit (Figure 5). The visual separation between the classes on the plot indicates the degree of separation – the criterion for one class being reasonably distinct from another is a minimum separation of 2 standard deviations, the units of measure along each axis.

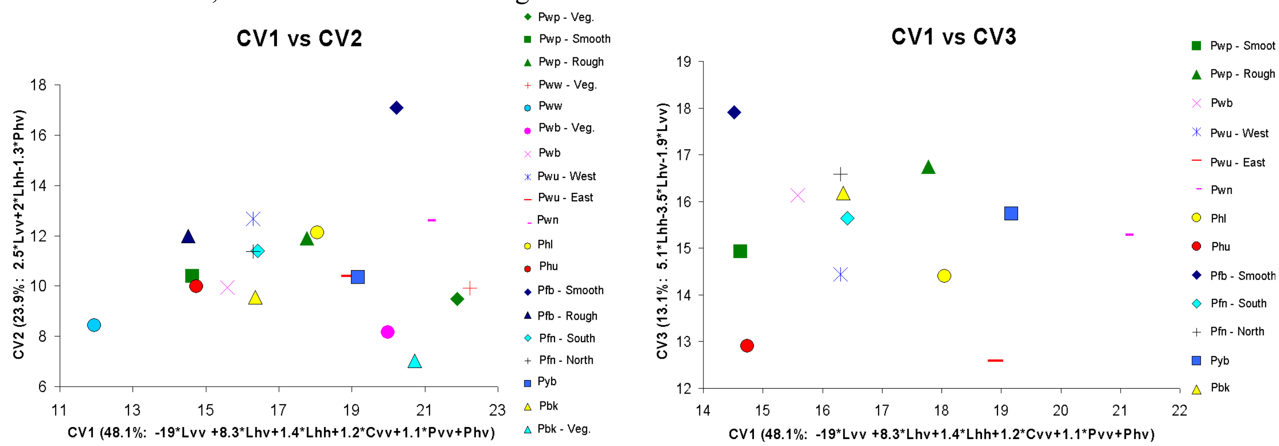


Figure 5: Canonical variate plots of CV1-CV2 (Left) and CV1-CV3 (Right) illustrate the polarimetric separation between the rock units of Arkaroola syncline

CVA demonstrates in a statistical manner that rock types of different composition can be mapped and discriminated between based on their distinct surface roughness properties according to their lithology, weathering and erosional characteristics

Draping the radar image in Figure 4 over a precision digital elevation model places the stratigraphic sequence in perspective with the local topography, and enhances the geological detail (Figure 6). Interactive viewing of 3-D perspective images on an image display screen is a simple technique for presenting the geology and landforms in a more informative way, and for understanding the relationships between landforms, geomorphic processes and terrain relief.

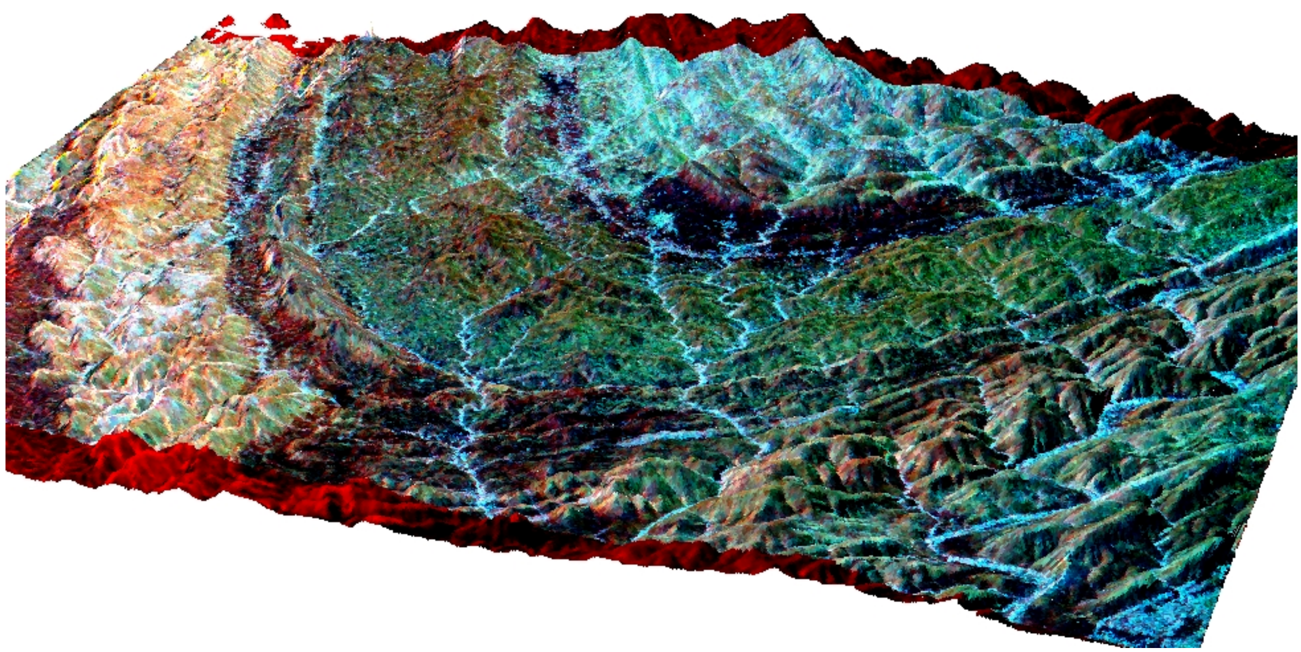


Figure 6: Shaded perspective image of AIRSAR radar bands Cvv/Lhv/Phv (RGB) draped over TOPSAR DEM shows the benefits of incorporating topographic detail into a 2D image by highlighting the radar and topographic signatures of the stratigraphic sequence forming the syncline. The image is oriented with the viewer looking southwest.

The highlighting and shadowing of the terrain by the side-looking illumination of radar is a distinct benefit for mapping geological structures in vegetated and non-vegetated terrains. In areas of prominent outcrop and relief, an image will commonly have a psuedo-3-dimensional perspective that highlights the position of lineaments, fault and fold structures, and morphological characteristics such as dip slopes and slope-asymmetry. For example, an enhancement of AIRSAR data in Figure 7 has provided a new insight into the geologic framework of the Ophthalmia Range region by highlighting several prominent structures within the synform, and linear extensions of these structures within the adjacent valleys. Their appearance seems to be caused primarily by surface roughness since the alignments are mostly coincident with topographic expressions including those of stream segments, boundaries of outcrop and lithological contacts.

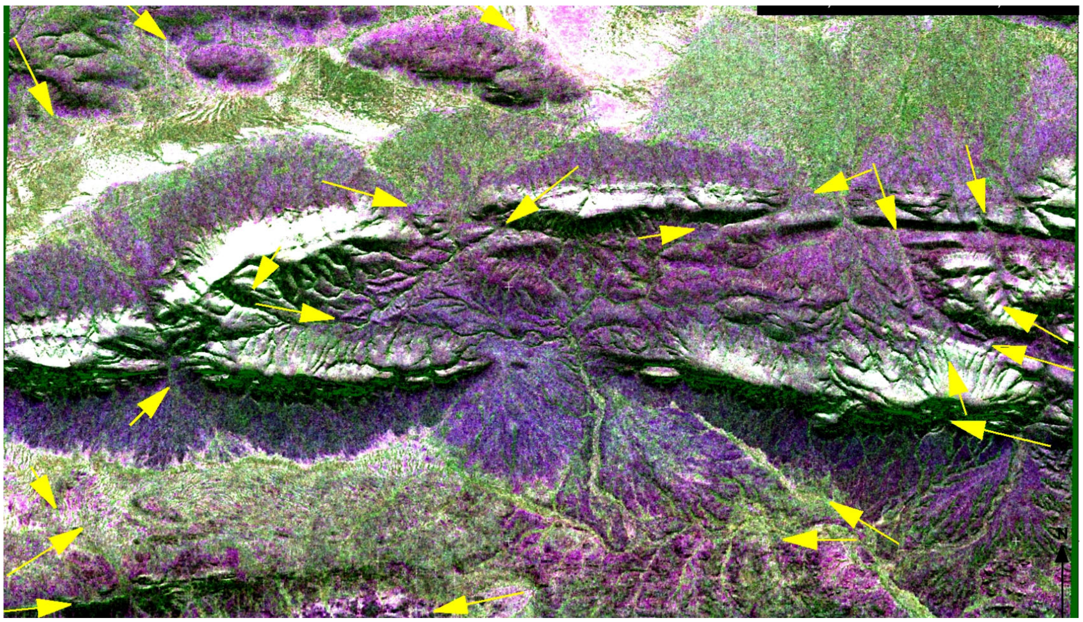


Figure 7: An interpretation of prominent linear structures from an enhancement of AIRSAR data of the Ophthalmia Range region in the Hamersely Basin, Western Australia. Site dimensions are 16x8 km, north direction to top of image. The band combination is negative C band in Red and Blue guns, and a Least Squares Fit analysis of P band, modelled on the information in C and L bands, in the Green gun. The LsFit technique was used to model landform detail below the canopy.

Use of radar data for mineral exploration

The following recommendations have been made on the use of operational imaging radar for providing detail about the morphologic and structural characteristics of most Australian terrains. The availability of operational radar data in Australia is currently limited to ERS-1 and ERS-2 (C band, VV polarization), JERS-1 (L band HH polarization), Radarsat (C band HH polarization).

- A combination of wavelengths similar to AIRSAR's C (~5.5 cm), L (~24 cm) and P (~68 cm) bands is optimal for unmixing the signal response of the surface from that of the subsurface, and the ground-surface scattering from the canopy. C band has the highest priority for mapping the presence of rock outcrops and for discriminating between depositional and erosional terrains. L band is most sensitive to scales of surface change that occur through erosion of the regimes, and P band is preferred for mapping subsurface structures. However, because of distortions to low-frequency signals beyond the earth's atmosphere, P band can operate effectively only from an airborne system. Therefore L band is currently the longest wavelength possible in a spaceborne system. The availability of multi-polarized PALSAR L-band data in 2004 from the Japanese ALOS satellite is eagerly anticipated.

- VV and HV (or VH) are the polarizations of choice for geological mapping in arid/semi-arid lands. Although VV and HH polarizations both result in useful SAR images for the majority of the terrains, VV is favoured because of its increased sharpness and ability to provide better discrimination between surfaces having similar roughness characteristics. The HV (VH) polarization for P band provides the best indication of volume scattering from the shallow subsurface. In woodland terrains, HH-polarization signals suffer less attenuation from the vertically aligned tree trunks and are more likely to provide information about the physical characteristics of the underlying ground-surface. The cross-polarized HV scattering coefficients are less dependent on incidence angle than the co-polarized (HH and VV) scattering coefficients. They are also less sensitive to variations in terrain slope. If geobotanical relationships exist or are being sought, VV-polarization data are preferred since they have increased interaction with the tree trunks.

- A spatial resolution of 5-10 m is necessary to resolve many of the narrow alignments of subcrop and lithic fragments found in sandy arid terrains. For general synoptic mapping and morphologic characterization, a footprint of 10-15 m will probably suffice.
- Incidence angles of between 30° and 50° are recommended for mapping surficial bedrock units and regolith materials based on variations in their surface roughness. Angles <30° can reduce the ability of the radar signals to discriminate between surfaces of different RMS roughness levels, although in sandy terrains, the steep 23 degree angle of incidence of ERS data is a distinct advantage since the majority of outcrop is low profile and intermittent.
- For maximum geological information, the flight direction should parallel the regional strike, or be within 45° of strike if there are several suites of geological structures present. In sand-ridge terrain, if there is no preferred direction, the flight lines are best positioned orthogonal to the dune direction. The current spaceborne radar sensors including those on the Radarsat and ERS-2 satellites collect data from ascending and descending passes meaning that both east-looking and west-looking azimuth directions are available.

Processing and limitations of radar datasets

Such is the high level of radiometric quality of AIRSAR data that enhancements derived from these data can be used in their original form for valid interpretations. Nevertheless, it is widely recognized that radar datasets collected from airborne platforms do regularly contain an unwanted signal component, commonly referred to as "noise" introduced by system and aircraft electronics. In addition, all radar datasets contain an inherent random and multiplicative "noise" component called "speckle" that has the capability to reduce the visual information content of the data, especially in the shorter wavelength bands. Much of this is due to the coherent nature of the return signals.

A technique used regularly to reduce speckle in spaceborne and airborne datasets has been that of spatial filters (Lee and Jurkevich, 1994). A common finding from examinations of speckle filters is the superiority of adaptive filters, such as Lee and Frost filters, over the standard digital noise filters such as low pass and median filters. Ideally, a filter should reduce speckle while preserving the radiometric information (the radar backscatter value), and the spatial sharpness in the data. Adaptive filters essentially retain important high-frequency detail in the form of point of small targets whereas the standard convolutions filter, for example the median filter, smoothes the data, obliterating narrow linear features. However, experience with processing ERS and JERS datasets of sandplain regions has demonstrated the benefit of a 3 x 3 median filter for suppressing much of the scene speckle. Speckle and "noise" reduction can also be achieved in the ENVI image processing software http://www.envi-sw.com/ by implementing the Minimum Noise Fraction (MNF) Rotation option. Advice on its proper use should be sought from the author.

Enhancements of ERS-1, JERS-1 or RADARSAT datasets cannot resolve the detailed information about the land-surface observed in images of equivalent AIRSAR wavelength-polarization band combinations. Maximum value for each can be gained from the synoptic view afforded by small-scale images and image mosaics of large areas. This is especially applicable to JERS data, where the scale of the data visually conceals the degrading effects of speckle and reduced radiometric integrity.

Designed for ocean observations, the ERS radar instruments are not ideally configured for geological applications. Over hilly terrains, the steep incidence angle will promote topographic distortion in the data.

However, in low-relief terrains, the steep incidence angle has the potential to provide maximum discrimination between outcrop and non-outcrop, and to differentiate between rock lithologies featuring surfaces with different and near-similar erosional characteristics. In sand-ridge terrains, where the radar signal responds strictly to the physical characteristics of the surface elements, the synoptic view can "piece-together" scattered outcrop into sensible alignments and patterns to allow an improved synthesis of the regional, geological picture.

Unfortunately the author's experience with RADARSAT data over Australian terrains has been limited to two scenes of Fine-1 Near Beam mode data – one in prominent sedimentary outcrop with minimal vegetation, another in low relief, degraded terrain with a regular cover of chenopod shrubs. Both scenes were severely contaminated by speckle that required vigorous spatial filtering and resampling to suppress. Once processed, the resultant images contained less information than are available from optical datasets, including aerial photographs.

Experience with AIRSAR data of degraded Australian landscapes has shown that colour-composite images of AIRSAR data, processed to remove geometric and radiometric errors, will generally permit the recognition of the principal and subtle attributes of the terrain when the multi-frequency bands are ideally assigned to the colour components of an RGB display. However, felsic erosional landforms such as stripped low hills are seldom discernible from equivalent units in mafic terrain owing to similar radar responses from the surficial regolith materials of these landforms. Their separation can be best achieved from mineralogical differences observed on enhancements of Landsat TM data. In the sub-tropical woodlands of northern Australia, images of AIRSAR data and relief models developed from TOPSAR DEMs are very useful for recognizing the structural fabric of a region, but they cannot resolve landforms with the same definition as 1:25 000-scale aerial photographs (Tapley, 1998).

Conclusion

Studies of AIRSAR data have contributed to a better understanding of the morphology and nature of landforms when compared with SPOT-PAN and Landsat TM images and available geological mapping. They demonstrated the potential of high-resolution, P-band data for identifying and mapping substructures of exploration significance in sand-ridge regions, and of multi-frequency enhancements for providing a local and regional perspective of both fault and fold systems, palaeodrainage networks, and landscape development, generally unobtainable through conventional methods. Apart from defining local areas of exploration significance, the regional context provided by the imagery permits the synthesis of the geological framework of an area, its landforms and their evolution.

Comparison of AIRSAR images with those of Landsat TM data often shows a strong similarity where there are large occurrences of gravels and outcrop. However, the Landsat images are unable to resolve the small and isolated patches of gravels that often indicate the shallow presence of bedrock. This is partly due to the reduced spatial resolution of Landsat TM compared with AIRSAR, and the fact that Landsat signals are in response to the chemical or mineralogical properties of the surface materials whereas radar responds to changes in surface texture. Where scattered gravels occur over sand the spectral response from the gravels is often disguised by that of the background sand, thereby reducing the ability to determine their presence. Radar's sensitivity to textural changes often results in a superior ability to map surface materials present in low amounts, even in the presence of tussock grassland vegetation

It is possible to discriminate between landforms developed in erosional and depositional regimes due to contrasting radar backscatter from their unique surface roughness attributes. Furthermore, AIRSAR data provides great interpretative value for discerning the level of removal of weathered materials within the erosional regime. This has enabled the level of stripping of the weathered landscapes to be predicted with confidence during field checking of the AIRSAR images.

AIRSAR imagery has demonstrated to the mineral explorer the potential benefits of radar data, particularly the longer wavelength L- and P-band data. The near future availability from spaceborne platforms of polarimetric C and L band datasets will provide explorers with an additional tool well-suited for geological and landform mapping. Unfortunately P-band data will only be available in the immediate future from airborne systems.

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