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Field Excursion Guidebook
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The Sinamwenda Impact Structure, Western Zimbabwe

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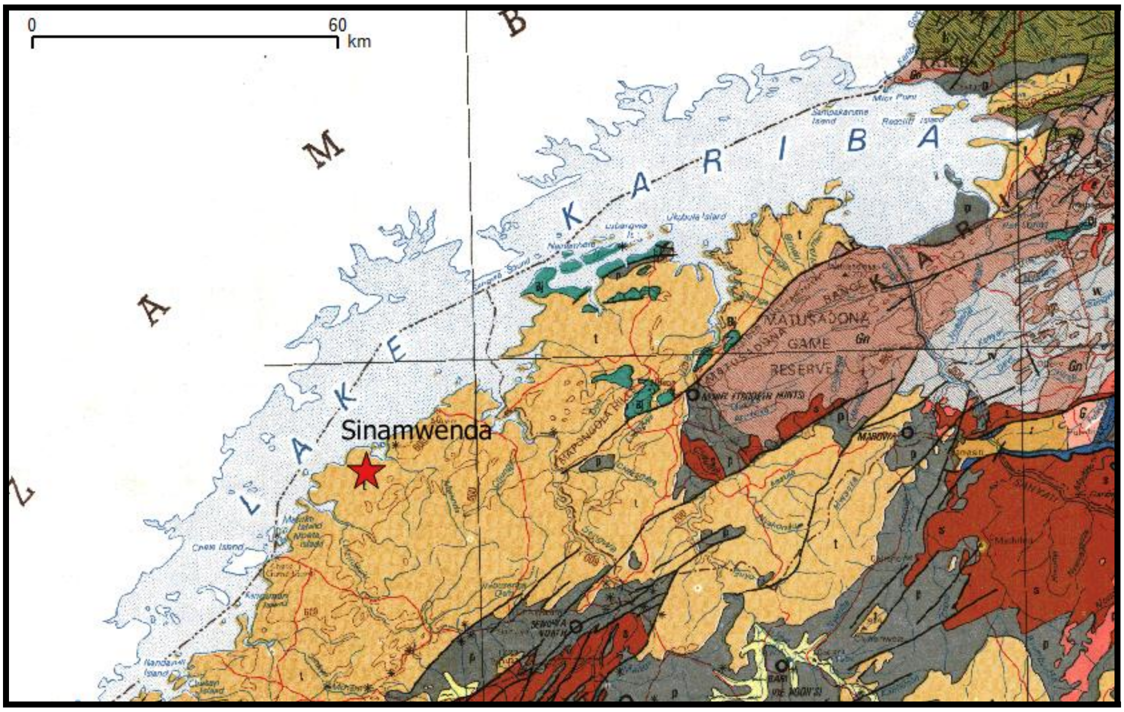

Figure 1: The location of the Sinamwenda Impact Structure in relation to Lake Kariba and the local geology of the Karoo Supergroup sandstones (beige colour) and overlying Karoo basalts (blue), and underlying lower Karoo Madumabisa Mudstones (grey), Sijarira Group (orange-red), and crystalline basement of the NW Magondi Belt (pink).

Sinamwenda Impact Structure

The Sinamwenda structure (Figures 1-6) is a small 220 m-diameter circular crater situated at 17º11’42”S, 27º47’30” E, near the shores of Lake Kariba in western Zimbabwe, about 4.8 km SSW of the Sinamwenda Research Station, after which it is named (Master 1994, 1999; Master et al., 1995, 1996; Master & Reimold 1995; 2000).

The structure was originally discovered on an aerial photograph by the late Dr Clive Stowe (then of the University of Rhodesia) in 1970. Dr Stowe and his party of geology students approached the area near the structure by boat on Lake Kariba, and moored in the Ruziruhuru (Luizilukulu) Estuary, from where they hiked several kilometres to the crater. They tried to map the circular structure using chain- and-compass surveys, but were interrupted in their work by a huge herd of elephants. They were forced to abandon their mapping and fled to their boat, never to return. They did not resolve the origin of the structure, and their partial map was unpublished and has now been lost (Stowe, pers. comm., May 1994).

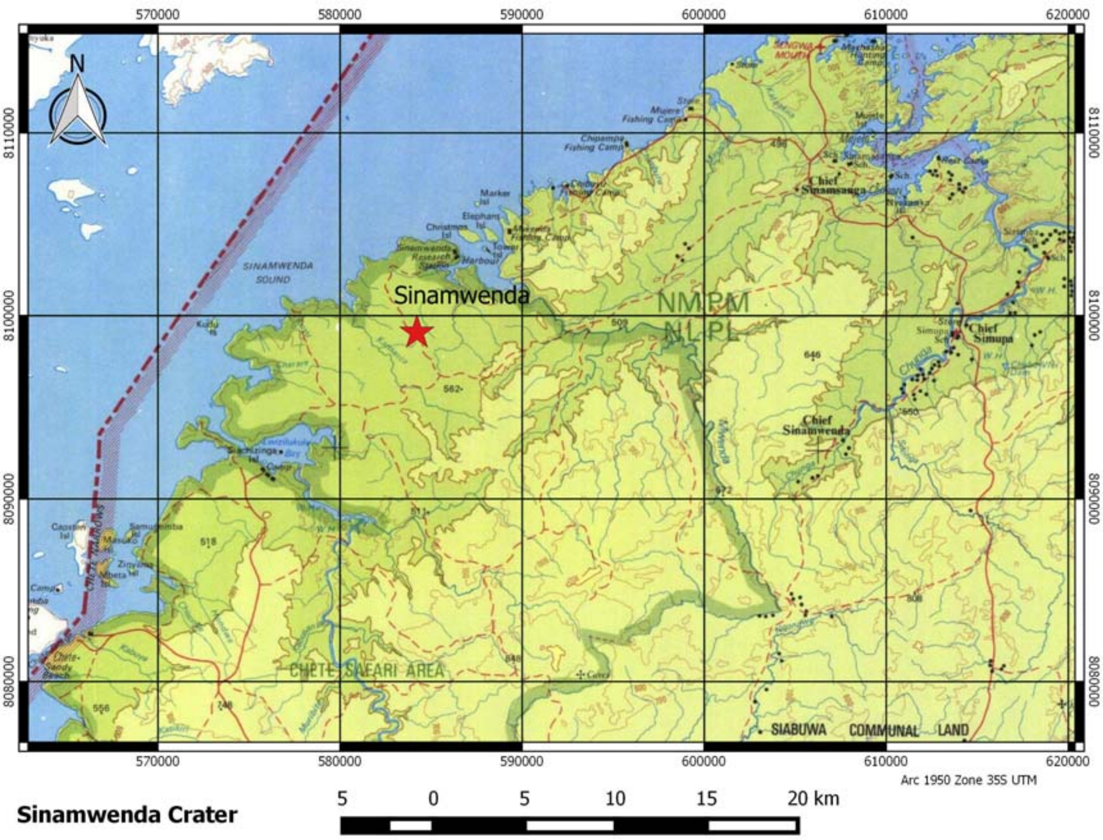

Figure 2. Topographic map of part of W Zimbabwe, showing the location of the Sinamwenda Impact Structure, SSW of the Sinamwenda Research Station on the shores of Lake Kariba.

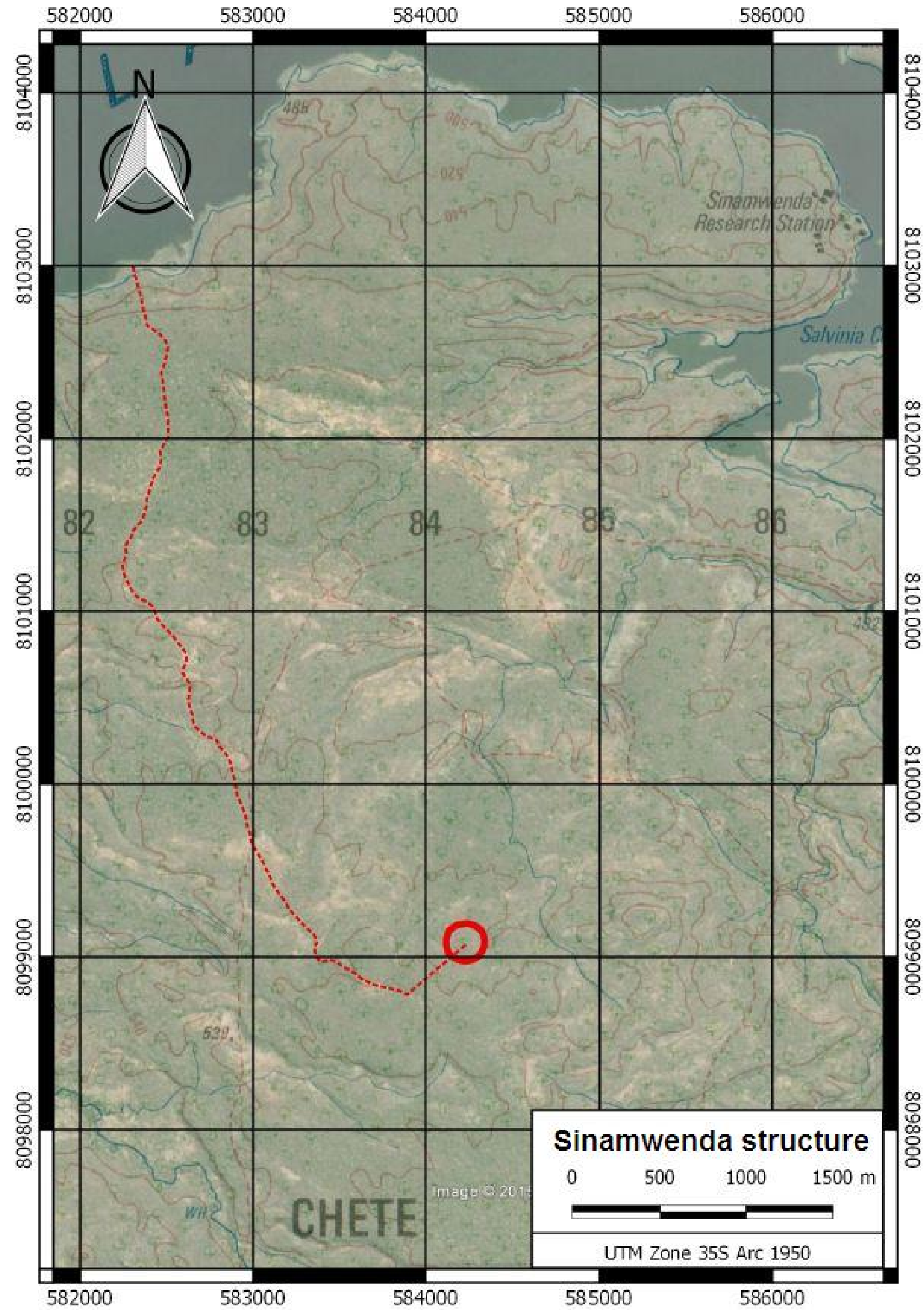

Figure 3. Hybrid satellite image and topographic map showing the proposed route to the Sinamwenda Impact Structure.

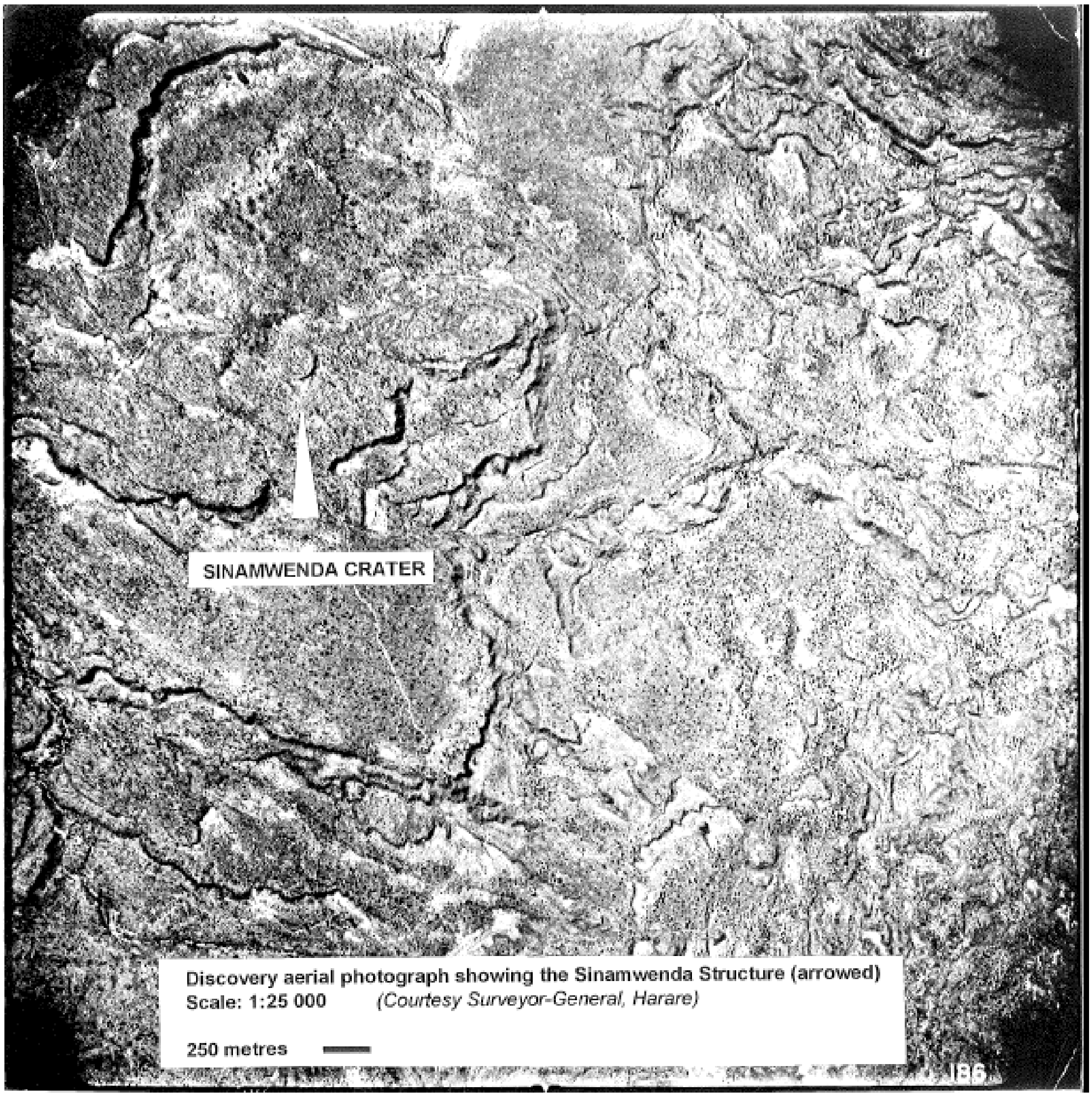

Figure 4: Discovery aerial photograph showing the Sinamwenda Structure.

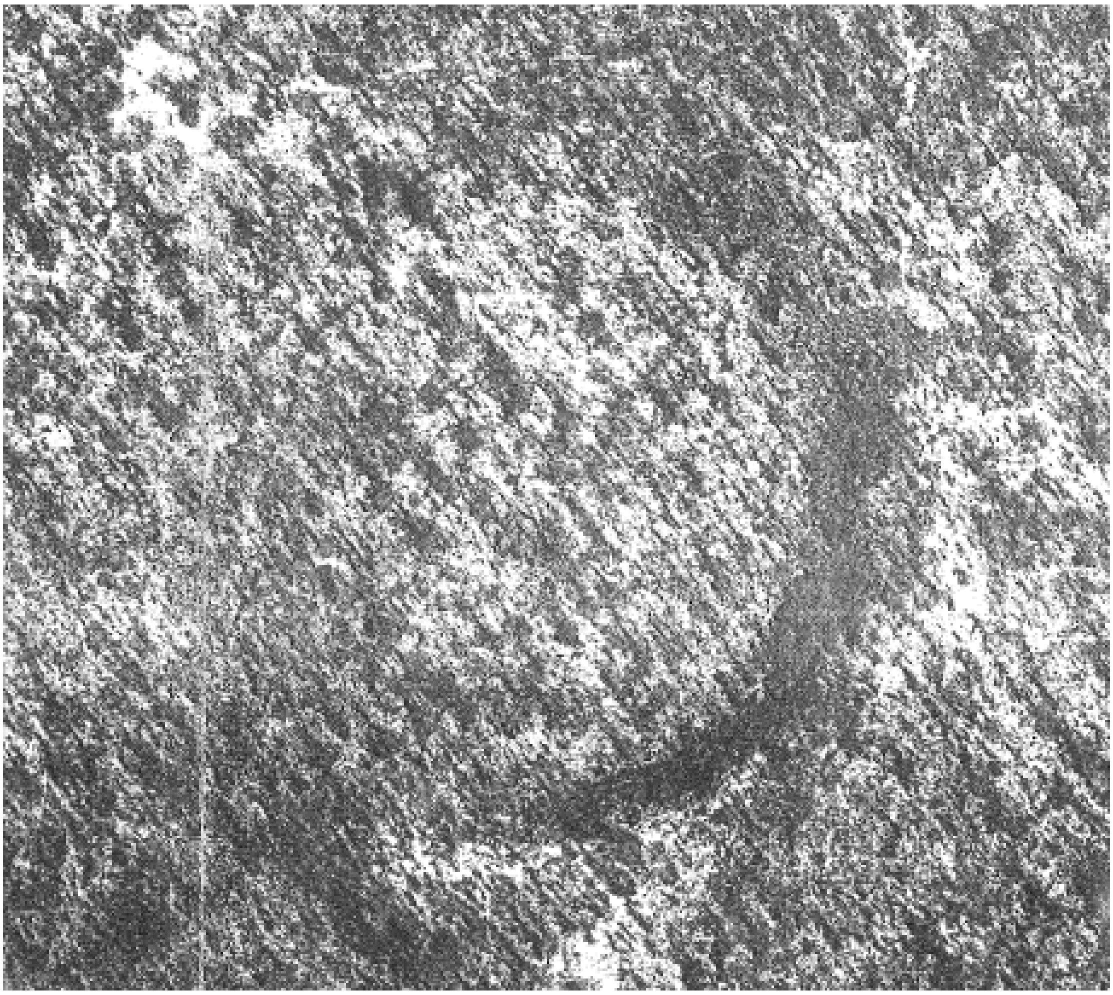

Figure 5. Close up of vertical aerial photograph of the Sinamwenda Structure, which is about 220 m in diameter.

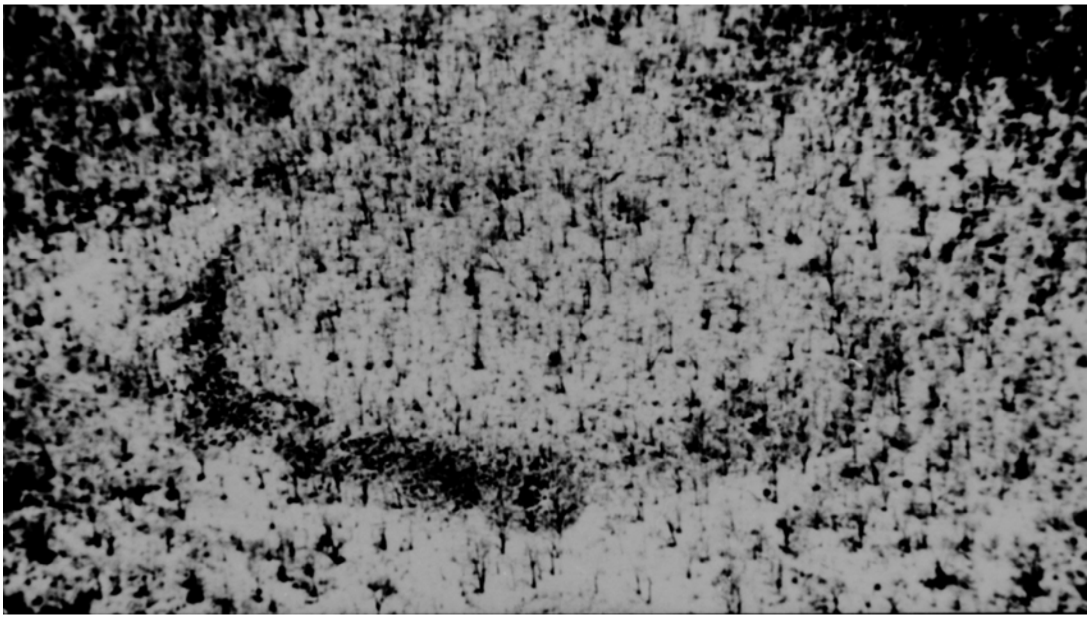

Figure 6. Oblique aerial photograph of the Sinamwenda Structure (from Master et al., 1995). Photograph by Dion Brandt.

The existence of the Sinamwenda structure as an enigmatic circular feature was revealed to Sharad Master by Dr Clive Stowe at the University of Cape Town in 1994, following a discussion on the Highbury Impact Structure, which had been discovered the previous year. Armed with Dr Stowe's hand-drawn sketch of the approximate locality, Sharad Master returned to Zimbabwe where he was working at the time, and resolved to track down this structure and to investigate its origin. He spent some time in the Office of the Surveyor-General in Harare, perusing aerial photographs of the Kariba shoreline area near the Ruziruhuru estuary, and eventually located the aerial photograph showing the circular structure (Figure 4). He ordered stereo pairs and blow-up photos of the structure, and proceeded to organise an expedition to investigate the structure. Having borrowed a 4x4 vehicle and a GPS from the Environment and Remote Sensing Institute (ERSI) in Harare, a three-man team finally headed for the structure on the 24th September 1994. The team consisted of Sharad Master (ERSI), Kevin Walsh (of the Department of Geology, University of Zimbabwe) and Dr David J. Robertson (a geophysicist at the Department of Physics, University of Zimbabwe).

The team spent the first night at the Chete Game Camp of the National Parks of Zimbabwe. The next morning they saw the gruesome sight of about 30 de-horned rhinoceros skulls neatly arranged in rows outside the Parks office at the Camp. All the rhinos had been killed for their horns by poachers who had come across by boat from the Zambian side of the Lake. During the decade of the 1980's, the rhino population in the Mid-Zambezi Valley had been decimated by poaching, and the remaining rhinos were relocated to a safer game park further inland. This meant that the rhino was now effectively extinct in the Mid-Zambezi Valley. Sobered by these devastating revelations, and accompanied by an armed game guide, Game-Scout Kamin, the party set off on dirt tracks, through the Chete Safari Area, for the Sinamwenda structure.

The country rocks around the crater consist of Middle Triassic coarse-grained to gritty crossbedded sandstones of the Escarpment Grit Formation (K6), of the upper Karoo Supergroup (correlated with the Molteno Formation of the Karoo in South Africa (Fick, 1970; Grant, 1970; Stowe, 1974; Master et al., 1995). The rocks are flat-lying, undeformed and unmetamorphosed, and appear to be unjointed when seen in in rounded outcrops and in pavement exposures. On approaching the Sinamwenda crater, one sees a low rise 1-2 m above the surrounding area, which marks the exposed upturned rim of the structure. The rim exposures are characterised by a jumble of blocks of sandstone which display abundant striated joint surfaces in all directions. Each joint has one set of striations, but the striations are in all directions. Some closely spaced joint sets have parallel sets of striations. The loose nature of the blocks makes it difficult to determine the *in situ* dips of the bedding. However, in 1970, Stowe had recorded, in the NW rim of the structure, steeply-dipping or overturned outcrops of Escarpment Grit Formation sandstone which was overlain by stratigraphically underlying shales of the Upper Madumabisa Mudstone Formation. The crater does not have the bowl shape of typical simple impact craters, but appears to have been filled by sediment, possibly aeolian sands of the late Pleistocene Kalahari Group, which range in age from 96 to 10 kyr (Munyika et al, 2000).

Figure 7. Multiply-Striated Joint Surfaces (MSJS) in coarse sandstone, N rim of Sinamwenda structure.

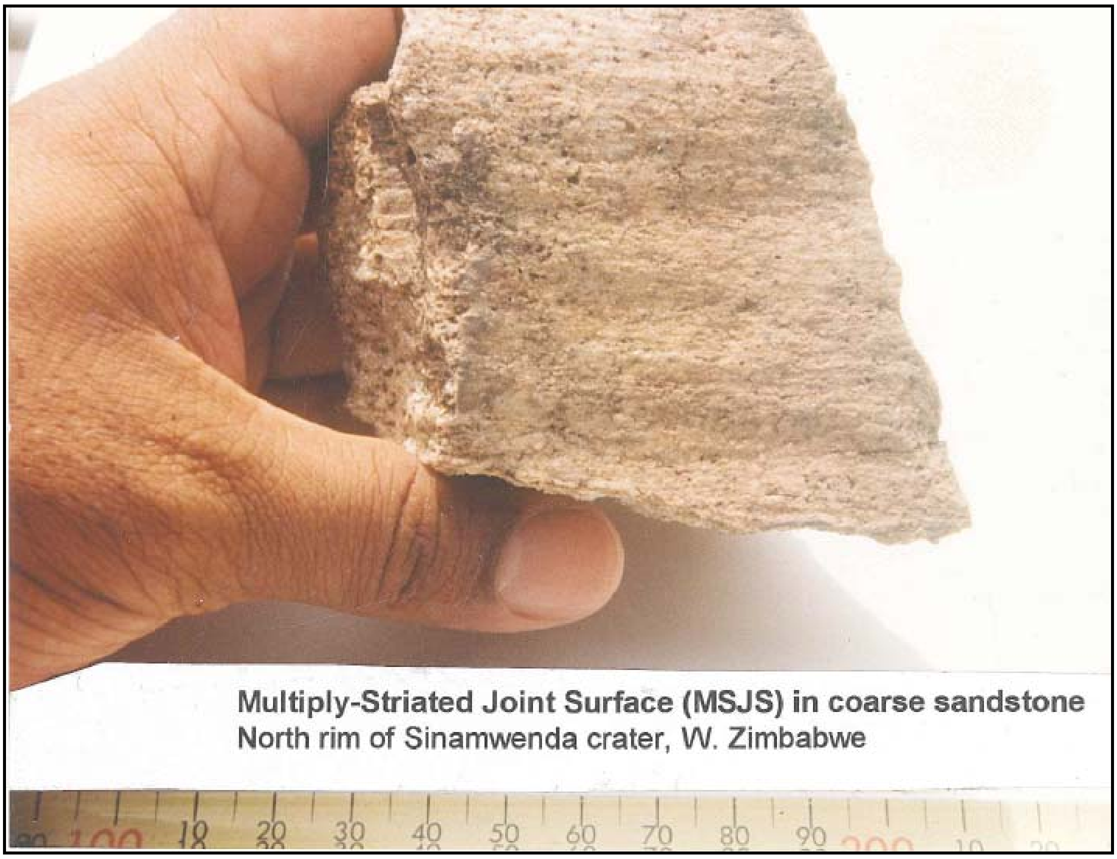

Figure 8. Multiply-Striated Joint Surface (MSJS) in coarse sandstone, north rim of Sinamwenda Structure.

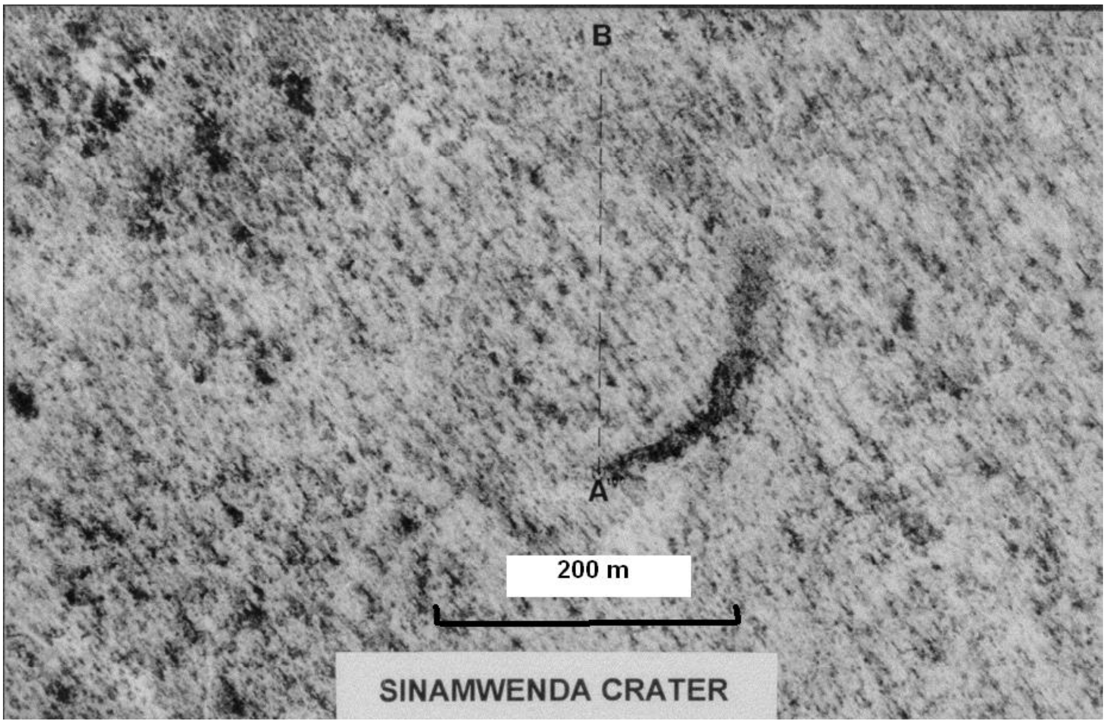

Figure 7. Vertical aerial photograph of the Sinamwenda structure, showing a topographically elevated rim which is most prominent on the southeastern sector. A-B represents the line of the ground magnetic traverse shown in Figure 5. From Master and Robertson (2009).

Figure 8. The September 1994 Sinamwenda Expedition team doing a ground magnetometer traverse. Left to right: Dr Kevin Walsh (holding a proton-precession magnetometer), Game-Scout Kamin (holding a rifle), and Dr David Robertson (holding a GPS). Photograph by Sharad Master.

During the 1994 expedition, a N-S ground magnetic traverse was conducted across the diameter of the structure (Figure 7), using a hand-held proton precession magnetometer (Figure 8). Total field measurements were made at 20m intervals. Periodic remeasurements at base stations allowed for the identification and correction of diurnal secular variations in the magnetic field. The results of this survey showed absolutely no change in the magnetic field as one moved from the flat undeformed country rocks, across the southern rim and over the structure, to the northern rim and onto the country rocks on the other side. The magnetic total field intensity measured (Figure 9) was at a constant value of around 31000 nT, with random fluctuations of ± 2 nT (which is the instrument resolution) along the traverse (Master and Robertson, 1999). The significance of this null result is that it implies the absence of any mafic intrusion. The magnetic survey showed that there was absolutely no magnetic anomaly over the structure, ruling out any possibility that the structure could be due to a mafic volcanic plug or kimberlitic intrusion.

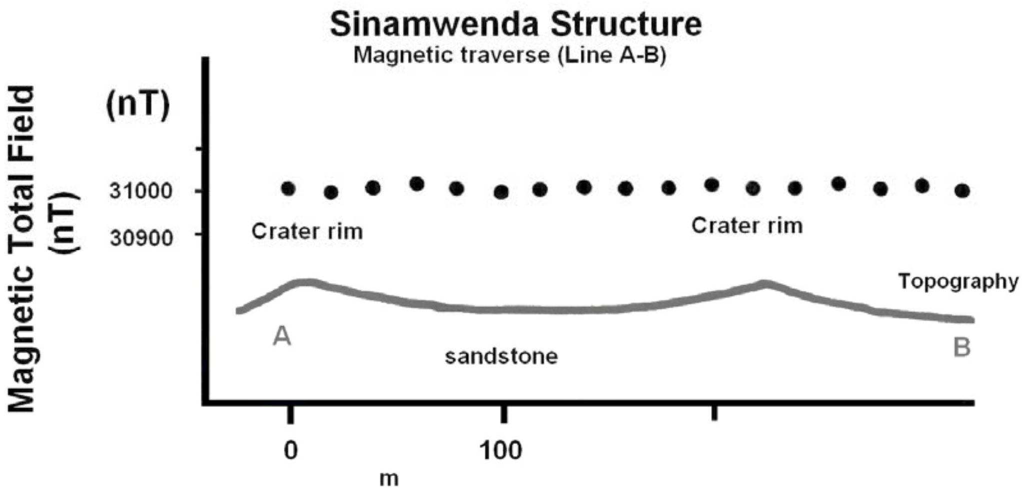

Figure 9. N-S magnetic traverse across the Sinamwenda Structure, western Zimbabwe. The crater rim to trough topographic relief is ~5 metres. From Master and Robertson (2009).

Initial petrographic examination showed that the rocks from the rim of the Sinamwenda were much more deformed than the surrounding country rocks. Most of the rim rocks are strongly fractured, and several samples displayed cataclasis in the form of pockets of cataclastic breccia or more linear zones of brecciation. The presence of an upturned rim, showing Multiply-Striated Joint Surfaces, and microscopic evidence for brecciation, was regarded as evidence for an impact origin of the SInamwenda Structure.

The Sinamwenda Structure has received plenty of publicity since its discovery. On 10th October 1994, just two weeks after the September 1994 expedition, Sharad Master presented the first preliminary data on the Sinamwenda Structure at the 20th Vernadsky-Brown Microsymposium on Comparative Planetology, at the Vernadsky Institute of Geochemistry and Analytical Chemistry in Moscow, Russia. The Zimbabwean geological community first became aware of the discovery of the Sinamwenda Structure at two talks given by Sharad Master in January 1995, at the Museum of Human Sciences (ex-Queen Victoria Museum), Harare (19^{th} January), and to the Geological Society of Zimbabwe at the Department of Geology, University of Zimbabwe, Harare (23rd January).

In March 1995, Sharad Master presented a full scientific paper regarding Sinamwenda as an impact structure, at the 26th Annual Lunar and Planetary Science Conference at the NASA Johnson Space Center, Houston, Texas, USA (Master et al., 1995). The same paper was presented later that same month at the Workshop on the Ames Structure and Similar Features, (University of Oklahoma, Norman, OK, USA, 28-29 March 1995). A further talk, dealing with both the Highbury and Sinamwenda Structures, was given at the Centennial Geocongress in Johannesburg, in April 1995 (Master and Reimold, 1995). In January and February 1996, Sharad Master gave talks on the two Zimbabwean impact structures at universities in Münster, Berlin, Halle and Würzburg, Germany, and at the Royal Museum of Central Africa in Tervuren, Belgium. On the 20th March 1996, an exhibition on “Meteorites and Impact Craters in Zimbabwe”, curated by Sharad Master, was opened at the Zimbabwe Museum of Human Sciences in Harare, to coincide with a big international Remote Sensing and GIS conference at the nearby Harare International Conference Centre.

More detailed studies of thin sections from the rim samples from Sinamwenda revealed some grains that appeared to have single sets of shock-induced Planar Deformation Features (PDFs), oriented along the $\{10\underline{1}1\}$ and $\{10\underline{3}1\}$ crystallographic directions (Figures 10-12). These grains were situated on the surfaces of the striated joints (MSJS) in the rim sandstones, and were used to infer a shock metamorphic origin of the multiply-striated joint surfaces (Master et al. 1996). However, the shock origin of the observed PDFs still awaits proper confirmation, since a TEM examination of a single such grain showed only concentrations of dislocations, and failed to find shock induced planar lamellae (Falko Langenhorst, pers. comm., 1998; Master and Reimold, 2000). Clearly, more study is needed of the striated joint surfaces, along which quartz grains are brecciated.

An interesting development concerning the origin of the Sinamwenda structure occurred in 1996 when Dr Clive Stowe of the University of Cape Town recalled to Sharad Master a crucial piece of information which he had previously completely forgotten about: during his original visit to the structure in 1970, he had picked up a dense rock with an oxidised coating. This rock lay on his shelf for a number of years, until he decided one day to make a polished briquette of it. This revealed a texture similar to that of Widmanstätten lamellae, and he interpreted the rock to be an iron meteorite. The rock with its unusual textures had been added to the teaching collection of the Department of Geology at the University of Zimbabwe, sometime in the 1970’s, when it was still the University of Rhodesia. A frantic search by Sharad Master of the existing ore microscopy teaching collection at the University of Zimbabwe in 1996 failed to relocate the specimen. If the rock found by Dr Stowe at Sinamwenda in 1970 was indeed an iron meteorite, and it wasn’t simply a coincidence that it was picked up near the Sinamwenda structure, then it implies that the meteorite was a fragment of the projectile responsible for producing the Sinamwenda crater.

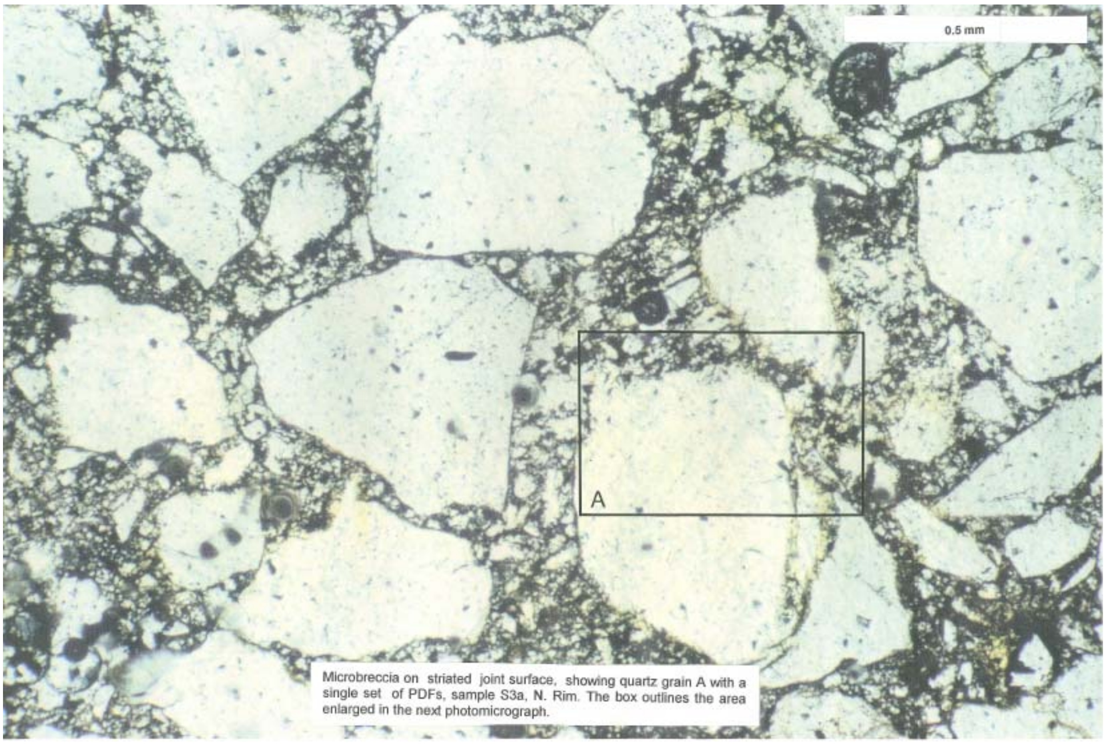

Figure 10. Photomicrograph showing microbreccia on striated joint surface showing quartz grain A with a single set of PDFs, sample S3a. The box outlines area enlarged in Figure 11.

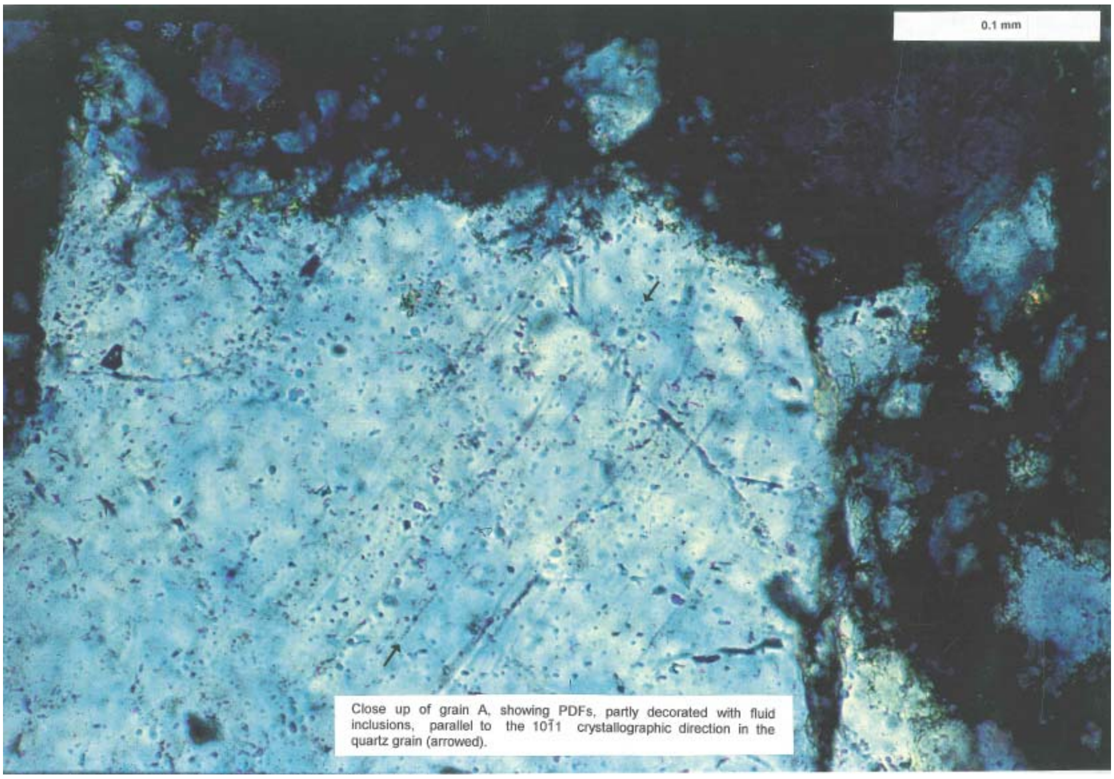

Figure 11. Photomicrographic close-up of grain A showing PDFs, partly decorated with fluid inclusions parallel to the $10\underline{1}1$ crystallographic direction in the quartz grain (arrowed). After Master et al. (1996).

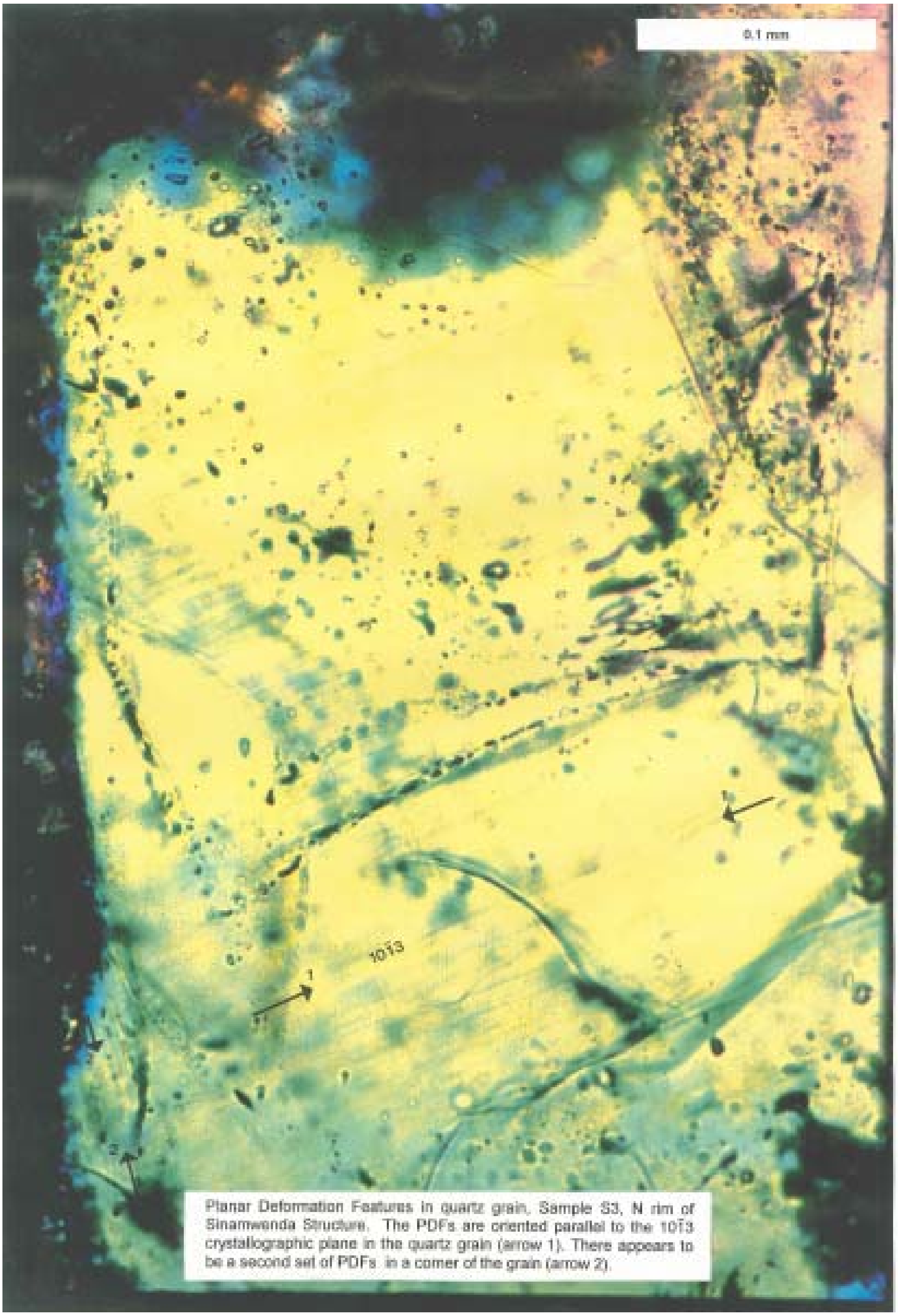

Figure 12. Photomicrograph showing Planar Deformation Features (PDFs) in a quartz grain, sample S3, N rim of Sinamwenda Structure. The PDFs are oriented parallel to the 10$\underline{1}$3 crystallographic plane in the quartz grain (arrow 1). There appears to be a second set of PDFs in a corner of the grain (arrow 2). After Master et al. (1996).

A simple calculation showed that the crater could have been formed by a spherical iron meteorite about 5 to 7 metres in diameter (Master, 1994). If one fragment of such a bolide had been found, then there must be many more such fragments lying around the structure awaiting discovery! Fragments of iron meteorites may be covered with a weathered crust of iron oxide, but they are generally quite magnetic, and can be found easily using most commercially available metal detector systems.

In 1999, the international Meteoritical Society hosted its first ever scientific meeting on the African continent at the University of the Witwatersrand, Johannesburg, South Africa. As part of this meeting, a field trip, led by Sharad Master, was made to Zimbabwe, to combine sight-seeing and game viewing at Victoria Falls and Lake Kariba, with visits to the two known impact structures in Zimbabwe, the Highbury and Sinamwenda structures (Master, 1999). There were about 35 participants on this excursion, including some of the most famous luminaries in the field of meteoritics, mainly from the United States and Europe. After some exciting misadventures involving half the group being bumped off a commandeered commercial flight from Victoria Falls to Kariba, an intrepid bunch of younger or more energetic scientists made the 4 km hike from Sinamwenda Research Station to the Sinamwenda structure, unarmed, walking through wilderness teeming with big game, including elephants, buffalo, lion, hippopotamus and crocodiles. They literally spent a minute at Sinamwenda, collecting a few samples and taking a few photographs, before turning around in a frantic rush to hike back to the houseboat before the sunset. Because of a lack of time (the planned vehicle support did not turn up because they could not cross rivers which were now full because of the high level of Lake Kariba), not much of scientific interest was achieved during that 1999 expedition. Fifteen years later, at the Meteoritical Society's second African scientific meeting, in Casablanca, Morocco (September, 2014), Sharad Master had a reunion with several participants of the 1999 excursion to Sinamwenda- and all were in agreement that it had been one of the most exciting adventures they had ever been on! There have been no further scientific expeditions to the Sinamwenda structure until the 2015 Geological Society of Zimbabwe expedition. The current status of the Sinamwenda Structure is that it is most likely an impact structure, and is officially regarded as a "probable impact structure" (Master and Reimold, 2000; Reimold and Koeberl, 2014, pp.146-147).

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References

Fick, V., 1970. Note on investigations on current directions in the Karroo Molteno outcrop around Sinamwenda, Lake Kariba. *Detritus*, The Mennell Society Journal, University of Rhodesia, **5**, 36-38.

Grant, D., 1970. A red-bed facies in the Upper Karoo of the Middle Zambezi Valley, and its lithological correlation. *Detritus*, The Mennell Society Journal, University of Rhodesia, **5**, 21-26.

Master, S., 1994. The Sinamwenda Crater- discovery, geological setting, origin. Guidebook, The 1994 Sinamwenda Crater Expedition, Zimbabwe, 23-26 September, 1994, Environment and Remote Sensing Institute, Harare, Zimbabwe, 4 pp.

Master, S., 1999. *Zimbabwe Excursion Field Guide*. 62nd Annual Meeting of the Meteoritical Society, Johannesburg, South Africa, 17-25 July 1999, 61 pp.

Master, S., Robertson, D.J., 2009. Distinguishing between impact craters and volcanic pipes using ground magnetics: field examples from Zimbabwe. In: Vogt, D., Fourie, C.J.S. (Eds.), *Proceedings of the 11th South African Geophysical Association Conference & Exhibition*, 16-18 September 2009, Ezulwini, Swaziland, "Ancient Rocks to Modern Techniques", 356-359.

Master, S., Robertson, D.J., Stowe, C.S., Walsh, K.L., Reimold, W.U., Brandt, D., 1995. The Sinamwenda Structure- a small new meteorite impact crater in Triassic (Upper Karoo) sandstones of western Zimbabwe. *Lunar and Planetary Science*, **XXVI**, 905-906.

Master, S., Reimold, W.U., 1995. Meteorite impact structures in Zimbabwe. Centennial Geocongress Geol. Soc. S. Afr, 3-7 April 1995, Rand Afrikaans University, Johannesburg, South Africa, Extended Abstracts, I, 574-576.

Master, S., Reimold, W.U., 2000. The impact cratering record of Africa: An updated inventory of proven, probable, possible, and discredited impact structures on the African continent. In: *Catastrophic Events & Mass Extinctions: Impacts and Beyond.* Vienna, 9-12 July 2000. LPI Contribution No. 1053, Lunar and Planetary Institute, Houston, Texas, USA, 131-132.

Master, S., Reimold, W.U., Brandt, D., 1996. Evidence for shock metamorphic origin of multiply-oriented striated joint surfaces (MSJS) in sandstones of the Sinamwenda meteorite impact structure, Zimbabwe. *Lunar and Planetary Science*, **XXVII**, 827-828.

Munyika, K., van den Haute, P., Vandenberghe, D., de Corte, F., 2000. The age and palaeoenvironmental significance of the Kalahari Sands in western Zimbabwe: a thermoluminescence reconnaissance study. *Journal of African Earth Sciences*, **30(4)**, 941-956.

Reimold, W.U., Koeberl, C., 2014. Impact structures in Africa: a review. *Journal of African Earth Sciences*, **93**, 57-175.

Stowe, C.W., 1974, Notes on the Karoo Succession at Sinamwenda, Kariba: *Detritus*, The Mennell Society Journal, University of Rhodesia, **9**, 20-24.