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The Nubian Swell

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Abstract

We use the name Nubian Swell to refer to a complex, east–west trending structural high in southern Egypt and northern Sudan. This 500 km wide zone of uplifted Neoproterozoic crystalline basement and Paleozoic sediments and parallel troughs extend westward for more than 800 km from the flanks of the Red Sea Hills. The Nile in this region is called the Cataract Nile and is in a youthful stage, particularly in northern Sudan where it is incised in the Neoproterozoic crystalline basement. The northern Cataract Nile flows through the rapids of the Batn el Hajar or 'Belly of Stones' region, characterized by structurally controlled 90° turns, frequent bifurcation and disruption by several cataracts, and near-absence of floodplains. Orbital imaging radar has advanced our understanding of the Nubian Swell, through the discovery and mapping of paleochannels and faults that indicate tectonic uplift during Cenozoic time. Earthquakes in southern Egypt during the early 1980s provide evidence that portions of the Nubian Swell are still tectonically active, with recent seismic activity concentrated where E–W trending structures intersect N–S trending structures of the Aswan corridor. We conclude that the Nubian Swell is an important tectonic feature of North Africa, with episodic but continuing uplift.

1. Introduction

From Aswan to the Mediterranean Sea, the Nile drains a broad floodplain, whose fertile soil has sustained Egyptian civilization for more than 5000 years. This segment, known as the Egyptian Nile, is underlain by a buried canyon that was carved during the late-Miocene desiccation of the Mediterranean and has subsequently been filled with sediment (Said, 1981). The buried canyon disappears south of Aswan, where the Cataract segment of the Nile has a limited floodplain localized along short stretches of the river. Here the Nile is a youthful stream, following narrow, structurally controlled channels that are controlled by faults and shear zones and frequently bifurcate as the river tumbles over rocky cataracts. The First Cataract at Aswan marks the boundary between the Egyptian Nile to the north and the less fertile Nile immediately to the south. This is the traditional boundary between Egypt and the interior of Africa. This boundary also marks the northern flank of a broad tectonic feature referred to here as the Nubian Swell (Holmes, 1965; Stern and Abdelsalam, 1996).

Holmes (1965) described Africa as a region of broad basins surrounded by irregular uplifts (Fig. 1A). One of these uplifts separates Egypt from the Sudan basin to the south, and four of six cataracts are formed along the upper Nile where the river traverses this structural high. Stern and Abdelsalam (1996) introduced the name Nubian Swell to refer to this structural uplift without detailed discussions of its extent and origin. In this contribution, geomorphologic, structural, and lithologic evidence are used to further define the extent of the uplift as well as to argue that the Nubian Swell is a neotectonic uplift. For the purposes of this paper, neotectonic is defined as Pleistocene or younger crustal

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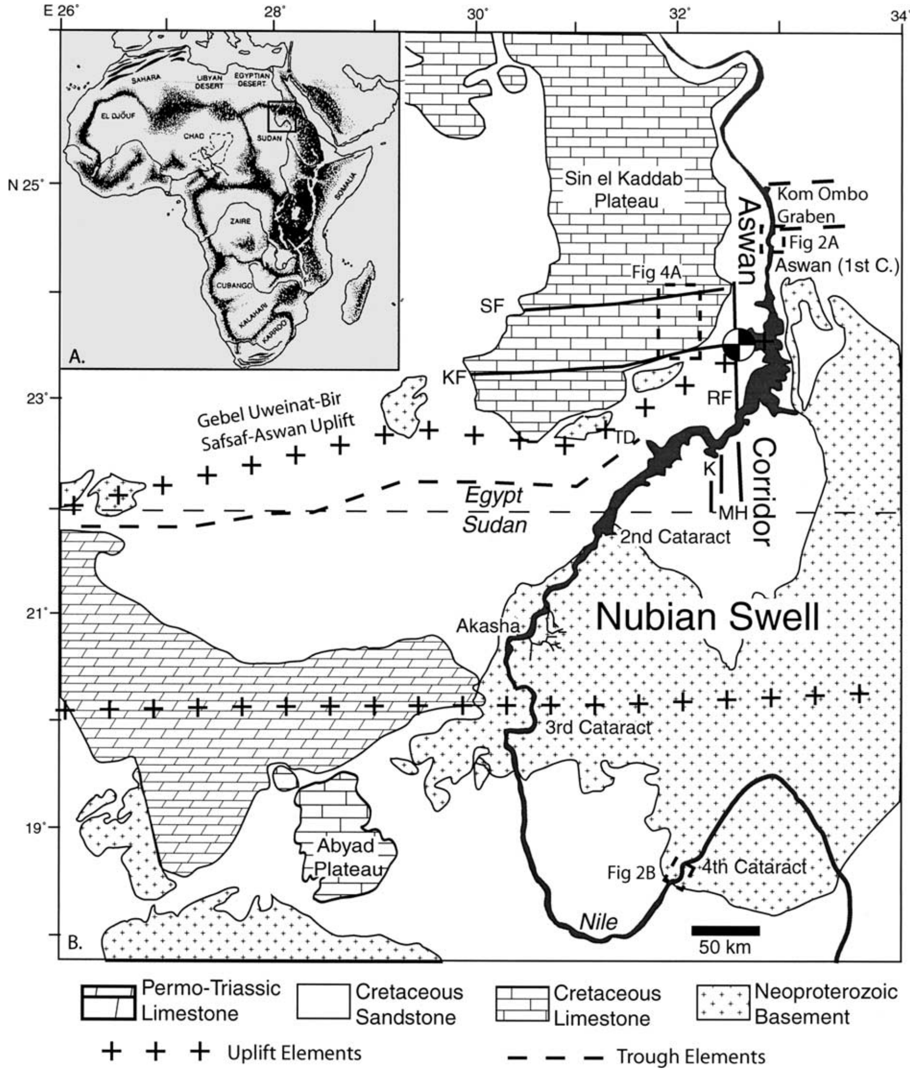

Fig. 1. (A) Africa is described as a region of broad basins surrounded by irregular swells. Modified after Holmes (1965); (B) generalized geologic map of the Nubian Swell, modified after Jas et al. (1988) and Klitzsch et al. (1987). SF = Seiyal Fault; KF = Kalabsha Fault; RF = Rofa Fault; 1st C = first Cataract, K = Korosko; MH = Madiq Hogback. Focal mechanism of the 1981 earthquake is from Toppozada et al. (1984).

movements. Most of the information comes from orbital remote sensing imagery, especially imaging radar, which is uniquely suited for defining major structural and morphological features in this broad and poorly studied region. This technology provides an overview of the Nubian Swell and permits identification of important features that were the focus of field studies. In this regard, our remote sensing field studies of the Nubian Swell demonstrate how this approach can be applied to study other regional geological problems in Africa.

2. Tectonic elements

Within the Nubian Swell, two sets of E–W trending uplifts and associated troughs can be identified (Fig. 1B). The northernmost set includes the relatively narrow (~150 km) Kom Ombo graben (Butzer and Hansen, 1968). This graben has also been referred to as the Kom Ombo–Atmur Nuqra Depression (Issawi et al., 1978), but in this paper we will refer to this E–W trending structure first identified by Butzer and Hansen (1968) as the Kom Ombo graben. The Kom Ombo graben is flanked to the south by the Gebel Uweinat–Bir Safsaf–Aswan Uplift System exposing Precambrian crystalline basement (Schandelmeier et al., 1983). The northern boundary of this uplift lies near the Kalabsha Fault, an active E–W trending dextral strike-slip fault (Fig. 1B).

The second set includes a northern trough defined by the Toshka Depression which is located west of the Nile. This region is being developed as part of Egypt's massive reclamation project known as the New Valley Project (Fig. 1B). This region is also the site of the New Saharan Lakes, formed by overflow from Lake Nasser since 1996. The southernmost element of the Nubian Swell

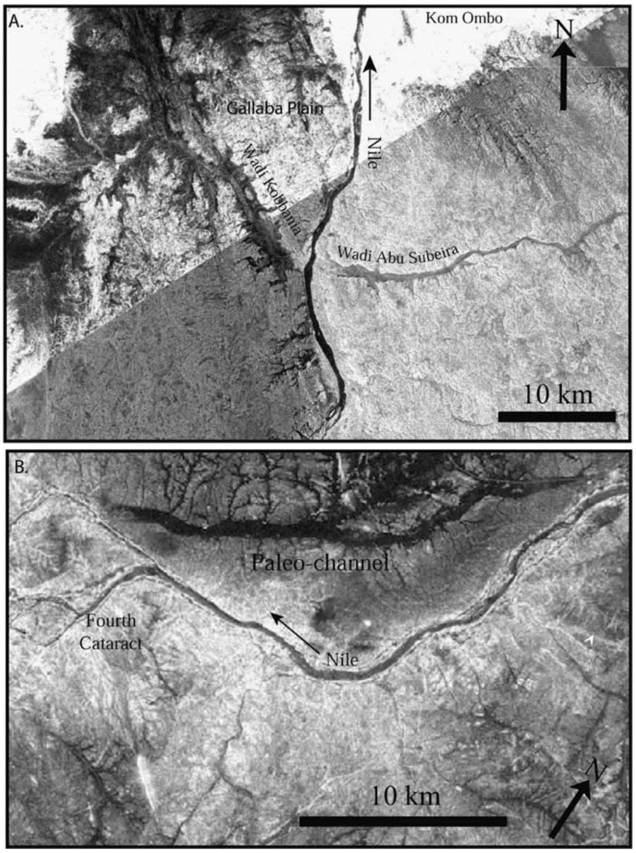

Fig. 2. L-hh SIR-C images of recently reorganized drainages on the flanks of the Nubian Swell. White areas are regions of high radar backscatter; dark areas are regions of low radar return. (A) Kom Ombo area, Egypt. An earlier, W- and NW-flowing local drainage is disrupted by the northward-flowing Nile. (B) Fourth Cataract region, Sudan. An older, abandoned channel of the Nile, incised in bedrock, marks where the Nile used to flow, as much as 10 km NW of its present channel. Disruption of these incised channels is strong evidence for important neotectonic activity on the Nubian Swell. Locations of the figures are shown on Fig. 1.

is a broad uplift that lies in the Sudan, referred to here as the Third Cataract Arch. Numerous E–W faults of the Third Cataract Arch are visible on Shuttle Imaging Radar-Synthetic Aperture Radar (SIR-C/X-SAR) imagery, and field relations indicate that at least some of these faults must be younger than 77 Ma. Recent disruption of the Nile at the Fourth Cataract (Fig. 2B), inferred to reflect neotectonic movements of the Third Cataract Arch, implies that uplift is much younger than 77 Ma.

3. Paleohydrological evidence

The course of the Nile through northern Sudan and southern Egypt has been strongly affected by the continued uplift of the Nubian Swell as manifested by the youthful geomorphology of the northern Cataract Nile (Stern and Abdelsalam, 1996). The relatively youthful nature of the northern Cataract Nile is also shown by the fundamentally different nature of tributaries that flow into the Nile to the north and south of Aswan. North of Aswan, the drainages mark deeply incised, buried canyons, whereas tributaries south of Aswan have shallow bedrock floors (Butzer and Hansen, 1968). These buried canyons mark where streams cut down to the lower level of the Nile canyon established during the Messinian stage (late-Miocene) when the Mediterranean was desiccated at ~5.3–6.0 Ma (Krijgsman et al., 1999). This implies that the drainages to the south were not active during the Messinian and thus are much more recent features than the northern drainages. Additionally, we see no new evidence for a south flowing Nile as has been highlighted by Issawi and McCauley (1992) and contested by Burke and Wells (1989).

Examples of shallowly buried paleochannels and fossil rivers that preserve a history of Nubian Swell tectonic movements are remarkably displayed by SIR-C/X-SAR radar imagery. Three examples of these drainages are (1) beneath the Selima Sand Sheet, (2) adjacent to Wadi Kobbania and (3) along the Fourth Cataract.

Pleistocene and possibly older drainages known as the 'Radar Rivers' are found within a trough extending west of the Toshka Depression to the Selima Sand Sheet (Fig. 1B). These buried, fossil rivers were one of the most spectacular discoveries of the SIR-A experiment (McCauley et al., 1982; Burke and Wells, 1989; Robinson et al., 2000). Discovery of the Radar Rivers, last active during the latest Pleistocene, has resulted in continuing controversy about their age and flow direction. The most recent interpretation (Robinson et al., 2000) suggests an interior drainage leading to a basin which is now buried beneath the Selima Sand Sheet. This basin lies on the western extension of the Toshka Depression, and for this reason we name this low the "Selima-Toshka Trough". We do not know if the trough is continuous because the topography across this region is poorly known.

All through late-Pliocene and early-Pleistocene time, the drainage basin of the river which flowed north through Egypt was much smaller than at present, draining only the Eastern Desert of Egypt and the northern flank of the Nubian Swell. Butzer and Hansen (1968) proposed that this drainage was fundamentally reorganized in Middle Pleistocene time by the appearance of a southerly-sourced, transcontinental stream which approximates the modern Nile. Our interpretation of radar images supports this hypothesis. The radar image (Fig. 2A) shows that Wadi Kobbania and Wadi Abu Subeira may be remnants of that older drainage, and that Wadi Kobbania, which now flows SE into the Nile, may have originally been the downstream continuation of Wadi Abu Subeira, perhaps joining the modern Nile channel north of Idfu (Fig. 2A). The radar image does not reveal any channels beneath the Gallaba Plain, but it seems likely that this expanse may be underlain by a buried extension of the old, NW-flowing channel. However, SIR-C/X-SAR imagery provides spectacular evidence of the hypothesis that tributaries of a north-flowing drainage of Plio-Pleistocene age in Egypt were disrupted by a younger stream that originated south of the Nubian Swell. We further infer that tectonic movements opened a N–S corridor that allowed water to flow across the Nubian Swell.

Through analysis of SIR-C/X-SAR imagery, Stern and Abdelsalam (1996) discovered a paleochannel near the Fourth Cataract of the Nile in northern Sudan (Fig. 2B). This paleochannel is approximately 25 km long and lies as much as 10 km north of the present Nile and appears to be incised in bedrock. Clearly, the Nile along the Fourth Cataract stretch has shifted to the south in recent times. Although the reason for this avulsion is unknown, Stern and Abdelsalam (1996) inferred that the presence of the Fourth Cataract Paleochannel was best explained by tectonic uplift to the north of the Nile which would have shifted the course of the river southward. This interpretation finds indirect support in the chaotic, immature nature of the Nile immediately downstream, where the river bifurcates into multiple, fracture-controlled channels around the Fourth Cataract. This further indicates recent tectonic disturbance of the stream. It is unknown whether the paleochannel avulsion and the Fourth Cataract rejuvenation were caused by the same tectonic events, but both must be recent and are interpreted to be related to tectonic activity of the Nubian Swell.

4. Structural evidence

The northern Cataract Nile has the characteristics of a youthful stream as it flows north across the Nubian Swell (Fig. 1). These characteristics include a narrow or nonexistent floodplain, frequent bifurcation of its channels, development of several cataracts, and many sharp 90° bends (Fig. 3A). Lineament analysis of the SIR-C/X-SAR imagery shows that there are predominant N–S and E–W fracture sets in the Third Cataract Arch region (Thurmond, 2002). Fig. 3B reveals a large igneous ring complex which is clearly visible in the western part of the image. To the north of the ring complex, a major E–W trending fault splits a second ring complex in half with the southern half preserved. The presence of lave plugs shown as bright spots in the radar image to the north suggests that this is a down-to-the-north normal fault. These ring complexes are part of an extensive tract of late-Cretaceous igneous activity, and the two ring complexes in Fig. 3B have been dated using K–Ar techniques at 77 Ma and 87 Ma (Franz et al., 1993). On this basis, the east–west trending fault in Fig. 3B is younger than 77 Ma. This and similar E–W trending faults and fractures control the course of the Cataract Nile when it flows east and west.

Outcrops of Cretaceous Sandstone in the Second Cataract region are largely obscured by windblown sand, hence making them difficult to be studied with optical imagery. Due to the sub-surface (down to ~6 m) imaging capabilities of the L band in this environment (Abdelsalam et al., 2000), analysis of the radar imagery better shows the extent of the Nubian Sandstone outcrops as well as numerous fractures and faults shallowly buried under sand (Fig. 3C). The sandstone in this region is late-Cretaceous in age, this again shows that the faults are Cretaceous or younger in age. The presence of post-Cretaceous faults located at the Second and Third Cataracts indicates that the Nubian Swell has been active in post-Cretaceous time.

Earthquakes have been documented in southern Egypt since Pharaonic times. The toppled head and torso of one of the four Ramses statues at Abu Simbel resulted from seismic activity about 1210 BC (Kebeasy, 1990). On November 1981, a 5.6-magnitude earthquake occurred 45 km SW of the Aswan High Dam (Fig. 1B). Up to 40 micro-earthquake events were recorded per day since then. The majority of the epicenters concentrated in the vicinity of Gebel Marawa, where the E–W Kalabsha fault (Fig. 4A and B), intersects a major N–S trending fault. Focal mechanisms (Toppozada et al., 1984) and field mapping (Issawi, 1969; Woodward-Clyde, 1985; Abdeen et al., 2000) indicate dextral strike-slip displacement along the E–W trending Kalabsha fault. The Seiyal fault just to the north has no record of historic activity but its surface expression and trend is similar to the Kalabsha fault (Figs. 1B, 4A). Additionally, the transtensional setting has produced sag synclines that have developed along the Seiyal and Kalabsha faults (Fig. 4A and C) and dextral offset of a recent drainage can be seen along the Kalabsha fault (Fig. 4A). These E–W trending faults are two of numerous Cretaceous and younger faults that are part of a ~600 km wide belt of E–W-trending faults that extend from the Bayuda Desert in northern Sudan up to the central part of Egypt (Stern and Abdelsalam, 1996). The presence of these neotectonic features supports the theory that parts of the Nubian Swell are presently tectonically active.

It must be emphasized that there is also evidence for important N-S trending structural elements associated with the Nubian Swell. We have already commented on the indications near Kom Ombo that the transcontinental drainage found a way across the Nubian Swell as a result of some transverse disturbance. This inference is supported by the nature of the course of the Nile downstream from Aswan and the edge of basement outcrops to the east, which further reflect the importance of the N–S structures. The 1981 earthquake occurred at the

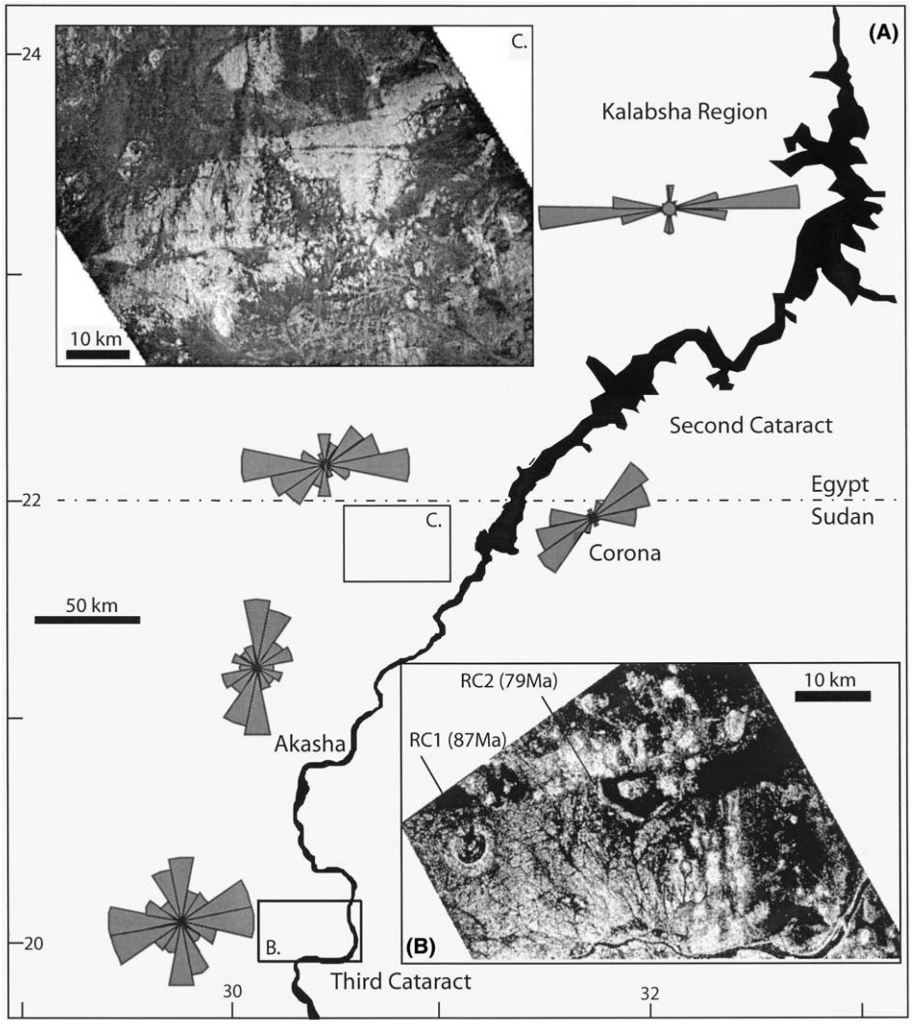

Fig. 3. (A) Lineament analysis of the Cataract Nile through the Nubian Swell. Rose diagrams are based on lineament analysis performed on SIR-C/X-SAR imagery and Corona Satellite Photography. (B) A portion of an L-hh band (wavelength = 24 cm; horizontally transmitted and horizontally received) SIR-C image over the Third Cataract region showing an unfaulted ring complex (RC1; 87 Ma) and another ring complex cut by an E–W normal fault (RC2; 77 Ma). C) Subset of L-hh SIR-C image showing faults and fractures through Cretaceous Sandstone, west of the Nile's Second Cataract.

intersection of the E–W trending Kalabsha and the N–S trending Rofa faults. Butzer and Hansen (1968) identified several N–S trending structures which affect Cretaceous sandstone in the region between Aswan and the Second Cataract. They suggested that the bend of the Nile at Korosko (Fig. 1B) is due to deflection of the river around one of these N–S structures. They further described the Madiq Hogback as"a zone of strong and complex disturbance" (p. 207). This complex, N–S trending structure, which we call the 'Aswan corridor' (Fig. 1B) also serves to truncate important E–W trending structures such as the Kom Ombo graben and the Seiyal and Kalabsha faults. We suggest that tectonic movements opened up a corridor for the Nile to flow across the Nubian Swell.

There are also numerous earthquakes that have been recorded in Egypt in locations that are quite distant from the Nubian Swell and have been interpreted to be reactivation on old structures by Red Sea-related tectonics (El-Araby and Sultan, 2000). While the N–S trending structures of the Aswan corridor may be related to Red Sea tectonics, the E–W structures of the Nubian Swell are not interpreted as being related as these structures trend perpendicular to the Red Sea.

5. Lithological evidence

Further evidence of Cenozoic uplift of the Nubian Swell comes from the distribution of limestone of Lower Tertiary age found south of the Nubian Swell on the Abyad Plateau in northern Sudan (Fig. 1B; Barazi and Kuss, 1987). These outcrops represent the southernmost outliers of the southern Tethys shelf, which was once continuous across Egypt and northern Sudan. Intervening exposures of Precambrian crystalline basement and

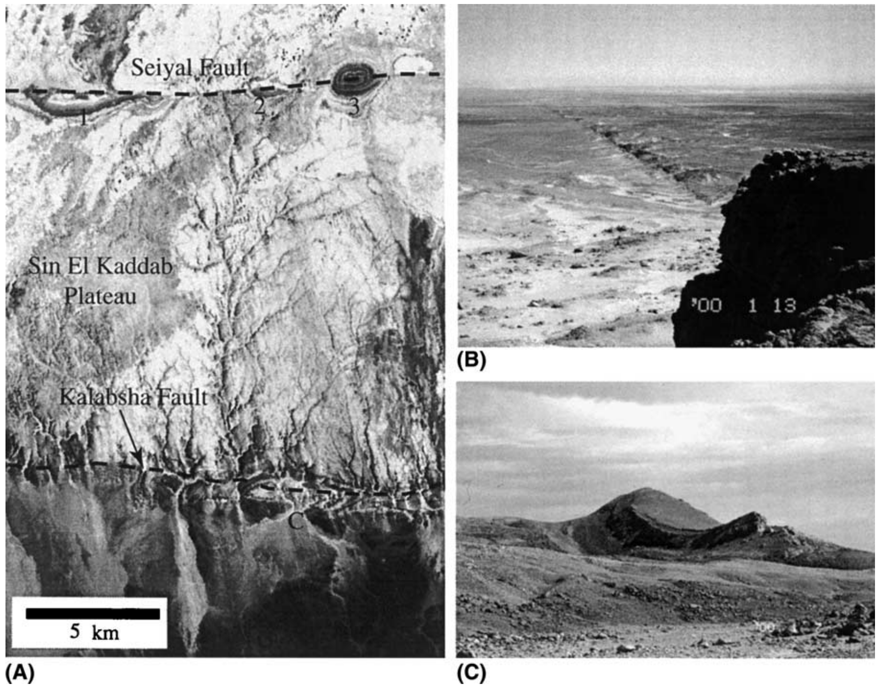

Fig. 4. Details of Kalabsha and Seiyal faults. (A) Landsat TM (RGB = 3–2–1 as grayscale) subscene over Kalabsha and Seiyal faults, southern Egypt. Location of 'sag' syncline in C is labeled 'C'. Other suspected sag synclines on the Seiyal Fault are marked 1, 2, and 3. Note apparent 3 km right-lateral offset of stream just to the west of the sag syncline. Location of (A) is shown in Fig. 1. Note youthful drainage and tension gashes north of Seiyal Fault. (B) View of Kalabsha Fault, looking east from Sin El Kaddab Plateau towards Lake Nasser. (C) Sag syncline on Kalabsha Fault, viewed from the west.

late-Paleozoic and early-Mesozoic sedimentary rocks now separate these limestone outcrops from correlative units in the Sin el-Kaddab Plateau in southern Egypt by 350 km (Fig. 1B). Tertiary limestone deposits between the Sin el-Kaddab Plateau and the Abyad Plateau are interpreted to have been removed by erosion along the Nubian Swell during mid- to late-Cenozoic time.

Additional evidence suggests that structural elements of the Nubian Swell have a long history. Klitzsch (1986) inferred from regional facies and stratigraphic relationships that the E–W trending Uweinat–Aswan uplift first formed in late-Paleozoic or early-Mesozoic time. It appears that the Kom Ombo graben controlled Middle to Upper Pliocene marine sediment deposition, suggesting that Nubian Swell structures were well-developed by this time. This is consistent with the fact that there appears to have been a significant drainage divide associated with the Nubian Swell during the late-Miocene development of the Egyptian Nile.

6. Conclusions

The Nubian Swell has been active since early-Mesozoic time with portions that are currently active. Two pairs of E–W trending uplifts and troughs make up the extent of the Nubian Swell: (1) the Third Cataract Arch/Selima-Toshka Trough and (2) the Gebel Uweinat–Bir Safsaf–Aswan Uplift/Kom Ombo graben. E–W structures north of the Third Cataract Arch have been disrupted by N–S trending structures of the Aswan Corridor, the formation of which allowed the transcontinental drainage of the modern Nile to cross the Nubian Swell. It is also clear that the Nile drainage across the Nubian Swell is younger than the late-Miocene river farther north. The existence of correlative Tertiary limestone units within the Sin el-Kaddab and Abyad Plateaus, now separated by 350 km of intervening Precambrian and Paleozoic strata, argues for a mid- to late-Cenozoic uplift and erosion. Seismic activity along the Kalabsha fault in 1981 as well as other documented instances of seismic activity during Pharaonic times supports the theory that the northern extents of the Nubian Swell are still active.

SIR-C/X-SAR imagery has revealed numerous post-Cretaceous faults and fractures throughout the Nubian Swell that are the cause for the sharp east–west bends in the Nile throughout the region. Imaging radar has proven to be a powerful tool in studying arid regions such as the Nubian Swell. The sub-surface imaging capabilities of SIR-S/X-SAR imagery have been invaluable in identifying paleochannels and fossil rivers that provide evidence of recent drainage reorganization. Future advances in imaging radar, such as data collected from the Shuttle Topography Radar Mission (SRTM) will further improve our understanding of this dynamic region of Northern Africa.

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