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TECHNICAL NOTE

Petrographic and geochemical study of rocks at Shakiso, Ethiopia: no evidence for shock metamorphism

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Abstract—We have performed field work and petrographic and geochemical studies on rocks from the area around Shakiso, Ethiopia, where the existence of an impact crater, based on the asserted presence of shatter cones and breccias, was previously suggested. We did not find any evidence that would support this claim.

Résumé—Nous avons effectué des études de terrain, pétrographiques et géochimiques sur les roches de la région de Shakiso, Ethiopie, où il a été suggéré la présence d'un cratère d'impact, d'après la présence affirmée de shatter cones et de brèches. Nous n'avons trouvé aucun argument permettant d'étayer cette affirmation.

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Currently, only 18 impact structures are known on the continent of Africa. In 1994, only 15 African impact structures were known (Koeberl, 1994). Since then, three new African impact structures have been identified: the small 220 m diameter Sinamwenda Crater in Zimbabwe (Master *et al.*, 1996), the 14 km diameter Gweni-Fada Complex Crater in Chad (Vincent and Beauvilain, 1996), and the large (about 200 km diameter) Morokweng impact structure in South Africa, near the border to Botswana (Koeberl *et al.*, 1997). Considering the density of impact craters elsewhere in the world, Africa does not have a comparable share of established impact craters. According to cratering rate estimates (e.g. Grieve, 1987), numerous craters must await discovery in Africa.

No impact structures are so far known in Ethiopia, with the exception of a suggestion by Evdokimov (1987) and Evdokimov and Abebe (1987), who studied rocks at Shakiso (centred at 5°46'N and 38°54'E), south central Ethiopia, about 500 km from Addis Ababa (Fig. 1). They interpreted their observations as indicating that an impact crater occurs centred on the town of Shakiso. In the first of the two reports, Evdokimov (1987) claimed that he found "impactites and explosion breccias" and Ni-Fe pellets, defining a structure of 1250 m radius centred directly on the town of Shakiso, extending about half way to the Hawata River (Fig. 1). An age of about 10 Ma was inferred based on geomorphology. No supporting evidence, i.e. photographs (macroscopic or thin section), of the alleged breccias were shown, and no data on the "Ni-Fe pellets" were presented. Shortly afterwards, Evdokimov and Abebe (1987) claimed the existence of shatter cones, supposedly defining a 6 km diameter "Shakiso Ring Structure", this time concluding (based on "tectonic relationships") that the structure could be 65 Ma old.

In order to study the outcrops that were shown on maps given by Evdokimov (1987) and Evdokimov and Abebe (1987), we conducted field work in this area in January-February, 1996. Shakiso is located in the Adola gold field, which has been the principal Au producer of Ethiopia since the 1930's. Because of this, the geology and structure of the area is relatively well studied.

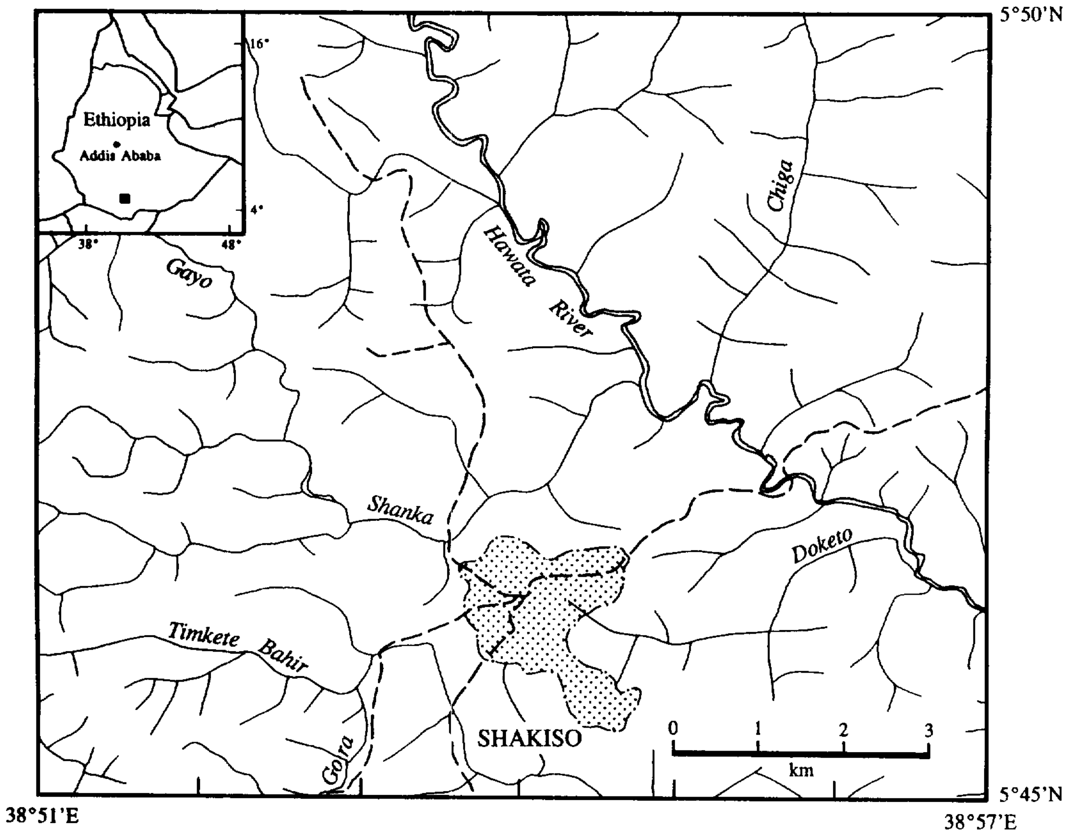

Figure 1. Location map of the Shakiso area showing the town of Shakiso (stipled area), the roads (dashed lines) and the drainage system (rivers and creeks; thin solid lines), which does not indicate the presence of a circular structure.

The rocks outcropping in the area are members of the Middle Complex in the classification of basement rocks of Ethiopia (e.g. Kazmin, 1972), which are 630-680 Ma old (Chater, 1971). These rocks are mapped as north-south trending biotite gneiss and muscovite-kyanite schists, which form the gneissic terrain that bounds the Adola greenstone belt with a thrust contact (Kozyrev *et al.*, 1982; Gebreab *et al.*, 1992).

In the field, we visited several of the locations described by Evdokimov (1987) and Evdokimov and Abebe (1987). While we were able to identify the locations, we did not find any of the geological features described by Evdokimov and colleagues, such as shatter cones or impact breccias, claimed to be present by these authors. It seems that slickensides could have been mistaken for shatter cones. No significant brecciation was found either. At each location, several samples were taken for more detailed petrographic and geochemical studies. These samples were selected in the field to represent the visually freshest rocks, avoiding obvious alteration. The analyses were done to rule out that any microscopic shock effects have been overlooked, and to check if an impact-characteristic geochemical anomaly might be present.

In hand specimen the rocks are massive, light gray and medium-grained. Quartz veins are common. Petrographic study shows that the biotite gneiss is composed of quartz, plagioclase, orthoclase, muscovite, biotite and opaque phases. Both plagioclase and K-feldspars (Fig. 2a) are widely replaced by epidote and sericite. Biotite is largely altered to chlorite. The muscovite-kyanite schist is composed of quartz, kyanite, sillimanite, muscovite and opaque phases. The schistosity of this rock is marked by the preferred alignment of syn-deformational kyanite and muscovite grains (Fig. 2b). Fractures in quartz and undulose extinction are common in all important rock forming silicates. Fluid inclusions are rare and do not occur in planar trails. In contrast to Evdokimov (1987) and Evdokimov and Abebe (1987), the detailed petrographic study of quartz in our rocks (Fig. 2c) shows no evidence of planar deformation features (PDFs) or any other microscopic features that could be linked to shock metamorphism

***Figure 2.** Photomicrographs of typical rocks from Shakiso. (a) Biotite gneiss (Sh-19) with a grain of seriticised feldspar (at centre), quartz and fine crystals of biotite. The quartz and feldspar grains exhibit strained extinctions. Crossed polars, field of view is 2.5 mm across. (b) Muscovite-kyanite schist (Sh-18), the schistosity being defined by the preferred alignment of the kyanite and muscovite crystals (lower central part of the image). (c) Quartz from a quartz vein (Sh-20) with no signs of shock effects. The lines across the grains represent irregular healed fractures, probably due to metamorphism. Crossed polars, field of view is 2.5 mm across.*

Table 1. Compositional data for rocks from the Shakiso area (southern Ethiopia)

	Biotite Granite			Quartzite
	Sh-18	Sh-19	Sh-20	Sh-21
SiO_2	81.01	75.24	98.04	71.55
TiO_2	0.15	0.23	0.02	0.67
Al_2O_3	16.60	12.78	0.01	19.81
Fe_2O_3	0.70	2.34	0.91	5.27
MnO	0.01	0.01	0.01	0.01
MgO	0.01	0.23	0.01	0.01
CaO	0.03	0.66	0.03	0.15
Na_2O	0.14	5.47	0.01	0.59
K_2O	0.53	1.94	0.10	0.20
P_2O_5	0.02	0.05	0.04	0.11
LOI	0.92	0.85	0.10	0.80
Total	100.12	99.80	99.29	99.17
Li	5.2	16.4	2.0	4.6
Be	0.5	2.4	0.5	0.6
Sc	4.21	2.92	0.27	7.23
Cr	9.65	8.75	5.89	8.88
V	9	12	4	21
Co	0.66	2.58	0.49	1.58
Ni	8	12	25	5
Cu	536	71	216	1280
Zn	7	28	10	9
Ga	16	13	2	4
As	0.95	<2	0.38	1.35
Se	0.25	0.55	0.41	7.91
Br	0.19	0.20	0.17	0.15
Rb	11.0	85.3	0.61	0.88
Sr	6	105	11	112
Y	9	1	25	5
Zr	129	126	22	310
Nb	8	5	10	14
Ag	0.08	0.13	0.05	0.05
Sb	0.25	0.16	0.02	0.31
Cs	0.42	1.5	5.12	0.056
Ba	152	455	16	95
La	17.2	19.2	1.39	64.0
Ce	26.9	56.8	2.42	108
Nd	8.15	18.7	2.16	46.4
Sm	1.28	3.12	0.62	5.07
Eu	0.15	0.41	0.19	1.07
Gd	1.9	3.5	1.3	6.27
Tb	0.32	0.57	0.24	1.34
Tm	0.29	0.60	0.063	0.34
Yb	1.64	3.21	0.25	1.48
Lu	0.22	0.45	0.024	0.28
Hf	4.62	4.55	0.086	6.79
Ta	0.52	0.50	0.01	0.63
W	3.79	2.93	0.3	4.86
Ir	<1	<1	<1	<1
Au	0.7	1	0.6	<2
Hg	0.08	<0.1	0.13	1.0
Pb	26	38	20	27
Th	9.77	13.0	0.74	19.2
U	1.99	2.45	0.18	2.59
Th/U	4.91	5.31	4.11	7.41
Hf/Ta	8.88	9.10	8.6	10.77
Zr/Hf	27.9	27.6	251.2	45.5
La_N/Yb_N	7.1	4.05	3.75	29.21
Eu/Eu*	0.29	0.38	0.64	0.57

All Fe as Fe_2O_3; major elements in wt%; Ir and Au in ppb; and all other trace elements in ppm.

(Stöffler and Langenhorst, 1994; Huffman and Reimold, 1996).

To further characterise the samples, and to determine if anomalous contents of Ni, Co, Ir, and other possibly impact-derived elements might be present, major and trace element contents of four samples that appeared to be representative of our larger sample suite after petrographic studies (biotite granites: Sh-18, 19, and 21; quartzite: Sh-20) were analysed by standard methods (XRF, AAS, DCP-AES, and INAA). The results are given in Table 1. The rare earth element (REE) patterns and abundances are typical for continental rocks (Taylor and McLennan, 1985) with a fairly appreciable negative Eu anomaly, high abundance relative to chondritic meteorites, light REE enrichment, and a relatively flat heavy REE pattern. No extraterrestrial component (e.g. Ir < 1 ppb) is present in any of the analysed rocks and we suspect that the "Fe-Ni pellets" of Evdokimov (1987) are actually surfacial Fe-Mn coatings (varnish).

Thus, our field work and petrographic and geochemical studies do not provide any of the macroscopic, microscopic or geochemical evidence required to confirm the presence of an impact structure at Shakiso, Ethiopia, as suggested by Evdokimov (1987) and Evdokimov and Abebe (1987).

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Geological map

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