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Australasian microtektites from the Central Indian Basin: Implications for ejecta distribution patterns

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Microtektites belonging to the Australasian tektite strewn field have been recovered in one (SK-16/176) out of three cores examined from the Central Indian Basin. The microtektites have been identified based on their physical appearance, stratigraphic position, chemical composition and geographic occurrence. Their chemistry reveals that among the analysed specimens, a majority belong to the 'normal' microtektite clan, one has a high Mg (HMg) composition shown by bottle green microtektites, and some have an intermediate composition. The absence of microtektites in the other two cores (SK-16/183 and F-2/88B) could be because of the small area of coverage by sediment coring. Therefore, given the vastness of the Australasian tektite strewn field, many more microtektite locations have to be identified in order to arrive at a microtektite distribution pattern.

TEKTITES, which are glassy ejecta generated by impacts, are distributed in large geographic domains called strewn fields. Four such tektite strewn fields occurring in four different geologic and geographic areas are known[1]. Microtektites are small (< 1 mm) glasses found only in the oceans. In three of the four strewn fields, microtektites are present, not only are the boundaries of the strewn fields determined by their occurrence in the oceans, but also mass calculations of the ejecta are carried out[2]. The youngest and also the largest strewn field is the Australasian tektite strewn field encompassing almost the entire Indian Ocean, the land masses from Indochina to Tasmania in the south and also parts of western Pacific Ocean (Figure 1), comprising of a mass of 10^9 tons of tektite material[3]. Since the time when Australasian microtektites were first discovered by Glass[4] (identified based on their physical properties, stratigraphy, geographic location and chemistry) up to 1979, out of the 100 deeepsea cores examined, microtektites were found in 33 (ref. 3). At present there are over 40 Australasian microtektite occurrences known[5]. Based on their pattern of occurrence, a possible ray-like distribution was suggested[6]. With the discovery of an iridium anomaly[7], and shocked minerals[6], associated with the Australasian microtektite layer, the impact origin of this strewn field is established beyond doubt.

We report here the recovery of Australasian microtektites in one out of three cores investigated which we suggest has significance for the Australasian microtektite distribution.

We examined three deep sea cores, two of which were collected during the 16th Cruise of ORV Sagar Kanya (SK-16/176 Core length: 3.75 m; Lat. 14°003′S, Long. 74°046′E; and SK-16/183 Core length: 4.6 m; Lat. 6°010′S, Long. 76°E) and the third core from the second cruise of MV Farnella (F-2/88B Core length: 0.88 m; Lat. 12°43′S, Long. 77°03′E), (Figure 1). All the cores were previously dated by radiometric[8] and biostratigraphic methods[9,10], and have ages which extend beyond the 0.77 Ma age of the Australasian strewn field. The cores were sub-sampled at 3 cm interval up to 52 cm core depth, further below at 10 cm interval for SK-16/176; at 5 cm interval for F-2/88B, and up to 100 cm depth for SK-16/183 and, below 100 cm for the latter, the sampling interval was 10 cm. The sub-samples were dried, weighed and wet sieved in a 63 µm mesh sieve and the dried coarse fraction was further dry sieved in 250 and 125 µm sieves. The > 250 µm fractions were scanned using a binocular microscope having a mag-

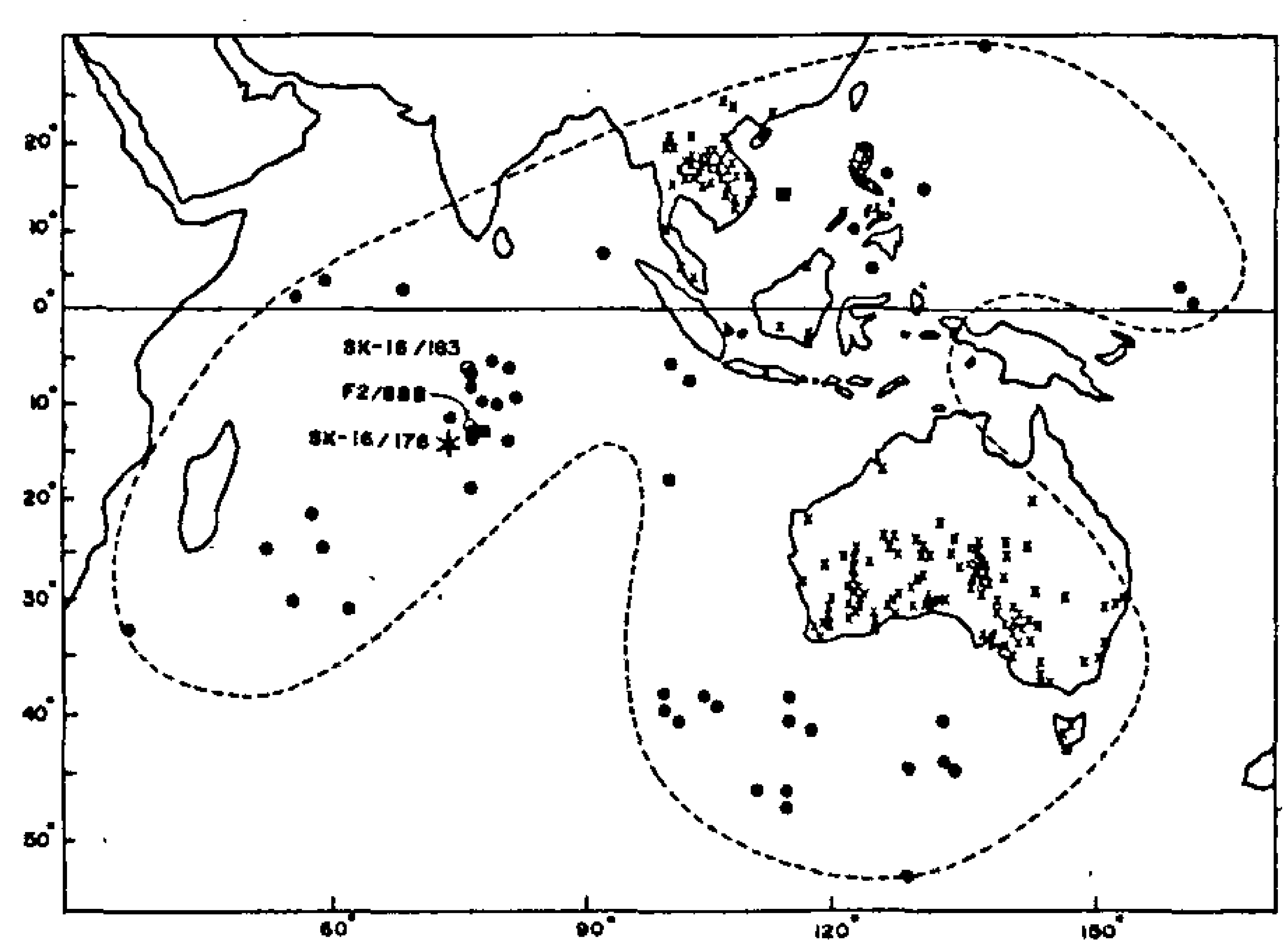


Figure 1. The Australasian tektite strewn field. The dotted lines show boundaries of the strewn field indicating a possible ray-like pattern of distribution[6]. The locations of the three cores (SK-16/176, SK-16/183 and F-2/88B) in this study are marked. The cross marks in the land masses indicate tektite occurrences, the dots in the oceans microtektite occurrences, the squares in the oceans indicate tektite occurrences.

nification up to 40 × directly, whereas the > 125 μm fractions were further separated by heavy liquids wherein the radiolarian shell material was floated, and the resultant heavy fractions were then dried and searched for microtektites.

Microtektites were recovered from the core SK-16/176, 11 of which were mounted in epoxy, ground and polished and the chemistry for a minimum of 3 spots per specimen was determined with a Cameca CAMEBAX Model 571 electron probe microanalyser using silicate and oxide standards and online corrections were made by using the method of Bence and Albee[11]. A synthetic tektite standard (USNM 2213) made by Corning Glass Company, analysed by the USGS was also mounted, polished and analysed for comparison. Scanning electron microscopy was done with a JEOL 100 CX electron microscope.

The peak microtektite abundance in the core SK-16/176 was found between 13 and 16 cm (Figure 2). Given the 0.77 Ma age of the Australasian strewn field[12], this horizon should occur much deeper in the core for the sedimentation rates of 2–3 m/Ma in this area[13]. However, from the multi-beam seafloor mapping in this area carried out by the NIO we found that the location of SK-16/176 is at the flank of an abyssal hill where the chances of either slumping or enhanced bottom current activity are possible and therefore could cause sediment removal. Also, Borole[8] observed an absence of ^{230}Th excess in this core which was attributed to the lack of sediment deposition in this area caused by the Antarctic Bottom Waters. Furthermore, Gupta[10] reported the first appearance datum (FAD) of Collosphaera Orthoconus (FAD 0.65–0.70 Ma) within the top 20 cm. Therefore, it appears that the top ~ 2 m of sediment in this core has been removed by bottom currents at this location.

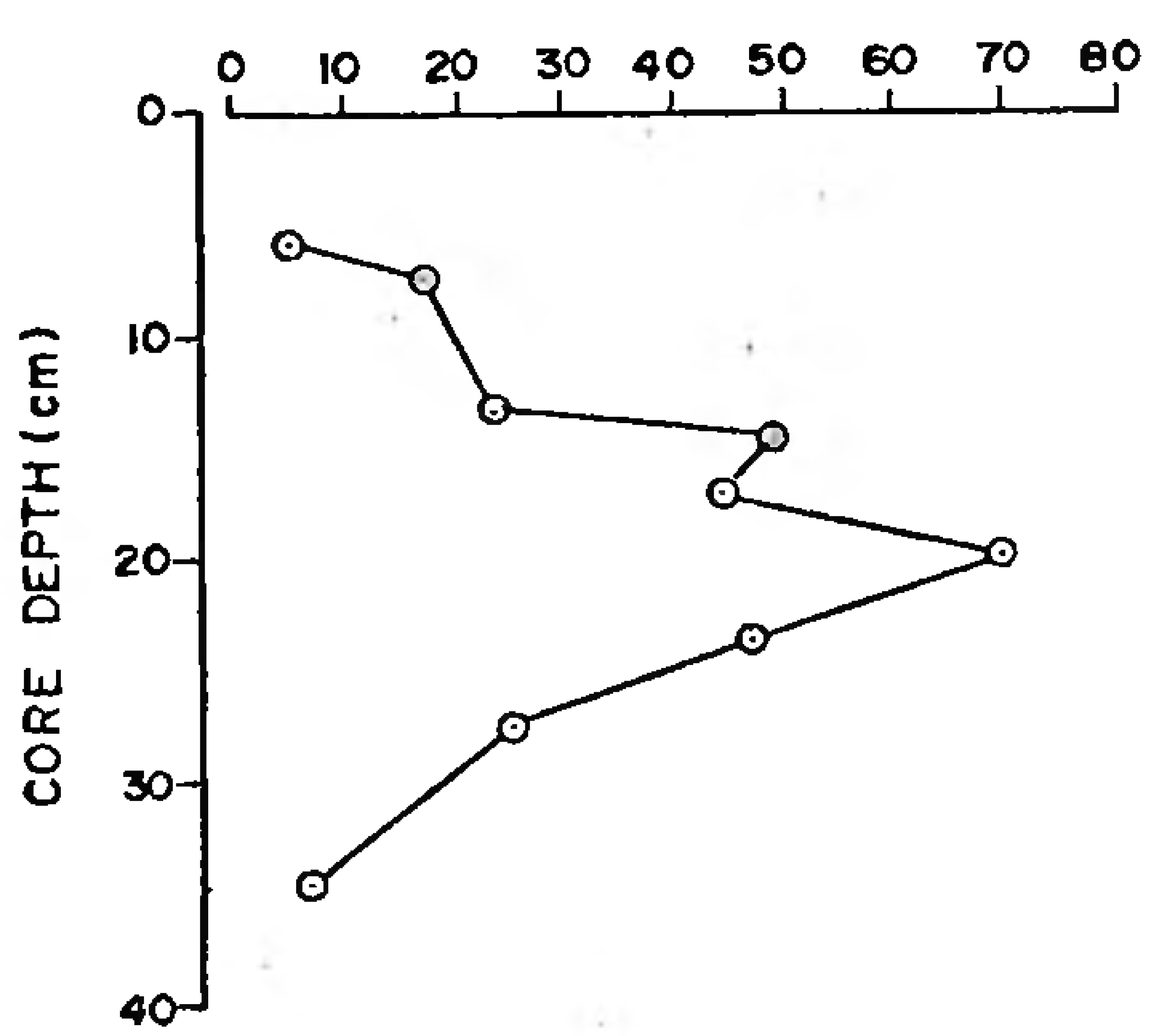


Figure 2. Downcore abundance of microtektites in SK-16/176. Core length is 375 cm.

The stratigraphic record further below was however, found to be in proper chronologic sequence[10].

In F-2/88B, which has a core length of only 90 cm, a hiatus of ~ 200 ka was observed between 0.4 and 0.6 Ma (ref. 9), and the extrapolated Australasian microtektite horizon should occur at 45–50 cm core depth. Borole[8] dated SK-16/183 and F-2/88B radiometrically by ^{230}Th excess method and the sedimentation rates calculated were 0.8 mm/ka and 2 mm/ka, respectively. At these rates, for the 0.77 Ma age of the Australasian tektite strewn field[12], the peak microtektite horizon should occur at a core depth of 60 cm in SK-16/183. However, microtektites were not found in both F-2/88B and SK-16/183, the reason could be the meagre ocean floor area sampled by sediment corers.

Microtektites have been found only in SK-16/176. More than 90% of the microtektites are spherical, however, dumbbells and disc-shapes are also observed (Figure 3). The smallest specimen observed was 110 μm, the largest 980 μm and, 75% of the microtektites were in the size range 125–250 μm. The colour of the specimens varied from honey-coloured, light yellow,

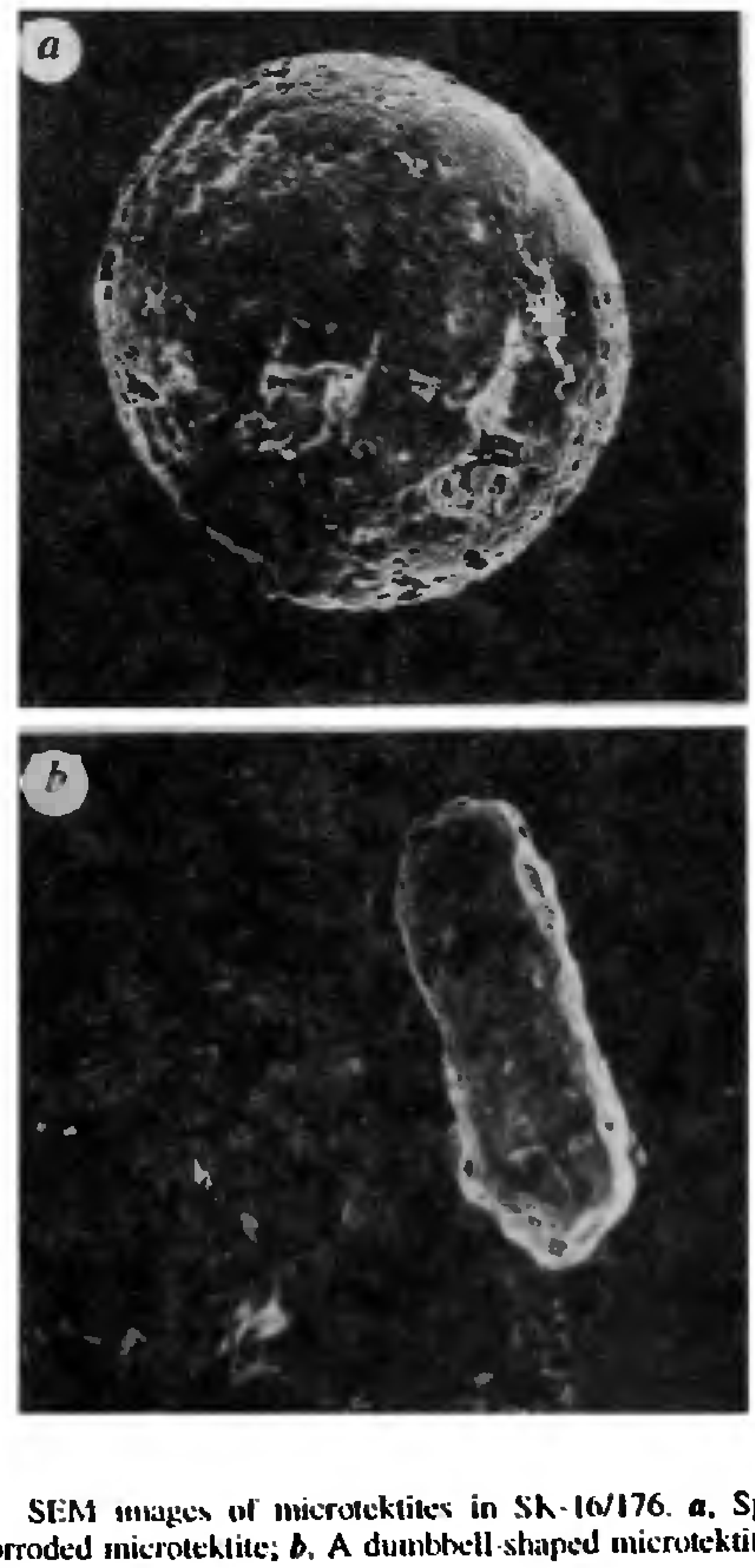


Figure 3. SEM images of microtektites in SK-16/176. ***a***, Spherical, slightly corroded microtektite; ***b***, A dumbbell-shaped microtektite. Scale bar = 50 μm.

Table 1. Chemical composition of microtektites in SK-16/176

	1	2	3	4	5	6	7	8	9	10	11	12*	13†
SiO_2	66.7	64.6	71.2	73.2	70.7	66.9	70.7	71.2	61.8	68.5	53.8	49.6–77.0	72.0
Al_2O_3	16.4	15.5	13.6	12.9	13.9	16.7	14.1	16.0	19.4	15.6	20.7	7.5–22.1	13.6
FeO	6.3	7.8	5.9	5.3	5.5	5.0	4.5	3.9	6.1	5.8	6.8	3.0–8.1	4.9
MgO	4.2	6.4	3.7	3.6	4.5	5.7	5.6	3.0	6.0	4.8	12.0	1.9–17.1	2.4
CaO	3.2	3.3	2.4	2.7	2.9	3.6	3.1	3.5	4.2	3.1	5.0	1.0–5.8	3.6
K_2O	1.1	1.0	1.4	1.2	1.1	0.7	0.8	1.0	0.9	0.9	0.4	0.1–3.7	1.9
Na_2O	0.3	0.3	0.5	0.4	0.5	0.3	0.3	0.3	0.4	0.3	0.3	0.2–2.8	0.6
Ti_2O	0.8	0.9	0.6	0.6	0.7	1.0	0.8	0.8	1.0	0.8	0.9	0.5–1.0	0.8
Total	99.1	100.0	99.9	100.0	99.9	100.9	100.0	99.8	99.9	99.9	100.0		

*Compositional range of Australasian microtektites from Cassidy *et al.*[15].
†Average Australasian microtektite composition from Glass[16].

yellowish green to opaque white. The microtektite abundance estimates were made by the method suggested by Glass and Zwartz[14], and the calculated abundance here is 62 microtektites/cm^2. In the Central Indian Basin the abundance values reported[6] for 7 microtektite-bearing cores varies from 20 to 106 microtektites/cm^2, with an average of 58. Our abundance values are close to the average.

The silica content varied from 53.8 to 73.3% SiO_2 (Table 1). The major oxide percentages fall within the compositional range determined for the Australasian microtektites[15]. All the microtektites analysed have MgO contents higher and Na_2O and K_2O lower than that of the average Australasian microtektite[16] (Table 1). One specimen (no. 11 in Table 1) has low SiO_2 and very high MgO contents.

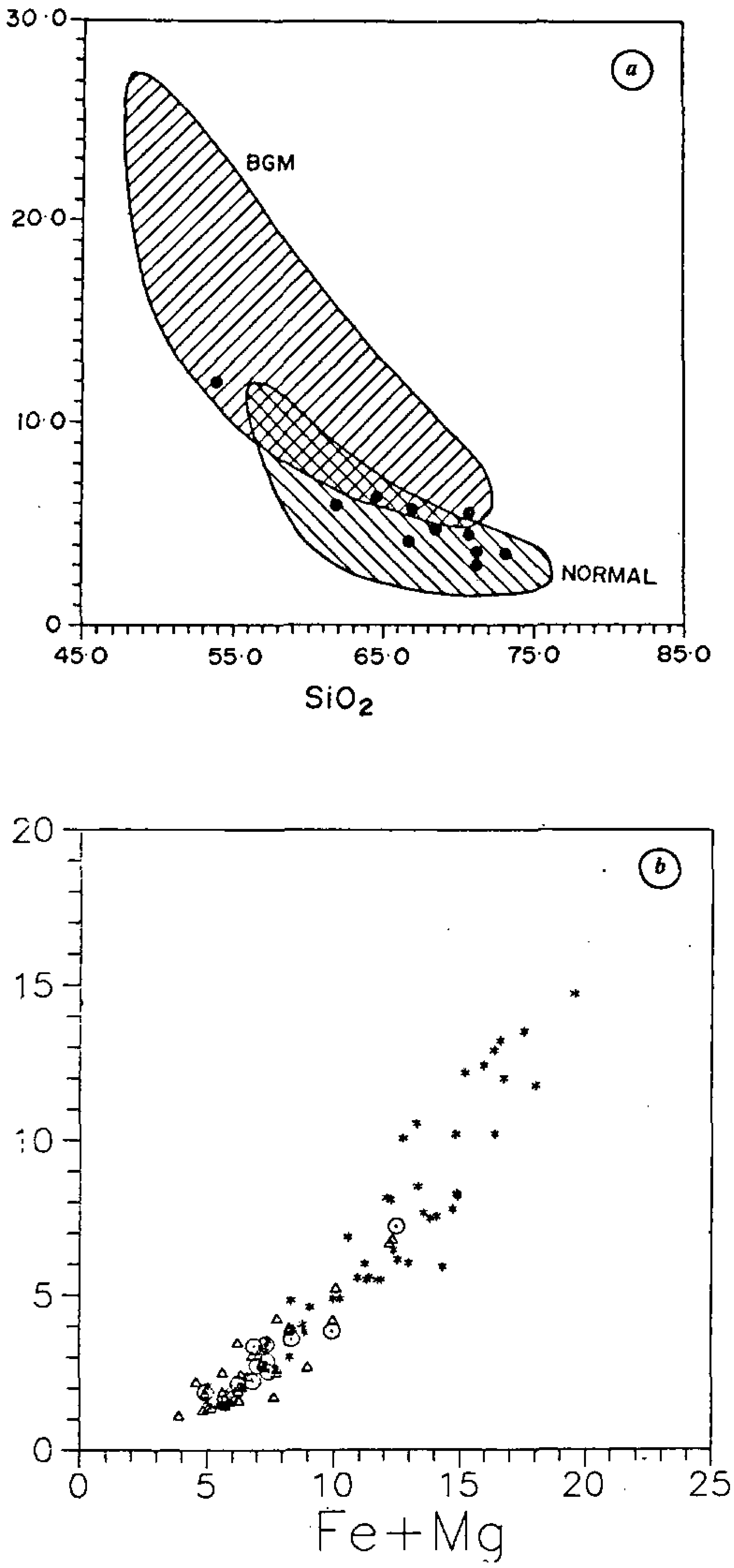
Based on their compositions, Australasian microtektites are either 'normal' or bottle-green (HMg), where the HMg microtektites have a higher refractive index (RI) and specific gravity (sp. gr.) and higher MgO for a given SiO_2 (ref. 15). Further, the HMg microtektites are characterized by higher ferro-magnesium contents (Mg/Mg + Fe) and low Na_2O and K_2O contents compared to the normal microtektites[17]. In a plot of MgO vs SiO_2 (Figure 4 *a*) we found two microtektites falling in the HMg zone, two in a zone overlapping between the normal and HMg areas, and the other 7 microtektites from this station plotted in the normal zone. In the plot for Mg/(Mg + Fe) (Figure 4 *b*) we observed one microtektite clearly plotting in the HMg area, and one specimen along the border between the HMg and an intermediate zone between the normal and the HMg zones. Two microtektites are observed to have a composition intermediate between the HMg and normal, and the others occur along with the normal microtektites. Cassidy *et al.*[15] and Glass[18] found that apart from the normal and HMg microtektites, a sub-group of yellow-green microtektites occur ubiquitously which have an intermediate composition between these two major groups. Specimens having high RI and of intermediate compositions were also identified recently by Prasad[19]. We have not come across a bottle-green microtektite in our study, and the specimen no. 11 (Table 1) is a honey-coloured sphere of 175 μm size, having a rough surface texture, which has high Mg, Al and low Si, Na, K.

The microtektites found in SK-16/176 occur within the geographic limits of the Australasian tektite strewn field[6] (Figure 1). The chemical composition of the eleven microtektites analysed in this study also falls well within the compositional range of the Australasian microtektites[15]. Therefore, by geographic location, age, physical appearance and chemical composition, the microtektites presented in this study are suggested to belong to the Australasian tektite strewn field. Glass and Wu[6] suggested the distribution of shocked minerals and microtektites from > 40 sites in the Indian Ocean and the western Pacific Ocean to represent possible ejecta rays (Figure 1). Prasad and Rao[20] also suggested the occurrence of the flanged button in the Central Indian Basin to belong to an ejecta ray in ocean. The location of all the three cores examined in this study is situated within the ray and in the proximity of the flanged button in the Indian Ocean (Figure 1). However, microtektites are found only in one of the three cores investigated. This is not surprising considering sediment coring covers only a few cm^2 of the ocean floor, the large aerial extent of this strewn field (50×10^6 km^2), and the great distance from the suggested source crater.

It is agreed by most workers in the field that the source for the Australasian strewn field is in Indochina (eg. refs 21,22). Moore *et al.*[23] proposed that the average radius of continuous ejecta (R_{ce}) surrounding craters of radius R is

$$R_{ce} = (2.3 + 0.5)R^{1.006}$$

Beyond the continuous blanket the ejecta would be discontinuous and farther away from the craters it would be in the form of lenses and patchy. The locations of the samples in this study are at a distance of ~ 3000 km from the Indochina region and, considering the approximate estimate size of the source crater for the



4. *a*, Plot of MgO vs SiO_2 weight percentages. 'BGM' refers e-green microtektites, and 'normal' refers to normal microtektites rom Cassidy *et al.*[15]; Glass[18]). The square hatched portion of between normal and BGM forms an area of intermediate ition. *b*, Plot of Mg vs (Fe + Mg) weight percentages. Dot in ndicates data from the present study, the triangles are normal ktites[15] and the stars refer to bottle-green microtektites[18].

alasian strewn field in the vicinity of 17 km (ref. he ejecta distribution here should be patchy. For ea of cross section sampled in each core (~4 cm) sence of microtektites in two of the cores studied be due to the expected patchy ejecta distribution s distance from the source crater and also due to nall area of cross section sampled.

The area of cross section examined in each core to delineate microtektite occurrences by Glass[25] is ~4 cm. The large area of the Australasian strewn field was arrived at after examining a hundred cores by Glass *et al.*[3] wherein the total area of the ocean floor sampled was about > 400 Cm^2. Keeping in view the above, and the distance from the source area shown by the spread of Australasian microtektites many more microtektite occurrences have to be discovered in order to confirm the existing microtektite distribution pattern.

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