

Caves and caverns: man-made

Description: Man-made caverns have been constructed for a diverse range of uses. It is convenient to divide them into those designed for short-term access, such as mines, and those designed as long-term structures.

Mines are man-made openings designed for the commercial extraction of minerals. The oldest mines are the Neolithic (2,000 to 4,000 BC) flint mines in the Chalk in England and northern Europe dug to depths of 6 -14 m (Barber & Topping, 1999). Some remain open today. Lead and silver were first mined around 1,500 - 2,000 years BC at the Laurion mines in Greece. Shafts were sunk to a depth of 111 m (Shepherd, 1993). Subsequent improvements in pumping methods and increased mechanisation have led to the sinking of larger and deeper mines. The deepest working mine is now in the Witwatersrand of South Africa (3.5 km deep) and the deepest in Europe is the 1.4 km deep Outokumpu mine in Finland. However, mines are by definition often designed to remain open for only a short period during mineral extraction and are then allowed to close naturally. It could be argued therefore that they are not very good analogues of repository openings with longer design lifetimes even though many have remained open for very long periods.

Other man-made underground openings have been designed for long-term utilisation. Examples of these include tombs, underground cities, road / rail tunnels, hydroelectric schemes, strategic military facilities, underground storage facilities, radioactive waste and astrophysics laboratories etc.

The Egyptians started excavating underground tombs in bedded limestone during the Eighteenth Dynasty (about 1,500 BC). Underground Buddhist temples were excavated into basalt lavas of the Deccan Traps, near Ajanta, India, from the C2nd BC to the C10th AD; at Ellora from the C5th to C10th AD; and at Sittanavasal from the C9th AD. In Cappadocia, Turkey, the underground cities of Kaymakli and Derinkuyu were excavated in a Tertiary rhyolite ash-flow tuff. Derinkuyu has a footprint of ~4 km² and housed 15,000 to 20,000 inhabitants throughout much of the first millennium AD. North of the underground cities at Goreme, churches were excavated into the same rock unit during the C9th to C13th AD. One of the churches has suffered collapse of the cliff face but otherwise the remaining churches are intact. Ten underground villages are inhabited today in Tunisia, 20-40 km south of Gabes. The largest has a population of 6,000. Some of the villages have been occupied for 900 years (Stuckless, 2000; Simmons, 2002). These domestic and religious structures demonstrate long-term stability of man-made caverns measured in hundreds to thousands of years but it should be noted that they are all at relatively shallow depths in unsaturated rock.

In 1995 and 1997 UK Nirex Limited undertook a review of long-term man-made caverns at repository depths below the water table (Geo-Engineering, 1995; 1997). A database of 450 long-term man-made caverns with spans more than 10 m was compiled. It was recognised as preliminary and incomplete. It excluded most mine caverns as these are deliberately designed to be short lived. The frequency of these long-term man-made openings showed a sharp reduction with increasing depth, especially below ~500 m (see Figure 1). However, it also clearly showed that there was precedence for long-term man-made caverns at repository depths (300 - 1,000 m).

The Nirex study also considered whether there was precedence for repository-sized openings at appropriate depths. The span (width), length and height of the openings were all considered, but the most relevant was span. With some obvious exceptions there is a tendency for decreasing span with increasing depth. However, even at a depth of 1,000 m there is precedence for openings with spans of up to ~17 m, which is larger than the dimensions proposed for the vaults in most repository concepts. It should be noted that spans reflect in part the ultimate use of the cavern and not necessarily the maximum span possible. The review of mine openings showed that there was precedence for much larger span openings but these were not necessarily constructed for long-term use. However, all the long-term man-made caverns considered at repository depths were

relatively recent, having been constructed since the 1940s (see Figure 2). Thus, even for these purpose-built long-term facilities direct precedence is limited to 60 years.

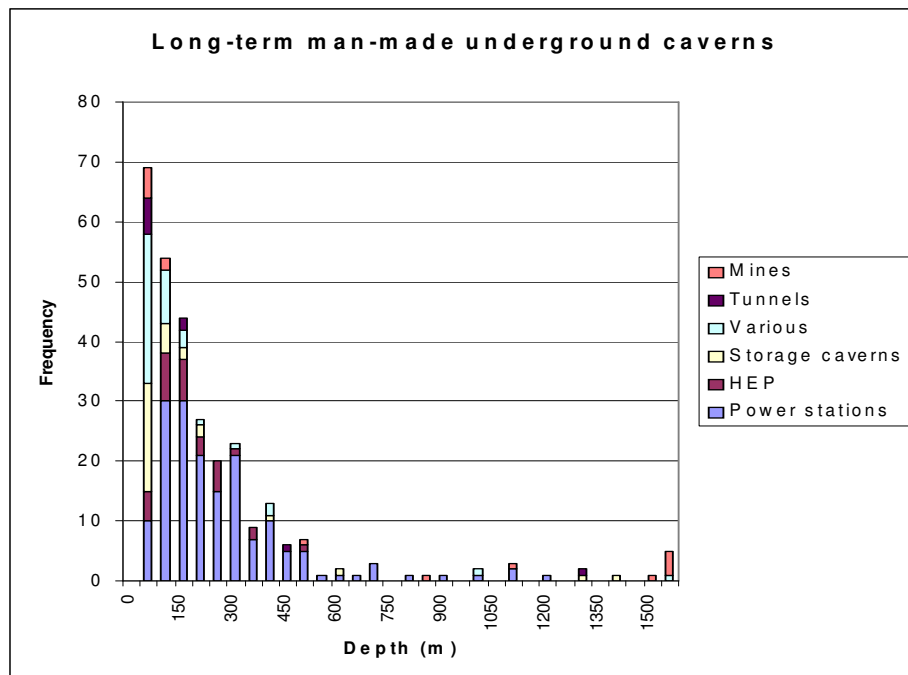


Figure 1. Frequency of long-term, man-made caverns as a function of depth

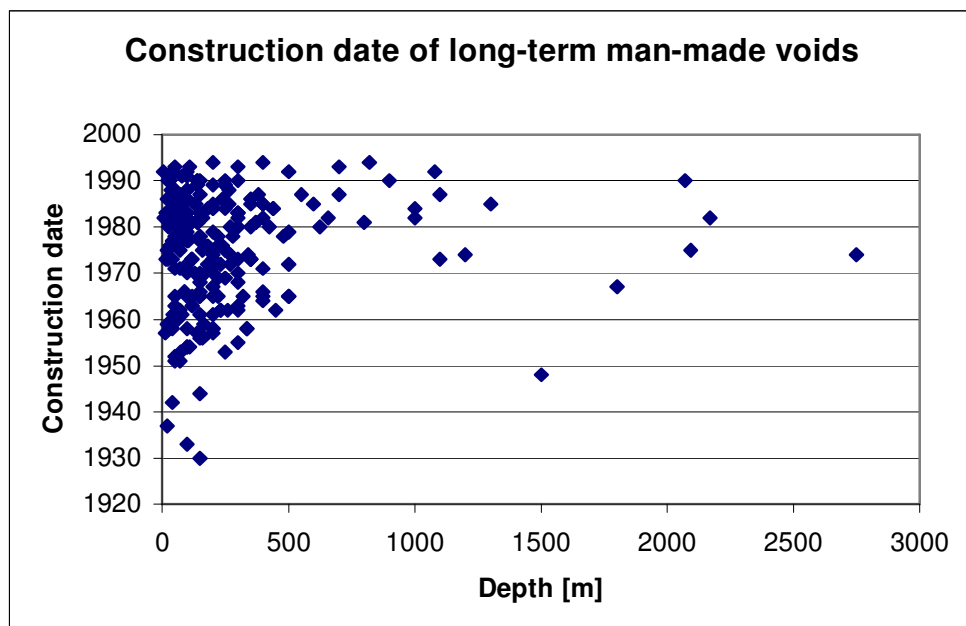


Figure 2. Construction date versus depth.

The Nirex precedence study showed that 90% of human activity in terms of underground construction occurs at less than 500 m depth and this is confirmed by an independent study by JNC of man-made caverns in Japan (JNC, 2000). Repositories constructed below these depths are therefore much less likely to be intercepted by such ‘human intrusion’.

In summary, there is ample evidence for relatively shallow man-made caverns lasting for several thousand years. The examples are all in generally strong rock, mostly limestone, basalt and

volcanic tuffs and constructed above the water table. Construction at greater depths is a relatively recent phenomenon and therefore there is less precedence extending back more than a few decades for deep non-mine caverns.

Relevance: The study of the stability of man-made caverns is relevant to all repository concepts. It demonstrates that there is precedence for construction of repository-scale caverns at depths considered for repositories in a wide range of rock types. 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: Most man-made caverns were constructed during mining activities and not designed for long-term stability. Only in the last 60 years have large underground caverns been constructed with long design lifetimes so that there is relatively little precedence for the long term stability of such caverns. In this context, refer to the parallel study on Natural Caverns.

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

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

Time-scale: The study is relevant to the human (0 – 100 years) and historical (100 – 1,000 years) time-scales.

PA/safety case applications: None known.

Communication applications: None known.

References:

Barber M, Field D and Topping P. 1999. Neolithic Flint Mines in England. English Heritage Publications, 106p.

Geo-Engineering. 1995. UK Nirex – Sellafield repository large underground caverns precedent experience study. Volume 1: Global survey, Summary index of key findings. Nirex Report 802.

Geo-Engineering. 1997. UK Nirex – Sellafield repository large underground caverns precedent experience study. Phase II Cavern excavation engineering assessment Sellafield specific options. Volume I Text. Nirex Report SA/97/019.

JNC. 2000. H12: Project to establish the scientific and technical basis for HLW disposal in Japan: Supporting Report 3. Safety assessment of the geological disposal system. Table A-4, JNC. Japan.

Shepherd R. 1993. Ancient Mining. Elsevier, New York, 494p.

Simmons AM. 2002. Natural analogue synthesis report. USDOE Civilian Radioactive Waste Management & Operating Contractor, Yucca Mountain Site Characterisation Office. Report TFR-NBS-GS-000027 REV00 ICN02.

Stuckless JS. 2000. Archaeological analogues for assessing the long-term performance of mined geological repository for high-level radioactive waste. U.S. Geological Survey, Open-File Report 100-181.

Added value comments: Man-made 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 presented here is generic. It would be possible to find particular examples of man-made caverns that more closely match specific repository concepts in terms of rock type, size, depth etc.

Keywords: Man-made caverns, mines, tunnels, bunkers, EDZ stability

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