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Integrating geologic and satellite radar data for mapping dome-and-basin patterns in the In Ouzzal Terrane, Western Hoggar, Algeria

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ABSTRACT

The In Ouzzal Terrane (IOT) located in the north-western part of the Tuareg Shield forms an elongated N–S trending block, more than 400 km long and 80 km wide. It involves an Archaean crust remobilized during a very high-temperature metamorphic event related to the Palaeoproterozoic orogeny. The IOT largely crops out in the rocky and sandy desert of Western Hoggar. It corresponds mainly to a flat area with some reliefs composed of Late Panafrican granites, dyke networks or Cambrian volcanic rocks. These flat areas are generally covered by thin sand veneers. They are favorable for discriminating bedrock geological units using imaging radar, backscattering measurements, and field checking, because the stony desert is particularly sensitive to the radar parameters such as wavelength or polarization. The main radar data used are those obtained with the ALOS-PALSAR sensor (L-band), in ScanSAR mode (large swath) and Fine Beam modes. The PALSAR sensor has been also compared to ENVISAT-ASAR and to optical imagery.

Detailed mapping of some key areas indicates extensive Archaean dome-and-basin patterns. In certain parts, the supracrustal synforms and orthogneiss domes exhibit linear or circular features corresponding to shear zones or rolling structures, respectively. The geological mapping of these dome-and-basin structures, and more generally of the Archaean and Proterozoic lithological units, is more accurate with the SAR imagery, particularly when using the L-band, than with the optical imagery. A quantitative approach is carried out in order to estimate the backscatter properties of the main rock types. Due to the large variety of configurations, radar satellite imagery such as ALOS PALSAR represents a key tool for geological mapping in arid region at different scales from the largest (e.g., 1:500,000) to the smallest (e.g., 1:50,000).

1. Introduction

In arid regions where only reconnaissance geological maps exist, remote sensing is known to represent the cheapest and efficient way to compile geological maps. In these regions, morphologies are particularly well expressed and it is relatively easy to follow the geological boundaries on large distance. Typical morphologies occur, especially in the Saharan desert. Rock surfaces are more or less rough (reg surfaces) and frequently invaded by sand (serir surfaces). Radar can penetrate dry sand and image shallow sub-surface features (Abdelsalam et al., 2000). Fig. 1 illustrates the complementarity of radar and optical images in arid regions. The main advantage of the radar for geological mapping is to be less sensitive than optical data to sand cover (A is a dune clearly visible on the optical image) and hydrographic network (B is a wadi too flat and smooth to modulate the radar signal), and to be more sensitive to surface roughness (see D). The radar generally emphasizes dykes and prominent outcrops (see C), but incidence angle conditions play an important role. Note that the incidence angle is defined as the angle between the normal to the surface and the incident ray. Experiments show that the SAR signal is attenuated to about 40% at the air/sand interface and completely attenuated

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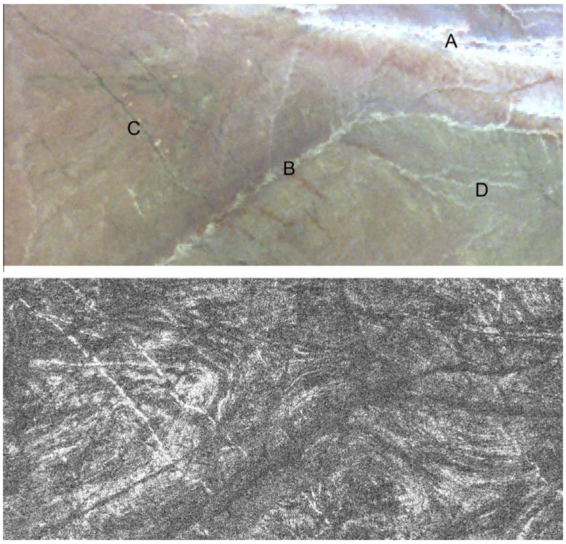

Fig. 1. Comparison of optical and radar data in arid region. Example of the Abeleyel area (see text for explanation).

at depth more than 2 m at 1% moisture content (Elachi and Granger, 1982).

The Hoggar is composed of well preserved and largely reworked Archaean (3200–2500 Ma) and Palaeoproterozoic terranes (2000 Ma) and juvenile Pan-African terranes (750–550 Ma) (Caby, 2003; Ouzegane et al., 2003b). The In Ouzzal area is known as one of the Archaean terranes. It is embedded between the West African Craton and the Saharan Metacraton. The size, remoteness, and inhospitable character of the area induce difficulties for field work. In this context optical remote sensing has been successfully tested by Djemai (2008). Now, the second step consists in evaluating radar data, particularly to focus on key areas in the heart of In Ouzzal Terrane, particularly those representing hypothesized dome-and-basin structures (Ouzegane et al., 2003b). The present paper emphasizes the results obtained mainly with the ALOS PALSAR data.

2. History of space borne imaging radar

The history of satellite imaging radar goes back to 1978 when SEASAT, carrying the first Synthetic Aperture Radar (SAR) instrument, was launched. SAR techniques have been widely used for various applications, including geological mapping in arid regions. With its 105 day-life the SEASAT mission provides seminal geological radar studies (Elachi et al., 1985; Deroin et al., 1991; Evans et al., 2005). The specific interest of radar remote sensing in arid subsurface studies has been illustrated in the Eastern Sahara, Egypt, from the SIR-A and SIR-B missions (McCauley et al., 1982; Schaber et al., 1986). These studies particularly revealed palaeodrainage channels along the Nile valley using the potential for penetrating sand veneer (McCauley et al., 1986; Schaber and Breed, 1999). The potential for geological mapping has been less frequently evaluated, but is known to be better when large wavelengths are used (Schaber et al., 1997). Radar bands used in satellite SAR systems have wavelengths such as about 3 cm for the X-band, about 6 cm for the C-band, about 10 cm for the S-band, and 24 cm for the L-band (Table 1). Note that the longer wavelengths corresponding to the so-called P-band at about 60 cm are only utilizable on board airborne vectors such as the AIRSAR (Schaber, 1999; Daniels et al., 2003).

The interest of SAR remote sensing increased in the early 1990s. After the seminal but limited SAR missions of the American SEASAT in 1978 and the Soviet ALMAZ in 1987–1989, SAR imagery became more common in geological studies with the successive launches of ERS-1 in 1991, JERS-1 in 1992, and ERS-2 and RADARSAT-1 in 1995, all in single polarization (Chorowicz et al., 2005). In 1994 NASA twice launched the Shuttle Endeavour in the frame of the SIR-C/X-SAR mission to collect multi-look angles and swaths data (Evans et al., 1997). The SIR-C/X-SAR data were simultaneously collected at three wavelengths (X, C, and L-band) and multiple polarizations. Geological applications show that the L-band is always preferable to the C-band (Schaber and Breed, 1999; Abdelsalam et al., 2000), and that a relatively high incident angle (35–50°) is required to avoid geometric distortion and lay-over problems, and to obtain deeper penetration (Rudant et al., 1994; Inzana et al., 2003; Raharimahefa and Kusky, 2006). However, some studies indicated that the C-band is also suitable for identifying surface roughness of relatively smooth surfaces in flat areas (Deroin et al., 1997, 1998; Singhroy, 2001; Thurmond et al., 2006; Pal et al., 2007). SARs on board ERS-2 and ENVISAT (ASAR) are similar to the one on board ERS-1. ALOS launched in 2006 represents the major advance in radar remote sensing for geological mapping. The radar sensor, the so called PALSAR, is able to acquire data in different modes (see also Section 3) and allows to develop interferometric applications (Chaussard et al., 2013).

Table 1
The SAR s/c systems and their main characteristics. ASI (Italian Space Agency), CSA (Canadian Space Agency), DLR (German Space Agency), ESA (European Space Agency), JAXA (Japanese Space Agency), NASA (US Space Agency), RSA (Russian Space Agency).

Satellite	Sensor (agency)	Mission	Band	Incident angle	Resolution (m)	Polarization
SEASAT	SAR (NASA)	1978–1978	L	20°	25	HH
Shuttle	SIR-A (NASA)	1981–1981	C	45°	30	HH
	“		L	“	30	HH
Shuttle	SIR-B (NASA)	1984–1984	C	15–55°	30	HH
	“		L	“	30	HH
COSMOS-1870	EKOR (RSA)	1987–1989	S	30–60°	15	HH
ALMAZ-1	EKOR-A (RSA)	1991–1992	S	30–60°	15	HH
ERS 1	EMI (ESA)	1991–2000	C	23°	25	VV
JERS 1	SAR (JAXA)	1992–1998	L	35°	18	HH
Shuttle	X-SAR (DLR)	1994–1994	X	20–65°	25	VV
	SIR-C (NASA)	“	C	“	25	All
	SIR-C (NASA)	“	L	“	25	All
ERS 2	EMI (ESA)	1995–2011	C	23°	25	VV
RADARSAT 1	SAR (CSA)	1995–2013	C	17–50°	10–100	HH
ENVISAT	ASAR (ESA)	2002–2012	C	23–45°	25	HH, VV
ALOS 1	PALSAR (JAXA)	2006–2011	L	10–60°	10–100	HH, VV, HV, VH
TERRA SARX	SAR (DLR)	2006-present	X	60° max	1–18	HH, VV or HV-VH
COSMOSkyMed	SAR2000 (ASI)	2007-present	X	60° max	1–100	HH, VV or HV-VH
RADARSAT 2	SAR (CSA)	2007-present	C	17–59°	10–100	HH, VV, HV, VH
TanDEM-X	SAR (DLR)	2010-present	X	60° max	1–18	HH, VV, HV, VH

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