Caves and caverns: natural

Description: Five types of natural caverns (or caves) can be recognised based on their mode of formation:

- Solution caves: These are formed in limestone, gypsum and rarely in salt formations by the slow dissolution of the rock by flowing groundwaters.
- Sea caves: These are formed by wave erosion at the base of sea cliffs and are often aligned along planes of weakness in the rock. They may form in virtually any type of strong rock.
- Erosion caves: These are formed by the erosional force of either water or wind. They may form in a wide range of strong rock types.
- Tectonic caves: Landslips may lead to joint dilation and the formation of caves. They may form in any strong jointed rock type but are usually of small size.
- Lava tubes (tunnels): Formed by the cooling of rapidly flowing basaltic lava.

Dimensions of natural caverns

The Nirex repository concept incorporates large caverns up to 15 m (wide) by 15 m (high) by 300 m (long) with an individual volume of 67,500 m^3. To put this in context there are fifteen natural caverns known with volumes in excess of 2 million m^3, the largest being the Luse cavern, Papua New Guinea with a volume of 50 million m^3 (Anon 2003a). Part of the largest solution cavern in Europe, the Salle de la Verna, France, is shown in Figure 1. The longest solution cave in limestone is the Mammoth Cave-Flint Ridge system in central Kentucky which as of 1989 had a surveyed length of 530 km (Encyclopedia Britannica, 2003). The Optimisticheskaya Cave in Ukraine is the longest gypsum cave with 165 km of passages. Lava tubes are typically several metres in diameter but can be very long. The longest is the Kazumura Cave in Hawaii which is 59.3 km long. Over ninety lava tubes more than 1 km long are known worldwide (Gulden, 2003).

Figure 1. Part of the Salle de la Verne natural solution cavern

Age of natural caverns

The oldest documented solution caverns noted in a recent review were in the Guadalupe Mountains of New Mexico. Here dates from alunite (a dateable K-bearing mineral) in undisturbed floor sediments as old as 11.3 million years were found. Alunite from Lechuguilla Cave and the Big

Room of the Carlsbad Cavern, yielded ages of 5.7 - 6.0 million years and 3.0 - 4.0 million years respectively (Polyak et al., 1998). Parts of the floor of these caves are covered by blocks presumably fallen from the roof of the cavern but they are not extensive and do not block the caverns (Simmons, 2002). In Great Britain, the age of limestone solution caves varies depending on whether they have been subjected to glacial erosion. The oldest caverns are found in southern areas, beyond the reach of Quaternary glaciers, with ages up to 900 ka (Waltham et al., 1997).

Most lava tubes are less than a few thousand years old but the San Antonio Mountain Cave, New Mexico, is a lava tube 170 m long formed 3.4 - 3.9 million years ago. Approximately 30% of the floor is covered by fallen blocks, but there are also parts of the floor that preserve a record of sedimentation without fallen blocks. These sediments are up to 1 million years old (Simmons, 2002).

Cave art is interesting in that it demonstrates the age and stability of cave wall surfaces. 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, with ^{14}C dates of 32,410 to 32,340 years BP. The Cosquer cave, France, contains artwork dated at 27,000 and 18,500 years BP and the Lascaux cave, also in France, includes more than six hundred paintings dated stylistically as 13,000 to 17,000 years BP. There is evidence in this cavern that one block has fallen out of the cavern wall since it was painted. In Spain, the Altamira and Palomero caves have yielded ^{14}C dates of 14,000 +/- 400 and 10,950 - 11,540 years BP respectively. Cave art is much less common outside of southern Europe but has been recorded from Great Britain (12,000 BP), South Africa (26,000 BP) and Argentina (*ca*.10,000 BP).

Depth of natural caverns
The World Caves Database, while incomplete, contains details of more than 1,000 natural caverns more than 300 m deep (Anon, 2003b). Figure 2 shows the frequency of these natural caverns as a function of depth. Clearly there is a rapid decease in numbers with increasing depth but there are 66 more than 1,000 m deep. The deepest is the Voronja Cave, Georgia, that extends to a depth of 1,710 m.

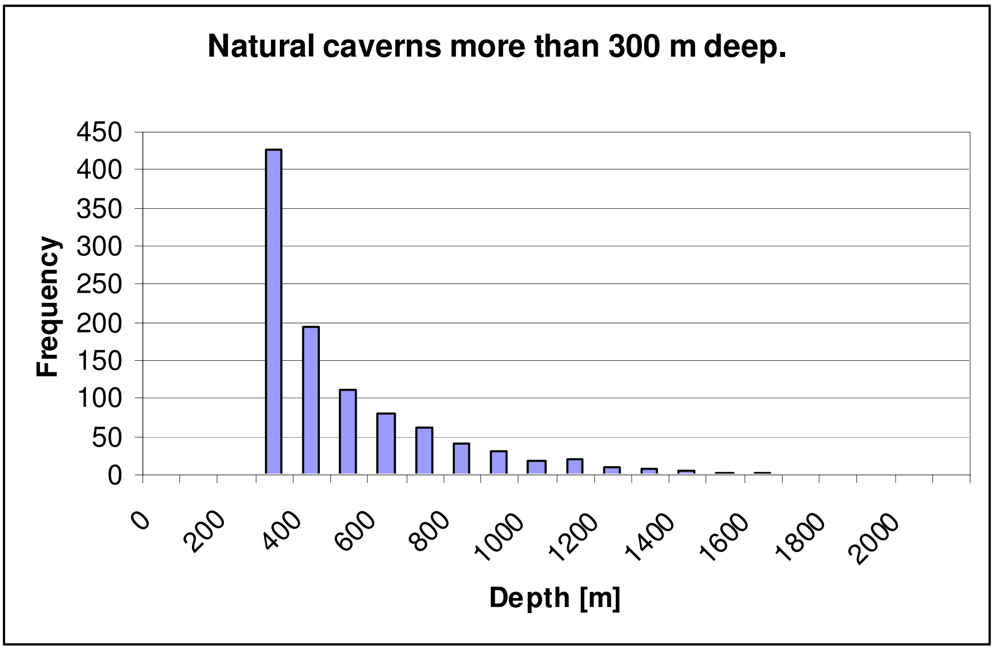

Figure 2. Frequency of natural caverns >300m deep

In summary, this volumetrically large and diverse range of evidence demonstrates the longevity of many natural caverns formed in strong rocks at repository-relevant depths and of comparable or larger size than repository vaults. Caution is needed, however, since by definition the caves described above are those that have not collapsed completely. Volumetrically there is more evidence for survival of caverns at relatively shallow depth and in the unsaturated zone than for caverns at much greater depth below the water table. In part this is an artefact of the discovery and exploration of such deep caves.

Waltham et al. (1997) raised issues concerning the longevity of relatively shallow caverns in locations subject to glaciation.

Relevance: The study of the stability of natural caverns is relevant to all repository concepts in strong rocks, particularly those at relatively shallow depths. It demonstrates that there is plentiful precedence for the survival of natural caverns of repository-size scales over prolonged periods of time at repository-relevant depths. The information is relevant to the stability of the EDZ.

Position(s) in the matrix tables: This study belongs to the NF Rock/EDZ-Barrier Containment/Physical Integrity box of the Near-field matrix table.

Limitations: There is a bias in that natural caverns that have totally collapsed are not available for study to the same extent as those that have survived. The absence of natural caverns in weak rocks such as mudstones means that the study is not relevant to repositories in weak rock.

Quantitative information: Quantitative data on cavern size, volume, depth and age are available.

Uncertainties: Uncertainties in most of the data used are not stated but are generally considered reliable in the current context where they are used comparatively.

Time-scale: The study is relevant to historical (100 – 1000 years); archaeological (1000 – 10 000 years) and geological (Quaternary <2 Ma and >2Ma) time-scales.

PA/safety case applications: None known.

Communication applications: None known.

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Added value comments: Natural cavern analogues offer the opportunity to address frequently asked questions from the general public concerning the stability of underground openings. Their main use, therefore, would be in communication.

Potential follow-up work: The information as presented here is generic. It would be possible to find particular examples of natural caverns that more closely match specific repository concepts. This could be in terms of size, depth, age, country of origin etc.

Keywords: Caves, lava tubes, natural caverns, EDZ stability

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