

Bellan-bandi Palassa, Sri Lanka: Formation processes of a Mesolithic open-air site identified through thin section micromorphology

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Introduction

Bellan-bandi Palassa is one of the most important pre-historic sites in terminal Pleistocene-Holocene Sri Lanka with the majority of Sri Lanka's pre-historic human skeletal material, popularly known as Balangoda Man, coming from this location. The site, discovered by Arthur Delgoda of Morahala, was excavated over several seasons in the late 1950's and early 1960's by P.E.P. Deraniyagala, yielding thirteen flexed human burials and a large collection of faunal remains and stone artefacts that provided the foundation for comparative assessment of ethnic origins (Kennedy, 1965; Deraniyagala, S.U., 1992). Subsequent excavation in 1971 attempted to clarify the stratigraphic and chronological context of the site; radiocarbon measurement yielded a date of ca. 2,070 years BP, considered to be too young and contaminated, and a thermo-luminescence measurement on fired quartz crystal directly associated with one of the burials gave a date of $6,500 \pm 700$ years BP, although again the date was considered young (Deraniyagala and Kennedy, 1972; Deraniyagala, S.U., 1992).

In this paper we set out to characterise the local environments of the burials and associated artefacts, thus addressing a significant omission in the analyses of the site so far. To do so we consider the soils and sediments from archaeological contexts as records of the environment in which they have been formed. Thin section micromorphology of undisturbed soils and sediments is our preferred analytical method as it allows systematic microscopic observation of soils and sedimentary features *in situ* and their relationship to one another, allowing interpretation of formation processes to be made (Davidson and Simpson, 2001).

Site and stratigraphy

Bellan-bandi Palassa is located on the right bank of the Uda Walawe river, above the bed of the Bellan-bandi stream in the Uda Walawa National Park in Ratnapura district. The site is at an altitude of ca. 381 m and is located at the ecotone between Wet zone (average annual rainfall greater than 3000 mm / year) and Dry zone (average annual rainfall, 2050 mm / year; Deraniyagala, S.U., 1992). The regional bedrock includes high-grade metamorphics (charnockites, gneisses) and metagranites / metapegmatites of the north-south trending Highland Series, metamorphosed and deformed during several metamorphic events of Precambrian to Lower Palaeozoic age (Coorey, 1984).

The archaeological strata are deposited above horizontally jointed Precambrian crystalline limestone exposed by erosion of the Bellan-bandi stream bed (Deraniyagala and Kennedy, 1972) with re-excavation of the 1970 trenches undertaken for the environmental analyses during 2005. Twelve contexts were identified in the field, divided into five phases (Figure 1). Phase II is of primary interest to this investigation and considered to be the location of prehistoric occupation of the site (contexts 10; 10YR 3/2-3, gravely silty sand; Perera, 2007) and lying immediately above the bedrock. AMS radiocarbon measurements on charcoal from context 10 are $10,086 \pm 142$ years BP (calibrated to 11,150 – 12,250 years BP, 95% probability) from the lower part of the context and $10,163 \pm 45$ BP (11,620 – 12,050 years BP, 95% probability) from the upper part of the context, indicating a Mesolithic age (University of Waikato, 2006; Perera, 2007). Phase III (context 9; 10YR3/4, gravely silty sand; Perera, 2007) represents a period of lighter use of the site between the Mesolithic and historical period with Deraniyagala and Kennedy (1972) reporting historical pottery along with faunal remains and Mesolithic stone implements. Above these phases are sandy loam deposits with lithics, interpreted as material deposited with the construction of a dam which overlies the earlier contexts and tentatively dated by association with the nearby Sandagiriya settlement to the 4th century AD. The Bellan-bandi Palassa stream, which now runs past the site, may have been used as a channel to fill this early historical dam. The stream now runs into a later dam built in the 1940s and maintained till around 1970, when the villagers were evacuated with the creation of the Uda Wallawe Wildlife Reserve.

Methods

Two undisturbed soil / sediment samples were collected in Kubiena tins, one from Phase II, context 10 (BBP C-10) and one from Phase III, context 9 (BBP C-9). Thin sections were manufactured from these undisturbed samples at the University of Stirling Thin Section Micromorphology Laboratory following standard procedures of resin impregnation, curing and slicing (<http://www.thin.stir.ac.uk/methods.html>). Descriptions of the thin sections were undertaken utilising plane polarised light (PPL), cross-polarised light (XPL), and oblique incident light (OIL) and using a range of magnifications (x10-x400) and standard visual aids were employed for semi-quantitative estimation (Bullock *et al.*, 1985). Terminology follows Bullock *et al.* (1985), Stoops (2003) and Goudie (1983; for calcrete). Grain size classes follow Tucker (1991).

Results

Features identified and their semi-quantitative estimates are given in Table 1 and more fully described below.

Thin section description - Sample BBP C-10

The coarse mineral fraction comprises granules (maximum clast 1.1cm) and coarse sand that are moderately rounded to angular and mainly equi-dimensional fragments of coarse-crystalline leucocratic lithologies (quartz, perthitic microcline, plagioclase, mica, clinopyroxene), probably derived from bedrock gneiss/granitoids. It is dominated by angular, elongate quartz grains, often with indented to mammillate periphery. Alkali feldspar (including perthitic microcline), plagioclase, clinopyroxene, mica, chlorite and garnet are also

present at lower frequencies. Alkali feldspar grains are angular and infrequently/moderately altered to clay minerals. Garnets are well rounded and commonly exhibit pellicular to linear alteration to goethite and, possibly, hematite. Bone fragments are also present at low frequency, ranging in size from 7000 μm to ca. 100 μm . Most are well rounded, dark orange to brown, and show pellicular blackening which can be attributed to burning. No calcification of burnt bone was observed. Intra-particle vughs occluded with calcite spar are common within bone fragments.

The silt fraction comprises mainly well-sorted, equidimensional, angular quartz grains and fewer plagioclase. Micromass and birefringent fabrics are red brown with black spots (PPL) and orange brown (OIL); birefringent fabric is mainly speckled and locally granostriated and porostriated and crystallitic birefringent fabric is also present locally. The coarse to fine related distribution is close to single-spaced porphyric and locally enaulic, and there is linear arrangement of inclined (ca. 25° from horizontal) elongate grains locally. The sediment is poorly sorted, although a trimodal distribution is discerned within the groundmass, with three distinct size clusters: granules, coarse sand and fine sand-coarse silt. The fine sand-silt population appears well sorted

Coarse organics are few angular to moderately-rounded with sand-sized fragments of burned plant material (charcoal) and lignified plant material. Fine and amorphous organics comprise frequent equi-dimensional fragments of burnt plant material (charcoal), disseminated evenly within the micromass.

Microstructures are channel and chamber, and complex granular. Peds are moderately separated blocky and granular, with moderately accommodated peds locally. Porosity is high (30-50%); voids include complex and compound packing pores, interconnected channels and chambers, moderately accommodated planes, star-shaped vughs (interpedally) and vughs (intrapedally).

Iron / manganese oxide staining in the micromass is very common. Few polycrystalline rock fragments are impregnated by manganese oxides (linear impregnation along crystal boundaries, microdendrites; Figure 2). Few quartz grains are coated with manganese oxides and there are occasional iron oxide hypocoatings in channels and chambers. In addition to diffuse micromass staining, discrete typic nodules with open to close porphyric intra-nodular coarse to fine related distribution are also observed. These include dark brown and red-brown nodules that are few, orthic and disorthic (Figure 3). One geodic nodule is present. And there is open to closed porphyric intra-nodular distribution.

Caliche nodules are present but very rare; they are equidimensional, ca. 500 μm across, with porphyric, 'floating grain' intranodular coarse to fine related distribution and calcite replacement/displacement rims around enclosed quartz grains. Disortitic boundaries consist of moderately to non-accommodating fissure passing into complex packing pores. Crystallitic coatings of calcite are present around few quartz grains. Most calcite occurs as infilling of vughs within burned bone fragments and as pendent coatings on the underside of bone fragments and mineral grains. An isopachous rim of calcite lines the wall of a vugh within the micromass. One rim of micro-stratified calcite coating with apparently pendent morphology is fragmented, with serrated margins, dissolved along lamination planes from fragmentation surface to the interior. Poikilitic spar encloses semi-amalgamated pellets within micromass locally.

Brown clay (cryptocrystalline) coatings are few, circum-granular, of uneven thickness, made up of non-oriented clay particles. Locally a brown grain coating appears superimposed on manganese oxide (or organic) coating of quartz grain. Faecal pellets are amalgamated and difficult to discern; locally they are manifest by the presence of star-shaped vughs within the micromass.

Thin section description - Sample BBP C-9

The coarse mineral fraction comprises few moderately rounded to angular fragments (maximum clast size 0.4 cm) of coarse-crystalline leucocratic lithologies (quartz, perthitic microcline, plagioclase, clinopyroxene, mica); these were probably derived from bedrock gneiss/granitoids. It is dominated by angular, elongate quartz grains, followed by plagioclase, mica, clinopyroxene, garnet, sillimanite, subhedral calcite and alkali feldspar (including perthitic microcline). The peripheries of quartz grains are often indented to mammillate. Alkali feldspar grains are angular and infrequently/very moderately altered to clay minerals. Garnets are well rounded and commonly exhibit pellicular to linear alteration to goethite and possibly hematite. Bone fragments are present at low frequency, mainly as well rounded, sand to granule-sized fragments.

The silt fraction comprises mainly well sorted, equidimensional, angular quartz grains and fewer plagioclase. Micromass is red brown with black spots (PPL) and orange brown (OIL). The birefringent fabric is stipple-speckled and locally granostriated and porostriated; crystallitic birefringent fabric is also present locally. Coarse to fine related distribution is complex, close to open porphyric and locally enaulic and chitonic to gefuric. The sediment is poorly sorted overall although the fine sand to silt-sized grain population is moderately to well sorted.

Coarse organics are rare, burnt (charcoal) and lignified plant material in angular to moderately-rounded, sand-sized fragments. Fine and amorphous organics are frequent equidimensional fragments of burnt plant material (charcoal), distributed evenly within the micromass.

Microstructures are complex channel and chamber and granular. Peds are moderately to well-separated blocky and well accommodated within the micromass. Elongate grains attain subvertical arrangement near large irregular chamber. Porosity is high (40-60%); voids include large irregular chambers (maximum dimension: 3.5cm) vertical to sub-vertical channels, complex and compound packing pores, interconnected channels and chambers at several scales (including micromass-scale) and intra-particle and intra-coating vughs. The largest chamber interrupts manganese oxide stained zones within the sediment.

Iron / manganese oxide staining in the micromass is very common. Iron / manganese hypocoatings are common in calcrete nodules and intra-nodular vughs and iron oxide hypocoatings line the surface of channels and chambers. Few dark brown nodules are present, mostly orthic, together with few disorthic red nodules.

Calcrete nodules are few; they are equidimensional to oval with porphyric intra-nodular coarse to fine related distribution of 'floating grains' set in crystallitic micromass (microcrystalline calcite). Calcite displacement/replacement rims around enclosed quartz grains are common. Intra-nodular features include vughs reduced to occluded by calcite spar,

and poikilitic spar enclosing microaggregates. At least one composite, amalgamated nodule and one geoidal nodule are present. Manganese oxide hypocoating lines the intra-nodular void within the latter. Nodule periphery is commonly demarcated with iron / manganese oxide hypocoatings and intercalations. Iron oxide stains are present within the intra-nodular micromass. Greenish (reduced iron) hypocoating is present on the underside of a large nodule. Crystallitic coatings of calcite are present around quartz grains. Calcite occurs mainly as pendants and less often as cappings, locally forming ferruginous bridges of prismatic spar (Figure 4). Poikilitic spar encloses semi-amalgamated pellets within the micromass locally.

Brown clay (cryptocrystalline) coatings are few, circumgranular and of uneven thickness, with non-oriented clay particles. Loose, discontinuous infilling of a large chamber comprises coated quartz and mica grains and aggregates. Faecal pellets are amalgamated and difficult to discern; mainly they are manifest by the presence of star-shaped vughs within the micromass.

Discussion

Deposition Processes

The coarse fraction of the poorly sorted gravely silty sands of BBP C-10 and BBP C-9 was derived from metamorphic/granitoid lithologies compatible with those referred to comprise the Highland Series (Deraniyagala, S.U., 1992). It is remarkable that clasts correlative with the immediate bedrock of the Bellan-bandi Pallassa sediments ('crystalline limestone') are totally absent from the lowermost sample (BBP C-10) and very few in the upper sample (BBP C-9). This, together with poor sorting and absence of cm-scale stratification and current-related sedimentary structures, probably suggests deposition by predominantly colluvial processes. The fining-up trend of the two samples suggests that colluviation diminished in intensity. Equidimensional shape of the angular quartz grains that comprise the silt fraction and good sorting of this fraction in both samples suggest contribution of aeolian processes to silt deposition, either directly, or in the form of colluvial reworking of fine aeolian sediment.

At the scale of observation human contribution to deposition is manifest by the unambiguous presence of burnt plant tissue (interpreted as charcoal) and burnt bone fragments. The broad size-range of charcoal fragments and their homogenous mixing with other sediment particles suggests some degree of transport and reworking of the former by colluvial (and aeolian) processes and/or redistribution as a result of bioturbation. Larger bone fragments almost invariably have blackened periphery demonstrating that burning followed, or was contemporaneous with bone splintering. Smaller, granule to sand-sized bone and charcoal fragments are also well rounded and evenly distributed suggesting that their depositional history was similar to that of charcoal fragments.

In view of the archaeological context of the site, with its abundance of quartz microlithic tools (Deraniyagala and Kennedy, 1972; Perera, 2007), it is possible that at least a portion of the angular rock and quartz fragments represent by-products of tool processing. No flake-like grains were noted in the two sections; however most of the site's microliths were trimmed by indirect percussion (Deraniyagala and Kennedy, 1972; Perera, 2007), a process which would not produce readily recognisable by-products in thin section. The coarse-crystalline texture of multicrystalline quartz primary materials would also inhibit flake production.

Post-depositional changes

The sediment has been subjected to intense bioturbation as evidenced by smooth-walled channels and chambers and the presence of recognisable faecal pellets locally. This might have contributed to rounding of charcoal and bone fragments and their even mixing with other sediment constituents and also to the, possible, local reworking of pedofeatures. The most noticeable pedogenic changes include pervasive impregnation by iron / manganese oxide (manifest as nodules, hypocoatings, spots and intercalations), apparently more intense in the lower Mesolithic context and calichification, mainly within the upper Mesolithic context (BBP C-9).

Iron / manganese oxide impregnations probably reflect waterlogged conditions (Bullock *et al.*, 1985). This inference is supported by the possible presence of vivianite within a bone fragment from the lower sample BBP C-10. It is possible that water-logging of the sediment was facilitated by local geology, with the underlying marble forming a hydrological boundary (a perched alluvial aquifer) during wet seasons and, also, during the operation of the overlying water dam in historical times. The presence of a thin '*ochrish weathering horizon*' at the marble/sediment interface (Deraniyagala and Kennedy, 1972) suggests that groundwater pooling took place at and above this lithological boundary.

Calichification and associated calcite spar deposition, mainly concentrated within the upper sample (BBP C-9), on the other hand, probably suggests pronounced dry seasons in broadly arid/semi-arid climatic conditions (Goudie, 1983), not unlike those prevailing in the area at present. This 'traditional' interpretation notwithstanding, it should be noted that calichification can take place in a broad range of climatic conditions, including subhumid climates (Khadkikar *et al.*, 2000). In the examined sediment crystalline calcite, and to a lesser extent microcrystalline caliche micromass, is spatially associated with dissolution of bone fragments. Prevalence of pendent calcite coatings suggests that deposition took place by percolating fluids within the vadose zone. Local dissolution of calcite spar coatings suggests that calcium carbonate dissolution / re-precipitation took place in more than one phase.

It is difficult to infer the temporal relationships between water-logging and calichification from the two examined thin sections. Were these broadly contemporaneous, with alternating wet and dry seasons responsible for iron / manganese and caliche deposition, or was there a longer-term succession of wet and dry periods? Palaeobotanical evidence from ombrogenic swamps in the wet Highlands further west suggests that intensification of the Southwestern Monsoon ca. 11,500 cal BP, during deposition of the Mesolithic sediments in Bellan-bandi Pallassa, the onset of the Southwestern Monsoon created humid conditions on the western slopes of the Sri Lanka Highlands, favouring expansion of upper montane rainforest (Premathilake and Risberg, 2003). Increasing humidity and associated montane rainforest expansion continued until ca. 8,500 cal. BP, followed by increasing aridity and associated expansion of grassland at the expense of upper montane rainforest until ca. 3,500 cal. Further shorter-term humid/dry cycles were resolved in the later part of the Holocene. It is uncertain whether the same succession of climatic conditions prevailed in the dry lowlands in the rain shadow of the Highlands, where in local climates are characterised by a marked wet/dry seasonality under the influence of the Northeast Monsoon (Deraniyagala, S.U., 1992). It is not unreasonable to infer, however, that increased aridity prevailed in this ecozone for long periods in the Holocene. The temporal window for post-depositional calcrete formation is, thus, very wide.

Some difficult to interpret direct evidence for the temporal relations between calcification and iron / manganese oxide deposition comes from a large calcrete nodule in sample BBP C-9. Black (manganese?) oxide intercalations are concentrated in the periphery of the nodule and appear associated with greenish hypocoatings, possibly suggesting reducing conditions consistent with water-logging. This could be interpreted to imply that water-logging succeeded dry conditions, as expected from the operation of a historic irrigation tank above the Mesolithic sediments.

Conclusions

Mesolithic sediments from Bella-bandi Palassa reflect a combination of depositional processes, with colluvial and aeolian processes yielding most of the mineral material and human activity (bone splintering and burning) yielding bone and charcoal. Slope wash (and, possibly, aeolian) processes may have reworked bone and charcoal from the close vicinity of the samples. Waterlogging and calcification are evidenced in the samples, pointing towards succession of wet and dry climatic conditions. The exact timing of climatic alternations (seasonal/longer-term) is however, difficult to resolve. This difficulty is further complicated by site-specific conditions (operation of a water tank in historical times). It is possible that arid/semiarid conditions were followed by water-logging during the operation of the overlying rice field irrigation dam in historical times. These findings are however consistent with the faunal and lithic evidence from context 10 which suggest successful hunting adaptation to seasonally wet and dry conditions (Perera, 2007).

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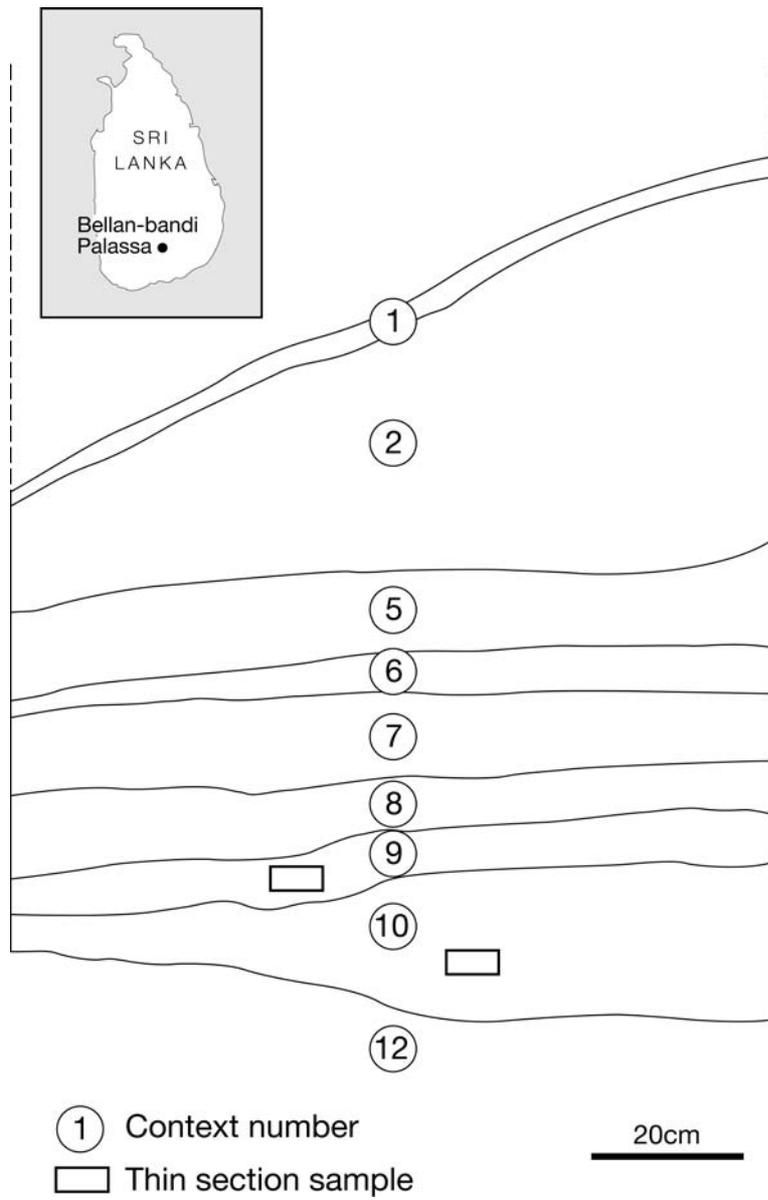


Figure 1. Bellan-bandi Palassa stratigraphy, showing contexts and location of thin section samples

Table 1. Summary thin section descriptions – Bellan-bandi Palassa

Context	Sample	Lithofacies	Microstructure and porosity	C/f63µm related distribution	Rock fragments	Quartz	Alkali Feldspar	Plagioclase	Pyroxene	Garnet	Mica	Chlorite	Other mineral	Bone	Charcoal	Micromass and birefringent fabric	Fe-oxide hypocoatings	Fe/Mn-oxide staining	Dark brown nodules	Red nodules	Calcite inclusions	Calcite coatings	Caliche nodules	Faecal pellets	Brown grain coatings	Comment
	BBP C-9	Matrix-supported granular conglomerate to sand. (Mc: 0.4 cm)	Channel and chamber <i>Complex granular</i> Voids: 40-60% Interconnected channels and subvertical chambers Max chamber: 4cm Planar in micromass Vughy (intraparticle)	Porphyric (close to open) <i>Enaulic</i> <i>Chitonic-Gefuric</i>	++	•••	+++	•	++	+++	•	++	•	++	•	Red brown with black spots (PPL) Orange brown (OIL) Stipplie-speckled <i>Grano-striated</i> <i>Porostriated</i> <i>Crystallitic</i>	•	••	•	+	•	•	•	+	•	Well-sorted silt-sized grains Calichification
	BBP C-10	Matrix-supported, poorly sorted granular conglomerate. (Mc: 1.1cm)	Channel and chamber <i>Complex granular</i> Voids: 30-50% Interconnected channels and chambers <i>Packing</i> Planar and vughy (interpedal) Vughy (intragranular)	Porphyric (close to single-spaced) <i>Enaulic</i>	••	•••	••	••	•	•	•	•	•	++	•	Red brown with black spots (PPL) Orange Brown (OIL) Speckled <i>Grano-striated</i> <i>Crystallitic</i>	••	•••	•	++	•	+++	+	+	•	Well-sorted silt-sized grains (Possible) vivianite in bone fragment Bone dissolution associated with calcite spar deposition

Note: +Very Rare (<0.5%), ++Rare (0.5-2%), +++Very Few (2-5%), •Few (5-15%), ••Frequent (15-30%), •••Common (30-50%), ••••Dominant/Very Dominant.
Italics: local occurrence (in order of frequency). Mc: maximum clast size.

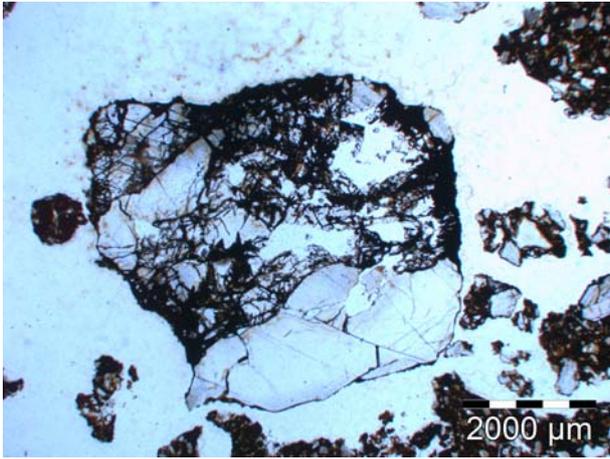


Figure 2. Pellicular-linear impregnation of manganese oxide in angular gneiss / granitoid fragment (BBP C-10; PPL).

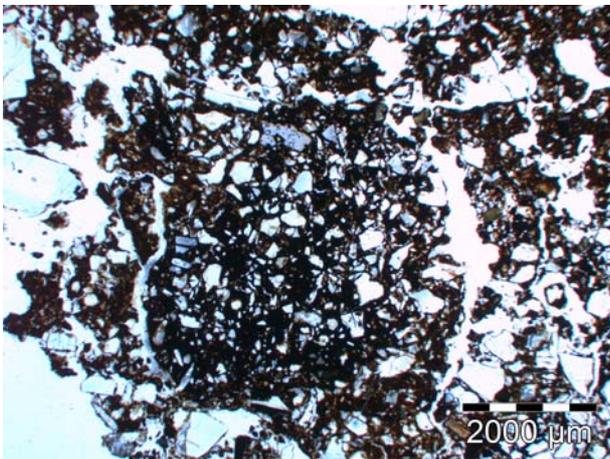


Figure 3. Iron / manganese oxide nodule; (BBP C-10; PPL).

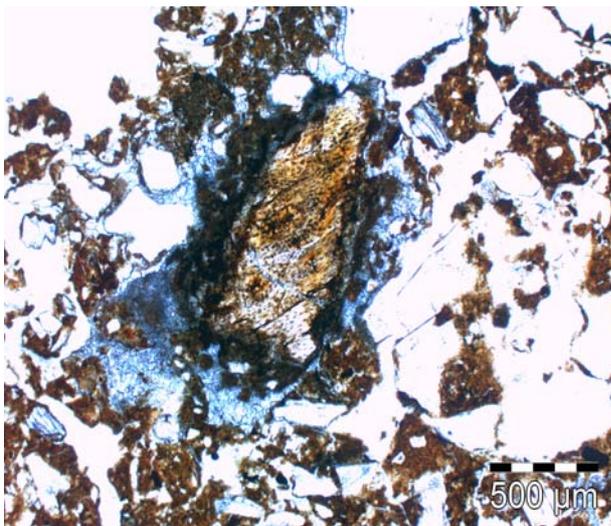


Figure 4. Caliche and calcite spar deposition around blackened bone fragment. Note pendent and gefuric habit of calcite coatings (BBP C-9; PPL).