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ACCRETIONARY LAPILLI ASSOCIATED WITH ARCHAEAN BANDED IRON-FORMATIONS OF THE KRAAIPAN GROUP, AMALIA GREENSTONE BELT, SOUTH AFRICA

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by

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ABSTRACT

The Kraaipan Group in the Amalia greenstone belt, South Africa consists of an Archaean volcano-sedimentary assemblage of mafic metavolcanic rocks and banded iron-formations, together with subordinate greywacke, slate, and carbonate rocks. The sequence is deformed and intruded by a variety of granites and gneisses. Interlayered with the volcano-sedimentary rocks, in close proximity to a small gold prospect, are pyroclastic rocks in which are described well-developed "coated" or "rim-type" accretionary lapilli of a variety hitherto rarely, if ever, recorded in association with oxide facies banded iron-formations.

The accretionary lapilli are discussed in terms of their significance and as palaeoenvironmental indicators. It is concluded that the accretionary lapilli probably developed in a proximal setting with respect to an ancient eruptive centre and that the lapilli themselves do not constitute exceptional environmental indicators but are useful mainly as time or stratigraphic markers. Their association with banded iron-formations suggests the accretionary lapilli here described were deposited from volcanic centres close to some shallow marine or barred lagoonal basin, the latter possibly analogous to a playa-lake complex developed in a primitive inter-arc or back-arc basin setting in existence during the evolution of the Kraaipan volcano-sedimentary assemblage found in the Amalia greenstone belt.

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CONTENTS

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INTRODUCTION

Documentation of accretionary lapilli from Precambrian rock formations, especially from Archaean greenstone belts in Southern Africa and Australia, is relatively rare. However, over the last decade numerous new discoveries and re-interpretations of known occurrences suggest that the presence of accretionary lapilli may be far more widespread and common than previously believed. Publications by Lowe and Knauth (1978), Reimer (1983a, b), Heinrichs (1984), Boulter (1987), and Bergh and Torske (1988) represent descriptive and interpretive accounts of accretionary lapilli found in various Archaean greenstone and Proterozoic terranes around the world.

The reports often aim to categorize the lapilli into various "types or groups" based on their physical appearance and/or their pre-supposed method and style of formation. The classified lapilli have then been used to determine the palaeoenvironment during their deposition. This knowledge has, in turn, been regarded as useful in assessing the depositional palaeoenvironments of the underlying and overlying lithologies. Accretionary lapilli deposits from the Barberton greenstone belt, South Africa (Reimer, 1975, 1983b; Lowe and Knauth, 1978; Heinrichs, 1980; 1984; Stanistreet *et al.*, 1981), and from the Pilbara Region, Western Australia (Trendall, 1965; Hickman, 1983; Boulter, 1987) have been most intensely studied in this regard.

Studies on the formation and deposition of modern day accretionary lapilli include those by Moore and Peck (1962), Brantley and Waitt (1988), Ayers and Early (1989), Bourdier *et al.* (1989), Charland and Lajoire (1989), and Nappi and Renzulli (1990). In each of these investigations a strong correlation between the formation and deposition of accretionary lapilli with warm, humid (wet), conditions was noted.

Lowe and Knauth (1978) similarly claimed that several major accumulations of accretionary lapilli in Archaean greenstone belts were formed in wetter atmospheric conditions than at present - conclusions that have subsequently been disputed by researchers providing support for the theory that drier conditions were necessary for the formation of accretionary lapilli deposits of the type commonly encountered in Precambrian terranes (Self and Sparks, 1979; Reimer, 1983a, b; Heinrichs, 1984; Boulter, 1987).

Some authors also maintain that accretionary lapilli are "excellent environmental indicators" and may be used to support subaerial or shallow water deposition because of their believed susceptibility to disaggregation whilst settling through deep water columns (Moore and Peck, 1962; Lowe and Knauth, 1979; Buick and Barnes, 1984). The environmental significance of accretionary lapilli has, however, become more dubious as several types of lapilli have been identified. Reimer (1983a) has, for example, drawn attention to differences that exist between fossil accretionary lapilli (those usually possessing a concentrically banded outer zone, which he termed "coated" or "type-B" accretionary lapilli) and examples formed during recent ash falls which are mostly of the uncoated or "type-A" variety. Reimer (1983a, b), Fisher and Schmincke (1984) and Boulter (1987) documented examples showing some accretionary lapilli to be extremely robust and able to survive the abrasive rigours of beach, sand dune, and river environments, as well as transport within pyroclastic flows.

These are essentially the coated accretionary lapilli which possess dense, fine-grained, cortical shells or glassy rinds that do not easily disintegrate when deposited in water.

Numerous examples have been cited cautioning against using accretionary lapilli as palaeoenvironmental indicators for, on their own, they may be subject to alternative explanations. Boulter (1987), for example, described parallel laminated accretionary lapilli that provided no definitive evidence for an environment of deposition, although their association with fluvial arenites suggested a subaerial air-fall origin. Earlier, Trendall (1965) had proposed that a well-developed lamination was indicative of a subaqueous mode of deposition, but such features are also typical of air-fall tuffs.

Reimer (1983a) emphasized that the importance of accretionary lapilli lay rather in the fact that they can represent excellent time markers in fossil-free sedimentary and volcanic formations. As is observed during modern-day volcanic eruptions, air-fall deposits from ash-charged eruptive clouds can at times be responsible for the deposition of laterally extensive accretionary lapilli layers. Although quantitative data are generally lacking, Moore and Peck (1962) were of the opinion that the eruptive vents from which the volcanic ash and the accretionary lapilli were derived, very likely occurred within about 160km or so of the deposit, with most known occurrences being within a few kilometres of the vent. Reports are available of Proterozoic and Archaean accretionary lapilli horizons extending over large distances, with a strike length of 500km in the Pilbara Block of Western Australia being indicated by Trendall (1965) and Hickman (1983). In New Zealand, Self and Sparks (1979) recorded accretionary lapilli layers up to 140km in extent, while Reimer (1983b) calculated that the original areal extent of accretionary lapilli units in the Fig Tree Group of the Barberton greenstone belt, South Africa indicated that an area of over 4000km^2 had been affected by the fallout event.

The present study documents and attempts to interpret the palaeoenvironmental setting of an accretionary lapilli unit interlayered with banded iron formations (BIF) of the Archaean Kraaipan Group in the Amalia greenstone belt located on the Kaapvaal Craton, approximately 320km southwest of Johannesburg (Fig. 1).

GEOLOGICAL SETTING

The area investigated constitutes part of the Amalia greenstone belt which forms the extreme southern extension of the areally extensive Kraaipan Group (Fig. 1). The Amalia belt occupies a narrow strip of country (4km wide) extending south of Amalia for a distance of 55km. The belt is generally extremely poorly exposed and its boundaries are ill-defined. The best outcrops occur in the Goudplaats-Bothmasrust area in the most northerly portion of the belt (Fig. 2).

The Amalia greenstone belt consists of a sequence of steeply dipping massive and schistose mafic metavolcanic rocks (altered tholeiitic basalts), together with intercalated BIF. The dominant schist type encountered in the field and in borehole core is a fine-grained, grey-green, quartz-chlorite schist. In addition, outcrops of greywacke, slate, carbonate rocks and felsic intrusives occur in places (Van Eeden *et al.*, 1963; I.M. Jones, in prep.).

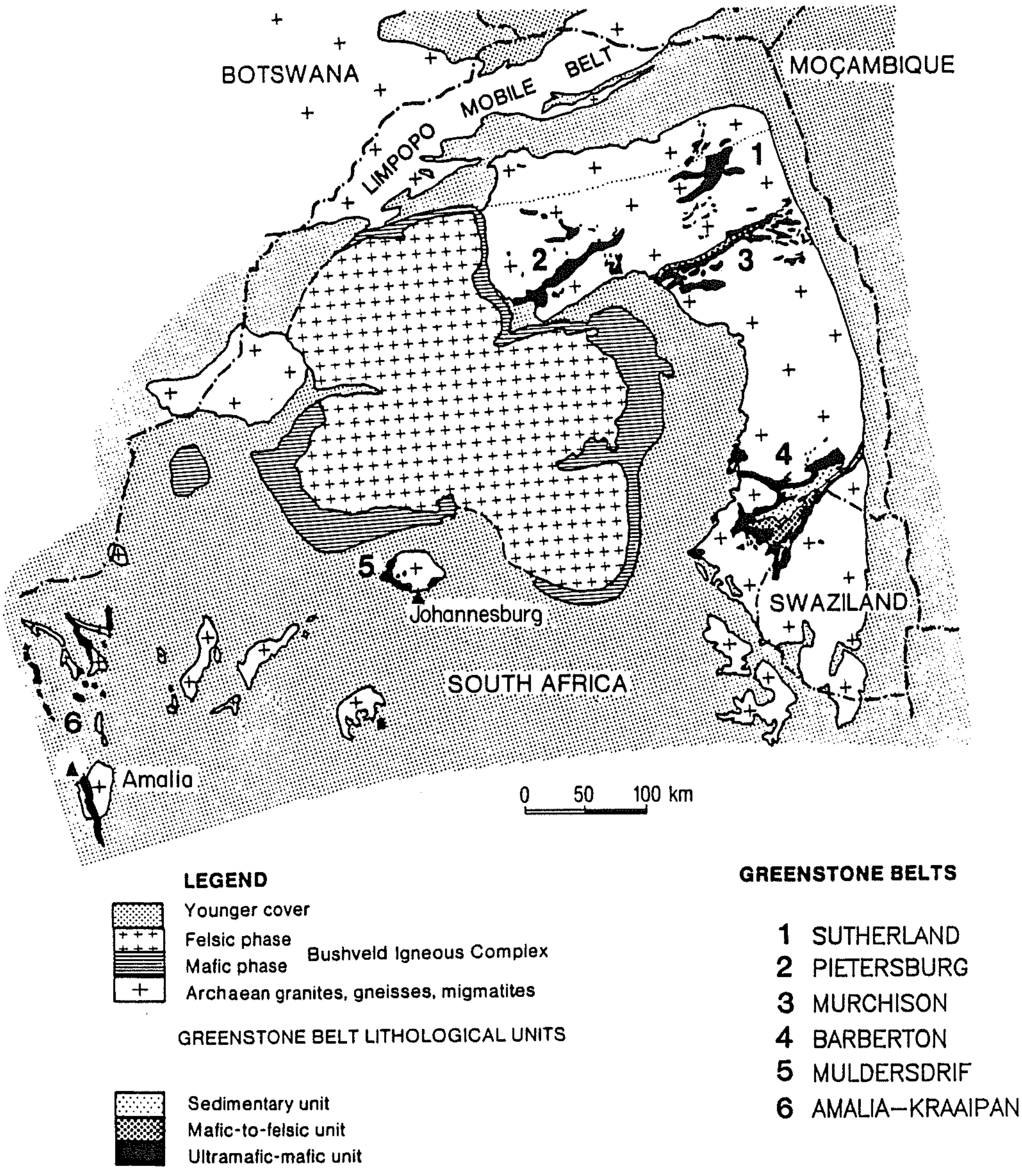


Figure 1: Map showing the locality of the Amalia greenstone belt in relation to the other Archaean volcano-sedimentary remnants on the Kaapvaal Craton, southern Africa.

A variety of granitic rocks, ranging in composition from tonalite/trondhjemite gneisses and migmatites to adamellites, surround and intrude the belt and were responsible for some of the deformation phases affecting the greenstone successions (Drennan, 1988; Jones and Anhaeusser, 1991; Robb, 1991a). The adamellites have yielded an age of 2880 $\pm$ 2 Ma (Robb, 1991a) and intrude older tonalitic gneisses and migmatites, the exact age of which is uncertain. Zircons from tonalite gneisses west of the Amalia belt have yielded an imprecise age of 2927 + 23/-6 Ma which is, within error, the same age as metamorphic overgrowths on zircons from similar tonalitic gneisses from the Kimberley region approximately 140km to the south. Drennan *et al.* (1990) reported that zircons from these rocks have cores which yielded ages of 3250 Ma and metamorphic overgrowths of 2940 Ma. The age of 2930 - 2940 Ma may therefore represent the period during which migmatization of these rocks

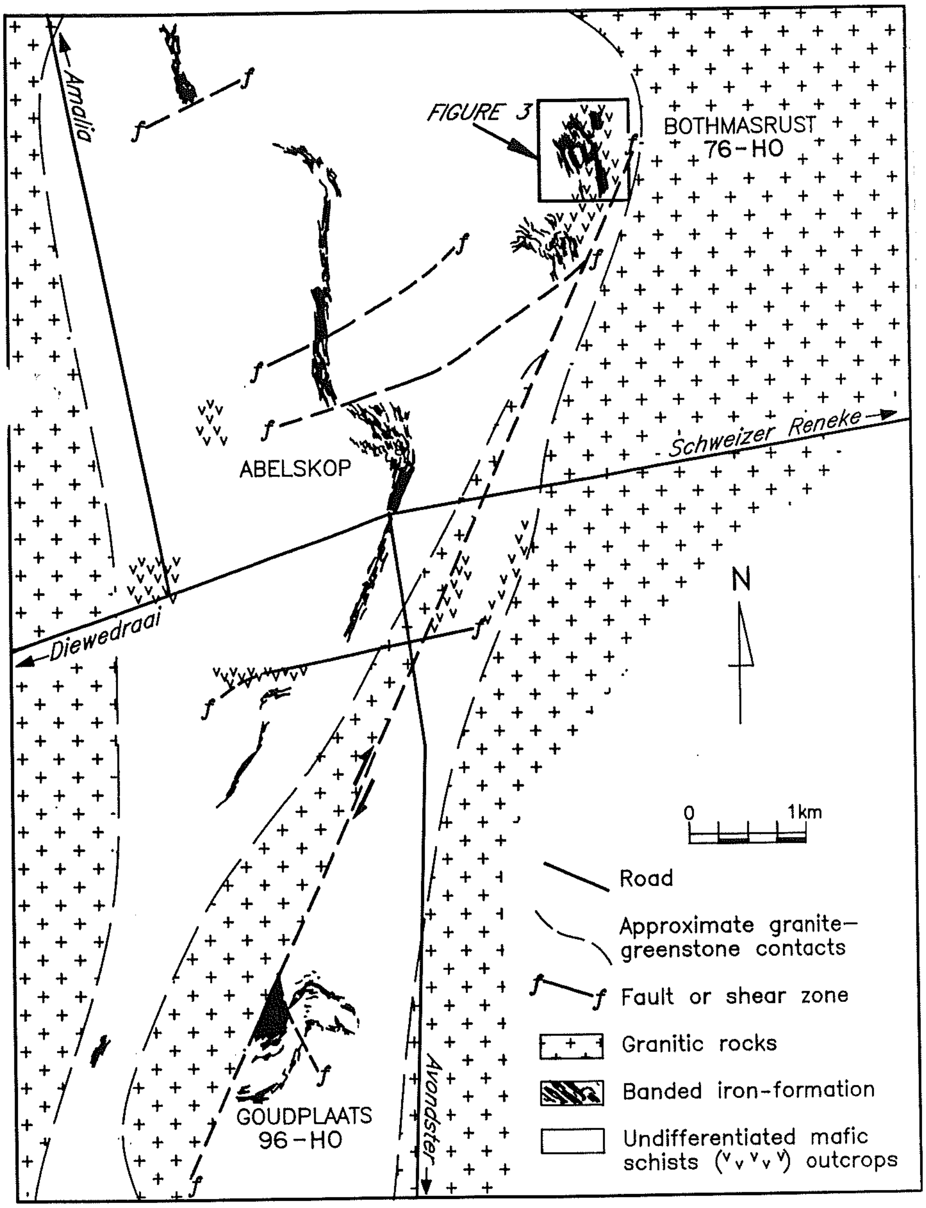


Figure 2: Simplified geological map of the northern part of the Amalia greenstone belt showing the distribution of the exposed banded iron-formation and metavolcanic rocks, and the locality of Figure 3 on the farm Bothmasrust 76-HO.

occurred. Amphibolite and BIF xenoliths, considered to form part of the Kraaipan volcano-sedimentary succession, occur in the granitic gneisses and migmatites west and north of the Amalia greenstone belt (Jones and Anhaeusser, 1991; Zimmermann and Anhaeusser, 1991) suggesting that the greenstone succession may be at least as old or older than 3250 Ma. Attempts so far by Robb (1991b) to date Kraaipan felsic schists have not yielded precise ages despite abrasion of the small, poor quality zircons found in these rocks. If proved correct an average age of 3075 Ma so far obtained suggests that the Kraaipan rocks are significantly younger than the 3,45 Ga Barberton greenstones found on the eastern side of the Kaapvaal

Craton (Fig. 1).

The area of interest in this study occurs on the farm Bothmasrust 76 HO and occupies the region in the vicinity of the old Bothmasrust gold prospect (Fig. 3). Detailed mapping in this area (I.M. Jones, in prep.) has revealed a complex discontinuous outcrop pattern of BIF units interspersed with poorly exposed mafic lithologies. The BIF's consist essentially of oxide facies iron formations and are formed of thin alternating layers of chert and hematite/magnetite. In places jaspilitic units as well as silicified and grunerite-rich layers were also noted. The layering in the BIF's generally dips steeply (70-85° NE), but local variations in attitude are common, especially in highly deformed areas. Contacts between the BIF units and mafic rocks are usually sheared and pyrite mineralization commonly occurs in both rock types adjacent to these contacts.

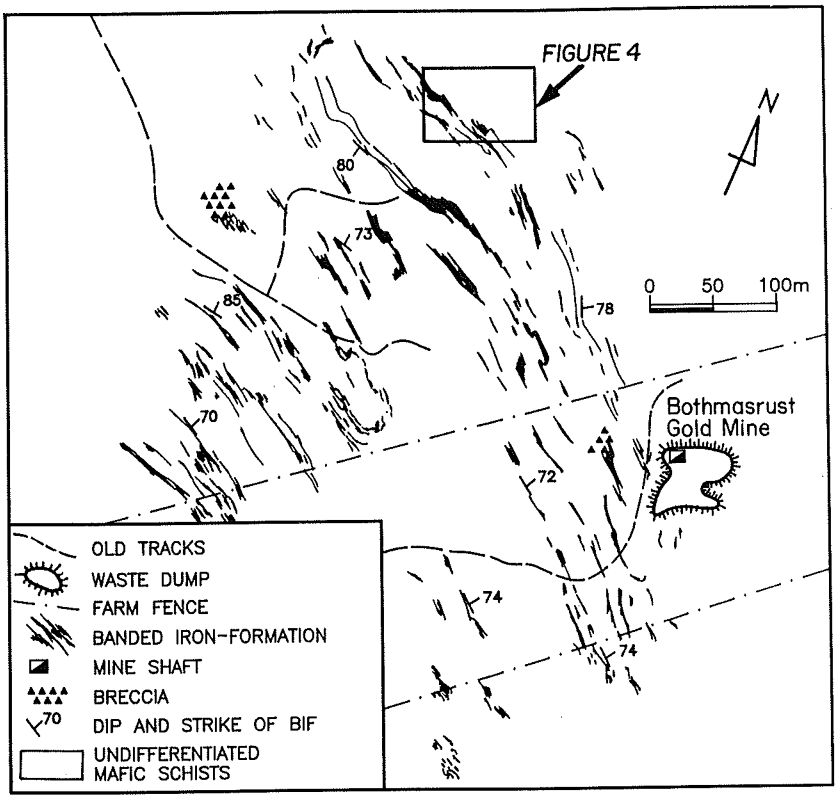


Figure 3: Geological map of the area in the vicinity of the old Bothmasrust gold prospect showing the locality (enlarged in Fig. 4) of the accretionary lapilli exposures described in this paper.

Several exploration trenches and pits occur throughout the area and provide many of the best exposures of the brecciated, dominantly oxide facies BIF, metamorphosed mafic lava, greywacke, and quartz sericite/fuchsite schist, as well as the partially auriferous stockwork-type quartz veins described by Vearncombe (1986). In the northeastern part of the exposed area, and shown in detail in Figure 4, are a few sporadic outcrops of accretionary lapilli interlayered between BIF units. The accretionary lapilli beds can easily be overlooked and field relationships are exceedingly poor. Samples from four localities, over a strike length of 35m, were collected for detailed study. Accretionary lapilli were also noted by Vearncombe (1986) in borehole core stored at the defunct Goudplaats Mine but the locality of the drill sites could not be determined. This mine is approximately 7km southwest of the Bothmasrust accretionary lapilli occurrence and, because no previous record of drilling at Bothmasrust can be found, it remains possible that the lapilli unit might represent a laterally extensive marker unit in the Amalia greenstone belt.

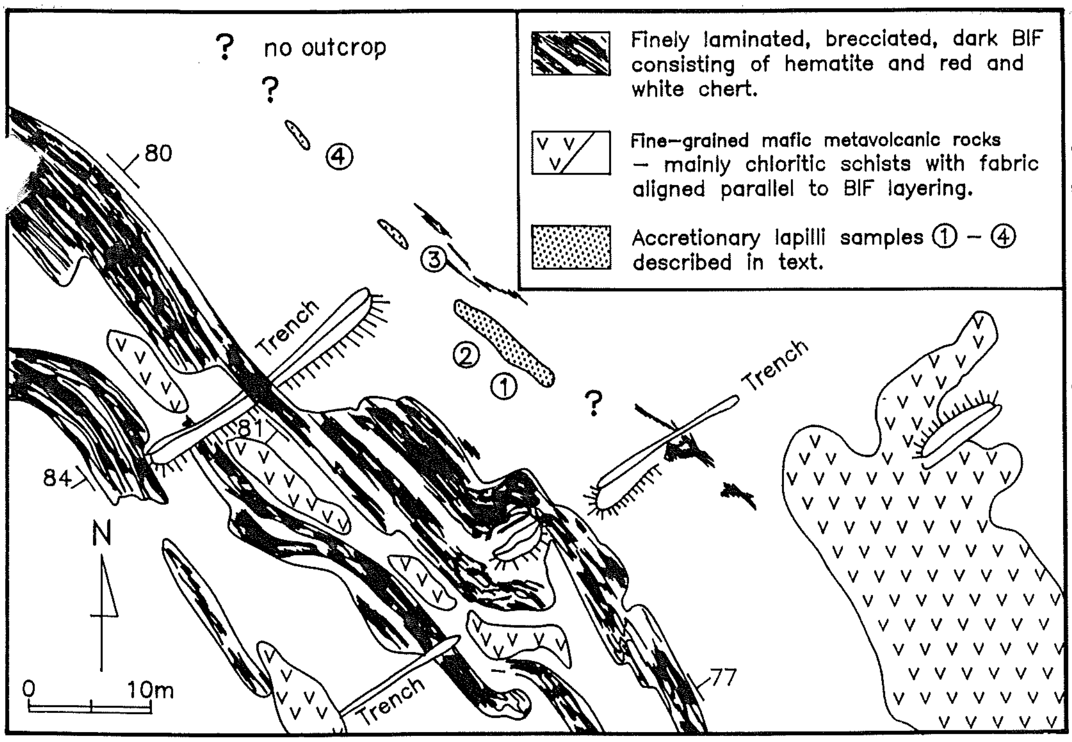


Figure 4: Detailed map showing the accretionary lapilli-bearing pyroclastic layer interbedded with oxide-facies banded iron-formations at Bothmasrust.

ACCRETIONARY LAPILLI FROM BOTHMASRUST

The accretionary lapilli samples were collected from fine-grained, well-bedded, light- and dark-green mafic tuffaceous and schistose rock exposures. The samples are all of a random nature as it was not possible to select material from a well constrained stratigraphic profile. Neither was it possible to gauge the stratigraphic thickness of the lapilli unit or to determine with any degree of certainty the direction of younging of the beds.

In general, the accretionary lapilli appear as small, pea-shaped structures attaining a maximum diameter of 7-9mm. The majority of the lapilli occur in the size range 3-4mm. As may be readily seen in the accompanying photographs (Figs. 7-9) the lapilli display distinct cores and rims. Employing Reimer's (1983a) classification these lapilli could constitute his type B or *coated accretionary lapilli* (Fig. 5). Schumacher and Schmincke (1991) referred to accretionary lapilli composed of a core of coarse-grained ash surrounded

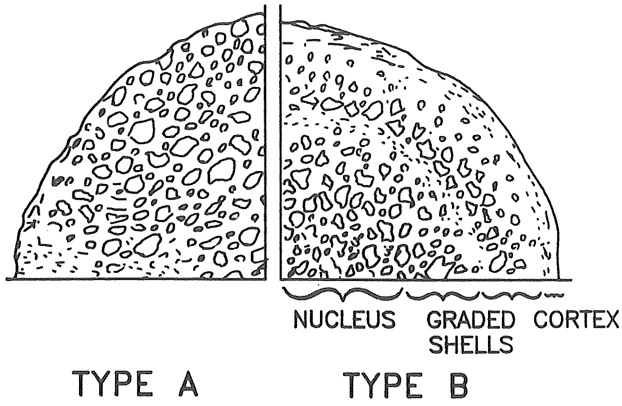


Figure 5: Schematic drawing after Reimer (1983a) showing his "type A" as well as his "type B" or "coated" accretionary lapilli, the latter made up of concentric bands of coarse and fine ash rimmed by vitric tuff or volcanic glass ("rim-type" lapilli of Schumacher and Schmincke, 1991).

by a fine-grained rim as *rim-type lapilli*. This morphological variety shows an abrupt change in grain-size distribution between the core and the rim and is distinguished from *core-type lapilli* which consist of ash aggregates and which lack fine-grained outer rims. In most examples from the Bothmasrust locality lapilli with alternating fine and very-fine ash layers occur as *multiple-rims* around a porous core consisting of pumice particles and aggregates (Fig. 6).

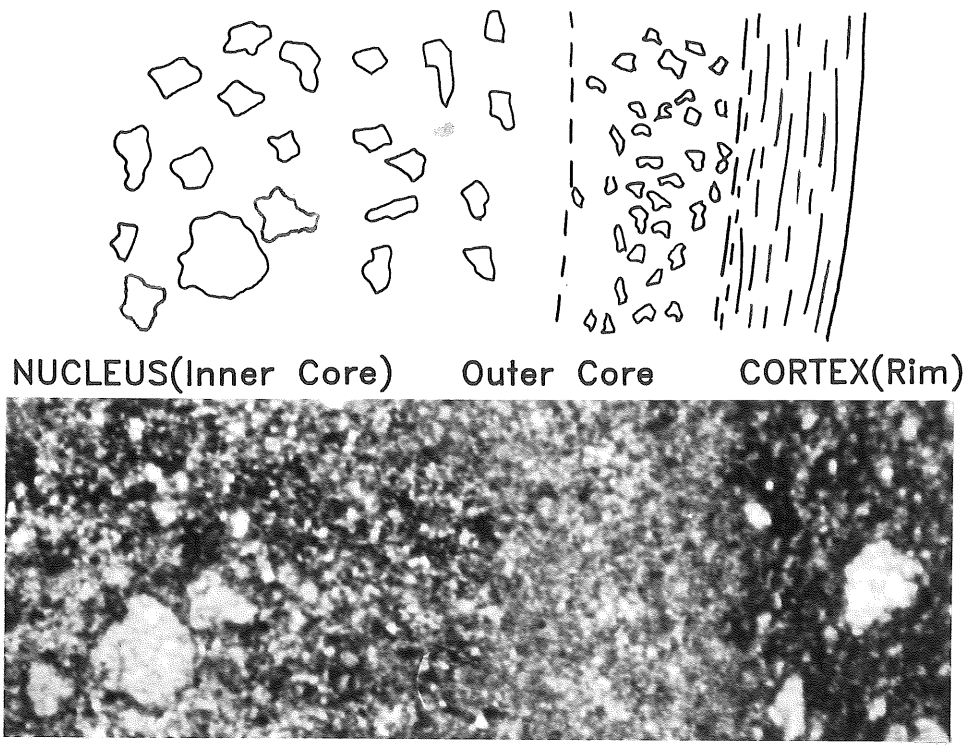


Figure 6: Photomicrograph of a rim-type accretionary lapillus from Bothmasrust (Sample 4, Fig. 10) showing the textural change in the ash from a relatively coarse, porous, inner core to a finer-grained, densely packed outer core and vitreous rim. Field of view approximately 2mm.

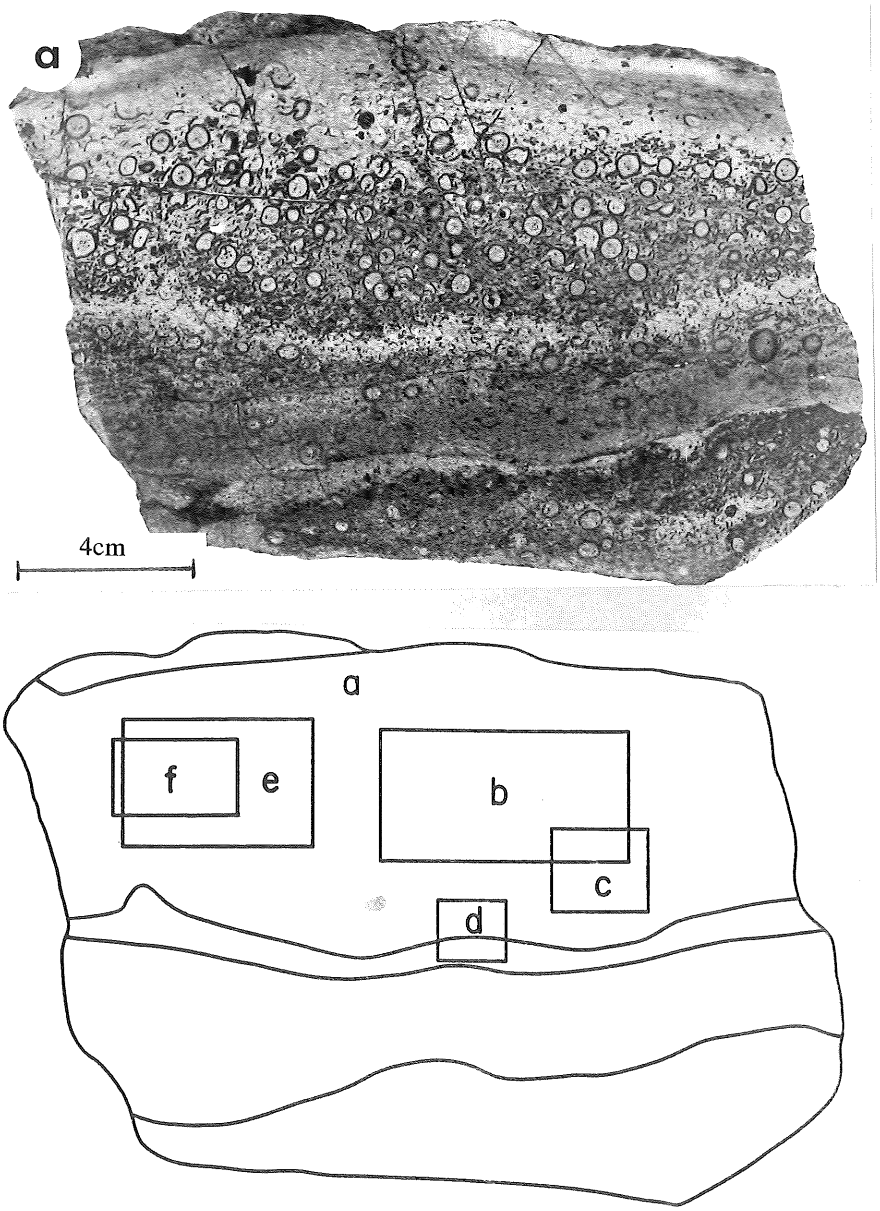


Figure 7: (a) Polished slab of Sample 1 showing examples of the largest accretionary lapilli found at Bothmasrust and schematic drawing outlining the positions of the photographic enlargements (b-f). (b) Rim-type accretionary lapilli and glassy fragments of broken lapilli rims transected by a microshear zone. (c) Spherical rim-type accretionary lapilli with pumice or porous ash inner cores and finer-grained, densely packed outer cores. Fragments of glassy rims from lapilli broken prior to deposition occur in the matrix. (d) Two well-developed accretionary lapilli, the one showing a core of loosely packed ash and the other an euhedral crystal of altered pyrite or magnetite. (e) Zoned accretionary lapilli in a matrix of fine ash and a lapillus consisting almost entirely of glass and a small nucleus of ash.

Four samples were chosen from localities 1-4 (Fig. 4) to illustrate the textural and depositional variations displayed by the accretionary lapilli and their tuffaceous host rocks. The samples were cut and polished to facilitate detailed examination of the intricate sedimentary and structural features preserved in the rocks.

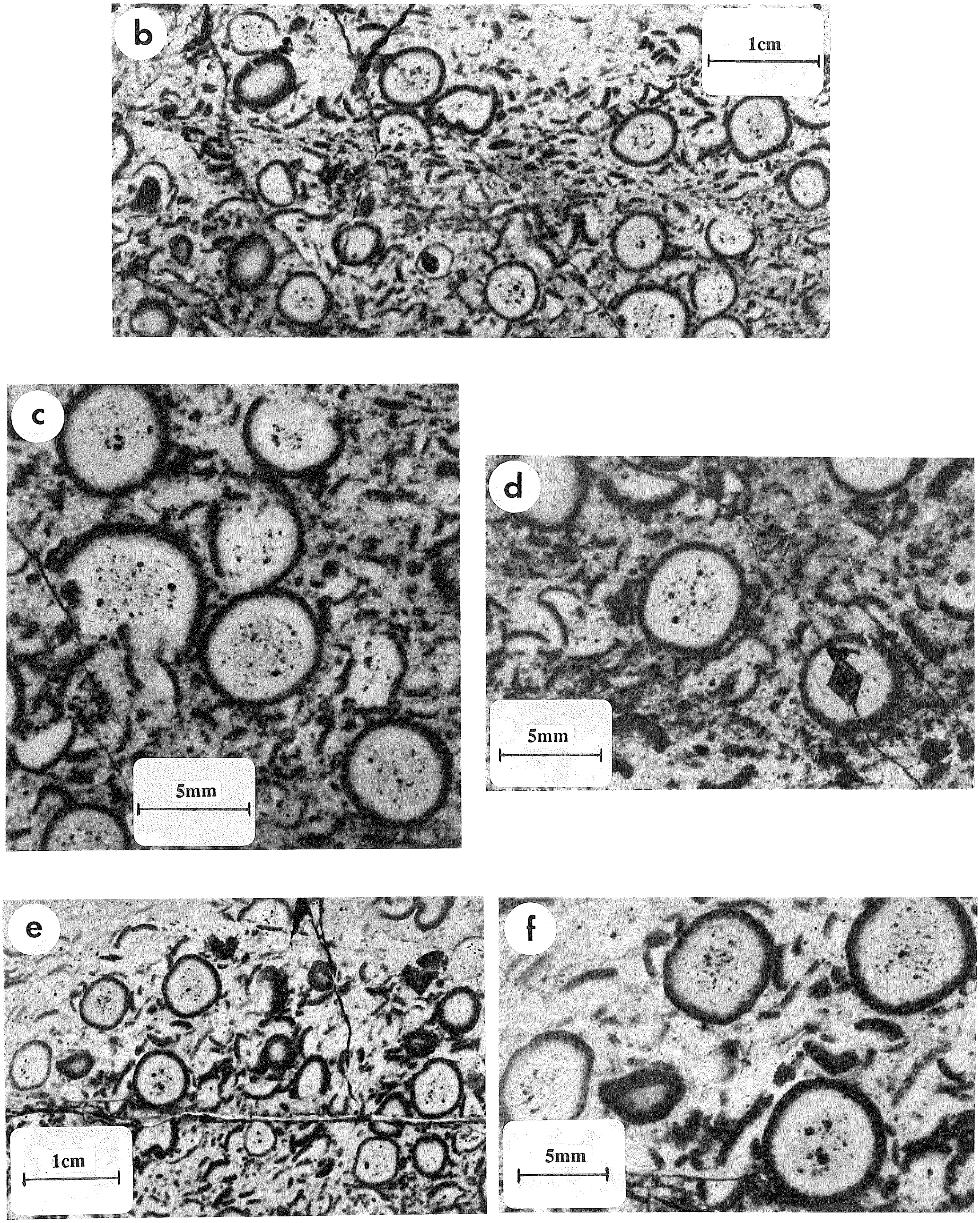
Sample 1: Illustrated in Figure 7a is a specimen containing the largest coated or rim-type accretionary lapilli recorded in the Bothmasrust area. The accretionary lapilli are broadly concentrated in the upper, fine-ash-rich layers of the bedding sets and form several discrete layers, each of which may be interpreted to represent an individual depositional episode (Moore and Peck, 1962; Schmincke, 1967). According to Schumacher and Schmincke (1991) coarse-grained rim-type accretionary lapilli may be typical of proximal (3km) pyroclastic flow and surge deposits, but may also occur in deposits of relatively dry surges farther away from the vent. In more distal regions the accretionary lapilli are generally irregularly distributed within the ash layers.

Selected enlargements, designed to illustrate detail seen in Sample 1, are shown in Figure 7 (b-f). The lapilli, which are clearly zoned, are similar to examples from the western continental United States described by Moore and Peck (1962) as having formed in an ash-charged phreatomagmatic eruption cloud by the accretion of ash particles around a core due to condensation of moisture on the core.

As may be seen in the photographs the accretionary lapilli are generally matrix supported and well rounded, but some have been partially flattened and many have been broken. Fragments of the fragile, thin, dark outer layers of the lapilli, which are composed predominantly of fresh or devitrified volcanic glass, occur randomly scattered throughout the matrix of the rock. The abundance of the fragments suggests the lapilli were mostly broken by an especially vigorous transporting agent prior to or during deposition. Evidence of some post-depositional breakage and heterogeneous deformation of the lapilli beds is, however, present in the top few centimetres of the specimen shown in Figure 7a where the lapilli have all but been destroyed along a narrow mylonite zone. Further tectonic destruction of lapilli is evident along a microshear zone (enlarged in Fig. 7b) which projects into the main accretionary lapilli layer.

The cores of the coated or rim-type lapilli consist of relatively homogeneous, in some cases porous, pumice or fine ash, similar in character to the matrix which surrounds the lapilli (Fig. 7c-f). Minute crystals and microlites of volcanic glass and iron oxides also occur randomly within the cores of the lapilli and an idiomorphic crystal of pyrite or magnetite, which may have formed after consolidation and deformation of the lapilli beds, is shown in Figure 7d.

Sample 2: Shown in Figure 8a is a specimen for which there is again no satisfactory field evidence indicative of the "way up" direction. Two lithologic layers are apparent - a "lower" light-coloured, fine tuffaceous ash bed containing scattered, variably sized, rim-type accretionary lapilli and an "upper", darker-coloured layer containing abundant, in part densely packed, accretionary lapilli, the latter also of the coated or rim-type.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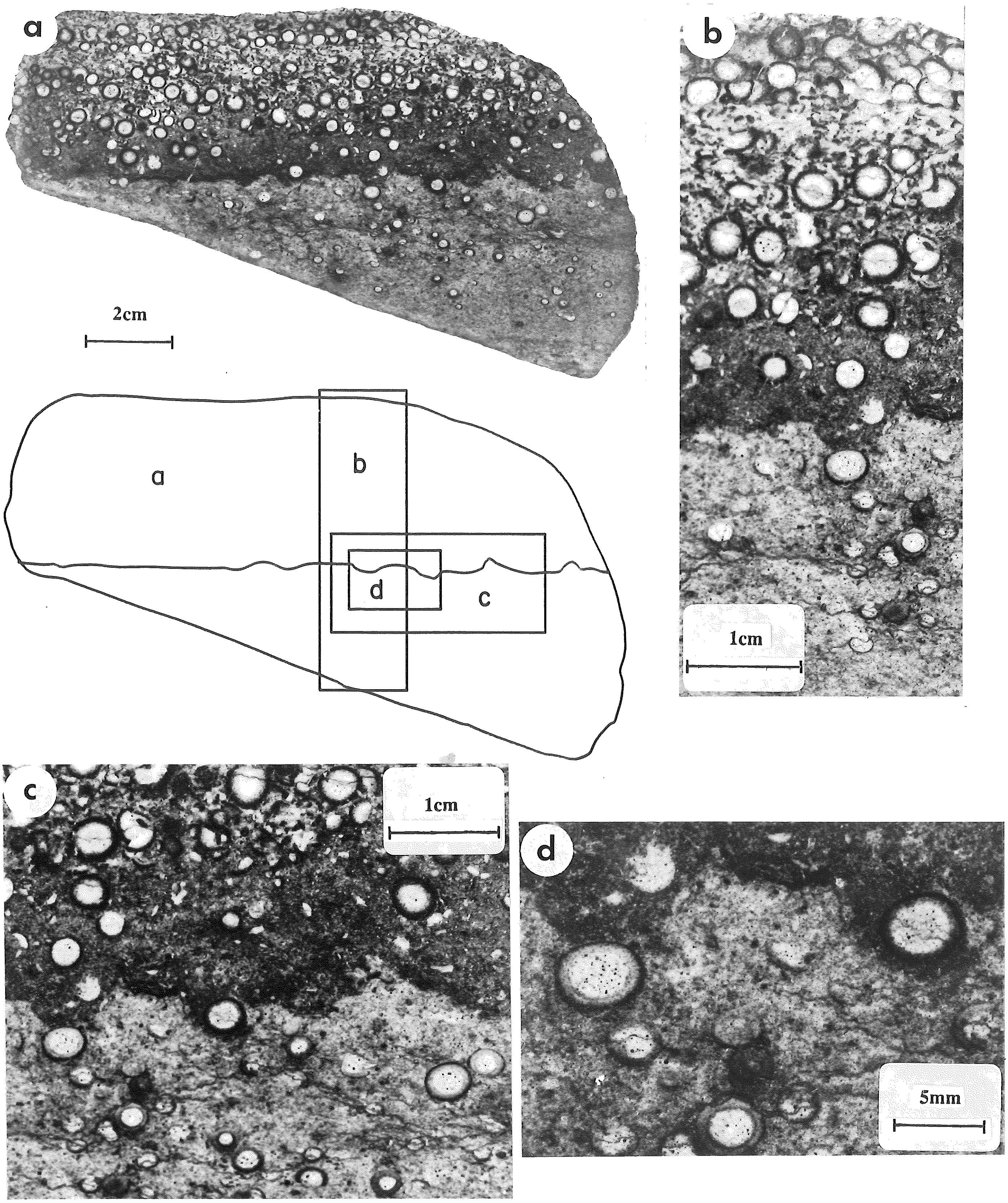

Figure 8: *(a) Polished slab of Sample 2 and schematic drawing outlining the positions of photographic enlargements (b-d). (b) Rim-type accretionary lapilli showing zoning, post-depositional fracturing, and upward fining of lapilli particles. (c) Accretionary lapilli impacted into light-coloured unconsolidated ash. Some lapilli penetrated the ash and were covered by fallback ash particles following impact. (d) Detail of part of (c) showing zoned accretionary lapilli in the upper 1cm of the ash layer.*

Ambiguous or conflicting directional indicator evidence is apparent in the specimen, but the preferred "way up" is as shown in Figure 8 (a-d) and is based on the following criteria:

1. some of the large lapilli have penetrated into the upper four millimetres of the substratum of loosely packed tuffaceous ash prior to consolidation of this layer, while others have only dented the layer, with individual lapilli having settled at the bottom of the indentations in the ash (Fig. 8b, d);

2. based on the findings of Schumacher and Schmincke (1991) accretionary lapilli in proximal deposits may be enriched in the upper parts of individual layers. In the example described the lower 2cm of the dark-coloured layer is made up of fine tuffaceous ash and volcanic glass, into which have fallen the larger rim-type lapilli (4-5mm). This was followed by rapid accumulation and impacting of smaller diameter (2-3mm) rim-type lapilli seen nearer the top of the specimen.

The lapilli are again of the rim or coated variety and show zonation from pumice-like cores to fine-grained inner rims of ash particles encased in a black glassy outer casing (Fig. 8c). Many of the lapilli in the example are broken and occur in a matrix of ash and glass. Some well-formed lapilli are cracked or show displacement of the segments (Figure 8b), but in general, the rock shows little sign of subsequent tectonic disturbance.

Sample 3: Figure 9a shows the effects of heterogeneous deformation of the tuffaceous and accretionary lapilli beds at Bothmasrust. The upper half of the specimen consists of a dark accretionary lapilli-bearing layer 2-3cm thick overlain by very finely laminated tuff. The lower half of the sample comprises a number of light and dark vitric tuff layers some of which interfinger with each other. These are overlain by a 2mm-thick, very fine-grained tuffaceous black shale layer which, in turn, is separated from the accretionary lapilli-bearing layer by a 15mm-thick band of vitric tuff containing flattened, ellipsoidal accretionary lapilli and elongate lapilli tuff particles (Fig. 9c). Shearing, accompanying deformation of the banded iron-formations and interlayered pyroclastic rocks appears to have been selective, with the strain being absorbed by the relatively porous, unconsolidated volcanic ash beds or layers.

By contrast, the accretionary lapilli layers shows minimal effects of the deformation with only the margins of the unit being affected and some lapilli being flattened or sheared. The accretionary lapilli preserved in the specimen are again mostly of the coated or rim type and few show signs of breakage (Fig. 9b). The lapilli are supported in a fine-grained, tuffaceous matrix which also contains remnants of the dark glassy rims of accretionary lapilli shattered in the eruption column or in a base surge following subsidence of the eruption column.

Of specific interest in the accretionary lapilli layer is a 1cm-sized, very fine-grained lapilli tuff fragment containing a rim-type lapillus as well as a lapillus pseudomorphically replaced by pyrite (Fig. 9a). An enlargement of portion of the accretionary lapilli layer (Fig. 9b) shows four additional lapilli partly replaced by pyrite. The replacement of the accretionary lapilli by pyrite probably occurred as a consequence of diagenesis involving the

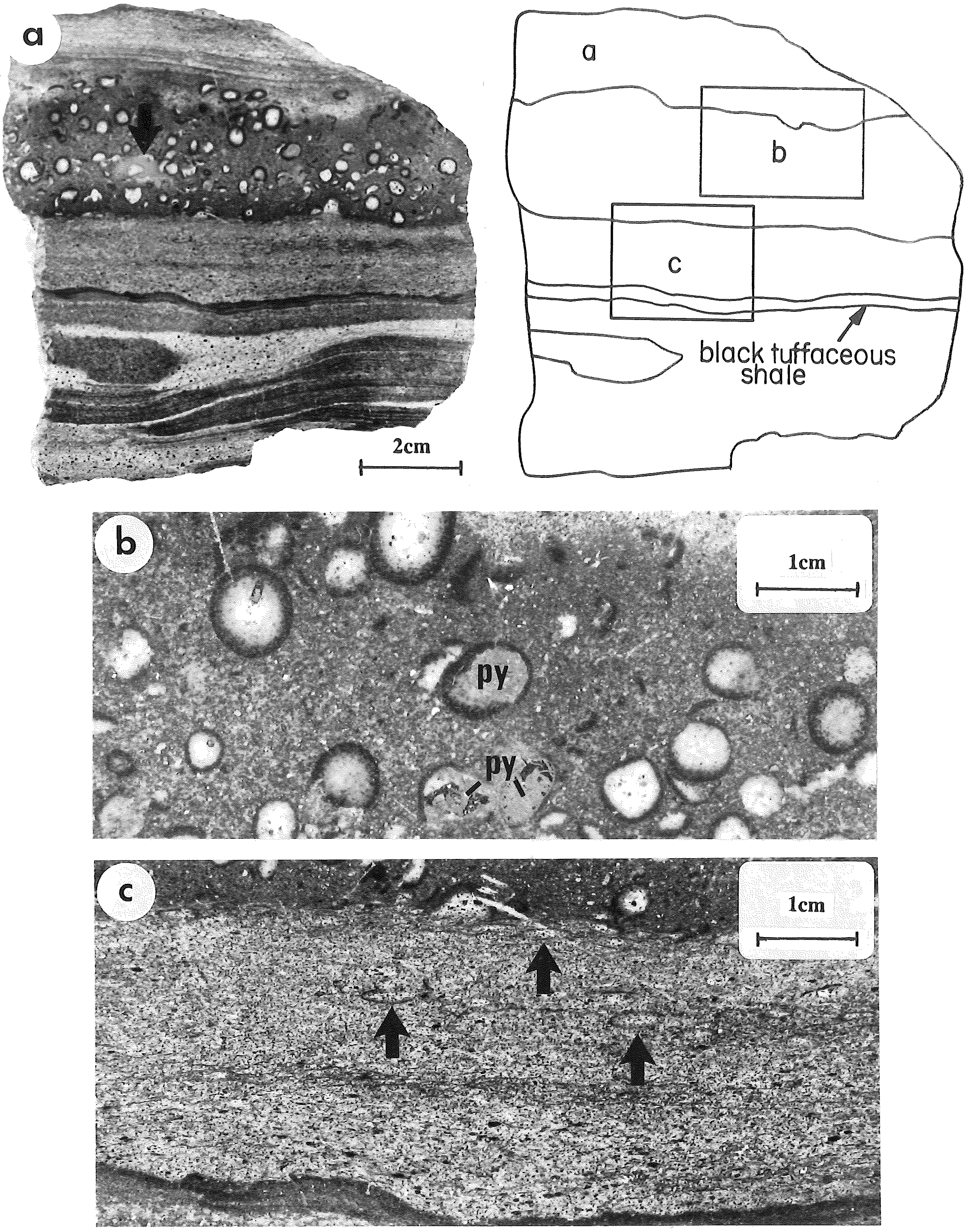

Figure 9: (a) Polished slab of Sample 3 showing various textural layers and schematic drawing outlining the positions of the photographic enlargements (b,c). The pyroclastic layers show heterogeneous deformation. Note the 1cm-sized lapilli tuff fragment entrapped within which is a rim-type lapillus and a lapillus replaced by pyrite (arrow). (b) Well-rounded, matrix-supported accretionary lapilli in a fine-grained tuffaceous ash layer. Diagenetic pyrite (py) selectively replaces the porous unconsolidated cores of some lapilli. (c) Tuffaceous black shale band overlain by a sheared, vitric tuff layer containing relic flattened tuff particles and ellipsoidal accretionary lapilli (arrows).

selective dissolution and conversion of the lapilli spheroids by authigenic sulphides derived from the tuffaceous deposits.

Sample 4: Displayed in Figure 10a is a polished slab illustrating some of the sedimentary and structural features found in the Bothmasrust pyroclastic sequence. The specimen shows a number of discrete, variably textured and coloured layers of tuffaceous sediment, including three units containing coated or rim-type accretionary lapilli. Some tuff layers are well laminated and others are more evenly textured. A thin (1mm), dark-coloured, fine-grained tuffaceous shale parting is also apparent. Below this shale parting the ash layering has a gently wavy character and the light-coloured ash layer in the unit has been disturbed either structurally or possibly by compaction and fluid release. Features resembling ripple marks occur higher in the specimen, but may be structurally induced as all the lapilli occurring in the topmost accretionary lapilli layer are deformed and appear as oblate spheroids which seem to be imbricately overthrust from right to left (Fig. 10a, b).

Below the middle accretionary lapilli layer and roughly in the centre of the specimen is a 4-5mm wide tuffaceous band that also shows strongly flattened rim-type accretionary lapilli and a shear fabric in the lapilli-tuff. It is thus apparent that the pyroclastic sediments from the Bothmasrust locality have been subjected to differential hetereogeneous shearing, the main strain event having taken advantage of differences in the texture and compaction states of the various ash layers.

As with Sample 3 described earlier fluids moving through the relatively porous pyroclastic layers have introduced or mobilized sulphur and the black specks seen in the specimen represent diagenetic replacement pyrite grains or particles (Fig. 10a-c).

PALAEOENVIRONMENTAL CONSIDERATIONS

Based on numerous examples previously cited and summarized by Fisher and Schmincke (1984) accretionary lapilli form as moist aggregates of ash in eruption clouds either from moisture condensation from the volcano itself or from raindrops passing through the fine airborne ash. Whereas the fine ash from unusually powerful eruptions may have been recognizable 1000km or more from the source, and some may even be dispersed worldwide (e.g. the May 18, 1980 eruption of Mount St. Helens, Washington; Lipman and Mullineaux, 1981), accretionary lapilli are generally larger and heavier than the ash particles that make up the lapilli. These lapilli therefore generally fall out of eruption clouds relatively close to the volcanic vent unless some unusual conditions such as high wind velocities prevail at the time of the eruption. The extremely fine-grained or glassy rims can be accreted mainly by electrostatic forces within relatively dry clouds of low solid concentrations. Rim formation therefore requires only a minimum of moisture condensation and a low concentration of solids to prevent the fine ash from clotting. Accretionary lapilli of the rim type develop under somewhat special conditions and, although generally regarded as having been formed proximally to volcanic eruption sources, may nevertheless have withstood sedimentary transport to more distal sites in certain circumstances. Accretionary lapilli units in the Msauli Chert in the Barberton greenstone belt were, for example,

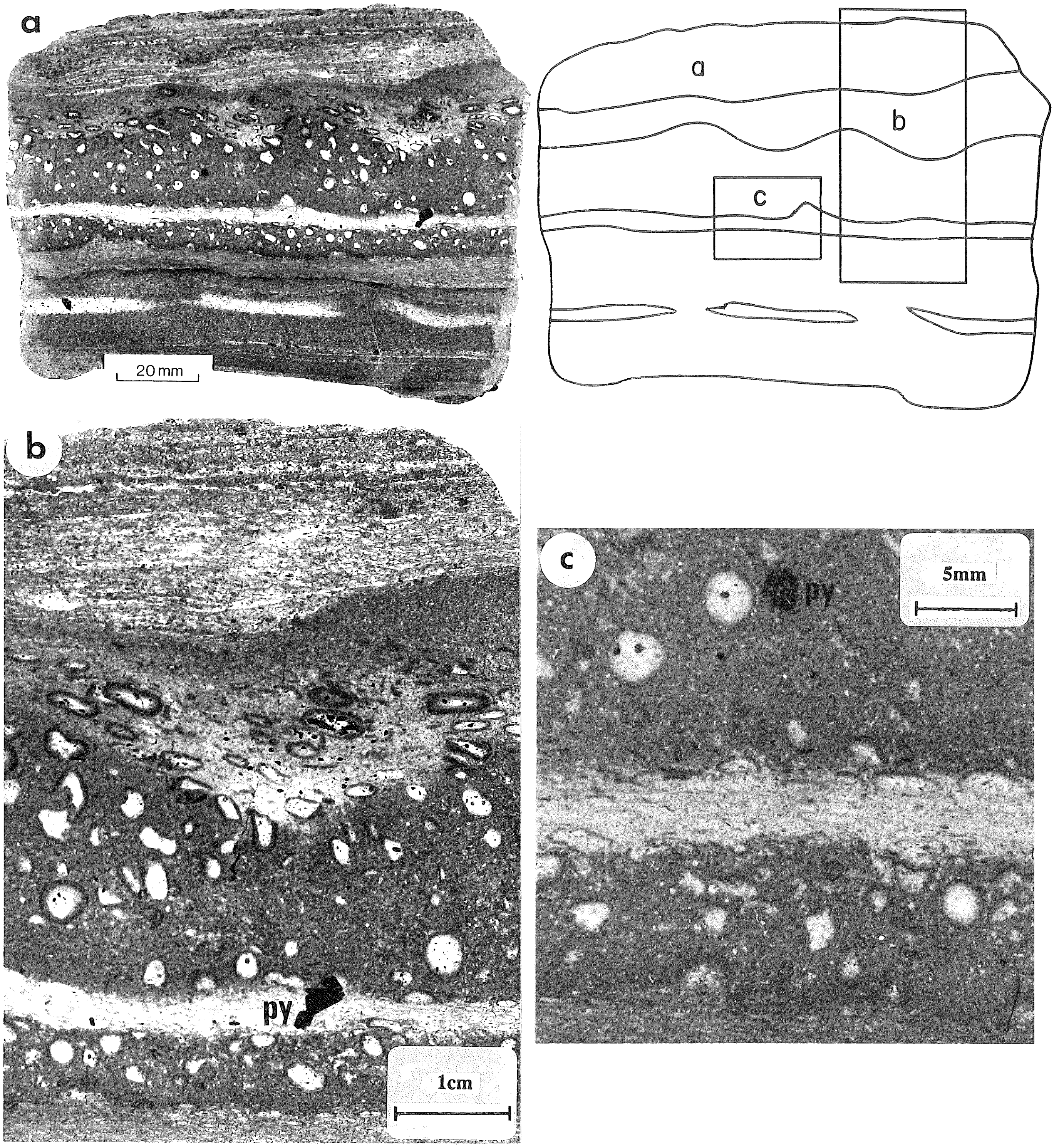

Figure 10: (a) Polished slab of Sample 4 showing compositional, textural, structural, and sedimentological features, and schematic drawing outlining the positions of photographic enlargements (b,c). (b) Detail of lapilli layers showing heterogeneous deformation caused by tectonic and possibly sedimentological processes. Black specks here and in (a) and (c) consist of pyrite (py). (c) Enlargement showing sheared, light-coloured, tuff band containing flattened rim-type accretionary lapilli, surounded by darker, fine-grained ash containing well-rounded lapilli, one pseudomorphically replaced by pyrite (py).

described by Stanistreet *et al.* (1981) as having been redeposited from an original shallow water or subaerial environment to a deep water setting by high-velocity turbidity currents. Distances covered by the depositing gravity flows would have been of the order of tens-to hundreds of kilometres.

Conditions of deposition of the Bothmasrust accretionary lapilli beds are not readily apparent because of poor exposure. The exceptional preservation state of the lapilli and their relatively large grain size suggests they may not have been transported very far. However, this viewpoint remains speculative and is not conclusive. Probably the most significant clues to the environment of deposition lie in the association of the accretionary lapilli and tuffaceous ash beds with the BIF units that occur on either side of the pyroclastic zone shown in Figure 4.

Numerous reports exist of volcanic or pyroclastic activity being contemporaneous with Precambrian iron-formations. Goodwin (1956, 1962) concluded that active volcanism occurred during much of the time in which iron-formations were being deposited in the Michipicoten, Gunflint, and Biwabik-iron-formations of Ontario, Canada and in the Mesabi district of northern Minnesota. Volcanism was also active part of the time in the Marquette and Gogebic districts of Michigan and Wisconsin (Tyler and Twenhofel, 1952; Huber, 1959) and in the iron formation areas of the Labrador Trough and the Hamersley Range in Western Australia (Frarey, 1961; La Berge, 1966a).

Closer at home volcanic activity, mainly in the form of altered pyroclastic rocks and as lava flows, have been reported in the extensive Proterozoic iron-formations in the Transvaal Sequence, South Africa (La Berge, 1966b; Beukes and Klein 1990). Beukes (1973) also noted the close association of volcanism with BIF successions in the Archaean greenstone belts of Zimbabwe and South Africa.

Despite extensive evidence showing a close genetic link between iron-formation development and the presence of volcanic and pyroclastic rocks in the areas mentioned above, the authors found no reference to accretionary lapilli of the type described in this paper being associated with these rocks. La Berge (1966a) did, however, report spherical structures, each about 0,1-0,3mm in diameter composed of exceedingly fine chloritic material and generally surrounded or coated by fine pyritic dust, in the iron-formations in the Hamersley Range, Western Australia. Goodwin (1956) likewise described "tuff-ball structures" in the Gunflint iron-formations that were thought to have formed by agitation or reworking of tuffaceous material or from the possible aggregation of minute particles about some nucleus. Raindrops falling through a cloud of ash was suggested as a possible mechanism of formation of these structures. Judging from a photograph of the ellipsoidal structures, which measure approximately 3mm in diameter (Goodwin, 1956, fig. 7), they appear to resemble core-type accretionary lapilli formed of small angular tuff fragments compacted around a larger central fragment. Spheroidal structures, interpreted to be relic microfossils, have also been reported by La Berge (1973) from iron-formations in the USA, Canada, Australia and South Africa. In view of the uncertain nature and origin of the abovementioned spherical structures the volcanic particles described from the Amalia greenstone belt may represent the first recorded association of accretionary lapilli with banded iron-formations.

Being conformably interlayered with the BIF units it is probably reasonable to assume that the accretionary lapilli beds were laid down in an environment similar to that in which the iron-formations were deposited. As pointed out by James and Sims (1973) the origin of iron-formations has proved to be controversial with hypotheses invoking magmatic, volcanic, replacement, biological, and even cosmic processes. Most favoured over the past two decades has been the view that iron-formations originated as chemical sediments, but many questions remain unanswered as to the source and method of transport of the iron and silica, the nature of the water in which the sediments accumulated (fresh, brackish, oceanic), and the importance of diagenetic processes in the formation of BIF deposits.

Depositional environments that have been proposed for BIF development are very variable suggesting that these diversified rocks probably do not fit a single depositional model. Important sedimentological constraints in the choice of any depositional model must account for the scarcity of clastics and the rhythmic compositional alternations of silica-rich and iron-rich bands. For oxide facies iron-formations, of the type similar to those encountered in the Kraaipan Group of rocks in the Amalia greenstone belt, some consensus does appear to have been reached. Many iron-formations display clear indications of relatively shallow-water deposition in areas that must have been tectonically stable for long periods of time. If such a depositional basin was in a marine environment the conditions must have been analogous to those in Bahama-type platforms which are inaccessible to terrestrial debris or to barred or partially barred basins or lagoons in a climate arid enough to exclude large perennial rivers (James, 1954, 1966; Beukes, 1973; Eugster and Chou, 1973; Goodwin, 1973). Other theories have been proposed suggesting that the iron-formations were deposited chemically in large stable basins analogous to younger evaporite playa-lake complexes with sodium silicate gels or magadiite regarded as the most likely precursor of the bedded cherts. Iron-rich solutions would, in this model suggested by Eugster and Chou (1973), inflow into the lake primarily through springs, accounting for the paucity of clastics found in the BIF. These authors, mindful of the abundant and ubiquitous occurrences of BIF throughout the Archaean and early to middle Proterozoic periods, also formulated a compromise model retaining the most attractive aspects of the playa-lake environment and combining them with access to seawater via barred lagoons in which water of continental origin might also be present.

Archaean volcano-sedimentary greenstone belts have been linked to primitive plate-tectonic modes of derivation involving thermal plumes or "hot spots", spreading centres, inter-arc or back-arc basin development and the generation of various oceanic and arc-type volcanic accumulations (Anhaeusser, 1973; 1981; Burke et al., 1976; Tarling, 1978; Kröner, 1981). Goodwin (1973) envisaged each basin representing a centre of crustal spreading with consequent accumulation of oceanic-type volcanics in the interior part and of arc-type volcanics at the margin. Volcanic exhalations and volcanic clastics were deposited mainly within the basins as chemical (iron-formation) and clastic sediments.

Thus to summarize, the accretionary lapilli beds in the Amalia greenstone belt were probably deposited in some shallow marine or barred basin setting in which the conditions for iron-formation development may have approached those described in the above section. As such the lapilli beds themselves are not environmental indicators and only reflect a period of pyroclastic volcanism accompanied by specific local conditions necessary to produce the accretionary or pisolitic structures described in this paper.

CONCLUSIONS

Coated or rim-type accretionary lapilli, possessing well-developed cortical shells or glassy rinds, occur within pyroclastic sediments interlayered with Archaean oxide facies banded iron-formations in the Amalia greenstone belt, western Transvaal, South Africa. Volcanic and pyroclastic rocks intimately associated with iron-formations are not uncommon and have beeen reported from numerous Archaean and Proterozoic terranes worldwide. Usually a close genetic link can be established between the iron-formations and the associated volcanic components.

As far as can be established, accretionary lapilli of the type described in this paper have not previously been recorded in association with iron-formations. The morphology and size of the lapilli indicate a proximal origin and hence, indirect evidence for a volcanic eruptive centre estimated to lie within approxinately 3-5km of the pyroclastic occurrence on the farm Bothmasrust. The possibility of more than one such eruptive centre in the region is not discounted.

The accretionary lapilli probably formed as a result of the nucleation of particles of volcanic ash that had been moistened from condensates from the volcano itself or from raindrops passing through the eruption clouds. In themselves the accretionary apilli do not constitute exceptional palaeoenvironmental indicators supporting the cautionary views expressed on this issue by Reimer (1983a), Fisher and Schmincke (1984), and Boulter, (1987). Instead they may rather be regarded as useful stratigraphic or time horizons in terranes devoid of fossils or other readily identifiable marker beds.

Clues to the environment of deposition of the accretionary lapilli in the Amalia greenstone belt derive not from the lapilli beds themselves but from the interbedded BIF horizons which suggest an origin in a shallow marine or barred lagoonal basin, the latter possibly analogous to younger evaporite playa-lake complexes as envisaged by Eugster and Chou (1973).

Finally, the presence of gold mineralization in the Goudplaats-Bothmasrust area of the Amalia greenstone belt (Vearncombe, 1986; I.M. Jones, in prep.) may be genetically linked to the eruptive centre from which the accretionary lapilli were derived.

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