The Origin of the Great Bend of the Nile from SIR-C/X-SAR Imagery

Robert J. Stern and Mohamed Gamal Abdel Salam

The course of the Nile in northern Sudan follows a contorted path through Precambrian bedrock. Radar imagery shows that basement structures control the river’s course in this region. Northward-flowing segments follow Precambrian fabrics, whereas east-west segments follow faults of much younger age. These faults may reflect recent uplift of the Nubian Swell and deflection of the river to the southwest to form the great bend of the Nile.

The Nile (6825 km long) (1) transports water from high-rainfall regions in Ethiopia and equatorial Africa across the Sahara Desert to Egypt. In northern Sudan, the Nile forms a great bend, first flowing north from Khartoum, then southwest for over 300 km before it resumes its northward course (Fig. 1). Bedrock fabrics are an important control on the course of the Nile in this region (2, 3), although relations between crustal movements and the river’s course are poorly understood. Here we present remote sensing data on this part of the Nile, acquired with the SIR-C/X-SAR imaging radar system (4) during two flights of the NASA space shuttle Endeavor in 1994. These data reveal how bedrock structures of different age control much of the Nile’s course. Many of these structures could be mapped on the ground, but such studies have been inhibited by the size and harsh climate of the study area. Other structures are revealed for the first time by the radar images (5).

The evolution of the Nile can be traced from the Late Miocene desiccation of the Mediterranean Sea (6). Lowering of the hydrologic base level led to the carving of a deep canyon [2.5 km deep beneath Cairo (1)] and vigorous stream piracy upstream from Aswan. Reflooding of the Mediterranean basin at the end of the Miocene drowned this canyon, and sedimentary filling of the estuary produced the broad and fertile Nile floodplains north of Aswan [the "Egyptian region" of (7)]. The Cataract region of the Nile extends 1850 km south from the first cataract at Aswan to the sixth cataract just north of Khartoum. Although parts of this region are occupied by broad floodplains, the Nile is mostly incising its channel into Precambrian basement (8) (Fig. 1).

We focused on the third, fourth, and fifth cataract stretches. The third cataract stretch extends north over basin exposures from about 19°45'N to Lake Nasser, as the river traverses the Nubian Swell (Fig. 1 and Fig. 2A) (9). The fourth cataract stretch extends SW from the bend at Abu Hamed, where the Nile flows over basement rocks for about 200 km before Cretaceous sandstones are encountered (Fig. 1). The fifth cataract stretch extends NNW from Arbatra for over 200 km to Abu Hamed (Fig. 2B) and is entirely over Precambrian basement rocks.

Cataract-region Precambrian granitic and metamorphic rocks (Fig. 1) (10-12) were covered by Cretaceous sandstones (13) affected by 47- to 81-million-year-old igneous intrusions and lava flows (14). Volcanic fields younger than 15 million years ago (Ma) are scattered across the Bayuda Desert (15). Pleistocene and younger alluvial cover occurs discontinuously along the river’s course. Cataract-region rocks preserve three sets of planar fabrics. The early structures formed at about 700 Ma (10, 12), have NE-SW to E-W orientations and are exemplified by the Abu Hamed and Dam et Tor fold-and-thrust belts (Fig. 2B). These structures rarely control the course of the Nile, probably because they generally do not dip steeply. They are overprinted by the younger NNW-trending sinistral Abu Hamed and Abu Dis shear zones in the east (Fig. 2B) (12) and the N-S trending Akasha and Kosha shear zones to the west (Fig. 2A). These formed about 600 Ma (16) and strongly control the Nile along the third and fifth cataract stretches. There is no evidence for NW-SE Mesozoic rift structures that control much of the course of the Nile in the central Sudan (17). E-W steep, normal, or strike-slip faults of late Cretaceous or younger age are common along the third cataract stretch. Faults with this orientation are rarely reported from the Sudan (18) but are common in southern Egypt (19). Because they affect Cretaceous sedimentary rocks, these faults must be Cretaceous and younger in age. An intrusion is truncated by an E-W fault (Fig. 2A), giving an apparent displacement up to the south. A similar intrusion at Jebel Sheikh (Fig. 2A) yields a K-Ar isochron age of 90 ± 2 Ma (20).

At the start of the fourth cataract stretch downstream from Abu Hamed, the river follows the northern margin of the Abu Hamed fold-and-thrust belt. Southwest of this, the river follows multiple channels controlled by NNE and E-W fractures (Fig. 3). The E-W portion of the Nile south of Us Island is controlled by a zone of "highly crushed granite," whereas the NNE-SSW portion of the Nile west of Us Island (Fig. 3) follows easily eroded dikes and "splintered granite" (21). A recent change in the river’s course is demonstrated by a previously unknown paleochannel 25 km long (Fig. 3), lying as much as 10 km north of the Nile. A shuttle photograph of the region SW of that shown in Fig. 3 shows a north-flowing stream course, now crossed by the Nile. These observations indicate that the course of the Nile along the fourth cataract stretch has recently shifted to the south, due to relative uplift of adjacent regions of the Nubian swell. NNE and E-W structural controls cannot be inferred from the course of the paleochannel, and we infer that fracturing accompanied or followed tectonic uplift. The Nile in Egypt has had dramatic changes in flow regime during Quaternary time (1, 22). These are generally ascribed to clastic changes in Ethiopia and equatorial
Africa (23). Our data suggest that tectonic activity in the cataract region may also have affected the hydrologic regime of the Nile during the Quaternary.

The fifth cataract stretch (12) of the Nile follows structures associated with the boundary between the Nile craton and the Arabian-Nubian Shield (Fig. 4A). These structures continue north of Abu Hamed (24), yet the Nile turns away to form the great bend. The course of the Nile in Egypt also approximates the Late Precambrian continental margin (25), and this structure might be expected to control the Nile north from Atbara all the way to the Mediterranean.

The great bend must be due to relative uplift of the Bayuda Massif or Nubian Swell or both, and it is generally thought that uplift of the Bayuda is responsible (3, 26). If so, the Nile should have been diverted away from the Bayuda to the east or north. Instead, the Nile follows a well-established course through the fifth cataract region to the east, and the diversion in the fourth cataract area is to the south. The Nubian Swell is interpreted as a late Paleozoic uplift (27), although the E-W faults reported here require a much younger age for some tectonic activity. Furthermore, the presence of marine sediments of Lower Tertiary age in northern Sudan south of the Nubian Swell indicates that this was not a positive tectonic element at that time (28). We thus suggest that recent uplift of the Nubian Swell diverted the Nile to form the great bend. In this case, E-W faults in northern Sudan and southern Egypt may be of late Cenozoic age and reflect Nubian Swell uplift. This hypothesis also explains the pro-

**Fig. 1** (left). Geological map of the Cataract region of the Nile. Lithological divisions are simplified after maps published in 1988 by the Geological Research Authority of the Sudan and Robertson Research. Structural trends are based on interpretation of an SIR-C/X-SAR mosaic that comprises data taken SRL-1 50.4, 66.5, 82.42, 130.4, and 146.4, and SRL-2 82.42. Locations of Fig. 2, A and B, and Fig. 3 are outlined with dashes. **Fig. 2** (right). Structural features of the third (A) and fifth (B) cataract stretches of the Nile, based on interpretation of an SIR-C/X-SAR survey product mosaic of Lp (total power) images. Colored portions of the Nile indicate regions controlled by different structures. Interpretation of the third cataract stretch is based on data taken SRL-1 130.4 and 146.4. KSSZ, Kosha shear zone; ASZ, Akasha shear zone; AHSZ, Abu Hamed shear zone; ADSZ, Abu Dis shear zone; DFTB, Dam et Tor fold-thrust belt.
Interplane Tunneling Magnetoresistance in a Layered Manganese Crystal


The current-perpendicular-to-plane magnetoresistance (CPP-MR) has been investigated for the layered manganese, $\text{La}_{2-x}\text{Sr}_x\text{MnO}_3$ ($x = 0.3$), which is composed of the ferromagnetic-metallic MnO bilayers separated by nonmagnetic insulating block layers. The CPP-MR is extremely large (10^4 percent at 50 kilo-oersted) at temperatures near above the three-dimensional ordering temperature ($T_N \approx 90$ kelvin) because of the field-induced coherent motion between planes of the spin-polarized electrons. Below $T_N$, the interplane magnetic domain boundary on the insulating block layer serves as the charge-transport barrier, but it can be removed by a low saturation field, which gives rise to the low-field tunneling MR as large as 240 percent.

The discovery of the giant magnetoresistance (GMR) in magnetic multilayers (1) has stimulated much interest in relating spin polarization-dependent transport phenomena from the viewpoints of both the underlying physics and their immediate application to magnetic storage and sensor technology. A variety of the GMR structures have so far been investigated, such as antiferromagnetically coupled multilayers (2), granular films (3), spin valve (4), and tunneling structures (5). In these structures, the effects of spin-dependent electron scattering have been assigned to the fundamen-