# Focus Earth

## The Velingara Circular Structure – A meteorite impact crater?

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Planetary exploration has shown that virtually all planet surfaces are cratered from impacts. It is now clear that impacts have been a dominant geological process throughout the early Solar System, and also that the Earth has experienced the same bombardment as the other planetary bodies. In more recent geologic time, there is evidence that at least one mass-extinction event, notably that of the dinosaurs and many other species 65 million years ago, is linked to global effects caused by a major impact event.

Most of the terrestrial impact craters that have ever been formed, however, have been obliterated by other terrestrial geological processes, such as sedimentation and over-thrusting. However, relatively recent events and impacts can still be found in very old geologic formations that remain exposed. To date, approximately 150 impact craters have been identified on Earth. Almost all of them have been recognised since 1950, and several new structures are being found each year.

Observing our Moon, the morphology of impact craters changes with crater diameter. Only the smallest impact craters have a bowl-shaped form. As the crater diameter increases, slumping of the inner walls and rebounding of the depressed crater floor create progressively larger rim terracing and central peaks. At larger diameters, the single central peak is replaced by one or more peak rings, resulting in what are generally termed ‘impact basins’.

On Earth, the basic types of impact structures are either simple structures, up to 4 km in diameter, with uplifted and overturned rim rocks, surrounding a bowl-shaped depression partially filled by breccias, or complex impact structures and basins, generally 4 km or more in diameter, with a distinct central uplift in the form of a peak and/or ring, an annular trough, and a slumped rim. The interiors of these structures are partially filled with breccias and rocks melted by the impact.

The study and understanding of impact craters has become a concern for the preparation of missions to the Moon and to other planets, notably Mars. Unlike most impact phenomena in the Solar System, such structures on Earth are easily accessible and can be imaged by many different Earth-observation satellites. In order to contribute to such a catalogue, observations have been collected from ESA’s two ERS spacecraft. An example of the potential for observing and measuring the morphology of possible impact events using the Synthetic Aperture Radar (SAR) aboard ERS is given below.

The 48 km-diameter Velingara circular structure in Senegal (Fig. 1) was first discovered on Landsat and NOAA AVHRR images. Developed in mid-Eocene marine sediments, it has been buried by up to 90 m of post-Eocene non-fossiliferous continental sediments. Its central part constitutes the Anambe basin, which hosts the SODAGRI agricultural enterprise, and in which centripetal drainage concentrates in a swampy area of hydromorphic sandy-clayey soils. According to drilling and geophysical data, the central part of the structure is occupied by sub-cropping (3 - 4 m depth) Neoproterozoic or Palaeozoic basement rocks. These features point strongly towards a possible meteorite-impact-crater origin for the structure. Decisive evidence of shock metamorphism is now being sought, by analysing thin sections from surface and drilling-core rock samples.

The series of images presented here shows first a Landsat-5 Thematic-Mapper image in which the existence of a ring structure is suggested by the concentric arrangement of the different land covers (Fig. 2). In corresponding data from ERS's SAR sensor (Figs. 3a and b), the structure is even less pronounced. The

Figure 1. Location map of the study area

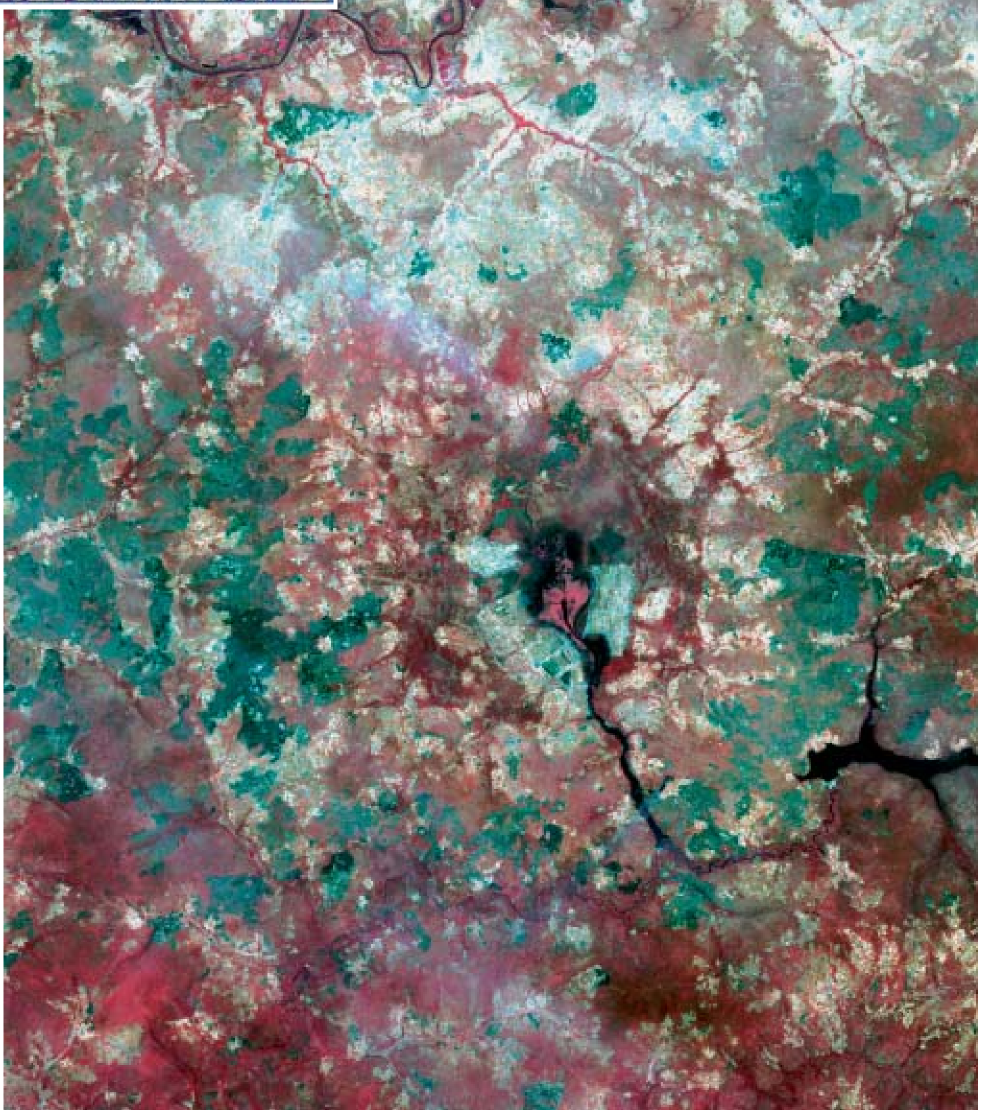

Figure 2. Landsat-5 Thematic-Mapper imagery (TM bands 4,3 and 2 in red, green and blue, respectively). The ring structure, first seen in such data, is highlight by the land-forms and drainage patterns:
- White: bare soil; white spots are spaces around a house or village
- Dark greenish-blue: laterite of bare soil covered with dry grass
- Cyan/green: bare soil of agricultural fields
- Light red/magenta: green trees of savannah vegetation and gallery forest
- Dark red: dense shrub or forest
- Red-brownish: extensive shrub, in leaf.

vegetated shallow lake is just visible in the centre, and the land cover is represented in different grey levels, with forested areas being brighter. Some of the towns and villages appear as bright points, including the town of Velingara.

Two radar images acquired by ERS-1 and ERS-2 during the tandem-configuration phase (with the two satellites acquiring data over the same ground area 1 day apart), were the basis for producing several SAR interferometric products, the first being a coherence image (Fig. 4). This image evaluates the degree of phase conservation, which is proportional to the temporal variation in the ground conditions between the two ERS acquisition dates. In this image, bright tones correspond to no change or high coherence. In general, they correspond to very low or scarce vegetation. This coherence image shows a similar pattern to Landsat, but with radial arrangements more pronounced, most likely due to the drainage system.

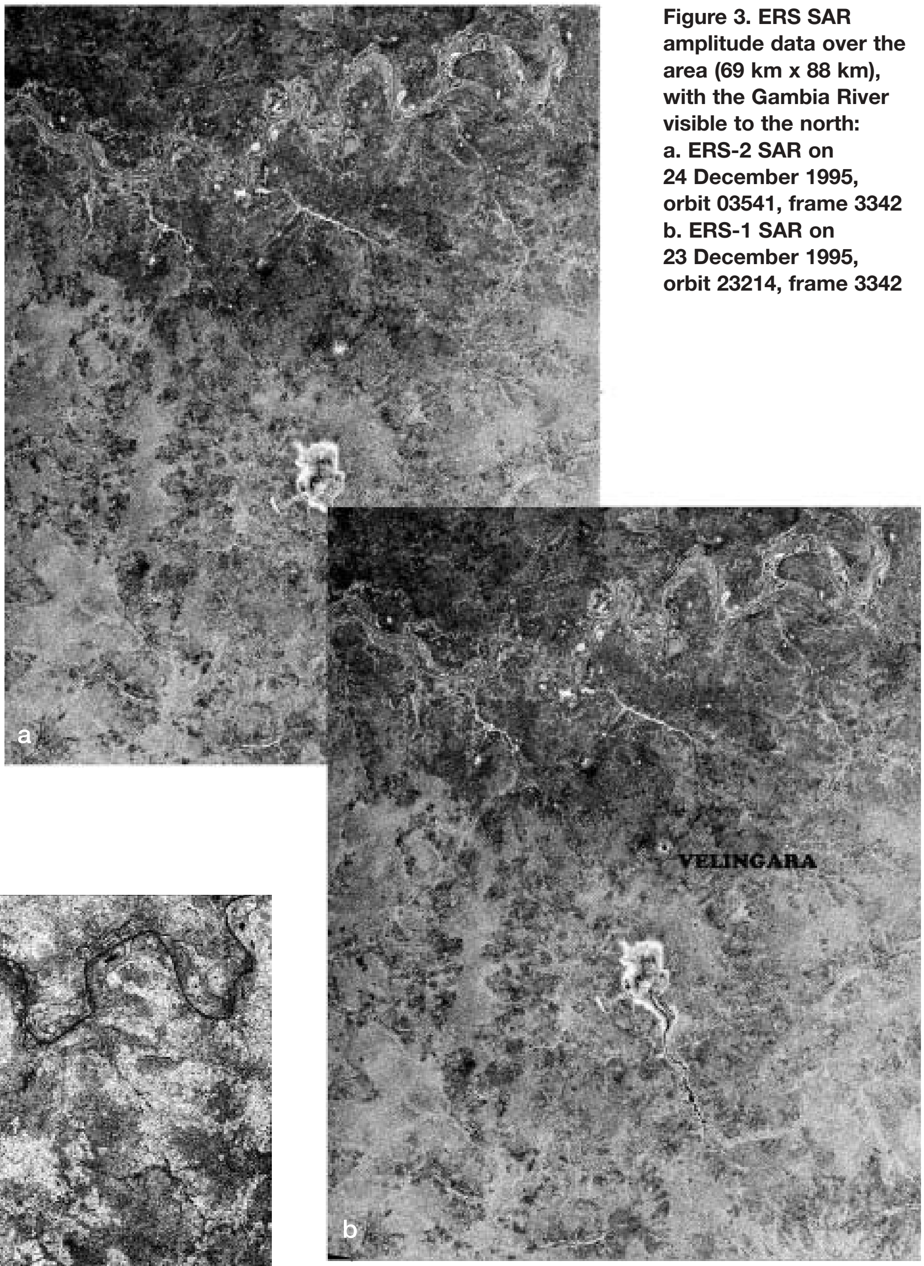

**Figure 3. ERS SAR amplitude data over the area (69 km x 88 km), with the Gambia River visible to the north:**
**a. ERS-2 SAR on 24 December 1995, orbit 03541, frame 3342**
**b. ERS-1 SAR on 23 December 1995, orbit 23214, frame 3342**

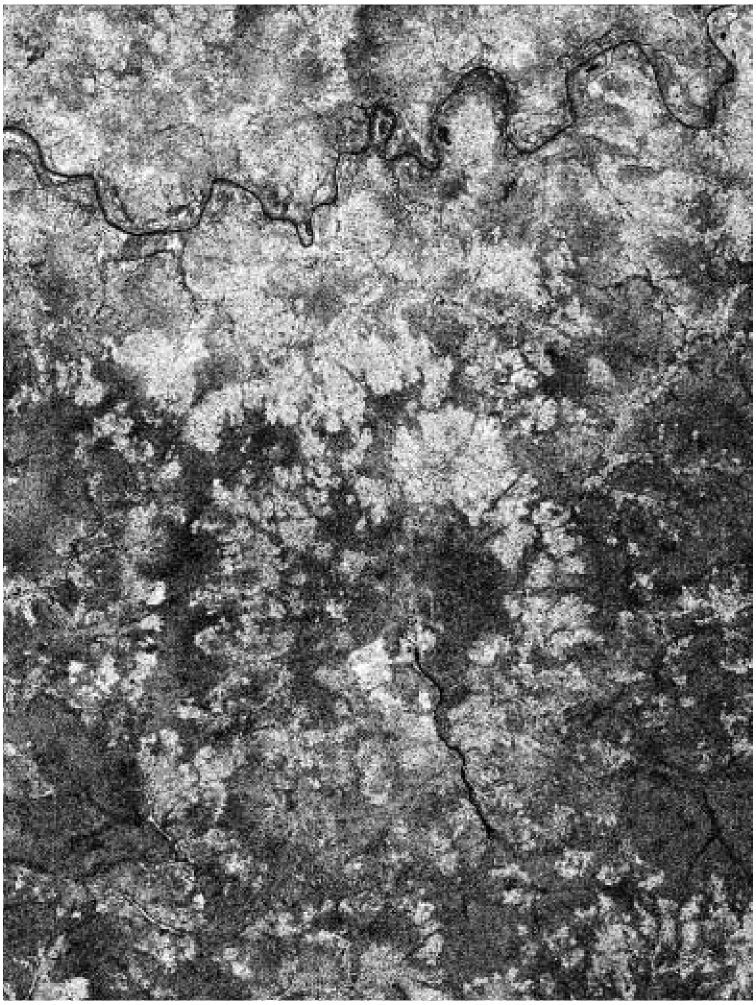

**Figure 4. Coherence image (phase correlation between the two acquisitions) computed from an ERS tandem pair of SAR images, taken on 23 and 24 December 1995. Bright areas represent high coherence, which include scarce vegetation and settlements. Dense vegetation is less coherent and appears darker, while water always appears black (no coherence). Coherence images are also useful for DEM quality assessment and for change detection**

*Interferometric Synthetic Aperture Radar (InSAR) is a technique for extracting three-dimensional information of the Earth's surface by using the phase content of complex radar data. The technique involves the use of pairs of SAR images from the 35-day repeat-pass ERS-1 or ERS-2, or the 1-day interval ERS-1/ERS-2 tandem orbits. An InSAR product is the interferogram, which is obtained by computing the phase differences between the corresponding pixels in the two input images. Another product is the coherence image, which depicts the changes in ground conditions between the two acquisitions. Using these products and passing through the phase-unwrapping (phase-to-height conversion), a Digital Elevation Model (DEM) is generated*

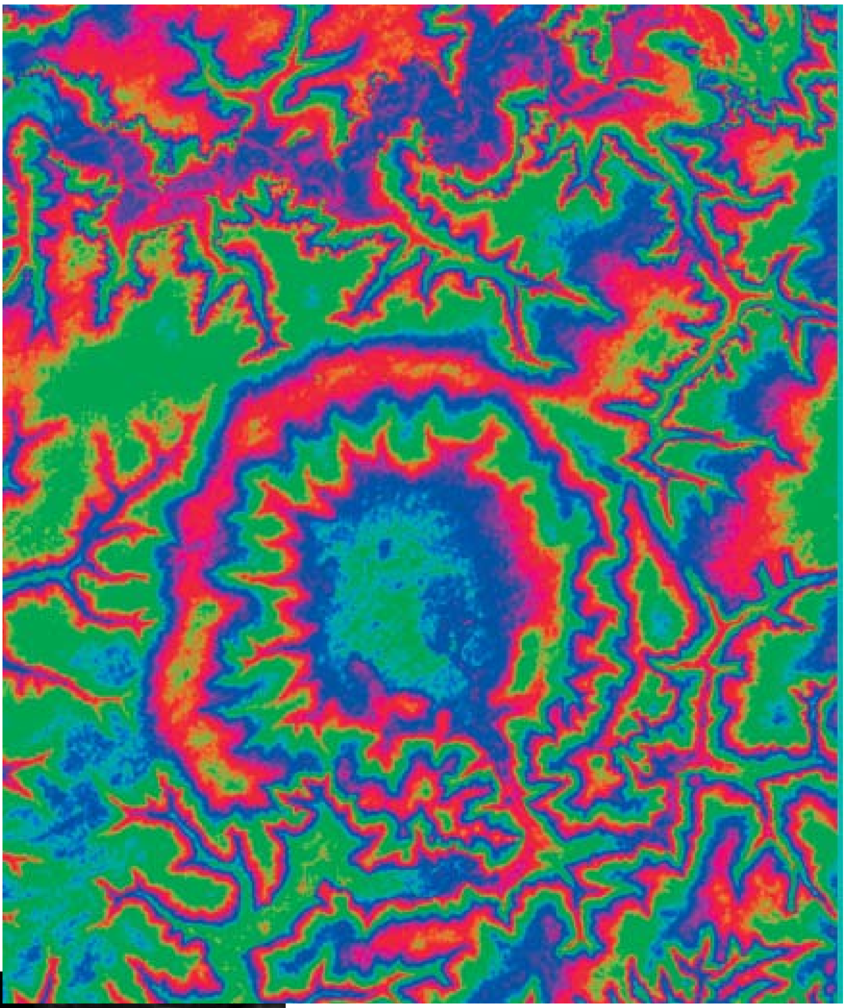

**Figure 5. Interferogram derived from the 23/24 December 1995 ERS SAR tandem pair. The interferometric fringes, which represent phase differences between the two data sets, are colour-coded (from blue = 0 deg, to red = 360 deg). They resemble contour lines on a topographic map. Each fringe cycle represents a relative height change of 26 m. Due to the height differences, the morphology can be appraised: a ring structure is clearly visible**

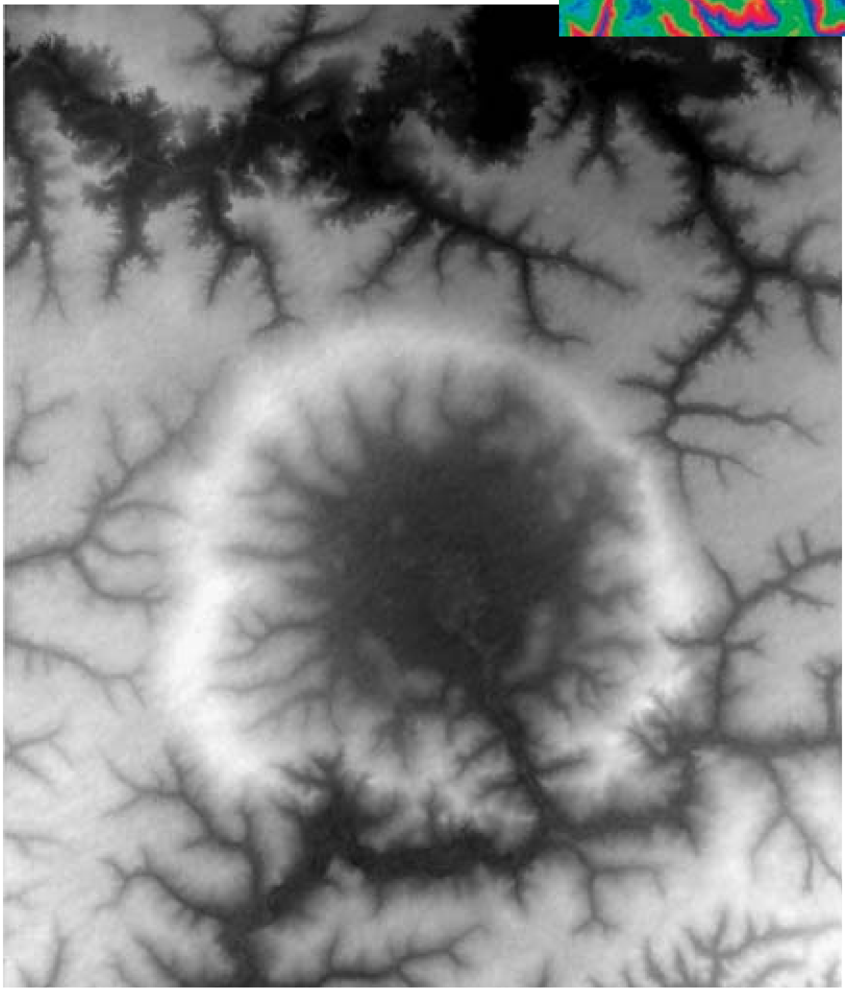

**Figure 6. A Digital Elevation Model (DEM) derived from the fringe image (interferogram) by phase unwrapping and phase-to-height conversion. Higher areas are bright, lower areas are dark**

Height differences can be visualised by quantifying the phase difference (Fig. 5) between the dual-input SAR data. In this fringe image, the circular structure becomes clearly visible, and the radial drainage system towards the centre of the crater is also evident. Similar to contour lines on a traditional topographic map, each fringe cycle, from red to green, to blue and again to red, represents a relative height change of 26 m in either direction. This value is derived from the perpendicular distance between the two precisely known orbits, which was determined to be 346 m.

A further computational step is the unwrapping of the fringes, resulting in quantitative height information. The final step of computing a Digital Elevation Model (DEM) consists of transforming the pixel values in the unwrapped image from radians to metres. Figure 6 shows the resulting data set in a black and white display, representing low and high elevations, respectively. The ring structure is now clearly visible, but details in the landforms cannot be distinguished. The morphology of the ring structure can be optimally enhanced by artificially illuminating such a DEM. This is illustrated in Figure 7.

Finally, a combination of illuminated DEM and colour-coded height information can be produced (Fig. 8), permitting a full appreciation of both the morphology and the absolute height. On this final product, not only is the height information on the well-developed circular structure evident, but it becomes clear that there are also indications of further elements typical for large impact craters, namely the remains of one or two concentric 'peak rings' in the 'impact' basin.

In conclusion, it can be said that, considering:
- the small altitude variations in the zone of interest
- the fact that the ERS SAR pair used in this case was not the best in terms of baseline and coherence,

the InSAR methodology seems very promising for producing DEMs of remote areas, even in low topography. DEMs generated with SAR interferometry can find a broad spectrum of applications, ranging from the planning of mobile-telephone networks and roads or railways, to geo-tectonic analyses in which land forms, fault mapping and geomorphic features in general, have a high priority.

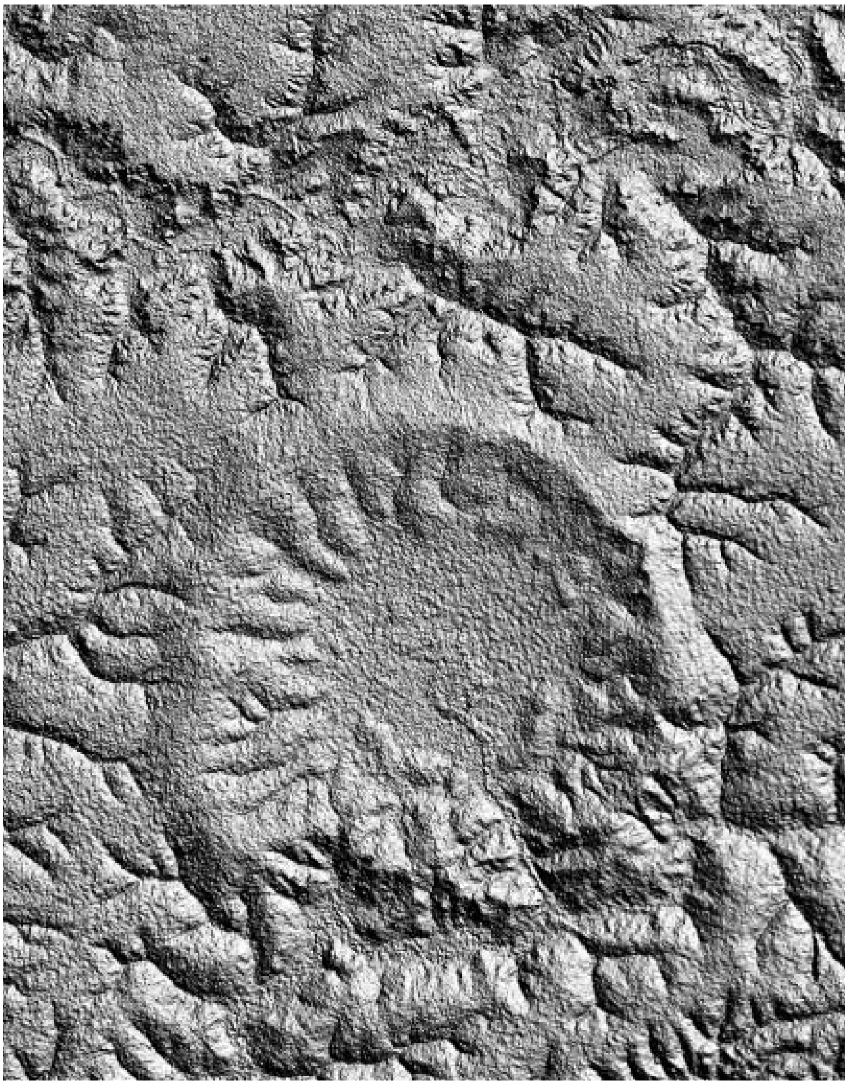

**Figure 7. Hill-shaded relief based on the DEM as shown in Figure 6. The relief scale has been exaggerated to emphasise the morphology of the ring structure**

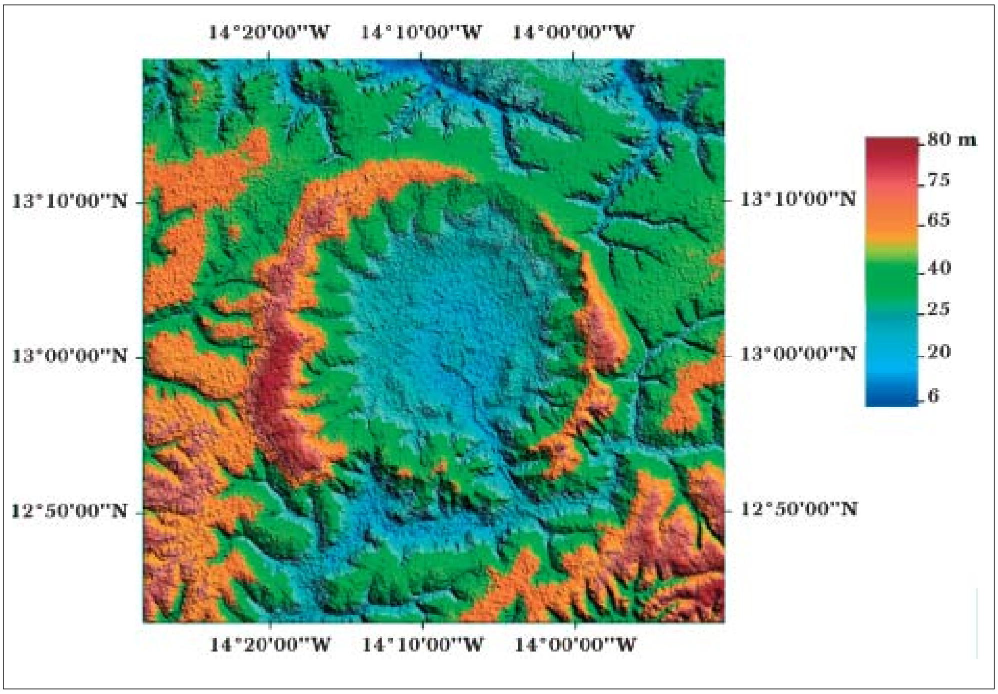

**Figure 8. After geo-coding of the data by using the ERS orbital information (SLCI product header file), the final product is an image-map including the hill-shaded relief of the DEM and the colour-coded height information. The remains of a multiple ring pattern, a characteristic for large impact craters, are apparent (image size 69 km x 67 km)**

## Acknowledgement

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