PETROGRAPHY OF LITHIFIED CAVE SEDIMENTS

R.A.L. Osborne

School of Professional Studies, A35
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Lithified cave sediments occur in palaeokarst deposits, relict caves and "caves without roofs". Lithification and diagenesis can transform the whole range of cave deposits into indurated rocks. These often contain fossils and are frequently misidentified as flowstone. In vadose conditions meniscus cement forms in coarse clastics. Water seeping through entrance facies emplaces spar and flushes out fines, forming pelletal and calcihe-like textures. Speleothem recrystallises, losing depositional texture. In phreatic conditions acicular cements form, which change by neomorphism to blocky spar. Carbonate sands and muds, deposited in caves flooded by the sea, resemble marine limestones. Lithified lime muds from caves resemble marine mudstones.

Introduction

Petrographic study of indurated cave sediments is in its infancy. Increasing international interest in palaeokarst and "caves without roofs" has drawn attention to the need for further research in this area. Lithified cave sediments at Riversleigh and Wellington Caves contain some of Australia's most important Cainozoic vertebrate fossil deposits. Strongly lithified Permian, Carboniferous and Devonian palaeokarst sediments are recognized in many eastern Australian karsts. Workers often incorrectly identify resistant layers in ancient cave deposits as flowstone, not realising that a range of sediments deposited in caves, can, over time, become substantially indurated and that crystalline deposits, including flowstone, are changed by diagenetic processes.

A great variety of clastic and non-clastic sediments is deposited in caves, in both vadose and phreatic environments. Over time, these sediments are transformed into well-indurated rocks. Lithification and diagenesis in caves takes place under generally stable temperature and pressure conditions with highly variable water tables and abundant dissolved calcium carbonate.

Vadose litihifcation and diagenesis

In vadose conditions, crystalline deposits, such as speleothem, undergo significant recrystallisation involving extensive cannibalisation of small crystals and loss of depositional texture. Primary cavities are frequently filled with druse while secondary cavities may be formed and later filled with druse. Meniscus cement is deposited in coarse clastics with stable grains such as sands, frost-wedging breccias and bone breccias.

Vadose water seeping through poorly sorted entrance facies deposits will both deposit spar and flush out some of the fines. This process can result in pelletal and calcihe-like textures and may, if continued over a significant period, replace much of the silt and clay with secondary spar.

Phreatic lithification and diagenesis

In phreatic conditions, acicular cements are frequently deposited in cave clastics. These often undergo neomorphic change to blocky spar. Marine carbonate sands and muds, deposited in caves flooded by the sea, frequently resemble normal limestones. Cave muds deposited in impounded karsts and then lithified, resemble carbonate-rich siltstones and mudstones. Lithified muds deposited in holokarsts are frequently difficult to distinguish from laminated marine mudstones.

Lithification of Entrance Facies

Entrance facies are generally poorly–sorted and frequently loosely packed. This loose packing allows vadose seepage waters to percolate through the matrix and deposit a complex range of cements including blocky spar, fibrous calcite and caliche-like cements.

Cement often surrounds peds within the matrix, producing a pelletal texture. OSBORNE (1978), following BRAIN (1958), described how percolating water not only deposited spar, but also carried away silt and clay from the matrix, resulting in friable silty diamictites being converted into dense rocks largely composed of calcite.

Lithification of Clastics

Lithified cave clastics resemble sedimentary rocks deposited in familiar fluvial environments. They preserve a range of textures and sedimentary structures. The feature common to most, but not all, lithified cave clastics is the overwhelming presence of carbonate cements.

Gravels

Gravels deposited in caves can be either well or poorly sorted. While in most cases the largest grains are allochthonous, in some cases as in the largest grains may be cave-derived limestone clasts and in others autochthonous grains such as pyrite, as in the *augenstein* of SEEMANN (1979).

A range of carbonate cements develop in gravels, including blocky spar, and plumose acicular forms. Often there is clear evidence of neomorphism, with zones showing inherited plumose texture going to extinction en masse.

While carbonate cements are common, ferruginous cements, either derived from weathering pyrite, or deposited by in-situ processes do occur, often in association with carbonate and manganiferous cements.

Sands

Of all lithified cave deposits, cave sandstones resemble most closely their surface equivalents. The grains in cave sandstones tend to be more angular and less spherical than those deposited by surface fluvial systems and carbonate cements, particularly coarse spar, tend to dominate.

The ease with which cave sandstones can be confused with surface materials makes the use of petrography essential when working with lithified sandstones from caves or suspected palaeokarst deposits. Quartz arenites and arenites composed of dolomite rhombs (not uncommon in hydrothermal palaeokarst) easily confused in hand specimen.

Muds

Cave muds deposited in holokarsts and then lithified, resemble carbonate-rich siltstones and mudstones (see below).

Muds deposited in impounded karsts are composed of common weathering products from the surrounding non-carbonate environment, such as kaolinite, illite and quartz.

Due to their low permeability and small pore size, non-carbonate cave muds are less likely to be strongly lithified than coarser-grained allochthonous sediments. While some allochthonous cave muds can become strongly lithified, forming mudstones, there is now evidence that in some situation cave muds can survive for millions or even hundreds of millions of years in a soft, pliable hydrated state.

Breccias

Coarse, angular, fragmental deposits are common in caves. They do not all, however, have the same origin and the term “breccia” is frequently misused in relation to cave deposits. Coarse-grained cave deposits in general, including: - diamictites, produced by slumping or rapid flood processes; conglomerates (organised and disorganised) from turbidite sequences and angular crystalline conglomerates (floe calcite) are frequently incorrectly described as cave breccias.

Three major groups of breccias can be recognised: -

Breakdown Breccias

Breakdown breccias are the best-known type of cave breccia. They consist of blocky fragments with great range of sizes (perhaps 10 mm- 10 m).

Breakdown piles continue to move after the fragments have separated from the bedrock, and clasts often continue to fragment due to crystal wedging while they are within the pile. Crushing, crystal wedging and gravity-deposited fines will contribute a small quantity of matrix to the breakdown pile.

Breakdown breccias can become lithified when fluvial sediments fill the pore spaces. Sandstone and conglomerate matrices are not uncommon in lithified karst breccias.

Breakdown breccias can also become lithified by precipitation of crystalline cements from groundwater or ore-bearing fluids. In these cases (see below) it is often to determine if the brecciation is due to breakdown, or to the ore emplacement process itself.

Cold-Climate Breccias

These consist of relatively small (2-200 mm) angular, platy, fragments of limestone. They may have a silty matrix or an open-packed grain-supported fabric. Intergranular spaces are angular.

Lithification begins with the growth of vadose meniscus cement, and may continue with spar filling the intergranular spaces.

Hydrothermal Breccias (including crackle breccias)

Hydrothermal breccias are produced by the emplacement of hot, mineral bearing, fluids into karst rocks. There are two main types of hydrothermal breccias and crackle breccias and massive breccias, which resemble breakdown breccias.

Crackle breccias (QUINLAN, 1972) are breccias in which the bedrock clasts are separated, but retain a jigsaw puzzle fit, ie. the matrix appears to have been emplaced into the bedrock. In most crackle breccias that matrix is crystalline, and is frequently composed of coarse calcite spar. Crackle breccias may zone into massive breccias.

Massive hydrothermal breccias are very similar in structure to breakdown breccias, however they tend to fill the containing void completely. They form by a process similar to crackle breccias (BALWIERZ & DZULYNSKI, 1976), however there is much more matrix and large clasts can be rotated and displaced.

Bone-Bearing Sediments

Bone fragments occur is a variety of cave sediments, both as major and minor components. Where bone fragments are a relatively minor component of the sediment or rock, it makes sense to classify the rock on the basis of the texture and/or composition of the major components. Thus coarse-grained sediments and rocks that containing a few bone fragments should be regarded as gravels or conglomerates, with no particular emphasis in their naming emphasis given to the bone component.

Caves do, however, contain sediments and rocks in which bone is a principal constituent or outstanding constituent. Because the bone component is frequently, but not always broken, bone-bearing cave sediments and rocks are frequently described as *bone breccias*. This usage is rather unfortunate as it groups together rocks whose only similarity is that they contain bones.

Three main groups of bone-bearing rocks are recognised.

Osseous Diamictites

Osseous diamictites are matrix-supported rocks containing gravel to cobble-sized bones and bone fragments. The matrix is usually composed of silt, clay or fine sand. The Pleistocene bone bearing “red earths”, reported from around the world, are examples of osseous diamictites.

While some deposits are both poorly sorted and lacking in structure, others have distinct bedding and aligned bones.

Osseous diamictites are generally vadose entrance facies deposits. The matrix, which often has an aeolian origin, is introduced into the caves by gravity and rain-wash, while the bones are frequently from victims of pit traps.

Clast-Supported Osseous Conglomerates

These rocks consist of small, closely packed bone fragments and teeth, which are initially cemented together by meniscus cement, forming quite strong, but highly porous rocks (the bone equivalent of a coquina). Little or no mud is present and petrographically they resemble carbonate rocks classified as packstones by Dunham (1962).

Over time the pores become filled with equant spar or radial calcite, depending on the diagenetic environment.

The teeth and bone fragments are accumulations from the regurgitation pellets of birds (usually owls) or the guano of carnivorous bats. Little or no post-depositional transport of the fragments has occurred.

Osseous Sandstones (Osseous Arenites)

Osseous Sandstones (OSBORNE, 1982) are clast-supported, graded-bedded coarse sandstones and fine conglomerates. They occur in turbidite sequences, which were deposited in still phreatic conditions when talus cones, rich in bone fragments, slumped into ponds producing turbidity currents.

These graded sands have a high primary porosity, and as a consequence become strongly cemented. The initial cement is often phosphate, or acicular carbonate, but later percolating water will often replace this with equant spar. As a consequence spar-cemented osseous sandstones are strong rocks, which can resemble quartz arenites to the naked eye, or be confused with bedrock.

The bone and tooth fragments in these rocks have a similar origin to those in clast-supported osseous conglomerates, but have been further fragmented and graded by transport.

Fresh water (phreatic) Carbonates

Lithified carbonate muds, deposited in caves in holokarsts are frequently difficult to distinguish from laminated marine mudstones. While they lack obvious fossils, so do many marine mudstones.

In the absence of convincing field or microfossil evidence, chemical and isotopic analyses may be the only means of distinguishing between lithified fresh water carbonate cave muds and their marine counterparts.

Marine (phreatic) Carbonates

Marine carbonate sands and muds, deposited in caves flooded by the sea, frequently resemble normal limestones. JONES (1992) described graded-bedded limestones that were deposited in caves of the Cayman Islands during periods of elevated sea level in the Cainozoic as Caymanites. Similar graded-bedded sediments of Carboniferous age were recognised in eastern Australia by OSBORNE (1995).

It is only the outcrop and stratigraphic relationships of these rocks, not their petrography, which allows them to be recognised as lithified cave deposits.

Subaqueous (phreatic) Precipitation Deposits

A range of crystalline deposits from in the phreatic zone. These are similar to speleothem, in that they are largely composed of calcite, but tend to have a coarser initial crystal size, and more pronounced crystal form. Because they from under water, these deposits are more often seen as relicts are, or in their lithified form in palaeokarst deposits, than in their active growth position.

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