SMOO CAVE, SUTHERLAND: ITS MORPHOLOGY AND FORMATION
By Tim Lawson

This article is based on a report on the geomorphological evolution of Smoo Cave and its environs, undertaken for Scottish Natural Heritage, to accompany the recently completed survey of the cave. The interested reader is directed to that report (available on CDROM in the GSG Library) for further details.

Introduction

Smoo Cave is located at the southern end of a narrow inlet of the sea (geo), some 600m long and varying in width from about *45m* to lOOm, called Geoclh Smoo. At normal low tide a beach is exposed in the landward 200m of the geo, and at normal high tide (taken from the upper limit of seaweed debris on this beach) the sea is still some lOOm from the entrance of Smoo Cave. There is anecdotal evidence for the sea reaching the back of Smoo Cave in exceptional tidal and meteorological conditions.Both Smoo Cave and Geodh Smoo have been eroded in the Dumess Limestone Group. Dolomitic limestone of the Sailmhor Formation is overlain by the younger Sangomore Formation, dipping at around 60 from the horizontal towards the south. To the soLah-east, a series of normal faults has resulted in the older False-bedded Quartzite Formation and Lewisian Complex rocks cropping out at the surface. The ~vhole of the area is covered in a mantle of coarse glacial till, composed of large quantities of quartzite and chert!quartz stones with occasional clasts from the Lewisian Gneiss outcrop, all in a brown silty-sand matrix which has probably been derived from the comminution of limestone and other less resistant rock types. The glacial drift is generally thin, except where it occupies depressions in the land surface. It is thick enough, however, to mask many of the karst features one would normally associate with an area of limestone (e.g. limestone pavements and enclosed doline depressions).

The morphology of Smoo Cave

The cave comprises two interconnected chambers and a stream passage approximately 30m long. The main chamber (33m wide and 48m deep) appears to have been excavated alcn2 two lines of weakness (either thrust faults or master joints in ih~ H;r.c92Konc 97 there is no discernible vertical displacement of adjoining beds). Between them, the cave roof reaches its lowest point at about 7m above the floor, but along the lines of weakness the cave roof soars into a number of avens. At three locations these have been illuminated to display extensive speleothem deposition, mainly in the form o flowstones. In the northeast and south-east corners of the main chamber the flowstone has fonned over debris cones deposited beneath the respective avens. In the latter case the flowstone-cemented cone has remained largely intact, and a small stream issues from beneath it. A low crawl under the lowest edge of the feature gives access to a small chamber. The other indurated 97cone has been partly eroded, providing a degraded section through the sediment it comprises. On the eastern side of the cave, near the entrance, a rock pillar supports the roof but across the rest of the main chamber the roof span is unsupported. It remains intact largely because it is composed of a thick bed of massive limestone; weaker beds would have collapsed. The roof in the southern part of the main chamber is punctured by two potholes 97 one large and the other small, separated by a narrow rock bridge- open to the surface.The second chamber (referred to as 91Lake Chamber92 by Jeffreys 1972) is separated from the main chamber by a rock bridge, utilised by the wooden gantry constructed to give visitors a view of this inner part of the cave. Lake Chamber is approximately 25mlong by lOin wide, and flooded to a depth of some *4.5m.* The Alit Smoo cascades into its southernmost end from a sinkhole on the surface. A smaller adjoining pothole to the north-west is located close above the entrance to a stream passage that makes up the third area of the cave, extending towards the south-west. This passage is separated from Lake Chamber by another rock bridge which arches over an extension of the lake occupying the first Sm of passageway, The passage has a largely ovoid cross-section and contains a small stream which issues from an inlet sump pooi at its south-western end. Above the inlet sump, the cave wall rises almost vertically into a narrow aven, which is reported as leading into a small chamber choked at the back with sediment. The aven and end of the passage contain various speleothem formations, mainly flowstones and stalactites.A number of sediment facies in the cave have been described by the author in the report for SNH. Details will not be repeated here except to state that they comprise a series of fluvial sands and gravels that have been reworked by marine action, with various pockets of fine grained sediments indicative of low energy environments. In the north-east part of the main chamber human occupation of the cave has resulted in the build up of a midden of shells, sand layers and silt. Further work is needed to decipher the exact interrelationship of the various sediment facies and their probably ages.

Other pertinent surface features in the Smoo locality

Along the sides of Geodh Smoo are a number of fissures that have been exploited by erosion processes to form small caves. In the vicinity of the old winch two small caves (one little more than a rock shelter) occupy a position elevated above the present cobble beach. The back of the deeper recess is choked with a brown silty mud containing local breakdown deposits. Although the cave is several metres above present normal high tide level, the presence of rounded cobbles incorporated into the deposits of the floor suggest that it was once occupied by the sea. A number of small, embryonic caves are present at sea level along the sides of the geo. There is also evidence of small, high-level cave passages 97 all largely choked with angular sediment 97 truncated on either side of the geo, evidence of former tributary passages leading to what was probably the main cave (and main aquifer) through the limestone in the area now occupied by the geo.On either side of the entrance to Smoo cave, substantial collapse of the sides of the geo has occurred, resulting in debris cones particularly in areas not currently affected by marine erosion. The precarious nature of perched blocks currently located above the slope on the eastern side next to the entrance to Smoo Cave is testimony to the likely continuance of rockfall and slumping processes in the future.To the north-east of the entrance to Smoo Cave a steep grassy slope leads up to a small, low chamber, the interior of which is well decorated with speleothems. This chamber is in line with the east side of the main chamber of the cave and the line of avens contained therein. It appears to have formed along the same line of weakness as these features, and is probably a remnant of a once larger Smoo Cave before roof collapse resulted in the enlargement of the geo and the retreat of the cave entrance towards its present position.The Alit Smoo river drains the north-west slopes of Meall Miheadonach across gneiss bedrock, through Loch Meadaidli, continues across the gneiss and part of the Cambrian quartzite outcrop (both impermeable) before flowing onto the limestone for about lOOm until it is engulfed by the open pothole above Lake Chamber in Smoo Cave. It is likely that, before its waters were captured by the opening up of this pothole, the Alit Smoo would have flowed farther on to the limestone outcrop. It almost certainly would have previously been swallowed up by the other large pothole, and therefore flowed directly into the main chamber of the cave in the past. Indeed, there may have been any number of such stream sinks along the axis of the area now occupied by Geodh Smoo. A series of large shakeholes parallel to Alit Smoo some way upstream of the sinkhole (Jeffreys, 1972) would suggest further cavern development along the same line of weakness. The other notable features in the vicinity of the cave are the numerous erratic boulders of quartzite and gneiss that can be found across the area to the north of Leirinmore, indicating former ice flow across the area from those outcrops to the south. Numerous instances of glacial striae were mapped by officers of the Geological Survey on the gneiss outcrop. A study of those marked on the *1:63* 360 scale geological map of the area has enabled the construction of approximate flow directions of the basal ice of the last ice sheet to cross this area. The distribution of erratic boulders mentioned above is in accordance with such an ice flow. That the ice sheet was relatively thin at the time the striae were cut is shown by the divergence of basal ice around the low hills south of Smoo. This ice sheet would have overtopped all of the higher ground in the immediate area. Recent work has shown that farther south maximum ice thickness around Cranstackie was 580m and around Beinn Spionnaidh was *565m,* the tops of both these mountains protruding above the surface of the last ice sheet (Ballantyne *et al* 1998).

The formation of Smoo Cave

Sea caves usually exhibit on their walls a lower zone where abrasion, hydraulic action and chemical activity have reduced the rock to a smooth surface, often showing distinct undercutting. Above this level, most sea caves are enlarged by mechanical weathering and associated breakdown of the roof and walls which leave angular, roughened surfaces. Smoo Cave nowhere possesses good evidence of the former: the undercutting on the western side of the entrance has most likely been effected by the stream issuing from the cave. There is much evidence that the cave has grown by roof collapse, the debris thus created being removed by a combination of fluvial erosion and marine erosion processes. It is not surprising that evidence of marine erosion within the cave is non-existent as wave energy in such a long geo is very restricted, even during stormy weather. However, there is good evidence that relative sea levels were once higher in this area, and the sea has clearly penetrated right to the back of the cave some time in the recent geological past, as evidenced by the presence of rounded beach clasts and marine microfaunal remains in the sediment examined by Gleed-Owen (1992).Although much of the evidence for past stages in formation is erosional, and therefore missing, it is possible for us to speculate how Smoo Cave has formed. It is likely that much of the present Smoo Cave is of some considerable age, and started life as a cave system created by karstic solutional processes and subsequently widened by subterranean fluvial processes. The presence of long lines of weakness in this area, whether they be thrust faults or major joints, is crucial to the formation of both the cave and the geo. These lines of weakness would have controlled the direction of both subterranean and surface drainage, as continues to the present day, and would also have offered the line of least resistance for marine erosion attacking the coastline to the north. It is likely that marine erosion broke into passages originally created by groundwater drainage through the limestone; that cave system most likely followed the axis of the present geo, and relict tributary cave passages are now visible in the walls of the geo, although they are now choked with sediment. Progressive marine enlargement of the breached cave passages by lateral undercutting would have resulted in a series of roof collapses and the cutting back of the cave entrance, lengthening the geo. To have cut back some 600m in this way would have taken a considerable time, probably several hundred thousand years. It would require relative sea levels to have been higher than they are currently. Such conditions are common features during a deglacial phase, when land surfaces are isostatically depressed from the loading effect of a previously thick ice sheet, yet melting of that ice sheet results in rapid rises in sea level as water melts and flows back to increase the volume of water in the ocean basins. As isostatic rebound is much slower than eustatic rises in sea levels, seas transgress onto coastal land before the land eventually rises back to its former level. As the last two million years of geological history have been characterised by dramatic climatic changes from interglacial conditions to glaciation and back again, there would seem to be many occasions in the recent geological past when a higher sea level relative to the land could have carried out the periodic erosion of the geo at the expense of the subterranean drainage system. Smoo Cave and the southern end of Geodh Smoo are currently experiencing a relatively quiescent period when normal sea levels do not reach the cave entrance. The role of glacial erosion in helping to de-roof the cave at various stages in its formation1 as well as to excavate the debris thus produced, should also not be underestimated.The duration of the last ice sheet is known from the distribution of radiocarbon dates on faunal remains and uranium-series dates on speleothems from caves in Durness Limestone in the Assynt area 50km to the south (Lawson and Atkinson 1995; Atkinson *et al* 1995). The ice sheet started to grow about 26,000 years ago and had melted away by 13,000 years ago. Deposition of glacial till across the surface of the land in the Smoo area by the last ice sheet disrupted pre-glacial drainage routes, particularly those subterranean water courses whose routes became blocked by the glacially-derived clastic sediment. One such drainage route appears to be the one that originally entered the stream passage at the very deepest part of the cave, through the aven above the current inlet sump. Present drainage finds its way into this passage through a lower-level route. The passage through which this stream now flows shows evidence in both its ovoid cross-section and the presence of solutional 91scallops92 on its wall that it originally formed phreatically, and was subsequently modified when local water tables (essentially sea level in this case) fell.

A similar situation may once have existed in the south-eastern corner of the main chamber. The current stream issues from beneath the cemented debris cone that leads up into the aven from which an earlier stream may have emerged. Again, the presence of thick speleothem formations may be blocking a former subterranean stream passage that is now choked with sediment. Subsequent build-up of the debris cone beneath the aven may have accompanied the diversion of drainage to a new lower level, or the initial collapse may have instigated thur 6x~crsion. The early phase in the buildup of debris appears to have progressed over a period of some time, as did the similar deposit nearer the cave entrance on the east side of the cave. This appears to have been followed by a period of wetter, possibly warmer climate during which the deposition of tufaceous flowstone on the upper surface of the debris occurred. In view of the extent of the speleothem deposition, and the paucity of such deposits actively forming today despite the rate of roof drip in parts of the cave, leads one to suggest that this probably pre-dates the last ice sheet in age, and possibly dates from the last interglacial. This can only be determined by sampling the flowstone and dating it directly.

The drainage route of the Alit Smoo seems to have long been dictated by the westernmost line of weakness of the two clearly visible in the cave today. It has been postulated that the Alit Smoo may have formerly entered the cave by way of the 91dry 92 pothole, or even flowed over the former entrance of the cave as a waterfall onto the beach, but progressive enlargement of joints and fissures resulted in the development of successive sinkholes that captured the river and led it underground to run through the cave. The present sinkhole is almost certainly post-glacial in age.

Previous glacial erosion may have aided the process by selective erosion along the line of weakness acting to reduce the thickness of the limestone at certain points, enabling a breakthrough to the cave below more likely, as well as helping to enlarge the geo by de-roofing part of the cave.

At some time in the post-glacial period, possibly coinciding with the Main Postglacial Transgression of around 6,500 years ago, sea water gently swilled around the main cave chamber, largely depositing layers of sand seen today in the small chamber beneath the cemented debris cone at the back of the cave. A layer of sand was also noted during recent archaeological investigation of the midden area, sealing in the lowest occupation level which is thought to be possibly early Mesolithic in age. If a postulated age of 7,000-8,000 years for this occupation level should be shown to be correct, this would lend greater credence to a marine transgression into the cave midway through the post-glacial period. Since that time, the streams running through the cave have re-worked the earlier deposits. Occupation of the cave by more recent human groups has apparently been restricted to the driest part of the main chamber, where the midden mound has accumulated.

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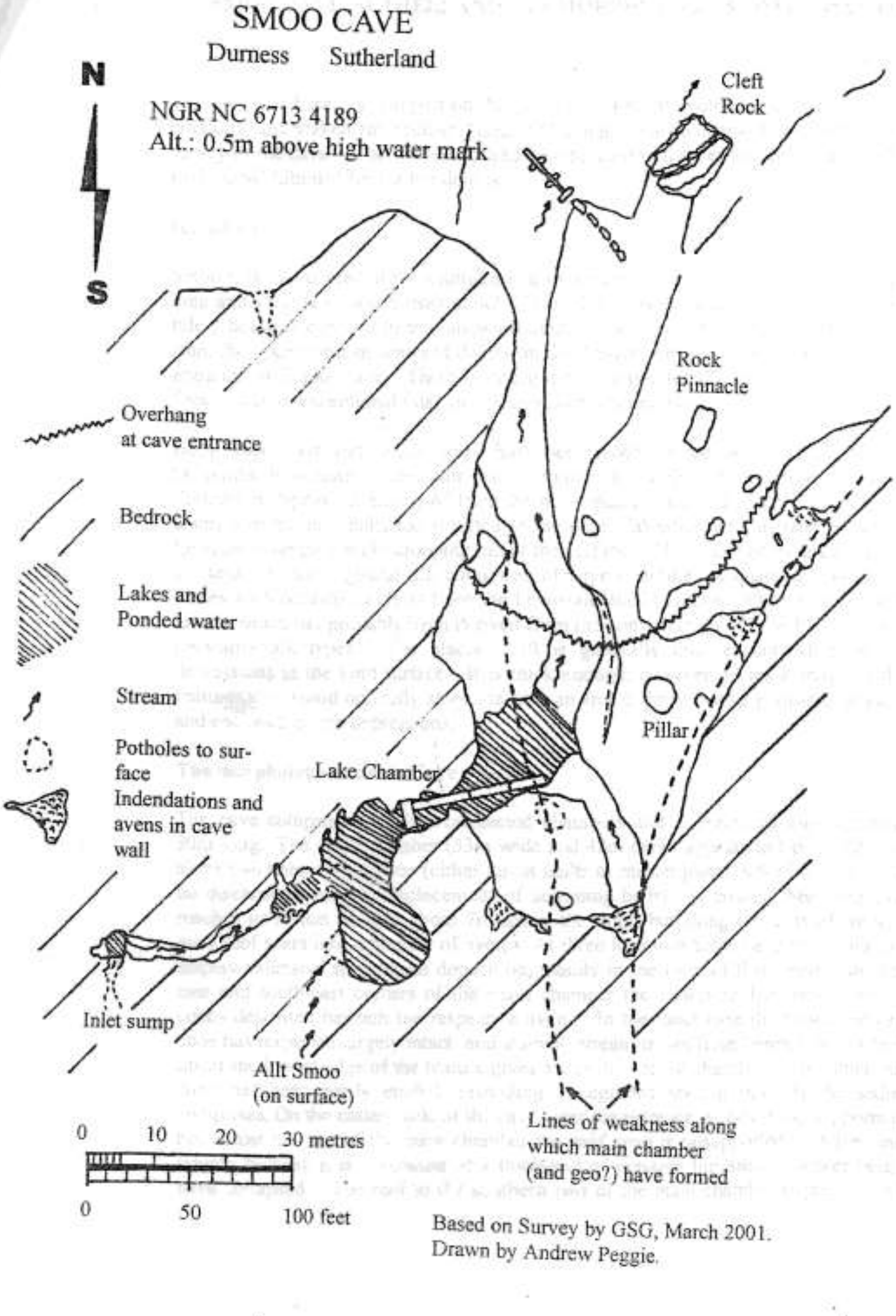
SMOO CAVE
Durness Sutherland
N
S
NGR NC 6713 4189
Alt.: 0.5m above high water mark
Cleft
Rock
Rock
Pinnacle
Overhang
at cave entrance
Bedrock
Lakes and
Ponded water
Stream
Potholes to sur-
face
Indendations and
avens in cave
wall
Lake Chamber
Pillar
Inlet sump
Allt Smoo
(on surface)
Lines of weakness along
which main chamber
(and geo?) have formed
0 10 20 30 metres
0 50 100 feet
Based on Survey by GSG, March 2001.
Drawn by Andrew Peggie.