The Thuathe meteorite of 21 July 2002, Lesotho: mapping the strewn field and initial mineralogical classification

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This article provides a first report of the fall of a meteorite over the Thuathe plateau of western Lesotho, approximately 9 km east of the capital Maseru, on 21 July 2002. The strewn field has been mapped, and the characteristics of stones recovered from various sectors in the strewn field are compared. Initial mineralogical investigations have established that this new meteorite is an H type ordinary chondrite, of petrologic type 4/5, and shock degree S2-S3. The name *Thuathe* has been accepted by the Nomenclature Committee of the Meteoritical Society for this new fall, as the major part of the strewn field extends over the Thuathe plateau. We believe that Thuathe is the first meteorite recovered from Lesotho.

Introduction

An extraordinarily loud noise was heard over a large area of Lesotho at approximately 15:49 (13:49 GMT) on the afternoon of Sunday, 21 July 2002. The noise lasted for some 15 seconds at a sustained high intensity, and was not consistent with such events as a ground-based explosion, sonic boom or lightning strike, all of which would have begun with an initially loud noise that tailed off with reverberations from the surrounding mountains.

The noise was heard by one of the authors (D.P.A.) in Roma, Lesotho (Fig. 1a), where it appeared to come mainly from a northwesterly direction. A telephone call a minute or two later from the capital, Maseru, 30 km to the northwest, reported that the same unexplained noise had apparently come from the east. Over the following two weeks, students at the National University of Lesotho returned for the beginning of term, and the opportunity was taken to ask a representative sample of students from more remote parts of Lesotho about what they heard on the afternoon of 21 July. This resulted in a map outlining the region where the noise had been heard (Fig. 1b). The map is simplified so that it mainly shows district headquarters towns (and also Ficksburg and Ladybrand in the eastern Free State province, South Africa). Superimposed on the map is a circle of approximately 125-km radius, which indicates the area within which the noise was sufficiently audible for those who heard it to remember it clearly. By this time, it had been long concluded that the only plausible explanation for the noise was a meteorite explosion, and this conclusion was published in the university's weekly newsletter, *Information Flash,* on 9 August. The article included a map drawn in perspective from the south together with a rather fanciful meteorite shown travelling from east to west and exploding over the centre of the circle, the hypocentre, or point immediately below the explosion. This point was estimated to be on the east side of a line from Maseru to Teyateyaneng (Fig. 1).

The conclusion that the source of the noise was a meteorite derived not only from the wide area over which the sound was heard, but also from reports of sightings of dust trails, said to be rather wider than the vapour trails of high-flying aircraft, and which were seen between and above the 80% cloud cover that formed on 21 July. Particularly useful was a report from Thaba-Tseka, which indicated that the trail had begun in the sky on the west side of the town, and had continued in a westerly direction. At other points, observers had been asked to estimate the altitude and direction of the trail.

The report as published on 9 August had not ruled out parts of the meteorite reaching Earth, but had assumed, in the absence of further evidence, that after the meteorite had exploded, it had reached the Earth only as dust.

An eyewitness report

The first report was circulated to a wide circle of colleagues and friends, and amongst these Mrs J. Jaques of Ladybrand inquired widely to discover who might have witnessed or heard the event. This resulted in a report from the manager of a Maseru insurance company and his wife, Richard and Pauline Austin, who provided a description of what they had observed in the Maseru direction from about 170 km southwest of the capital while driving on the road from Bethulie to Smithfield in the Free State. An object variously described as resembling a sparkler or flare was seen descending from right to left at an angle ('one o'clock') of approximately 60° to the horizon. The object had white sparks coming from its head, and some redder sparks from its tail. It was seen for about 2.5 seconds, during which time it descended from about 40° to 25° above the horizon, before disappearing into a cloud bank. The timing and date given were the same as those for the loud noise over Lesotho, although this sound was not heard by the Austins.

Rocks falling from the sky

The title of the Sesotho fortnightly newspaper *Leseli ka Sepolesa* suggests that it throws light on the work of the police, and the headline story on the front page of each issue is typically an account of a serious crime. However, the issue of 15 August 2002 had a rather different headline: *Naledi e oela Thuathe* ('a star falls on Thuathe'). The sequence of events which had led to this report was that a group of villagers from the village of Ha Ralimo on the Thuathe (or Berea) plateau (Fig. 2) had come to the main police station in Maseru to complain that rocks had fallen on them from the sky. They had brought samples of what had fallen, and these were taken to the Commissioner of Mines and Geology, after which a police reporter and a geologist had visited the Thuathe plateau and been given a first-hand account of what had happened by the headman of Ha Ralimo, Mpho Moseme (Fig. 3a).

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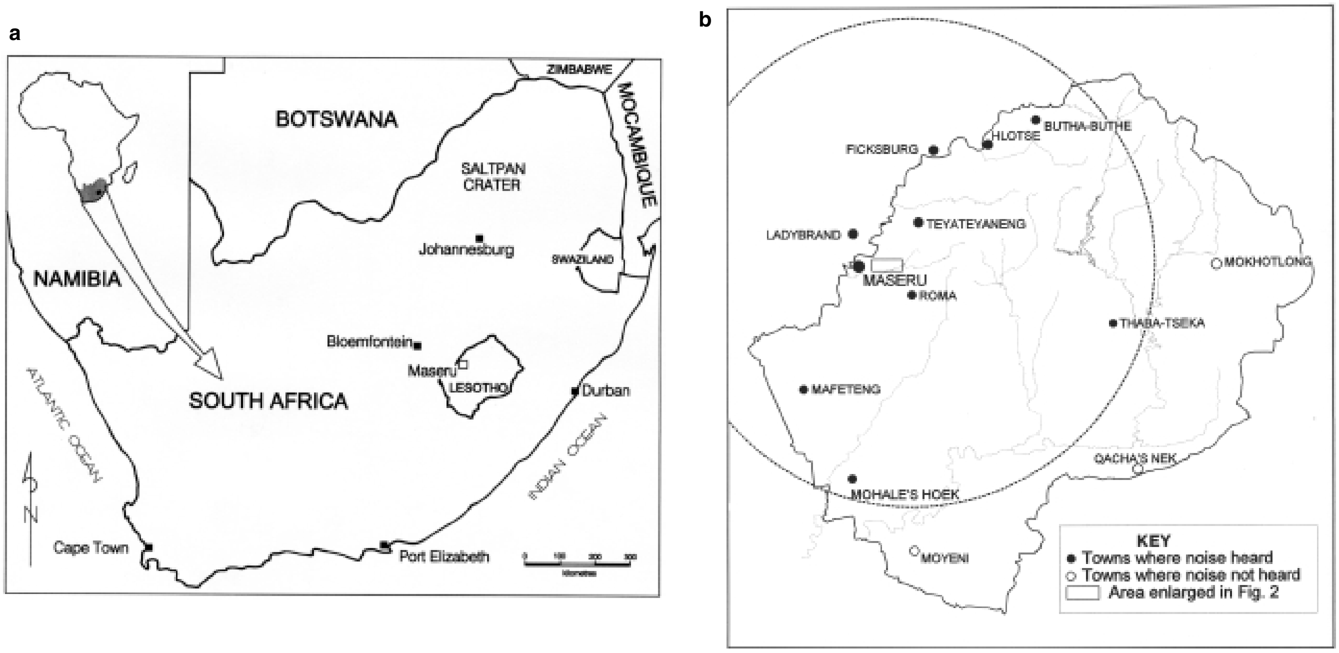

Fig. 1. Study area. **a**, Schematic map of southern Africa, indicating the location of Lesotho and its capital Maseru, just each of which the Thuathe meteorite fall occurred. **b**, The region of Lesotho and the southern Free State province of South Africa, with a 250-km-diameter circle that indicates the region where the noise of the 21 July 2002 event was heard.

Moseme had been walking between the village of Baruting and his home at Ha Ralimo on the afternoon of Sunday, 21 July. Like everyone else in the vicinity, he had heard a truly extraordinary noise overhead, after which he had seen red objects in the sky. A few moments later, he was startled by the sound of an enormous splash in the Phororo/Monyake Dam (Fig. 2) he was passing. Then followed the thud of other objects hitting the ground nearby. He started running, but did not know which way to run, because the objects seemed to be falling on all sides. He was relieved to get home unscathed. Later, he pointed out the depression caused by this large (>1 kg) stone to us, which apparently formed less than a metre from his position at the time.

While many villagers had been momentarily convinced that doomsday had arrived, after mature reflection that it had not actually arrived, they wondered whether they could not turn

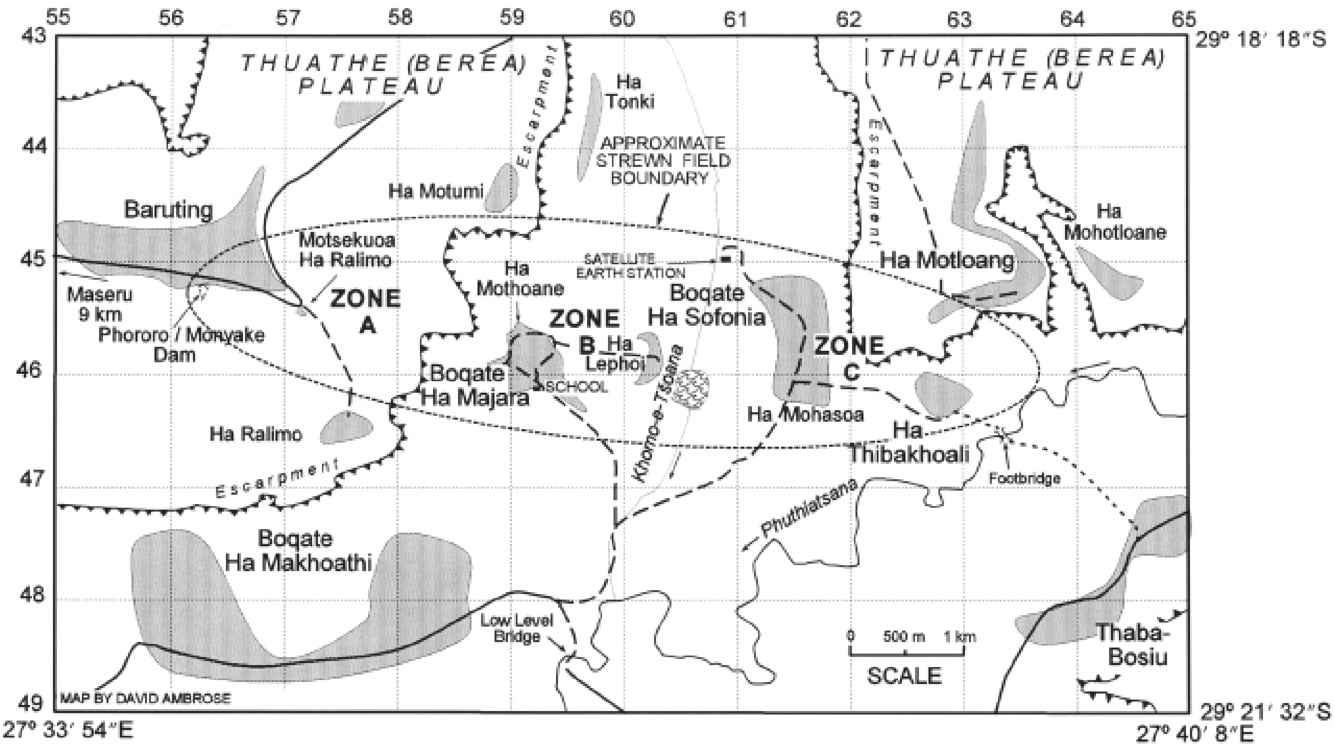

Fig. 2. Map of the Thuathe meteorite strewn field and surrounding region (view towards the north), based on a 1:250 000 topographic sheet of the region. Tarred roads are shown by thin continuous lines, tracks by dashed lines, and streams by very thin continuous lines. Shaded areas are villages, and two dams are indicated by wavy patterns. Grid numbers relate to the South African Lo 27° survey grid system.

Fig. 3. **a**, Ha Ralimo headman Mpho Moseme, with his wife and other family members, showing a chunk split off the largest meteorite sample found close to his village. **b**, A view of the Thuathe Plateau, on top of which the village of Ha Ralimo is located just to the right of the bushes on top, and the escarpment leading towards the lower level, where the more western zones (B and C) of the strewn field occur (compare zones marked in Fig. 2). **c**, Stone no. 6 (2.387 kg, measuring roughly 13 × 13 × 8 cm), the second largest stone found. This specimen has nine fracture surfaces, each with typically concave, thumbprint-type depressions. The entire stone is covered with thin fusion crust. Several small areas have been chipped off (presumably due to handling by 'collectors'). Independent from these chipped areas, several hairline fractures cut across the fusion crust, for example at the bottom right.

the situation to their advantage. The largest rock to fall, weighing an estimated 3–4 kg, was excavated from where it had embedded itself in a fallow field (later showings of the site suggest at a depth of about 50 cm) and was split in the hope that it might contain diamonds. A portion of this rock was later acquired by Molisana Molisana of the Department of Physics & Electronics of the National University of Lesotho, and another portion by the authors. Meanwhile a series of visits were paid to the impact area, including a joint visit by W.U.R. and D.P.A. on 28 September 2002. By this time, something of a meteorite market had developed in the vicinity of Ha Ralimo, with small meteoritic stones in plastic bags being offered by a number of people, particularly herdboys, whose time spent wandering the plateau with their animals had given them many opportunities to pick up these strange stones.

A number of samples weighing between several hundred and several tens of grams were taken by the second author for mineralogical and chemical analysis, and the first author worked on the problem of delimiting the strewn field, the area over which stones had fallen. We proposed to name the new meteorite *Thuathe,* after the plateau on which it was first discovered, and this name has recently been approved by the Nomenclature Committee of the Meteoritical Society.

Extent of the strewn field

It was the villagers of Ha Ralimo who had reported rocks falling from the sky, but from the accounts of the dust trail and noise, it seemed plausible that the strewn field of meteoritic stones might extend further eastwards. Ha Ralimo is situated on the westernmost lobe of the Thuathe or Berea plateau, some 12 km east of the centre of Maseru. The plateau is situated at an elevation of about 1850 m and is bounded by an escarpment formed by Clarens Formation sandstone cliffs, which together with the talus slope below result on the east side in a drop of some 200 m to a heavily populated area below, commonly known as Boqate after a massive isolated rock of that name (Figs 2 and 3b).

A visit was paid on 8 October, already more than two months after the explosion, to the village of Boqate Ha Majara. The villagers were attending a pitso, a village meeting, which provided an opportunity, with the permission of Chieftainess 'Mabotle Theko, to speak to them about the noise on 21 July. Everyone had heard it, and many reported stones falling, in some cases in their gardens; in one case a woman claimed she had picked a stone up and it was hot! No stones were actually produced, however, and a return visit was promised to see what villagers could find in the meantime.

On 8 October, the village of Boqate Ha Sofonia, further to the east in the strewn field (Fig. 2), was also visited, and here more positive evidence was obtained from Chief Tšekelo Sofonia, because he had kept a meteoritic stone, collected not far from his house. We were recommended to visit a villager, 'Malineo Mantsoe, who, on 21 July, told us that she had been sitting at the very same spot when there had been a terrible noise overhead. She had run round to the back of the house, expecting to see a thunderstorm, but there was none. Hardly had she returned to the front of the house when '*wheeeeee bang!*', a stone had landed in the cooking area with a walled enclosure, just three metres in front of her, cracking one of her plastic water containers. Fortunately, as she told us, she was prepared for such occasions. No villager could have thrown a stone at such a speed, so it must have been a *thokolosi* (spirit). She had holy water in the house, blessed in church, and she had sprinkled it on the stone and elsewhere and around, and it worked! No more stones had fallen.

Table 1. Information about the 10 largest stones recovered to date.

Catalogue No.	Mass (g)	Zone of strewn field	Grid reference	Comments
61 64	*c.* 3500	A	571458	Broken up before mass ascertained
6	2387	A	567457	Intact with no recent fractures
102	685	B	590464	Intact and shaped like a fat fish
82	503	B	595455	2.5 km E of most massive stone
118	483	A	*c.* 5745	Purchased near Motsekuoa Ha Ralimo
103	453	B	592452	Found over three months after 21 July
270	431	A	*c.* 5745	Purchased near Motsekuoa Ha Ralimo
191	338	B	586452	Found just below the escarpment
241	332	A	*c.* 5745	Purchased near Motsekuoa Ha Ralimo
60	309	A	*c.* 5745	Purchased near Motsekuoa Ha Ralimo
–	Unknown	A	563453	Stone fell into Phororo/Monyake Dam
262	6	A	585446	Closest stone to Ha Motumi village
250	24	B	596447	Northernmost stone below escarpment
190	6	C	608450	Recovered from Satellite Earth Station
–	Unknown	C	629456	Reliably reported from Ha Motloang
81	20	C	637459	Easternmost stone recovered
100	30	B	600465	Southernmost stone recovered

A variety of very different stories of falling stones was eventually collected, as well as actual stones, and this extended the strewn field over an approximately elliptical area with major axis of approximately 7.4 km and minor axis of 1.9 km. The area included the Satellite Earth Station at Ha Sofonia, which provides international links for Lesotho's telecommunications system via a geostationary satellite over the Atlantic. The initial map of the strewn field showed the Earth Station as just outside the boundary, but permission was obtained to visit the station, which is within a security area. The staff had noticed nothing unusual on 21 July apart from the noise. The two 13-m-diameter dishes showed no sign of any impact, nor of any stones that might have bounced off them and fallen below. But on the concrete apron outside the offices, a field assistant, Mamhlongo Maphisa, who had by this time become skilled in identifying meteoritic stones, found a small stone, of mass 6 g, having the characteristic fusion crust as well as fractures exposing its interior.

In refining the boundaries of the strewn field, particular assistance was obtained from the children of the Boqate Lesotho Evangelical Church Primary School, the only school within the strewn field. Once they realized that stones could be sold, they went to great trouble to find them, and — moreover — discovered that in doubtful cases meteoritic stones could be distinguished by the use of a magnet. They were able to relate stones to some twenty different named locations within the village and the immediate vicinity. The greatest density of stones was found to be close to the escarpment west of the village and between two defining landmarks: Letsatseng, a dyke that runs down southeastwards from the escarpment halfway between the villages of Ha Mothoane and Ha Tonki, and 'Mamolalana, a rock pinnacle which stands clear of the escarpment, just west of Boqate Ha Majara village (Fig. 2). Many stones fell in the villages of Boqate Ha Majara and Ha Mothoane and were retrieved from gardens and the graveyard; at Ha Lephoi, a stone was collected from the roof of a house.

Most stones were collected by A. Ashworth and D.P.A., and by November 2002, 418 different stones had been catalogued and examined for identifying features. The mass of these stones ranges from 2 g to 2.4 kg, and although presumably from the same parent body, they were found to be rather diverse in appearance and internal structure.

The strewn field as delimited on the map naturally falls into three zones determined by geographical features (Fig. 2). Zone A on the western side is the area on top of the plateau, with the Clarens Formation escarpment forming its eastern boundary. Zone B consists of the area between the escarpment and the north–south-flowing Khomo-e-Toana stream. Zone C is the area east of this stream and, although mostly lowland, includes a small portion of a more eastern lobe of the Thuathe Plateau.

Although stones were found to be relatively sparse in Zone C, particularly at the eastern end, great efforts were made to find them, so that the eastern extent and alignment of the strewn field could be more accurately determined. The easternmost stone at approximate grid reference (South African Survey Grid Lo 27°) 637459 had been found by a herder, Thibakhoali Ntlama, in a field. He had noticed a strange stone, broken it in two, taken one half home and hidden the other half under a rock, from which he was able to retrieve it on request. We were also able to obtain a reliable report of a stone at Ha Motloang on the plateau above at grid reference 629455. An old lady, Nkhono Makhala Ramotse born in 1914, experienced a stone fall with a whining sound near her rondavel (hut). Villagers had gathered around it and cautioned one another not to touch in case it exploded. The old lady, however, had picked it up and said, 'It's just a stone' (*Ke lejoe feela*). She had put it in her rondavel and later thrown it away. Although the stone could not be found, the story was considered sufficiently reliable to include Nkhono Makhala's stone as a defining stone for the strewn field.

It is remarkable how many eyewitnesses reported falls of stones close to themselves and onto their houses, yet all of them escaped unharmed.

Differences in characteristics of stones across the strewn field

The detailed catalogue of stones so far compiled (February 2003) contains 418 entries. Entries 61 and 64 in the catalogue are believed to be part of a single stone, the largest of all, which was broken up into at least different pieces by Ha Ralimo villagers. Of these, one other surviving piece (not catalogued) is known to have a mass of 1020 g. The stone before having been broken is considered in what follows to have had a total mass of about 3.5 kg. Table 1 provides details of the ten largest stones recovered to date. Treating stones 61 and 64 as a single stone of mass 3500 g, we catalogued 417 stones from the three zones.

In addition to this collection compiled at the time of submis-

Table 2. Differences in areal densities and masses of stones recovered from zones A–C.

Zone	Area (km^2)	Number of stones	Areal density (stones per km^2)	Total mass (g)	Mean mass (g)	Mass (g) per km^2	Smallest stone (g)	Largest stone (g)
A	2.94	293	99.7	19 348	66.0	6 581.0	2	*c.* 3 500
B	4.08	112	27.5	7 575	67.6	1 856.6	2	685
C	4.02	12	3.0	620	51.7	154.2	6	121
A+B+C	11.04	417	37.8	27 543	66.1	2 494.8	2	*c.* 3 500

sion of this manuscript, a further 60 stones had been collected, but not yet catalogued, by the authors, more than a hundred specimens have been reported to have been collected by staff and students of the University of the Free State, Bloemfontein, and an unknown number of stones has since been purchased from the local population in the Thuathe region by traders and collectors.

Table 2 shows that whereas stones recovered have similar mean masses (range 51.7–67.6 g) over the three zones, their density on the ground was far greater in Zone A (100 stones per km^2, or about 1 per hectare) compared with the zones to the east (28 per km^2 and 3.0 per km^2, respectively). Similarly, the mass that fell per km^2 (on the basis of the existing statistics) appears to have been far greater in the westernmost Zone A. The largest stones recovered were also obtained in descending order in the three zones from west to east (see Table 1). The mass of the smallest stones is probably not significantly different among the three zones. Villagers in zones A and B had become more conscious of the monetary rewards from finding stones and, as time went on, provided smaller and smaller examples.

A full analysis of the differences between stones from the three zones has yet to be carried out. Initial indications are that more stones from zone A show indications of fractured surfaces only partly covered with fusion crust, and that stones showing mature smoothed fractured surfaces are more often found in zones B and C. Fusion crust is typically about 0.1 mm thick on stones in Zone A, but tends to be slightly thicker towards the east, up to 0.2 mm or more in stones from Zone C. Many stones show evidence of as many as six or even more, apparently successively formed, fractures. The earliest fractures are maturely fused and smoothed, indicating loss of material from the surface. Other fractures may have a fused surface following closely the contours of the fracture, indicating little loss of material. Fractures that formed relatively late may display a surface which had been heated, often with the formerly molten fusion crust bleeding over the edges or even streaked across the surface. Finally, there are fresh fractures showing no evidence of heating, and some of these may well be the result of impact on rocks on arrival at the Earth's surface or subsequent human intervention. These fresh fractures show the interior of the stones as grey, sometimes brecciated material, frequently with white chondrules and metallic specks of nickel-iron alloy. In the case of stones retrieved after several weeks' exposure to the weather, the fresh faces show brown rust stains.

Apart from fractures, many stones are chipped, chips being considered to be breaks in the surfaces, which are less than what can be considered as a well-defined face. Chips range in size from being comparable to fractures, to minor blemishes, at least some of which are the result of stones having been struck together after collection.

The fusion crust on most stones is almost jet black in colour and often displays shiny specks of metallic alloy and is sometimes interrupted by white chondrules. However, on a few stones the fusion crust is a slightly darker grey than the interior. Stone 102, the third largest recovered, is particularly interesting. It is shaped like a fish, and the grey fusion crust is overlaid by black streaks from nose to tail.

The shapes of stones vary from rather angular, like the example shown in Fig. 3c, to subangular or with well-rounded lobes. Most surfaces are covered with smooth, extended or thumbprint-like depressions.

Tentative estimate of total mass of fall

The 418 catalogued stones have a total mass of 24.67 kg, and one uncatalogued stone is known to have a mass of 1.020 kg. Several other known stones have not been included in our catalogue, including a specimen held in the Department of Mines and Geology and another that was sent by the department for analysis to the Council for Geoscience in Pretoria. Members of the public are also known to have purchased stones from Zone A, which has tarred road access, but not from the other zones. We estimate that, on the basis of the samples in our possession or known to us, the minimum total mass of recovered stones is of the order of 30 kg. It must, however, be assumed that the meteorite material retrieved by others could be of the order of another 5 kg.

Catalogued stones range in mass from 2 g to 2.4 kg. In addition, the stone that fell into the Phororo/Monyake Dam has still not been recovered and likely weighed at least 1 kg. The catalogue has 59 stones with masses between 100 g and 1 kg, two of which are believed to be part of one of the >1 kg stones that had been broken up. There are 133 stones with masses between 10 and 100 g, and 73 with masses between 2 and 10 g. Given that many people have searched the strewn field, that stones did not embed themselves deeply into soil, and that most fields were at the time unploughed, we consider that there are very few additional stones of >1 kg mass. As the size diminishes, the fraction of stones recovered is proportionately less, and possibly only half the stones between 100 g and 1 kg have been recovered, 10% of those between 10 and 100 g, and perhaps not more than 1% of those between 2 and 10 g. Although these figures are inevitably uncertain, they point to a total mass of some 100 kg for the meteorite falling to Earth in pieces of 2 g or more.

It is clearly impossible to estimate the mass that represents dust or burned-off material (all material with mass <2 g), but given the many smooth surfaces on recovered pieces and the extent of the trail, much molten material must have been lost. In addition, fracturing and chipping has led to further loss of mass. We estimate that the amount of lost material was at least of the same order as the fallen mass, and perhaps up to ten times as much. This leads to an estimate of the total mass of the body that entered the atmosphere of between some 200 and 1000 kg.

Spatial and temporal coordinates

It is rare that sufficient information about a meteorite is available to work out its orbit with some precision and, therefore, where in the Solar System it originated. Although this is a matter for further investigation, the following information is available. Early indications were that the meteorite was travelling almost directly from east to west. The strewn field largely confirms this,

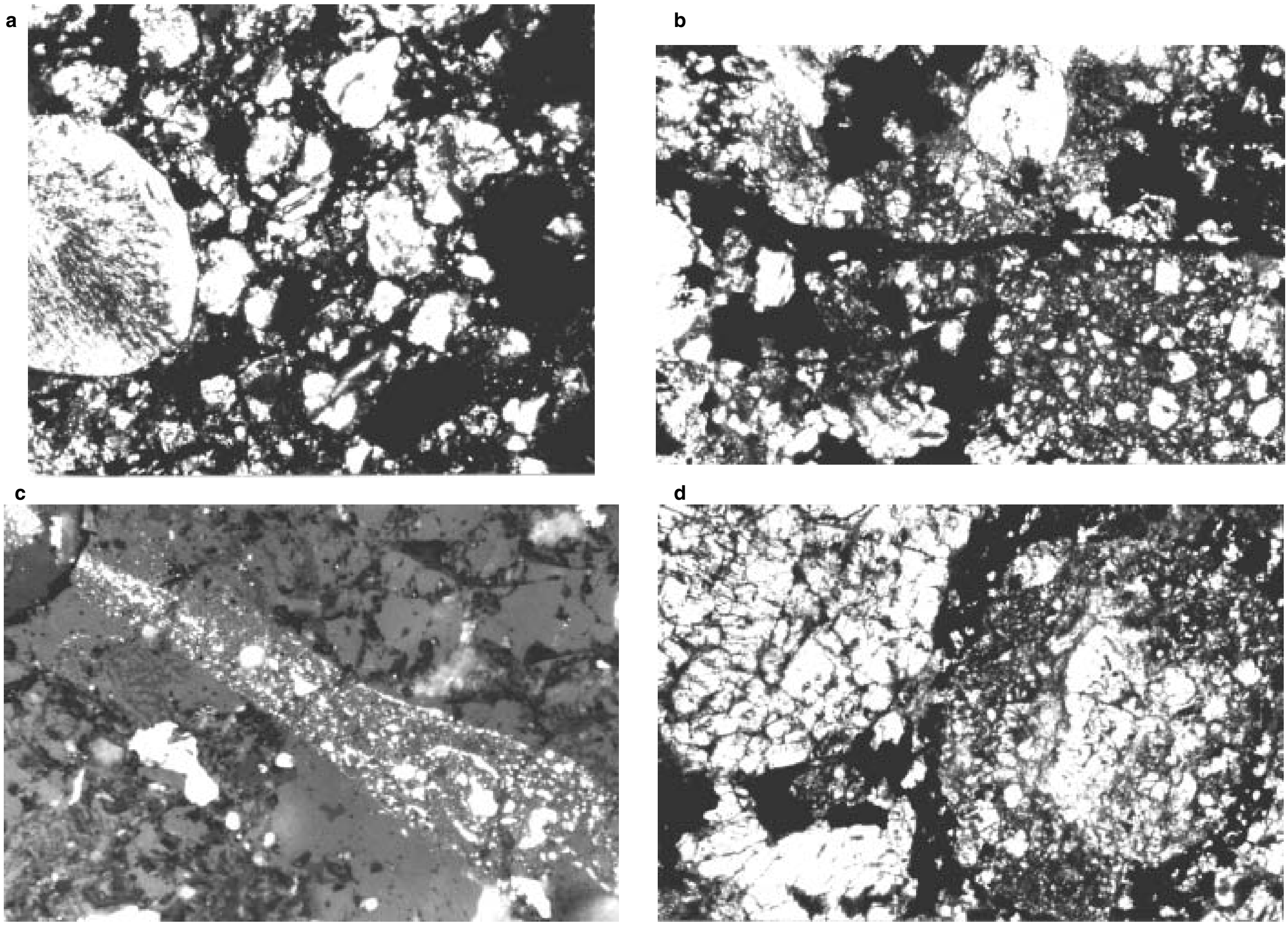

Fig. 4. **a**, Stone no. 58: Typical micro-texture of the Thuathe meteorite, with a droplet-shaped, perfectly defined excentro-radial olivine chondrule in a groundmass of mineral fragments (mostly olivine), small chondrules and chondrule fragments, many of which are fractured or brecciated. Width of field of view: 2.2 mm, crossed polarizers. **b**, Stone no. 61, section B: Shock vein cutting here across fine-grained, dark-grey groundmass, with a section of an ovoid, coarser-grained and lighter-grey inclusion shown at top of this image. Width of field of view: 3.4 mm, crossed polarizers. **c**, Stone no. 61, section A: High-magnification reflected-light image of part of a shock vein, showing the intimate intergrowth of silicate melt and metallic particles, many of the latter with droplet shapes and streaks that appear to be aligned, which is suggestive of melt flow. Width of field of view: 220 µm, plane polarized light. **d**, Stone no. 61, section A: Two well-defined chondrules embedded in metal-rich groundmass. Chondrule at upper left is of the olivine porphyritic type, whereas the chondrule on the right side of the image is a compound chondrule with a porphyritic olivine core surrounded by a much finer-grained zone that closely resembles the dark-grey phase of this meteorite and, like that, contains significant metal (lower right). Width of field of view: 2.2 mm, crossed polarizers.

but refines it slightly, indicating a grid bearing of about 275°.

Much more problematic is the angle at which the meteorite entered the atmosphere, and the height at which the final explosion took place. The most useful report has already been mentioned and describes a sparkling object seen through a car windscreen falling for about two seconds from right to left (that is, east to west) at an angle of approximately 60° to the horizon from a point to the south-west, which is on a bearing of approximately 220° and distance of 180 km from the centre of the strewn field. The object was described as descending from about 40° to 25° above the horizon before disappearing into a bank of cloud. This corresponds to it falling from a height of about 151–84 km. However, these figures are likely to be substantially in error, with the angle of fall ('one o'clock') probably being 60 ± 15°, whereas the angles as seen through the windscreen could easily have been half those estimated in the recollection of the event several weeks later. Thus, the object might have been seen descending from a height of about 66–40 km.

There is further detail available from observers in Ladybrand to the northwest of the event, on a bearing of approximately 325° and at a distance of 21 km from the centre of the strewn field. People attending a braai (barbecue) saw both the dust trail and later heard the loud noise. At least one saw the 'sparkling path' of the meteorite, and all saw the dust trail and heard the sound, which was said to have been some minutes after the initial sighting of the sparkling trail. The dust trail was said to be like the vapour trail of an aircraft, but also contained a number of 'puffs' or pulses that later developed into S-shaped curls. Estimates of its height in the sky varied, but Jurg Steppat, a helicopter pilot, who observed it from the ground in Ladybrand, stated that the trail appeared to be from north to south, not greatly sloping and about 80° above the horizon, which would correspond to a height of about 58 km. Another observer estimated 70° above the horizon.

A report from near Roma, at a bearing of approximately 145° and from a distance of approximately 20 km from the centre of the strewn field, stated that the meteorite trail was seen between clouds at an angle of 70° above the horizon. This corresponds to a height of 55 km, but as the trail disappeared into the clouds, the bottom of the trail might well have indicated a significantly lower height. Furthermore, the length of the strewn field ellipsoid compared to its width suggests that the angle of the path with the vertical was ~75°.

Finally, we consider the timing of the event. This was recorded by one of us (D.P.A) at Roma as 15:49 (13:49 GMT), considered to be accurate to ± 1 minute, with the sound duration of about 15 seconds considered to be subject to an error of ±5 seconds. Indeed several people reported the duration as about 10 seconds. The point at which the sound was heard is 16 km from the centre of the strewn field on a bearing of 143° from the centre. In recovering the actual time of the event, allowance has to be made for the speed of sound, and if, for example, the origin of the sound was at a height of 40 km above the centre of the strewn field, it would take just over 2 minutes for the sound to reach Roma. Thus, the timing of the event should rather be taken as 13:47 ±1 GMT.

Classification of the meteorite

Seven polished thin sections were prepared from four different stones and studied by optical microscopy. Compositions of minerals were determined using the JEOL JXA-8800M Superprobe electron microprobe at the National Institute of Polar Research in Tokyo, Japan. The electron microprobe was operated at 15 kV and 20 nA. Counting times were 30 s for most elements. Natural and synthetic standards were used and corrections were made for absorption, fluorescence, and atomic number effects using JEOL on-line programs.

Most freshly cut slices of Thuathe meteorite specimens showed homogeneous beige to light-grey material, which is speckled by quite large amounts (estimated 20 to>50 vol%, but mostly <35 vol%) of metallic phases. In some pieces, very narrow veinlets of black material were visible, the widths of which are of the order of 0.1 mm. These veinlets are not abundant but common. Several — but not all — specimens cut so far displayed two distinct phases on fresh cuts: roundish to ovoid, light grey to beige material was present between often distinctly vein-like patches of a darker grey material which was generally richer in metallic phases than the lighter material. Where this darker grey phase was relatively abundant (20–35 vol%), its occurrence can no longer be regarded as vein-like but rather gave the impression of a breccia groundmass. Chondrules were recognizable in all samples, not in great abundance, but they were distinct. Many of them had perfectly round or droplet shapes, and a variety of olivine chondrule types (including concentro-radial, porphyritic, microporphyritic, and zoned: Fig. 4) was recognized.

Thus, the Thuathe meteorite represents a chondritic meteorite that is characterized by significant amounts of metallic phases and, at least in part, is brecciated. Olivine is by far the most important mineral, besides some orthopyroxene and comparatively much less clinopyroxene. Besides chondrules and fragments of chondrules, metallic phases (taenite and kamacite) form the next most abundant minerals. In addition, angular fragments of extremely fine-grained, dark material with olivine porphyroblasts were observed. This material occurs in the form of clasts as well as groundmass. Larger idiomorphic to hypidiomorphic olivine crystals were also abundant. The narrow veins, by analogy with occurrences in other chondrites in which they have been regarded as shock veins (melt caused by shock compression in excess of 45 GPa), may cut across large mineral grains or chondrules, or meander around them. Locally, displacements of up to several tens of micrometres were noted. Several typical microphotographs of this meteorite are shown in Fig. 4.

The average composition of olivine was measured at $Fa_{17.4}$ (0.8 mol% standard deviation) and that of orthopyroxene was $Wo_{1.04}En_{83.3}Fs_{15.7}$ (0.71, 1.3, and 2.2 mol% standard deviations, respectively), which corresponds to the H chondrite type based on the discussion by Rubin[1]. As chondrules are distinct but not abundant, and the mineral compositions so far determined suggest strong equilibration, this meteorite is classified as of petrologic type H4 to H5 (see Lombard *et al.*[3]). Alteration of this fresh fall was obviously minimal and oxidation of metal observed must be considered the result of sample processing (associated with cutting and thin-section preparation). Besides undulatory extinction in both olivine and pyroxene, fracturing was strongly developed in many mineral fragments, and many fragments were internally brecciated (Fig. 4a). According to the shock classification for ordinary chondrites by Stöffler *et al.*,[2] the Thuathe meteorite is, thus, classified as an H chondrite of petrologic type 4/5 and shock degree of S2–S3. This means that it is a weakly shocked meteorite that locally is characterized by the occurrence of shock melting.

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