# K&C Science Report – Phase 1
# Mapping Subsurface Geology in Desert Areas

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Abstract—**Using JERS-1 and PALSAR radar images provided by JAXA, we built regional and continental scale mosaics of Sahara that allowed to discover major geological features. The unique capability of L-band SAR to map subsurface structures in arid areas revealed several impact craters and paleo-rivers in Egypt and Libya.**

Index Terms—**ALOS PALSAR, K&C Initiative, Sahara, subsurface geology, impact craters, paleo-hydrology.**

## INTRODUCTION

Low frequency orbital Synthetic Aperture Radar (SAR) has the capability to probe the subsurface down to several meters in arid areas. Previous studies have shown that L-band SAR is able to penetrate meters of low electrical loss material such as sand. The first Shuttle Imaging Radar (SIR-A) obtained some of the first subsurface imaging results for a site located in the Bir Safsaf region, in southern Egypt: SIR-A L-band radar revealed buried and previously unknown paleodrainage channels, which afterwards were confirmed during field expeditions. Subsequently, SIR-C data were used to map subsurface basement structures that control the Nile's course in northeastern Sudan : numerous hidden faults were detected, thus helping to better understand the Cenozoic uplift of the Nubian Swell. More recent studies have shown that combining SRTM – Shuttle Radar Topography Mission – topographic data with SAR images better reveals subsurface features which still present a topographic signature. New paleodrainage flow directions have been mapped in the eastern Sahara, allowing better definition of drainage lines leading to oases and valleys, as well as a better understanding of the Nubian aquifer in Libya.

While the geographical coverage of the Shuttle Imaging Radar missions was limited, a more complete L-band radar coverage of the eastern Sahara by the Japanese JERS-1 satellite was used to realize the first regional-scale radar mosaic covering Egypt, northern Sudan, eastern Libya and northern Chad. This data set helped discover numerous unknown geological structures, particularly impact craters: a double impact crater was found in southern Libya, in a flat and hyper arid area covered by active aeolian deposits. More than 1300 small crater-like structures, distributed over an area of 40,000 km2, were also detected in the western Egyptian desert. Continental-scale exploration is now being conducted using higher quality data from the new high-performance PALSAR L-band radar of the Japanese ALOS satellite. A new mosaic of the eastern Sahara made from PALSAR scenes shows excellent data quality, allowing a better detection of subsurface features. Using this unique data set, we discovered a major paleodrainage river in eastern Libya.

## SUBSURFACE IMAGING USING JERS-1 DATA

JERS-1 was launched in 1992 and acquired L-band (1.275 GHz) SAR images of the Earth until end of 1998. It provided 18m resolution images in HH polarization, with an off-nadir angle of 35$^o$. Due to power feed problems, the data present a high NE$\sigma_0$ (noise equivalent $\sigma_0$) of -18dB. It is a crucial parameter for subsurface imaging since buried structures are likely to have a low backscattering return. Also, geocoding of JERS-1 SAR data was poor, with location errors reaching several hundreds of meters. A complete L-band radar coverage of the eastern Sahara by the Japanese JERS-1 satellite exists and was used in 2003 to realize the first regional-scale radar mosaic covering Egypt, northern Sudan, eastern Libya and northern Chad [1]. The production and scientific analysis of more than 1600 SAR scenes was used to study the near-surface geology hidden by the superficial sand layer, and we discovered numerous unknown geological structures.

We thus revealed a double impact crater in southern Libya: the structure is located 110 km west of Djebel Arkenu and 250 km south of Kufra oasis in Libya, at coordinates 22°04'N, 23°45'E. It is a flat and hyperarid area covered by active aeolian deposits. The optical Landsat 7 image of the region shows a sandy region with large sand dunes trending SW-NE, while the corresponding L-band radar image extracted from our JERS-1 mosaic reveals two circular structures partially hidden by Quaternary deposits (fig. 1). The NE crater, 6.8 km in diameter, is composed of concentric inner and outer rings separated by a depression filled with sediments. Its morphology is very similar to the Aorounga crater in Chad, corresponding to a typical complex crater. Shatter cones and breccia were observed during field work in April 2003. Planar fractures were also found into rock samples, confirming the impact origin of the craters [2].

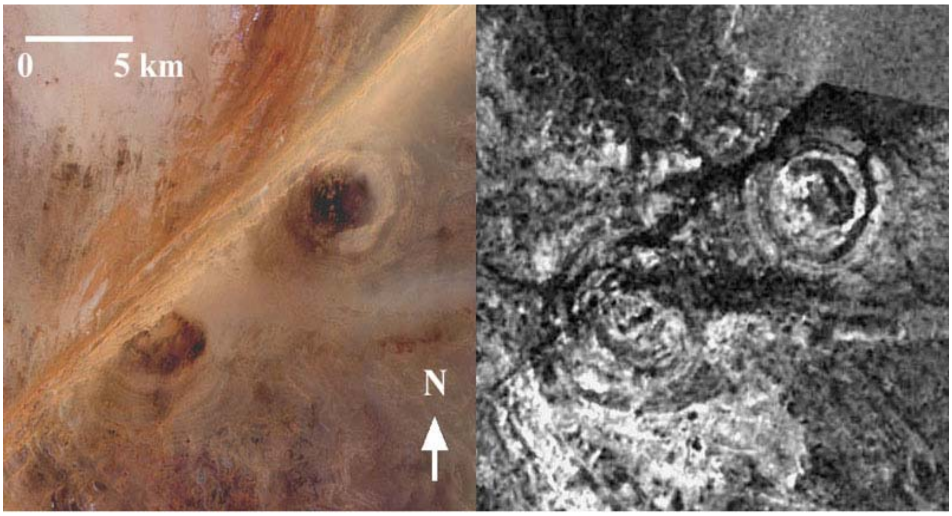


Figure 1. Landsat 7 ETM+ image of the Arkenu double crater (left), and corresponding JERS-1 radar image (right) at a resolution of 50m (JAXA/METI ).

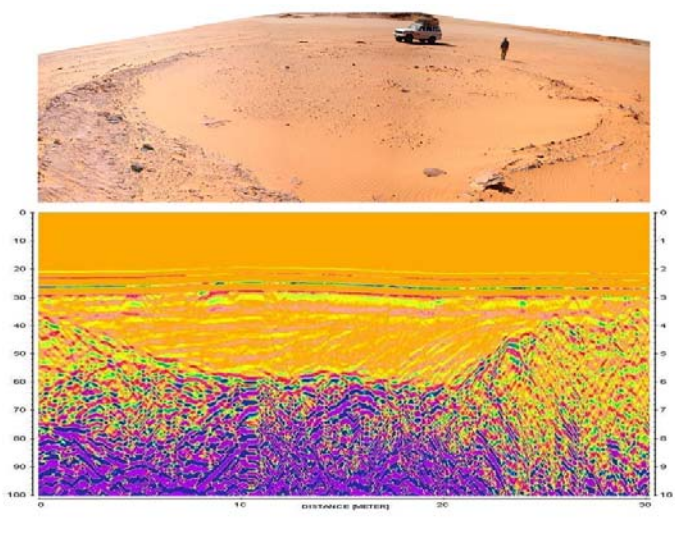

Figure 2. Surface view of the outcropping part of GKCF28 crater (40m in diameter, top) and corresponding GPR profile at 270 MHz (bottom) showing its subsurface shape.

We also detected more than 1300 small crater-like structures distributed over an area of 40,000 $km^2$ in the Western Egyptian Desert, close to the Gilf Kebir plateau. Sixty-two of them were visited in the field during February and December 2004 [3, 4]. Morphological observations, rock samples and ground-penetrating radar data were obtained [5] (fig. 2). Shatter cone-like features, breccia and sub-planar fractures were observed in the vincinity of most of the craters, but the impact origin of the field still has to be confirmed: hydrothermal vent complexes could also explain some of our observations [6]. Whatever its origin, the Gilf Kebir crater field is of great scientific interest and is a major element of the geological history of Western Egypt. Further field and laboratory studies are required in order to better understand its nature and origin.

## FIRST RESULTS USING ALOS/PALSAR DATA

In January 2006, the JAXA successfully launched the Advanced Land Observing Satellite (ALOS). It carries two high resolution optical sensors (AVNIR-2 and PRISM) and one full polarimetric L-band SAR, PALSAR. This phased array SAR provides high resolution (10m) imagery with variable incidence angle, with a much improved value of NE$\sigma_0$ around -25dB. The geolocation accuracy is better than 10m and the radiometric accuracy is better than 1dB. The PALSAR instrument is operated to provide systematic wall-to-wall observations of all land areas on the Earth on a repetitive basis. First acquisitions over North Africa took place during ascending cycle 9 in January 2007 (Fine Beam mode, HH polarization, incidence angle 34.3$^o$). We produced a first small mosaic of 50 PALSAR scenes, extending between 18-23$^o$N and 24-30$^o$E over southern Egypt and northern Sudan. Comparison between the JERS-1 SAR and PALSAR data clearly shows the superior capacity of the PALSAR sensor to map subsurface features (fig. 3). Due to its improved NE$\sigma_0$ and finer resolution, PALSAR allows in particular a better detection of fine paleo-hydrological networks [7].

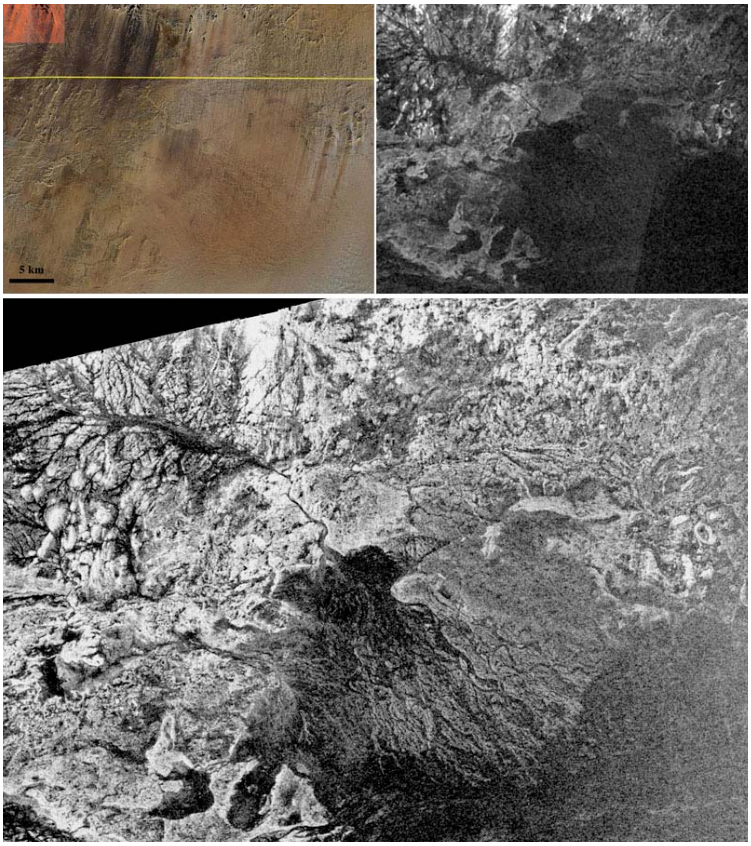


Figure 3. Landsat (top left), JERS-1 (top right) and PALSAR image (bottom) of a region located around 21$^o$55'N, 26$^o$36'E. PALSAR much better reveals paleodrainage channels in the lower part of the scene (JAXA/METI ).

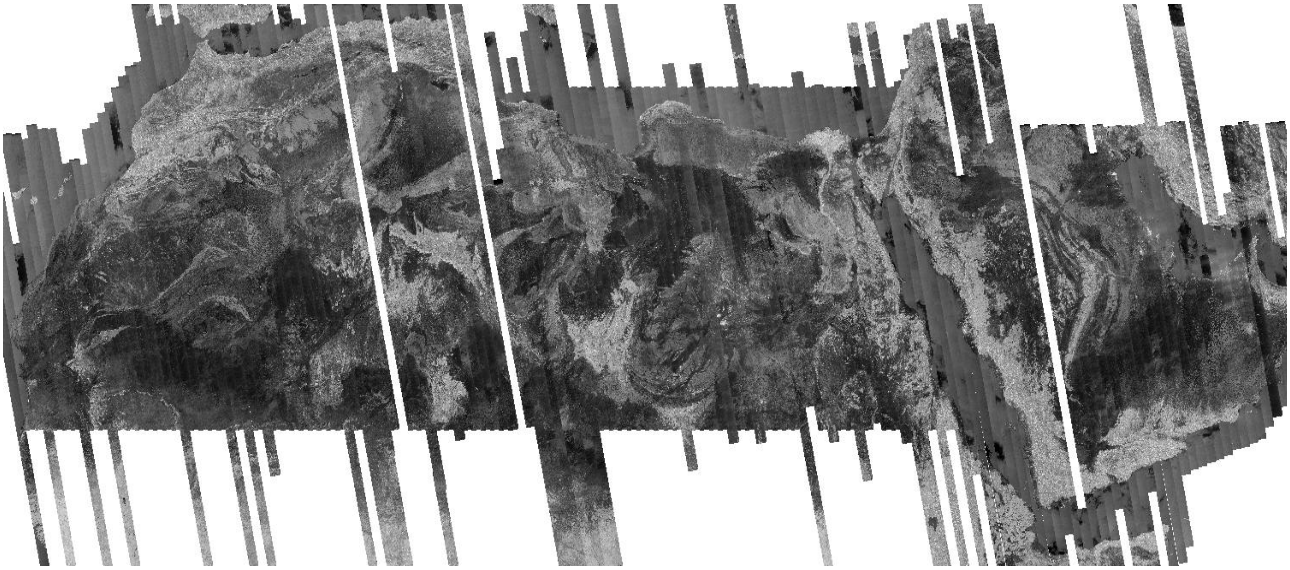

Figure 4. PALSAR mosaic from acquisition cycles 12 and 13, covering Sahara and Arabia (JAXA/METI ).

A full coverage of Sahara in HH and HV polarizations was acquired in June and July 2007 (ascending cycles 12 and 13). Using our own data processing chain, we produced a geocoded mosaic of Sahara and Arabia from more than 400 dual-polarization PALSAR strips (fig. 4). It covers latitude between 17-37$^{o}$N and longitude between 17$^{o}$W and 60$^{o}$E. This dataset constitutes a unique tool for the scientific community to study the paleo-environment and paleoclimate of North Africa. It will also help build more complete geological maps in support to future water prospecting in arid and semi-arid regions [8].

We started the analysis of the PALSAR mosaic over eastern Sahara. As a first result, we mapped a major paleodrainage system in eastern Libya, that could have linked the Kufrah Basin to the Mediterranean coast through the Sirt Basin, possibly as far back as the middle Miocene. Images from the PALSAR sensor clearly reveal a 900 km-long river system (fig. 5), which starts with three main tributaries (north-eastern Tibesti, northern Uweinat and western Gilf Kebir / Abu Ras) that connect in the Kufrah oasis region. The river system then flows north through the Jebel Dalmah, and forms a large alluvial fan in the Sarir Dalmah. The sand dunes of the Calanscio Sand Sea prevent deep orbital radar penetration and preclude detailed reconstruction of any possible connection to the Mediterranean Sea, but a 300 km-long link to the Gulf of Sirt through the Wadi Sahabi paleochannel is likely. If this connection is confirmed, and its Miocene antiquity is established, then the Kufrah River, comparable in length to the Egyptian Nile, will have important implications for the understanding of the past environments and climates of northern Africa from the middle Miocene to the Holocene [9]. Future work concern the analysis of tha PALSAR mosaic to map paleodrainage networks in western Sahara (Mauritania, Niger, Mali). We aslo plan to apply the same approach to study subsurface geology in arid regions of northen China (Sinkiang and Badain Jaran deserts).

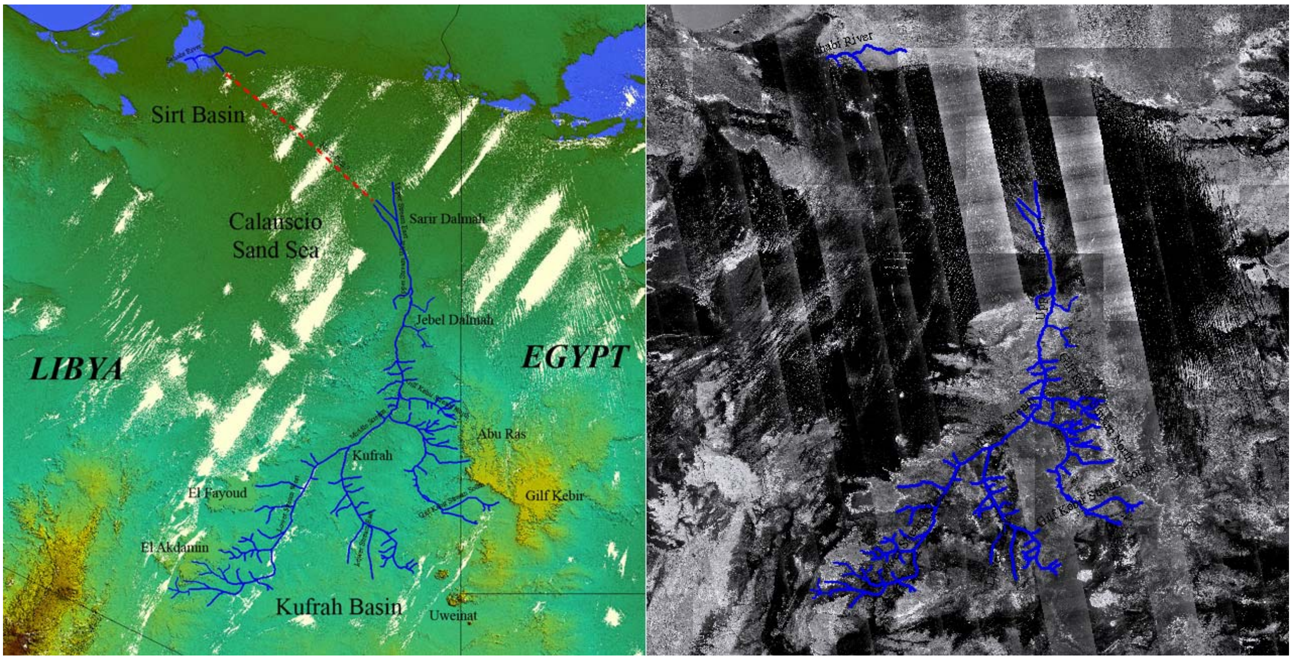


Figure 5. The Kufrah River (in blue) mapped onto SRTM topography (left) and PALSAR mosaic (right). The red dotted line represents a possible path to the Mediterranean coast (JAXA/METI ).

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