# RECONSTRUCTING THE ANCIENT WATERSCAPE NEAR THE MEIDUM PYRAMID COMPLEX IN EGYPT

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## ABSTRACT

The location of the Meidum Pyramid on the Western Desert Plateau of Egypt, distant from the Nile River, suggests the presence of a nearby ancient river that was used as a logistical route for transporting construction materials and personnel to the site. Radar satellite data led to the discovery of two buried river courses bordering the pyramid structure. The termination of the pyramid's causeway exactly at the bank of the eastern river course implies that this ancient channel was active concurrently at the time of the pyramid's construction. Furthermore, given that the plateau, where the pyramid lies, is encircled by the two river channels, it is likely that this plateau was formerly an unstable river island that did not favor heavy structures. This study offers a potential explanation as to why the pyramid structure has partially collapsed and the site was abandoned.

***Index Terms***— Radar remote sensing, GIS, digital elevation model, sandy desert, ancient waterscape.

## 1. INTRODUCTION

Since the beginning of the Pharaonic time, the Nile River has played a fundamental role in the rapid growth and expansion of the Ancient Egyptian civilization. Serving as their lifeline in a largely arid landscape, the Nile provided sustenance and functioned as the main water corridor that allowed for the transportation of goods and building materials. For this reason, most of the ancient key cities and monuments were located in close proximity to the banks of the Nile River and its branches. Over time, however, the main course of the Nile River laterally migrated, and its peripheral branches silted up, leaving behind many ancient Egyptian sites distant from the present-day river course [1-3].

A multitude of research efforts conducted in the region have provided essential information regarding the ancient Nile course. Nevertheless, no prior study has been yet conducted near the site of the Meidum Pyramid Complex (Fig 1). Meidum, built by Pharaoh Snefru, founder of the Fourth Dynasty (~4613 - 4494) of the Old Kingdom (~4613 - 4181), was the first known attempt in Egyptian history to construct a true, smooth-sided pyramid. The pyramid, while completed, appears to have shown signs of collapse and was, therefore, abandoned. The cause of the pyramid collapse is still under debate. Snefru instead opted to move his pyramid construction projects to Dahshur, some 40 km to the north of the Meidum pyramid, where he built two other pyramids (the Bent Pyramid and the Red Pyramid).

The main goal of this work is to utilize radar remote sensing to understand the environmental parameters that may have influenced the decision to locate the pyramid at this specific site and the possible cause for the pyramid's partial collapse and eventual abandonment.

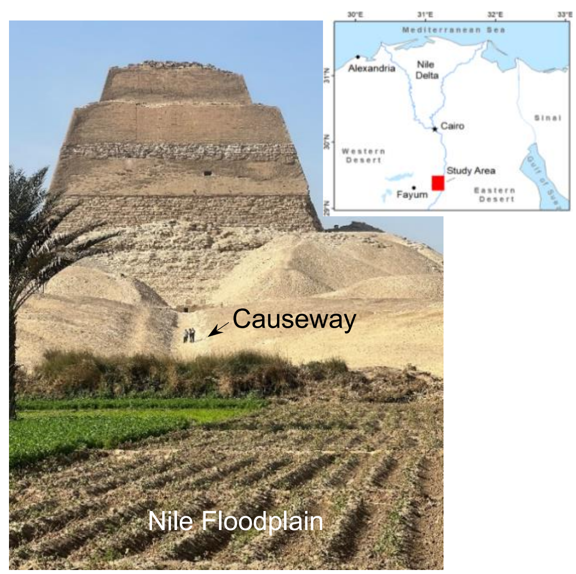


**Fig. 1.** Photo of Meidum Pyramid showing its causeway leading to the cultivated Nile floodplain in front of the structure. The location of the study area is marked in a red box on the upper right map. (Photo was taken by the authors).

## 2. MATERIALS AND METHODS

This work used satellite remote sensing and GIS complemented by archaeological resources to provide insight into the ancient waterscape near the Meidum Pyramid Complex. Unlike optical sensors, which image the Earth's surface, radar sensors are able to image the subsurface terrain due to its unique ability to penetrate the ground and produce images of hidden features. In the present study, Radarsat-1, the standard mode C-band satellite data, an active microwave sensor using a single wavelength of 5.7 cm horizontally polarized (HH) from year 2001, was employed. The SAR processing sequences, using ENVI v. 5.7 SARscape software, have generated geo-coded, orthorectified, terrain-corrected, noise free, radiometrically calibrated, and normalized radar images.

In low electrical, loose, fine grain material, Radarsat-1 has the capacity to penetrate below the surface, stripping away the aeolian desert sands to expose hidden sub-terrains. This satellite was used primarily for its old and extensive archive (dating back to 1995), which pre-dates the urban development boom that occurred in Egypt. Such development, which intensified drastically after the construction of the Aswan High Dam in the 1960s, has created a so-called "imaging barrier" for the radar beam (owing to roughness effect and dielectric constant), thus preventing it from penetrating the desert sand to image the subsurface terrain [4]. Radarsat-1 has been proven to be successful in detecting paleo-hydrological features buried under shallow desert aeolian sands [5]. As radar data alone makes it difficult to determine whether the detected landforms are on the surface or below, optical satellite data must be incorporated into the analysis. As a result, an early Landsat TM scene from 1984 was used in this study.

Previous studies have shown that combining radar topographic imagery (e.g., SRTM) with SAR images improves the extraction and delineation of mega paleo-drainage systems and lake basins concealed under present-day topographic signatures [6]. In low lying areas, such as the Nile floodplain, detailed elevation data can detect abandoned channels and fossilized natural levees, which are crucial elements for reconstructing ancient waterscapes. Here, TanDEM-X (TDX) topographic data, from the German Aerospace Centre (DLR), has been utilized in ArcGIS Pro v. 3.1.2 software due to its fine spatial resolution of 0.4 arc-second (∼12 m) (DLR contract # DEM_OTHER2886). TDX shorter wavelength (X-Band) of of 3.1 cm (9.65 GHz) and has a relative vertical accuracy of 2 m. In this study, Radarsat-1, Landsat 4 imagery (1984) and TDX derived DEM were fused, using the principal components (PC) spectral sharpening in ENVI, to generate a hybrid imagery for the site for better visual interpretability.

## 3. RESULTS AND DISCUSSION

Radar observations and high-resolution elevation data for the Nile floodplain and its desert margins provide evidence for the existence of two ancient river branches bordering the Meidum Pyramid Complex on both the western and eastern sides.

### 3.1. Meidum Pyramid Back Branch

Despite being invisible in optical satellite data due to its buried state beneath aeolian sand, the former branch on the western side (referred to hereafter as the MB Branch, which stands for the Meidum Back Branch), is distinctly visible in Radarsat-1microwave image (Fig 2a and Fig 2b) due to its instrumental sand penetration capability. In Radarsat-1 imagery, the valley floor of this ancient river course appears darker than the surrounding surfaces, indicating subsurface fluvial deposits. The smooth deposits appear dark owing to the radar signals attenuation. Radar incidence angle plays also a crucial role in influencing the penetration depth [7]. In desert regions, paleo-drainage, in particular, can be discriminated preferentially at large incidence angles [7, 8]. Analyzing the study area using ALOS PALSAR longer wavelength (L-band) of 23.62 cm, from 2007, revealed that the MB Branch is partially obscured, likely due to the rapid urbanization in Egypt before the PALSAR satellite was launched.

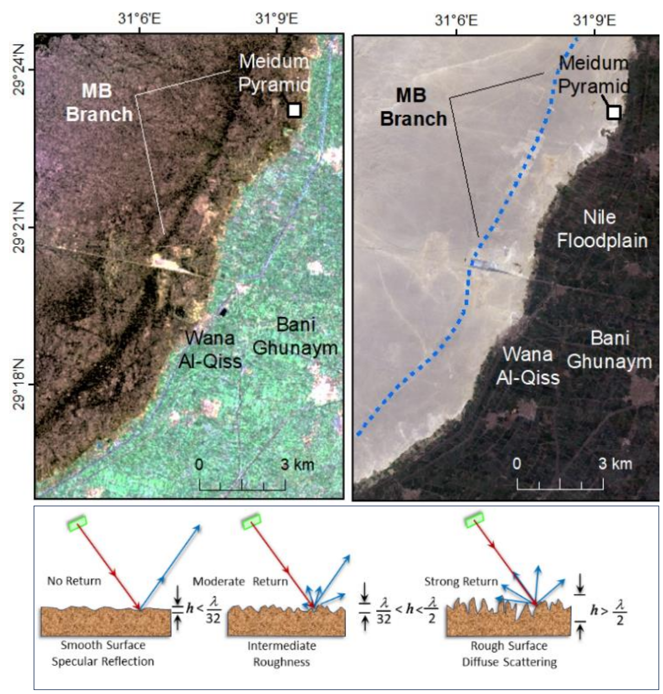


**Fig. 2.** Radar data revealing an ancient river branch passing in the back of the pyramid structure. (a) A hybrid Radarsat-1, Landsat 4 and DEM imagery showing the MB Branch to the west of the pyramid. (b) LS optical imagery where the MB Branch is invisible (path marked in dashed blue line) and hidden beneath the desert sand. (c) Conceptual sketch of the dependence of surface roughness on the sensor wavelength λ (modified after [9]).

In areas of sandy desert, specific requirements must be fulfilled to image subsurface structures. This includes finegrained, physically homogenous, and very dry sand (less than 1% moisture content) [7, 8]. In dry sandy areas, smooth surfaces typically seem darker in radar imagery because specular reflection tends to reflect more radar energy away from the radar receiving antenna whereas the rough surfaces appear brighter because of the diffused reflection, which reflects more of the radar energy toward the radar sensor (see Fig 2c) [7- 9]. The penetration depth varies according to the radar wavelength used at the time of imaging. Considering that Radarsat-1's C-Band has a penetration capability of approximately 50 cm in dry sand surface [8, 10], this would suggest that the riverbed of these channels is covered by at least half a meter of desert sand.

The MB branch, which is presently located more than 7 km away from the present-day Nile course, is 0.8-1 km wide and approximately 21 km long. TDX topographic data shows this branch to be a narrow-elongated depression with a depth ranging between 5 and 10 m. Its western position in relation to the Meidum Pyramid suggests it to be pre-Old Kingdom since in ancient Egypt, pyramids and cemeteries were almost always built on the western side of the Nile at the dry desert margin.

### 3.2. Meidum Pyramid Front Branch

Furthermore, the TDX topographic data unveiled a second major former river course directly in front of the Meidum Pyramid on its eastern side (Fig 3). Unlike the MB Branch to the west, this eastern channel (referred to hereafter as the MF Branch, which stands for the Meidum Front Branch) is invisible in Radarsat-1 data due to the presence of dense farmlands (mostly of high moisture content) in the floodplain, which limits the radar detection of underlying fluvial deposition.

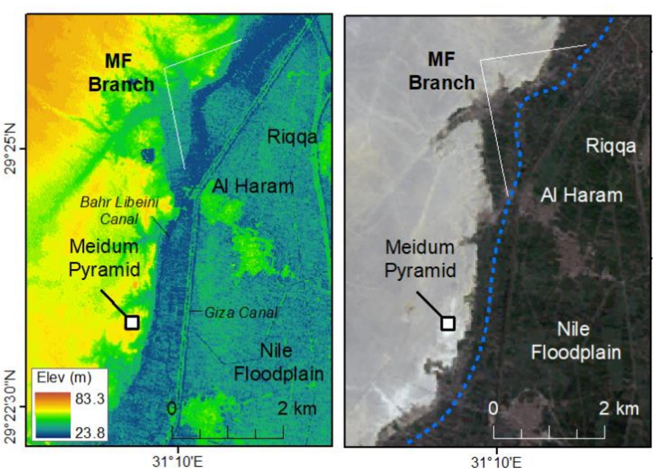


**Fig. 3.** Radar data revealing an ancient river branch passing in front of the pyramid structure. (a) TDX radar topographic data showing the MF Branch east of the pyramid. (b) LS satellite image (RGB true color) where the MF Branch is invisible by the Nile cultivated land (path marked in dashed blue line).

Topographic analysis of TDX data shows that the visible segment of this river branch is about 12 km long and 2 - 4 m deep. The branch has a channel width of 250-500 m, similar to that of the contemporary neighboring Nile course and is situated around 4.5-6 km away from the modern Nile River. This waterway could have simply been a secondary branch of the Nile or the main course of the Nile River before its eastward migration. If this river was indeed the earlier main Nile River course and was active during the Old Kingdom, it would indicate an eastern migration rate of 1-1.3 km per millennium, which is similar to the river migration rate estimated near the ancient city of Memphis in the north [11].

The size and longitudinal continuity of the MF Branch and its proximity to the Meidum Pyramid site implies a functional waterway of great significance. Furthermore, the west-east orientation of the Meidum Pyramid's causeway, perpendicular to the MF river course, and the termination of this causeway at the western riverbank of the MF Branch to the east (Fig 4), imply that this ancient river branch was simultaneously active at the time of the pyramid's construction. A causeway is a ceremonial raised walkway, which provides access to the pyramid site and was part of the religious aspects of the pyramid itself [12].

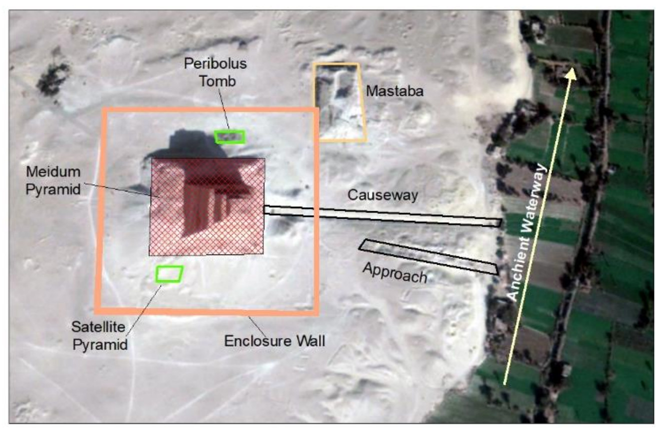


**Fig. 4.** Showing the west-east orientation of the causeway of the Meidum Pyramid, perpendicular to the MF Branch. The termination of this causeway at the western riverbank of the MF Branch implies that this branch was active during the Old Kingdom of Ancient Egypt, particularly at the time of the pyramid's construction. (Base image is from Google Earth Pro).

The existence of the two river courses (MB and MF branches) around the plateau where the pyramid lies suggests this plateau to be a former river island (Fig 5). An island at this specific site could have developed from a major riverbank deposit which is still being compacted, or it could have formed as a result of a river bifurcation into two courses. A structural geology investigation of the site indicates that this proposed river island is densely fractured. Similar to other known river islands, the Meidum island might not have been stable enough to bear the substantial weight of a pyramid structure. The implication of the potential island and its instability could shed some light on the possible cause of the abandonment of the Meidum pyramid construction site.

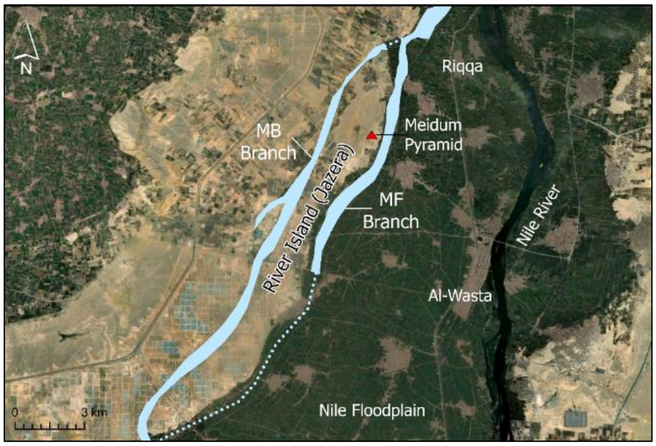


**Fig 5.** The newly discovered river branches hidden beneath the desert sands and farmlands forming a river island. The Medium Pyramid is situated on the eastern side of the island which could explain the reason behind the abandonment of the site in ancient times.

## 4. CONCLUSION

Radar satellite data utilized in this study is useful in locating similar former hidden river systems in arid regions worldwide. In this study, analysis of radar satellite data has led to the discovery of two previously unknown buried ancient river courses that passed behind and in front of the Meidum pyramid complex providing the first ever map of the paleo-hydrological setting in the Meidum area. While invisible in optical images, these buried river channels are clearly visible in radar imagery due to radar's ability to penetrate sands in desert regions as well as distinguish subtle surface topographic features in flat river floodplains. No inferences about the age of these ancient rivers or the dominant climatic condition can be made at this stage, however, the enormity of their channels implies that these rivers were active when rainfall was plentiful in the past.

Mapping these hidden rivers allowed us to piece together a complete picture of ancient Egypt's former landscape and water transportation routes in the site of Meidum. As these river courses surround the plateau where the pyramid lies, suggests this plateau to be once a former river island with an unstable subsoil that does not favor heavy structures. This hypothesis provides a possible answer to the yet unsolved mystery of why the pyramid structure has partially collapsed and the entire site was abandoned. This could provide insight into how earlier inhabitants lived and how the changes in the landscape shaped human activities in the region.

## 5. ACKNOWLEDGMENT

This work was funded by NSF grant # 2114295 and the Explorer Club Discovery Grant. TanDEM-X data was awarded to E.G. and R.E by the German Aerospace Centre (DLR) (contract # DEM_OTHER2886).

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