Caves and caverns: preservation of materials

Description: Modelling suggests that a capillary barrier will form in unsaturated rock adjacent to a cavern and that this will act as barrier to water inflow into the cavern (Philip et al., 1989; Philip, 1990), although inflow may not be totally precluded (Williams et al., 1990). The effectiveness of the capillary barrier will depend on the dimensions and shape of the cavern, the percolation flux, heterogeneity in rock properties, the ambient flow field, and relative humidity (Williams et al., 1990). There is also some experimental support for the formation of a capillary barrier (Wang et al., 1999).

The USDOE have sought analogues for the volume and nature (drips vs. diffuse flow) of water seepage into natural and man-made caverns in the unsaturated zone. Evidence for the preservation of water sensitive materials in natural caves and rock shelters in the unsaturated zone is considered here. There are separate critical reviews of the evidence for water seepage into natural and man-made caverns.

Activities by hominids and other biota have left a range of remains in natural caverns and rock shelters that would have been destroyed if contacted by water. This selective preservation in the unsaturated zone was first reported by Winograd (1986). This is especially the case for objects in natural or man-made caverns. The fact that these have been preserved, in some cases for many thousands of years, often in past and present climates wetter than Yucca Mountain, has been used as evidence for the capillary barrier shielding effect of natural caverns in the unsaturated zone (Simmons, 2002). Materials considered included cave art, painted rock shelters, human artefacts, and packrat middens.

Cave Art

The pigments used by early man to decorate natural caverns consist of mixtures of iron and manganese oxides and charcoal, none of which are likely to survive prolonged contact with water (Stuckless, 2000). For example, moisture introduced by the breath of visitors to the Lascoux cave is believed to be one of the causes of the deterioration of the cave art after its opening to the public (Stuckless, 2000).

The best examples of Palaeolithic cave art are from northern Spain and southern France where more than a hundred caves with paintings are known. The oldest authenticated example is Chauvet, France (Cahuvet et al., 1996) where charcoal used as a black pigment has yielded ^{14}C dates of 32,410 – 32,340 years BP (Stuckless, 2000). The cave is located in an area with present-day precipitation of 580 to 780 mm yr^{-1} but there is little evidence of water damage to the paintings. There is some evidence of diffuse surface water flow as a film across some paintings leaving a thin calcite coating (Balter, 1999), and one stalagtite has formed across the artwork demonstrating the operation of very localised drip seepage.

Lascoux cave, also in France, includes more than six hundred paintings and is perhaps the most famous of the painted caves (Ruspoli, 1986). Stylistically the art is dated as 13–17 ka (Stuckless, 2000). There is evidence that one small block has fallen from the cavern wall and landed face down on the wet cavern floor which has destroyed the artwork. As noted above, moisture from human breath has damaged the artwork indicating its sensitivity to water and demonstrating the shielding effect of the cavern.

The most famous cave in Spain is the Altamira cave (Saura Amos, 1998). ^{14}C dating of charcoal pigment has given a date of 14,000 $\pm$ 400 years BP (Stuckless, 2000). The limestone is highly fractured and fractures cut the paintings but there does not appear to be any associated water damage (Simmons, 2002).

In contrast there is evidence of loss of cave art from the Cosquer, and Palomera caves due to flooding. The Cosquer cave, France, contains artwork dated at 27,000 and 18,500 years BP (Clottes and Courtin, 1996) providing evidence for two separate periods of artwork. The entrance is currently 37 m below sea level and flooded. All paintings up to the high water mark have been destroyed. There is evidence for diffuse surface flow over some of the remaining paintings with the precipitation of a thin calcite film (Stuckless, 2000). The Palomera cave, Spain, contains paintings dated as 10,950 – 11,540 years BP (Corchon et al., 1996). It too is subject to flooding which has destroyed the paintings up to the flood level.

Cave art is much less common outside of southern Europe. Stuckless (2000) has reviewed cave art from the rest of the world which tends to be younger than that described above. Cave art, probably from the Apollo Cave in South Africa has been dated at 26,000 years BP (Prins and Woodhouse, 1996). Two sites in Argentina have provided ^{14}C dates on charcoal in the range 9,200 – 10,600 BP (Poseta, 1996). Similar and perhaps older cave art is suspected from Brazil but most art probably dates from 4,000 to 7,000 years BP (Prous, 1996). What little cave art there is from China only dates back to 5,000 years BP (Fu, 1996).

The survival of water-sensitive cave art for prolonged periods, often through periods of increased precipitation compared to today, demonstrates the relatively low seepage rates into many natural caverns in the unsaturated zone. It can be argued that only a biased sample of cave art has survived. However, Stuckless (2000) has pointed out that caves are either found with art intact or without cave art or large areas are lost due to flood events. Caves showing progressive degradation of the cave art appear not to exist. This is taken to infer that painted cave surfaces have survived. Note however, that within individual caves there is likely to be a bias in the location of the artwork, with early man avoiding wet areas where paints would run or not dry.

Painted rock shelters

These structures comprise a protective rock overhang but are otherwise open to elements. They are much more common than caves since they may be formed in a wide range of rock types. Easier access and the presence of daylight mean that there is a very large portfolio of painted rock shelters world-wide. More than 400 examples are recorded from India (Mathpal, 1996) in a variety of climatic zones with rainfall in the range 1,000 – 1,500 mm yr^{-1}. They are believed to be Megalithic in age, 10 – 7 ka, and appear to display water damage only where tree roots have provided routes for water infiltration. In Africa 3,931 sites are known (Lewis-Williams, 1981), generally only a few thousand years old and often in arid environments where wind abrasion may be more significant than water in destroying the artwork. There are a large number of painted rock shelters in North America with the oldest dating to 3,500 years BP (Stuckless, 2000).

Taken together the survival of artwork in rock shelters demonstrates that under appropriate circumstances an overhang of a few metres can protect paintings from water seepage in the unsaturated zone.

Human artefacts

There is limited evidence for the preservation of water-sensitive artefacts in natural caverns. Clay figures have been reported from four caves in the Ariege Pyrenees, Labouiche, Bedeilhac, Montespand and Tuc d'Audoubert. and dated at 14 ka old (Stuckless, 2000). Cloth, ivory, reed mats and bronze items dated at 3,912-3,770 B.C. have been reported from caves in Israel (Ozment, 1999).

Packrat middens

These comprise piles of twigs, faecal pellets and other debris cemented by dried packrat urine. More than one thousand have survived in caves and rock shelters in semi-arid areas of the south western United States and date back up to 50 ka (Stuckless, 2000; Spaulding, 1985). They are very sensitive to contact with water and are good indicators of shielding. Those that are more than 20 ka old have survived wetter climatic conditions than present.

Relevance: These analogues are relevant to underground facilities constructed within the unsaturated zone. It is therefore of direct relevance to the Yucca Mountain repository concept and to shallow storage concepts such as those being considered in France.

Position(s) in the matrix tables: Near-field RN release from barriers.

Limitations: Percolation rates and inflow rates in the unsaturated zone depend on many factors ranging from present and future climate, infiltration rate, host rock properties especially percolation flux and the shape and size of the caverns. In practice this means that while these analogues are useful, analogues in conditions more closely matching the conditions at a specific site will be of maximum relevance.

Quantitative information: These analogues provide only qualitative data on seepage rates but demonstrate that water inflow into caverns in the unsaturated zone may be only a small percentage of the local groundwater infiltration rate. Localised inflow cannot be precluded.

Uncertainties: There must be considerable uncertainty over the groundwater inflow at a specific location since inflow is in part controlled by local heterogeneity in unsaturated rock flow properties.

Time-scale: These analogues cover the human (0 – 100 years), historical (100 – 1000 years) and archaeological (1000 – 10 000 years) time-scales.

PA/safety case applications: Utilised in the TSPA developed for Yucca Mountain.

Communication applications: Not known, but probably used by the U.S. DOE.

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Added value comments: These analogues have already been used by the US DOE in the development of their conceptual model for seepage at Yucca Mountain.

Potential follow-up work: Further data acquisition at a larger number of these types of analogue sites could be used to provide additional quantitative data and build confidence in the general applicability of the results.

Keywords: Seepage, Caverns, Unsaturated Zone, Cave art, Rock shelters, Packrat middens

Reviewers and dates: J.L. Knight, Nirex (October, 2003).