Sedimentation in a high-latitude karst cave: Sirijordgrotta, Nordland, Norway

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Sirijordgrotta is 1400 m long with a vertical range of 90 m, and is a multistage, looping phreatic system. The cave is situated in the glacially sculptured valley Eiterådalen in Nordland, northern Norway. Four main environments of deposition during ice-covered periods have been recognized; clay deposited subglacially during full ice cover, coarse gravel and alligogenic boulders associated with high-energy emptying of water from the cave, predominantly sandy cut-and-fill facies associated with alternating high-energy water flow, and laminated fine sand and silts during almost stagnant conditions. The last three facies were probably deposited during deglaciation. A coarse gravel fill preserved in a stream-cut canyon is recognized as the oldest post-dated sediment in Sirijordgrotta with a minimum age of 128 ka BP (U-series). This sediment may represent a high-energy environment during the deglaciation of the Saalian ice sheet or an older deglaciation. Laminated clay deposited during glacial damming of the cave contains a paleomagnetic excursion which has been tentatively correlated to the Lake Mungo excursion (28 ka BP). Based on paleomagnetism, we have correlated different sand and silt sections in the cave and proposed a regional correlation to British and Swedish (Torreberga) secular variation curves.

**Introduction**

With few exceptions, glacially sculptured terrains display a polished bedrock surface and are, in consequence, devoid of deposits much older than the last few glacial events. Therefore, owing to their protected nature, cave and fissure fills become important sources for paleoenvironmental information. Deposits in Norwegian karst caves have been dated back to more than 500 ka BP (Lauritzen 1990a, b; Lauritzen et al. 1994); some of them may predate the Quaternary glaciations (Haugane & Gronlie 1988; Lauritzen 1988, 1990a) and have yielded paleoclimatic information from interglacials predating the Eemian (Lauritzen et al. 1990). The preservation of fossils and sediments in caves is unique, as also is the nature of the processes that put these deposits in place. Therefore, reliable environmental interpretation from cave deposits is dependent on a thorough understanding of the underlying processes of transport and deposition.

During their classic descriptions of karst cave morphology of Rana, north Norway, Oxaal (1914) and Horn (1947) identified glaciolfluvial clastics and angular breakdown as the predominant cave sediments. Later, the fine-grained facies of the caves was recognized and investigated in Gronligrotta, a 3-km-long karst cave in Rana (Fig. 1) (Noel & St.Pierre 1984; St.Pierre 1988). Based on the remanent magnetization residing in a laminated clay sequence in this cave, Noel and St.Pierre (1984) correlated the deposit to secular variations of the Holocene (9.6–6.8 ka BP). This was later rejected by Løvlie et al. (1988) on the basis of the deglaciation history of the area and by a better resolved paleomagnetic record which correlated to 9.5–8.9 ka BP on the British secular variation curve of Thompson & Turner (1979). Yet another study of laminates deposited over an altitudal range of 500 m in the Hellemofjord karst caves (Heap 1969; Lauritzen et al. 1991) suggests that deposition took place either between 10.9 and 9.8 ka BP or during several subglacial events (Løvlie et al. 1995). A 13-m-thick sediment section in Norcemgrotta close to Hellemofjord (Fig. 1), has yielded a rich interstadial vertebrate fauna from a diamicton horizon that carries a paleomagnetic excursion (Nese & Lauritzen 1996; Lauritzen et al. 1996). U-series dates suggest that this excursion may conform with the Blake event at 117 ka BP (Smith & Foster 1969).

Laminated clays from marine non-karstic caves have recently attracted attention because such sites are fossiliferous, and alternating sequences of laminates and breakdown strata can be closely matched with ice-contact environments (Larsen & Mangerud 1989; Larsen et al. 1987). Laminated sequences of Skjonghelleren, Olahola and Hamnsundhelleren, marine caves close to Alesund (Fig. 1), have yielded well-resolved paleomagnetic records with excursions which are valuable for further correlation (Larsen et al. 1987; Løvlie & Sandnes 1987; Valen et al. 1995).

Generally, one may surmise that karst cave systems consist of multi-input, interconnected conduits of variable size and extent. When active, the free surface flow in vadose passages transports sediments into phreatic (subwaterable) sections which in turn act as sediment traps. Relict- and often sediment-filled cave galleries did in general convey water and sediments until surface erosion processes disconnected them from the groundwater drainage system. Similarly, cave ‘entrances’, with the exception of those originally from sinks and springs, are the result of erosional intersection between the topo-
graphic surface and underground galleries. Most cave systems display a combination of passage types, depending on their position relative to the watertable and surface of the surrounding landscape.

In formerly glaciated areas, the dominating environmental control is the presence or absence of glacier contact, which has a profound impact on the cave environment (Ford & Williams 1989). During periods of full ice cover, the cave may become a part of the englacial groundwater system. This will generally provide stagnant, or lacustrine-like conditions with large-scale deposition of fine-grained laminates (Schroeder & Ford 1983).

Variations in the englacial hydrological budget may induce cyclic sedimentation. At the same time, cave entrances may experience subglacial injection of till-derived diamictons (Ford & Williams 1989). On the other hand, non-glacial conditions provide vadose stream channel erosion accompanied with coarser deposits. Side galleries within the epiphreatic zone experience backflooding and levee-type deposition. In drained sections, speleothems (cave drips) are precipitated. Closer to the surface, in the so-called entrance zone, annual and diurnal temperature oscillations are significant and produce frost-related breakdown and mass-waste debris. In northern latitudes or alpine environments, such entrance deposits often indicate subaerial, non-glacial conditions.

Sirijordgrotta, a karst cave in the Eiterådalen valley in Nordland, north Norway (Fig. 1), contains a wide variety of clastic sediment fills. The open pit-fall shaft of the cave makes some of the entrance deposits very rich in fossil vertebrate remains (St. Pierre & St. Pierre 1980; Lauritzen 1985). As part of the excavation of the fossiliferous debris from the ‘Elgsjakta’ (Elk shaft) that was initiated in 1985, it was felt that a closer study of the sedimentary history of the entire cave was needed. A deeper understanding of the sedimentary processes that have acted in the past would help correlate the surface environment and the various clastic deposits in this and other caves.

Geologic and geomorphic setting

Eiterådalen is a strike-controlled valley that is developed within a series of N–S oriented, steeply dipping layers of micaeous gneiss, mica schist, diorite, quartz schist and calcareous marble of probable Precambrian or Cambro-Silurian age (Gustavsson 1981). Culminating with the Caledonian overthrusting of the Helgeland Nappe, later deformation and metamorphosis have produced the steeply dipping, sandwiched alternations of soluble marbles and impervious, but often thin, silicate bands that have given rise to the ‘Stripe karst’ setting (Horn 1937). Mapping of the area revealed a complex structure with folds and thinner schist bands that is compatible with the observed hydrology and cave morphology (Fig. 2).

With respect to the late-glacial stages in Nordland (Andersen 1975; Andersen et al. 1981), the cave is situated proximally to the pre-Boreal stage D, 9.5–9.7 14C ka BP, and the Younger Dryas (Tjøtta) stage (B), which runs close to the coastline (Fig. 1). These data suggest that the site was deglaciated shortly after 9.7 14C ka BP.

The cave

Sirijordgrotta is 1400 m long and has a vertical range of 90 m (Faulkner 1980) (Fig. 3). During the present work,
it was felt that the existing survey (Faulkner 1980) was inadequate for exact plotting of sediment location and speleogenetic analysis. The whole cave was therefore resurveyed to BCRA grade 6 B/C (Ellis 1976) (Fig. 3 is a reduced scale). We also felt that Norwegian names are appropriate for a Norwegian cave, and we therefore translated previous names where possible and added new names when translation was difficult. More details of the survey and new names will be published elsewhere together with cave morphology and the speleogenetic history.

Previous discussion of morphology and speleogenesis was done by the original explorers (Faulkner 1980; St. Pierre & St. Pierre 1980). The cave was later recognized as a multistage, looping phreatic system (Lauritzen 1983) of the same basic type as the classic Swildon’s Hole (Ford 1965; Ford & Williams 1989). Lauritzen & St. Pierre (1982) dated a stalagmite overlaying a diamictic sediment in ‘Tåkeheimen’ (Eccles gallery) in the inner parts of the cave to 7.6 ± 0.4 ka BP (U-series). Since then, the main interest has been focused on excavation of an exceptionally rich, fossiliferous talus beneath a 40-m-deep pitfall shaft, ‘Elgsjakta’ (Elk shaft) (Lauritzen et al. 1996) (Fig. 3).

Sediment distribution

For practical reasons, the cave was divided into four different zones based on the sediment distribution. Sediments are concentrated in ‘Tåkeheimen’ (Eccles gallery), in ‘Kvitgangeren’ (White arch) – ‘Elgsjakta’ (Elk shaft) and in ‘Kornettgangeren’ (Arctic passage) (Fig. 3). Sediments elsewhere are sparse, except for a fossil, infilled canyon in Generasjonsgangeren (sect. X, Fig. 3). Field correlation between these sites is difficult because of lateral discontinuity. We have described 25 isolated sediment sections, but only the most significant of them will be presented as examples in this study.

Sediment facies

The sediment facies in Sirjordgrotta vary from clay and silt, deposited in a stagnant water environment, to rounded boulders deposited under very high water velocities. This reflects the enormous range of hydrological regimes encountered in glacially dammed karst caves. We have divided the facies into high-energy facies, including all sediments deposited from streaming water, and stagnating water facies which include sediments deposited in quiet water. The high-energy facies were deposited either along the cave brook during ice-free periods or during elevated stream discharges during glacials and then probably close to the glacier front. Stagnating water environments are either present during glacial damming or in backflooding areas of the cave, such as low-level passages and side galleries.

The sediment facies are summarized and given facies codes in Table 1.

Stagnating water environment

Laminated fines (FI). – This facies consists of laminated fines varying from fine grey clay, with more than 60% clay, to mainly light brown silt. The laminae of clay are usually a few millimeters thick, while some of the silt laminae are up to 30–40 mm thick. Each lamina is generally homogeneous with no grading, but the coarseness changes from lamina to lamina. There is no detectable cyclicity.

The thickest accumulation of clay and silt is found in section V in ‘Kornettgangeren’ (Arctic passage). There are also four 20–30-cm-thick layers of clay in section U situated behind a levee of a fossil brook which runs through ‘Kornettkammeret’ (Cornet chamber). The grain-size distribution from section V is shown in Fig. 4.
Laminated silts are found within the cut-and-fill facies in ‘Kornetgangen’, and below and above the drying crevasses described in ‘Tåkeheimen’ (Eccles gallery).

**Homogeneous silt (F).** – This facies consists of a homogeneous light brown to brown silt, which is found to drape other sediments and bedrock in ‘Tåkeheimen’ (Eccles gallery) and related passages. The surface of the sediment cap is undulating with the depositional surface below. This sediment gets finer laterally to the main passage. Grain-size analyses of the draping sediment from the main passage are presented in Fig. 4.
High energy environment

Laminated to massive sand (Sl/Sm). – This facies consists of laminated sand to sand without structures, and represents short, relatively quiet periods mostly as fill in the cut-and-fill facies (Sc). Where lamination is present it is uncontinuous, strong to weak and with no detectable cyclicity. This facies is described from ‘Tåkeheimen’ (Eccles gallery) and from ‘Kornettgangen’ (Arctic passage).

Cut-and-fill sediments (Sc). – This sediment is a compound facies which consists of silt to gravel, but mainly fine sand with structures ranging from horizontally laminated to large channel cuttings. Typically, different facies are deposited in a complex sequence of channel erosions and fills. In ‘Tåkeheimen’ (Eccles gallery) sediments are mainly horizontally laminated. However, cross-beddings exist in section J at ‘Bandittstupet’ (10 m pitch) (Fig. 3), where they dip downstream, and in section D at the entrance towards ‘Tvillingdammen’ (Twin ducks), where they dip upstream indicating reversed flow. The sediment structures in ‘Kornettgangen’ (Arctic passage) are more varied with parallel accretion, small-scale cross-bedding, horizontal-, horizontally graded-, and horizontal discontinuous stratification. This reflects changes from almost stagnating water to a high flow regime environment in a vadose stream.

Fig. 4C shows granulometric analysis from this facies taken throughout the cave. Eighteen fine-sand samples (Md = 50% between 4 φ and 2 φ) from the cave, and one sample from a glaciofluvial deposit outside the cave, define a narrow envelope shown as a shaded area in Fig. 4C. This envelope cannot reflect one episode since the samples are from different parts of the cave and also from different stratigraphic levels in the same sections.

Table 1. Facies codes used in this manuscript. Modified from Eyles et al. (1983).

<table>
<thead>
<tr>
<th>Facies</th>
<th>Lithofacies</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Allogenic boulders</td>
<td>Rounded to subrounded boulders with lithology different from the cave walls</td>
</tr>
<tr>
<td>Bc</td>
<td>Blocks, cast-supported</td>
<td>Sharp-edged clast-to-clast contact with matrix of sand to pebbles, soil and bones</td>
</tr>
<tr>
<td>Dcm</td>
<td>Diamicton, cast-supported, massive</td>
<td>Matrix of silt to sand. Some voids between clasts</td>
</tr>
<tr>
<td>Dm/De</td>
<td>Diamicton, matrix to clast-supported</td>
<td>Chaotic mixture of grain sizes. Contain clay clasts</td>
</tr>
<tr>
<td>Dcw</td>
<td>Diamicton, cast-supported, weathered</td>
<td>In situ weathering down 1.5 m to bedrock</td>
</tr>
<tr>
<td>Gm</td>
<td>Gravel, homogeneous</td>
<td>No structures</td>
</tr>
<tr>
<td>Gmb/Gcb</td>
<td>Gravel, matrix to clast-supported, massive with boulders</td>
<td>Sandy to gravely matrix. Rounded clasts.</td>
</tr>
<tr>
<td>Sl/Sm</td>
<td>Sand, laminated to homogeneous</td>
<td>Weak to strong lamination when present</td>
</tr>
<tr>
<td>Sc</td>
<td>Mainly sand with cut-and-fill structures</td>
<td>Some fines and gravels. There are different facies within the fill structures</td>
</tr>
<tr>
<td>F</td>
<td>Silt</td>
<td>Homogeneous</td>
</tr>
<tr>
<td>FI</td>
<td>Fines (silt/clay), laminated</td>
<td>Brown silt and grey clay</td>
</tr>
</tbody>
</table>

Fig. 4. Cumulative grain distribution curves. A: Fine sediments from Sirijordgrotta compared with clays from Castleguard cave in Canada (Ford & Williams 1989). B: Fine sediments from Sirijordgrotta compared with sediments from the Papua New Guinea Highlands (PNG) (Gillieson 1986). C: Sand to gravel deposits from Sirijordgrotta. The grey area is a cluster of 18 samples from different localities within the cave and one from a small sand deposit north of Sirijordgrotta (Fig. 2).

Other facies within the cut-and-fill facies, which are found elsewhere, are described separately.

Massive gravel to pebbly gravel (Gm). – This facies consists of homogeneous gravel with no detectable layering. It is found mainly as fill within the cut-and-fill facies (Sc), but is also described separately.

Matrix to clast supported bouldery gravel facies (Gmb/ Gcb). – The grains are subrounded to rounded and supported by a sandy to gravely matrix. The sediment was recognized in the bottom of three excavations, sections O (formation B), R (formation C), and U (formation C) in ‘Kornettgangen’ (Arctic passage) (Fig. 3). Largest grain size decreases downstream, from sections U and R where it is more than 100 cm, to section O where it is 20–30 cm. The boulders in sections R, U and
between these sections in some places exceed the thickness of the sediment, while in section O they are more or less normally graded with the 20–30-cm-large boulders at the base. The boulders are the largest boulders found in Sirijordgrotta and are also described separately as allogenic boulders.

A similar facies was also recognized in an incised canyon in Generasjonsgang (section X).

**Massive clast supported diamicton facies (Dcm).** – This facies is described from formation D of section H in 'Tåkeheimen' (Eccles gallery), and consists of a 4–5-m-thick diamicton. The clasts are edge-rounded to rounded in shape and have a maximum diameter of 60 cm, with a mean maximum of 15–20 cm (mean of ten largest). The matrix consists of unsorted silt to sand, giving rise to a bimodal total grain-size distribution (Fig. 5). The bimodality is probably due to an infilling of some matrix at a later stage. The sediment structure is uncompacted and there are cavities between the larger grains indicating fast deposition. Since this facies is rather extensive and is situated on both sides of the passage, it probably filled most of the 'Tåkeheimen' chamber (Eccles gallery).

**Weathered clast supported diamicton facies (Dcw).** – This facies consists of a saprolithic (strongly weathered) diamicton described from the lower formation of the sections in 'Elgsjakta' (Elk shaft) (formation C in Fig. 6). Some gneissic rocks are easily cut through with a knife. These clasts would not survive transport, suggesting that the weathering is in situ. The diamicton has clasts that are edge-rounded, with maximum diameter smaller than 15 cm (with the exception of two larger boulders, Fig. 6) and a matrix which is unsorted (Fig. 5). The genesis of this facies is uncertain. The saprolithic nature of this sediment, which is totally absent in the Holocene sediment above this diamicton, and the fact that it is weathered in situ down to 1.5 m depth, indicate the possibility that this is a sediment older than the last glaciation. The diamicton has a main fabric direction along the passages towards 'Kvitgangen' (White arch) and 'Elgsjakta' (Elk shaft) (Fig. 6). It is therefore difficult to draw any conclusion on depositional direction based on the fabric.

Analysis of clay mineralogy with X-ray diffractometer did not reveal any enrichment of kaolinite, which might be expected for an old sediment. However, the process of clay mineral formation is not very well studied on terrestrial deposits, and we still cannot exclude the presumed high age of the sediment.

**Allogenic boulder facies (A).** – This facies consists of allogenic boulders (i.e. different from rock types encountered in the cave walls) displaying a wide range of sizes (up to 140-cm-long axis) and found widely spread throughout the cave. Such boulders are transported into the cave from the outside, necessarily through discrete 'entrances'. We have found that the mean size of such clasts decreases downstream from the point of injection (Valen & Lauritzen 1989). A sudden increase in size of allogenic clasts therefore indicates the approximate position of a paleoinlet. We found only two possible inlets for the largest clasts; 'Øvre galleri' (Birch passage) above 'Tåkeheimen' (Eccles gallery), and 'Kornettkammeret' (Cornet chamber) in 'Kornettgangen' (Arctic passage) (unpubl.) (Fig. 3).

**Clast supported block facies (Be).** – This facies is described only in formation A in 'Elgsjakta' (Elk shaft) (Fig. 6), and consists of a clast-supported diamicton with up to 70–80-cm-long blocks (blocks are angular boulders sensu Bates & Jackson 1984). The matrix consists of unsorted pebbles to sand, soil and literally tens of thousands of bone fragments from different animals 14C dated to the Holocene (Lauritzen et al. 1996). Grain-size distribution is shown in Fig. 5.

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**Fig. 5.** Cumulative grain distribution curves of different diamictons and coarse gravels from Sirijordgrotta compared with sliding-bed facies reported elsewhere.
Matrix to clast supported clayey diamicton facies (Dm/De). – In the upper parts of ‘Kornettgangen’ (Arctic passage) there is a matrix to clast-supported clayey diamicton, consisting of a chaotic mixture of clay and silt clasts, sand, gravel and pebbles. The sediment is found in sections W, S and some remnants in section R (Diamicton A, Fig. 7).

Stratigraphy of the cave sediments

The sediment stratigraphy in Sirjordgrotta is complex and it is even difficult to correlate sections that are situated only a few meters apart. Nevertheless, the stratigraphy is described in general, and not for each section.

‘Tåkeheimen’ (Eccles gallery)

Section H has the most complete stratigraphy (Fig. 8), and is therefore used to describe the sediments of ‘Tåkeheimen’ (Eccles gallery) (Fig. 3). Formation D consists of a 4-5-m-thick massive clast-supported diamictic sediment (Dcm). This formation is restricted to the area between the passage leading to ‘Øvre galleri’ (Birch passage) and ‘Bandittstupet’ (10 m pitch).

The sand formation C in ‘Tåkeheimen’ (Eccles gallery) is a cut-and-fill facies consisting of parallel laminated sand and silt, crossbeds and cuttings. The formation is horizontally laminated (Sl) in section H and drapes the underlying formation D. Some of the cavities between the boulders further down in formation D are filled with sand. In section H it ends in a horizon with desiccation cracks, which also exist on top of section D. These are
Section V in Kornettgangen

Legend

- Clay
- Gravel with box de a
- Calcite concretions
- Lamination
- Cross lamination

Fig. 7. Description of sections R, U and V in ‘Kornettgangen’ (Arctic passage). Sections U and R are examples of the complexity of deposition in Sirjordgrotta. Multiple erosion and deposition events, depositions from large boulders to clay and the fact that erosional structures are in scale with the size of the passage, hamper lateral correlation of sediment sequences.

Section U in Kornettgangen

Sample for paleomagnetism

Section H in Tåkeheimen

Fig. 8. Section H from ‘Tåkeheimen’ (Eccles gallery) in Sirjordgrotta. The surface of unit C is interpreted as drying crevasses. The extension of unit D is unknown at this site, but is deposited directly on the bedrock not far away.

probably contemporaneous. There is cross-bedding towards the ‘Tvillingdammen’ (Twin ducks) underneath the desiccation cracks in section D, reflecting a reversed water flow at a specific time.

Above the drying crevasses there are horizontally laminated sand facies (SI), formation B, in section H and F. The composite stratigraphy ends in a maximum 5-cm-thick homogeneous brown silt formation (F), A, which can be traced into the side passages, but is scarce within the main passage. It is not found in section H, but this is presumably due to trampling by cavers. A fine line of silt on the wall at ‘Bandittstupet’ (10 m pitch) corresponds with the spillover point towards ‘Stalaktittgangen’ (Stalactite passage), and organic debris levels, indicating recent water fluctuations, can be seen 2–3 m above the present-day stream.

‘Kvitgangen’ (White arch) – ‘Elgsjakta’ (Elk shaft)

The excavation of ‘Elgsjakta’ (Elk shaft) started at ‘Ulvehallen’ (Elk hall) and sediments were removed up to what is described as section N (Fig. 6). Section M was originally excavated in order to gain access to the oldest part of the scree material, and became later an attempt to link ‘Kvitgangen’ (White arch) with ‘Elgsjakta’.

The sediments in ‘Elgsjakta’ (Elk shaft) are made up of three formations. Formation C is a 2–3-m-thick weathered clast-supported diamicton facies (DCw) which rests directly on bedrock. Contrary to formation A, formation C is apparently devoid of bones. Above formation C, with an erosional boundary, there are two homogeneous sand members (Formation B); B2 consists of medium to
coarse sand and B1 of medium to fine sand. The formation is thickest in section M and wedges out towards ‘Ulvehallen’ (Elk hall) (Fig. 6). The uppermost diamicton formation A consists of a clast-supported block facies (Bc) with soil and large amounts of Holocene bones. The thickness varied from zero, towards ‘Ulvehallen’, to 2.5 m in section M. It is possible to separate two block layers within the diamicton in section M (A1 and A3), with the uppermost block layer as the most discrete.

The excavation in ‘Kvitgangen’ (White arch) did not give any further information about these sediments. Based on the mapping and the sound of digging from one side to the other, however, these passages are most likely connected.

‘Kornettgangen’ (Arctic passage)
The higher part of ‘Kornettgangen’ (Arctic aven) is the only area in which a thick sequence of laminated clay could be found (Fl) (Fig. 7). This sequence of clay may be considered as glacial rhythmites (Schroeder & Ford 1983; Larsen et al. 1987). The amount of very fine laminae (down to some few millimeters thick) indicates deposition over some time. Section V has a 10 cm layer of a clayey silt, formation D, resting on bedrock. Above this formation is C, which is a 25 cm indistinctly laminated clay. Within this formation there are U-series dated calcite concretions (‘Marleiker’, sample 100390-2) (Table 2, Fract. 1), which provide a minimum age of ca. 10.0 ± 1.8 ka BP to the sediment. Above the erosive surface of formation C, there is a homogeneous sand formation, B, which wedges out upwards in the passage (Fig. 7). The top formation, A, consists of 30 cm of a laminated silt.

Section R and U further down the passage (Fig. 7) are representative of the other deposits in ‘Kornettgangen’ (Arctic passage). The lowermost formation, C, consists of a massive, matrix to clast-supported gravel facies (Gmb/Gcb), deposited on bedrock. Above the gravel is a formation, B, consisting of cut-and-fill facies (Sc). Section U shows cuttings which are in the same size range of the passage itself, illustrating the difficulties of lateral correlation. The members within formation B are mainly homogeneous with weak lamination (Sl). However, member B2 in section R contains small-scale cross-bedding towards ‘Ulvehallen’ (Elk hall) (Figs. 3 and 7) and member B3 in section U contains three to four layers of clay representing some kind of repetitive short-term damming. These clay layers are not found in section R or elsewhere. Member B3 in section U also differs with a silt and sand layer containing several calcareous concretions (‘Marleiker’).

‘Generasjonsgangen’
The gallery named ‘Generasjonsgangen’ consists of two passages, one above the other, which occasionally merge into a single passage. A canyon incised from the upper passage is filled with a massive matrix to clast-supported gravel facies (Gmb/Gcb), deposited on bedrock. Above the gravel is a formation, B, consisting of cut-and-fill facies (Sc). Section U shows cuttings which are in the same size range of the passage itself, illustrating the difficulties of lateral correlation. The members within formation B are mainly homogeneous with weak lamination (Sl). However, member B2 in section R contains small-scale cross-bedding towards ‘Ulvehallen’ (Elk hall) (Figs. 3 and 7) and member B3 in section U contains three to four layers of clay representing some kind of repetitive short-term damming. These clay layers are not found in section R or elsewhere. Member B3 in section U also differs with a silt and sand layer containing several calcareous concretions (‘Marleiker’).
Dating and paleomagnetism

Uranium-series dating

Samples of carbonate speleothems or carbonaceous concretions were digested in acid, speleothems in 7M HNO₃, and concretions in progressively stronger acids (0.1M HCl, 1M HCl and 7M HNO₃). The spiked acid extracts were preconcentrated by scavenger precipitation (Fe(OH)₃), then U and Th were separated and purified by ion exchange chromatography and finally electroplated on stainless steel disks and counted for α-particle activity with silicon barrier detectors.

A commercial ²²⁸Th/²³²U spike was used as an internal standard, the activity ratio of which is calculated for each uranium sample of ‘infinite’ age. Raw counts were corrected for background and time elapsed between nuclide separation and counting and processed to final dates, using standard algorithms (Ivanovich & Harmon 1982).

One ‘already broken’ stalagmite collected in 1979 (Faulkner 1980; St.Pierre & St.Pierre 1980) (Fig. 3), was later dated at its broken base, to 7.6 ka BP (Lauritzen & St.Pierre 1982). In order to post-date the sediment fill in ‘Elgsjakta’ (Elk shaft) (vide infra), a large in situ stalagmite resting on the gravel fill at the terminal choke of ‘Kvitgangen’ (White arch) was taken (WA-1, Table 2) (Fig. 6). Similarly, a small, corroded flowstone covering a gravel fill in ‘Generasjonsgangen’, was sampled (110390-1, Table 2) (Fig. 9).

Laminates in caves are generally devoid of fossils or organic material, and they rarely rest on datable material, like flowstone. It is therefore generally difficult to obtain a date for the paleomagnetic record of such sequences, unless they contain calcareous concretions (‘marleiker’). ‘Marleiker’ are common in glaciolacustrine silts, and they are very common in some Norwegian karst caves (Lauritzen 1982). It has been demonstrated that they may form quickly in glaciolacustrine sediments, within a few hundred years (Hillaire-Marcel & Causse 1989). Owing to the large supply of carbonate-saturated pore water in karst caves, we may expect cave concretions also to form rapidly. However, the date of the cement in a concretion will have to be considered a minimum age for the surrounding sediment. Two sites contained concretions that have stratigraphic significance. One concretion (310788-1, Table 2) grew in ‘Kornettkammeret’ (Cornet chamber) (sect. U, Fig. 7), the other (100390-2, Table 2) in the laminated clay in section V in ‘Kornettkjengen’ (Arctic passage) (Fig. 7).

One complication with U-series dating of calcareous concretions is that the calcite cement becomes contaminated with non-authigenic ²³⁰Th from the surfaces of the silt particles. This is seen by the presence of detrital ²³²Th in the sample, which occurs together with ²³⁰Th on the particles. For ²³⁰Th/²³²Th < 20 the contribution from non-authigenic ²³⁰Th becomes large enough to affect the age within the precision attained by alpha particle counting. This renders the age significantly higher than it really is, and the correction is performed by the isochron technique (Schwarcz & Latham 1989). About 100 g crushed concretion was successively leached with stronger acids and analyzed separately. This yields dates with increasing ²³²Th contamination, as can be seen from decreasing ²³⁰Th/²³²Th ratios during each leaching experiment (Fractions 1–3, Table 2).

Only one of these fractions displayed sufficiently high ²³⁰Th/²³²Th to permit correction directly, applying a modelling technique where the initial, detrital ²³⁰Th/²³²Th was set to 1.5, a generally accepted ‘average’ value (Schwarcz 1980). Fraction 1 of Sample 100390-2 (Fig. 7), gave an uncorrected age of 11.5 ± 1.6 ka with a relatively high ²³⁰Th/²³²Th ratio of 11.4 (Table 2). It was therefore possible to apply Schwarcz’s (1980) model to this sample to yield a corrected age of 10.1 ± 1.8 ka BP. Isochron correction is performed by plotting ²³⁰Th/²³²Th against the composition ratios used in isochron plots.
Radiocarbon dates

All dates are AMS 14C dates. Sample preparation (target) was performed at the Laboratory for Radiocarbon Dating in Trondheim, Norway, and the accelerator measurements at the Swedberg Laboratory in Uppsala, Sweden. All of the bones dated were single bones of identified species (Table 4). The radiocarbon dates are commenced growth at about the same time (Lauritzen 1982). The basis of the flowstone (110390-1) above the gravel fill in 'Generasjonsgangen' gave 127.9 ± 0.2 ka BP (Table 2), i.e. the commencement of the last interglacial, isotope substage 5e. Consequently, the gravel fill was laid down during Termination II or earlier.

Paleomagnetism

Most of the sediments in karst caves lack absolute dating possibilities. However, paleomagnetic directions and magnetic characteristics measured in each section can be used as a correlation tool within the cave, and to a certain degree also regionally.

The samples are taken from a selection of layers based on sediment coarseness that is finer than medium sand. Two different methods were used for sampling. In one of the samples from section V we used a 110-mm-diameter core which was hammered down into the sediment. The rest of the cores were cut in place in the section using 40–60-cm-long square trays (6 cm wide and deep). Since the latter method does not involve any pushing on the sediments, this method is the most gentle with the sediments. The cores were resampled with small plastic cubes (2 cm on side) before measurement.

The samples from the retrieved trays were measured on a three-axes SQUID magnetometer (sensitivity 0.02 mAm/m). Noise measurements on an empty sample-holder show a mean of 0.015 mAm/m (milli Ampere per meter). Samples from the cylindrical core were measured on a DIGSPIN magnetometer with a sensitivity between 0.5 and 1.0 mAm/m. Bulk susceptibility of all samples was measured on a Kappabridge KLY 2 susceptibility meter.

‘Tåkeheimen’ (Eccles gallery). – Nine sections in ‘Tåkeheimen’ were sampled for paleomagnetism, but only the results from sections F and H are consistent enough to be correlated. Sections F and H are also the sections consisting of the finest sediment, which is preferable when using paleomagnetism, because the alignment of the grains in the magnetic field is better. The inclination, declination and intensity during demagnetization from sections F and H are presented in Fig. 11. The natural remanent magnetization (NRM) intensity pattern of sections F and H, which is a lithological parameter, is relatively easy to compare. The correlation of intensities indicates that the source of magnetic material is the same for these two sections over time. The paleomagnetic directions deviate somewhat in the two sections. Inclination of NRM is somewhat lower in section F, but there is a good correlation between the two sections in the pattern. Declination in section F changes during demagnetization towards the same values as in section H.

Table 4. 14C-datings from Elgsjakta (Elk shaft). All samples are single fragments.

<table>
<thead>
<tr>
<th>Lab. ref. No.</th>
<th>Species</th>
<th>Sample reference</th>
<th>Age ka BP ± 1σ</th>
<th>δ13C 0/00 rel. PDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-8090</td>
<td>Hare</td>
<td>Bed A4, Elgsjakta</td>
<td>7.255 ± 0.85</td>
<td></td>
</tr>
<tr>
<td>Sir-43-1988</td>
<td>Elk</td>
<td>Bed A1, Elgsjakta</td>
<td>2.370 ± 0.70</td>
<td>-21.9</td>
</tr>
<tr>
<td>Sir-012</td>
<td>Elk</td>
<td>Bed A1, Elgsjakta</td>
<td>3.740 ± 0.70</td>
<td>-21.2</td>
</tr>
<tr>
<td>T-6455</td>
<td>Elk</td>
<td>Bed A1, Elgsjakta</td>
<td>2.370 ± 0.70</td>
<td>-21.9</td>
</tr>
<tr>
<td>Sir-001</td>
<td>Elk</td>
<td>Bed A1, Elgsjakta</td>
<td>1.260 ± 0.60</td>
<td>-19.7</td>
</tr>
</tbody>
</table>

Fig. 10. U-series isochron plots for sample 310788-1 from section U in ‘Kornett­kammeret’ (Cornet chamber) and for sample 100390-2 from section V in ‘Kornettgangen’ (Arctic passage). Plotting the data from Table 3 yields regression lines whose slopes represent uncontaminated 230Th/234U and 234U/238U for the two samples. This converts to the isochron ages discussed in the text.
Mean declination/inclination of NRM in section H is 001/65 ± 4 (±2σ), while the intensity changes from 140 towards 4 mA/m at the top. Susceptibilities in both sections range between 80 and 1180 (10^-6 SI), but are generally around 400 to 600. Median destructive field (MDF) is 26 ± 20 mT in section F (18 samples) and 20 ± 12 mT in section H (24 samples).

'Kornettgangen' (Arctic passage). – Samples for paleomagnetism were obtained from sections P, Q, R, S, T, U, V and W in 'Kornettgangen' (Fig. 3). Sections S and W consist of a matrix to clast-supported clayey diamict with a strong paleomagnetic signal, but with scattered directions.

We have tried to remove a viscous magnetization component that is present in most samples from sections P, Q, T and U. The characteristic remanent directions (ChRM) are based mainly on the 20 mT demagnetization step, but some samples were rejected since they never became stable. Most samples were unstable after the 40–50 mT demagnetization step, which is probably due to movement of magnetic particles during sample treatment, including the rotation in an alternating field demagnetizer. The ChRM and the susceptibility from sections P, Q, T and U are compared in Fig. 12. Samples from section R were rejected because of too much noise during demagnetization.

By first comparing susceptibilities, we made the correlation in Fig. 12. Correlation of susceptibilities indicates that the amount and size of the magnetic grains in the sediment are the same in these sections over time. The mean susceptibility is 94 ± 27 (10^-6 SI) in the lower part of sections P and Q, and in sections T and U. The upper part of section P has an undulating susceptibility changing from 86 to 1406 (Mean: 615 ± 495). In general, the declination in sections P, Q and U is north and the inclination 60 to 70°. Intensities are ca. 100 mA/m, but increase towards 1000 mA/m in the upper part of sections T and Q. The declination in sections P, Q and U is approximately north, while it is somewhat more easterly in section T. However, this could be caused by torsion of the tray during sampling (Valen et al. 1995). The inclinations are undulating between 60 and 80°. Mean declination/inclination of NRM from sections P, Q and U is 355/73 ± 3 (±2σ). MDF is variable with 31 ± 14 mT in section P (22 samples), 22 ± 7 mT in section Q (14 samples), 47 ± 16 mT in section T (11 samples) and 40 ± 16 mT in section U (21 samples).

Based on this correlation, we infer that all the sand and gravel sediments in 'Kornettgangen' (Arctic passage)
were deposited during the same period in a sequence of sedimentation and cuttings. The individual correlation of each parameter between the sections in 'Kornettkammeret' is not good enough, but in total the correlation is reasonably good since four different physical parameters are compared.

The clay section (V) in the higher parts of 'Kornettkammeret' (Arctic passage) have been sampled twice for paleomagnetism. Declination and inclination in these samples differ from each other (Fig. 13); however, the intensity and susceptibility are easily correlated. The tray was cut directly into the section wall and presumably acquired minor disturbances; we have therefore interpreted the difference as a result of disturbances in the core when it was hammered down. Note that the magnetic changes in the core are towards the present-day field (Fig. 13).

The paleomagnetism from this tray shows a major excursion (South and horizontal, Fig. 13) and a mainly easterly direction, which is not found elsewhere in the cave. Demagnetization shows only one component and mean MDF is 58 ± 8 mT on the six samples that were demagnetized below 50% of NRM intensity.

Sediment facies discussion and interpretation

Subglacially deposited clay

Laminated fines (F1) in section V in ‘Kornettkammeret’ (Arctic passage) are situated in an upper level of the passage, which make local ponding highly improbable. Hence, the sediments must have been deposited during a period with a higher regional watertable than at present. The grain-size distribution from section V in ‘Kornettkammeret’ is shown in Fig. 4. Fine sediments like these have been described either as backflooding sediments, in small side galleries or deep recesses of the cave, or as glacial varved sediments resulting from glacial damming (Ford & Williams 1989).

Lateral fining silt

Massive silt (F) which fines laterally to the main passage in ‘Tåkeheimen’ (Eccles gallery) is interpreted as lateral fining from sedimentation in a nearly stagnating water-flow through the main passage. The draping surface is typical of sediments deposited from suspension. Since the sediment is without any structures, the water flow and sediment supply had to be relatively constant. The fine line of silt on the wall at ‘Bandittstupet’ (10 m pitch), which corresponds with the spillover point towards ‘Stalaktittgangen’ (Stalactite passage), indicates that the ponding was local.
Glaciofluvial cut-and-fill sediments

The sediment stratigraphy in the cut-and-fill facies (Sc), with repetitive cuttings, channels and changes in grain sizes (Fig. 7, sections R and U), reflects a constantly changing hydrological environment.

A U-series date within the ‘Generasjonsgangen’ passage (Fig. 3, sect. X) makes this passage, which is situated lower than the Sc facies in ‘Kornettgangen’ (Arctic passage), older than the last glaciation (127.9 ka). Assuming that the water-deposited cut-and-fill sediments in the higher ‘Kornettgangen’ are younger than ‘Generasjonsgangen’, and taking into account the height of these sediments above the present stream level, it should be reasonable to suppose that the water somehow was dammed to raise the groundwater level. The damming had to be rather extensive to produce water-layed sediments at such a high level (Fig. 3 sect. U), and was probably external. Together with the constantly changing hydrological environment, this points towards a glacial damming with deposition of glaciofluvial material.

The clustering of many samples within fine sand (Fig. 4) may be explained in several ways, including sampling bias or coincidence, or that it reflects a real sorting process which was repeated several times. Some of these sediments have been deposited during reversed flow, which indicates ice-covered conditions. The paleomagnetism also supports an age somewhat older than the deglaciation of the area (Andersen et al. 1981).

Flush event gravel

Assuming that the lowermost massive matrix to clast-supported gravel (Gmb/Gcb) in sections O, R and U (Fig. 3) are contemporaneous, the extreme decrease in maximum grain size down the ‘Kornettgangen’ (Arctic passage) passage supports a short high-energy flush event from the paleoinlet in ‘Kornettkammeret’ (Cornet chamber) towards the main passage. Again, the high elevation needs an external, and probably glacial damming, of the cave. The clast sizes, which are the largest in this cave, also point towards a high-energy environment very different from the present stream, probably a deglaciation flush event or a sudden emptying of the water-filled cave.

The sediment in section X in ‘Generasjonsgangen’ has the same lithology as in ‘Kornettgangen’ (Arctic passage), and the clast sizes reflect a high-energy, probably glacial, environment. The dating of a flowstone above the sediment fill (Fig. 9), dates the depositional event to older than 127.9 ka BP.

Infilling diamicton

The top surface of the massive clast-supported diamicctic sediment fill (Dcm) in ‘Tåkeheimen’ (Eccles gallery) has been levelled with the spillover point towards the downstream passage ‘Stalaktittgangen’ (Stalactite passage) (Fig. 3). We have interpreted the sediment to be an infilling facies under high-water discharge, probably
through the paleoinlet in ‘Øvre galleri’ (Birch passage) (Valen & Lauritzen 1989), since we do not find the diamicton further into the cave. Unless the sediment was deposited when this passage was formed, the change from today’s inlet to ‘Øvre galleri’ was in all probability glacially induced.

Old weathered ‘sliding bed’ or till-injected diamicton

Formation A above the weathered, clast-supported diamicton (Dcw) in formation C in ‘Egsjakta’ did not show any signs of weathering, implying an extensive hiatus between these two sediments. Formation A was deposited during the Holocene, and formation C is therefore preferably older than the last glacial stage and weathered during previous ice-free periods. We propose that formation C was either deposited here fluviually before the shaft was opened, or injected as a till down the shaft and that older interglacial/interstadial sediments have been removed.

Diamictons are common in karst caves, and have in several cases been described as ‘sliding beds’ (e.g. Gale 1985; Gillieson 1986; Ford & Williams 1989). The sliding-bed transport regime was first found in pipelines (Newitt et al. 1955). The driving-force for the sediment movement is the pressure gradient through the fluidized sliding bed (Newitt et al. 1955). A sliding-bed sediment in nature was first reported by Sauderson (1977) in esker deposits, which may be understood as a subglacial analogue to sediment-filled cave conduits. Gale (1985) proposed these sediments to be an identifier for fossil phreatic cave sediments. Later, Gillieson (1986) reported sliding-bed facies as the only possible transport mode for diamictons in Papua New Guinea (PNG) caves. Here, the diamicton were apparently transported 3 km into the conduits.

The diamicton in ‘Elgsjakta’ (Elk shaft) could have been transported as a sliding bed from a paleoinlet in ‘Kornettkammeret’ (Cornet chamber) (Fig. 3), through ‘Kornettgangen’ (Arctic passage), to this location. Scallops in ‘Elgsjakta’ (Fig. 6) show evidence of reversed flow at least once.

The granulometric analysis of the weathered diamicton falls between the sliding-bed esker sediments of Sauderson (1977) and sliding-bed cave diamictons reported by Gale (1985) and Gillieson (1986) (Fig. 5). We believe that the observed differences between Sauderson’s, Gillieson’s and our data are due to compound differences in the source material, transport distance and environment. Eskers consist of material which has been transported over quite a distance and is therefore to a certain degree sorted. If the diamicton in ‘Elgsjakta’ (Elk shaft) was originally a till, it has been transported no more than 100 m, and is therefore not surprisingly less sorted than the sliding beds described by Sauderson (1977). Gillieson’s samples from tropical regions (PNG caves) are probably more weathered and therefore contain more clay than elsewhere.

Scree sediment

The clast-supported block facies with Holocene-dated bones (Table 4) is described in formation A in ‘Elgsjakta’ (Elk shaft) (Fig. 6). The blocks were probably frost-weathered from the walls at the top of the shaft, and the shaft functioned as an animal trap.

Slump sediment

The chaotic texture and a fan-like surface of the matrix-to-clast-supported clayey diamicton (Dm/De) indicate a slump sediment. The scattered paleomagnetic directions probably reflect a distortion of the sediment without subsequent remagnetization, which further supports the slump interpretation. The slumping seems to be dependent on the degree of tilting of the floor (Valen & Lauritzen 1989). The slumping has caused faulting and folding of deposits where the cave floor slopes more than ca. 25°.

Regional correlations

Paleomagnetic correlations

In the sections sampled for paleomagnetism, there is only one sequence presumed to have been deposited over a long timespan: the clay sequence in ‘Kornettgangen’ (Arctic passage). The other sequences of sand and gravel are assumed to have been deposited over a relatively short timespan. This short timespan makes regional correlation by the pattern of inclination and declination difficult. In Fig. 14 the mean paleomagnetic directions from sections P, Q and U in ‘Kornettgangen’ and section H from ‘Tåkeheimen’ (Eccles gallery) are plotted together with the British Holocene (Thompson & Turner 1979) and the Swedish Torreberga (Sandgren 1986) secular variation curves. These are converted via pole (CVP) (Noel & Batt 1990) to the site coordinates of Sirijordgrotta (13°10'E/65°33'N).

The mean direction from formation B in section H in ‘Tåkeheimen’ (Eccles gallery) plots at around 5.6 or 9.8 ka BP on the Holocene curve (Fig. 14A, white square), and around 11.5–11.6 ka on the Torreberga curve (Fig. 14B, white square). Based on the paleomagnetic results, lithostratigraphy in section H, evidence of present-day high-water levels and the desiccation cracks below the samples for paleomagnetism (B/C transition), we interpret the upper part of section H to have been deposited as a result of local damming either toward the end of (9.8 ka BP), or long after deglaciation (5.6 ka BP).

The mean direction from sections P, Q and U in ‘Kornettgangen’ (Arctic passage) shows a remanence which is comparable with the Torreberga record at 10.4 ka BP (Fig. 14B, black square). Considering the dates from Andersen (1975) and Andersen et al. (1981) (Fig. 1) of 9.7 ka BP on moraine D distal to Sirijordgrotta, this
could indicate that high-energy flushing reached the cave before final deglaciation. The reversed flow through the cave, indicated by cross-beddings below the dessication crack in section D in ‘Tåkeheimen’ (Eccles gallery), supports this. To get a reversed flow through the cave, the potentiometric watertable needs to be higher than the cave.

The formations C and D of section V in ‘Kornettgangen’ (Arctic passage) have been difficult to correlate with any known secular variation curves from Norway. Two excursions are reported from Skjonghelleren, close to Ålesund (Løvlie & Sandnes 1987) (Fig. 1). The youngest in Skjonghelleren, which is correlated to Lake Mungo, has an inclination from −30° to 30°, and the declination is stable on East–Southeast. However, this is not a recording of the complete excursion, because the signal does not change back to normal. Results from Olahola (Valen et al. 1995) and Hamnsundhelleren (Valen et al. 1996), which are coastal caves close to Skjonghelleren, show quite different patterns in an excursion also correlated to Lake Mungo. The excursion in Olahola has in part a southerly declination and an inclination down to 30° which are comparable with the results from section V in ‘Kornettgangen’ (Arctic passage). The upper part of the older excursion in Skjonghelleren, correlated to Laschamp (42 ka BP) (Levi et al. 1990), has a southerly declination and an inclination pattern varying from horizontal to steep.

The U-series date at 10.5 ka BP from a concretion in section V in ‘Kornettgangen’ (Arctic passage) has to be considered a minimum date, leaving both Laschamp and Lake Mungo as possible correlations. It is not unreasonable that the excursion in ‘Kornettgangen’ (Fig. 13) could be a compressed version of one of the excursions observed on Sunnmøre. From Løvlie & Sandnes (1987) and Valen et al. (1995) it seems that the laminated clays in coastal abrasion caves are deposited within less than 2000 years and during ice build-up. If this is the case also for karst caves, the youngest excursion (Lake Mungo) would be the most reasonable correlation.

Depositional history

The depositional chronology in Fig. 15 is based on lithostratigraphical similarities, paleomagnetic correlations, U-series dates and 14C dates. We also assume that glaciofluvial deposition and changes in flow directions are connected to the changing environment during and close to deglaciation, and preferably the last one when lacking absolute dates.

The 128 ka BP U-series date in ‘Generasjonsgangen’ (Fig. 9) is the oldest absolute dating from Sirijordgrotta, and post-dates the sediments in the canyon. The massive grain- to matrix-supported gravel needed high-energy for transportation, and was presumably deposited during a deglaciation of the area. This event could be the end of the penultimate (Saalian) glaciation or any older event. This sediment is not weathered, unlike the lower diamicton (C) in ‘Elgsjakta’ (Elk shaft) (Fig. 15), but we are uncertain whether this really indicates that the ‘Elgsjakta’ diamicton is older. Since ‘Elgsjakta’ is an entrance zone, it would be more exposed to changing temperatures than ‘Generasjonsgangen’.

Section V in ‘Kornettgangen’ (Arctic passage) is interpreted to have been deposited when the cave was filled with water caused by a damming glacier. A paleomagnetic excursion within this section is tentatively correlated to the Lake Mungo excursion (28 ka BP) (Fig. 15).

We have divided the deglaciation sediments from ‘Tåkeheimen’ (Eccles gallery) and ‘Kornettgangen’ (Arctic passage) into two main environments, the lower one consisting of a coarse gravel/diamicton and allogenic boulder facies associated with high-energy deglacial emptying of water in the cave. This is followed by a cut-and-fill facies associated with alternating flow energy with deposition of laminated fine sand and silts during a period of quiet flow and erosion during periods of high-energy flow. The cross-bedding towards ‘Tvillingdammen’ (Twin ducks), displayed in section D, indicates a subglacial reversed water flow during a certain period. Scallops on the wall of ‘Elgsjakta’ (Elk shaft) also indicate a period of reversed flow (Fig. 6).
The desiccation cracks in sections H and D in 'Tåkeheimen' (Eccles gallery) are evidence for a period when this part of the cave was drained. Laminated sands deposited above these cracks in section H were probably deposited during a flood either at the end of deglaciation (9.8 ka BP) or after (5.6 ka BP) based on paleomagnetism. The upper diamicton (A) in 'Elgsjakta' (Elk shaft) has been $^{14}$C dated to the Holocene.

Owing to the fluvial, erosive nature of the cave environment, exact correlations are difficult to assess. We have to emphasize that the correlation, as shown in Fig. 15, is one of several possible solutions.

Conclusions
1. Probably the oldest sediment in Sirijordgrotta has a minimum date of 127.9 ka BP (U-series), and could represent the deglaciation prior to the Eemian or from an earlier glacial cycle.
2. Laminated clay deposited during glacial damming of the cave comprises an excursion which has been tentatively correlated to the Lake Mungo excursion (28 $^{14}$C ka BP).
3. The 'deglaciation flushing sediments' of the cave were probably deposited around 10.4 $^{14}$C ka BP based on paleomagnetism, and therefore close to, but before actual deglaciation of the cave sometime after 9.7 $^{14}$C ka BP (D-moraine, Fig. 1).
4. We have identified three main associations of sediments deposited during ice cover; (1) deposition of laminated clay during periods of full ice cover, and stagnant environment, (2) deposition of coarse gravels, or diamictons, and allogenic boulders associated with high-energy (catastrophic) floods in the cave, and (3) deposition of predominantly sandy cut-and-fill facies associated with an alternating flow energy. Laminated fine sand and silts were deposited during periods of quiet flow, probably due to a raised watertable within the ice, and erosion was predominant during periods of high-flow energy, probably due to a lowered watertable within the ice.

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References


Haugane, E. 1981: Virveldyrrester og dryppsteinsdateringer i karsthuler. En lvanovich, M.


Lauritzen, S. E. 1982: The paleocurrents and morphology of Pikhåggrottene, Lauritzen, S. E., Haugen, J. E., Gilje-Nilsen, H.


Lauritzen, S. E. 1989: The Sedimentology of Sirijorda Cave, Lauritzen, S. E., Løvlie, R., Moe, O.


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