

# Tracking polar dinosaurs - new finds from the Lower Cretaceous of Svalbard

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A new discovery of ornithopod dinosaur tracks from Svalbard is described. The Lower Cretaceous (Barremian) section at Isfjorden consists of sandstones and interbeds consistent with an alluvial flood plane. The newly discovered tracks are situated on two different horizons stratigraphically below the original horizon found in 1960. Footprint evidence from Festningen and Kvalvågen suggests that during the Early Cretaceous there was a diverse dinosaur fauna on Svalbard and that both theropods and ornithopods were present at the time.

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## Introduction

In 1960, the discovery of ornithopod dinosaur footprints from Svalbard was received as a sensation because they constituted the first indisputable evidence that dinosaurs had inhabited the polar latitudes (Lapparent 1960, 1962). Later, in 1976, tracks of a medium-sized theropod were discovered at a second locality in the same formation at Kvalvågen, eastern Spitsbergen (Edwards et al. 1978). These two records (Fig. 1a), together with a find from Kempendajay, Siberia, were isolated discoveries until the late 1980s and polar environments were not considered of further importance for dinosaur research. However, this has since changed, and in the last 20 years, more than ten arctic areas have yielded both skeletal remains and footprints of dinosaurs, ranging from the Late Jurassic to Late Cretaceous in North America, Siberia and Svalbard (Rich et al. 2002; Fiorillo 2004, 2006), demonstrating that the finds of dinosaurs at polar latitudes were not isolated phenomena.

During the 2001 SVALEX excursion to the Festingen locality at Isfjorden, and later with the SVALSIM group mapping in April 2002 of the Festningen sandstone, Helvetiafjellet Formation (Early Cretaceous, Barremian), several new dinosaur tracks were discovered on the same escarpment as the 13 footprints found in 1960 (see Lapparent 1960, 1962). Based on superficial resemblance, the latter were identified as belonging to *Iguanodon* (Lapparent 1960, 1962; Heintz 1963; Steel et al. 1978) but have since been considered to belong to a different, although

related, ornithopod dinosaur (Sarjeant et al. 1998). Unfortunately all of the tracks discovered in 1960 have since been lost due to erosion by the sea.

The aim of this study is to describe the newly found tracks, their ecology and the importance of such finds at polar latitudes

## Methods

### *In-situ laser scanning*

The tracks were found on the hanging wall of a crevice some 30 cm in width, making observation and mapping difficult. We constructed a simple laser profiler with a horizontal laser line that was projected obliquely onto the bedding plane and tracks. The equipment consisted of a laser with a cylindrical lens and a digital camera with remote control, both mounted on an aluminum frame. The frame was suspended on ropes and could be raised and lowered inside the crevice from the top as far as hidden ice would allow. The frame was hoisted upwards at 2.5cm intervals and the bedding plane and tracks scanned at a horizontal width of 30-40 cm. Because of the limited width, the apparatus had to be moved laterally 14 times to cover the full length of the crevice. Each of the 14 strips was aligned manually using the computer. A total of 3,850 laser profiles were scanned and later converted to 3-D coordinates and triangulated using in-house software. Finally, the resulting polygonal 3D mesh was visualized on a Silicon Graphics workstation. The

result was mixed, with clear images in some areas, while others were blurred or missed because of shadows due to high-amplitude topography. Additional footprints were also identified without laser scanning.

#### *Casting of tracks*

Three tracks were covered with silicone to make moulds in April and May 2002. A problem with the setting time of the silicone was severe while making the first mould in April 2002 when the crew experienced air temperatures down to minus 40 degrees Celsius (with the calculated wind factor). During the second fieldwork in 0 degrees Celsius we had no problems with the silicone.

#### *Geological setting*

The Festningen Sandstone Member (Parker 1967; Dallmann 1999) forms the lowest stratigraphic unit of the Helvetiafjellet Formation (Barremian - Aptian) with type locality at the vertical sandstone cliffs on Festningsodden (festning = fortress, odden = spike of land). The Helvetiafjellet Formation represents a wide range of depositional environments and occurs over much of Spitsbergen. It was deposited following a significant regional fall in relative sea level that exposed the shelf deposits of the Janusfjellet Sub-group (Dypvik 1985). At this time, strong tides were active

along the coasts. Inland, relief was low, with areas of relative stability at the fringes of rivers and streams, where levees and bars provided ideal sites for the growth of large plants including trees. Elsewhere, changing conditions along the coastal plain inhibited plant growth and large tidal flats were bare, save for vegetation along the sides of narrow channels (Nemec 1992). It is estimated that Spitsbergen was located at about 65° N at the time the sediments of the Helvetiafjellet Formation were being deposited, and that there was some connection to Greenland to the south (Fig. 1).

#### *The Festningen locality*

The Festningen profile is known for its almost vertically inclined strata where a nearly continuous succession of sediments from Permian into Cretaceous are exposed along 5 km of beach cliffs facing north at the mouth of Isfjorden. Due to the vertical orientation of the strata, only a 5 – 10 m wide section of the strata can be seen at any stratigraphic level. The Helvetiafjellet Formation is exposed at the eastern limit of the profile, facing east into Grønfjorden. At the type locality, the Festningen Sandstone Member is composed of two channel sandstone bodies, separated by a fluvial erosion surface and fine grained heterolithic sediments (Fig. 2). Immediately above the Festningen Sandstone Member, two separate horizons of dinosaur tracks are contained within a 3 m silt- and sandstone unit (Fig. 2, ~20m). Above this strati-

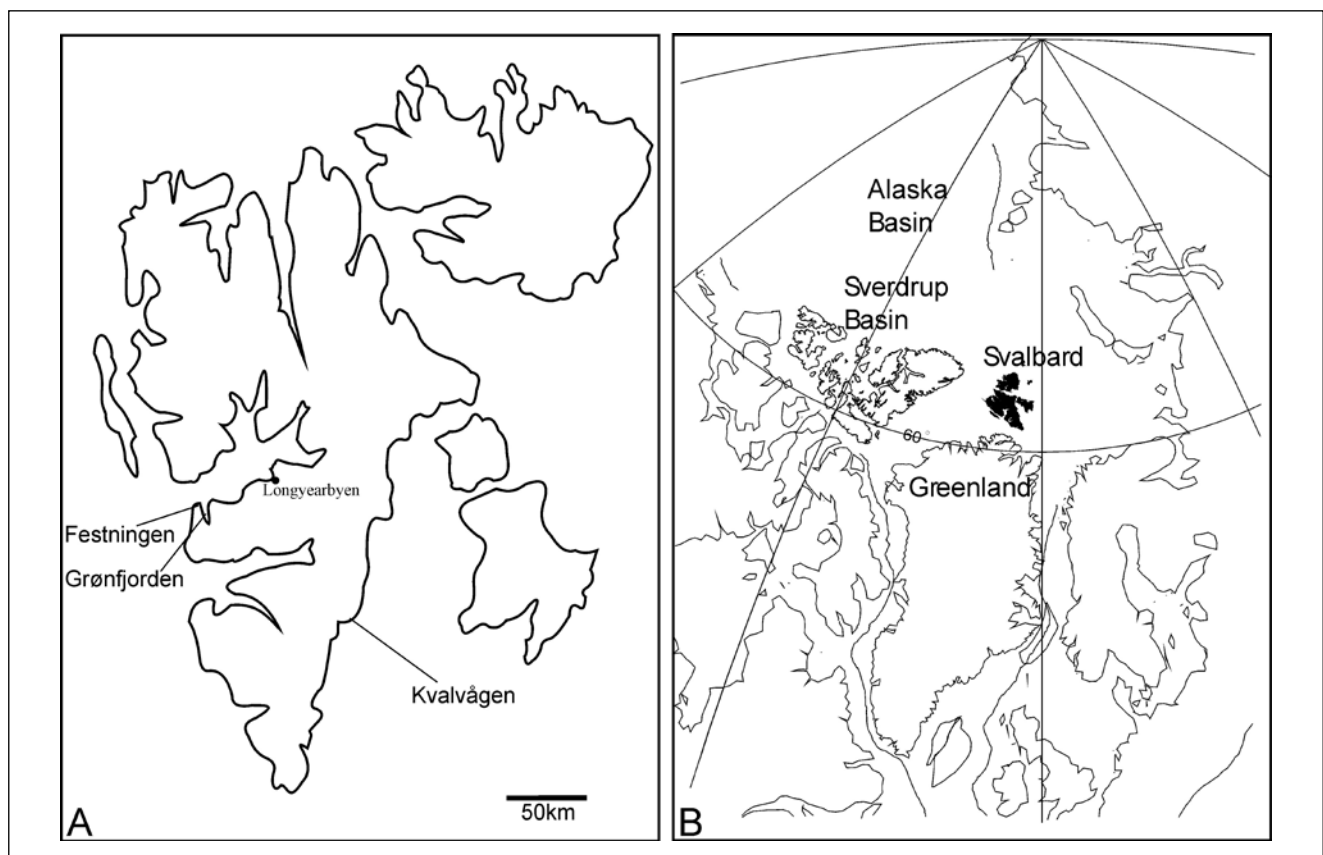


Fig 1. :A. Map of Svalbard showing the two Early Cretaceous tracksites. 1. Ornithopod tracks (Lapparent 1960). 2. Theropod tracks (Edwards et al. 1978). B. Svalbard at 125 Ma. Before the opening of the Atlantic, Svalbard was located north of Greenland, with a probable connection to large landmasses to the south. From Torsvik et al. (2001).

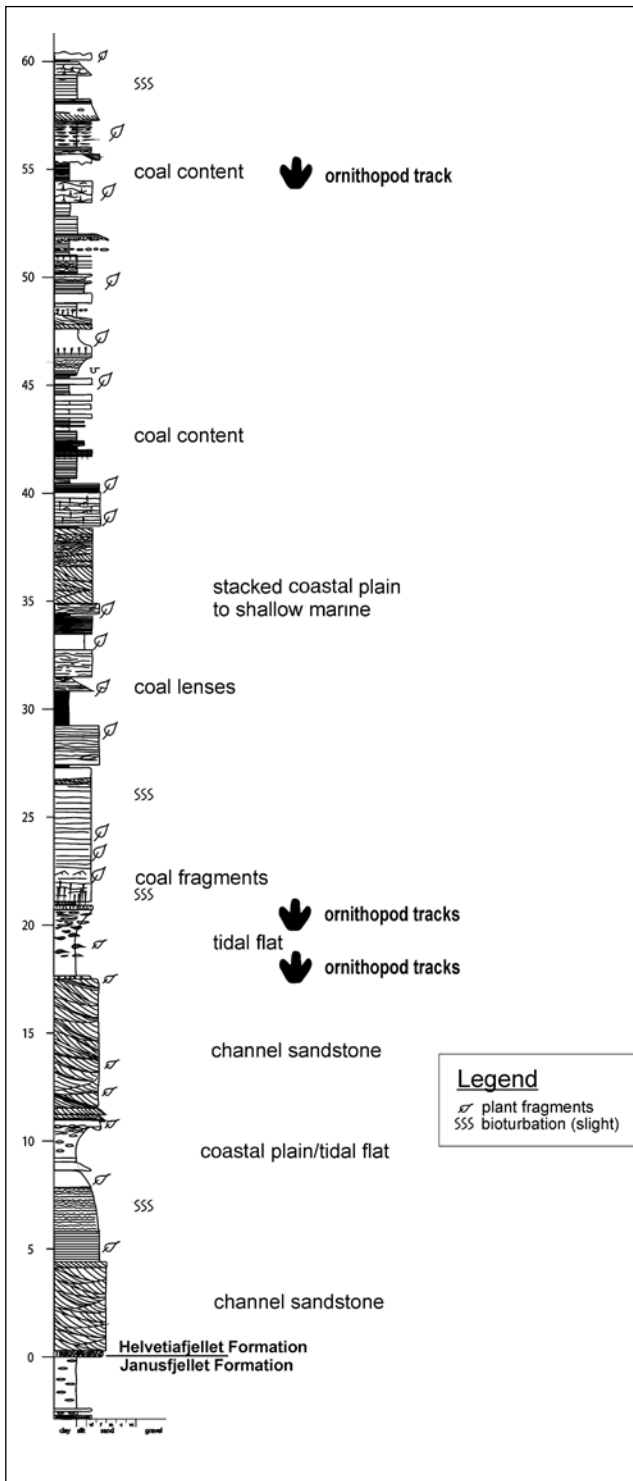


Fig 2. Sedimentological log of the Helvetiafjellet Formation at Festningen, showing the stratigraphic position of the dinosaur tracks (modified from Midtkandal 2002).

graphic level, nearly 100 m of heterolithic coastal and shallow marine sediments are stacked, forming the middle and upper Helvetiafjellet Formation at Festningen. A single dinosaur footprint is recorded in the upper Helvetiafjellet Formation at Festningen (Fig. 2, 55 m). The crevice containing the tracks is the result of selective erosion by the sea of a coal rich mudstone bed interbedded between the sandstone beds.

## Results

The results from the in-situ laser scanning (Fig. 3) showed at least five ornithopod tracks in the crevice. Several other tracks were seen in the crevice outside the scanned area and in two other stratigraphic levels at the locality (Fig. 2). All the tracks are from ornithopod dinosaurs, measured around 60 cm in length and are of equal width, with impressions of relatively short blunt digits (Fig. 4).

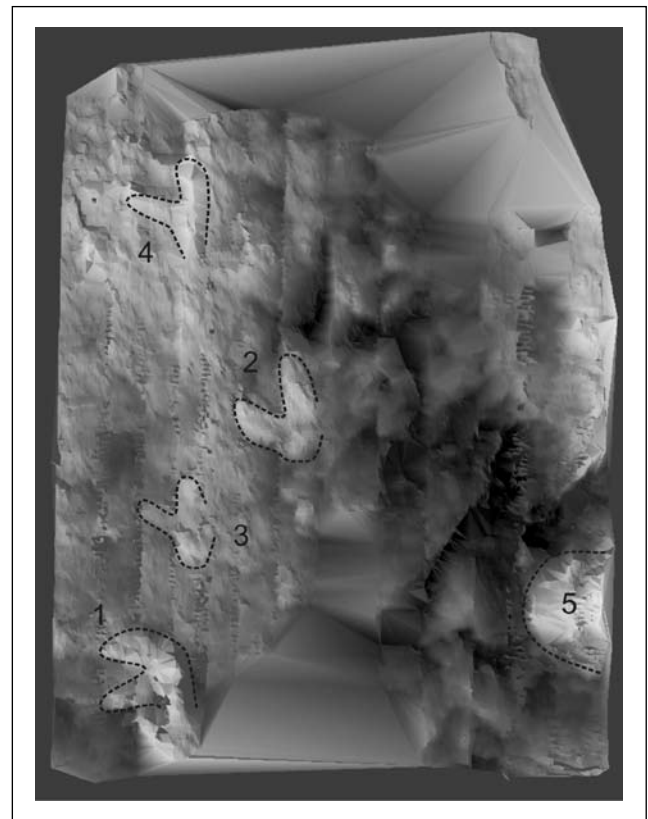


Fig. 3. Digital model of the tracks in the crevasse at Festningen. Computer reconstruction of part of the dinosaur trackway site at Festningen, Svalbard, based on laser scanning in 2002. The vertical surface covered, seen from the fissure side, is approx. 3x3.5 m. Higher relief is given brighter shade. Flat areas represent missing data and openings in the wall. Features seen in the scan include an almost complete footprint pointing to the lower left (1), an almost complete footprint pointing upwards (2) it is the footprint cast and pictured in figure 4 and 5b, a smaller, less clear footprint pointing upwards (3), an unclear footprint possibly pointing upwards (4), and a large, blurred footprint with unclear orientation (5). Several other footprints are blurred or distorted, and a number of footprints were also observed outside the scanned area.

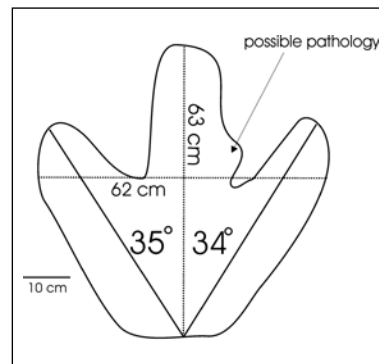


Fig. 4. Schematic drawing of footprint with measurements. Drawn from a cast of the best preserved track in the crevice PMO 210.570. PMO - Paleontological Museum Oslo. The orientation of the footprint is shown as the number 2 in figure 3a and a cast is figured in 5b.

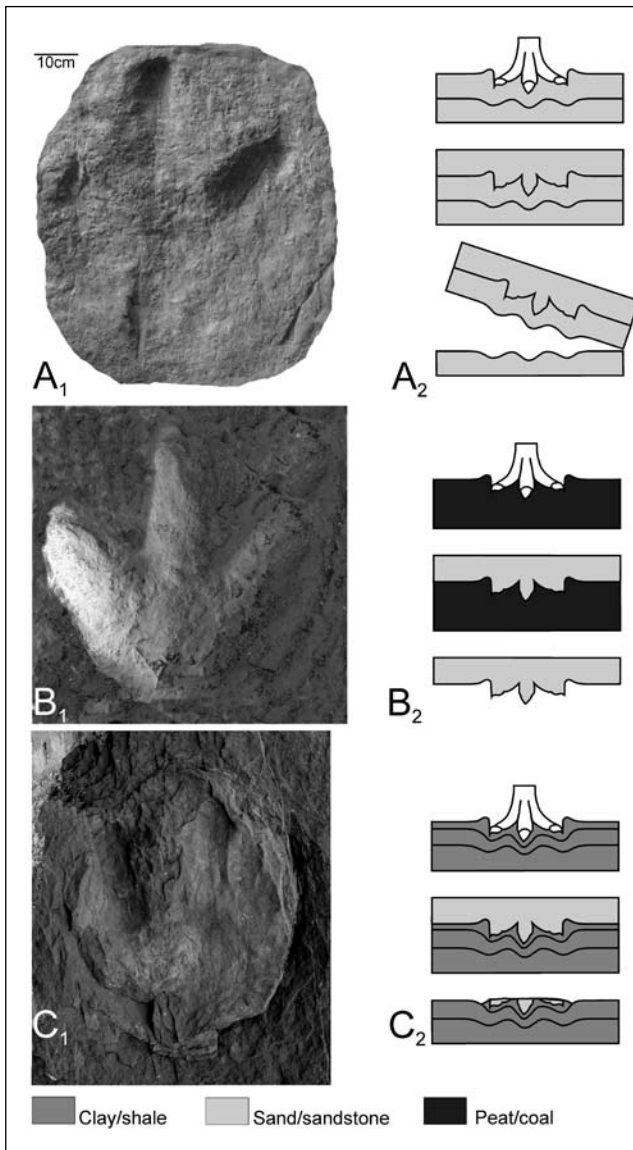


Fig 5. A<sub>1</sub>. The first tracks described from Festningen, which are now lost to erosion, were preserved as shallow imprints in the sandstone beds. Photograph of a cast of one of the best tracks, PMO X621. A<sub>2</sub>, schematic series of possible formation of the tracks. Upper illustration: the track is imprinted in sandstone layers separated by thin mud layers. The weight of the animal causes the formation of undertracks in the layers subjacent to the foot. Middle illustration: the track is covered by other sediment and is lithified. Lower illustration: present day erosion of the cliffs has exposed the horizon with the shallow-relief undertrack. B<sub>1</sub>. Tracks in the crevice are found as natural casts on the underside of a sandstone bed, due to erosion of the coal seam. Photograph of cast PMO 210.570. B<sub>2</sub>, schematic series of possible formation of the tracks. Upper illustration: the track is emplaced in an organic-rich swamp. Middle illustration: after removal of the foot, the track is covered by sand. Lower illustration: present day erosion has removed the softer coal seams and exposed the natural sandstone casts of the tracks. C<sub>1</sub>. Photograph of original track preserved as isolated sandstone casts in organic rich shale. C<sub>2</sub>, interpretative schematic series explaining the unusual type of preservation. Upper illustration: the track is imprinted in soft, layered organic-rich clay. Undertracks are formed along several subjacent horizons. Middle illustration: subsequently to lifting of the foot, the tracks become filled with sand. Lower illustration: present day erosion level has exposed the track as an isolated sandstone cast. The clay layers around the sandstone cast seem to form a bowl shaped structure below the sandstone cast. This is due to differentiated erosion of the clay layers the track was emplaced in.

## Description of the tracks

The tracks at the Festningen locality are found in three distinct preservational types:

1. preserved as concave low-relief impressions in sandstones (concave epirelief) (Fig. 5a).
2. preserved as natural sandstone-casts in the eroded coal bed (convex hyporelief) (Fig. 5b).
3. preserved as isolated sandstone casts in organic rich shales (full relief) (Fig. 5c).

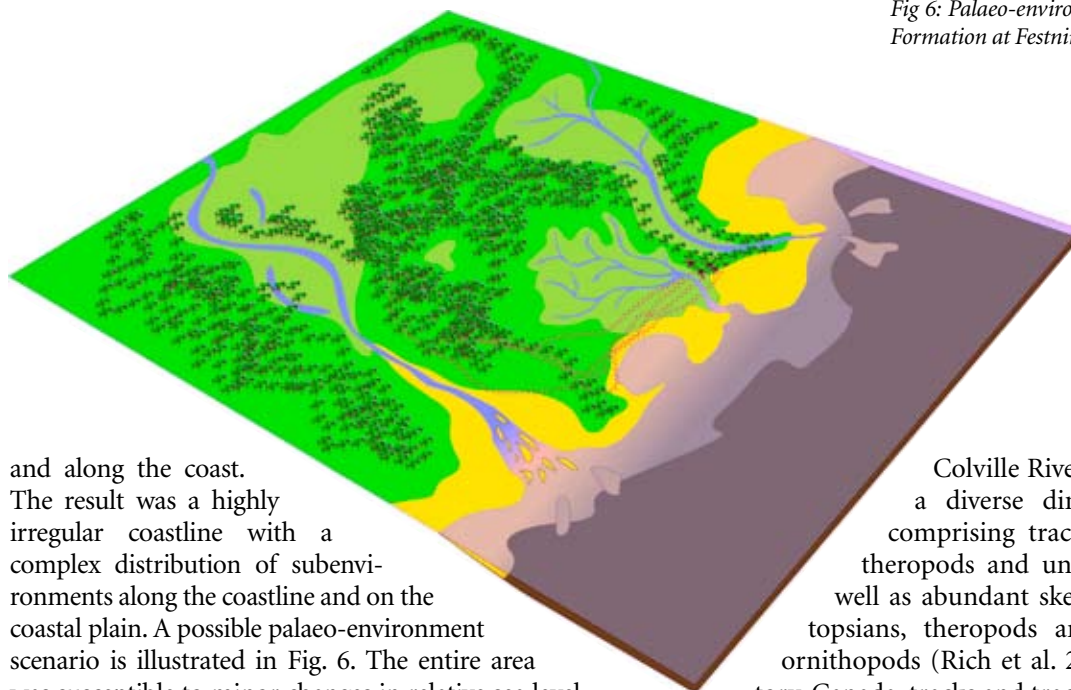
In type 1, the tracks are rounded in appearance and only the gross overall shape is preserved (Fig. 5a). This morphology can either be the result of a true track exposed to erosion, or that the exposed track is an undertrack originally formed along a subjacent horizon, due to the pressure of the dinosaur's foot being transferred down into the subjacent layers (Lockley 1991). Experiments using artificial substrates show how the shape of a tridactyl track can change from being well defined with sharply defined digit impressions, to rounded, shallow-relief depressions as undertracks along successive subjacent horizons (Manning 2004; Milàn & Bromley 2006).

In type 2 (Fig. 5b), the tracks are thought to have been formed when the dinosaur walked in soft organic rich swamp mud that was subsequently flooded and the tracks were infilled by sand. Later erosion of what subsequently became a coal-seam left the sand infillings as natural casts (Lockley 1991) on the underside of the overlying sandstone bed. This situation is very common and numerous such dinosaur tracks have been exposed during coal mining (eg. Peterson 1924; Parker & Balsley 1989; Parker & Rowley 1989; Milàn & Gierlinski 2004). This is the most common track type in the locality, and all the scanned tracks are of this kind of preservation. The exposed part of the sandstone contains at least nine single tracks and several distorted multiple tracks. They are all of similar size (length: 63 cm and width 62 cm.). A tennisball-sized outgrowth on the side of the middle toe is present in at least two of the tracks. This is probably a pathological phenomenon (see Fig. 4).

In type 3, the isolated sandstone casts in organic rich shale are preserved as a combination of both under-track formation and erosion (Fig. 5c). First, the tracks were emplaced in soft layered mud and, depending on the weight of the animal, could extend into underlying beds. Subsequent infilling by sand shows this extension and how the sides of the former mud layer are dragged downwards into the undertracks.

## Interpretation of the palaeo-environment

The lower portion of the Helvetiafjellet Formation at Festningen and in other areas is interpreted to represent a low relief coastal plain to shallow marine environment (Steel et al. 1978; Midtkandal 2002). A high influx of sediment from the hinterland was reworked by tides and redistributed at



and along the coast. The result was a highly irregular coastline with a complex distribution of subenvironments along the coastline and on the coastal plain. A possible palaeo-environment scenario is illustrated in Fig. 6. The entire area was susceptible to minor changes in relative sea level, which could relatively quickly submerge or dry out large swaths of land. Anomalous events such as floods or storm surges deposited sand sheets in places where sediment otherwise would not reach. Areas left undisturbed for longer periods of time would have the potential to sustain a significant vegetation cover. All the dinosaur tracks at the locality are preserved in the sandstones and interbedded coal-rich mudstone beds. The interbedded coal-rich mudstone beds and the upward thickening sandstone beds seen at Festningen reflect a subaerial environment with sediment input occurring in pulses between relatively long periods of time in which peat accumulation is favorable.

## Discussion

The dinosaurian ichnofauna from Svalbard bears evidence of the presence of medium sized theropods with a foot length around 30 cm, and larger ornithopods with a foot length in excess of 60 cm. The new findings show that the presence of dinosaur tracks is not limited to a single stratigraphic horizon in the Festningen area. The distribution of the ornithopod tracks of equal size found in the crevice (Fig. 3 and 4) suggests either a herd of similar sized animals or repeated trampling from the same individual, maybe during browsing for food.

Dinosaur tracks in modern polar regions are only known from a few localities on the northern hemisphere. In addition to the Cretaceous tracks from Svalbard, so far, five Cretaceous and one Jurassic tracksite are known from Alaska (Fiorillo 2006). The Late Jurassic tracks were found in the Black Lake area of the western Alaska Peninsula, and consist of a hitherto undescribed slab of rock containing several tracks from a medium sized theropod (Fiorillo 2006). The Upper Cretaceous deposits in

Fig 6: Palaeo-environment of the Helvetiafjellet Formation at Festningen.

Colville River, Alaska, have yielded a diverse dinosaurian ichnofauna comprising tracks from ornithopods, theropods and unspecified tetrapods as well as abundant skeletal material of ceratopsians, theropods and several genera of ornithopods (Rich et al. 2002). In Yukon Territory, Canada, tracks and trackways of ornithopods, theropods and unspecified tracks from quadrupedal dinosaurs have been reported (Weishampel 1992; Rich et al. 1997; Rich et al. 2002). This shows that a diverse dinosaur fauna inhabited the northern hemisphere during the Late Mesozoic.

So far no dinosaur footprints has been reported from within the modern polar latitudes of the southern hemisphere, but skeletal remains of theropods, sauropods and thyreophoreans have been found in New Zealand (Molnar & Wiffen 1994), and skeletal remains of theropods, ornithopods and thyreophoreans are known from Antarctica and southern Australia (Rich et al. 2002).

Dinosaur remains are now known from more than ten Arctic areas in North America, Siberia and Svalbard in sediments of Late Jurassic to Late Cretaceous age. At this time the area was landlocked around the North Pole except for the strait between Alaska and the northeastern parts of Asia (Allen et al. 1993; Briggs 1995), and oceanographic conditions may have resembled those of the present Antarctic Sea. Polar currents circulating around a polar ice cap would have lowered the sea temperature and the adjoining areas, with the interiors of the northern continents experiencing severe winters. If this is the case, then the dinosaurs of the Alaskan Peninsula, northern Canada, Siberia and Svalbard would have to cope with snow.

Lockley (1991) suggested that in North America some dinosaur species could make long distance migration down the shores of interior seaways as the arctic caribou do today. This idea he supported by finds of numerous north-south heading shoreparallel trackways along the palaeocoast deposits of the interior seaway together with records of the same dinosaur species found at both ends of the hypothetical migration paths (Dodson 1997). Fiorillo & Gangloff (2001) found these statements unlikely on the basis of growth studies of hadrosaurs and migration patterns and growth studies

on extant caribou. They concluded that dinosaurs probably remained year-round in the Arctic in the Late Cretaceous.

Protection against the cold is a problem that theropod dinosaurs solved by developing down and feathers (Norell & Xing 2005 and references therein), but so far no ornithopods have been found with feathers. However, featherlike structures are known from other ornithischians, as bristle like integumentary structures have been found on the tail of a Psittacosaurus, a small horned dinosaur (Mayr et al. 2002). This is of interest since both theropods and ornithopods inhabited Svalbard in the Early Cretaceous. Small dinosaurs may have been able to hibernate but this is unlikely for large ornithopod genera. Unfortunately no skeletal remains of dinosaurs are known from Svalbard, which has an important position midway between North America and Siberia.

## Conclusion

The newly found ornithopod tracks from Festningen, Svalbard, demonstrate that previous finds of dinosaur footprints from the area were not isolated phenomena, and that dinosaur tracks occur at several stratigraphical levels within the Formation, proving a spatial presence of dinosaurs in the area. In the early part of the Early Cretaceous a “greater Wealden” dinosaur fauna (Holz et al. 2004) lived throughout most of Laurasia. It consisted of iguanodontians, basal euornithopods, nodosaurid ankylosaurians, brachiosaurids and various theropods. Together with the other finds of dinosaurs from areas that were located in polar latitudes in the Mesozoic, the tracks from Svalbard represent important information about the distribution and composition of the “greater Wealden” polar dinosaur faunas.

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