TECTONIC DEVELOPMENT OF THE SOUTHERN RED SEA HILLS OF SUDAN
Evidence from Landsat TM-Mosaic Interpretation

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ABSTRACT

An interpretation of the rather complex tectonic development of the southeastern part of the Red Sea Hills in Sudan is presented. Under adobtion of Landsat TM-mosaicing in combination with LFC-images a tectonic interpretation has been conducted and thus improved the understanding of the tectonic evolution of the region. Fieldworks were carried out to verify the small scale remote sensing data interpretation and also incorporate observations made at outcrop scale. The presentation is adopted on sample areas with features typical for the whole region, and which are not always readable in this quality, to represent the Pan-African dynamometamorphic influences during the terrane accretion.

ZUSAMMENFASSUNG

In diesem Artikel wird eine Interpretation der komplizierten tektonischen Evolution eines Teils der südlichen Red Sea Hills im Sudan vorgestellt. Durch Verwendung eines Landsat TM-Mosaiks in Verbindung mit LFC-Bildern wurde eine tektonische Interpretation vorgenommen, die ein verbessertes Verständnis der tektonischen Entwicklung dieser Region ermöglichen soll. Über mehrere Jahre verteilte Geländeaufenthalte lieferten Ergebnisse, die die kleinmaßstäbigen Fernerkundungsdaten ergänzten. Um den Einfluß des Pan-African mit seiner dynamo-metamorphen Entwicklung während der Terraneakkretion darzustellen, sollen einige Bildbeispiele typische Strkturen aufzeigen, in einer Qualität wie sie allerdings nicht immer auf Landsat TM-Szenen erkennbar ist.

1. Introduction

The Red Sea Hills of NE Sudan form a part of the Arabian-Nubian Shield. These hills constitute a semi-desert plateau of mountains, in a narrow strip of rugged terrain no more than 200 km wide and rising to 2000 m above sea level. The Geology comprises strongly deformed and metamorphosed late Precambrian granite-greenstone terranes. The tectonic setting and evolution of this region in terms of the general structural framework of the southern Red Sea Hills in the Arabian-Nubian Shield is still under debate. Despite the work conducted during the last two decades there are numerous tectonic models under consideration (e.g. VAIL et al. 1983; KLEMENIC 1985; KRÖNER et al. 1987; REISCHMANN 1986; SCHANDELMEIER et al. 1994).

This paper presents a model to establish the various deformations and also estimate major displacements in that region under inclusion of metamorphic events which took place during the Pan-African tectono-thermal event, and their reactivation in the Phanerozoic. Two sample sites will be examined and the regional major faulting and folding patterns presented.

2. Data

Data sources are principally the Landsat Thematic Mapper Images 171/46, 171/47, 171/48, and 172/46, 172/47 aquired in the period between 1985 and 1989. In Addition two MSS images were used to cover cloudy parts of the TM-imagery. The Data sets were radiometrically adjusted and than mosaiced. This gave some problems because of the scanner sensitivity for atmospheric influences like humidity, dust, variations in intensity and directions of wind and elevation differences ranging from sea level upto 2000 m, and the different scanner calibrations of Landsat TM 4 and 5.

Additional valuable information were optained from a series of stereoscopically overlapping Large Format Camera (LFC) frames (1321 - 1324, b/w, Roll 6, STS Mission 41-G (Spaceshuttle), scale 1:751.600, c:306 mm, Hg:230 km). The LFC-images gave a good spatial impression of the terrain.

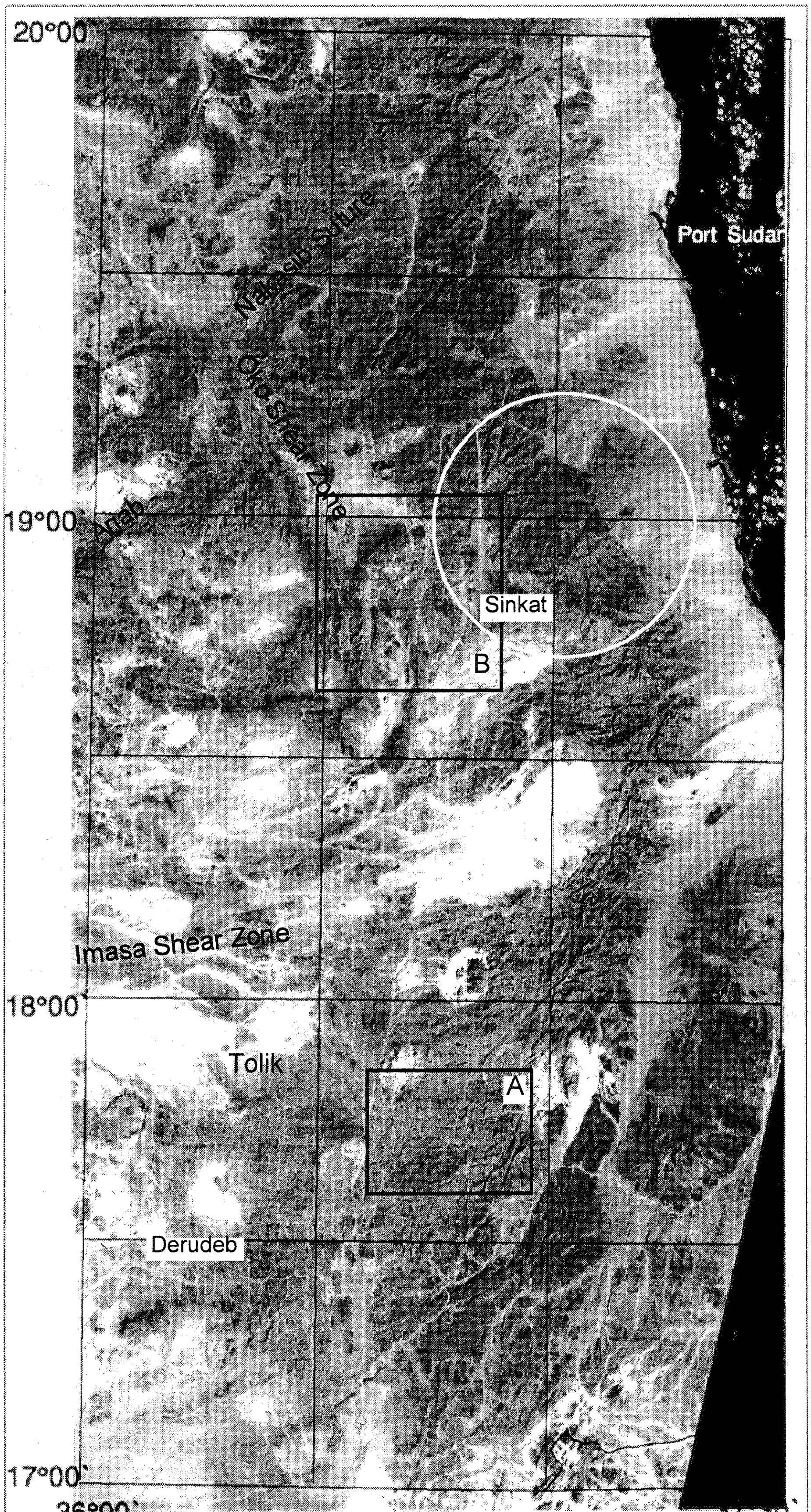

Figure 1: Landsat TM and MSS mosaic for the area of the three quatermillion map sheets of Port Sudan, Sinkat and Derudeb. The frames A and B repesent the position of subsets later on used for detailed illustration of tectonic phenomena. The circle marks the area of a rotated crustal block. (Mosaic from Ott, 1996).

For further interpretation also some small scale arial photograhs of poor quality were used. Ground chekkings were conducted during three field trips of each two to five weeks duration.

3. Interpretation and Discussion

Due to the deformation of lithologic sequences as observed in the images and during the ground check theauthors discriminate 9 stages of structural reworkings. These stages could be further subdivided in varying localities but in this work only regional aspects have been considered.

The first two stages are only visible in outcrop dimensions because they represent a foliation D_1 and the isoclinal folding of this foliation D_2. At most the foliation shows strike directions of E-NE and sometimes more deviation due to the later deformation stages. The dip is in most cases steep but flattens close to thrust planes.

The next two stages D_3 and D_4 developed, in contrast to D_2, folding structures well seen only on the satellite images. They produced axial planes with steeply plunging fold axes, and open to isoclinal limbs. The b-c-plane strikes E-W with undulations of upto 20° N and S. The orientation of the folds with their axial planes striking E-W to NE-SW indicates a crustal shortening along the N-S-direction in deeper crustal levels under conditions of plastic deformation (fig.2, axial traces of syn- and antiforms). Similar structures are reported by MATTAUER (1986) for Tibet.

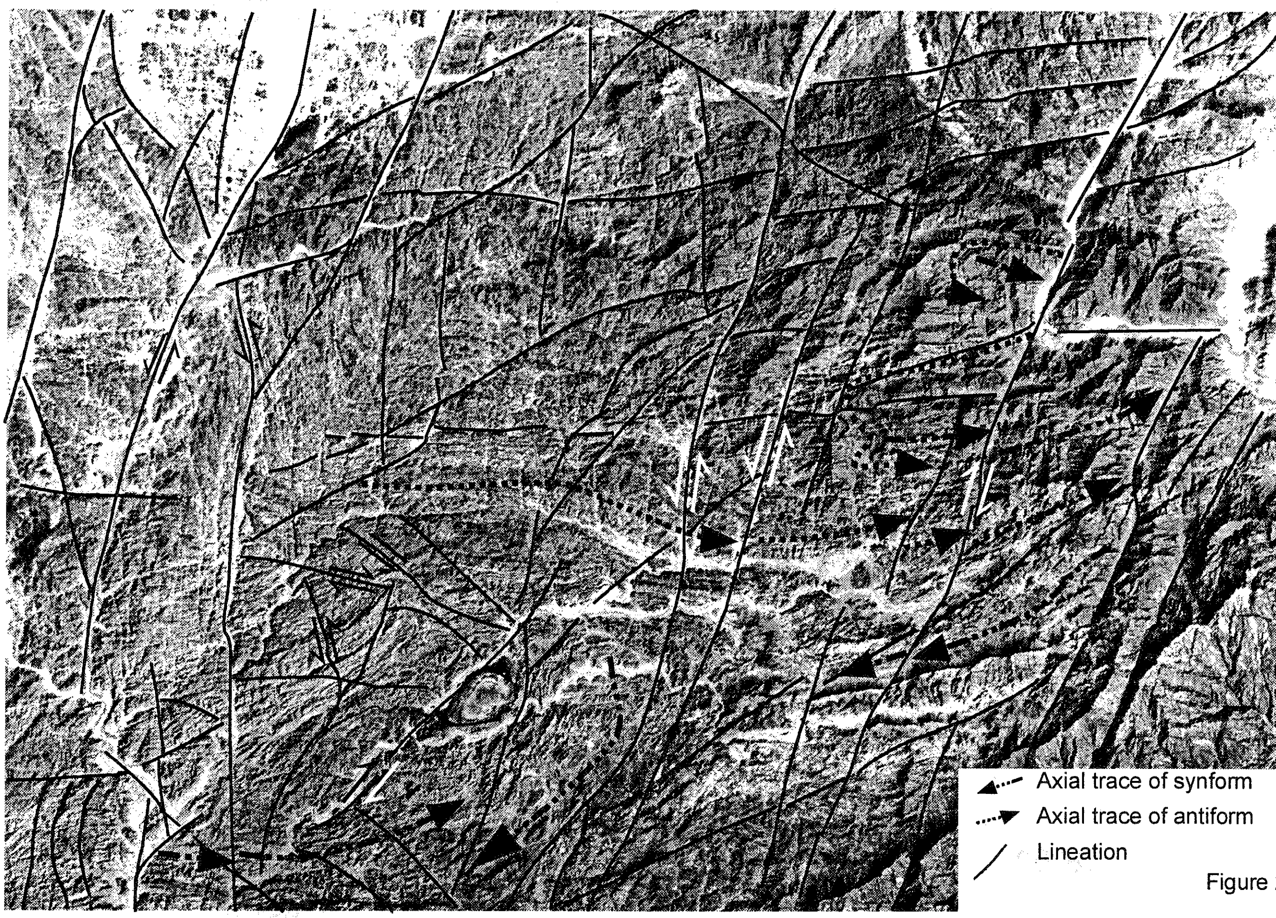

Figure 2: This image displays window 'A' of fig.1. The subset is esspecially interesting with respect to the folding and refolding pattern of the metamorphic series with their ± E-W striking foldaxes.

D_5 is a result of dextral shearing developed under different pT-conditions because of its brittle-ductile nature. The observed transportation along one such a shear plane accounts for more than 1 km lateral offset (fig.2, elliptical structure in the lower part of the image). It is also displayed as open folds in the Ariab-Nakasib suture W of the Oko Shear Zone (KOCH 1995) and Imasa Shear Zone (GUYOT et al. 1983, WIPFLER 1994, HAENISCH 1996). These shear zones trend NE subparallel to the ophiolite belts in the area.

Closely related to the previous shearing is a sinistral displacement of much more intensity (D_6). It can be considered as crustal shortening during the accretion of the Red Sea Hills terrane sequence against the Nile craton to W / NW (ABDELSALAM 1993). Good examples occure E of Khor Langeb and along the Emasa Shear Zone 80 km SSW of Sinkat the latter exhibiting displacements of upto 5 km. Penecontemporaneously evolved structural elements include the brittle displacement along the NW to NNW striking Oko shear zone. The motion along this fault zone amounts to 6,5 km on a single displacement face (fig.3).

migration path, and deformed the already exiting tectonic patterns in the sheared complexes. This fact allows to conclude that the shearing (D_6) predate known ages of intrusions which took place in the late- to postorogenic span of ca. 720 to 550 Ma (fig.2 upper right) (KRÖNER 1985, ALMOND et al. 1989, KÜSTER et al. 1993).

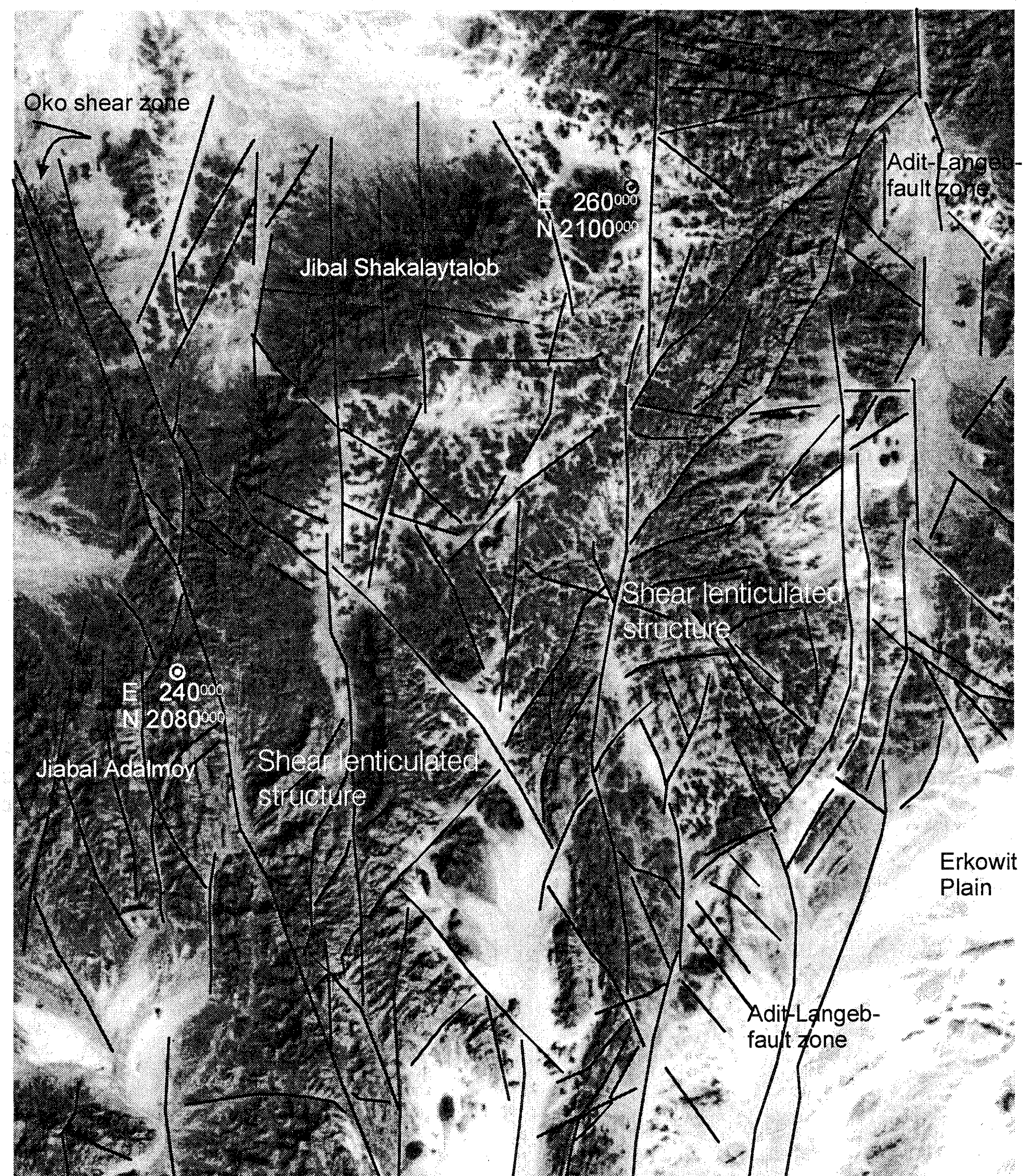

Figure 3: In this subscene the southern terminal of the Oko shear zone is displayed with its left-lateral NW to NNW trending strike slip offset of approximately 6.5 km. Further explanation see text.

D_7 is a result of crustal thickening that gave rise to anatexis at deeper levels and its emplacement as diapiric bodies of often granitic to granodioritic composition into the upper crust. These intrusions heavily relied on the previously developed steep faults as a

D_8 is of particular interest because of its N-S directed strike-slip faulting. Representing A-C-faults parallel to the principal stress (σ_1). This deformation has sinistral sense of movement and is differently displayed in the whole area as seen on the processed images. Displacements may have reached well over 10 km, the large off-sets appear to be distributed over many smaller faults with one case having a displacement at a scale of 0.1 - 0.5 km.

The next deformation (D_9) happend during the Phanerozoic and is related to the Red Sea rifting, starting in the Mesozoic to Tertiary time. It is a combination of rifting with the resulting isostatic motions: graben low, shoulder high (VENING MEINEZ 1964), and tilting of crustal segments along listric fault faces (VOGGENREITER et al. 1988). The tilting is predominatly oriented along the main faults given during D_8.

Complications grew up during displacement between blocks with varying movement rates, that consequenced a rotation as can be seen NE of Sinkat (fig.1, encircled area). Here a block of more than 30 km x 30 km has been forced to rotate counter clockwise because of the regidity of its western support. In effect sinistral large scale shearing has developed in which younger small scale dextral shearing elements occured (MACLEOD & MURTON 1995).

4. Conclusion

The tectonic development of the region, as could be reconstructed from the interpretation of Landsat TM mosaiced data appears to have been predominantly modified by large scale sinistral shearing particularly in the eastern Red Sea Hills. These structures are comparable to the Najd fault system in Saudi Arabia with similar motions of descrete crustal segments. The N-S leading faults are related with crustal shortening in the Proterozoic and represent thus an old but still active deformation pattern.

Lack of the third dimension in the Landsat TM-data obviously restricts interpretation but still allows recognition of prominant structural features. Very helpful to bypass this problem were the LFC-frames on which reactivated younger structures are well shown. This paper proves the significance of remotely sensed satellite data for stuctural studies in vast areas with often poor accessibility within a relatively short time.

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