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SERIE C NR 785 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 75 NR 6

KARNA LIDMAR-BERGSTRÖM

PRE-QUATERNARY GEOMORPHOLOGICAL EVOLUTION IN SOUTHERN FENNOSCANDIA

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ABSTRACT

Lidmar-Bergström, Karna, 1981-11-16: Pre-Quaternary geomorphological evolution in southern Fennoscandia. Sveriges geologiska undersökning, Ser. C, No. 785, pp. 1—202. Uppsala.

Studies of south Swedish bedrock morphology are few, with the result that the morphology has been poorly known and understood. The southwest margin of the south Småland peneplain was supposed to be capable of giving some clues to various geomorphological features. The margin was therefore selected as the site for a rectangular study area.

The following conclusions have been drawn. The existence of locally derived residual flints, a characteristic uneven morphology with small bedrock knolls and large boulders regarded as core stones from a former kaolinitic saprolite, and small remnants of supposed kaolin provide evidence for interpreting much of the study area as an exhumed sub-Cretaceous erosion surface. However, the higher parts are interpreted as having been cut by a Tertiary erosion surface tentatively dated to the Oligocene and later affected by tectonic movements.

A larger part of southern Fennoscandia is considered in the second part of the thesis. Two sets of erosion surfaces are recognized in southern Sweden. These are the exhumed sub-Cambrian, sub-Jurassic, and sub-Upper Cretaceous surfaces on the one hand, and surfaces moulded mainly during the Tertiary on the other. The latter surfaces form steps with the oldest at about 300 m above sea level, and the youngest at about 75 m below sea level. On the west coast and in northeast Skåne areas with sub-Cretaceous relief occur below 125 m and coincide in part with areas with Neogene relief.

Flat erosion surfaces arranged in a stepped sequence occur throughout North and Central Europe. The climate was tropical to subtropical from Devonian to Late Tertiary times. The erosion surfaces in south Sweden are interpreted in relation to the theory by Melhorn & Edgar (1976) and results of modern research on the development of plain surfaces in the tropics. A model is presented for the pre-Quaternary geomorphological evolution of southern Sweden.

The geomorphology described in this paper is known as historical or evolutionary geomorphology.

INTRODUCTION

On the ancient shields of Precambrian igneous and metamorphic rocks there are large areas where peneplains, in the sense of almost level plains, have evolved. In Sweden, southern Småland is situated on such a peneplain, with a relative relief for the most part of less than 20 m (Rudberg 1970a). This paper describes and discusses the southwestern marginal zone of this peneplain together with adjacent areas in southern Fennoscandia.

Rudberg (1954) summarized the available knowledge relevant for a discussion of bedrock morphology in Sweden and presented a general picture of the gross morphology. From his compilation it is obvious that there is a general lack of detailed investigations of pre-Quaternary morphology. Since the studies by Rudberg (1954) in northern Sweden and Mattsson (1962) in southern Sweden, almost no investigations of this kind have been made.

The prevailing opinion regarding the area concerned here is summarized by Rudberg (1970a) as follows: The southSmåland peneplain ''may be said to be of Mesozoic age, with reservation for later development. In southeastern Småland this peneplain forms a facet, truncating the tilted sub-Cambrian peneplain; in the far south it has most probably been partly covered by Cretaceous sediments. In the west it is dissected by valley systems, starting from the coastal plain of Halland. A less marked dissection can be observed in northeastern Skåne. This latter region has been interpreted as regenerated relief from late Cretaceous. The hypothesis has here been extended to embrace a wider boundary zone, both in south and in southwest.''

I. STUDY AREA

GEOMORPHOLOGICAL PROBLEMS AND CHOICE OF STUDY AREA

It is obvious from the maps published by Rudberg (1954 and 1970a) that there are areas that can be regarded as geomorphological key areas. For example, there are some question marks in areas in which the causes of the relief are obscure. There are also other potentially interesting areas, as can be concluded from the following somewhat contradictory statements. Firstly, the Upper Cretaceous sediments in the northern part of the Kristianstad area (northeast Skåne) rest on a deeply weathered surface with strong relief at a level below the peneplain. Secondly, Mesozoic sediments are considered to rest on the peneplain south of the Småland border (Rudberg 1954, p. 24), for example at Bjärnum, where there are Upper Cretaceous deposits. According to Rudberg (1970a), the south Småland peneplain extends to the southwest on the horsts in Skåne, viz. Hallandsåsen, Nävlingeåsen, Linderödsåsen, and Söderåsen. Is it true that the peneplain extends from under the Cretaceous cover and, if so, how can it be explained that the same Cretaceous rocks rest in part on a rugged, kaolinized surface below the peneplain level? Why are there no Cretaceous outliers above 120 m? Studies of the southwestern margin of the south Småland peneplain should throw new light on the question of the relationship of the peneplain to the coastal plain on the west coast, to the Kristianstad plain, and to the horst region in Skåne.

On the west coast, the coastal plain with its residual hills is bounded to the south by the Hallandsåsen horst. To the east it is bounded by a zone of marked relief. East of this lies the south Småland peneplain at a height of 125–185 m. South of the E–W section of the River Lagan there is no distinct boundary between the coastal plain and the peneplain, which extends here in the form of a low (100–125 m), ill-defined tongue. The situation is analogous at the edge of the Kristianstad plain, which is bounded by horsts in the south and by marked relief and the peneplain in the north, but the situation in the northwest is more obscure. The study area was purposely chosen in order to elucidate the diffuse boundaries between the south Småland peneplain and the coastal plains (Fig. 1). The study area forms a rectangle oriented perpendicular to the morphological trends of the largest valleys, with the long side directed N 55° W. The study area embraces 1562.5 km^2.

The bedrock is uniform and consists mainly of Precambrian gneisses, the knowledge of which is poor. In the west a small part of the area is underlain by Upper Cretaceous sediments (the Båstad area). In the southeast the area extends over a projecting part of the south Småland peneplain according to Rudberg (1970a) and reaches a region with numerous Upper Cretaceous remnants northwest of the continuous Cretaceous cover of the Kristianstad plain. In the northwest the area extends to the sea and includes part of the Swedish west coast, while in the southeast it terminates where the terrain begins to descend towards the Kristianstad plain and the Cretaceous remnants increase in

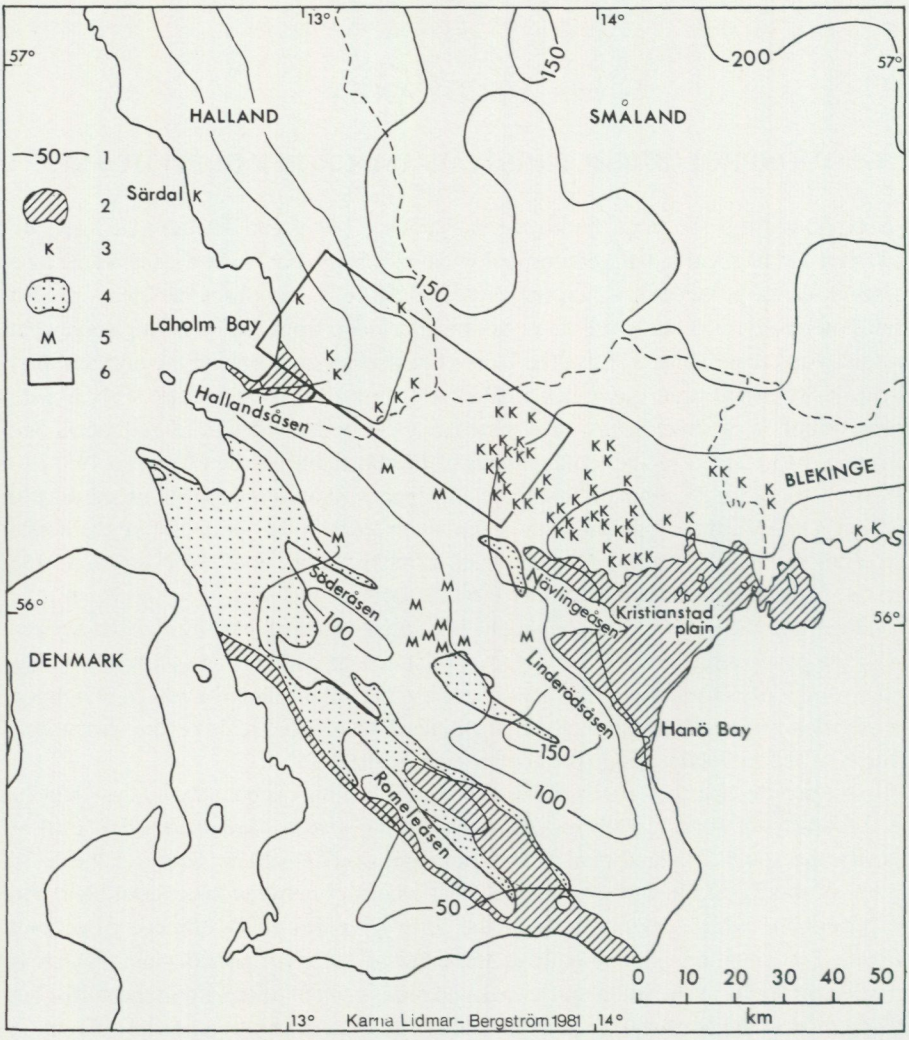


Fig. 1. Skåne and adjacent areas, showing the topographical and geological setting (according to previously published evidence) of the study area. 1. Contour lines for mean heights at an interval of 50 m (Mean Height Map of Sweden 1963). 2. Cretaceous rocks. 3. Scattered localities with Cretaceous rocks. 4. Mesozoic rocks older than the Cretaceous. 5. Scattered localities with Mesozoic rocks older than the Cretaceous. 6. The study area. Blank areas consist of Precambrian and Lower Palaeozoic rocks. (Mesozoic rocks plotted mainly from *Karta över Sveriges berggrund*, 1958.)

frequency. At the time this study was started there were no new topographical maps available northeast of the study area. The resulting lack of morphological background data limited the possibility of extending the study further in this direction. However, limited field work has also been undertaken here. As the main purpose of the field work was to map the occurrence of flints, and as none were found northeast of the proposed study area, I chose not to extend this area when the new maps were

TABLE 1. Opinions on the provenance of flints along the Swedish west coast.

The flints along the west coast are:	
1. Remnants from eroded Cretaceous deposits on or outside the coast.	2. Transported to the coast from distant depositional areas (Skåne, Denmark).
	Olbers 1866
Erdmann 1868 on	
Ljungman 1870 on	
	De Geer 1884, 1893
Blomberg 1902 (Bohuslän) outside	
De Geer 1904 outside	
Eichstädt 1908 on	
Wiman 1912 on	Wiman 1912
	Munthe 1924
Asklund 1928 on	
	Sandegren 1931, 1943, 1952, 1953
Lidmar 1965 b outside	
Brotzen 1966 on	
Caldenius 1966 outside	Caldenius 1966
	Werner 1967
Hillefors 1968 a, b outside	Mohrén 1968
Lidmar-Bergström & Johansson 1971 on (some of the flints in the southern part)	
	Werner 1974

published. In the southwest the tectonic line from Hallandsåsen to Nävlingeåsen was regarded as a natural limit for the study area.

The original reason for studying this area was the result of earlier investigations of flint occurrences on the west coast (Lidmar 1965a, b). If Pleistocene ice brought the flints to the west coast from distant Upper Cretaceous and Danian deposits, then they have no significance for the interpretation of the local bedrock morphology. However, if they derive from deposits near or on the west coast their presence may be of great value for the interpretation of the morphology of this and adjacent areas. The occurrence of flints on the west coast of Sweden has been discussed in several publications. Table 1 summarizes various published opinions on the provenance of the flints. A more thorough review was presented by Werner (1974, pp. 15–20).

After the discovery of Cretaceous rocks *in situ* at Särdal (Fig. 1) on the west coast (Bergström *et al.* 1973) and the find and recognition in the southern part of the west coast of a characteristic type of flint (Lidmar-Bergström & Johansson 1971), it seemed increasingly probable that some of the west coast flints were of local origin. The flints are similar to, but not identical with, those of the Kristianstad area. The finds of local flint and Cretaceous rocks *in situ* were made in 1968–1970. Preliminary investigations along the west coast to find some proof of a local flint origin were started in 1971 and 1972. The most promising results were obtained from southern Halland. The study area promised to be a key area in the search for a provenance of the flints as well as a critical area in the study of erosion surfaces.

PREVIOUS INVESTIGATIONS IN THE STUDY AREA AND ADJACENT REGIONS

There have been few geological and geomorphological research projects in the study area, which is situated within the following geological map sheets: SGU Ser. Ab No. 2 Ljungby (Hummel 1877b); Aa 61 Hessleholm (Lindström 1877); Aa 113 Vittsjö (Blomberg 1895); Aa 114 Örkelljunga (Lindström 1898); and Aa 197 Laholm (Mohrén & Larsson 1968). Two small sectors are within map sheets Aa 60 Båstad (Hummel 1877a) and Aa 67 Herrevadskloster (Lindström 1878). The Cretaceous remnants in the area are dealt with by several authors as referred to in Table 3. Geological studies have also been undertaken for the construction of a water tunnel from Lake Bolmen on the south Småland peneplain to Skåne (Sydvatten 1966, 1967; Sjöstrand & Stanfors 1975). A general survey of the fracture pattern in southern Sweden is given by Röshoff (1979).

The general geomorphology of southern Sweden has been discussed by Rudberg (1954, pp. 24–26, 32–33). The prevalent opinion of the bedrock morphology of the west coast stems chiefly from Asklund (1928). In a lecture for the Geological Society of Stockholm he showed some profiles across southern Sweden (two of which are published in Ramsay 1931, p. 378), which together with some fieldwork on the west coast resulted in the following conclusions: ''1) The coastal plain or strandflat is a Precambrian bedrock surface with the character of a peneplain which is limited both towards the highland in the east and towards the monadnocks by a terrace which has no tectonic origin. The strandflat and its terrace border are preglacial. 2) On the strandflat lie some isolated Cretaceous deposits, which indicates that the surface is sub-Cretaceous (sub in its local sense = under).'' (Asklund 1928, p. 805; my translation.)

Following the synthesis by Rudberg (1954) only a few papers on bedrock morphology in southern Sweden have appeared. Behrens (1957/58) discussed bedrock morphology in Skåne, Behrens (1960) summarized the pattern in southern Sweden, Mattsson (1962) treated the non-glacial bedrock morphology in Skåne, and Markgren (1962) dealt with weathering phenomena in Skåne. The preglacial morphology of the west coast was discussed in an unpublished seminar paper by Åberg (1963, referred to in Rudberg 1970b), who presented a profile extending from Laholm Bay to Hanö Bay. He stated that the profile showed no faults but that the surface was rather bent in a flexure. He also stated that the sea connected the Båstad and Kristianstad areas in the Late Cretaceous but gave no reason for this statement. The conclusion by Åberg concerning the formation of the coastal plain and the hydrographical fall zone in Halland was that the jointing of the bedrock is of great significance, which had previously been overlooked. The old landscape in the basin of Ivön (northeast Skåne; outside the study area but closely related to it genetically) was discussed by Bergsten (1972). The Quaternary history of southern Sweden was dealt with by Nilsson (1968), the Late Quaternary history of the west coast by Mörner (1969), and the glacial morphology in parts of the study area by Persson (1972 and 1975a). The deglaciation of southern Sweden is being studied at the Department of Quaternary Geology,

TABLE 2. Different opinions on erosion surfaces and bedrock relief in southwestern Sweden.

Author	South Småland peneplain	Marginal zone	Coastal plain
De Geer 1913	pre-Cretaceous	fractures sculptured by Pleistocene ice	
Ahlmann 1920	Late Cretaceous-Early Tertiary	new Tertiary erosion cycle (also tectonics)	new Tertiary erosion cycle
Asklund 1928	middle Mesozoic	erosional	sub-Cretaceous
Rudberg 1954	Mesozoic with reservation for later development.	regenerated pre-Senonian	
Eklund 1961	Early Tertiary		Miocene

University of Lund, and preliminary reports have been published by Berglund (1976, 1979) and by the Project Group for deglaciation studies in the south Swedish upland (1979). Recently Mörner (1979) also published a report on the deglaciation of southern Sweden.

The main opinions on the morphology of the Precambrian bedrock in southwestern Sweden can be summarized as follows (see Table 2). S. De Geer (1913) showed that southern Småland is a flat surface. As he considered the surface to emerge from under the Cretaceous deposits in the south, he considered it to be of pre-Cretaceous age. He believed that the broken topography in Halland showed that the bedrock was penetrated by many fractures in different directions. The Pleistocene ice was suggested to have excavated along the fractures.

Later, Ahlmann (1920) proposed a Late Cretaceous to Early Tertiary age for the peneplain. The surface of denudation was supposed to have been elevated in connection with horst movements in Skåne. In Halland, zones of weakness in the form of fractures appeared in conjunction with the changes in level. A new cycle of erosion ''began to actualize the fracture zones into valleys''. He regarded the Kristianstad plain as being ''limited towards the north by a slope that is even tectonically conditioned''.

Asklund (1928, in Ramsay 1931, pp. 365, 378) suggested a middle Mesozoic age for the peneplain as he interpreted it to be the same surface that is overlain by Rhaetian-Liassic sediments at Höör in central Skåne. He regarded the coastal plain in Halland as sub-Cretaceous.

Rudberg (1954, pp. 24–26, 32–33; 1970a) mainly discussed Asklund's ideas. He suggested a possible Mesozoic age for the peneplain. With reference to Lundegren (1931) among others, he regarded the relief in Halland and north of the Kristianstad area as being regenerated and of pre-Senonian age.

In a paper on geology and landforms in Närke (Central Sweden), Eklund outlined his views on the bedrock morphology in southern Sweden. He considered the Småland surface to be of Early Tertiary age and the coastal surface in Halland to be of Miocene age (Eklund 1961, p. 169).

The different opinions were discussed by Mattsson (1964) in a paper on erosion surfaces and valleys in eastern Blekinge.

PROBLEMS AND METHODS

There are four main problems related to preglacial geomorphology on the southwestern margin of Fennoscandia: 1, the age and mode of formation of the south Småland peneplain, 2, the origin and shape of the bedrock surface on the west coast, 3, the origin of the marked relief east of this coastal plain and north of the Kristianstad plain, and 4, the relationship of the peneplain to the horst region in Skåne.

In order to solve these problems, it would help if more information could be obtained about a, the weathering and shape of the sub-Cretaceous surface and the bedrock surface outside the present Cretaceous deposits, b, the extent of former Cretaceous deposits and its implications for the relief, and c, tectonic features in the relief. This paper addresses itself to a discussion of these problems with the selected study area as base.

Firstly, morphometric studies of the terrain were undertaken and borehole data were collected to obtain an accurate picture of the bedrock relief. Secondly, the tectonics in the area were interpreted with the aid of these data, a detailed examination of the contours on the topographical map, and general knowledge from the literature. Thirdly, field studies of Cretaceous erratics were undertaken, mainly involving flints, and a compilation of data from the literature was made about the Cretaceous rocks in the area and neighbouring regions. The same work was undertaken with respect to weathering phenomena. Since an awareness of the significance of weathering for the morphology in the study area resulted from the fieldwork, observations of weathering phenomena originate to a great extent from the later field trips and are not as comprehensive as would have been desirable. Finally, descriptions of the surrounding sediments were examined in order to obtain a better understanding of the preglacial morphogenesis of the southern margin of Fennoscandia.

To place the study area in its wider context part two of the text considers a larger part of southern Fennoscandia and the development of erosion surfaces.

MORPHOMETRIC STUDIES OF RELIEF

CONTOUR MAP

A contour map (Fig. 2, folded map after text) was drawn from the new topographical map of Sweden, using a contour interval of 20 m and with the contour lines drawn somewhat generalized. It is desirable that the contour interval should be as small as possible to bring out the relief, but the strong relative relief in the northwestern part of the study area made the use of an interval below 20 m less suitable. 20 m was also the interval used by Mohrén (1968) to show the bedrock morphology around Laholm Bay. Glaciofluvial deposits and recent drainage have also been marked on the map.

In the west the area extends from sea level to just above 160 m, and in the east from just below 60 m to 160 m on Hörjaåsen (named the Hörlinge Ridge by Lidmar-Bergström 1973, 1974). The southeastern half of the area is flat except for the southernmost corner, where the Hörjaåsen horst rises to 160 m and the nearby rivulet of Hörlingeån drops to below 60 m, resulting in a local relief of more than 100 m.

The northwestern half of the area is quite different; the southern part is a flat area descending gently to sea level or to the foot of Hallandsåsen. The northern part has a broken topography. The contour lines below ML (the postglacial marine limit, just below 60 m) indicate a morphology related mainly to Quaternary sediments, a conclusion verified by existing geological maps. Only a few small bedrock knobs protrude through the sediments as small hills. Fig. 5 shows the transition between the sedimentary plain and the broken bedrock topography.

In the centre of the map, just to the southeast of this central area, there are four more or less marked valleys trending NE–SW. The easternmost of these is indistinctly defined, but it runs through the lakes west of Vittsjö and was followed by the glaciofluvial drainage. The second valley is supposed to be the old continuation of the Lagan river valley (Troedsson 1928, 1932; in any case the Lagan followed this valley during the deglaciation). The valley is now filled with glaciofluvial material. The third valley is the most distinct, and a possible continuation can be seen in the valley of Lemmeshult on Hallandsåsen. The westernmost valley is clearly seen in the north and especially at and north of Lake Grötsjön. Farther south it is not evident. Possibly the glaciofluvial material southwest of Lake Oxhultasjön indicates yet another valley in the bedrock. All these valleys seem to be remnants of old drainage systems and/or tectonic lines.

An obvious lineament (straight physiographic element according to Hobbs 1911 in Hills 1972, p. 466) with an almost E–W direction extends from the River Helgaån to Hallandsåsen, while there is another distinct line along the fault that marks the northeastern border of Hörjaåsen.

In the images from ERTS-1 (LANDSAT-1), a line extending into the study area has been detected (Lidmar-Bergström 1973). This line is believed to be tectonic and begins just where Hörjaåsen ends in the north. It has a NW–SE alignment and passes through Lake Fedingesjön and Lake Storesjö, but is then lost until outside the study area.

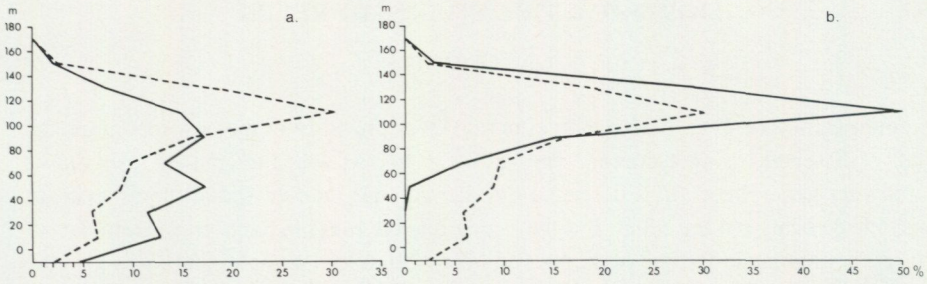


Fig. 3. Area-height diagram of the study area. a. Northwestern half. b. Southeastern half. The dashed line relates to the whole area.

To complete the picture of altitudes in the area, an area-height diagram was constructed. The area between the contour lines was measured by using a dot grid with a dot for every 500 m. The result is shown in two diagrams (Fig. 3), one for each half of the study area. The diagram for the northwestern half shows a peak for the area between 40 and 60 m. This is the area around the ML (53–54 m a.s.l. at Kårarp, at localities 46–49 in Fig. 2, according to Mörner 1969, p. 117), where there are many glaciofluvial delta deposits. Another maximum between 80 and 100 m is caused by the artificial delimitation of the area. The diagram for the whole study area shows that this peak has no significance. The picture of the southeastern half is simple. It shows a maximum (45.6%) for the area between 100 m and 120 m. 90% of this part of the area lies between 80 m and 140 m.

PROFILES

Ten profiles (Fig. 4) were constructed across the study area along lines 2.5 km apart. To give the local relative relief, each profile was associated with one upper and one lower profile. These yield the highest and lowest points for each km in a 2.5 km wide zone extending on both sides of the true relief profile. The extreme values are indicated in the middle of each reference area and are thus moved up to 500 m along the profile. This procedure was convenient and was not considered to affect the interpretation. The vertical scale of the profiles is exaggerated 50 times.

In order to obtain an idea of whether the profiles show the approximate Precambrian bedrock surface, rock outcrops (from the geological maps) were indicated in the profiles (elevation from the topographical maps). This could be done quite accurately with the aid of the 1:50 000 geological map sheets. However, for the part that falls within the old 1:200 000 Ljungby map sheet (SGU Ser. Ab No. 2), the exact positions and elevations were more difficult to determine. From knowledge of the terrain in the field, however, I consider that even here the profiles give a reliable picture of the conditions. In addition, information on borings and on the Precambrian bedrock surface from the Geological Survey of Sweden (in Uppsala and Lund), from Roy

Stanfors, Department of Geology, Lund, from Sydvatten (1966, 1967), and from Mohrén (1968) was added to the profiles.

In general, there are many bedrock outcrops in the northwest and southeast of the study area, but not in the intermediate area with low relative relief. As seen from the profiles, where bedrock crops out it is found both in valley bottoms and close to hill summits. The report from Sydvatten (1967), which covers a large part of the central map area, states that the bedrock in the till areas lies 4–8 m below the surface except in the high areas, where the cover is thinner. In the bog areas the bedrock lies 6–10 m below the surface. In valleys with glaciofluvial material, for instance the old Lagan valley south of Markaryd at Skånes Fagerhult, depths of about 20 m are reported. With these figures in mind, I think that the profiles present a good picture of the bedrock surface. The northwestern parts of profiles I–IV form an exception to this generalization.

PROFILE I

This profile begins in the southeast at the Hörjaåsen fault. The first and second valleys (defined above, p. 15) can be seen. Here the old Lagan valley (II) passes through an elevated area and is rather deep with many bedrock outcrops in the vicinity. The third valley can not be seen since its position in the profile is close to the still lower lakes in the crossing east-west lineament. The highest section just to the south of these lakes represents a part of Hallandsåsen, which is omitted in the profile (but indicated with a dashed line). East of the lakes the highest parts of the terrain drop 30 m. From about 20 km the tops of the bedrock surface disappear under the sediments. At 9 km there is a boring that gives the level for the bedrock surface at 47 m below sea level. In the northwestern part of the profile the relative relief never exceeds 30 m, as far as surface relief is concerned, and in the southeast the maximum relative relief is 80 m. The relative relief in the bedrock of the northwestern part is unknown from about 35 km onwards.

PROFILE II

The profile begins in the southeast at the Hörjaåsen fault and then descends almost all the way to the sea in the northwest. There is a break in the top curve at 37.5 km, with a slightly steeper inclination in the northwest. Northwest of about 18 km the bedrock surface dips under the sediments. The first three valleys (p. 15) can be traced fairly easily. The relative relief is greatest (90 m) at Hörjaåsen. At the break in the slope it is 50 m, and this is also the value at 21 km. For the rest of the profile the relative relief is very small. As in profile I, the amount of the relative bedrock relief is unknown in the northwest. The known bedrock levels in this area vary between -38 m and -70 m.

PROFILE III

This profile also starts at Hörjaåsen, but the uplift is less than in the preceding profiles. To the northwest follows a gradually descending high area, interrupted at 39 km by an

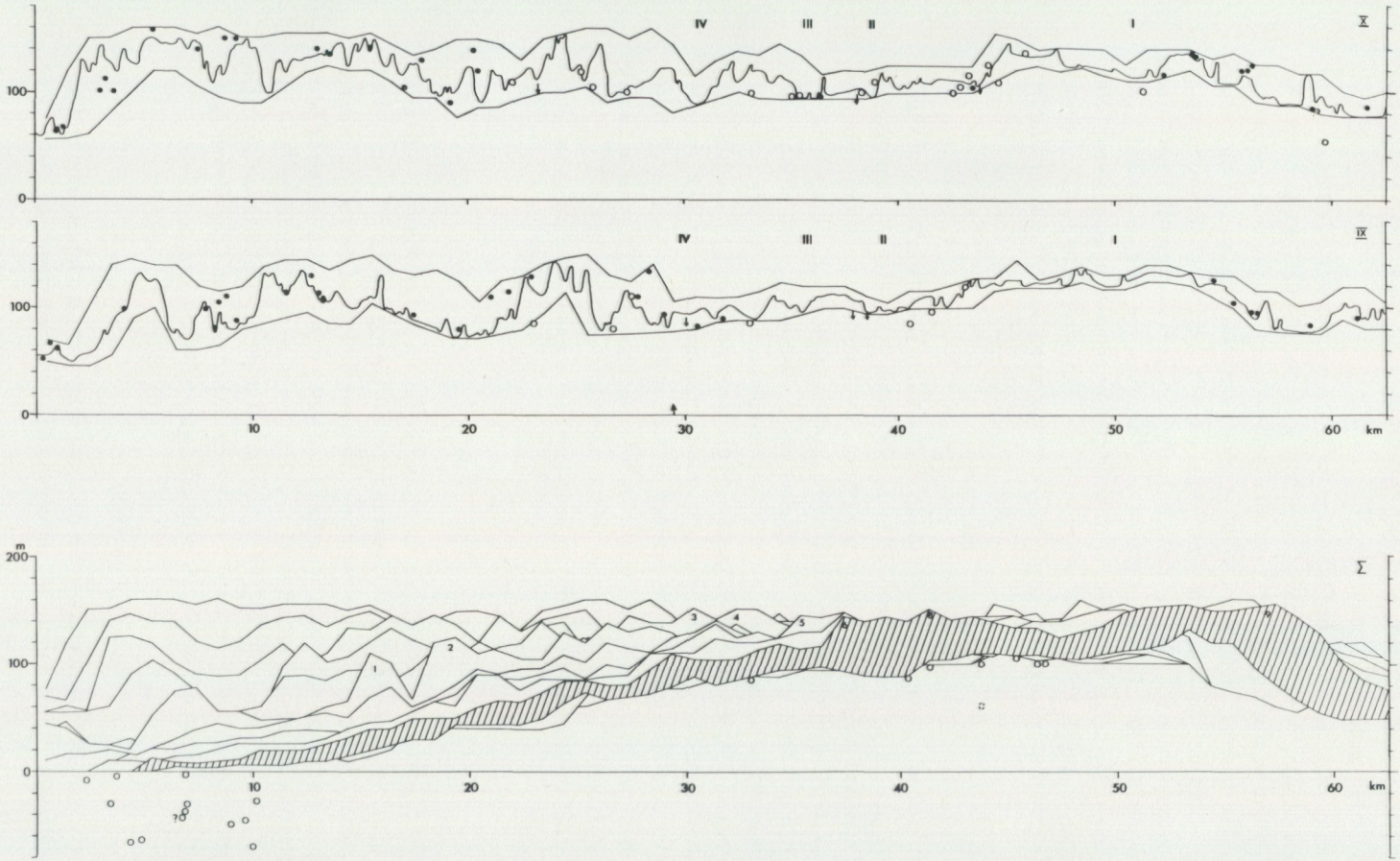


Fig. 4. Morphological profiles across the study area; for locations see Fig. 2 (folded map after text) and for their construction see the text. Filled circles indicate outcrops of basement rocks, open circles basement in borings, dashed circle bottom of weathered bedrock (saprolite). Downward pointing arrows show depth of borings in which the basement has not been reached. Upward pointing arrows indicate morphological knickpoints discussed in the text. Bottom illustration of Fig. 4a (this page) shows all the upper and lower profiles projected from the southwest.

elevation, and at 31.5 km there is a break in the top curve and the terrain begins to slope down towards the coast. The first three valleys (p. 15) can be traced. The relative relief nowhere exceeds 50 m, which is the value at the margin of Hörjaåsen. A value of at least 65 m for the relative bedrock relief is indicated in the northwest by a boring at 5 km. Here, the bedrock summits are level with the bottom curve.

PROFILE IV

From the southeast this profile rises to a plateau between 100 and 120 m a.s.l. (cf. profile V). At 51.5 km there is only a faint sign of Hörjaåsen in the top profile. Then follows a high area, and at 31.5 km there is a break on the curves and the surface descends to sea level. From 31.5 km bedrock crops out in several places, and the top curve shows the surface of the bedrock almost all the way. The first three valleys (cf. p. 15) can be identified and the old Lagan valley is distinct. In the latter, the bedrock is at least 20 m below the valley surface. This gives a height difference of 60 m between the bedrock in the valley bottom and the top to the southeast. For the rest the relative relief is low and reaches just above 40 m in the northwestern part. The relative relief in the bedrock is probably greater.

PROFILE V

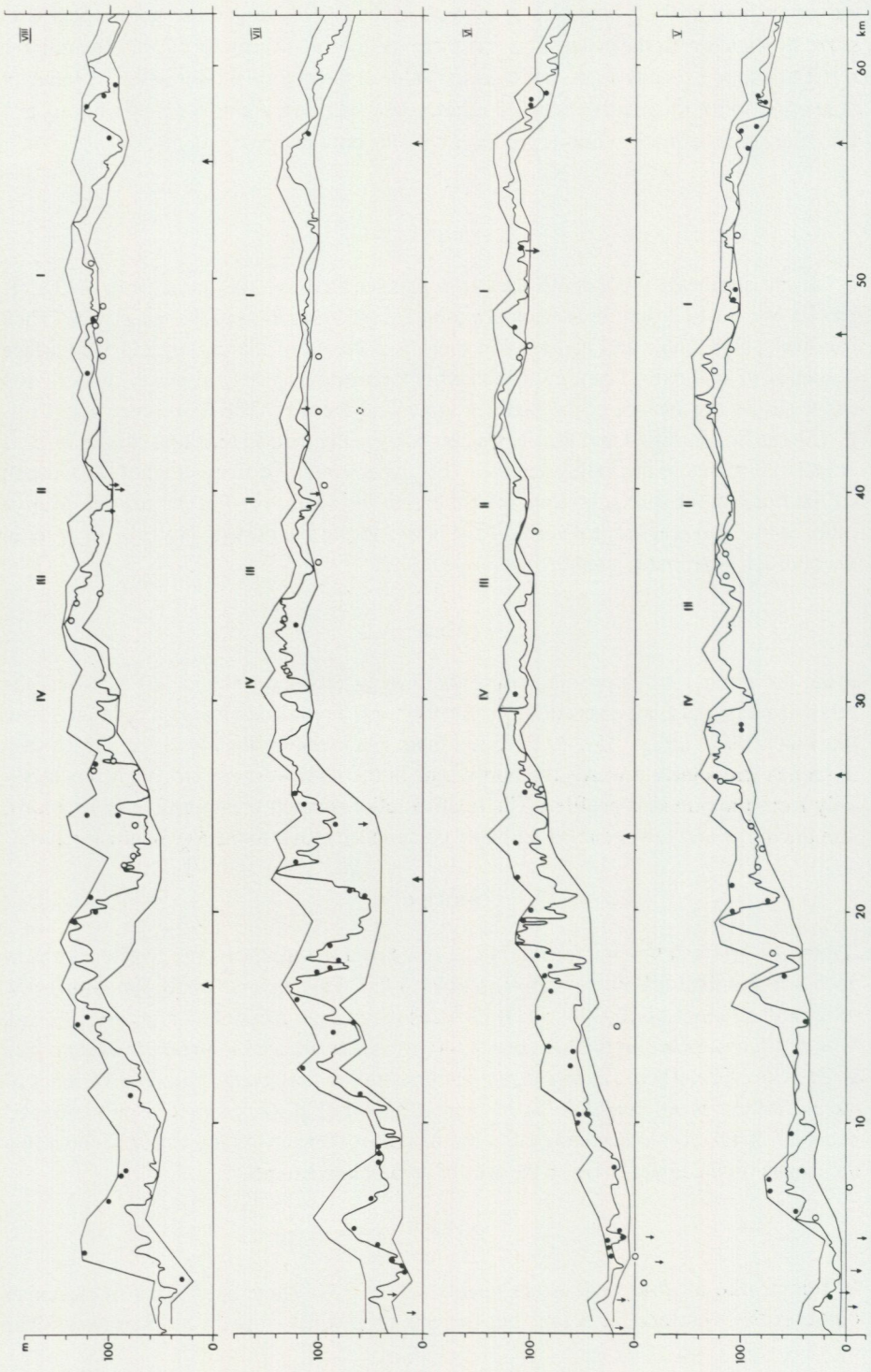
From the southeast this profile rises to the plateau between 100 and 120 m, where the relative relief does not exceed 20 m. To the west the profile crosses a high area with the four valleys (cf. p. 15). At 26.5 km there is a break on the top curve, which then descends irregularly towards the northwest. In the northwest the profile differs markedly from the previous profiles. The relative relief is much greater (80 m at 18.5 km), and the upper and lower curves probably come much closer to the true bedrock relief.

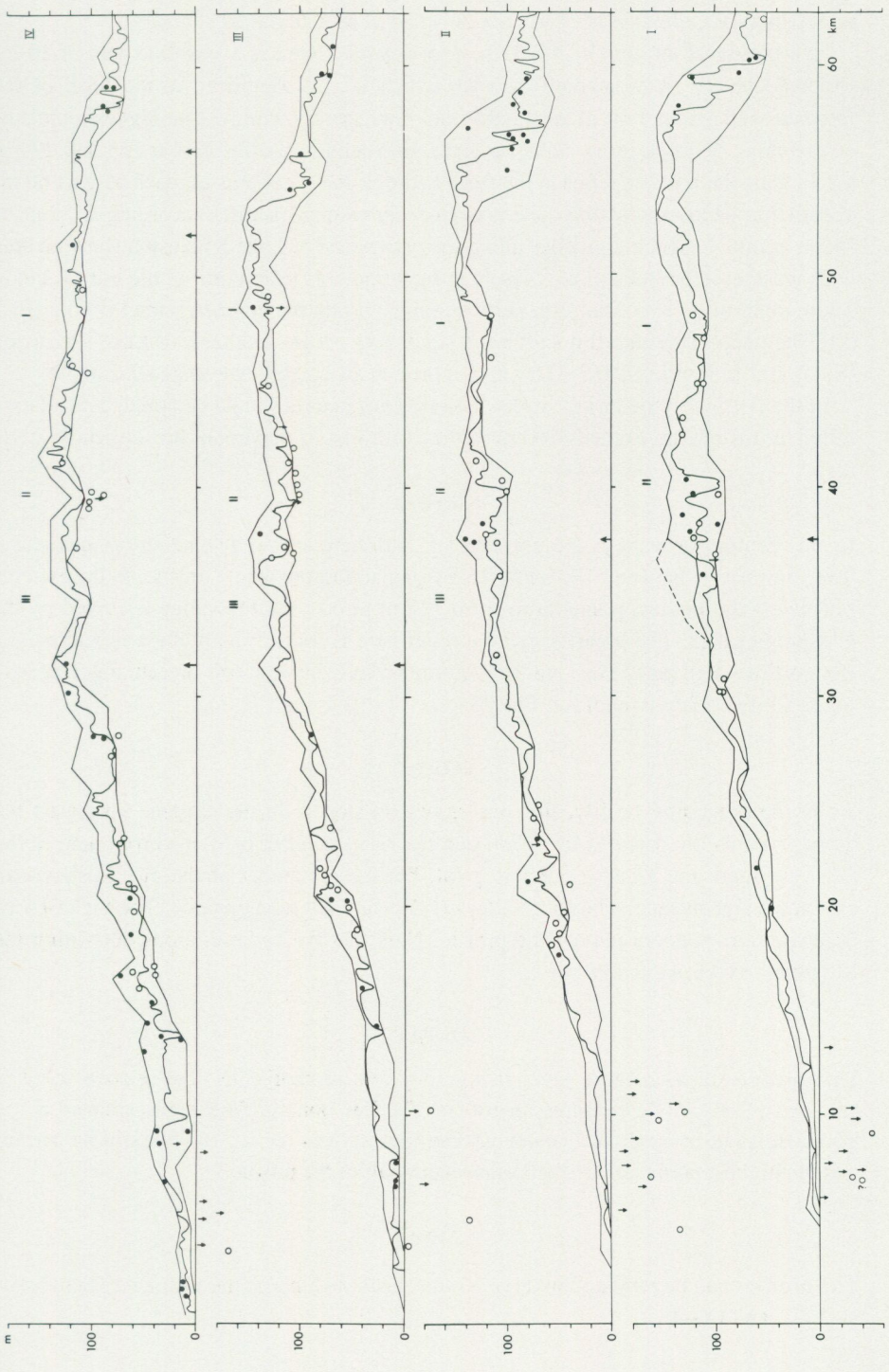
PROFILE VI

All the valleys can be recognized (cf. p. 15). From the southeast the profile climbs to 56.5 km and then follows a high area to 23.5 km. This area is mostly flat with a low relief and a height of 100–130 m. It includes the plateau mentioned in profiles IV and V. The highest point on the top curve (140 m) is now situated in the northwestern part at 23.5 km. From here the top curve descends to the northwest. The relative relief in the northwest is as much as 70 m, and if a boring at 14.5 km (top of weathered bedrock) is taken into account, the relief is almost 80 m. Note the valley occupied by the Lagan on the lower curve in the area of great relative relief.

PROFILE VII

In this profile all four valleys are visible (cf. p. 15). There are breaks in the upper curve at 56.5 km and 21.5 km, but there is no distinct slope in the northwest. The


VIII
VII
VI
V
I
II
III
IV
m
100
0
10
20
30
40
50
60
km


IV
III
II
I
m
100
0
km
10
20
30
40
50
60
?

highest peaks lie in the middle. Southeast of these the area is flat, with a relative relief mostly not exceeding 30 m. The plateau is visible around the 50 km mark.

In a boring at 44 km (VC132523), 115 m a.s.l., there is a soil thickness of 15 m, followed below by weathered bedrock which is still weathered at the level of the Bolmen water tunnel 60 m a.s.l. (Roy Stanfors, pers. comm.). The highest points of outcropping bedrock in the adjacent areas are found in profile VIII at 115 and 120 m a.s.l. Thus the relative relief in the fresh bedrock surface seems to reach at least 60 m. Weathered bedrock probably occurs even deeper along fractures according to Stanfors (pers. comm.). Seismic profiles along the tunnel east of Lake Kraxasjön show an area with weathered bedrock along closely spaced fractures from north of the boring site to 1 km south of it (Roy Stanfors, pers. comm.). Along the Bolmen tunnel profile (Fig. 39), the deepest weathering within the study area occurs southeast of Lake Kraxasjön (Sjöstrand & Stanfors 1975). This may represent an exceptional weathering depth.

In the northwest the large ''valley'' on the lower curve should be noted. The relative relief in this profile exceeds 100 m in the northwest, a maximum for the whole study area.

PROFILE VIII

In this profile the valleys are not distinct, and there are no distinct slopes or breaks. The summits lie between 120 and 140 m along almost the whole profile. In the extreme northwest the highest points drop from 125 m to 60 m in the valley occupied by the Eldsberga esker. The greatest relative relief here is 90 m. The highest elevation is in the northwestern part. The ''valley'' on the bottom curve is still present together with considerable relative relief (cf. Fig. 6).

PROFILE IX

As in the preceding profile, this one shows no slopes. In the extreme northwest the highest points are reduced by 70 m, and the relative relief is 85 m. From here to the 29.5 km mark the relative relief is great, but the remainder of the profile shows an extremely flat surface. The four valleys (I–IV) are still recognizable. The highest area is in the northwestern part of the profile. Note that the bedrock crops out within the Eldsberga esker in the northwest.

PROFILE X

This profile shows a more level topography. As in profile IX, the relative relief is greatest (90 m) in the extreme northwest. The low point at 59.5 km is situated at the River Helgaån in an E–W lineament. The four valleys (cf. p. 15) can still be traced, and the highest points are in the northwestern half of the profile.

SUMMARY

The profiles can be arranged in three groups, each with particular characteristics: I–IV, V–VIII, and IX–X.

I–IV — These profiles begin in the southeast with the fault at Hörjaåsen. The small horst is followed to the northwest by a plateau, which is interrupted by three valleys (cf. p. 15). The relative relief is mostly less than 40 m and does not exceed 55 m (with the exception of a bedrock relief of 60 m in the Lagan valley). Northwest of a break in the profiles a very even slope follows with low surface relief, reaching a maximum of 50 m in profile II. Northwest of the break the bedrock relief is poorly known but may be as great as further northeast. The highest known value, 65 m, is along profile III. It appears from the few observation points that the slope in the bedrock is steeper in the two southern profiles than in the other two. It must be observed, however, that the northwestern parts of the profiles are not parallel with the dip of the bedrock surface.

V–VIII — The southeastern half of the area (southeast of the fourth valley) is flat with low relief. However, the investigation along the Bolmen water tunnel indicates a maximum relative relief of 60 m in the fresh bedrock. The distinct plateau between 100 and 120 m on profile V can be seen in all the profiles except for VIII, but is bordered by a higher area in the southeast in profiles VI and VII. The slope in the northwest is not as distinct as in I–IV, and the break in the slope almost disappears with profile VII. Instead there is considerable relative relief with a maximum of just over 100 m.

IX–X — The relative relief is low in the southeast, rarely exceeding 30 m. However, the boring at 59.5 km in profile X indicates that the bedrock relief may be greater in the southeast than indicated by the surface profiles. The profiles show a low area (with valleys II–IV) in the middle, where the relative relief is low. These profiles have the greatest altitude in the northwest. In that area there is also fairly considerable relief, up to 90 m.

PROJECTED PROFILES

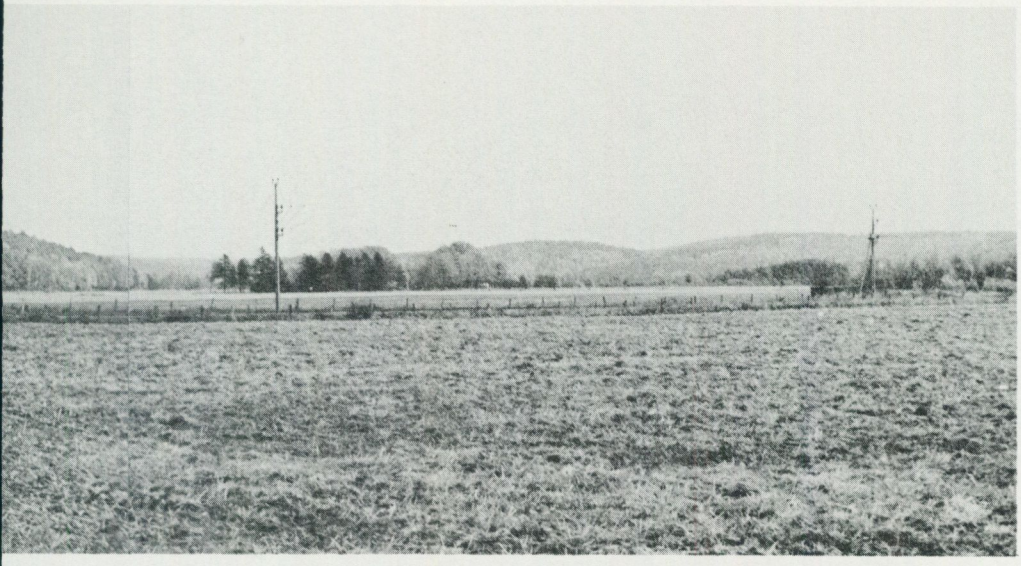
If the top and bottom curves are projected from the southwest, a picture of the summits and low points can be obtained for the whole area (Fig. 4a). The highest summits in the area reach just 160 m. The Hörjaåsen fault is clearly shown at the right. At a height of 88 m, the old Lagan valley intersects profile I (shaded) at the 40 km mark in an elevated area in which the summits are at 140 m. Between the old Lagan valley and the Hörjaåsen fault, the bedrock surface is not known to be lower than 100 m at any point (although weathering has penetrated deeper). In the extreme northwest, it can be seen that the highest points of the bedrock descend from 160 m a.s.l. on profile X to well below sea level on profiles I and II. At Båstad, southwest of the study area, the basement surface may be as deep as 125 m below sea level (Erik Norling, pers. comm.). In the northwest the summits in profile V at 16 (1) and 19 (2) km should be noted.



Fig. 5. Transition between the broken topography (sub-Cretaceous relief) and the plain covered with

DRAINAGE

The drainage pattern (Fig. 2, folded map after text) shows the presence of three main drainage areas viz. 1, the northwestern part with drainage to Laholm bay through the Genevadsån, Lagan and Stensån rivers over the Laholm plain; 2, the southeastern part with drainage to Hanö Bay through the Helgaån over the Kristianstad plain; and 3, a small area between Åsljunga and Skånes Fagerhult in the middle of the southwestern side of the study area, with drainage through Rönneån to Skälderviken Bay in northwestern Skåne. In this study the lowest points on the water divides between the main areas are of interest because they provide information about the most probable Late Cretaceous sea connections between the Laholm and Kristianstad plains. The lowest point on the divide between these plains lies southeast of Lake Kraxasjön at just above 115 m. The lowest points on the divide between the Rönneån drainage system and the Laholm plain are at 105–110 m (both the Stensån and the Lagan drainage systems). The lowest point on the divide between the Rönneån drainage system and the Kristianstad plain is at 110–115 m (south of the study area).



Quaternary sediments at Kårarp, southern Halland.

SUMMARY OF MORPHOMETRIC STUDIES

The morphology of the southeastern part of the study area is fairly simple. The bedrock surface is rather flat. The only pronounced relief is caused by the Hörjaåsen fault. However, there is a relative relief of up to 60 m locally but this is not seen on the surface. The high values are related to the fracture zones. A notable feature is a platform with very low relief at 100–120 m.

In the northwestern area the configuration of the bedrock surface is much more complicated and to some degree unknown. South of the Lagan the bedrock surface dips towards the southwest and disappears beneath Quaternary sediments. Below some 55 m a.s.l., these sediments form a thick, partly marine sequence. However, at higher levels south of Lake Oxhultsjön, Quaternary deposits also form a cover with flat surface, under which the bedrock topography is unknown. Between this lake and Lagan there is a marked topography with a relative surface relief as great as 100 m and a similar relief of the bedrock surface. At the border of the study area north of the Lagan is the edge of the south Småland peneplain at a height of around 160 m. On the



Fig. 6. Knäred, southern Halland. Broken topography caused by the regeneration of the sub-Cretaceous relief and by tectonics.

peneplain northeast of this edge the summits reach 194–230 m (Fig. 32). Between the Lagan and the peneplain edge the relief is pronounced, even if it is less so than just south of the Lagan. The few borings that have reached the basement below the Laholm plain indicate that the area with marked bedrock relief extends to the west under the thick Quaternary cover (Fig. 4, profiles I–VI).

The lowest points on the water divide between the Laholm and Kristianstad plains lie around 115 m. The rather flat surface in the southeast is largely at a height of 100–120 m, but part of it reaches 120–140 m. Small areas reach above 140 m.

TECTONICS AND LINEAMENTS

DESCRIPTION OF LINEAMENT PATTERN

Some information on lineaments in the area is given above in the discussion of the contour map (Fig. 2, folded map after text). In order to obtain a more thorough view the contours on the topographical map were subjected to a detailed examination with a technique described by Lidmar-Bergström (1975, p. 8). All morphologically well-marked directions indicated by the contour lines (several closely spaced lines, parallel along a distance of at least 250 m, or a few parallel lines along a greater distance, in many cases associated with a stream) were plotted on a map (Fig. 7) and determined with respect to length and direction. Two direction roses were constructed, one for the northwestern half and one for the southeastern half of the study area. The roses present two quite different patterns which can also be recognized directly from the map.

In the southeast the dominant features are the NE–SW trending valleys as described above (p. 15). Their directions vary from N20°E to N50°E. The second dominant direction is N20°W, caused mainly by Hörjaåsen. The two dashed lines on the map are not included in the diagram as they are not sufficiently distinct in the contours. Nevertheless they indicate a major break in the morphology. The northwestern line represents part of the northern limit of Hallandsåsen. The southeastern one coincides with a fracture zone at Slättsjö (Sydvatten 1968). Some E–W directions also occur.

In addition to NE–SW directions, the dominant direction in the northwestern area is N–S. This direction was previously shown to be a dominant feature in southern Halland (Lidmar-Bergström 1975, pp. 8–12; see also De Geer 1913, p. 17). The N–S trending valleys are shorter than those aligned NE–SW, and in most cases they are comparatively narrow. The exceptions, as for example the Krokån valley, could be explained by crossing tectonic lines. A third important direction is NW to WNW. This main direction can be separated into two more or less discrete direction groups, namely N50°W and N70°–80°W. The northern boundary of Hallandsåsen falls within the latter group.

TECTONIC PATTERN

The lineament pattern described above is thought to be of tectonic origin (*i.e.* caused by stress and movements in the solid earth crust). Fig. 8 shows the main tectonic features of the area, drawn from the contour map (Fig. 2, folded map after text) and the morphological pattern in Fig. 7, with influences from Sydvatten (1967) and Lidmar-Bergström (1973, 1975). The thick lines represent elevated margins of tectonic blocks (numbered 1 to 9). Numbers 1 and 2 can be seen in profile V, 3 and 4 in profile VII, 5 in profile III, and 6–9 in profile I (number 7 is the dashed line; Fig. 4). These elevated margins stand out clearly in the projected profiles (Fig. 4a).

The central area and the area to the southeast seem to be divided into blocks by

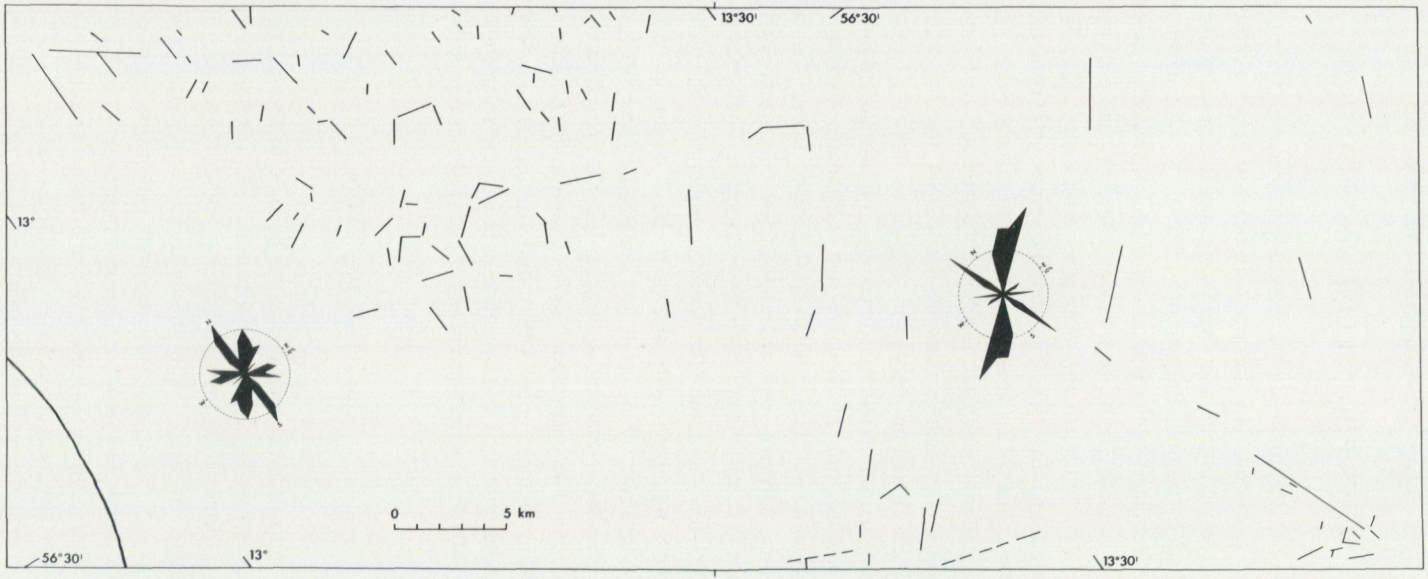


Fig. 7. Map of morphological directions in the study area, with two rose diagrams, one for the northwestern half and one for the southeastern half. The rose diagrams are constructed with respect to the total length of each direction and not to number of lines.

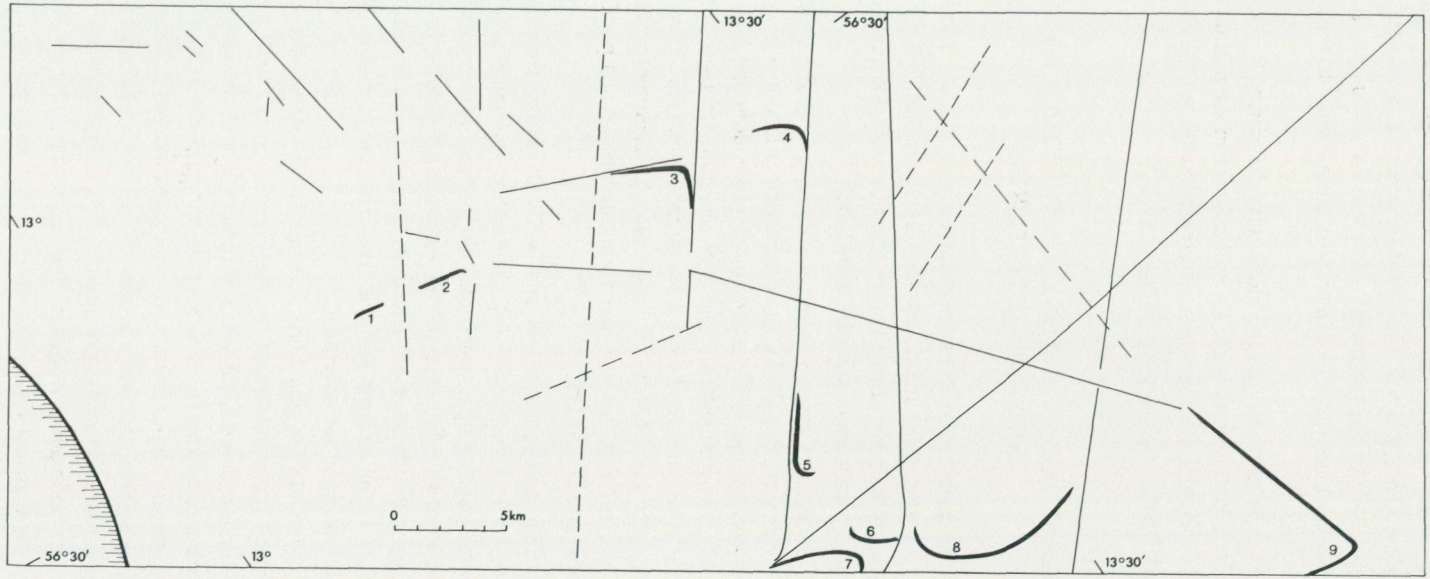


Fig. 8. Tectonic sketch map of the study area. Solid lines mark distinct lineaments, dashed lines less distinct lineaments, and thick lines indicate elevated ends of tilted blocks. For figures see the text.

NE–SW lines and WNW–ESE lines. The blocks are tilted, the two southeasterly blocks (with margins 5, 6 and 8; cf. Fig. 39) to the northeast and the northwesterly blocks (with margins 1–4) to the southwest. Note that Lake Värsjön (Fig. 2) drains to the northeast, as also do Lake Fedingesjön and the lakes further to the northeast in the old Lagan valley.

The profile of Fig. 39 runs through the block with the margin 8. The fracture zone southeast of this block is visible as is the E–W lineament in the middle of the block at 50 km. The two E–W directed dashed lines are crossed by the profile east of Kraxasjön at 40 km and east of Markaryd at about 35 km.

LITERATURE ON TECTONICS IN THE STUDY AREA AND ADJACENT REGIONS

Sydvatten (1967) has made the most thorough investigation in the middle of this area. The investigators reported three main tectonic directions, viz. NNE, N and WNW. The latter was thought to have formed in connection with the horst movements in Skåne, while the other two were considered to be older.

The large-scale pattern interpreted from satellite images (Lidmar-Bergström 1973) shows that the study area partly falls in the continuation of a zone with N–S lineaments. It was thought that movements had possibly taken place along the N–S lines, close to the Carboniferous-Permian transition. The NW direction (including the long line in Fig. 8) was thought to be connected with the horst movements in Skåne. A comparison can also be made with the LANDSAT based map by Ehrenborg (1978 in Röshoff 1979), in which he identifies the NW line mentioned above and parallel lines, some NE lines, N–S lines, and E–W lines.

Dolerite dikes in Skåne aligned in NW and WNW directions are of a Late Carboniferous age (Bylund 1974; Klingspor 1976). On the new geological map sheet Kristianstad SO, the dolerite dikes gather round the two slightly different directions N45°W and N60°W (Kornfält in Kornfält *et al.* 1978). According to Lindström (1967), N40°W represents the Dinaric direction (the ''Tornquist Line'') in the Baltic and N60°W the Hercynian direction. It can be supposed that fractures along the same directions as the dolerites are at least as old as the dolerites.

According to Bölau (1973), the horst movements in Skåne, though initiated by Variscan (Hercynian) tectonics, began in the Early Jurassic, with a main orogenic phase in the Late Jurassic (Late Kimmerian tectonics). These conclusions are based on observations of Triassic and Jurassic sediments in northwestern Skåne.

The Cretaceous, mostly Upper Cretaceous, in the Båstad and Kristianstad areas rests directly on the Precambrian surface. Southwest of the Hallandsåsen–Nävlingeåsen line, Triassic and Jurassic deposits rest directly on the Precambrian. Southwest of a parallel line through Söderåsen, however, they commonly rest on Cambro-Silurian strata (Fig. 1). As there are no Triassic or Jurassic sediments below the Cretaceous in

the Båstad and Kristianstad areas, it can be supposed that these areas occupied a higher position during sedimentation than the areas with preserved remnants of Triassic and Jurassic sediments. Bergström (in Bergström *et al.* 1973, p. 86) has suggested that the northeastern part of Skåne and adjacent parts of Blekinge were uplifted before the other horsts in Skåne were formed. His opinion is based on the fact that the morphology is comparatively mature here, with a maximum relative relief of more than 200 m (cf. p. 126). Bergström has also shown that the Kristianstad basin tilted to the southeast in connection with a rise of Nävlingeåsen and Linderödsåsen, with the main movements beginning in the Santonian and with most of the tilting during the Campanian. Sediment studies along the northern border of Nävlingeåsen indicate a transport direction from the northwest along the border of the ridge, as well as open marine conditions towards southern Halland during the Early Campanian. This may indicate a later rise of the area between the Båstad and Kristianstad areas (Bergström in Kornfält *et al.* 1978, p. 90).

During the Subhercynian deformation phase (Senonian), inversion axes developed in Poland and western Europe. Ziegler (1975, p. 1090) placed one of them through Skåne from Linderödsåsen to Hallandsåsen (Fig. 4). Lagerlund (1977) suggested that tectonic movements took place during the Quaternary in Skåne.

A summary of the preceding compilation gives the following result with respect to the study area. All the main lineaments, NE, N–S, E–W, NW, and WNW, seem to have been in existence at the beginning of Mesozoic times. During the Triassic and Jurassic the area northeast of a line along Hallandsåsen–Nävlingeåsen seems to have had a more elevated position than the area just to the southwest. In connection with the Cretaceous transgressions (Fig. 33), the Kristianstad basin subsided and Nävlingeåsen and Linderödsåsen rose, mainly during the Santonian and Campanian. The conditions along the northern border of Hallandsåsen are not so well known but cannot be very different. It can be assumed therefore that movements occurred there at approximately the same time, with subsidence of the Båstad basin and uplift of Hallandsåsen. The intervening area may also have subsided and then experienced a later rise.

TENTATIVE INTERPRETATION OF THE TECTONIC SKETCH MAP

In a similar way to the more eastern part of Skåne, there are two northwesterly aligned tectonic trends within the study area. The N50°W trend seems to correspond to N40°–45°W in eastern Skåne (the Dinaric trend) and N70°–80°W to N60°W (the Hercynian trend). Within the study area it appears that fractures aligned WNW, together with some trending NE, were reactivated in connection with Late Cretaceous and probably also Tertiary horst movements when the blocks were tilted.

On the basis of conclusions from the distribution pattern of the Cretaceous remnants in the area (see next chapter) and the literature referred to above, the following interpretation of the tectonic pattern (Fig. 8) is suggested.

During the Late Cretaceous sedimentation, part of the area in the northwest was

tilted southwestwards in connection with the uplift of Hallandsåsen. The area between Hörjaåsen and a zone northwest of Åsljunga was probably in a relatively lower position than today. The Hörjaåsen block lacks known occurrences of Cretaceous rocks despite the presence of many remnants just to the east. This may indicate that the block was uplifted relatively early. The blocks with margins 5, 6, 8, and also at least the western side of the block with margin 9 (Hörjaåsen), may have experienced a later rise. A support for this idea is that both the block including Värsjön (8) and the one to the northwest (5, 6) contain flints in the southwestern areas but not in the northeast (except for an area east of the prolongation of Hörjaåsen). One conclusion may be that a very late Cretaceous or post-Cretaceous rise took place. The absence of flints in the Lagan valley between Markaryd and Krokån indicates the same age for the rise of margins 3 and 4. (A part of the study area may be an Oligocene erosion surface consisting of blocks that were tilted at the Oligocene/Miocene transition. Cf. pp. 140 and 176.) This means that the thick lines in Fig. 8 show margins that were uplifted earliest in the Late Cretaceous (and possibly at the Oligocene/Miocene transition).

CRETACEOUS OUTLIERS AND ERRATICS

FIELD METHODS

The field work was based on the assumption that there was previously a continuous Cretaceous cover from Laholm Bay to the Kristianstad plain. The discoveries of flints in the southern part of Halland (Lidmar-Bergström & Johansson 1971) made it probable that a search for flints between Laholm Bay and the Kristianstad plain would give positive results. A record by Lindström (1898, p. 19) of flints in the till in the Örkelljunga map area was also encouraging. Initially the work was random, but the area was traversed repeatedly, with particular attention directed to large road cuts and gravel pits. The lowest areas between the Laholm and the Kristianstad plains were especially searched, as a connection between the two areas seemed most probable here. As the work progressed it was detected that very small road cuts could yield numerous flints even when a larger gravel pit in the vicinity seemed to lack them. It was observed that flints have a scattered local distribution which is difficult to map. In many cases it was just good luck and a firm belief that flints should exist in the area that made the findings possible. The great interest in my investigations shown by geographers and geologists resulted in several new flint localities being located and was of great help in the attempt to sketch the first general picture.

In the second phase of the investigation, when many localities were plotted on a map, it was possible to follow the alignments of the flints to source areas and also to fill in the central gap, a remnant of which is still seen in the middle of the map (Figs. 2, folded map after text, and 32).

At the beginning of the field work, negative localities were noted only if they were large road cuts or gravel pits where a lot of material was searched through. In that case they were considered to be representative of the area and the absence of finds was assumed to indicate that the area was devoid of flints. When it was realized that this



Fig. 9. Road net used for car transport to show the coverage of the field work within the study area.

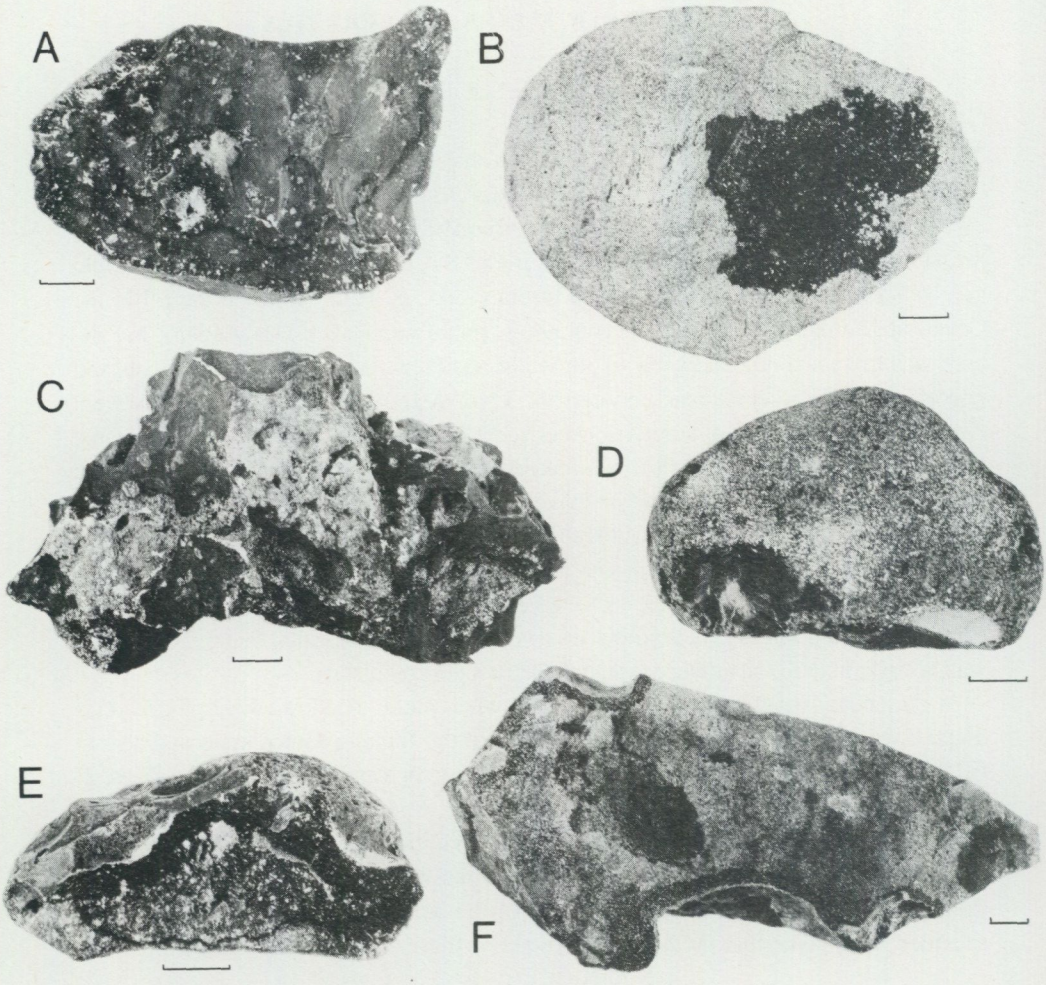
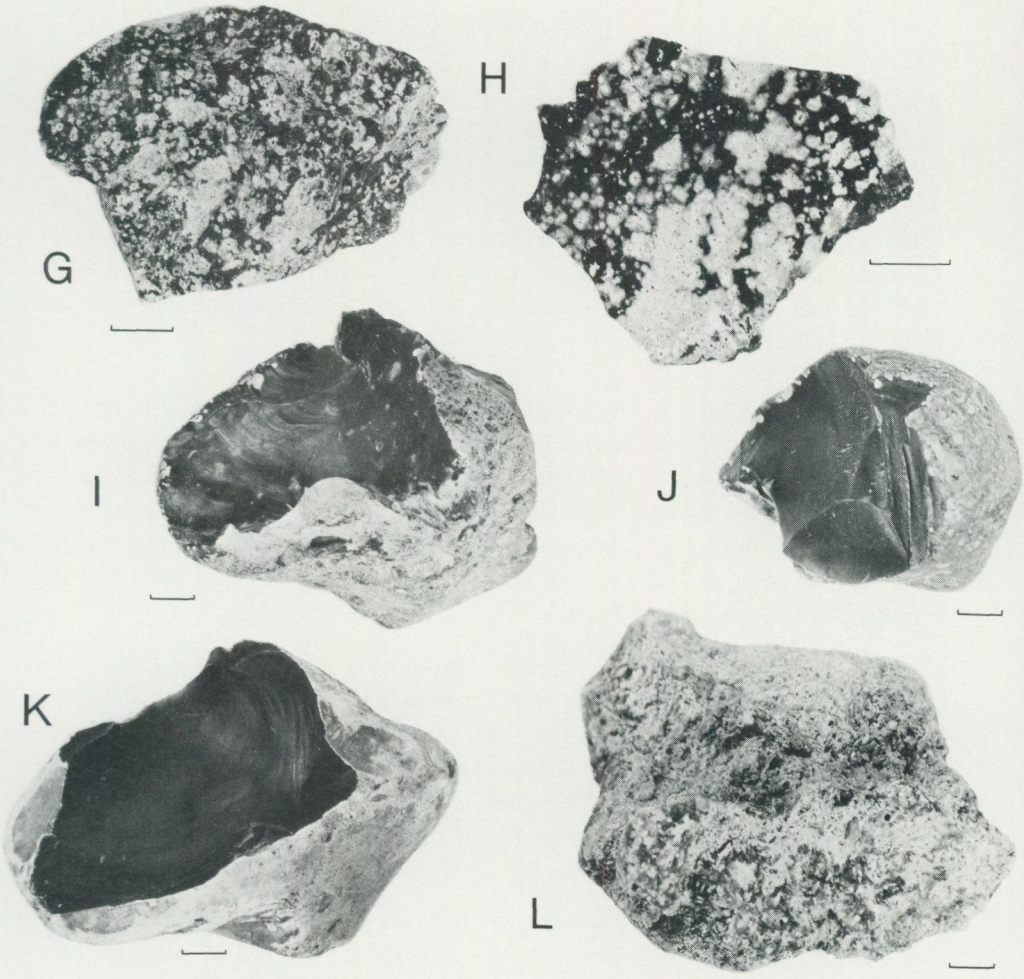


Fig. 10. Characteristic local kinds of flint from the study area and the Swedish west coast.
A. Flint type B from 70 Körsveka.
B. Flint type B from Hanaskog, Kristianstad area.
C. Flint (type B) with an uneven surface from 67 Källshult.
D. Flint (type B) with a smooth nodule surface from 10 Perstorp.
E. Weathered flint (type B) from 14 Göstorp. Note the weathered crust.
F. Weathered flint (type B) from 70 Körsveka. Note the weathered crust.

was not the case and that a negative locality just showed that no flints have been found at that particular site, all negative localities were marked, including small road cuts with small quantities of material. These localities show only part of the extent of the field work. Fig. 9 forms a complement in showing all the roads that have been searched and along which cuttings have been visited. It is thus important to notice that in this investigation it is positive localities that are by far the most interesting, while negative localities can not be regarded as representative of any area. This reflects the very local distribution of the flints and the difficulties in finding these local sites.



G. Flint type D from 104 west of Änglarp.
H. Flint type D from 113 Vedema.
I. Flint type E, variety 1, from 249 Agerörsmalen in the area around Falkenberg.
J. Flint type E, variety 2, from 212 northwest Skreanäs in the area around Falkenberg.
K. Flint type E, variety 3, from 53 Morups tånge, north of Falkenberg (Lidmar 1965a).
L. Flint type F from 52 Glommen, north of Falkenberg (Lidmar 1965a).
Scale 1 cm. Photos: Sven Stridsberg.

At the flint localities the kind of deposit was classified. Normally all flints were counted, apart from a few cases in which a percentage count was made. In most cases the flints were collected. It was my intention to investigate the material with micropalaeontological methods in order to determine the age of the source rock. Investigations have been made together with Göran Kjellström (Geological Survey of Sweden, Uppsala), based on dinoflagellates. As a revision of the dinoflagellates for stratigraphical purposes is not yet finished, the prepared samples unfortunately can not yet be evaluated.

FLINT TYPES

Fig. 33 shows the stratigraphical ranges of Cretaceous occurrences in the Kristianstad area and on the Swedish west coast. In addition, known occurrences of flint are marked (cf. p. 126).

An important observation is that there are local flint types in southern Halland. These types are somewhat reminiscent of Kristianstad flint but still distinct, and typical Kristianstad flints are not generally found with the local Halland flints (Tab. 3, Fig. 32b). Lidmar-Bergström & Johansson (1971) described the following flint types from southern Halland:

A. Båstad type of flint — The colour is brownish grey to black, the fresh fracture is lustrous, there are 0.5 mm large white spots, and the nodule surface is more or less even. This type occurs at Båstad on the Laholm plain in strata of Campanian age (Regnéll in Magnusson *et al.* 1963) and was found along the foot of Hallandsåsen and at locality 35 in this investigation (loc. 13 in Lidmar-Bergström & Johansson 1971). It was also found at several localities on Hallandsåsen southwest of Båstad, but only rarely on the beaches around Båstad.

B. Hishult type of flint — The colour is light grey to greyish black, the fresh fracture is dull, it has 1–5 mm large lighter spots (mottled flint) and an uneven nodule surface. This type is usually similar to flints at Hanaskog in the Kristianstad area. From Hanaskog grey, uniformly dark, and speckled flints have been reported in addition to mottled ones (Hennig 1895). The strata at Hanaskog are of Late Campanian age (Christensen 1975). The Hishult type of flint occurs in many varieties and is the most abundant type within the study area (Fig. 10A–F).

C. Lycke type of flint — The colour is light grey, the fresh fracture is dull, it is somewhat mottled, and has an uneven nodule surface. This type was only found at a few localities, namely one specimen at loc. 14, three at 51, two at 63/64, one at 70 (see Table 3), and some outside the study area at the foot of Hallandsåsen (Table 7, loc. Nos. CJ12 and CJ57).

D. Kristianstad type of flint — This type is characterized by the abundance of white spots that may fuse and form large white areas in the nodule (speckled flint, Fig. 10G, H). There are many intermediate kinds of flint between the various types.

Types A–C will be referred to here as the Halland type and type D as the Kristianstad type of flint. The latter type was described by Gry & Søndergaard (1958).

A second characteristic of the Halland type is that the flints in many cases are brownish at the surface and to a depth of about 5 mm (Fig. 10E–F). This must be a kind of weathering crust and will be discussed later.

PRESENTATION IN MAP AND TABLE

Localities with Cretaceous rocks *in situ*, isolated Cretaceous flint erratics, and other Cretaceous erratics are shown in Fig. 2 (folded map after text). 63 of the flint localities yielded less than 5 specimens (see Table 3 and Fig. 11). The highest number from a single locality is 84 flints. In such a rich locality there is no point in counting every flint. The localities have been grouped after flint abundance in Fig. 11. The visual impression of this diagram indicates three good limits between classes of abundance, namely between 5 and 6, between 9 and 12, and between 17 and 20 flints. As it is technically difficult to illustrate four classes on the map, only two classes are distinguished. The limit between these was placed between 9 and 12 flints. When the flint erratics number more than 10 or when they constitute more than 1% of a count, the locality is regarded as rich in flint. It could be argued that this division does not take flint size into account. There are a few cases where such an argument may be of some importance for the interpretation. These are localities 14, 15, 42b, and 82, which contained few but fairly big nodules, and 47 and 90 with just 12 predominantly small flints.

To show how the distribution may be influenced by glaciofluvial transport, the glaciofluvial deposits are marked on the map. The information is taken from available geological maps and from Lidmar-Bergström & Johansson (1971). As pointed out above, the geological maps of the area are of varying quality. This is one of the reasons why particular localities situated in glaciofluvial material are placed outside glaciofluvial symbols on the map, and *vice versa*.

Find localities are listed in Table 3, and are numbered from 1 to 150, beginning in the lower left corner of the map. The localities are arranged in six geographical groups: 1–25, 26–70, 71–91, 92–99a, 99b–109, and 110–150. The height above sea level is judged from the topographical map. With regard to limestone and kaolin localities in the southeastern part of the study area, the table indicates *"in situ"* only in those comparatively few cases where such a designation is clear from the literature. The kaolin localities are discussed separately in a later chapter.

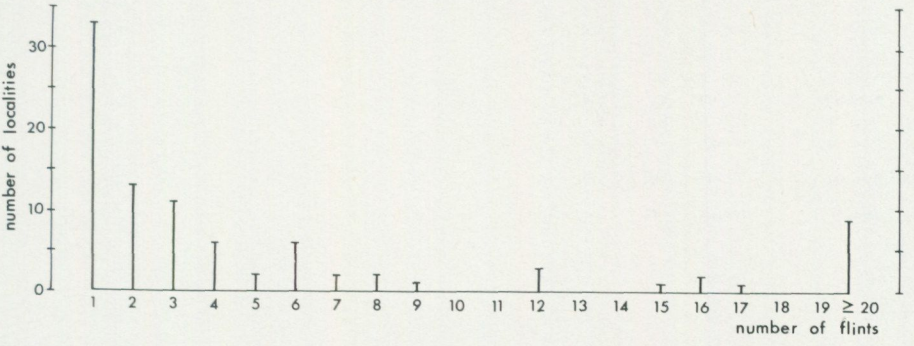


Fig. 11. Frequency diagram showing the number of localities plotted against number of flints.

TABLE 3. Localities in the study area.
Most localities with Halland type flints have yielded only the Hishult type of flint (type B, cf. the text and Fig. 10). The Båstad type (type A) is known from locality 35, and the Lycke type (type C) from localities 14, 51, 63/64, and 70 (cf. the text). Finds of Kristianstad type flint (type D) are marked (k). Below the postglacial marine limit there are also some foreign flint types (localities 5 and 6, cf. the text). For explanations, see pp. 40–41.

No.	Name	U T M	H.a.s.l. (m)	Type of locality and material	Kaolin	Limestone	Flints of Halland and Kristianstad (k) types: number < 2 cm	2–6 cm	6–20 cm	total/%	References
1	Rännenäs	UC758598	7	boring		55–58 m					SGU Uppsala 4C SO:2
2	Östorp	UC774678	15	boring		? 22–23 m					SGU Uppsala 4C SO:6
3a	Ränneslöv, Yttergård	UC783612	14	boring		? 78–80 m					SGU Uppsala 4C SO:16
3b	Ränneslöv, Åkesholm	UC780613	13	boring		? 43–54 m					SGU Uppsala 4C SO:17
4	Laholm	UC757628	9	boring		? 48– m					SGU Uppsala 4C SO:18
5	Tönnersa	UC755726	25–30	g.p. glac.				2		2/	SGÅ 71:16 CJ 23
6	Veinge	UC813686	50	g.p. glac.				4		4/	420
7	Veinge	UC825685	50	g.p. glac.			1	5		6/	421
8	Eldsberga	UC762747	30–35	g.p. glac.				1		1/	SGÅ 71:17 151
9	Eldsberga		35	boring		36–44 m					SGU Lund no. 1310
10	Perstorp	UC786776	45–50	g.p. glac.				43	7	50/1	SGÅ 71:18 CJ 31, 373
11	E Lundsgård	UC825758	80	r.c. till (s)				1		1/	542
12	E Lundsgård	UC825762	80	till (s)				1		1/	543
13	SE Boarp	UC829766	70	till (s)			2	1		3/	541
14	Göstorp	UC856745	55	g.p. glac.				5	2	7/	SGÅ 71:14 333, CJ 53
15	S Linghultsberget	UC854764	65	r.c. glac.				4	2	6/	SGÅ 71:15 CJ 54
16	Bröden	UC853781	100	till			1	2		3/	540
17	Tönnersjö	UC834795	90	c. local till				1		1/	422
18	Ormåsvägen	UC824813	55–60	r.c. esker				20	1	21/	SGÅ 71:19 (CJ 20), 20 (CJ 21,27)
19	Hålelyckevägen	UC829815	65–70	g.p. glac.				8		8/	SGÅ 71:21 (CJ 19), 22 (CJ 25,28)
20	E Iglasjön	UC834809	85	c. local till			10	15		25/2,4	424
21	E Iglasjön	UC837808	90	c. local till			2	1		3/	423
22	SW Bökhult	UC848800	120	c. till?			1	1		2/	425
23	Hatten	UC857798	120	c. till?			1	1	1	3/	426
24	Allared	UC884779	100	c. glac.				1		1/	429
25	Stora mad	UC893737	90	g.p. till (s)			4	11	2	17/	545
26	Öahus	UC844527	50	g.p. glac.				1		1/	SGÅ 71:3 CJ 10
27	S Ränneslöv	UC805575	30	g.p. glac.				1		1/	SGÅ 71:12 CJ 40
28	Våxtorp	UC843547	50	g.p. glac.				3	1	4/	SGÅ 71:4 176 HS CJ 11, 96
29	Skrårnered	UC862543	50	g.p. glac.			1	4		5/	400
30	Ränneslöv	UC814580	30	g.p.				1		1/	174 HS
31	Ränneslöv	UC822577	40	g.p. glac.				1		1/	175 HS
32	N Tormarp	UC838575	45	g.p.				2	1	3/	SGÅ 71:11 147
33	S Tormarp	UC840563	55	g.p. glac.				3		3/	SGÅ 71:10 CJ 17
34	Tormarp	UC844569	40	marl pit	gneiss kaoli-nized	in situ					Moberg 1886 Lundbohm 1888 Lundgren 1889 Hägg 1940
35	SW Ysby	UC827604	35	g.p. glac.				1		1/	SGÅ 71:13 148
36	Edenberga	UC833604	35	g.p. glac.				1		1/	418
37	NW Lejeby	UC830646	45	g.p. glac.				1		1/	419
38	Höggrostret	UC873619	50–55	g.p. glac.				7		7/	378
39	Bockastensbygget	UC903603	60	g.p. glac.			1	3		4/	398
40	Höggrostret	UC896644	45	g.p. glac.				2		2/	380

No	Name	U T M	H.a.s.l. (m)	Type of locality and material	Kaolin	Limestone	Flints of Halland and Kristianstad (k) types: number < 2 cm	2-6 cm	6-20 cm	total/%	References
41	Vippentorpet	UC917637	60	r.c.			2	1		3/	381
42a	Knäred	UC935649	70	r.c. glac.				1		1/	396
42b	Knäred	UC950660	75	g.p. glac.				4	2	6/	178 HS
43	Kattarp	UC878670	53	boring	40-121 m gneiss kaolinized						SGU Uppsala 4C SO:3
44	Skogaby	UC885668	50-55	glac.				2		2/	482
45	Skogaby	UC873674	50	glac.				1		1/	285
46	Kårarp	UC877682	55	field, glac.					1	1/	286
47	Kårarp	UC878688	60	g.p. glac.				11	1	12/	287
48	Kårarp	UC883685	55-60	g.p. glac.			16	28	3	47/	483
49	Kårarp	UC890689	60	field, glac.				2		2/	484
50	Krontorp	UC885695	65	r.c.				2		2/	288
51	Krontorp	UC888698	65-70	field				12	4	16/1	289
52	NE Kårarp	UC908706	100	r.c. glac.						x	
53	NE Kårarp	UC909707	100	glac.						2/	514
54	NE Kårarp	UC910708	105	g.p. glac.				9	3	12/	485
55	NE Kårarp	UC915708	105	r.c. esker				5		5/1	515
56	NE Kårarp	UC916712	100-105	on the esker						1/	516
57	NE Kårarp	UC918715	105	esker c.						1/	517
58	NE Kårarp	UC920715	115	esker c.						16/	518
59	Filshult	UC928706	135	on the road local mat.?						1/	491
60	Sibbasjön	UC925714	103	glac.at the shore				1		1/	512
61	Pukabjäret	UC928715	110	glac.						1/	513
62	Källshult	UC934718	100	r.c. esker				2	2	4/	511
63-64	Källshult	UC942723	95	3 g.p. glac.				12	3	15/	507
65	Källshult	UC943723	95	on the road					1	3/	335, Werner 1974:1036
66	Källshult	UC946723	95	till and on the road			1	5		6/	509
67	Källshult	UC944724	100	r.c. till and on the road				14	18	32/50	480, 510
68	Källshult	UC941729	110	field						2/	549
69	Källshult	UC941731	125-130	field, artefacts?						2/	550
70	Körsveka	UC972701	85-95	r.c. till				26	10	36/10	290, Ekström 1934 p.15
71	Drakabygget	UC925465	95	boring	4-29 m in fissures						SGU Lund 3C NO:8
72	V.Tockarp	UC940458	85	g.p. glac.				1		1/	536
73	Bastena	UC909514	75	at the road				1		1/	401
74	Bastena	UC916517	80	r.c. glac.				2			416
75	Floalt	UC927496	80	g.p. esker				4		4/	SGÅ 71:2, 236
76	Ö.Tockarp	UC963463	110	till (s) ?				1		1/	284
77	Höjaholm	UC982461	105	c. glac.				2		2/	431
78	Lönsjöholm	UC981475	110	r.c. glac.			1			1/	372
79	Krogshult	UC906550	80	glac.				4			CJ 56
80	Bjärnared	UC956530	100	till					1	1/	TP
81	Bjärnared	UC956535	100	till cut					1	1/	280
82	Oxhult	UC928564	85	r.c. till (s)				4	1	6/	481, Werner 1974:1071
83	NE Oxhult	UC932568	90	r.c. till				1		1/	553
84	Dansbygget	UC944574	90-95	g.p. esker				60	24	84/	SGÅ 71:9 CJ 55
85	Hishult	UC958559	100	till cut			1	2		3/	392
86	Stubbhult	UC987565	90-95	r.c. till				40	7	47/	SGÅ 71:8 CJ 42, 234
87	Kåphult	UC967585	115	till cut				1		1/	393
88	V.Kåphult	UC956594	95	till cuts						x	
89	V.Kåphult	UC963595	90-100	till cut			2	10	3	>20/	555
90	Smedhult	VC005508	105	field glac.				11	1	12/	531

TABLE 3, continued.

No	Name	U T M	H.a.s.l. (m)	Type of locality and material	Kaolin	Limestone	Flints of Halland and Kristianstad (k) types: number < 2 cm	2-6 cm	6-20 cm	total/%	References
91	S Össjö	VC015517	110	field glac.			1	1		2/	530a
92	Lärkesholm	VC008405	100	g.p. esker				9		9/	461
93	Jälla	VC008413 VC005413	100	on the road local mat.				1 4			462
94	E Åsljunga	VC010420	95	g.p. glac.			4	4		8/	466
95	Vanås	VC025432	110	r.c. till			2			2/	463
96	Järingsholm	VC043454	110-115	r.c. glac.					1	1/	523
97	Järingsholm	VC054455	110-115	field glac.				1		1/	524
98	Boalt	VC088447	surface ~130	tunnel		calcite					R. Stanfors
99a	Skånes Fagerhult	VC055484	115	boring	in fissures						Mohrén 1975
99b	Harastorp		120		in till						Lindström 1883 Lundegren 1934
100	Tallmo	VC077381	120	r.c. esker				1		1/	282
101a		VC064391	115-120	g.p.						x	Sydvatten 1969
101b	Lerbacken	VC069393	120-125	c. glac.			1	1		2/	355
102	Lerbacken		125		in till						Lundegren 1934
103	W Änglarp	VC091392	125	r.c. glac.				4(k)	2(k)	6/	283
104	Hårsjö	VC135427	115							/0,5(m.k)	351
105	Havraljunga	VC165473	100-105							x	HS
106	Snärshult	VC142476	115	glac.				3		3/	559
107	Emmaljunga		115			x					34
108	Emmaljunga		115	esker		x				x(k)	32 Weimarck 1942
109	Emmaljunga	VC172502	115	esker		x		2(k)	1(k)	>3(k)	33 + HS
110	Hörja	VC147304	80	g.p. glac.					4(k)	4/	341
111a	Gunnarstorp		50		in till						Lindström 1883 Lundegren 1934
111b	Hörlinge gård	VC188286	~60	boring	9-22 m grey gneiss somewhat kaolinized						SGU Lund 3D NV:119
112a	Humlesjö	VC108353	130-135	glac.			1	1+6(k)			564
112b	Lergravstorp		140		in till						Lindström 1883 Lundegren 1934
113	Vedema	VC171313	65	g.p. glac.						/1,7(k)	342
114	Björkeröd	VC179319	80	r.c. glac.						/0,9(k)	343
115	Kattatorpet		100			in till					Lindström 1877
116a	Mala		100		10m clay	x					Lindström 1877 Lindström 1883 Lundegren 1934
116b	Möllarp	VC155371	85	g.p. glac.			6(k)	8+8(k)	2+1(k)		565
117	Kvidala	VC127395	135	g.p. glac.						/(0,3k?)	350
118	Kvidala	VC132397	135	esker c.		x		2	1(k)	3/	349
119	Olastorp	VC144396	115	r.c. röad material?			1(k)	1		1/	347
120	Olastorp	VC143398	115	g.p. glac. road material?			1(k)	2(k)	1	1/	348
121	Hessleberga		100			x					Blomberg 1895 Lundegren 1934 Weimarck 1942
122	Torrarp	VC167385	100-105			in local till					Blomberg 1895 Lundegren 1934 Weimarck 1942
123	N Mala	VC202354	70-75	g.p. glac.						/0,6(k)	344
124	Bjärnum skog	VC200370	80			in situ					Blomberg 1895 Lundegren 1934 Weimarck 1942
125	W Bjärnum	VC186388	110	sand cut						/7(k?)	345
126	Slätteröd	VC188398	100	local till	x	x					Lindström 1883
127	Slätteröd	VC182399	100-105	local till		x					Blomberg 1895 De Geer 1899 Troedsson 1921 Lundegren 1934 Weimarck 1942 Hägg 1947

Abbreviations used in Table 3.

SGU	Sveriges geologiska undersökning (Geological Survey of Sweden)
4C SO:2	Topographical map sheet with borehole number
CJ	Christer Johansson, Halmstad

No	Name	U T M	H.a.s.l. (m)	Type of locality and material	Kaolin	Limestone	Flints of Halland and Kristianstad (k) types: number < 2 cm 2-6 cm 6-20 cm total/%	References
128	Björnum	VC195396	95		in situ	in situ		Grönwall 1915 Troedsson 1921 Stolley 1930 Troedsson 1930 Lundegren 1934 Weimarck 1942 Hägg 1947 Troedsson 1954 Christensen 1975
129	Ramsberga	VC196386	95			in till	x(k)	Blomberg 1895 Lundegren 1934 Weimarck 1942
130	Porrarp		108			in situ		Troedsson 1921 Lundegren 1934 Weimarck 1942
131	Porrarp		110	esker		x		
132	Porrarp		110	esker		x	x(k)	Weimarck 1942
133	Björnum norra		110	g.p. till		x		Weimarck 1942
134	Hemmeströ II		105			x		Lundegren 1934 Hägg 1947
135	Dalsjö västra		115	g.p. till		x	x(k)	Weimarck 1942
136	Björlången	VC213398	100-105			in till	x(k)	Moberg 1884 Lundgren 1894 Blomberg 1895 Troedsson 1921 Lundegren 1934 Weimarck 1942 Hägg 1947
137	Dalsjö		100		x			Lindström 1883 Blomberg 1895 Lundegren 1934
138	Hemmeströ I	VC209422	115-120			in situ	x(k?)	Troedsson 1921 Lundegren 1934
139	Hackatorp		115-120			in till	x(k?)	Troedsson 1921 Lundegren 1934 Weimarck 1942 Hägg 1947
140	Björkefalla västra	VC193443	115	r.c. esker			x(k)	Weimarck 1942
141	Kulleröd södra		110	mat. fr. rivulet			x(k)	Weimarck 1942
142	Kulleröd	VC213450	120		in situ	in situ		Troedsson 1921 Lundegren 1934 Weimarck 1942 Hägg 1947
143	Gundrastorp	VC197473	105-110	g.p. glac.sand			1	367
		VC199471	105	g.p.			2(k)	HS
144	Ekholmen		110		x			Lundegren 1934
145	Tviggasjö	VC237389	75		x			Persson 1972
		VC236395	85		x			
		VC241395	80		x			
		VC237401	75		x			
146	Ubbarp	VC255406	80		x			Persson 1972
		VC253406	85		x			
		VC254410	90		x			
147	Verum I		108?			in till	x(k?)	Lundegren 1934 Hägg 1947
148	Verum II		107?		gneiss kaolinized			Lundegren 1934
149a	Verum III		110?		in till			Lundegren 1934
149b	Vesljunga	VC238543	~120	boring	21-28 m grey gneiss somewhat kaolinized			SGU Lund 4D SV:5
150	Hörlinge		80-85		x			Lundegren 1934

SGÅ 1971	Lidmar-Bergström & Johansson 1971
HS	Harald Svensson, København
TP	Torsten Persson, Helsingborg
x	The actual object occurs but quantities are unknown
c.	Cut
glac.	Glaciofluvial material
g. p.	Gravel pit
r. c.	Road cut
(s)	Sandy and gravelly material
(k)	Kristianstad type of flint
(m.k)	Mainly Kristianstad type of flint

DESCRIPTION OF LOCALITIES

At localities 1–4 and 9 there is Cretaceous limestone *in situ*. For some of the borings the records are vague, indicating ''probably limestone''. In principle there are two kinds of flint localities, namely those where the flints are found in till and those where they are found in glaciofluvial deposits.

The first localities on the list are Nos. 11–13, which have yielded comparatively few and small flints. The next till localities are Nos. 16, 17, 20, 21, 22, and 23. These are located southwest of a pronounced valley trending N 54° W.

To the northwest, the prolongation of this valley is crossed by the Eldsberga esker, which carries flints from the crossing point all the way downstream. Northeast of the map area the esker has been searched in vain for flint (three sites indicated in Fig. 32a). Not far to the south and east of the till localities there are other glaciofluvial localities with flint: Nos. 14, 15, and 24. Further southwest, the glaciofluvial localities 6 and 7 are located at Veinge. No. 6, as well as No. 5, are situated below the marine limit (ML) and contain some flints not belonging to the A–D suite but typical of coastal Halland (Lidmar 1965a, b).

Of the localities mentioned, Nos. 10, 18, 20, and 25 are rich in flint. At localities 10 and 25 some of the flints are intact nodules while 25 also includes some siliceous limestone. The NW–SE trending valley mentioned above seems to be a probable source area for the flints at several of the localities.

Localities 26–38 and 40 are all situated in the area of glaciofluvial delta deposits at or below the ML (Mörner 1969, p. 117). The flints are few and comparatively small. The richest locality is No. 38. It is difficult to indicate any plausible source area. Locality 34 is a marl pit (now water filled) where kaolinized bedrock and a Cretaceous



Fig. 12. Locality 67 Källshult. The flints were found at the spade in the overgrown till cutting on the right side of the road.

conglomerate once were found. The age of this sequence was determined by Hägg (1940) as Gault-Cenomanian (see Fig. 33). The conglomerate was overlain by a till containing both Silurian and Cretaceous erratics. This locality is discussed further below.

Except for No. 59, localities 44–65 are situated in glaciofluvial material. Nos. 44–51 are situated in delta deposits formed at the ML. An esker extending to the northeast from these deposits was mapped with the aid of aerial photographs, which means that only the morphologically protruding parts were distinguished (Fig. 17).



Fig. 13. Close-up of till cutting shown in Fig. 12. The stones at the hammer are flints. The very local dominance of flints in the till indicates a local derivation from weathering residuals preserved on the leeside of a hill (cf. Fig. 17).

There are many localities in this esker (52–58, 60–65), and many of them are rich in flints. The esker passes south of the till localities 66 and 67. No flints were found in any material northeast of these localities. At No. 67 several large flints were first observed in the road surface. After much searching a spot at the roadside was discovered from where the flints were obviously derived (Figs. 12, 13). Digging here exposed a till deposit, rich in flint and silicified limestone, from which samples were collected. Many flints were large, with an irregular nodular surface, which indicates that they have not been transported far.

A comparable locality is No. 70 at Körsveka in the Krokån valley. This locality was already known at the beginning of this century, although the only published record is a note by Ekström (1934, p. 15). The find is probably represented on maps by Josef Eklund, *e.g.* on *Karta över Sveriges berggrund* (1958), where there is a small sign for Cretaceous rock at the right point (see also Fig. 1 in this paper). Important information on the locality was presented in a letter from J. Gudmundsson to the Geological Survey of Sweden in 1932. Jan De Geer provided me a copy of the letter. It is stated that about 15 years earlier, when the new road was under construction, flints were found in the till between the river Krokån and the village of Körsveka. Before I received this information I had visited a number of gravel pits and road cuts in the area (even between Krokån and Körsveka) in search of the locality indicated by the map sign, but without success. With the more exact information at hand, it was possible to walk along the roadside all the way until at last flints were found in the road cut. They were found only along the east side of the road and only along a distance of 200 m, and they were abundant only along a few tens of metres. Adjoining glaciofluvial deposits, only a few metres away, apparently lack flints. Thus the two localities (67 and 70) are characterized by flints concentrated at small points in till. The discovery of such points must depend on chance. A detailed map of locality 70 is shown in Fig. 14.

My interpretation of the Körsveka locality is that the flints were picked up from a niche in a small hill, probably transported over the small valley (dashed line in Fig. 14) and deposited on a slight upward slope. The conclusion is that the flints are found close to the place where they were originally formed. Compared with the Källshult (No. 67) flints, the flint pieces are somewhat smaller. However, the flints can not have been transported far as the concentration is as high as 10%. This percentage can be compared to 50% at Källshult (No. 67) and 2.4% east of Iglasjön (No. 20).

Locality 67 (Källshult) is situated in a peripheral part of the Krokån valley system and No. 70 (Körsveka) in the central part of the Krokån valley. This valley may also be the source area for the flints at localities 41, 42a, and 42b.

The flint localities 72–79 are characterized by their location in glaciofluvial material (questionable for 76) and by the fact that the surrounding till seems to be free from flints. In this area the bedrock rarely reaches the surface (Fig. 4). The flint pieces are small and few. The source areas should be looked for further to the northeast and for locality No. 77 also further to the east.

Nos. 80 and 81 are till localities, each with one fairly large flint. One of these is an

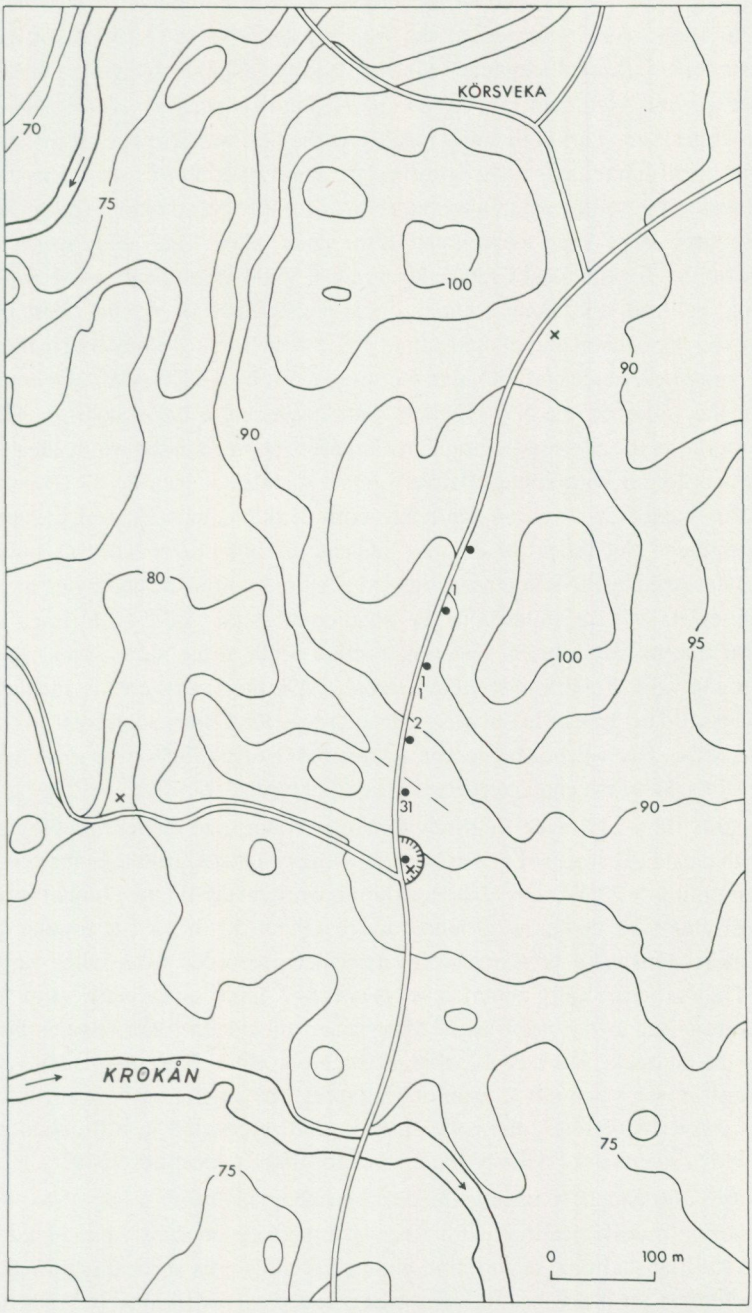


Fig. 14. The locality at Körsveka (70). The figures along the road show the amount and position of flints in the road cut (till). The small gravel pit (glaciofluvial material) to the south has not yielded any flints (x). Black dots are lamp-posts. Dashed line indicates the continuation of a small valley.

intact nodule. Nos. 82, 83, and 86 are also till localities, the latter being rich in large flints. No flints were observed in the esker east of No. 86. The esker extending northeastwards to Kåphult includes the rich locality 84 (Dansbygget). Further to the northeast the very rich flint locality 89 (V. Kåphult) is situated, which also contains siliceous limestone. This is the only locality in the northwestern part of the study area where the local inhabitants have observed the concentration of flints. The locality is situated just to the southwest of a marked NW–SE (N 55°W) trending valley. No. 86 is situated southwest of a less marked part of the same valley. This valley seems to be the probable source for the local Cretaceous erratics. The flint at localities 38 and 39 may very well be from the same source. Localities 90 and 91 are in tilled fields on glaciofluvial deposits in one of the distinct NE–SW valleys. The material is most likely derived from local loose material, and the source may be the NE–SW valley mentioned above or the valley on the NW–SE line from Hörjaåsen to Lake Storesjö. These two valleys merge in the Storesjö region. The largest flint piece in the whole area is 22 cm long. It was found with some relatively intact nodules at locality 84 (Dansbygget). Taking this locality with many flints into consideration, with its well preserved and large specimens, localities 80–85 may indicate a flint provenance not only in the valleys mentioned but also in other protected positions within the nearby area.

Localities 92–97 are situated in the southernmost part of the old Lagan valley, except for one in glaciofluvial material. Further north in the valley, flints have been looked for in vain. Therefore it seems probable that the source area is situated in this southern part. This glaciofluvial course has also yielded flints southwest of the study area (Fig. 32a). Sven-Erik Magnusson discovered the first flints from this area. Some of these flints are of the characteristic Kristianstad type (Table 7).

At locality 98 a 2 m wide fissure with clayey contacts to the surrounding gneiss is filled with a calcite cemented gneiss breccia with crystallized calcite in the centre. This fissure, trending N 20°W, was observed during work on the Bolmen tunnel (see p. 11), at a level about 30 m below ground surface (about 50 m a.s.l.). Similar fissures, though more narrow (a few cms wide) have been recorded from other parts of the tunnel. They are especially common southwest of Värsjön and southwest of the study area. Even as far to the north as Markaryd narrow calcite filled fissures have been found in the bedrock. The possible role of fissures north of Markaryd is not yet known (Roy Stanfors, pers. comm.). Stanfors interprets the calcite as fissure fillings from previously overlying limestone beds. Locality 98 is situated in a pronounced E–W valley, which seems to be a likely source area for flints at localities 92–97.

Localities 100 and 101b have yielded a few rather small flint pieces. Nos. 107–109 are the northernmost localities with finds of limestone erratics. Flint of the typical speckled Kristianstad type occurs first within the study area at locality 103 and is the dominating type for the rest of the area, that is to the east of locality 103. The material at No. 103 is found in glaciofluvial deposits emanating from the northeast. The other flints west of Hörjaåsen (Nos. 100, 101a, b) may have a more local origin, even if they are also found in glaciofluvial deposits (cf. the situation at localities 92–98). The

limestone erratics indicate that there may still be a small remnant of Cretaceous limestone in the vicinity of Emmaljunga. The erratics at 104–106 must also have their source in the vicinity of Emmaljunga.

Data for localities in the southeasternmost part of the study area are extracted from the literature in most cases and will not be discussed in detail. It is obvious from the many localities with Cretaceous bedrock *in situ* and from the common occurrence of limestone erratics that the Cretaceous erratics are of local origin. Many of the localities are situated on the plateau between 100 and 120 m. Mostly, but not exclusively, the flints are of the typical speckled Kristianstad type (D). Some are transitional between the Halland and Kristianstad types (as are also some flints from the northwestern part of the study area).

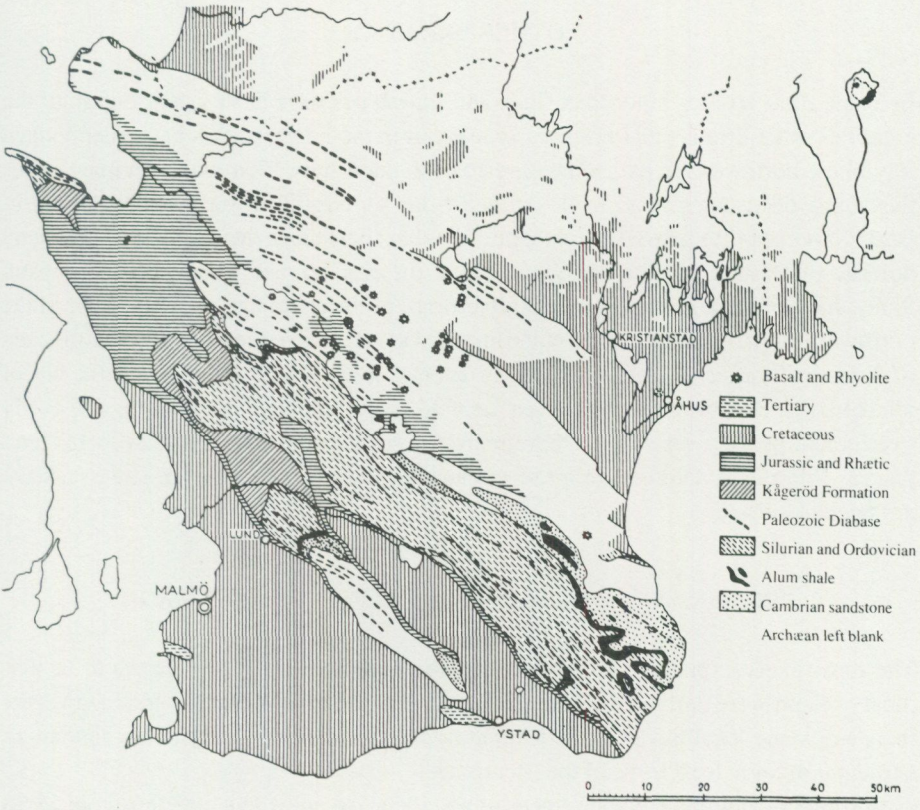


Fig. 15. The bedrock of Skåne. This map (from Hessland 1950, after J. Eklund) presents the largest number of small occurrences of Cretaceous rocks in northern Skåne. Some of the mapping was apparently based on erratics.

SUMMARY OF SOURCE AREAS OF FLINTS AND AREAS WITHOUT FLINT FINDS

In the northwestern part of the study area there is Cretaceous bedrock in the lower left corner of the map. The source areas for most of the erratic flints in the northwest seem to be the NW–SE trending valleys, the Krokån valley, and other areas protected from the northeast by more or less protruding hills. In the southeast particularly the western parts of the E–W trending valley passing Vittsjö, the area to the south of this valley (cf. Eklund 1944; Fig. 15 this paper), and the area west of Hörjaåsen are likely source areas for Cretaceous erratics. East of Hörjaåsen and its prolongation, Cretaceous limestone is still found *in situ*, and there are erratic flints and limestones.

Flints have not been found in the corner of Småland that extends into the study area. The area devoid of flints extends about 5 km beyond the Småland border into Halland and about 3 km into Skåne.

OTHER ERRATICS

In Table 3 no erratics other than flints and limestones have been listed, but at all the localities other erratics that might have assisted in the interpretation have been looked for. In the northwestern part some sandstone boulders have been found. In many cases they have been determined to be derived from Västergötland (or possibly Östergötland, Närke; Jan Bergström, pers. comm.) and in some cases they are accompanied by dolerite of Västergötland type. Sandstone of the characteristic Hardeberga type from Skåne has not been found. Sedimentary erratics of uncertain age are also found in the northwestern part, both together with flints and alone. It is not improbable that they are of Triassic/Jurassic or younger age. An attempt to date some pieces with the aid of microfossils was unsuccessful (Sven Laufeld, pers. comm.). The pieces are easily overlooked as they are mostly represented by small fragments that tend to fall into pieces. Silurian or Ordovician erratics, characteristic of the Baltic ice streams, have not been identified.

PROVENANCE OF THE ERRATIC FLINTS — DISCUSSION

The most likely explanation of the flint occurrence in the study area seems to be that most of them were derived from former Cretaceous deposits within the area. However, there are some localities described in the literature which may suggest an alternative explanation for at least some of the occurrences.

In southern Halland there are traces of an old ice stream with a direction from SE to NW (Lundbohm 1888; De Geer 1893; Lindström 1898; Mattsson 1962; Persson 1975b). One of the localities is the same as my locality 34 (Tormarp), where Cretaceous rocks were found *in situ* (Moberg 1886). Following on Precambrian rocks

and a small Cretaceous remnant, there is said to be a till with a number of ''Silurian'' (Ordovician and Silurian according to modern terminology) erratics, overlain by another till characterized by a large number of Cretaceous erratics and a few ''Silurian'' ones. The upper till was interpreted by Lundbohm (1888) as a weathered part of the lower one. He found that the lower till also contained a few Cretaceous erratics, while the upper one did not carry as many as he first thought, when inspecting the locality in the field. The re-evaluation was the result of a study of collected material, in which many of the alleged Cretaceous erratics were found to be strongly weathered and were determined as ''Silurian'' by their fossil content. Lundbohm gave the direction of the glacial striae in the locality as S 47°E to S 68°E. He interpreted the till as deposited by an Old Baltic ice stream coming from the southeast. A similar association of erratics in till at Bjärnared (close to localities 80 and 81) and in varved clay at Värestorp (just southeast of No. 27) was suggested by Lundbohm to have a similar origin. Erik Lagerlund (Department of Geology, Lund, pers. comm.) has found till layers (characterized by their content of Palaeozoic limestone) from a Baltic ice stream belonging to an older glaciation than the Weichselian in northwestern Skåne. Similar tills are also mentioned by Mohrén (1975, p. 24) and Daniel (1980, p. 103). A fossil in a sample from Tormarp (in the collections of the Department of Geology in Lund) is determind by Anders Martinsson (pers. comm.) as a species of a beyrichiacean ostracode which occurs in the Öved-Ramsåsa beds (Upper Silurian) and may indicate central Skåne as a possible source area.

The arguments for the opinion that the majority of the flints in the study area have a local origin are as follows. 1. Occurrence of flints above the ML in till and glaciofluvial deposits as well as in undisturbed glaciofluvial deposits below the ML. 2. Noticeably concentrated sites with a very high flint concentration in till. 3. Abrupt proximal occurrence of flint in glaciofluvial deposits. 4. Presence of numbers of noticeably undamaged flint nodules and large irregular pieces in certain localities. 5. Fairly distinct boundary between area in northwest dominated by the Halland type of flint (mostly completely devoid of characteristic Kristianstad flint) and area in the southeast dominated by Kristianstad flint; even if the Halland type of flint may occur rarely in the Kristianstad area, the completely different ratios make a provenance of the northwestern flints in the Kristianstad area completely impossible. 6. If the flints were derived from the Kristianstad area, there should be a steady decrease in their amount with distance away from the area, not an increase from the middle of the study area as is the case. (It could possibly be objected that erratics brought into the area by an ice stream from the southeast may have been removed by or protected from a northeasterly ice just in the same places as local material.) 7. Although Lundbohm (1888) found erratics characteristic of Baltic ice streams at Tormarp, Värestorp and Bjärnared, I have not found a single fragment of Palaeozoic limestone and must conclude that a southeasterly derivation of erratics is very exceptional within the study area.

PREVIOUS DISTRIBUTION OF CRETACEOUS BEDROCK IN THE STUDY AREA

This investigation has revealed that in several cases the supposed Cretaceous outliers indicated by the letter K in Fig. 1 (from *Karta över Sveriges berggrund* 1958) are obviously Cretaceous erratics rather than outliers. In southern Halland it is just two of the ''K:s'' that represent Cretaceous rock *in situ*. No reasons are published for plotting the position of individual Cretaceous symbols on the map, and the Geological Survey of Sweden has no additional unpublished information. As to the localities in Skåne, just five in the study area have been stated to be *in situ* localities (Lundegren 1934).

The flints and other Cretaceous erratics in the study area seem to be derived from previous local Cretaceous deposits and thus to indicate a former Cretaceous cover. It is likely that Cretaceous bedrock once covered the northwestern part of the study area up to a level of 100–120 m. The Lagan valley between the Krokån and Markaryd probably did not exist during the Cretaceous, which would explain the local absence of erratics. A Cretaceous cover between Båstad and Kristianstad areas seems to have existed at a fairly late date south of Hörjaåsen and in the Lake Värsjön area. This interpretation is in good agreement with the map of the bedrock in Skåne by Josef Eklund (1944; Fig. 15 in this paper; Eklund is also responsible for the ''K:s'' on *Karta över Sveriges berggrund* 1958). He placed symbols for Cretaceous rocks both in the Lake Värsjön area and southwest of Hörjaåsen, presumably because of flint finds. A thicker Cretaceous cover may have been present in the southwesterly area, which was not uplifted until after the Cretaceous sedimentation. An originally thinner cover may in part then explain the absence of flint in the Småland part of the study area (if flints were originally present in the local Cretaceous rock, which is not certain). A thorough discussion of the Cretaceous transgressions is given in a later chapter.

WEATHERED FLINTS

WEATHERED FLINTS IN THE STUDY AREA

A question that still has to be answered is why there is never any Cretaceous limestone present with the flints in the northwestern parts of the study area. A paper by Dury (1971) brought my attention to the conditions in northern Ireland where Cretaceous rocks are overlain by Tertiary lava beds. According to Charlesworth (1963) the geological history is as follows: The uppermost Chalk (Maastrichtian) was being eroded under terrestrial conditions before the first lavas were extruded. The vegetated land surface overridden by the first basalts carried a residual mantle of clay-with-flints. The red and yellow staining of these flints, according to Lamont (1946), are due to weathering under tropical conditions (but Charlesworth prefers another explanation). From very late in the Cretaceous to the end of the Paleocene the conditions were favourable to deep weathering (Dury 1971, p. 517).

As I had observed that many flints in the study area have a brown surface, I made a closer examination of the specimens in my collections. Most of localities 1–100 contain weathered flints with a brown surface. The colour often penetrates about 5 mm into the flints (Fig. 10 E, F). At the following localities more than 40% (at least two specimens) are weathered: 14, 18, 19, 28, 29, 38, 41, 48, 49, 51, 54, 70, 79, and 94. As the examination was not made in the field (which means that not every specimen from each locality has been examined because I became aware of the weathering too late) and because I do not have material from all localities, especially not from the southeastern part, it is difficult to draw any definite conclusions from the distribution. However, in my material from the southeastern part there are no weathered flints.

WEATHERED FLINTS IN OTHER PARTS OF EUROPE

ENGLAND

The Atlas of Britain (1963) illustrates the distribution of clay-with-flints in southern England. The flints are commonly angular or originally nodular, but well-rounded flints also occur. The well-rounded types occur in the lowermost Tertiary immediately above Cretaceous strata. Clay-with-flints is commonly thought to have been formed by solution of the chalk and contribution of clay from deposits above (Waters 1960; Loveday 1962; Green 1969; Hodgson *et al.* 1974).

Wooldridge & Linton (1955) consider the clay-with-flints to be the surface material of a subaerial platform, the remnants of which have survived on the Chalk uplands at about 210 to 245 m in southeast England. Here and there the surface has been stripped

by erosion or disturbed by solifluction. They propose a Mio-Pliocene age for the surface.

Waters (1960) describes a Late Tertiary peneplain in southwest England (Devon, Dorset, Somerset) at a height of 230–280 m on Chalk and Upper Greensand with clay-with-flints. The eastern part of this upland plain has an undulating character and comprises substantial relics of an Early Tertiary marine-trimmed surface with well-rounded chattermarked flints. The Late Tertiary surface can also be traced on to the surrounding rocks.

Loveday (1962), who has made a thorough investigation of the plateau deposits of the southern Chiltern hills, distinguishes between clay-with-flints and plateau drift. He restricts clay-with-flints to reddish coloured highly tenacious clay containing flints found immediately over the Chalk. It contains montmorillonite. He refers to other associated heterogenous flinty and clayey upland deposits, usually containing considerable quantities of sand, as plateau drift. The latter contains kaolinite and mica. The clay-with-flints underlies the plateau drift and reaches the surface above the Chalk in valley sides and on spurs, while the plateau drift covers the plateaus. Loveday considers the clay-with-flints to have been formed during Early Pleistocene interglacials and in Late Tertiary times. He regards the formation of clay-with-flints to include the dissolution of chalk, which provided the flints, and the weathering of overlying pervious deposits, which resulted in clay illuviation. The plateau drift is thought to be a more or less crude mixing of clay-with-flints with the previously overlying Tertiary Reading Beds, and at particular elevations with marine and fluviatile gravel and sand. According to Loveday, the formation of the plateau drift may have resulted from either periglacial or glacial conditions early in the Pleistocene. The high kaolinite content is thought to be the result from weathering either of the drift components in the Late Tertiary or of the drift itself in interglacial periods. The localized occurrences of laterite-like concretionary ferruginous material and secondary chalcedonic silica may possibly be related to a prolonged stable weathering period during the Mio-Pliocene.

Dury (1971, p. 518) suggests that the clay-with-flints might be a result of deep weathering during humid-tropical conditions prior to Middle Miocene times.

Hodgson *et al.* (1974) point to the sub-Tertiary surface as an important feature of the landscape in southern England and believe that the clay-with-flints is a unifying feature of remnants of this surface. They believe that the surface was exhumed during the Quaternary and that once the clay-with-flints was formed it played a protective role for the sub-Tertiary surfaces during cold periods in the Pleistocene. During warm periods the surface was lowered slightly by dissolution. ''However, it is clear that in some areas it is difficult to distinguish between remnants of the folded sub-Tertiary surface, irregularly lowered by dissolution and covered by Clay-with flints formed *in situ*, and younger erosion surfaces covered by similar deposits derived by mass movement from elsewhere or formed *in situ* from transported Eocene and/or other material.'' (Hodgson *et al.* 1974, p. 127).

SCOTLAND

In the Buchan district of Aberdeenshire there are small areas with well-rounded material. In the west it consists, on an average, of 80% quartz and 20% flint, in the east of 80% flint and 20% quartz in a matrix of sandy clay. The areas are situated on summits at a height of about 120 m. The flints are weathered grey, brown, red, and green. Here and there the deposits are overlain by till. The deposits are certainly Tertiary and possibly Pliocene according to Flett & Read (1921), either Pliocene or Early Pleistocene according to Gemmel & Kesel (1979).

FRANCE, BELGIUM, HOLLAND, AND GERMANY

Clay-with-flints *(argile à silex)* are found in France as well as in Belgium, Holland and in Aachener Walde in West Germany. Voigt (1943) compares these flints with the abundant flint in till in northern Germany. He gives the following summary: ''1) Durch die festländische Verwitterung des Tertiärs, unter deren Einfluss eine tiefgreifende Entkalkung des baltischen Kreidegebietes stattgefunden haben muss, sind mächtige und ausgedehnte feuersteinreiche Restlehme entstanden, die ein Analogon zu dem französischen Feuersteinlehm dem ''Argile à silex'', darstellen. 2) Diese vom Inlandeis aufgearbeiteten Feuersteinlehme haben den Hauptanteil der im Diluvium verbreiteten Feuersteingeschiebe geliefert. 3) Die aus den Feuersteinlehmen stammenden Geschiebefeuersteine sind im allgemeinen an ihrem Verwitterungsgrad (Bleichung, Braunfärbung, Zertrümmerung, Entkalkung) zu erkennen. . . 4) Die den Feuersteinmassen des Diluviums entsprechenden Kreidemengen sind nur zum geringen Teil glazial aufgearbeitet worden; der grösste Teil der Kreide ist bereits während des Tertiärs in Lösung gegangen. 5). . . .''

Pepper (1973) has compared the *argile à silex* of northern France to the clay-with-flints in southern England. The main French opinion has been that the *argile à silex* is a product of chalk dissolution that took place in the Early Tertiary. However, if deposits comparable with clay-with-flints as interpreted by Loveday (clay-with-flints *sensu stricto*) are considered, there is little remaining written evidence to counter the British views that clay-with-flints resulted from weathering and reworking processes operating on earlier deposits in the Pleistocene (according to Pepper).

CONCLUSIONS

This compilation reveals that flints remain in the landscape long after the carbonate of the original Cretaceous rock has disappeared by dissolution. My interpretation of the conditions in the study area is as follows. After the Cretaceous sediments were deposited, the sea regressed and the area was exposed to subaerial weathering. The northwestern part of the area may have experienced the following history. The

Cretaceous limestone was eroded and dissolved, leaving a residual flint nodule concentration with only a small amount of terrigenous material (cf. the clay-with-flints in England, with flints as weathering residue and clay presumed to have come from overlying Tertiary beds). The flints were exposed to subaerial weathering. Most of the weathering residue must have been removed during the intermittent glaciations throughout the Quaternary. The first ice stream, of which there are some known remnants in the study area, is one with Baltic erratics at or around localities 27, 34, 80, and 81. The erratics and glacial striae indicate transport from the southeast. This old Baltic ice stream probably had little erosive capacity in southern Halland, where it must have been close to its distal limit. The general ice movements over the area, including those with the strongest eroding power, must have been from the northeast. Ice streams from the northeast must have removed most material from older ice streams together with most of the local weathering residue. Residual flints have been left longest in positions protected from the northeast. Also, small patches with limestone may have been left. It is possible that residual flint concentrations may still occur in the supposed source areas (p. 48) beneath a till cover. The flints found today are those that were removed from their protected positions at the end of the Weichselian glaciation and deposited just before the melting of the ice. Many of the flints were picked up and transported by glacial rivers and deposited in eskers and glaciofluvial deltas. To a large extent the flint in the northwestern part of the study area may be considered as a Tertiary weathering residue. In the southeastern part the Cretaceous rocks were preserved much longer, and residual flint may have rested more on a reduced Cretaceous cover than directly on the Precambrian bedrock. Moreover, the flat topography offers few positions protected against glacial erosion. In line with this reasoning, and contrary to the condition in the northwest, weathered flints have not been observed in the southeasternmost part of the study area.

TOPOGRAPHY AND WEATHERING

DEEP-WEATHERED BEDROCK

Kaolin localities are relatively sparse in the study area (Table 3), with most of them in the southeastern part. The kaolin is mostly contained in till. In the northwestern part two findings are reported from borings. Kaolinized gneiss and weathered greenstone are also found beneath the Cretaceous conglomerate at locality 34 (Tormarp). (See Lundbohm 1888, p. 10.) In the boring at No. 43 (Kattarp) 80 m of kaolinized gneiss covered by 3.4 m of weathered basic gneiss are reported. This occurrence is probably in a fracture. Kaolin was found in fissures in a boring at locality 71. Mohrén (1975, p. 18) reports deep-weathered bedrock at Skånes Fagerhult (No. 99a). 100 m SSE of the church a boring was made 115 m a.s.l. A greenstone was reached after 28 m. At 33.75 m red, kaolinized rock with soft intercalations was met with. At 52.5 m more solid gneiss was reached (Erik Mohrén, pers. comm.). Mohrén has interpreted the occurrence as an oblique fracture and the weathering as subaerial. No mineralogical analysis of the reported kaolin deposits in the area have been made. Reservation must therefore be made for the possibility that the reported kaolin may be other types of clay. Along the Bolmen water tunnel (Fig. 32a), samples of clay from fractures all contain smectite and no kaolinite within the study area. Southwest of the study area kaolinite occurs at Perstorp (VC0022, Fig. 32; Roy Stanfors, pers. comm.).

From the Kristianstad area there are some analyses of kaolin. In borehole 2 at Odersberga (Bergström in Kornfält *et al.* 1978) north of Kristianstad, there is kaolin *in situ* with 80% kaolinite and some illite, muscovite and quartz 14–15 m below the ground surface. At 19–25 m there is 50% kaolinite with increasing amounts of illite, muscovite, quartz, and feldspar. At 28–30 m the kaolinite content is 20% and smectite begins to occur. At 34–34.7 m the kaolinite content is 10% and illite, muscovite, chlorite, and smectite occur in increasing amounts (the figures are estimates based on washed samples; Jan Bergström, pers. comm.). The unweathered bedrock was not reached. This profile shows that a kaolin weathered saprolite may contain a downwards decreasing amount of kaolinite. Thus the area with weathered rock southeast of Lake Kraxasjön (profile VII) may contain kaolinite even if the deeper parts at the tunnel level mainly contain smectite.

In the southeastern part of the study area there is kaolin *in situ* below the Cretaceous at localities 128 (Bjärnum) and 142 (Kulleröd). At No. 116a (Mala) there is 10 m of kaolin which perhaps also lies *in situ* as rounded corestones are reported from the deeper parts. At locality 148 kaolinized gneiss is found *in situ*. Perhaps the kaolin at locality 150 is also *in situ* as it is reported to contain stones at a depth of 2 m.

BOULDERS AND TOPOGRAPHY

Bergsten (1972) made the interesting observation that numerous well-rounded boulders are found in the till in the vicinity of Lake Ivösjön in northeastern Skåne. They were interpreted as corestones from the bottom zone of the kaolinized granite that had been moved a short distance and deposited immediately before the stagnation of the ice. In the region discussed here areas with abundant boulders have also been observed, and the explanation may be the same.

There is a conspicuous knoll between localities 14 and 15 (UC 853756, Fig. 16), reaching 60 m a.s.l. and with boulders on the southwestern side.

Boulders occur at several localities west and northwest of No. 67 (Källshult). Just southwest of Källshult a small hill rises from 110 m to 130 m a.s.l. (Figs. 17, 18, 19), and its southwestern side is crowded with boulders. The hill is situated in a lee position from the land ice that advanced from northeast.

Another area with boulders and bedrock knolls is situated around localities 84 (Dansbygget) and 89 (V. Kåphult). (See Fig. 20.) The abundance of flints once made an archaeologist interested in the area at No. 89 (V. Kåphult), and he was said to have had plans to excavate the small knolls. Actually they are not man made but made up of bedrock (Figs. 21, 22). The knolls are at 100–105 m a.s.l. set on the southwestern side of a larger hill reaching 115 m. A great number of boulders occur in the terrain. Large boulders also occur in hummocky terrain north of locality 84 (UC 947578, Fig. 20). The detailed topography (Fig. 23) may be caused by a dead-ice morain. It is not known whether the hills rising above 100 m in the southwestern corner of the map (Fig. 20)



Fig. 16. Small hill between flint localities 14 and 15 (Fig. 2, folded map after text), northwest of Göstorp, southern Halland. A typical example of sub-Cretaceous relief.

have a core of bedrock or not. Large boulders also occur on the glaciofluvial deposits west of locality 82.

Boulders that may be corestones have also been observed in the old Lagan valley in the vicinity of localities 94 and 95.

The boulders concerned consist of the local bedrock (gneiss) and are subrounded to subangular in shape (Fig. 24).

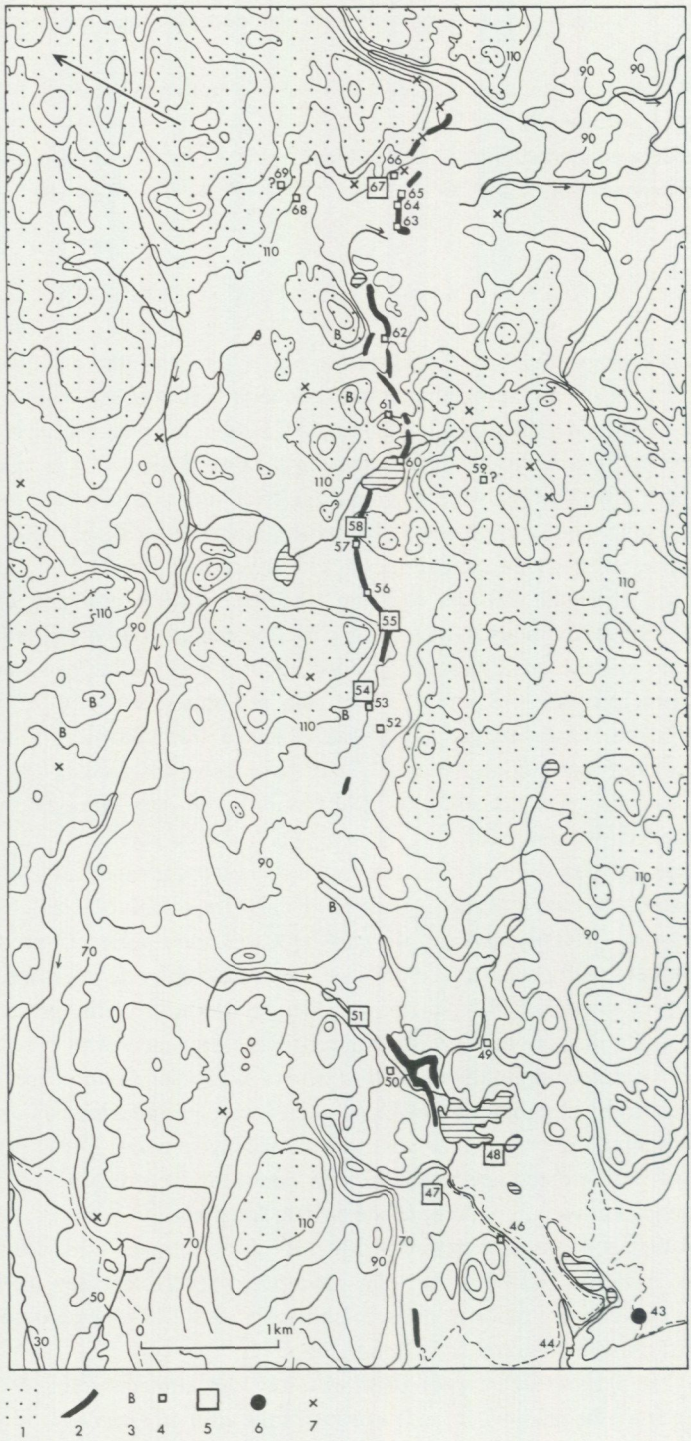
BOARPA BACKE — A WEATHERING LOCALITY

Fig. 2 (folded map after text) includes a symbol for a weathering locality in the northwest (UC 826773). A weathered greenstone was first observed in a temporary road cut on the hillside 100 m a.s.l. (A, Fig. 25). Further down along the road, beyond an exposure of fresh bedrock, the weathering locality B (Fig. 25) is at a height of 90–95 m a.s.l. Two profiles were studied (Fig. 26). At the surface both were covered by a black humus layer. In profile 1, below the humus layer there was a red-brown soil, and below this the weathered gneiss with a yellow-brown colour. In profile 2, somewhat higher in the hillside, weathered bedrock with core stones was exposed immediately below the black humus layer. The weathered zone measured about 125 cm. The core stones had a weathering crust about 5 mm thick. Two samples were collected from profile 1, viz. ''b'' from the red-brown soil and ''c'' from the weathered gneiss. One sample, ''d'', was collected from profile 2. The analysed samples excluded core stone material. They have been analysed at the Geological Survey of Sweden (SGU), Geochemical Division, by Dr Ann Marie Brusewitz, who has given the following report:

''The three samples were all coloured brown by iron oxides and had a high moisture content. (See table below.) The evaluation of the clay minerals is chiefly based on X-ray diffraction (XRD) analysis of the clay fraction using a variety of pre-treatments, such as treatment with potassium chloride or magnesium chloride to get information of the presence of degraded illite and of vermiculite. Because of the presence of iron oxides that might obscure the clay mineral reflexions, treatment with citrate-dithionite was carried out according to the method of Mehra & Jackson (1960). Specimens with clay particles oriented parallel to the basal planes were run airdried and glycolated to get information of the presence or absence of swelling minerals. XRD patterns were also taken of non-oriented specimens packed sidewards (Byström-Asklund 1966), of the clay fractions as well as of some of the coarser fractions.

The moisture at room temperature and at 110° dried samples were determined and also cation exchange (CEC) of the clay fractions. (See table below.) Particle size distribution curves were made at the soil laboratory of SGU. (They are not presented here. Instead, three histograms are given in Fig. 27.)

Results. The particle size curves all show a low clay content around 5%. This can also be seen from the table where the moisture of the airdried samples is very low (0.7,


110
90
98
90
65
69
67
68
65
64
63
110
B
62
B
61
60
59
110
58
57
56
110
55
110
90
54
B
53
B
52
B
110
90
B
110
90
70
51
49
50
48
47
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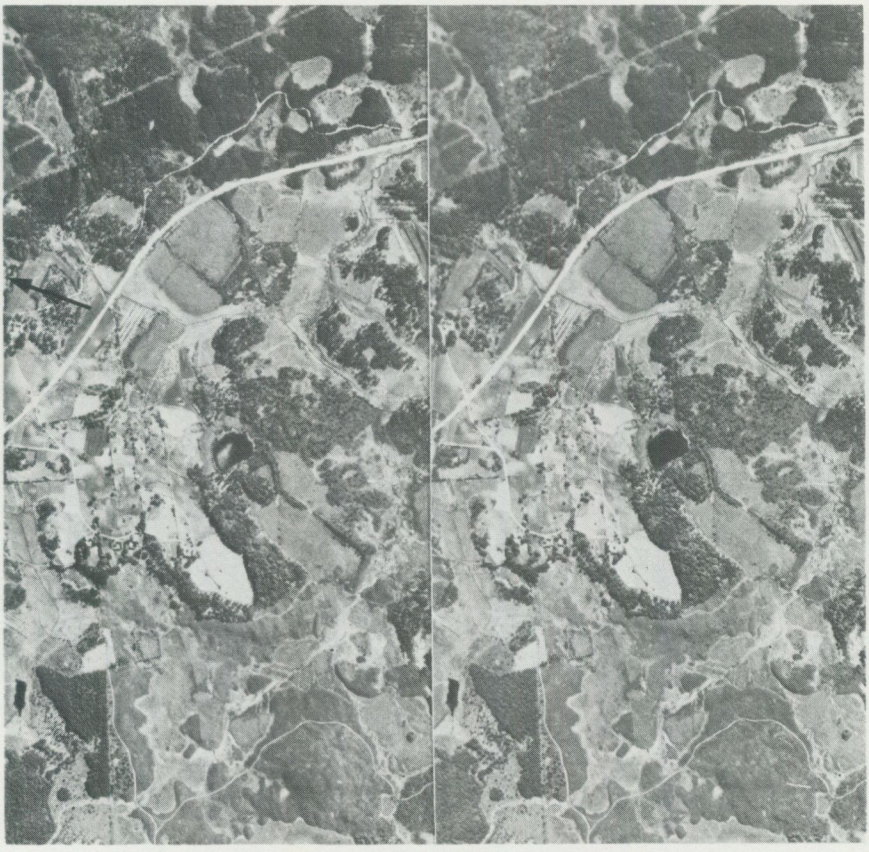


Fig. 18. Stereopair photograph of the hill southwest of Källshult. For location see Fig. 17 (hill north of locality 62). Note the boulders on the southwestern side of the hill, as well as on the hill without trees to the southwest. Note also the depression with the small lake and the esker alongside. From airphotos Na 47 63 55, and 56. Approximate scale 1:20 000.

Fig. 17. The topography in the Kårarp–Källshult area. The very high concentration of flints in the till at locality 67 indicates that at least residual weathering products of Cretaceous rocks have been preserved in a sheltered position at the foot of the adjoining hill.
1. Area above 110 m. 2. Esker. 3. Concentration of large boulders. 4. Cretaceous flint erratics, <10 pieces. 5. Cretaceous flint erratics, >10 pieces or 1%. 6. Kaolin (?) *in situ* (no analyses exist). 7. Locality visited, no Cretaceous erratics found. Contour lines at 10 m intervals. The dashed line is the 55 mm contour and approximates to the ML. The hill north of locality 62 is situated in a depression and rises from 110 m to 130 m a.s.l. See also Fig. 18. Flints, boulders (presumably detached corestones) and small hills often occur together in the study area. The map shows an example of a dominantly stripped etch-surface (sub-Cretaceous relief).



Fig. 19. View towards the hill southwest of Källshult (Figs. 17 and 18) from southwest.Note the boulders.

0.6%). Fine-grained weathering products are often found to have moisture contents of around 5%.

		b	c	d
Moisture wet to airdried	%	18	13	15
Moisture airdried to 110°C	%	not determined	0.7	0.6
CEC mequ./100 g		38	29	13
Clay fraction	%	6	5.5	5.5
Non silicate minerals		amorph. iron oxides + organic material	goethite	goethite

The introductory XRD runs of non-oriented samples all give poor diffractograms. Sample b, for instance, from the uppermost part of profile 1 does not give any distinct reflexions at all and this material gives impression of being amorphous. The sample further down from the same profile shows some reflexions from hk-planes indicating a sligthly higher crystallinity. Reflexions from goethite are present in this sample. The sample from the other profile shows goethite reflexions and a small peak from the strongest quartz reflexion. The background of all samples is high. The ''oriented'' specimens give some indication of the presence of clay minerals of interstratified

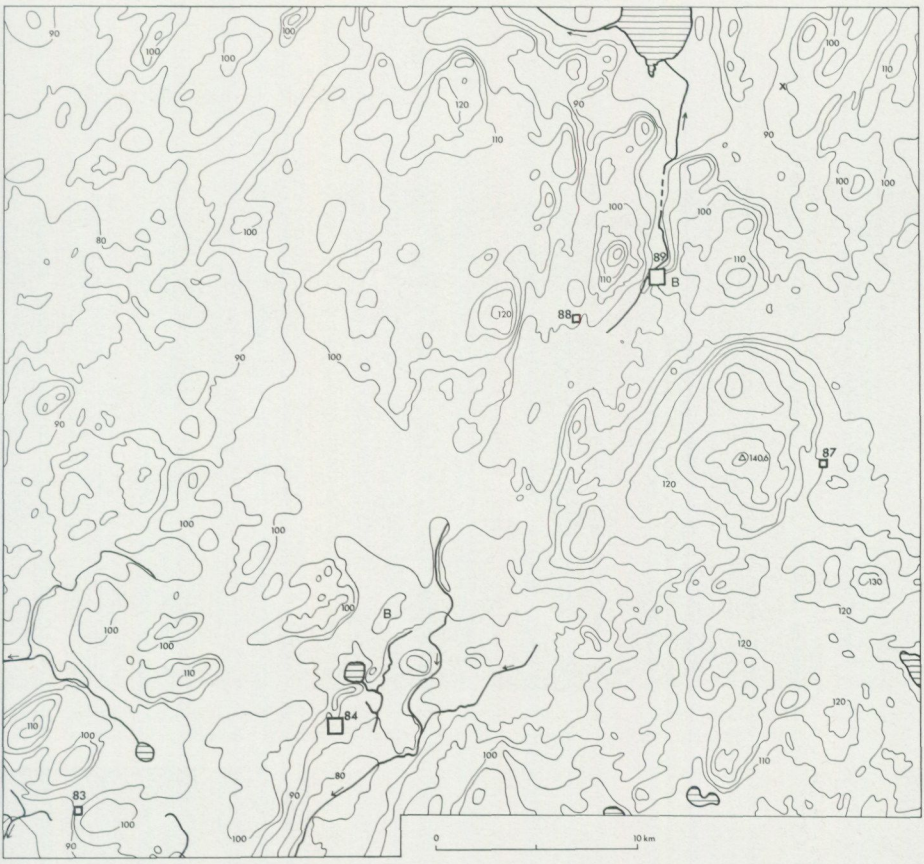


Fig. 20. Topography around the rich flint localities 84 and 89. Contour lines at an interval of 5 m. For legend see Fig. 2 (folded map after text) or 17. An example of a dominantly stripped etch-surface (sub-Cretaceous relief).

nature. The XRD curves from material with removed iron oxides give somewhat more clear patterns, also the XRD pattern of sample b shows reflexions similar to those of the other samples, but weaker. The dominating clay mineral can be described as a mixed layer mineral of chlorite and vermiculite. There may be some smectite layer present but not to give definite reflexions of this mineral. A 7Å reflexion present most probably belongs to chlorite, but kaolinite cannot be excluded. No HCl treatment has been made. Heating of the samples c and d to 600°C gives slightly different results indicating a higher degree of weathering products in sample c than in sample d. Sample b has not been heated. It can be noted that illite reflexions are lacking.

The coarser fractions all show a similar mineral composition of quartz, feldspar and amphibole. Plagioclase is the dominating feldspar.

Sample d from profile 2 has a small content of mica. The fractions > 20 μm lacks mica altogether. This fraction, however, seems to hold chlorite partly altered to vermiculite.



Fig. 21. Hummocky terrain at V. Kåphult (southeast of locality 89) with boulders. An example of sub-Cretaceous relief with the stripped etch-surface and presumed detached core-stones.



Fig. 22. Rock outcrop at V. Kåphult (southeast of locality 89), the stripped etch-surface.



Fig. 23. Boulders in a hummocky terrain (possibly caused by a dead-ice morain) southeast of Dansbygget (northwest of locality 84).

The mineral study has shown that the three samples resemble each other. They all show poorly crystallized material in the clay fraction and, where better crystallized, the minerals can be classified as interstratifications of chlorite and vermiculite most probably mixed with a certain amount of layers of undefined character. The samples are coated with iron oxides. The top sample of profile 1 (b) also contains organic material. Most likely amphibole and chlorite constitute the parent material of the weathering products. Illite does not seem to be present.''

DISCUSSION

The grain size distribution is shown in Fig. 27, which gives about the same picture for the three samples. Sample b is more fine-grained than c and d, which instead have more medium-grained sand. The mineral content from the three Boarpa backe samples is much the same. The clay mineral content shows that weathering has not gone very far, since the minerals present are those produced first by alteration. ''The initial stages such as vermiculite in biotite or montmorillonite in plagioclase, are found under all types of climates. These are commonly intermediate stages in the weathering of



Fig. 24. Closely spaced boulders (presumably detached core-stones) at Torör, south of locality 25.

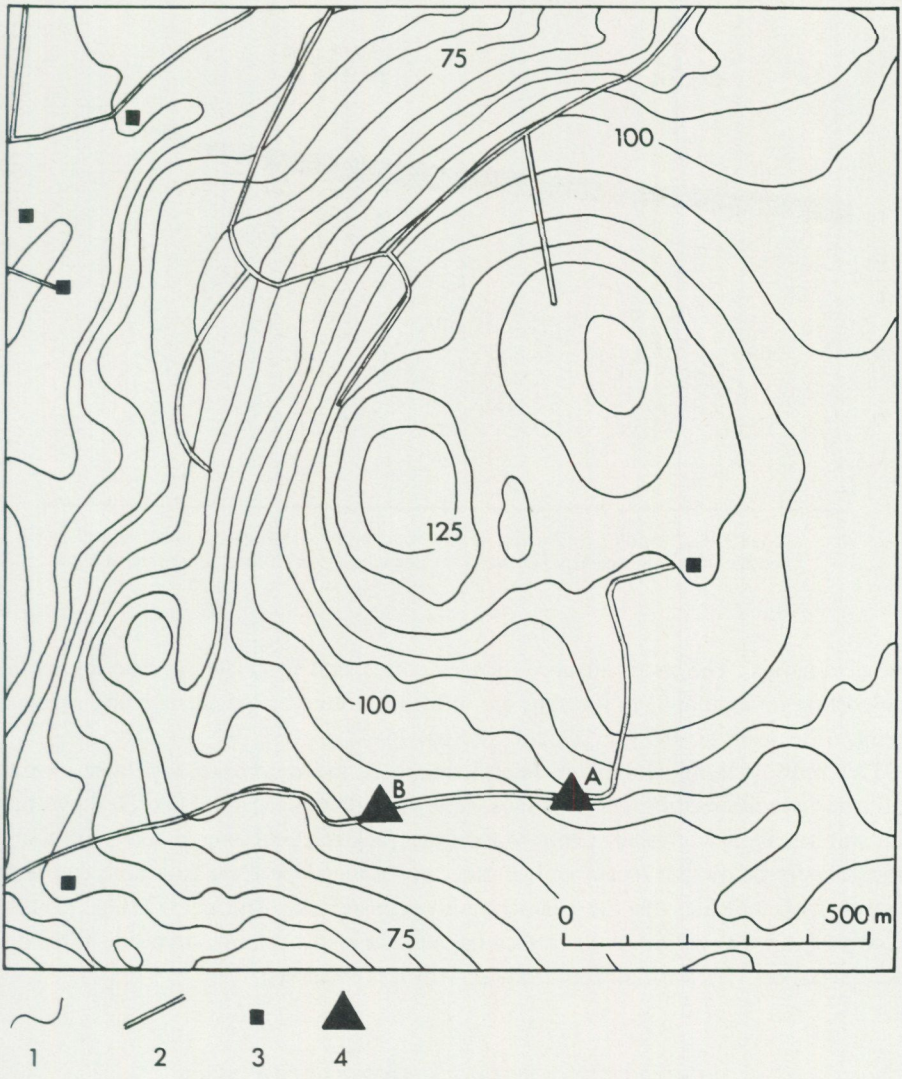


Fig. 25. Boarpa backe. 1. Contour lines at 5 m interval. 2. Road. 3. House. 4. Weathering locality.

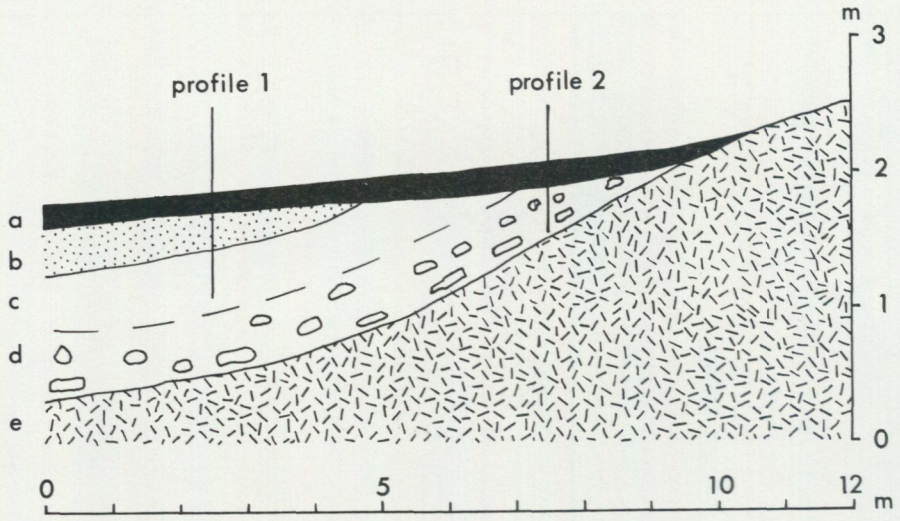


Fig. 26. Road cut at locality B, Boarpa backe, with the two sampling sites: a, humus layer; b, red-brown soil; c, weathered gneiss; d, weathered gneiss with corestones; e, fresh gneiss.

these minerals. The more advanced stages correspond to greater weathering of the supporting mineral and, as a result, are influenced more by the surrounding environment.'' (Tardy *et al.* 1973, p. 275; cf. also pp. 75–77.)

The most striking feature at Boarpa backe is the red-brown top layer, which indicates conditions different from those now prevailing in the area. Fig. 26 shows that the soil profile is truncated. Close to the fresh rock the least altered layers are found immediately below the recent soil. Further down the slope there is a more complete profile. This indicates that the weathering is not postglacial. The locality (Fig. 25) is in a lee position with regard to the last ice movements on the southwestern side of the hill Boarpa backe. This position could explain why it is preserved.

LOCALITIES WITH WEATHERED BOULDERS

Loose boulders of weathered rock have also been observed during field work in the area. At the locality directly to the south of No. 17 (UC 835788), a large block of gneiss was observed in which the white feldspar was weathered red a few centimetres in from the surface. At locality 46 a weathered greenstone was collected. Red-weathered boulders were observed at locality 68 and at localities in the Vänneå valley north of the Lagan River (VC 005656 and VC 015655). Granite boulders that suffered granular disintegration were observed at one locality north of No. 58 (UC 919731) and also at locality No. 76. In the middle of the area north of the Lagan River well-rounded and weathered boulders occur in a till cut (VC 087626).

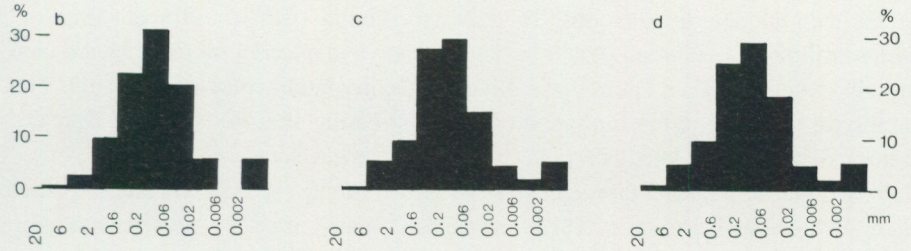


Fig. 27. Grain size distribution at Boarpa backe. Analysis: Geological Survey of Sweden. Letters indicate sampling position, see Fig. 26.

WEATHERING IN GRANITOID ROCKS IN ADJACENT AREAS OF EUROPE

Remnants of preglacial weathering occur at several sites in formerly glaciated areas of Europe. The following account concentrates on deep weathering phenomena in granitoid rocks (Thomas 1976, p. 412) in adjacent regions of Europe and even outside the glaciation limit. The purpose is to obtain a picture of when and where deep weathering took place and where landscapes can be found with a morphology caused by deep weathering.

SWEDEN

Kaolin occurs at some localities in Sweden, especially in northeast and central Skåne, where Mattsson (1962, p. 127) came to the conclusion that the deposits occur below Senonian (Kristianstad area), Keuper/Rhaetian–Jurassic (Fig. 1: Mesozoic rocks older than the Cretaceous) and Lower Cambrian strata. There are no known sediments in Sweden from the time interval between the Silurian and the Triassic. There always seems to be weathered bedrock below the Keuper (Upper Triassic) strata. In some cases there are large amounts of kaolin, but in many cases it is not known what kinds of clay minerals are present in the weathered material. Another difficulty in dating the beginning of the kaolin weathering is that the dating of the strata overlying the weathered substratum is generally unreliable due to poor palaeontological control. Thus it is often not known if sedimentation on the weathered surface began in the early or middle Keuper, the Rhaetian or the Lias.

Troedsson, who studied the Triassic and Jurassic in Skåne and the tectonics and weathering in connection with these strata, came to the following conclusion (1942, p. 322, in my translation): ''As a summary it can be said that the Precambrian surface in Skåne was still covered by Cambro-Silurian sediments in Carboniferous time and thus protected against chemical weathering. Conditions were produced for uncovering of the Precambrian surface first through the Variscan movements in the Permian, con-

nected with the dolerite eruptions. Thereafter the Permo-Triassic arid weathering, *i.e.* montmorillonite weathering, could be activated to yield material for the Kågeröd beds (middle Keuper). Then, during the Rhaetian, came humid weathering of the Precambrian, resulting in the formation of kaolin at Färingtofta, Forestad and Djupadal (central Skåne) and of kaolin clays in the Rhaetian-Liassic beds.''

Nilsson (1958) made a thorough analysis of two borings at Sandåkra and compared them with one at Tormastorp. These borings are situated in a north–south trending rift valley at the northwestern end of the Nävlingeåsen uplift (Fig. 1). In one of the borings at Sandåkra (No. 2, the only one that penetrates to the Precambrian bedrock) 21 m of weathered Precambrian bedrock were found overlain by 1 m of conglomeratic kaolin. Above this follow strata which Nilsson supposed belong to the Vallåkra Beds (Lower Rhaetian, see Fig. 29) and strata of later Rhaetian-Liassic age. According to D. Guy-Olsson, Swedish Museum of Natural History, Stockholm (pers. comm.), the level 38–62 m in the Sandåkra 2 boring belongs to the Lias and not to the Upper Rhaetian as suggested by Nilsson. Thus, it is probable that the unfossiliferous strata directly above the kaolin are younger than Early Rhaetian. At Tormastorp the following sequence is recorded from the bottom: 20 m of weathered Precambrian bedrock, 120 m of kaolin, followed by Rhaetian-Liassic strata (according to Nilsson 1958, p. 103, younger than the equivalent section at Sandåkra 2, which means that they would be younger than the Rhaetian).

Three borings were described by Bölau (1966) in the Söderåsen area (Fig. 1). In the two borings from Bonarp the kaolinized Precambrian bedrock is overlain directly by Liassic strata, which are overlain by basalt. In the boring from Knutshög the kaolinized bedrock is overlain by about 20 m of pure kaolin with pyroclastics in the upper part, succeeded by basaltic tuff and basalt. The age determinations of the basalts in Skåne are not yet conclusive. The volcanism had probably started as early as during the transition from Early to Middle Jurassic as suggested by Tralau (1973) on palynological grounds. Age determinations by Printzlau & Larsen (1972, K/Ar), Bylund (1973, paleomagnetic) and Klingspor (1976, K/Ar) give Jurassic but also Early Cretaceous ages. Bölau (1966) suggested that the basalts in the Sandåkra-Råbockamölla area (on the western side of Nävlingeåsen, Fig. 1) were older than those at Bonarp and Knutshög. The Sandåkra-Råbockamölla basalts are deeply weathered while those from Bonarp and Knutshög are fresh. More precise age determinations of the basalts in the future may give us information about the duration of kaolin weathering in Skåne.

Also in northwestern Skåne the Precambrian gneisses are kaolinized in the border district between Hallandsåsen and the Ängelholm Trough. The kaolin weathering is dated to the transition between the Triassic and Jurassic (Norling in Daniel 1978, p. 22–24).

The kaolin occurrences in Skåne and Sweden as a whole are summarized by Byström-Asklund (1969). The Geological Survey of Sweden has started a detailed survey of kaolin occurrences in Skåne. Preliminary results indicate that there is much

more kaolin than previously known (Bergström & Shaikh 1980). The best known kaolin localities are situated in the northern periphery of the Kristianstad area where the Precambrian emerges from the Cretaceous cover (Moberg 1903, Grönwall 1915, Lundegren 1934, Troedsson 1954). At the old quarry at the northern end of the Ivö Island the residual kaolin is reported to have been 40 m thick. The kaolin contains core stones. It is covered by Campanian strata (cf. p. 127). Tors were discovered north and west of Ivö (Bergström & Lidmar-Bergström in Wikman *et. al.* in prep.; Lidmar-Bergström & Rapp 1979). These tors were probably prepared by chemical weathering in a warm humid climate in the Mesozoic and/or possibly also in the Tertiary.

Mattsson (1962, p. 329) pointed out that pre-Quaternary weathering remnants are more abundant in Sweden than usually realized. Additional information on deep weathering in southwest Sweden is provided by Hillefors (1969, pp. 16–22), who also gives some references from other parts of Fennoscandia. One of the localities with alleged kaolin is situated about 200 m a.s.l. in zone 1 just east of the map edge, Fig. 35 (Larsson & Sandegren 1956, pp. 120–122, locality at Kvarntjärn).

Agrell (1973, 1974) described deeply disintegrated rocks from the Sommen-Åsunden region in southeastern Sweden. The disintegration reached at least 6 m below the surface and the weathered mass contained rounded residual boulders.

Samuelsson described weathering of granitic gneiss from the Swedish west coast which he ascribed to ''some kind of mechanical disturbance''. He meant ''that even in recently deglaciated areas, e.g. Scandinavia, a considerable regolith might have had time to develop. It should also be possible for post-glacial weathering to develop beneath a cover of till.'' The circumstance that mechanical disturbances make rocks weather easier does not preclude a greater age. Hence these disturbances do not present any argument against pre-glacial weathering. I have observed weathering of probably the same kind at Stensjö (UC 544965) on the west coast. Weathering pits of supposed post-glacial age are also reported from southwest Sweden (Samuelsson & Werner 1978). When visiting the flint locality at Lake Fegen (p. 121), I observed that the shore consists of weathered material, indicating that the bedrock here is also easily weathered.

NORWAY

Kaolin also occurs in Norway, but the known amounts are fairly small. The largest known occurrence is situated near Flekkefjord on the southern coast (Låg 1963). Kaolin is also reported from Andøya island in northern Norway (Reusch 1903, referred to in Låg 1963). This occurrence may have something to do with the presence of Jurassic and Cretaceous rocks on Andøya. These rocks, which are now downfaulted, rest on an uneven surface (Ørvig 1960, p. 568) comparable to the sub-Cretaceous surface in the Lake Ivösjön area (Gjessing 1967, p. 116). Other cases of presumed pre-glacial weathering are referred to by Låg (1963) and Dahl (1961).

DENMARK

The exogenic origin of the kaolin occurrences in Skåne has never been questioned, but for those on Bornholm, Denmark, different authors have different opinions (Callisen 1934; Hansen 1940; Almeborg *et al.* 1969). It seems very likely, however, that the kaolin in the two neighbouring areas have the same origin. The thickness of the kaolin occurrences at Rönne on Bornholm may reach more than 50 m (Rasmussen 1966, p. 35). It is overlain here by clays of Purbeckian (youngest Jurassic, see Fig. 29) age (Gry *et al.* 1969, p. 50). Besides kaolinized basement rocks, kaolinized Silurian strata are also found on Bornholm (Rasmussen in Nørrevang & Meyer 1967, p. 85), which indicates that the kaolin at least is not older than the Silurian. The granular disintegration of the Svaneke granite on eastern Bornholm is described by Mattsson (1962). Remnants which I would call tors originated at the shore when recent wave action removed the weathered material. These remnants are illustrated by Mattsson (1962, pp. 43, 58, 59). The age of the weathering may be interglacial or older (Mattsson 1962, pp. 89–90).

SCOTLAND

Fitzpatrick (1963) mentions 125 localities with weathering from Buchan and 17 from other parts of Scotland. The weathered crust may be as thick as 13 m. The weathered rock is generally described as consisting of a homogeneous sandy material. The weathering is supposed to be of pre-glacial age. Both tors and rotted granite occur in the Cairngorm mountains and are presumed to be of pre-glacial age (Linton 1955; Sugden 1968).

ENGLAND

In Cornwall and Devon the kaolin saprolite on Carboniferous granites has been interpreted until recently as being of hydrothermal origin. The reason for this interpretation has been that the kaolinized zone may exceed 200 m in places, that there are occurrences of kaolinization at depths beneath relatively unaltered aureole rocks, and that the deposits usually are funnel-like in form, narrowing downwards. However, in some areas of Bodmin Moor there is a thinner crust of poorly kaolinized granite. There is also an exact correspondence of this crust with the present topography and the funnel structure is absent. It has been suggested that deep tropical weathering during the Tertiary could be a possible cause (Bristow 1969, pp. 279–280). The following notes on the morphology are interesting in this respect: ''There is a clear relation between landform and china clay deposits in those areas where the depth of erosion below the roof of the granite has been sufficiently great to expose hard granite in the areas

between the funnels, *e.g.* Bodmin Moor, Lands End and Dartmoor. In areas such as these the topography can be used as a guide to the location of china clay deposits.'' (Bristow 1969, p. 282.) The different opinions on the origin of the china clay are discussed by Thomas (1976, pp. 415–417). In a new investigation into the genesis of kaolinite in the china clay deposits in southwest England, hydrogen and oxygen isotops have been used (Sheppard 1977). Sheppard states that the kaolinites from the major china clay deposits originated by subaerial weathering but that the intense supergene kaolinization was probably localized by earlier postmagmatic processes. He suggests that ''much of the kaolinization was probably Tertiary or earlier because near the edge of the Dartmoor Granite at Bovey Tracey a deep tectonic basin is filled with Eocene to Miocene sediments including kaolinite rich beds derived at least in part from the Dartmoor Granite'' (Sheppard 1977, p. 575). However, as low as in the Lower Cretaceous Gault Clay west of Bournemouth kaolin is found that was probably derived from a source in eastern Dartmoor (Groves 1931, p. 73). The provenance was determined by analyses of the heavy minerals.

The literature on deep weathering in southwest England is rather confusing. One reason may be that the granite is disintegrated in different ways at different localities. Eden & Green (1971) describe a sandy weathering type, growan, from Dartmoor. They made grain size and mineralogical analyses of the growan and made comparisons with analyses of china clay. They found that the growan is distinct in composition from samples of china clay and came to the conclusion that the growan is a product of subaerial weathering. Tors are found in the same granite. Their origin has been discussed several times (Linton 1955; Palmer & Neilson 1962; Eden & Green 1971). Both Linton, who brought the idea to prominence, and Eden & Green come to the conclusion that the tor formation is the result of a two-stage process. The opinion now prevalent, held by Eden & Green seems to be that the tors have been exhumed from a sandy weathering zone, located principally in or near main river valleys. The exhumation is probably due to periglacial processes.

As a summary it can be said that on the granites in southwestern England there seem to be three kinds of weathered bedrock, namely 1, china clay produced by subaerial weathering localized in areas where late-magmatic processes and/or post-magmatic vein systems have prepared the ground for subsequent deep weathering processes and generation of kaolinite, 2, poorly kaolinized granite, and 3, growan, the sandy weathering type.

CENTRAL EUROPE

Bakker has described two different kinds of weathering products on granites in Central Europe. 1. Clayey weathering types, in general down to about 6 m, containing 15–30% clay of a mixed illite/kaolinite composition. Bakker says that this ''is an example of a soil type, formed under marginal tropical conditions, such as may be

found today at about 20°N on the eastern side of the continents, *i.e.* either under a seasonal climate with a pronounced dry period, or a perennially wet climate, but with a lower annual total than at the equator''. He dates this type of weathering to Late Oligocene and Miocene. 2. Sandy deep weathering types, to a depth of 6–10 m, containing 2–7% clay of a mixed kaolinite/illite composition. He says that ''the most probable date of the kaolinitic-illitic sandy weathering types appears to be early or pre-Quaternary. . . In our opinion, the climate conditions for the deep, sandy granite weathering were intermediate between those of the Gulf-state climate near the palm boundary (Cfa-climate) and the Mediterranean Cs-climate, . . .'' (Bakker 1967). He also reports another sandy weathering type with large quantities of gibbsite at higher altitudes in the Morvan (France) and Harz (Germany) mountains. He interprets this type as the lower parts of a more clay-rich soil type that has been truncated. He refers the origin of this type to the Paleocene–Early Eocene.

In the Bohemian Massif of the Variscan Mountains kaolinized igneous rocks occur at several places (Störr *et al.* 1977). Kaolins are found in the Lusatian Granodiorite Massif southeast of Dresden. The whole Lusatian block was tilted to the north in the Neogene and the kaolin crusts are covered by Upper Oligocene–Miocene sediments in the north. Most of the German kaolins occur in the area around Leipzig and Halle (the Main Central German block). In the northwest, the kaolin crust is covered by Eocene sediments. In the westernmost part of the North Bohemian Tertiary Graben the kaolinized granites of Fichtelgebirge occur together with Upper Oligocene–Miocene sediments.

In Czechoslovakia kaolin weathering has penetrated 50 m into the granite at Karlovy Vary, situated in the North Bohemian Tertiary Graben. In the Saxon-Bohemian Upper Chalk basin the Cenomanian rests on kaolin weathered granites, gneisses and porphyries. Demek (1964) described tors in the Bohemian highland that had been developed by chemical deep weathering in the Tertiary and denudation during periglacial conditions.

Kaolinized granites occur in the Sudeten Mountains in Poland. At Eulengebirge the biotite granite is weathered to a depth of 40 m at one locality. Most of the kaolin crust in the Sudeten Mountains has been removed by erosion as the area was uplifted to nearly 2000 m in the Neogene (Störr *et al.* 1977).

Dumanowski (1961) described a granular regolith in the Karkonosze Mountains (Riesengebirge, Sudeten Mountains). He suggested that the regolith mantle was formed either during interglacial periods or in the Tertiary. Jahn (1962) discussed the ''Origin of granite tors'' in the same area. The granitic grit is said to reach a thickness of 15 m locally. He came to the conclusion that ''the tors were formed by deep weathering of the granite chiefly during the Interglacials, and by exhumation, chiefly during the Glaciations (Periglacial).'' He also stated that ''not the character of weathering, but rather the type of the granite stucture leads to spheroidal structures'' (Jahn 1962, p. 43). Borkowcka & Czerwiński (1973) made some mineralogical and textural analyses of granite regoliths in the Karkonosze Massif. They came to the

conclusion that ''the Karkonosze granite regoliths should be assigned to granular regoliths of growan type'' and that mechanical disintegration had been more prevalent than chemical decomposition. They also concluded that the weathering had proceeded from the surface downwards. Deviations from the normal conditions were taken as evidence of ''the existence of zones which were metasomatized and hydrothermally metamorphosed at an earlier stage''. The processes that have produced the regolith ''might have been acting at the latest during the decline of the Tertiary, under conditions of a moderately humid and warm climate'' (Borkowcka & Czerwiński 1973, p. 54).

SOVIET UNION

On the Kola peninsula there are two different types of weathering crusts formed during two different geological intervals (Kiselev 1975). The older type is clayey, contains kaolin, and is found only occasionally. The younger one with clay, sand and gravel occurs widely. It is generally situated on high, even surfaces and can be 10 m thick. A belt with a weathering crust of clay, sand and gravel can easily be followed from the boundary of Finland to the foot of the Volnye tundra, a distance of 120 km. A weathering crust is also found in many places to the north of this belt.

The kaolinitic weathering crust of the crystalline complexes of the Ukrainian Massif is probably of Late Triassic to Jurassic age (Vachtl 1969, p. 21).Kaolin also occurs at Soanlathi in Karelen (Frosterus 1928).

FINLAND

Kaolin of the same kind as at Soanlahti is also known from one locality in the province of Uleåborg and one in southern Lappland (Frosterus 1928). In southwest Finland kaolinized granite occurs at Tyrvää (Härme 1949) and Nådendal (Hausen 1933, p. 146).

Bedrock weathered down to 100 m below the surface is reported from Laanila (Rosberg 1908; Sederholm 1913) and Tankavaara (Virkkala 1955) in eastern Lappland. This occurrence is a continuation of the weathering belt in the Soviet Union referred to above. Pre-glacially weathered bedrock is also reported from western Lappland (Kujansuu 1967, p. 23).

Kaitanen (1969) described tor-like forms from northern Finland, which he thought could not have been formed entirely during a postglacial climate. Granite tors are also described from the western side of Lauhavuori hill in southwest Finland (Fogelberg 1973), where they are located close to a remnant of Cambrian sandstone. The age of the weathering that caused the forms is unknown. Littoral washing removed the weathering debris when the area emerged from the Ancylus Lake 6200 B. C. The tors have also been affected by subaerial weathering in postglacial time.

This review of weathered bedrock in Northern and Central Europe is not complete. Additional references can be found *e.g.* in Gjessing (1967). Kužvart & Konta (1968) made a survey of localities with kaolin and weathering crusts in Europe and concluded that the weathering is of Carboniferous, Early and Middle Jurassic, and Cretaceous to Palaeogene ages (Table 11). Störr *et al.* (1977) distinguished the following periods of kaolinization: Ordovician, Carboniferous and Early Permian, Late Triassic to Early Jurassic, and Cretaceous to Miocene or possibly Pliocene. The examples of weathering remnants mentioned in this paper are intended to illustrate the fact that weathered bedrock of considerable age is not uncommon in Sweden and neighbouring areas of Europe. In places the weathering may also have contributed to the shape of the landforms.

BEDROCK MORPHOLOGY IN TROPICAL AREAS

If some of the weathering remnants found today in Northern Europe are the result of weathering in a warmer climate, it will be of interest to know the nature of the saprolite and the weathering forms in tropical areas. The information from the tropics comes from different parts of the world and is very heterogeneous. In particular, it must be realized that Quaternary times also introduced changes in climate to the present tropical areas. In many cases therefore, existing landforms and regoliths are not due to recent processes but to those acting in the past and in a different climate. Thus some of our current ideas about tropical geomorphology are based on suppositions rather than facts. In the following discussion I have attempted to extract information from the literature based on observed facts.

Thomas (1974, pp. 89–91) found that deep weathering in the humid tropics is generally not less than 20 m. Depths are usually 50 m or more but rarely exceed 150 m, but in general too little is known about the weathering depth. Ruxton & Berry (1957) described the typical zones of a mature profile of weathering in granite from Hong Kong. They are, from above: zone I, residual debris; zone II, residual debris with core stones; zone III, core stones with residual debris; and zone IV, partially weathered bedrock. It is not known if there is a distinct front surface of weathering or if the transition from saprolite to fresh rock is gradual through several metres. However, information provided by Thomas (1974, pp. 83–87) indicates that conditions at the weathering front can be rather variable. In his summary (p. 88) Thomas states: ''it becomes clear that profile characteristics vary according to rock type, texture and fracture patterns, and also according to the site history''. In Nigeria, Thomas (1966) found a marked irregularity of the basal surface of weathering. In the Jos area he found good agreement between the directions of observed fractures in the outcropping bedrock and lineations in the weathering pattern.

Thomas (1965, republished 1974) made a scheme for the classification of weathered and stripped land surfaces which he calls etchplains and etchsurfaces. As I find the

scheme rather useful I give here a brief summary of the six stages as illustrated by Thomas (1974, p. 236):

A) "*Lateritised etchplains* are surfaces of low relief underlain by extensive laterite deposits. . . ."
B) "*Dissected etchplains*" are "recognised as the first stage in modification of lateritised etchplains, following accelerated stream erosion, . . . Exposures of the basal surface of weathering in the form of tors or domes are unusual . . . but rock may be exposed extensively in the more important stream channels."
C) "*Partially stripped etchplains*" result from "further dissection and stripping of the deep regolith . . . Rock outcrops in the form of tors and low domes may be common and occasional bornhardts may appear. . . ."
D) "*Dominantly stripped etchplains and etchsurfaces* represent a further development of the stripping process . . . Where the basal surface is markedly uneven this type of terrain merits the term etchsurface rather than etchplain. Such stripped surfaces are usually a result of important tectonic warping, or are a response to climatic changes, especially in the savannas. . . ."
E) "*Incised etchsurfaces* occur where the basal surface of weathering has not simply been exposed but has become subject to widespread modification by stream erosion. This will frequently occur in conjunction with dominant stripping and as a result of important baselevel changes. . . ."
F) "*Pedimented etchplains and etchsurfaces* evolve from stripped or incised etchplain types, when stream incision ceases and valley sides undergo slope retreat beneath shallow weathering profiles. . ."

Good examples of domes, tor forms, stripped and unstripped core stones and related phenomena in the tropics are given by Thomas (1965, pl. 1–6; 1974, pl. 10–24) and Twidale (1976, pp. 45–50).

SIGNIFICANCE OF CLAY MINERALS IN SAPROLITES OF GRANITOID ROCKS

It is difficult to find relevant information on this subject. Millot (1970, p. 97) and co-workers have come to the following conclusions concerning clay minerals in the arenaceous products of granite and gneiss *(arènes):*

"1) The predominant clay mineral in *arènes* is illite, which corresponds to the fine fraction of sericite coming from feldspars and alumino-silicate minerals;
2) Its possible companion is chlorite from ferromagnesian minerals;
3) The weathering products of the illite and chlorite are illite-vermiculite and chlorite-vermiculite mixed layers, and vermiculite. Even montmorillonite may be produced in the finest sizes;
4) If drainage is impeded, either in the past or recently, a neoformed montmorillonite can be found;
5) On the contrary, if the drainage is excellent, and if plagioclase residues and bivalent ions have been removed from the *arène* as a result of a long history, kaolinite will appear. The latter will continue to increase, then become massive, as the climate, always remaining humid, becomes warm, then tropical."

Tardy *et al.* (1973, pp. 271–284) published an interesting article entitled ''Formation of clay from granite and its distribution in relation to climate and topography''. They found that ''on granitic rocks it is possible to define both climatic and topographic sequences of distribution of clays in association with weathering products: gibbsite–kaolinite–hydrous iron oxides–hydrous manganese oxides–iron-rich montmorillonite–calcium carbonate– calcium sulfate–sodium carbonate and silicates. These stages appear as an absolute accumulation formed by filling of intergranular pores. . . In this climatic sequence of absolute accumulation, each stage appears downslope from the preceding one. What is found downslope under one climate, foreshadows what is to be found upslope in a more arid climate.'' The sequence pertains to tropical climates. ''Another sequence can be found not in intergranular pores but in the cracks and along the cleavages of primary minerals from which they are derived by relative accumulation. The order of appearance of these secondary minerals remains the same regardless of the nature of climates and the topographic position. . . The sequences in which the secondary minerals appear within the primary minerals in a simplified manner are as follows:

K-feldspar–kaolinite–gibbsite

Biotite– (chlorite)–montmorillonite
↘vermiculite–Al-vermiculite–kaolinite
Plagioclase–(sericite)–vermiculite–montmorillonite–Al-montmorillonite–kaolinite–gibbsite''

The direction of change is from left to right during progressive weathering. The authors give the following summary of the associations most often found in sandy saprolites:

''For temperate climates:	biotite–vermiculite plagioclase–montmorillonite and kaolinite
For arid climates:	biotite–montmorillonite plagioclase–kaolinite
For humid tropical climates:	biotite–kaolinite K-feldspar–kaolinite plagioclase–kaolinite
For very humid tropical areas:	biotite–kaolinite K-feldspar–kaolinite and gibbsite plagioclase–gibbsite''

With regard to the climatic significance of clay minerals they state that ''it is difficult to determine which minerals are characteristic of different climatic zones. Only those which occur most frequently can be considered here. In addition their place of formation must be differentiated: either within primary minerals or as absolute accumulations in pores. Montmorillonite could thus appear within plagioclase under all climates. This primary stage of weathering of highly siliceous minerals can be ephemeral in humid, tropical climates if rejuvenation of relief is not great. In temp-

erate climates this mineral does not represent a phase of equilibrium; it is only a prolonged transitory event. The vermiculitization of biotite has exactly the same meaning.''

The clay minerals formed during the prevailing climate in Sweden are mainly siliceous minerals of type 2:1, *e.g.* illite (Wiklander 1976, p. 122).

The present distribution of principal clay minerals in parts of America, Europe and Africa is shown on a map by Bakker (1963). This map can be compared to a diagram by Strakhov (1967, *e.g.* in Ollier 1969, p. 116) and to the statement by Millot (1979): ''Kaolin minerals tend to appear in a belt along the Equator, smectites in Mediterranean and tropical zones with contrasting seasons, mixed-layer clay minerals and vermiculites in temperate zones, and illites and chlorites in cold regions.''

DISCUSSION AND CONCLUSIONS

Mapping of the flint occurrences was emphasized in the field work. However, I became successively more aware of the possibility that weathering processes could be responsible for features in the morphology. Taking into account the observations of weathering within the area and in adjacent areas of Europe, it seems clear that this is probably a previously overlooked factor in the geomorphology of Sweden and neighbouring countries that were once glaciated. Observations and compilations of weathering phenomena within limited areas of Sweden and comparisons with non-glaciated areas in the vicinity should be valuable for interpretation of morphology and for discussion of the erosional work of the Pleistocene ice sheets.

KAOLIN WEATHERING

Localities with deep weathered bedrock are rare within the area. However, as discussed above, the Cretaceous cover previously had a greater extension. At most localities where the boundary between the Cretaceous limestone and the underlying gneiss has been uncovered, kaolinized gneiss is reported (Nos. 34, 116a?, 128, 142). Together with the other kaolin occurrences this indicates that a thicker and more widespread saprolite once existed. To a large degree this saprolite may already have been removed by erosion prior to Cretaceous sedimentation.

In Skåne there is no evidence to contradict an explanation of the kaolin as being of subaerial origin. Opinions as to the origin of the kaolin on Bornholm differ. For the rest of Europe the situation is such that an exogenous origin is mostly accepted in eastern and central regions, while hydrothermal kaolinization has been advocated in Western Europe (Vachtl 1969, pp. 23–24) until recently (Sheppard 1977).

One conclusion based on the occurrence of clay minerals in saprolites is that large quantities of kaolinite (unless hydrothermal in origin) give a distinct indication of

formation in a humid tropical climate. Therefore, such conditions should have prevailed during the formation of kaolin in the Kristianstad area some time before local Cretaceous sedimentation took place. It is probable that the study area was also covered for some time by a kaolinitic saprolite. The question of the age of the kaolinitic weathering is further discussed in the next chapter.

TOPOGRAPHY

Within the study area I have found a maximum relative relief in the bedrock of 70–100 m related to the youngest tectonic lineaments. In other settings, a relative relief of 15–40 m seems to be normal in the southeastern half of the study area, while in the northwest 40–70 m is common. The deepest zones in the bedrock surface seem to be concentrated along the fracture lines. My interpretation is that much of the relief in the northwest was caused by deep weathering in pre-Late Cretaceous time and then sharpened locally by very late Cretaceous or post-Cretaceous tectonic movements. The morphology may be compared with the basal weathering front in the tropics as described above (p. 74). Such a front tends to follow the fracture pattern and is therefore often irregular. Thus the bedrock shape in parts of the study area may be the basal surface of a kaolinitic saprolite, with slight modifications caused by the Pleistocene glaciations.

The large numbers of boulders occurring at certain localities (Fig. 2, folded map after text) may be core stones from the basal zone of weathering, although it is difficult to prove this. The boulders mentioned above consist of local gneiss. They do not seem to be particularly rounded (Fig. 24), but as stressed by Jahn (1962) and Dumanowski (1968) it is the structure of the bedrock that determines the shape and not so much the character of the weathering. The well-rounded boulders in the Lake Ivösjön area (Bergsten 1972) consist of granitic rocks, while the more angular boulders in the study area consist of gneissic rocks.

I regard the surface (especially the areas with flint remnants) as a dominantly stripped etchsurface (stage D in Thomas' scheme, see p. 75). Most of the stripping probably occurred prior to Late Cretaceous sedimentation. The sediments resulting from the stripping should be found in the Fennoscandian Border Zone and in the Danish Embayment. In some places remnants of the weathering mantle have been left. The topography within the study area was protected by a cover of Upper Cretaceous sediments during part of the Tertiary. The topography was later regenerated and modified in places. The most striking examples of this regenerated relief are the localities mentioned above (p. 56).

BOARPA BACKE

The grain size distribution in the samples from Boarpa backe can be compared to that of weathered granites (growan) on Dartmoor, England (Eden & Green 1971, p. 95), St. Pierre de Varennes, France, and Harz, Germany (Bakker & Levelt 1964, pp. 35–36). (See Table 4.) The grain size analysis of the Dartmoor sample was based on the fraction below 2 mm. The analyses from St. Pierre de Varennes and Harz did not include any material larger than 1.7 mm. The figures show much the same grain size distribution with a low clay content for all localities. The soil sample from Dartmoor is more weathered than that from Boarpa backe. The weathering depth is also greater in Dartmoor.

The above account of weathering phenomena elsewhere in Europe shows that sandy weathering types are common in Scotland, England, Central Europe, the Kola Peninsula in the Soviet Union, and in Finland. Thus, sandy weathering is found both in previously glaciated areas and in areas that have never been glaciated. Most authors came to the conclusions that weathering occurred during the Late Tertiary under conditions of a moderately humid climate that was somewhat warmer than at present. Interglacial and even humid tropical conditions have been suggested. Another view is held by Ragg & Bibby (1966), who studied weathered greywackes (hard arkosic sandstones and grit) at Broad Low in southern Scotland. The grain size distribution is similar to that at Boarpa backe. As in profile 2 at Boarpa backe (Fig. 26), the Broad Low profiles contain core stones. The upper part of the section at Broad Low is

TABLE 4. Composition of decomposed rock at Boarpa backe, southern Sweden; Dartmoor, England; St Pierre de Varennes, France; and Harz, Germany.

	samples, N	gravel	sand[1]	silt[1]	clay
Boarpa backe saprolite	2	6.0	65.0	23.5	5.5
Soil material over saprolite, Boarpa backe	1	4.0	63.5	26.5	6.0
In situ growan, Dartmoor	19		78.5	17.0	4.5
Soil material over *in situ* growan, Dartm.	6		58.0	30.5	11.5
St. Pierre de Varennes			69	25	6
Harz			63	31	6

[1] In the samples from Boarpa backe the limit between sand and silt is 0.06, for the rest the limit is 0.05 mm.

influenced by periglacial surface processes and can not be compared with the material from Boarpa backe. The authors came to the conclusion that their material ''represents the result of intense frost weathering'' and that the higher parts of the Southern Uplands probably escaped the last glaciation (Ragg & Bibby 1966). The layers are thus supposed to be periglacial in origin.

The clay mineral content at Boarpa backe points to conditions not very different from those prevailing now. The absence of illite is confusing but perhaps indicates a low supply of K^+. The profile is truncated, which shows that it is not postglacial. The red soil colour may indicate weathering in a climate with alternating wet and dry seasons (Millot 1970, pp. 110–111). Comparison can be made with a red weathered soil developed on Silurian limestone at Bjärsjölagård in Skåne and covered by a thin till (Thomé 1932). Thomé compared this soil with *terra rossa*. As *terra rossa* is developed on limestones, the soil at Boarpa backe can not be called *terra rossa*, but the high iron content is comparable. My conclusion is that the weathering profile at Boarpa backe was produced during somewhat warmer conditions than now, in a climate with alternating wet and dry seasons during an interglacial or, more probably, in Late Tertiary time.

THE WEATHERED BOULDERS

Weathered boulders were observed in parts of the study area, although no clear conclusions can be drawn from the few observations. There are three main possibilities as to their formation. Firstly, they may be derived from bedrock weathered in Tertiary or interglacial times. Secondly, they may have belonged to pre-Weichselian glacial deposits, which became weathered during interglacial times. Thirdly, they may have weathered *in situ* in till and glaciofluvial deposits where they are now found.

A COMPARISON WITH SOUTHWEST ENGLAND

Before leaving the subject of topography and weathering it is relevant to stress the similarity with conditions in southwest England. Both there and in southern Halland and northern Skåne there are kaolin occurrences and a similar characteristic topography in areas which were probably flooded by the Late Cretaceous sea (Ziegler 1975, p. 1090 and Fig. 45 herein). The kaolin weathering in south Sweden is of pre-Late Cretaceous age, and the same dating may be at least partly correct for southwest England (cf. p. 71). In both areas it is mainly residual flint that is suggestive of a former Cretaceous rock cover.

SUMMARY OF PRE-QUATERNARY MORPHOLOGICAL EVENTS IN THE STUDY AREA

According to my conclusions, the following events have occurred within the area:

1, fracturing (before the Mesozoic);

2, kaolinitic weathering (particularly deep along fracture zones) and stripping of the resulting saprolite;

3, Cretaceous sedimentation in connection with tectonic lowering;

4, tectonic rise of the central area in very late Cretaceous or post-Cretaceous time (possibly at the Oligocene/Miocene transition), with tilting of blocks and development of fault scarps;

5, dissolution of the limestone during the Tertiary, leaving a flint nodule concentration as residue;

6, weathering and erosion during the Tertiary (resulting in *e.g.* weathered flints, probably the weathering at Boarpa backe, and possibly weathered boulders).

SEDIMENTS IN ADJACENT AREAS AND THEIR IMPLICATIONS FOR INTERPRETATION OF THE GEOMORPHOLOGICAL EVOLUTION

THE SIGNIFICANCE OF CLAY MINERALS, QUARTZ/FELDSPAR RATIO AND TERRIGENIC/CARBONATE CONTENT

It is obvious that terrigenous sediments can provide valuable clues to the weathering conditions at the time of sedimentation. Schwarzbach (1974, pp. 124–126) presents a compilation of relevant data. In this chapter the following items are discussed: clay minerals (most information taken from Millot 1970); quartz/feldspar ratio; and terrigenic/carbonate content.

CLAY MINERALS

The significance of clay minerals in saprolites of granitoid rocks was treated on pp. 75–77. To a high degree the clay minerals of sedimentary rocks reflect the nature of the source rocks, the weathering, and the soils of adjacent land masses (Weaver 1958, p. 254). However, they can also result from transformation during sedimentation or diagenesis. Neoformation of glauconite and montmorillonite can occur during sedimentation. This is not the case with kaolinite. The majority of sedimentary illites and chlorites are inherited from land. Kaolinite (especially in permeable sediments), chlorite and illite can be neoformed by diagenetic processes. On the whole, however, clay grade sediments can be regarded as the most reliable witnesses of past weathering conditions. Their conservatism is largely caused by their impermeability.

Since kaolinite is stable in the hydrosphere, in soils, and sediments, it can probably be regarded as the most typical and most resistant inherited clay mineral.

Although stable in alkaline environments, illite and chlorite are regarded as less stable. They will evolve by transformations of degrading or negative type, chlorite being most vulnerable.

Montmorillonite is a mineral of many possible origins and of unstable nature according to Weaver (1958) and Millot (1970, p. 305). The clay fraction in chalk is composed chiefly of montmorillonite. Heim (1957, referred to in Millot 1970, p. 200) regarded montmorillonite as being derived from the continents, while Millot *et al.* (1957, referred to in Millot 1970, pp. 200–201) thought that the montmorillonite of the chalk was neoformed.

Maps of the present day distribution of the main clay minerals in the seas have been published by Füchtbauer & Müller (1970). According to these authors, kaolinite distribution, being restricted to the tropical belt, shows a more distinct pattern than that of other clay minerals (cf. p. 77).

QUARTZ/FELDSPAR RATIO

The higher the figure for this ratio, the more intense the weathering has been. Thus, a great amount of quartz indicates that the feldspar is weathered.

TERRIGENIC/CARBONATE CONTENT

The more terrigenic material that is found in sediments, the more intense the weathering on neighbouring continents seems to have been. Carbonate production appears most efficient in tropical marine areas adjacent to tectonically stable land masses and in provinces with a minor fresh-water runoff (Wilson 1975).

MESOZOIC–PALAEOGENE SEDIMENTATION IN SKÅNE

The clay mineral content, the quartz/feldspar ratio and the terrigenic/carbonate content are especially considered in this and the following sections. The purpose is to elucidate the weathering conditions in southern Fennoscandia, especially in the study area.

In Cambro-Silurian times large parts of Sweden were submerged under the sea. In the Devonian, Carboniferous and Permian periods, however, no sediments were deposited in Sweden as far as is known and the land surface was denuded.

The morphology discussed in this paper may at least in part include characters of Late Palaeozoic–Early Mesozoic origin. It is therefore reasonable to start a review here at the base of the Mesozoic (Fig. 29).

The surface distribution of Mesozoic rocks is shown in Fig. 1. In Skåne, the area southwest of the Mesozoic outcrop is covered by Tertiary strata (including the Danian), whereas other areas are represented by Precambrian and Lower Palaeozoic rocks.

The following main structural units can be recognized in south Sweden and Denmark (Fig. 28):

1) North German Basin
2) Ringkøbing-Fyn High
3) Danish Embayment
4) Fennoscandian Border Zone (including north Jylland, part of the Kattegat, the horst region of Skåne, and Bornholm)
5) Fennoscandian Shield

Triassic and Jurassic sedimentary rocks in the Fennoscandian Border Zone and the Danish Embayment sections of Skåne are restricted to three main belts, viz. 1, the area southwest of Romeleåsen (including the Vallåkra Trough in the northwest), 2, the central basin northeast of Romeleåsen with its extension to the northwest (the Höganäs Trough) and southeast (the Vomb Trough), and 3, the Ängelholm Trough south of

Hallandsåsen with its southeastward extension. The latter area is characterized by numerous outliers indicative of a former more extensive sedimentary cover. On the other hand, the sediments of this zone are commonly terrestrial, which suggests that the shore line might have oscillated within this part of Skåne.

Mesozoic sedimentation in Skåne was controlled to a large extent by tectonic events. Bölau (1973, p. 179) stated that "die kimmerischen Bewegungen umschliessen eine einleitende epirogenetische Gestaltung der Strukturen, die wohl bereits im unteren Jura, aber sicher jungkimmerisch in eine orogenetische Strukturbildung überging". This means that important tectonic movements took place in the Late Jurassic. Thus, during most of the sedimentation the troughs did not exist.

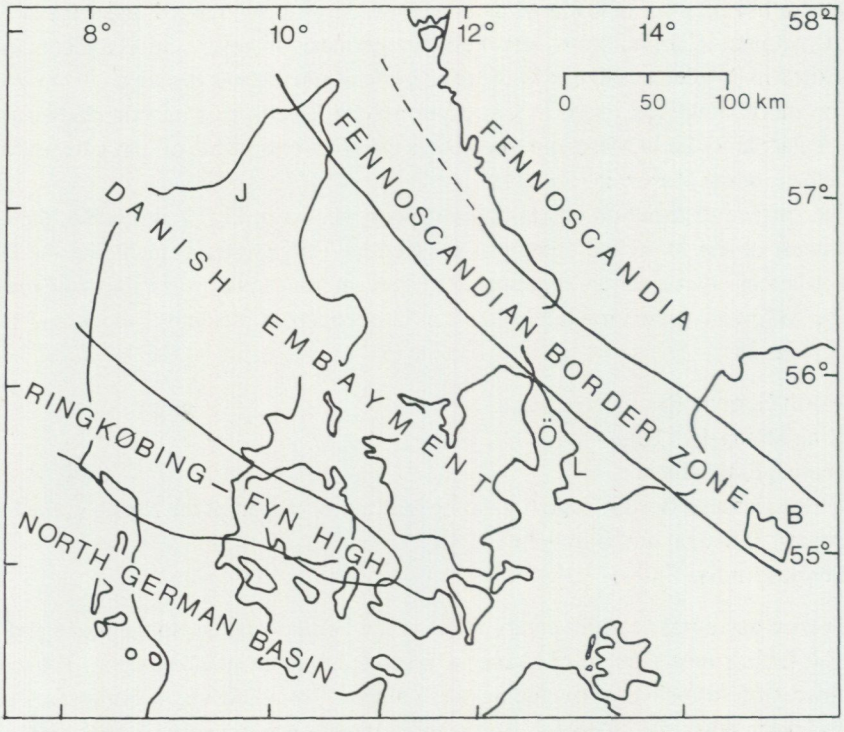


Fig. 28. Main structural units in southern Sweden and Denmark according to Larsen 1966 and Bergström in Bergström *et al.* 1973. J, Jylland; Ö, Öresund; L, Limhamn; B, Bornholm.

TRIASSIC

The lower parts of the Triassic succession are known only from deep wells in southwest Skåne. The basal Mesozoic sediments are characterized by red and green sandstones and shales which have not yielded any fossils. The sequence possibly corresponds to the Upper Buntsandstein (upper Lower Triassic) of Germany (Brotzen 1950). The strata are overlain by grey sandstones and shales with marly layers, referable either to the Muschelkalk (Middle Triassic) or to the Lettenkohle (lower Upper Triassic). These rocks are overlain by red and green sandstones, arkoses and conglomerates, which in turn are succeded by a fine-grained sequence of red and green shales. Brotzen (1950) correlated these rocks with the German Gipskeuper (middle Upper Triassic). They are overlain by clayey and sandy layers of predominantly dark colours. The change in colour is considered to be due to a climatic change from arid to humid conditions (Regnéll in Magnusson *et al.* 1963, p. 304). The dark-coloured sequence is referred to the Rhaetian.

The beds in southwest Skåne regarded as equivalent to the Gipskeuper correlate with the Kågeröd beds, which form the oldest known Mesozoic sediments of the Fenno-scandian Border Zone. In the Vallåkra and Höganäs Troughs, Kågeröd beds rest on Lower Palaeozoic strata, and in the Ängelholm Trough on Precambrian basement; they are typical continental deposits. Until recently these beds were regarded as devoid of fossils useful for dating. However, in a preliminary note Tralau (1968) confirmed a Keuper (Late Triassic) age on palynologic grounds. The climate of ''Kågeröd time'' is thought to have been tropical or subtropical. The sediments show such weak chemical weathering that they have most probably originated in a relatively dry, but not necessarily desert-like zone (Regnéll in Magnusson *et al.* 1963, p. 308). According to Norin (1941, referred to by Troedsson 1942), the uppermost clays of the Kågeröd beds consist mainly of montmorillonite.

The Rhaetian starts with the Vallåkra Beds, which comprise clays with lensoid green sandstones, shales and clays, and subordinate layers of coal and clay-ironstone. These beds were deposited in quiet, shallow waters in a delta environment. X-ray analyses of the clays at Margreteberg in the Höganäs Trough have shown that the Vallåkra Beds are represented principally by clays made up of quartz and clay minerals of the montmorillonite type. From the base upwards in the sequence the crystallinity of the clay increases and at the top of the Vallåkra Beds there is a sudden change in the mineral composition in that the montmorillonite minerals are replaced by kaolinite (Norin 1949). The clays in the overlying coal-bearing beds mainly comprise kaolinite (Regnéll in Magnusson *et al.* 1963, p. 309). In a boring at Sandåkra (Nilsson 1958; see also p. 68) X-ray analyses of the minerals were made from four sample levels, the uppermost belonging to the Lias (see p. 68), whereas the lowest is of unknown age. From top to bottom the analyses have shown a predominance of the following minerals: 1, siderite, kaolinite; 2, kaolinite, montmorillonite, quartz; 3, quartz, phosphorite, unknown mineral; and 4, montmorillonite, quartz, calcite. Nilsson

		DENMARK		SKÅNE except for Kristianstad area		BORNHOLM	
TERTIARY	Pliocene	clay and sand	M				
	Miocene	micaceous clays and sands with lignite	(M) 305				
	Oligocene	*m+k+i* clay and sand	M 90				
	Eocene	*m/i+k+i* Sövind Marl	M 20				
		m+k+i Lillebelt Clay	M 60				
		m+i+k Rösnaes Clay	M 50				
		Mo Clay Formation	M 50	mudstones	>5		
	Paleocene	*m* greensand and marl	M 170	greensand and marl	M 30		
	Danian	consolidated lst w. *flint*	M 150	finegrained lst w. *flint*	M 180		
		m+i bryozoan lst w. *flint*	M	lst w. bryozoans and *flint*	M		
CRETACEOUS	Upper Cretaceous: Maastrichtian	*m+i* chalk w. *flint*	M 200	chalk w. *flint* and lst	M 700		
	Campanian	limestone and chalk	M 500	lst w. sand and clay, ss, conglomerate	M 400		
	Santonian	marlstone and lst	M 300	clayey lst, sandy and marly layers	M 470	Bavnodde Greensand	M 180
	Coniacian	limestone w. glauconite and *flint*	M 150		100		
	Turonian	dark shale	M 50	lst w. *flint*, cgl	M 75	Arnager lst w. some *flint*	M 20
	Cenomanian	clay, marl and lst	M 100	greensand, cgl, lst	M 65	Arnager Greensand	M 130
	Lower Cretaceous: Albian	reddish marl and sand	M	greensand	M		
	Aptian / Barremian / Neocomian	*Q* sand, ss, clay and shale w. glauconite (incl. Skagen Formation)	(M) 400	shale	M		
				shale and ss	(M)		
				ss, sand, clay, shale, cgl	F 120	grey clay w. sand and clayironst.	F 250
						sand and gravel	F
JURASSIC	Upper	sand and ss w. glauconite	(M) 275	variegated clays	F 70	*k+i* clay series	F
				quartz sand and ss	F 40	gravelly sand and ss	F
		claystone	M	*k* variegated clays and marl	F 145		270
	Middle	*Q* light grey to whitish ss (Haldager Formation)	(F) 320	*k* quartz sand and silt	F 30	*k+i* clay w. boulders of k-weathered granite, sand, coalseams	F
				sand and clay w. coal seams	(M) 120		
	Lower (Lias)	*(Q)* dark claystone	M 350	sh, clst, ss and ferrug. beds	M 205	? ?	M 100
				k variegated clays, coal, ss	(M) 60	clay and clayironstone	
				ss, siltstone, clay and marl	M 170	? ?	
				k ss, clay, coalseams, ferruginous and calcareous beds	(F) 200	*k* clay, sand and lignite	F 350
TRIASSIC	Upper: Rhaetian	*Q* ss, coalseams	(F) 200	*k+i* coal and clay	(F) 50		
		dark shale	M	*m* Vallåkra dark clays	(F)		
		green, limerich claystone		*m* red and green shales	F 270	*m*	F
		red and brown clay, dolomite, anhydrite	(F) 410	red and green ss, arkoses cgl	F	red and green clays	>70
	Middle	lst and marl w. dolomite and anhydrite	M 180	grey ss and shales w. marly layers	M 120		
	Lower	red and brown ss, claystones, salt	(F) 1280	red and green ss and sh	F 40		
PERMIAN	Upper	lst, dolomite, anhydrite, salt	M 1020				
	Lower	red ss, volcanic ash	(F) 260				

suggests that this composition supports the view of a more arid climate during the deposition of the oldest beds than when the younger ones were formed. The results of Nilsson's analyses correspond fairly well with those of Norin.

Not far to the south of the study area (Fig. 1) there are four borings of interest in this context. Three of these, on the map sheet 3C Helsingborg NO, correspond to the northernmost letter "M" of Fig. 1. The fourth is located at Blaholma and corresponds to the other "M" southwest of the study area (Fig. 1; Table 5). The age determinations are probably based on lithological correlation and therefore rather uncertain. The borings show that there are up to 15 m kaolin on the Precambrian bedrock immediately southwest of the study area. The kaolin is overlain by Rhaetian or Liassic beds.

JURASSIC

Jurassic deposits are fairly thick in all three troughs mentioned above. However, in deep borings in southwest Skåne they are only sparsely represented, with only the lowest and highest levels present. Some occurrences of basal Liassic beds have been discussed above. The most extensive distribution of Jurassic rocks is in northwest Skåne, with particularly important occurrences along the northern margin of the Vomb Trough.

The Lower Jurassic begins with the Helsingborg Member, comprising alternating non-marine and marine deposits. The basal layers, referred to as the Boserups beds, include alternating sand and clay. The coarse sediments are "rich in half-weathered feldspar. The grains are angular and mixed with powder and pieces of kaolin . . . The clays are sticky . . . The pure ones consist mainly of kaolin, are white, and sometimes used for fire-clay . . . The Boserup beds have been washed out from an Archean surface with deep decay (probably also from the Kågeröd arkoses)". The overlying Fleninge sandstone is dominated by quartz but strongly weathered white and red feldspars are common, "the sandstone thus being kaolin-dotted . . . The Fleninge beds consist of rock débris, removed from a deeply weathered Archean region and spread over the adjacent sedimentary plain" (Troedsson 1951, pp. 103–111). The remaining strata of the Helsingborg Member are mainly fine-grained and consist of siltstones, grey and dark clays, coal seams, and calcareous and ferruginous layers. The total thickness of the Member is more than 200 m.

The succeeding Döshult Member (Lower Jurassic) is characterized by coarse,

Fig. 29. Schematic stratigraphical column for Denmark, Skåne (except for the Kristianstad area) and Bornholm. Figures show known maximum thicknesses of strata in metres. The clay mineral content, as far as known, in the upper left corner of each unit. The first letter indicates the dominant of those mentioned; viz. m = montmorillonite, k = kaolinite, and i = illite.
Q means high quartz/feldspar ratio, (Q) fairly high quartz/feldspar ratio. Sedimentation conditions are indicated in the upper right corner of each unit; viz. M = marine, (M) = mainly marine, F = freshwater, and (F) = mainly freshwater.

TABLE 5. Lithological description of four borings in northern Skåne.
Location of borings:
No. 39: Örkelljunga, Månstorps gård. UTM co-ordinates UC 985393. Elevation about 110 m above sea level (a.s.l).
No. 40: Örkelljunga, Ö. Spång. UTM co-ordinates UC 958393. Elevation about 80 m a.s.l.
No. 42: Örkelljunga, Ö. Spång. UTM co-ordinates UC 970395. Elevation about 90 m a.s.l.
Blaholma. UTM co-ordinates VC 052346. Elevation about 125 m a.s.l.

Numbers 39, 40 and 42 correspond to numbers in the Well Record Archive of the Geological Survey of Sweden (SGU), Lund. Data on the Blaholma boring are from Sydvatten (1968).

	Depth in metres (below surface)	Lithology	Age (or lithostratigraphical unit)
No. 39	0 - 10	sand	Pleistocene
	10 - 20	sandy till	Pleistocene
	20 - 25	sand	Pleistocene
	25 - 30	clayey, sandy till	Pleistocene
	30 - 33	clayey sandstone	Rhaetian-Lias
	33 - 35	claystone, calcareous	Rhaetian-Lias
	35 - 40	clay	Kågeröd beds
	40 - 43	clay	probably Rhaetian-Lias
	43 - 45	sandstone, here and there clayey	probably Rhaetian-Lias
	45 - 60	kaolin clay	
	60 - 78	red gneiss, basal part kaolin weathered	Precambrian
	Remark: The boring was made in a fault zone		
No. 40	54.5 - 58.0	clayey till	Pleistocene
	58.0 - 61.7	coal	Rhaetian-Lias
	61.7 - 68.5	sandstone with clayey layers	Rhaetian-Lias
	68.5 - 77.0	sandstone	Rhaetian-Lias
No. 42	51.5 - 59.0	clayey till, local	Pleistocene
	59.0 - 62.0	claystone with silty layers	Rhaetian-Lias
	62.0 - 69.0	sandstone, slightly clayey, calcareous	Rhaetian-Lias
	69.0 - 71.0	sandy claystone with coal	Rhaetian-Lias
	71.0 - 72.0	sandstone, slightly clayey, calcareous	Rhaetian-Lias
	72.0 - 82.0	clay, rich in kaolin	
Blaholma	0 - 37	Quaternary layers	
	37 - 38	clayey sandstone	Triassic?
	38 - 42.5	kaolin clay with quartz grains and a gneissic structure	Precambrian
	42.5-50.0	weathered gneiss	Precambrian

cross-bedded sandstones, siltstones, clays and marls, which are more distinctly marine than the cyclic sediments of the Helsingborg Member. The thickness of the Döshult Member seems to vary between 70 m and 170 m.

The succeeding Pankarp Clays (with kaolinite, Kjell Ekdahl, Bjuv, pers. comm.) and the Katslösa Member (middle Lower Jurassic) mainly comprise claystones, siltstones, sandstones, shales, and ferruginous beds. Then follows a 50–100 m thick sequence referred to as the Rydebäck Member (upper Lower Jurassic). This sequence includes clayey, silty and sandy ferruginous deposits characterized by variegated portions. This is also true of the Pankarp Clays commented on above.

Middle Jurassic strata have long been known to crop out in the sand pit of Fyleverken Company, Eriksdal, in the Vomb Trough in southeast Skåne. However, the stratigraphical position has not become clear until recently (Norling 1972). In this pit and in the adjacent Kurremölla valley a sequence of steeply dipping Jurassic beds is exposed. From ENE to WSW the section can be subdivided into the following units:

1. Ferruginous, partly variegated sandstones, siltstones, and claystones of a late Early Jurassic age (partly corresponding to the Rydebäck Member).
2. "Erikdal Beds" (Middle Jurassic); alternating sands and clays with several coal seams (corresponding to the Vilhelmsfält Formation in northwest Skåne).
3. Glass Sand (Middle Jurassic); mainly whitish sand and silt containing kaolinite.
4. Fyledal Clay (Upper Jurassic); mainly bluish, greenish and dark clays and claystones.

A corresponding, though more complete Jurassic sequence is known from borings in western and northwestern Skåne, including also the Fortuna Marl (Middle Jurassic–Upper Jurassic transitional beds) and a much thicker Fyledal Clay (Norling 1972; Norling in Daniel 1978). The Fyledal Clay contains kaolinite (Erik Norling, pers. comm.).

The top of the Jurassic in Skåne is formed by the Nytorp Sand and the Vitabäck Clays, the latter comprising grey, blackish and variegated sandy clays (partly shaly and bituminous). These two lithological units correspond mainly to the uppermost stage of the Upper Jurassic. However, the Vitabäck Clays may span the Jurassic-Cretaceous boundary (Norling in Norling & Skoglund 1977; Norling in Daniel 1978).

CRETACEOUS

The Cretaceous in the Kristianstad and Båstad areas (Fig. 1) are discussed in the following chapter. The two remaining Cretaceous areas of Skåne are discussed here, viz. 1, southwest Skåne within the Danish Embayment, and 2, the Vomb Trough and its southeastward extension within the Fennoscandian Border Zone.

While in the Båstad and Kristianstad areas the thickness of Cretaceous rocks hardly exceeds 150–200 m as far as is known, the corresponding deposits in the Vomb Trough and southwest Skåne are fairly thick reaching maxima of 1133 m and 1770 m respectively (Norling in Norling & Skoglund 1977, pp. 455–456).

Lower Cretaceous rocks are known only from borings. The basal Cretaceous sediments were formed in fresh water and brackish environments. The first marine transgressions took place in the Late Neocomian. A more widespread marine transgression did not occur until the Barremian/Aptian, as indicated by foraminiferal faunas and scattered ammonite finds. The marine development of the Cretaceous is indicated in Fig. 29. From a lithological point of view there is a fundamental difference between the Lower and Upper Cretaceous deposits in Skåne and elsewhere in Northwest Europe. In many respects the Lower Cretaceous deposits form a continuation of the Jurassic sedimentation, while the Upper Cretaceous limestone-chalk facies represents quite different palaeogeographic conditions (Norling in Norling & Skoglund 1977, p. 455).

The rate of subsidence of southwest Skåne (Danish Embayment) increased gradually from Santonian time throughout the Cretaceous, with a maximum in the Maastrichtian. In the Vomb Trough and Hanö Bay (Fennoscandian Border Zone) the major subsidence took place in Santonian time (Norling in Norling & Skoglund 1979, p. 456), while in the Kristianstad area (Fennoscandian Border Zone) it occurred in the Campanian (Bergström in Kornfält *et al.* 1978, p. 90).

TERTIARY

Tertiary strata are represented mainly by the Danian, which covers the whole of southwestern Skåne (Danish Embayment). The Danian sequence comprises limestones with flint, its thickness varying between 50 and 180 m. Sedimentation, as seen for example in Limhamn quarry (Fig. 28), seems to have been controlled largely by the formation of bryozoan bioherms or mounds and also, but less commonly, by patchy coral reefs. Only a few minor areas with Paleocene (younger than the Danian) and Eocene strata are known from Skåne (*e.g.* Gustafsson & Norling 1973; Norling 1973, 1980).

In this account of Mesozoic–Palaeogene sedimentation in Skåne, including Fig. 29, the compilation by Sundquist (1976) has been used as a convenient source of information. It includes relevant information from Troedsson (1951), Bölau (1959), Brotzen (1960), Norling (1972), and others. Additional information has been extracted from Magnusson *et al.* (1963) and Norling (1973, and in Norling & Skoglund 1977).

LATE PALAEOZOIC, MESOZOIC AND CENOZOIC SEDIMENTATION OF DENMARK

Denmark can be subdivided into two major NW–SE trending basins isolated from each other by the Ringkøbing-Fyn High (Fig. 28). In the following summary the Danish

Embayment is discussed (see also the above account of the Swedish part of the embayment).

The subsidence and deposition of sediments in the Danish Embayment probably began in the Early Permian. The oldest strata known from deep borings rest either on the Precambrian basement or on Lower Palaeozoic sedimentary strata. Only a few of the Danish deep wells penetrate deeper than the Permian. It should be noted that one of the wells on the island of Falster reached Carboniferous strata.

PERMIAN

Permian sedimentation in the Danish Embayment began with deposition of red continental sandstones, indicating a desert climate. There was also an influx of volcanic ashes. During the Permian, the Zechstein sea invaded the embayment from the northwest, and calcareous sediments were deposited. To the south was the Hercynian continent, and south and southeast of this landmass lay the Tethyan sea, which had no connection with the Zechstein sea of the Danish Embayment.

TRIASSIC

Like the Lower Permian sediments, the lithologically similar Buntsandstein (Lower Triassic) was formed during a period of dry climate. The Buntsandstein is regarded as a freshwater sequence. During Late Permian and Early Triassic times more than 2000 m of sediments were deposited in the subsiding central part of the Danish Embayment.

In the Middle Triassic the sea reached Denmark again, but this time from the south. The Danish Embayment now formed a north trending bay of the Tethys with sedimentation of calcareous deposits (Muschelkalk). Later, in the Late Triassic, Jurassic and Early Cretaceous, the sea frequently fluctuated over the area, and the marginal parts in particular were characterized by alternating transgressions and regressions.

In northern Jylland the Precambrian basement is overlain directly by coarse Triassic arkoses (Frederikshavn 1), interpreted as a marginal facies of the Triassic basin and comparable to the Kågeröd Formation in Skåne. The material seems to originate mainly from basement rocks (Larsen & Friis 1975).

In Rhaetian time (latest Triassic) there was a sharp change in sedimentation. The anhydrite and salt deposits, dolomites, red and green sand- and claystone series were now followed by grey clays and sands with coal-seams. Larsen (1966, p. 11), who made a thorough study of the Rhaetian to Lower Cretaceous sedimentation of the Danish Embayment, has given the following characterization: ''The youngest part of the Triassic succession, the Rhaetic, is lithologically quite different from the rocks lying below, and can instead be grouped with the succeeding Jurassic formations in that it consists of an alternating series of light sandstones and dark claystones con-

taining plant material, including occurrences of coal as well as marine fossils in places. The same lithological development is found in the rocks immediately above the Jurassic, the Lower Cretaceous beds. In marked contrast, the Upper Cretaceous strata consist of predominantly light grey to whitish marl and limestone deposits. It can be seen from the foregoing that the Rhaetic–Jurassic–Lower Cretaceous succession in the Danish Embayment occurs as a lithological and lithogenetic unit, which stands out clearly from both the underlying variegated Triassic sequence and the succeeding whitish calcareous formations.''

In this interesting study, Larsen presents palaeogeographical maps for the Rhaetian, Lias, Middle Jurassic, Late Jurassic, and Early Cretaceous, each showing the main facies distribution.

In Rhaetian time the sea invaded the Danish Embayment from the northwest (but it was still a bay of the Tethys). At the same time, sandy deltaic deposits were formed in some areas along the basin margin. Along the Fennoscandian border of the Embayment the ''Gassum delta'' was built up.

''The river courses that led to the building of the ''Gassum delta'' presumably drained those parts of the Fennoscandian land area that lay to the north and northeast of the Danish Embayment. The parts of Fennoscandia that were exposed in the area of fluviatile erosion consisted to a large extent of metamorphic complexes, but older sedimentary formations, possibly in the forms of areas downfaulted into the basement, are also considered to have played some part'' (Larsen 1966, p. 103). It is the mineral content that gives support for these ideas.

JURASSIC

In the Early Jurassic the whole of the Danish Embayment was covered by the sea. ''Because there are in the northern part of the depositional area . . . approximately the same mineral assemblages in the Lias as in the underlying Rhaetic sediments, it is considered likely that the supply of material to the basin took place from the same areas and through the same river systems as in the Rhaetic. . . , while the material in the Öresund area seems to be derived from older sedimentary formations'' (possibly situated outside Fennoscandia proper). ''In the river systems that already existed in the Rhaetic, the Liassic rise in sea level . . . probably resulted in such changes in the erosional base-level that considerable amounts of sediments were deposited in the original river courses; *i.e.* the Lower Jurassic depositional area presumably had offshoots in the Fennoscandian area'' (Larsen 1966, p. 106). For the Rhaetic–Liassic deposits Larsen (1966, p. 94) also stated: ''It is especially likely that an originally high content of hornblende has been largely removed by weathering but it must, however, be emphasized that apart from this no evidence was found to suggest that the weathering processes had any significant effect.''

In the Middle Jurassic a considerable regression took place. Deltaic deposits (Hal-

dager delta) developed outwards from the Fennoscandian coast into the northwestern part of the Danish Embayment. Compared to the Rhaetian and Liassic environments these deltaic deposits are characterized by a very low feldspar content and a lesser amount of the readily weatherable hornblende, epidote and garnet. This is explained by the suggestion that material deposited in the Liassic deltas and river terraces was now redeposited and occurred in a more mature stage of weathering (Larsen 1966, pp. 92, 108). In the Late Jurassic the sea transgressed again in the northern area.

EARLY CRETACEOUS

In the Early Cretaceous there was a distinct regression along the Fennoscandian margin of the Danish Embayment, while Denmark was flooded by the sea. ''It seems logical to explain this development as being the result of tectonic events, namely an uplift of Fennoscandia relative to the Danish Embayment'' (Larsen 1966, p. 111). Like the Haldager Formation, the Skagen Formation has a low content of feldspar and unstable minerals (epidote), which is explained in the same way by Larsen. The reddish colour of the Albian marl is supposed to ''be derived from the carrying into suspension of material from the weathered surface that probably covered considerable parts of the land area that the sea invaded'' (Larsen 1966, p. 112).

Since one of my purposes is to date the kaolin weathering in southern Sweden, I have found it important to give a fairly full review of Larsen's interpretations of the Rhaetian–Early Cretaceous time interval. No analyses of the clay minerals were made in his study. For the weathering as a whole Larsen (1966, p. 91) says: ''It is really very little that can be concluded about the significance of weathering in the composition of the mineral assemblages. So much is clear, however, that the chemical weathering can hardly have been especially intense in sediments whose content of minerals susceptible to weathering (*e.g.* feldspar, garnet, epidote) is large. It seems, for instance, that this must apply to the Rhaetic–Lias in Jylland.''

QUARTZ/FELDSPAR RATIO DURING THE RHAETIAN–EARLY CRETACEOUS

When examining the quartz/feldspar ratio in the borings dealt with by Larsen (1966) I have found the following. In strata older than the late Rhaetian the ratio is always low. In the late Rhaetian the figure rises for most of the borings and is very high in a few borings in the southern part of the embayment. For the Early Jurassic fairly high figures occur in the Öresund area and varying figures for the rest of the area. The Middle Jurassic has a very high ratio for most of the area, while the Upper Jurassic has much lower figures. For the basal Lower Cretaceous the figures are again high.

LATE CRETACEOUS

The succeeding Upper Cretaceous sequence is marine and characterized by limestone and chalk. The clay mineral in the chalk is montmorillonite (p. 82 and Christensen *et al.* 1973).

TERTIARY

The Tertiary of Denmark is described briefly by Spjeldnæs (1975). In the Danian the sea retreated from northwest Europe. In the central part of the North Sea area and eastwards to northern Denmark a restricted sea remained and deposition was continuous from the Cretaceous into the Tertiary. The Danian limestone contains montmorillonite (Christensen *et al.* (1973). The Upper Paleocene consists of glauconitic clay, sand and marl (Kerteminde Clay and Marl). The clays have a high montmorillonite content but are devoid of kaolinite (Tank 1963).

In the Eocene, volcanic ash and extremely fine-grained clays were deposited. According to Tank (1963), the clay mineral composition of the Mo Clay Formation is ''predominantly amorphous material with minor or trace amounts of montmorillonite, illite and kaolinite''. The overlying clays have a predominance of montmorillonite with smaller amounts of illite (more in the Rösnaes Clay) and kaolinite (more in the Lillebelt Clay). The lower part of the Sövind Marl contains ''predominantly random mixed-layer montmorillonite-illite with lesser amounts of kaolinite and illite''. The overlying Oligocene clays have a varying amount of montmorillonite, kaolinite and illite (Tank 1963). Because of their fossil content and extremely fine-grained composition Spjeldnæs comments that the Eocene sediments ''mimic abyssal, oceanic sediments in a way which reflects rather unusual geological and oceanographic conditions'' (Spjeldnæs 1975, p. 298).

In the Upper Oligocene strata terrigenous clastic sand begins to appear in quantities, and the Miocene is dominated by an alternation between terrestrial/limnic micaceous sand with lignite and marine, glauconitic and micaceous clays and sands. In the Pliocene the sea only covered the southwestern part of Denmark.

MESOZOIC SEDIMENTATION OF BORNHOLM

Triassic sedimentation appears to have begun in the Late Triassic with the deposition of red and green clays containing montmorillonite. The nature of the sediments is thought to prove a warm, arid climate. No Rhaetian sediments have been found on Bornholm (Rasmussen in Nørrevang & Meyer 1967, pp. 87–89). In the basal Lias there follows a 350 m thick sequence containing freshwater kaolinitic clay, sand and brown coal. Then follow 100 m of marine clays and ferruginous claystone, succeeded by 270 m of freshwater deposits. The latter consist of clay with kaolinite and illite,

sand and brown coal. In the clay and coal beds at Bagå, boulders of kaolin weathered granite occur (Rasmussen 1966). Outside Rönne, uppermost Jurassic strata rest directly on the kaolin weathered basement. Clays are found above the kaolin; at the base they are multicoloured, followed by lower kaolinitic clays and upper illitic clays (Graff-Petersen & Bondam 1963, referred to by Almeborg *et al.* 1969). The Cretaceous succession begins with freshwater sand and clay, but then there are large gaps in the sequence. In Cenomanian time the Arnager Greensand was formed, in the Turonian the Arnager Limestone, and in the Santonian the Bavnodde Greensand, the latter forming the youngest known pre-Quaternary deposits on Bornholm.

The account of stratigraphy in Denmark is based on the works by Rasmussen (1966), Nørrevang & Meyer (1967) and Sorgenfrei & Buch (1964). For the stratigraphical column of Bornholm I have used information from Gry *et al.* (1969).

KAOLIN IN SEDIMENTARY ROCKS IN EAST GERMANY

Störr (1975) provides a good survey of the kaolin deposits in East Germany. According to him, conditions for a kaolinitic weathering prevailed during the Ordovician, Carboniferous to earliest Early Permian, Late Triassic to Early Jurassic, and Cretaceous to Tertiary. Sediments from these intervals contain considerable amounts of kaolinite. In two diagrams Störr shows the kaolinite content in sediments from the northern and southern East Germany. He also demonstrates the correspondence of high kaolin content to weathering crusts in the Bohemian Massif (cf. Table 11). These weathering crusts fit in with the high kaolinite content in the Carboniferous, Upper Cretaceous and Tertiary. In the Cretaceous and Tertiary kaolinization reached its maximum in the southern part of East Germany, but the picture for the northern part of the country is different. Here the maximum in the Carboniferous is higher than in the south. The maximum in the Upper Triassic to Lower Jurassic is as high as for the Carboniferous. The Middle Jurassic also shows a fairly high kaolinite content. The situation for the Lower Cretaceous is unknown. In the Tertiary the kaolinite content is fairly low in the north. Störr (1975, p. 53) also makes a noticeable statement about the Late Triassic to Early Jurassic kaolinization in Scandinavia: ''To the north in this time the Baltic Shield presented a weathering crust. Possibly the kaolins from Bornholm, which are covered with Early Cretaceous sediments are relics of this weathering crust.''

WEATHERING CONDITIONS IN SOUTHERN FENNOSCANDIA DURING TRIASSIC–TERTIARY TIMES AS JUDGED FROM SEDIMENTS IN NEIGHBOURING AREAS

The Rhaetian–Liassic beds rest on a kaolin weathered basement surface in the Ängelholm Trough in northwest Skåne (cf. Norling in Norling & Skoglund 1977, p. 453,

and Norling in Daniel 1978, pp. 22–24) and in central Skåne. I have never found any definite evidence of a kaolin weathered surface below the Kågeröd Beds (lower Upper Triassic). The sediments in Skåne, Bornholm and Denmark all indicate a warm and arid climate in the Triassic before the Rhaetian. In the Rhaetian there is a change in the sediments both in Denmark and in Skåne, indicating that more humid conditions set in. The Upper Rhaetian sediments of Skåne contain kaolinite and in the Danish borings the quartz/feldspar ratio increases. Kaolin occurs in the sediments in Skåne both in the basal and middle Lias and in the Middle and lower Upper Jurassic. On Bornholm the situation is similar. In the marine sediments of Denmark the quartz/feldspar ratio shows varying figures in the Lias but is never very low. In Middle Jurassic sediments, ratio figures are high. The clay sequence of the uppermost Jurassic on Bornholm contains kaolinite in the strata directly overlying the kaolinized basement rocks. The clay above contains illite. The Skagen Formation (basal Lower Cretaceous) in Denmark has a very high quartz/feldspar ratio.

My conclusion is that in south Sweden and Bornholm the kaolin weathering began in the Rhaetian. Troedsson (1942; see p. 67 in the present paper) reached the same conclusion for Skåne as did Norling (Norling in Daniel 1978, p. 24). The kaolin weathering conditions continued during the Early and Middle Jurassic. During the Late Jurassic the climate may have been somewhat drier (this opinion is not shared by Larsen; cf. p. 159). In the Early Cretaceous the kaolin weathering may have continued. On the other hand, the Skagen Formation may also be interpreted to indicate the stripping of an older kaolin weathered surface in connection with the uplift of the Fennoscandian Shield relative to the Danish Embayment (see p. 93). The occurrence of kaolin in the Upper Triassic to Lower and Middle Jurassic sediments of the northern part of East Germany supports these conclusions fairly well. A more exact dating of the basalt necks in Skåne may help to solve the question of the duration of the kaolin weathering period (cf. p. 68).

Beginning in the Albian there was a change from terrigenic to carbonate sedimentation in the central part of the Danish Embayment. Carbonate sedimentation continued through the rest of the Cretaceous into the beginning of the Tertiary. The marine conditions that now began were caused by the opening of the Atlantic. The sedimentation of pure carbonate at the Turonian/Coniacian transition and during the Late Maastrichtian and the Danian indicates that only a small amount of terrigenic sediment reached the Danish Embayment. The carbonate sedimentation may point to more arid conditions during these intervals (cf. p. 83). The significance of the clay mineral montmorillonite in the sediments is not clear. According to Troedsson (1942, p. 322) it might indicate arid conditions on land during the early and middle Late Triassic. The montmorillonite in the Cretaceous chalk has been interpreted both as being derived from the continents and as the result of neoformation in the sediments. It is possible that it indicates arid conditions on land (cf. Tardy *et al.* 1973; p. 76 and discussion p. 82, this paper) during the Late Cretaceous and the Danian, but this has by no means been confirmed. The montmorillonite in the Upper Paleocene is thought by Tank

(1963, p. 35) to be detrital and a product of the surrounding carbonate terrain. In the Late Paleocene there was again an abrupt change in sedimentation, this time from carbonate to terrigenic character, possibly indicating more humid conditions.

The abundance of montmorillonite in the Eocene can be attributed to the alteration of volcanic ash (Tank 1963, p. 37). During the Early Eocene fairly dry conditions may have prevailed along the Fennoscandian coast (Bonde 1973; cf. p. 163). The kaolinite in the Middle and Upper Eocene is more likely to be regarded as a weathering product of feldspars (Tank 1963, p. 37). This may indicate more humid conditions during later Eocene times.

During the Late Oligocene there was again a change in sedimentation. The sediments are darker and contain more silt and sand rich in mica. For the Late Miocene, Spjeldnæs (1975, p. 304) states: ''The content of fresh mica (dominantly muscovite) in flakes from more than 1 mm in diameter down almost into the clay fraction, indicates rapid transport and sedimentation, and unusually immature weathering considering the climatic situation where the source rock normally would be exposed to much more mature weathering. This indicates that the relief of the Shield had been considerably sharpened, and that this process continued throughout the Miocene, supplying fresh terrigenous material.''

DATING OF MORPHOLOGICAL EVENTS IN THE STUDY AREA

The sequence of events in the study area (p. 81) can be dated tentatively on the sedimentary evidence as follows. Kaolinitic weathering seems to have started in the Rhaetian and continued at least into the Middle Jurassic. Stripping accompanied the weathering. Early (and Late) Jurassic seas may have reached the west coast (see maps by Larsen 1966, pp. 105, 109). Accelerated stripping of the saprolite may have occurred during the Early Cretaceous in connection with an uplift of Fennoscandia (pp. 93). Thus the interpretation by Larsen (1966) of the weathering conditions is not followed here. The information from Lower Cretaceous sediments in Skåne does not yet tell very much about the weathering conditions on land. The clay mineralogy is unknown. Kaolinitic weathering conditions probably also existed during the Early Cretaceous. The Upper Cretaceous limestone then covered and protected the study area until some time in the Tertiary. The Tertiary conditions in south Sweden are discussed in a later chapter (pp. 165, 174–175).

II. SOUTHERN FENNOSCANDIA AND THE DEVELOPMENT OF EROSION SURFACES

APPROACHES TO AN UNDERSTANDING OF THE GROSS MORPHOLOGY IN SOUTHERN FENNOSCANDIA

Conclusions on the geomorphological evolution of the study area necessitated a comparatively detailed account of weathering and sedimentary rocks in adjacent areas. To put the study area in its wider context a survey of the gross morphology in southern Sweden seems necessary. With few exceptions recent accounts explain bedrock morphology in Sweden in terms of tectonics, glacial (and periglacial) processes and recent processes. Studies of erosion surfaces have only been performed in northern Sweden, and the last ones are almost thirty years old (Rudberg 1954; Ängeby 1955). Besides, Rudberg (1954, 1970a) has presented an outline of southern Sweden, an area that has never been investigated with focus on surfaces. In the second half of this paper an analysis of erosion surfaces in southern Sweden is made based on firstly, considerations of the extent of a former Cretaceous cover in south Sweden and secondly, analyses of profiles along five main rivers and profiles constructed on data from the Mean Height Map of Sweden (1963).

In recent years geomorphological research in Sweden has focused on process studies, the application of remote sensing technique, and periglacial and glacial phenomena. As a consequence, the knowledge of geographers a generation ago on bedrock geology and gross morphology, both descriptive and interpretive, is almost lost. To add to the understanding of the large scale erosional geomorphology it is necessary to revive the old knowledge and survey the progress in adjacent areas with fairly detailed summaries of the literature in Sweden and neighbouring countries, and to stress the implications of recent progress in the study of plate tectonics and earth history. Thus, in order to reach a better understanding of long-term geomorphological evolution in southern Scandinavia, the evolution of nearby continent and sea areas and of climate is surveyed. Models for the evolution of erosion surfaces and for the explanation of erosional landforms are reviewed and discussed. Attempts at world wide recognition of synchronous surfaces are reviewed and the mode of formation of erosion surfaces examined.

THE FLINT PROBLEM OF THE SWEDISH WEST COAST

Erratic Cretaceous and Danian flints occur along the entire Swedish west coast and also along the Norwegian coast as far north as Andøya in Vesterålen. Their provenance has been discussed since the 19th century. The question is whether the flints are remains of former Upper Cretaceous and Danian deposits on the coast or whether they have been brought to the coast by ice during the Quaternary (cf. p. 10).

PREVIOUS INVESTIGATIONS

Literature on the problems of the Swedish west coast flints is summarized in Table 1 (see also p. 10). Lidmar-Bergström & Johansson (1971) concluded that most of the flints are of Danian age. A few palaeontological determinations have been made (for references see Lidmar 1965a), but most determinations are based solely on ocular examinations of the flint types.

The speckled flints (D types, Upper Cretaceous) of the Kristianstad area are easy to recognize by ocular examination. They resemble flint types in southern Halland (types A–C, p. 36). Lidmar-Bergström & Johansson (1971) studied flints with the expectation that there might be a gradual change in appearance from localities with flint in primary glaciofluvial and till positions in southern Halland to localities with reworked flints further north. It was realized in that study that a similarity between such flint in a primary position in the south and in a secondary position in the north unfortunately did not allow the conclusion to be made that they are of the same age. A palaeontological analysis of the material appeared necessary. Initial attempts were made together with the late Hans Tralau (Museum of Natural History, Stockholm) and a few brief papers (Lidmar-Bergström 1972; Tralau 1972) were published. A new attempt to date the material palaeontologically has begun (see p. 35), but results are not yet available.

During my initial investigations in the beginning of the 1960s I recognized that there is a wide variation in flint appearance from locality to locality. However, no good method has been found to quantify all important aspects of variation.

One attempt to map the occurrence and variation of flints was made by Fåhræus & Engwall (1965). They found it difficult to classify the material as Senonian (Coniacian–Maastrichtian) or Danian, but distinguished between light and dark flints in order to obtain some picture of the variation. Bohuslän was mapped by Fåhræus, who noted a dominance of dark flints at most localities. Halland was mapped by Engwall, who found mostly light flints in the north but a dominance of dark flints from south of Varberg to Hallandsåsen. Another interesting result is the relative abundance of white spotted flints reported from Varberg northwards in Halland. This type is reported from 9 localities, only one of which being a rich flint locality. It seems that this type tends to occur at localities with comparatively few flints (Fig. 30).

In this context it is noticeable that Blomberg (1883) reported dark, black and mottled flint on the shores and in redeposited gravelly till and glaciofluvial material in northern Halland. Only a brief note is published (Lidmar 1965b) on a special type of white spotted flint on the coast of southern Halland (11 flints) and central Halland (3 flints). (See Fig. 30, which also includes a new locality in northern Halland.) This type of flint (type F) is described on p. 117. It has not been reported from Denmark.

Pieces of Upper Cretaceous and/or Danian limestone do occur on the west coast but they are rare.

From the above discussion it is evident that there is a variation along the coast not only in quantity but also in quality. In my opinion, based on experience of the flint

types and still to be proved in detail (cf. p. 10), the flint on the west coast has two components, viz. local flint and flint transported into the area. My main aim in this respect has been to prove that flint of local origin really exists and to localize it. In the discussion as to the origin, the provenance of the foreign flint is also important. One main difficulty is to find criteria that seperate the two components.

WEST COAST FLINTS IN THE THESIS BY WERNER 1974

In her thesis Werner (1974) states that the main purpose of her field work was to map the presence/absence of flint. She mapped a large area in Bohuslän and Halland, but because of my earlier work in southern Halland she visited comparatively few localities in this area. She concludes that Cretaceous rocks may have had a greater extension in Halland than at present and that some flints may be derived from local deposits. She considers it unlikely that glacier tongues or icebergs were responsible for the present distribution of flint. Her conclusion is that the bulk of the west coast flint was transported into the area by driftice. As a consequence, she concentrated on the problem of transport in the sea and along the coasts, the problem of when the transport occurred, and the problem of foreign provenance. When discussing Werner's thesis here, I am particularly interested in possible criteria for separating foreign and local components in her flint material. The large quantity of her material, which is also potentially useful for my purposes, motivates an examination of her thesis.

Localities along the shores — At the shores Werner used test areas of 100 × 1.5 m. All flints from a test area were counted and weighed, and the colour was determined by reference to a rock colour chart (ed. Geological Society of America, New York 1963). The test area was located where she happened to reach the shore. In addition, 27 localities were subjected to detailed studies with many small test areas (2 × 1 m). The results are as follows: 1. The flints tend to be between 2 and 10 (15) cm in size. 2. A map showing the flint distribution was constructed. No data on variation in amount or colour are included. A map published earlier (Werner 1967) shows fewer localities than presented in her thesis, and there is no easily interpreted variational pattern. However, in a zone from Varberg to Fjällbacka (north of Uddevalla) some localities yielded noticeable large amounts of flints. Werner (1974, p. 123) does not stress this circumstance but only talks about a weak maximum. However, the maximum is also obvious from the report of Fåhræus & Engwall (1965), who presented a statistically good background of 140 localities (against 92 for Werner). The pattern also agrees with the results of Wiman (1912) and Lidmar (1965a, b). 3. There is a great local variation from one locality to another according to Werner. She found that the amount of flint depends on the type of shore material, with less flint on sand beaches and in boulder heaps than in beach shingle. Considering the normal size range of flints, this distribution pattern is not surprising. If counts are restricted to material of ordinary

flint size (2–15 cm), another pattern would probably appear and facilitate the search for a large–scale spatial pattern.

In my investigation (Lidmar 1965a, b) I examined several points of land in the southern part of the west coast and found the largest amount of flint on the northwest sides (cf. p. 108). Werner (1974) could not confirm this result, apparently for the following reasons: 1. Most of her localities are in the northern part of the west coast, and it is possible that the pattern actually differs from that in the south. 2. Points of land without protecting islands occur only in south and central Halland. 3. She did not examine any point of land around its complete extent, and her detailed investigations mostly cover very small areas. 4. Werner's test areas are not easily comparable with one another as they were located in different types of material (cf. discussion above). 5. She believes (Werner 1974, p. 57) that my localities with low flint amount on the south sides of land points are sand beaches, which would explain my result. This is incorrect. In fact, the localities are in washed till or beach shingle except in one case, where it is situated on a sand beach with a great number of stones (Lidmar 1965a, pp. 22–47).

When the purpose of the field investigation is to map whether flint is present or not, the test area method seems to present problems because it must be easy to miss flints altogether at localities with only small amounts of them. With regard to the Cretaceous/Danian limestone, Werner found it at 4 of her 92 localities, with 3 in areas investigated in detail. This result can be compared with those of Fåhræus (14 localities with limestone out of 71), Engwall (13 out of 69), and Lidmar (15 out of 74). As percentages the localities with limestone count 4, 20, 19, and 20, respectively, which indicates strongly that the test area method in fact failed in the search for a comparatively rare element.

As Fåhræus & Engwall only estimated the amount of flint and the colour classification was rather subjective, the most reliable investigation of the relative abundance of dark and light flints was made by Werner, and I have therefore used her data. In doing so, I have called her greyish black and dark grey (2 and 3 in the rock colour chart) flints just dark and counted them as a percentage of the number. In the areas investigated in detail by Werner there are never more than 26% dark flints and there is a gap in the amount below 19%. On Fig. 30 I have plotted all localities with more than 5 specimens and more than 19% dark flints. Dark flints occur in greater numbers at a few places.

The greatest difference between Werner's results on the one hand and those of Fåhræus & Engwall on the other is in the data from the Kungsbacka fiord. Engwall's map indicates mostly light-coloured flints, while Werner (in my map interpretation) has three localities with much dark flint. Werner and Engwall have only one locality in common, namely the large land point Ölmanäs. There Engwall has one locality in recent beach shingle with only light-coloured flints, while Werner found 18 dark flints in 7 out of 20 test areas along 2 km of the coast. Thus 65% of Werner's test areas were devoid of dark flints. Two test areas at the northern end yielded one dark flint each. All

others were found in the southern part, with 10 in the southernmost test area. The distribution was remarkable at the southern end, where flints were counted at three levels, namely at the shore line, 0.5–1 m a.s.l., and about 2.5 m a.s.l. At the shore line the flints were light-coloured (only two boulders, weighing 15 kg together), at the next level all were dark (10 flints), and at the highest level all were again light (5 flints). I return below (p. 120) to similar observations from other localities. In Werner's material the variation between neighbouring test areas and localities makes it difficult to describe generalized patterns such as those produced by Fåhræus & Engwall.

Werner has only a few localities south of Falkenberg, which can explain the absence of localities with a large number of dark flints in her representation of this area.

Analyses of soil samples were made at 31 localities along the coast. All except two in the inner part of a fiord in Bohuslän contained flint. More than 30% flint (by weight, 15% by number) was found in the 8–16 mm size range at two localities, just south of Strömstad and at Kungsbacka.

Localities in gravel pits, clay pits and cultivated fields — Werner studied 1025 inland localities. In gravel and clay pits all the flints encountered were noted, and 1041 test areas measuring 100 × 1.5 m were used in cultivated fields. One noticeable result of this part of Werner's study is that localities with flint in till above the ML (marine limit) were found only in southernmost Halland. Two localities in till directly below the ML are interesting because of the possibility that the flints were derived locally. One of these is Lindome (No. 658) north of Kungsbacka at 85 m a.s.l. There one dark flint with a thick white crust was found 1 m below the surface in an end moraine (see Fig. 35). The other locality is at Dagsås SSE of Varberg, 65–70 m a.s.l. (zone 12 in Fig. 35), where the flint was somewhat lighter in colour than at Lindome (4 in the rock colour chart). One locality northeast of Falkenberg is noticeable in having more than 30% flint (by weight, 15% by number) in the size fraction 8–16 mm.

SUMMARY OF FLINT OCCURRENCE ALONG THE COAST

The studies by Wiman (1914), Lidmar (1965a, b), Fåhræus & Engwall (1965) and Werner (1967, 1974) show that most of the flints are found close to the coast. The belt with flint is widest in central Bohuslän, apparently because of the broken coastline with deep fiords. In Fig. 32a the flint limit has been based on Werner's (1974) observations (presented on maps). Four flint occurrences in the Ätran valley reported by Åberg (1963) are considered both by Åberg and Werner to be a result of introduction with limestone used as agricultural fertilizer (four dotted circles in Fig. 32a). The richest flint localities lie roughly between Uddevalla and Falkenberg (cf. Fig. 30). The number of flint localities decreases with increasing altitude. In southern Halland there is flint above the ML, which is situated at 50–60 m a.s.l. Further north the flint is found up to the ML, which in northern Halland reaches a maximum of 86 m. In

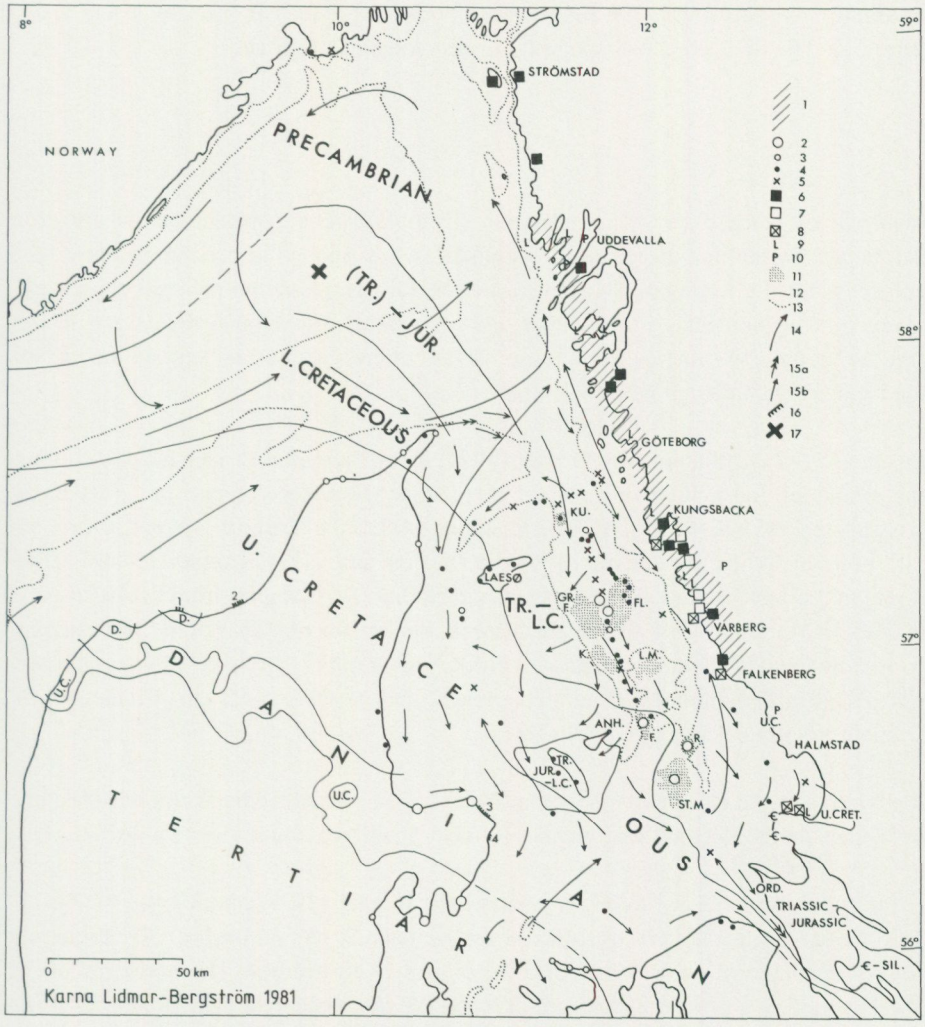


Fig. 30. Bedrock and distribution of flint along and west of the Swedish west coast.
Different flint types are marked along the Swedish west coast. 1. Area with > 2% of flint (Lidmar 1965a; Wiman 1912; Fåhræes & Engwall 1965; Werner 1967). 2. Localities with > 50% (per cent of number in Denmark, St. Middelgrund and Fyrbanken, per cent of weight in the Kattegat), with flint size >16 mm (Werner 1974; Mörner 1969). 3. Localities with 25–50% (as for point 2), flints > 16 mm (Werner 1974). 4. Localities with < 25% (as 2) of flint, or flints < 16 mm (Werner 1974). 5. No flint found (Werner 1974). 6. Localities with at least 5 pieces and 19% of dark flint (Werner 1974). 7. Localities with white-spotted flint (Fåhræus & Engwall 1965). 8. Localities with white-spotted flint (Lidmar 1965a, b). 9. Limestone as erratics, moderate amount (Fåhræus & Engwall 1965; Werner 1974). 10. Upper Cretaceous pollen (Fries & Ross 1950; Linnman in Caldenius *et al.* 1966). 11. Shoals. 12. Boundary between different stratigraphical units. 13. Isobath for 40 and 200 m. 14. Prevailing surface currents (long arrows). 15. Surface currents in the Kattegat during strong west winds: a, > 75 cm/sec; b, < 75 cm/sec. 16. 1, Bulbjerg klint (and earlier also the now destroyed Skarreklitt); 2, Svinkløv klint; 3, Karlby and Sangstrup klints; 4, Bredstrup klint. 17. Supposed area of origin of Mio-Pliocene conglomerate of Danian flint and quartzite (Ødum 1968).

northern Bohuslän flint is not found above 50 m, while the ML rises to 175 m a.s.l. (Fig. 35). The flints are always found at or near the ground surface.

FLINTS IN ADJACENT AREAS

Methods of calculation of percentages — In Werner's presentation, figures for percentage by number are given for Denmark, while figures for percentage by weight are given for the Kattegat. The figures for the soil samples from the west coast were given both in percentage by number and by weight. This is also the case with the figures for the soil samples from Laesø. These differences must be kept in mind when the figures are compared with each other.

Denmark — Investigations by Werner (1974) along the shores of Denmark, including the island of Laesø in the Kattegat, were undertaken for comparison. Test areas measuring 1 × 1 m were used. The localities around the Kattegat are plotted on Fig. 30. Four localities yielded more than 50% flint and nine localities 25–50%. The remaining nine localities yielded less than 25% flint. Soil samples from Laesø have up to 30% (by number, 46% by weight) flint in the size fraction 2–16 mm. Soil samples from Djursland (the point of land with cliffs 3 and 4 in Fig. 30) have 50% by number. The flints in Denmark are generally rounded and measure 5–20 cm. Cretaceous or Danian limestone is rare along the shores.

Norway — In the Oslofjord area 43 localities were investigated by Werner (1974), but only four, on the Recent shore, contained flint. The flint amount was very low.

Flint occurrences in the Kattegat reported by Werner (1974) and Mörner (1969) — Information from the investigations in the Kattegat is plotted on Fig. 30. There is a high percentage of flints larger than 16 mm at five localities. The northernmost of these localities is in a clay at a depth of 45 m. All material larger than 16 mm consisted of flint (total weight 14.9 g). At Rödebank 134 g were sampled as specimens larger than 16 mm, 50% of which consisted of flint. A sample from Stora Middelgrund contains 69% (by number) flint and limestone (107/177; Mörner 1969, p. 33). A small amount of coal and sandstone is also present, while the remainder consists of Precambrian rock fragments. The high figure at Fyrbanken (Fig. 30) is based on information from fishermen (Mörner 1969, p. 31, 33).

More than 30% of flint in the grain sizes below 16 mm is reported from two of the localities southwest of Laesø, two of the localities southwest of Anholt, the locality outside Halmstad, and the southernmost locality at Fladen. All these localities are in sand or sand with clay.

The opinions and findings of Eichstädt 1908 and 1909 — Eichstädt (1908) reported finds of flints in true till from northern Halland, Göteborg, and Kungälv. Later (Eichstädt 1909) he also reported flints from localities far inland. The northernmost localities are at Lugnås in Västergötland, two of them at Lake Vristulven 111 m a.s.l. (they are in zone 6, Fig. 35). Eichstädt was convinced that these flints were of Cretaceous age and that they were no artefacts. He reproduced a picture of a flint from Öxabäck in southern Västergötland (140 m a.s.l., zone 11, Fig. 35), which judging from the picture looks like Cretaceous flint. He also mentioned two black, partly speckled, flints from the shore of Lake Vänern (about 45 m a.s.l.) at Bohlstad and Grindstad in Dalsland (zone 5, Fig. 35). Eichstädt reported additional finds from even higher localities. In Fig. 32a, the isolated area in the Viskan valley marks his finds at Öxabäck.

As indicated above at least some of Eichstädt's flints look like, and may be Cretaceous flints. However, in Västergötland there is Cambrian flint (chert) which is impossible to distinguish from certain Cretaceous types from illustrations only. Another difficulty is that flint artefacts occur at several of Eichstädt's localities.

Eichstädt considered that his finds lend support to the theory of a former cover of Mesozoic strata on the west coast and even further inland.

BEDROCK OF THE SWEDISH WEST COAST, THE KATTEGAT, THE SKAGERRAK, AND DENMARK

The result and conclusions reached by Werner, Fåhræus & Engwall, Eichstädt, and Lidmar are best discussed against a background of the bedrock in the area (Fig. 30). Knowledge of the bedrock in the Kattegat was summarized by Bergström (in Bergström *et al.* 1973). The Fennoscandian Border Zone extends through the Kattegat and is characterized by the development of ridges and grabens trending either NW–SE or NE–SW. Several shoals in the Kattegat indicate this border zone. For example, echo-soundings indicate that Stora Middelgrund consists of basement rocks and is surrounded by areas with sedimentary rocks (Mörner 1969, p. 33).

On the Swedish west coast, Cretaceous rocks are found primarily in the Båstad area (Figs. 32, 33). Cretaceous rocks (Cenomanian and Santonian) have also been found *in situ* at Särdal between Halmstad and Falkenberg (Bergström *et al.* 1973). From Stensjö north of Särdal, Lundbohm (1887) reported a piece of Cretaceous limestone, possibly of the same variety as at Gräseryd (Santonian). Upper Cretaceous fossils have been collected from the bottom of the harbour at Varberg (Hägg 1946). Bergström points out that the Cretaceous cover may have been comparatively thin from the beginning in the border zone even if several stages were represented. This would also mean that remnants younger than the Santonian might be preserved locally.

Baartman & Christensen (1975) interpreted seismic data from the southwestern part of the Kattegat. They drew the limit of the Upper Cretaceous cover through Vendsys-

sel (northern Jylland), Laesø, to the east of Fyrbanken, and to the Öresund area. South of Laesø, east of the Upper Cretaceous border, a sequence containing Triassic to Lower Cretaceous rocks is directly overlying the basement. The interpretation of Baartman & Christensen is followed in Fig. 30. However, later seismic soundings in eastern Kattegat (*Marin geologi och oceanografi* 1979) have made it possible to draw the boundary between Mesozoic sedimentary strata and the Precambrian basement. As it has as yet been impossible to differentiate the sedimentary sequence in eastern Kattegat, the information is not brought into the map (Fig. 30). However, the limit for Mesozoic strata is close to the coast at Halmstad, about 10 km off the coast at Falkenberg, close to the coast at Varberg from where it extends to the northwest.

Information on the Skagerrak (Fig. 30) is taken from Flodén (1973) and Sorgenfrei (1969). These two authors do not agree completely on the limit of the sedimentary cover towards the north (dashed section in Fig. 30).

Fries & Ross (1950) reported finds of Upper Cretaceous (and Paleocene?) pollen grains from Bohuslän. The pollen may be either of local origin or transported into the area (Fig. 30). One similar pollen grain was found in the Viskan valley by Lennart von Post. A similar find is reported from Undarsmossen in Halland (Linnman, in Caldenius *et al.* 1966).

The Danian deposits in Denmark that are closest to the Swedish west coast are in Djursland and Själland (Fig. 30). The Danian limestone forms cliffs at localities 4 (Bredstrup klint) and 3 (Karlby klint and Sangstrup klint). At Bredstrup it is Upper Danian and is alternately hard (Saltholmskalk) and friable. It contains much flint in the shape of grey nodules (Ødum 1926, pp. 32–33). The limestone at Karlby klint and Sangstrup klint belongs to the Lower Danian and consists of bryozoan limestone. The flint is white-grey and appears in bands which are usually thin but occasionally thicker (Ødum 1926, pp. 34–35). On the northwestern coast of Denmark the Lower Danian limestone forms a cliff at Bulbjerg (locality 1 in Fig. 30). The rock is a bryozoan limestone with thick bands of light or dark grey to brown flint, sometimes closely spaced (Ødum 1926, p. 86). Bryozoan limestone of the same age at nearby inland localities is less rich in flint. Here the flint is dark with a thin white crust, but white flints also occur (Ødum 1926, pp. 85–86). Further to the southwest there are inland localities with coccolith limestone of younger Danian age and bands of white flint with a core of black and grey white-spotted flint (Vegebjerg) or grey flint (Hansted III; Ødum 1926, pp. 88, 118). At Svinkløv (locality 2 in Fig. 30) there is a cliff in the Upper Cretaceous (Senonian) chalk. The cliff is not on the present shore but it was affected by the sea in the past. The flint is black to grey black (Jessen 1905, pp. 11, 23). The amount is small as is true of other localities in the vicinity. (This section includes some general information from Ravn 1922).

The flint conglomerate found as erratics in northern and western Jylland is an indication of former Danian deposits north of Denmark. The conglomerate is of Tertiary age (Miocene or Pliocene according to Koch 1959 in Ødum 1968), but contains flints from the Danian. The supposed area of origin is indicated by a cross on

Fig. 30 (Ødum 1968). Thus it is possible that there was a cover of Danian rocks further to the north. Hillefors (1968b, p. 332) found erratics of a flint breccia (the conglomerate found in Jylland is said to be in part breccia-like) in Bohuslän.

FLINT DISTRIBUTION IN AND AROUND THE KATTEGAT WITH DISCUSSION ON THE PROVENANCE IN THE KATTEGATT

The quantity of flint on the Swedish west coast is greatest along the shores between Uddevalla in Bohuslän and Falkenberg in Halland. The amount never seems to exceed 10% (Lidmar 1965a; Werner 1974, Bil. 2) except in soil samples. Apart from the shores around Båstad in the south, this area also contains all localities with any appreciable amount of limestone erratics.

In Denmark the highest flint ratio is more than 50%, at three localities even more than 75%. Many of the Danish shores show amounts of 25–50%. The localities on Laesø yield 5–25% flint.

The results from the Kattegat indicate about the same flint amount in the west as along the shores of Jylland and Laesø. Flint debris less than 16 mm in size is common. This material is probably derived from the immediate surroundings. The high percentage of flint on the three shoals in the southern Kattegat can only be compared with the figures from Djursland. The figures for the west coast of Sweden are of a different order, with 10% as an extreme maximum. A sample from Stora Middelgrund (borrowed from N. A. Mörner, Department of Geology, Stockholm) shows a rough flint surface without sign of transportation. The flint is grey and probably of Danian age, an age also indicated by associated limestone (Saltholm Limestone). The large quantity and irregular morphology of the flint indicate a local origin. Mörner (1969, p. 33) explains the occurrence by concentration through mechanical erosion during the low shorelevel of ALV-1 (7750–7330 BC) and chemical solution of the chalk by the sea.

In the area between Groves Flak and Fladen there are two localities with more than 50% flint, one with more than 25% flint larger than 16 mm and one with more than 30% in sizes smaller than 16 mm. The samples are small but there is a possibility that also those flints are of local origin.

One locality southwest of Halmstad also yielded a large quantity of flint in the size range 8–16 mm. This locality is close to the known Upper Cretaceous deposits in the Båstad area and at Särdal, and the flint may be of local origin.

This summary of flint distribution in Denmark, Kattegat, and along the Swedish west coast indicates that much flint in the Kattegat seems to be derived from local deposits. Flints on the west coast of Sweden are discussed below, first transported flint and then flint of local origin.

DISCUSSION ON THE PROVENANCE OF FLINTS ON THE SWEDISH WEST COAST

TRANSPORTED FLINT

Werner (1974, p. 123) uses the following criteria to prove that flints have been transported into the area by drift ice from the time of deglaciation until the present (remarks in brackets are mine). 1. The flints are distributed evenly along the coast (in my opinion there are great local variations). 2. The flints are distributed evenly in different material (but shore material should yield greater amounts if transported by drift ice). 3. The flint is found far to the east and at high levels, indicating transportation over a long period, which also explains the increase in amount of flint to the west (provenance from local deposits could result in the same picture).

The main criterion, even if it is not stressed in connection with Werner's conclusions, must be that the flint is mainly found at or near the surface in wave washed material, seldom deeper than 1–1.5 m (Werner 1974, p. 101; cf. also Lidmar 1965b, p. 67).

The theory of flint transport by drift ice has good merits. It became discredited when the glacial theories proved to be correct. A survey of literature on this subject was presented by Overweel (1977, pp. 54–56) who, however, had not seen the account by Werner.

Fig. 30 shows the currents in the Kattegat and Skagerrak as developed today. The long arrows indicate the general circulation pattern, while the short arrows show the pattern during strong west winds (Svanson 1975, including also map information from Dietrich 1951). The concentration of flints between Uddevalla and Falkenberg seems to fit in with such a pattern. Today the drift ice reaches only the outer archipelago in Bohuslän and northern Halland, while in southern Halland it can be carried high up onto the low shores (Werner 1974, p. 124). The greater quantities of flint on the northwestern sides of points of land in central and southern Halland could also fit into the theory of ice rafting.

As Werner has pointed out (1974, p. 72), the conditions along the shores change both from one year to the next and from one storm to the next. If the same beach is visited on different occasions, counts of numbers of flint and stone will give different results. Thus, it would be interesting to pursue repeated investigations. Waves and algae contribute to redeposition of stones (including flints) along the shores (Werner 1974, pp. 119, 121).

Werner discussed transportation of material from the time of deglaciation until the present. She interpreted the large amounts of grey (Danian?) flint as pointing to Djursland–Kattegat–Själland as a probable provenance area.

During the period 8000–7500 BC the western coast of the Kattegat was situated along a line over Laesø–Anholt–Öresund, with the shoals of Stora and Lilla Middelgrund above sea level (cf. Mörner 1969, Pl. 7). The southern shores and the shores of

Stora Middelgrund probably contained large amounts of Danian flint, probably as a weathering residue. This area is probably just outside the limit of continuous Danian limestone. It is uncertain whether Danian flints occurred in large quantities further to the north between Anholt and Laesø. However, the occurrence of a certain amount of Senonian flint also seems possible. Another possible source is the area northwest of Jylland where the sea is now not deeper than 40 m. During the time in question, the coastline moved over this area of Danian and Senonian rocks. At about 6500 BC, circulation in the Kattegat and Skagerrak may have been the same as today (Werner 1974, pp. 43, 115).

How is it possible to prove that flints on the west coast of Sweden derive from Denmark? Are there any special types of flint that could be used as indicators? As long as the flints can not be dated it is difficult to compare with those from distant areas. The white spotted flints (type F, p. 117) found at a few localities along the Swedish west coast have a distribution that could very well be explained by transportation. Does this type of flint occur in Denmark?

During an excursion in 1973 I visited Skagen, the northernmost point of Denmark. There, the beach shingle contained black Senonian flints, and all material was well rounded. Werner (1974, p. 75) also states that the flint material in Denmark is usually well rounded. On the Swedish west coast the flints are usually not rounded. If transport is still occurring today from Skagen, rounded flints should be found in the middle part of the west coast.

Are there any other erratics on the Danish beaches that could be used as indicators? Investigations for good indicators and a search for these along the middle part of the Swedish west coast would perhaps give results that could answer the question of provenance of the transported flints. Werner (1974) discussed the transportation in greater detail and also analysed the winter-ice situation in the Kattegat.

LOCAL FLINT

At least along the southern part of the west coast, the sea transgressed higher in the Late Cretaceous than in the Danian. During the Danian the sea regressed and may just have reached the present west coast of Sweden. Thus, it seems most probable that local flints are derived from the Upper Cretaceous (Senonian). Local concentrations of Senonian flint derived from local bedrock should show a distribution independent of the general distribution pattern, which is thought to reflect transported flint. Since flints are much more abundant in Danian deposits than in Senonian strata, the contribution of local Senonian flint needs not result in equally high concentrations as in those cases in which the local flint material emanates from the Danian.

The difficulties in determining whether a flint is of Senonian or of Danian age have been pointed out above (pp. 35, 99). As it is more common to find black to dark grey flint in the Senonian than in the Danian, I used Werner's (1974) data to plot localities

with notably high concentrations of dark flint on Fig. 30. It is thus possible that the resulting pattern shows where locally derived flint is particularly common. The white-spotted flints reported by Engwall (Fåhræus & Engwall 1965) were found commonly in localities with few flints. This distribution would not be expected from a rare element transported with the bulk of the flints into the area. The white-spotted flints may therefore also be of local origin, and they are presumably of Senonian age. The four localities richest in white-spotted flint are plotted on Fig. 30. Thus the black and white squares on this map indicate localities in which comparatively many flints could be remnants of local Cretaceous deposits. Some additional information that strengthens this idea is presented below.

The northernmost localities with dark flints at Strömstad lie outside the area with high flint quantities. At another locality just south of Strömstad there are virtually no large flints, but a soil sample (Werner 1974) showed an extremely high flint content (30.9% by weight, 18.2% by number; cf. p. 102).

The locality with dark flint south of Uddevalla (Fig. 30) is south of the Gullmarsfjord, where Upper Cretaceous palynomorphs have been found (Fries & Ross 1950).

Three localities with dark flint and one locality with a large flint amount in the soil are in the Kungsbacka fiord area (p. 102). The white-spotted flints found by Engwall (p. 99 this paper) were also found in this area. In addition, Blomberg (see p. 99) reported dark, black and mottled flints from the Kungsbacka area.

In the Varberg area both dark flints and white-spotted flints are found. Campanian fossils have been recorded from Varberg harbour (see p. 105). One Upper Cretaceous palynomorph was reported from the Viskan valley (see p. 106).

The third locality with high flint quantities in the small size fractions is northeast of Falkenberg (p. 102), and dark flints are found on the coast at Falkenberg.

In summary therefore, Upper Cretaceous strata occur in the Båstad area, as a small remnant at Särdal, and further to the north along the coast some flints may be remnants of local Cretaceous deposits. If the flints reported by Eichstädt from Västergötland and Dalsland are really of Cretaceous age, and if ice rafting and transportation by man can be ruled out for these flints, interesting perspectives open up. A Cretaceous cover may have existed not only along the coast but may also have extended over parts of the Central Swedish Lowland.

HALLAND: COMPILATION OF DATA AND FIELD INVESTIGATIONS

$CaCO_3$ CONTENT

The $CaCO_3$ content in the glacial marl in Halland is shown on a map by De Geer (1893; redrawn here as Fig. 31). De Geer interpreted the distribution pattern in the south as indicating that the $CaCO_3$ was introduced by a Baltic glacier tongue, while in the north it would have come with Cambro-Silurian erratics along the Viskan and

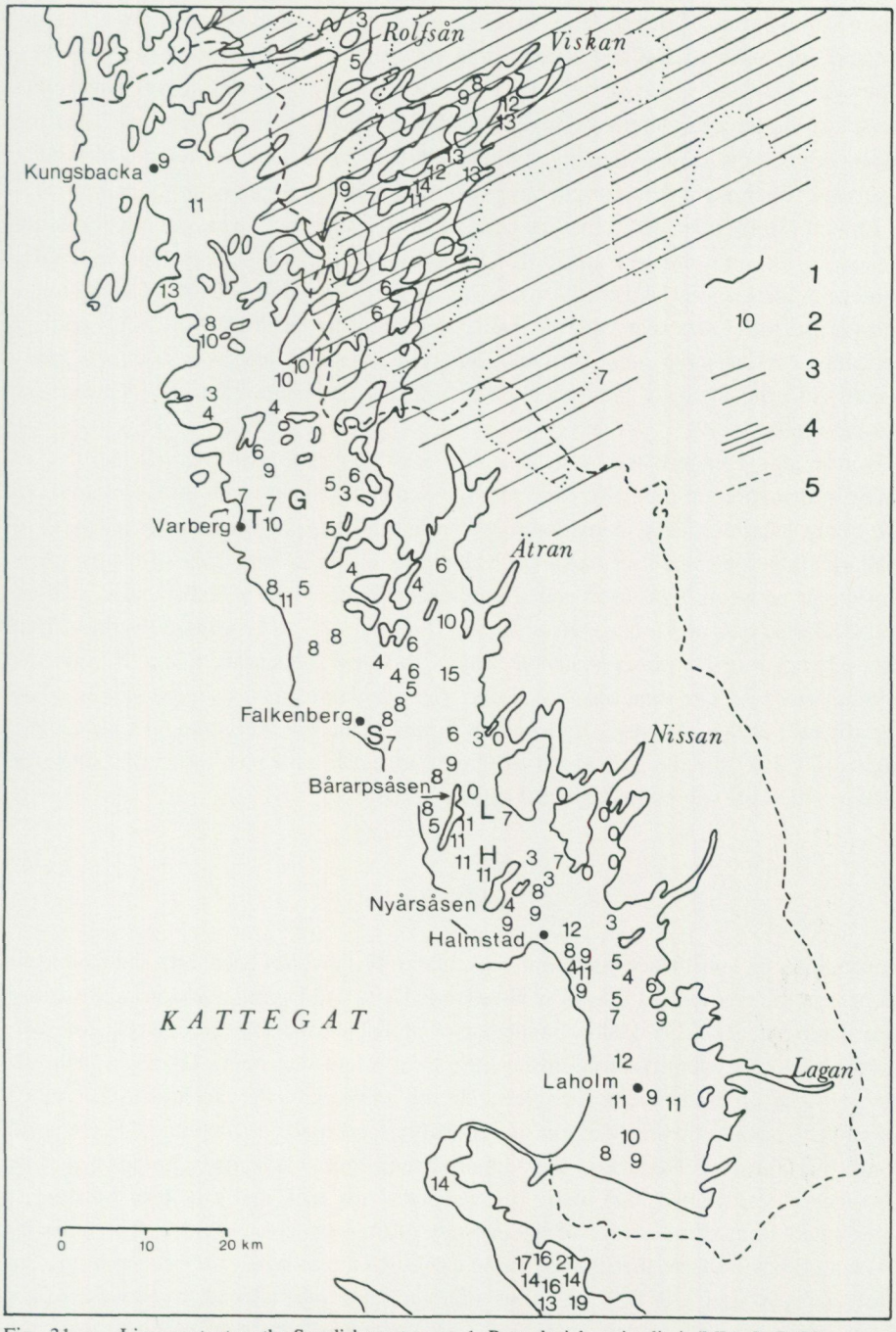


Fig. 31. Lime content on the Swedish west coast. 1. Post-glacial marine limit (ML). 2. $CaCO_3$ content (%) in marl (De Geer 1893). 3. $CaCO_3$ content in till < 1.5% (Gillberg 1955). 4. $CaCO_3$ content in till 1.5–5% (Gillberg 1955). 5. Boundary of Halland. T = Träslöv, G = Gödestad, S = Skrea, L = Lassagård, H = Harplinge.

Ätran valleys from Västergötland. Investigations on till by Gillberg (1955) in Västergötland and northern Halland confirm this view for the Viskan valley (see Fig. 31). However, De Geer's map shows how the $CaCO_3$ content increases again closer to the coast. Along the coast there are several localities with more than 10% $CaCO_3$. In the Ätran valley there is an extremely high value (15%) which De Geer did not include in his map as he thought that it might have been caused by shell fragments in the sample.

Eklund (1953) considered that the bedrock components have a favourable influence on soil fertility in southern Halland. Caldenius (1966, p. 62) concluded that the $CaCO_3$ content in the clay derived partly from drift ice carrying Cretaceous and Danian rocks and partly from Quaternary marine shells. As regarding the flint, the $CaCO_3$ content appears to reflect both local bedrock components and calcareous rock debris transported into the area. A third factor affecting the carbonate content is Quaternary marine shells.

Soil mapping undertaken by local authorities *(Hushållningssällskapet)* in 1958–59 gives information on the pH conditions. In southern Halland south of Halmstad there are many localities with many samples yielding a high pH value. In other parts of Halland only four localities had a pH value over 6.5 in at least 25% of the samples: Harplinge between Nyårsåsen and Bårarpsåsen, Skrea south of Falkenberg, Träslöv and Gödestad east of Varberg (H, S, T, and G in Fig. 31). At Lassagård (Getinge, L in Fig. 31) north of Harplinge a sample from 1 m below the surface had a pH value as high as over 7. The material was a clay *(Lantbruksnämnden i Hallands län)*. The significance of these values is uncertain as liming of the soil is common. However, the high pH values for the area south of Halmstad indicates a possible correspondence between high pH values and the local calcareous bedrock.

DRILLINGS

Information on subsurface conditions in southern Halland has been obtained from drill records at the Geological Survey of Sweden in Lund and Uppsala, and from the driller Bror Hellring, Björklid, Holm. Sandstone or probable sandstone is reported from five boreholes in the vicinity of Halmstad, the most interesting being Övraby (Table 6), where 10 m of sandstone are recorded. In the archives of the Geological Survey of Sweden, Uppsala, there is a report of "probably sandstone" in a borehole at Genevad south of Halmstad. The age of the supposed sandstone is unknown, but a Jurassic or Cretaceous age seems most likely (provided that the rock really is a sandstone), as interpreted from a knowledge of the geology of the west coast (p.105). The maps by Larsen (1966) indicate that the sea came closest to the Swedish west coast during the Early Jurassic (Lias). (Cf. p. 92.) Thus a Liassic age for the alleged sandstone does not seem impossible. However, an early Late Cretaceous (Cenomanian–Santonian) age may equally be suggested. Sandy sediments of this age occur in the Kristianstad area. Deposits of this age are known both from Särdal and from the Båstad area.

TABLE 6. Drilling record from Övraby, Sperlingsholm 19. 13.5–19.5 1959. 1302. Geological Survey of Sweden, Lund.

Depth in metres (below surface)	Lithology
34.20 - 38.00	fine sand mixed with clay
38.00 - 38.40	medium coarse gravel
38.40 - 43.00	sandstone mixed with clay
43.00 - 45.00	sandstone with less clay
45.00 - 48.50	sandstone, purer

There are also several reports of kaolin. As in the study area no analyses have been made, and the drillers' determinations are therefore provisionally accepted. From an area around Halmstad (in the north to Bårarpsåsen, in the east including part of the Nissan valley and in the south to Laholm, see Fig. 31), kaolin is reported in fissures from 18 borings and an undetermined green material reported from 3 borings. The most interesting locality is southwest of Harplinge (UC 586899), where the complete boring down to 60 m is said to have penetrated kaolin (Bror Hellring). Two of the above mentioned sandstone localities also contain clay with gravel, probably kaolinized. At one of these localities the clay lies above the supposed sandstone with a fragmented gneiss below. At the other locality the clay is below the supposed sandstone. Weathered bedrock or kaolin is reported from four additional localities, one of which (at Harplinge) yielded 60 cm white and green kaolin.

From the Skintan rivulet valley, between Nyårsåsen and Bårarpsåsen, Hellring reported a high $CaCO_3$ content in ground with several cm-sized pieces of limestone (Lassagård, mentioned on p. 112, is situated in this area). This is important because it shows that the high pH and high $CaCO_3$ content need not be due to marine shells.

FIELD INVESTIGATIONS

As is clear from the introductory chapters of this paper, the flint problem of the Swedish west coast initiated the investigations in the study area. The discussions immediately above indicate reasons for believing that some of the west coast flints are of local origin. In order to find a good method of identifying local flints I spent some time along the coast of Halland. The most reliable indication of local provenance was found to be the casual occurrence above the ML. As only southern Halland yielded flints above the ML, I soon concentrated my investigations to this area. After all, however, the field work along the coast of Halland had brought material of particular interest from various new localities.

TABLE 7. Localities on the Swedish west coast.

No.	Name	U T M	H.a.s.l. (m)	Type of locality and material	Cretaceous rocks total amount %	Size (cm)	Flint type	Limestone	Other erratics/ref.
SE of investigated area									
	Edran (Filkesboda)	VC631393	76		>100			conglomerate quartz sand belemnites	Lundegren 1934 pp. 186-189
	Ylsudden	approx. VC615403	81						
	Filkesjön	approx. VC636394	76		1				
	Karseboda	approx. VC625380	76		1				
	Baggeboda	VC677367	68		1				
	Alltidhult	approx. VC665356							
	Lunnom	approx. VC445349	74					in till	Lundegren 1934 pp. 177-178
SW of investigated area									
340	Angsholma	VC114275	105	gl.fl.	1	1	B		
M5	Rya	UC887353	65	g.p.	2		1B, 1D		
M4	Örkelljunga	UC913378	70	road cut	1		B		
377	Örkelljunga	UC925382	75	gl.fl.	2	small	B		1 Rhaetian-Liassic (M7)
M3	Örkelljunga	UC942382	80		4		B		
458	Hjälmsjö	UC942371	90		3		B		
M1-2	Örkelljunga	UC951391	80	field	46		43B, 3D		
459	Pålsholm	UC976378	110	gl.fl.	2		B		
460	Lärkesholms-sjön	UC985390	100	gl.fl. field	1		B		
M6	Lärkesholms-sjön	UC996387	90	shore	1		B		
	Lemmeshult	approx. UC935430	125-140	stratified	x		dash grey and white spotted		Lundbohm 1808
535	Mattarp	UC943448	95	gl.fl. field	3		B		
CJ12	N. Lycke	UC905461	80-85	gl.fl.	18		16B, 2C		SGÅ 1971:1
CJ57	Smedjeryd	UC901463	75	gl.fl.	10		3B, 7C		
370	Vråkärr	UC902476		gl.fl.	1		B		1 ss (Vg)
417	Ön	UC848515	50	gl.fl.	1	1	B		
143	Yllevad	UC827513	50	field	1		B		SGÅ 1971:5
336	Kärr	UC815515	55	gl.fl.	1		B		
160	Flintarp	UC786533	35	till	1		B		
CJ52	Hasslöv	UC769536	50	gl.fl.	1		A		
	Tjuvhult	approx. UC753524						fossils	Hägg 1954
	Gräseryd	approx. UC743552	15				grey-yellow	fossils	Hummel 1871, 1877 Lundgren 1883 Moberg 1884, 1886 Lundgren 1889 Hägg 1935, 1954
	Ö. Karup	approx. UC735554	15	marl pits, till				fossils in situ?	S. Nilson 1847 Hummel 1871, 1877 Moberg 1886 Lundgren 1889 Hägg 1954
	Tvehöga	approx. UC733537		marl pit, till				fossils	Moberg 1886 Hägg 1954
	Tiehaga	approx. UC712546	150	marl pit, till				fossils	Moberg 1886 Hägg 1954
	Lya	approx. UC695540	175					fossils	Hägg 1954
	Boarp	approx. UC638567	130-140					fossils	Hägg 1954

No.	Name	U T M	H.a.s.l. (m)	Type of locality and material	Cretaceous rocks total amount	%	Size (cm)	Flint type	Limestone	Other erratics/ref.
The area south Halmstad										
201	Grevie	UC633512	75	gl.fl.	39	3.9	2-10	21A	16	Hummel 1872, 1877 Moberg 1886 Hägg 1954
202	Axeltorp	UC662533	120	field, till	11	1.1	2-10	5A, 2 dark	4	
203	Bjärröd	UC670525	125	g.p. till	31	3.1	2-10	13A	18	
204a	Kattvik	UC620598	0	beach shingle	19	1.2	2-6	1A, 5F whole concretions; A difficult to find	1	12,2 % Cambr.ss (S)
204b	Kattvik	UC620598	4-5	beach shingle		1.4	5-10			14,2 % Cambr.ss (S)
205	E Kattvik	UC633593		beach shingle	15	1.5	2-10	1D2	1	10,5 % Cambr.ss (S)
369	Norrviken	UC644583	0	beach shingle				1E	x(local)	6-11 % Cambr.ss (S)
206	Malen	UC683563	0	sand beach	25	12.5	2-10	4A, 1E	3	
CJ29	NW St.Skärsjön	UC816834	65	gl.fl.	1			B		SGÅ 1971:23
	Snöstorp								belemnites	SGÅ 1971 pp. 67, 70
223	Fyllinge	UC726806	15	field	1		150	grey		
224	S Steglebacken	UC716768	0	washed till		0.3				Kinne Diabase, ss (many)
225	NW Steglebacken	UC716773	0	rocky beach	12	1.2		1E	1	2ss
The area around Halmstad										
CJ30	Vapnö	UC673855	50	gl.fl.	2			B		SGÅ 1971:24
169	Eketånga	UC658809	0	washed till	11	2.2	-5	grey-black; 3A		1 chalky siltstone
177	Tylesand 1973	UC616803		beach shingle	22	4	-6	dark; 4E, 3light		
235	Tylesand 1971	UC616803		beach shingle	less than 1973			dark		
29	Skallen	UC566892	0	beach shingle	2			1B		Lidmar 1965a
The area north Särdal										
277	Busören	UC549913	0		1					
278	Busören	UC547913	0		1			dark with bryozoans		Kinne Diabase size 50 cm (many)
168	Särdal	UC552919	3	coarse silt (layer D acc. to Bergström 1973)	1			dark		
331	Särdal	UC547924	0	shore		7		Danian and Senonian	x	1 big piece Cambr.ss (S)
332	Flinten	approx. UC520905	-18	shoal	10		10-	knotty 3E	3	
275	Högen	UC565923	30	g.p.	5	1.6	2-6 18-50	Danian		
	Skintaby	approx. UC5793							belemnite	SGÅ 1971 p.70
269	Glassvik	UC543957	0	shore		(6)	4-12	light Danian; also dark	1	Kinne Diabase, 1 ss congl. local material
270	Glassvik	UC544957	0	shore		(3)	6-12	dark (Danian?)		
271	Glassvik	UC545956	0	sand beach	38	(35)	1-5	dark-black; 1B; 1 "wallstein"		
272	Glassvik	UC545955	0	washed till		(18)	1-5	black; "wallsteine"		
163	Stensjö	UC544964	0	water line		4.9	2-6 (-15)	dark	2Si	1 ss
158	Stensjö	UC543962		storm water line	14			3E		1 Cambr.ss (S)
162	Stensjö	UC544964		storm water line	14	1.4	2-4	1A	1 with bryozoans	
164	Stensjö	UC544964		old beach ridge		1.4		light		
157	Stensjö	UC545966	6	P-place	9			3E		
159	Stensjö	UC545966	6	P-place	7			2A, dark		

TABLE 7, continued.

No.	Name	U T M	H.a.s.l. (m)	Type of locality and material	Cretaceous rocks total amount	%	Size (cm)	Flint type	Limestone	Other erratics/ref.
166	E L.Stensjö	UC555971	15	field	37	7.4	-13	dark-black, even light	7 (Si)	1 Kinne Diabase
167	N L.Stensjö	UC554972	15	field	many		10-	a.o. light with bryozoans 1E		
274	Ugglarp	UC541983	0	rocky shore	12	2.2		black; 2E		1 unidentified
123	Salleberget	UD541002	0	beach		6			many (Si)	1 ss hard, 1 ss loose
273	Långasand	UD537008	0	beach		0.2				local material
274A	Garnbjär	UD528018	0	beach	5			1E		
291	Mokrik	UC578991	20	g.p.	x			light		
CJ9	Börsingagård	UD628015	45	gl.fl.	2			1B		
The area around Falkenberg										
212	NW Skreanäs	UD486065		old beach ridge	31 1	2.9	2-10 >10	2E		1 hard ss, 1 loose ss
213	E Skreanäs	UD490059	0			1.1				
214	Kalvhult	UD403513	30-40		x		5-10			1 ss (Vg)
217	SW Veddige	UD392499	5-10	stratified	5 3	0.9	2-10 >12	1E	1	
219	SE Årstad	UD596099	50	restored g.p.	1		10			
220	NW Sannarp	UD574125	15-20	clay pit	1		3		2	
221	SSE Sannarp	UD584118	53	gl.fl.	1		22x14			
237	S Morups hallar	UD389149	0	washed till	45	1.9	2-15	4E	1	Kinne Diabase
238	Lönestig	UD403150	10	beach ridge		1.2	2-15		1	1 ss
240	N Vinberg	UD509150	40	washed till	2	0.2	8-10		1 Si	
242	S Lyngsjö	UD514180	50	gl.fl.	4		4-6			1 ss
244	Långås	UD454175	22		8		2-10		2	
245	SW Lindhult	UD457147	15	redep. sand	1			1E		
246	Nygård	UD428158	12	field		1,8				
247	Breås	UD446164	16	gl.fl.	9	0,6	2-8		2 Si	
248	NW Bjärnhult	UD441130	14	endmoraine, field		2,5	4-22		2	
249	Agerörsmalen	UD418100	0	beach shingle beach shingle storm water line	60 32	5,4 6,6	2-10 6-20	black; 42E 2E	 2 (1 dark)	1 ss, Kinne Diabase
250	Agervik	UD418101	3 0	field washed till		(5) 4.6	2-10 2-14			
251	S Vinberg	UD504137	25	gl.fl. till		1.4	2-15			
253	Stafsinge K:a	UD471115	40	washed gravel		(3.5)	2-10		chalk	
254	S Huvhult	UD436163	13-14	endmoraine, field		(14)	2-10		1	
256	Agerör	UD420108	4	field		1.4			1	
257	Skogstorp	UD431096	0	beach gravel		3.6	0.2-3.6	black		
258	Hästhagsudden	UD438092	0		5	1.2		dark; 2E		
259	Hästhagsudden	UD441092	0		2				1	
260	Brinkendal	UD507094	20		7					ss
261	NW Jonstorp	UD508130	25	gl.fl.	4		8-12	dark	1	
	W Kätabo, Fegen	UD910434	133	till	1		8	speckled with a chalk crust		T.Carlsson, Sm. Burseryd/CJ
Northern Halland										
292	Näsbokrok	UD278578	0		many					Kinne Diabase
293	Råö	PJ764654	15	g.p.	4	(1)		1E		
294	Råö	PJ764650	0	shore	3	3.6		light and dark Danian prevail		
296	Onsala	UD210680	30	g.p.	2	1.5	2-10	1E	1 Si	
298	Draget	UD211629	0			4.7	2-17		4	Kinne Diabase; local material
299	Hållsundsudde	UD197616	25	old beach shingle	18	8.5	2-15	light; 5E, 1F		1 rhomb porphyry; cambr. ss foreign material
300	St. Utholmen	UD214648	0		12			3E	1	1 ss (Vg); local material

No.	Name	U T M	H.a.s.l. (m)	Type of locality and material	Cretaceous rocks total amount	%	Size (cm)	Flint type	Limestone	Other erratics/ref.
302	Rabben	UD257699		g.p.	x	0				
304	Ulvsbäck	UD263679	0	shore	23	5.6	2-8	black; 5E		Kinne Diabase; local material
311	Tjolöholm	UD259655	0		5	(2)		1E		
313	Ölmevalla	UD274636	0			(5)	~45	grey and black; 1E		
314	Kålebrygga	UD255628	0	beach shingle	4	3.4		2E, 1 breccia	1	1 ss (Vg); Kinne Diabase
315	Ölmanäs	UD245615	0			1.7	2-50		1	Kinne Diabase (many) 1 unidentified with unique character
317	Ölmanäs	UD237597	0	beach shingle	11	0.9	2-12	2E		Cambr. ss (S), Kinne Diabase
318	Ölmanäs	UD233592	0		6	1.2		3E, 1F	many	
319	Ölmanäs	UD253593	0		3	(0.3)		grey	1	3 Cambr. ss (S); Kinne Diabase
320	Videbergshamn	UD258492	0			8.2		light and black; 7E		1 Cambr. ss (S); Kinne Diabase

The new west coast localities are listed in Table 7. They are concentrated on the following areas: 1. Northernmost Halland. Engwall's report of white spotted flint (Fåhræus & Engwall 1965) triggered the investigation in this area. 2. The area around Falkenberg. 3. The area north of Särdal. It was selected because of the new find of Cretaceous rocks *in situ* and the report of a calciophile plant (*Asplenium ruta muraria*, see Ahlfvengren 1924, p. 183). 4. The area around Halmstad. 5. The area on Hallandsåsen. This area was selected in order to observe how a known occurrence of Cretaceous rock (Båstad area) has influenced the occurrence of flint in till. Table 7 is supplemented with some information from the literature and also includes some localities situated southwest and east of the study area.

Flint types — As mentioned previously, seperation of the flints into different types by ocular examination is difficult. In field descriptions I have often used only general terms such as light, grey, or dark. However, besides the A–D types, I have also recognized the types E and F (Fig. 10). Flint type E consists of three varieties. One is black and mottled and resembles the B type, the fresh fracture being lustrous. It mostly occurs as nodules with an uneven surface. The second variety is less mottled and more homogeneous, either black or grey, with lighter parts. The nodule surface has a characteristic uneven smoothness resembling some of the B types in southern Halland. The third variety is homogeneous and black to dark grey. All these flints have either a very thin crust or no crust. They are judged to be of Senonian age. Flint type F is the white spotted flint (p. 99) found by Lidmar (1965 b). It is a kind of coarse-grained flint.

The flint types were identified not in the field but on material brought back to the laboratory for examination. In this way it was possible to select typical specimens which were used for successive flint type determinations. When specimens of the different types are dated by palaeontological methods there will be firmer ground for

defining and recognizing the types. There may also be a more definite method of determining whether the flints are of local provenance. As far as is known, flint in Denmark (cf. p. 106) and southwestern Skåne occurs in the Danian, Upper Maastrichtian, Coniacian and Turonian (Fig. 29). In the Kristianstad and Båstad areas it occurs in the Upper Campanian and Lower Maastrichtian, and possibly also in the Turonian (Båstad area). (See p. 126 and Fig. 33.) If it could be demonstrated that flint from the Campanian or Lower Maastrichtian occurs along the west coast, the probability that flints from this stratigraphical interval are of local provenance would be fairly high.

Flint localities — All the localities in Halland have been plotted on a map together with localities where Cretaceous rocks occur *in situ* (Fig. 32a). Localities outside the study area that have not yielded flints are also plotted. In the next chapter the map is used to set the study area in its wider context.

Within the study area the solid circles represent localities where flint types A–D have been found. In the northwestern part a few localities below the ML (marine limit) also contain other flints and may even be dominated by them. Other inland localities denoted by solid circles contain flint of A–D types, or in a few cases belemnites. A few of the solid circles on Hallandsåsen and those in the Kristianstad area do not indicate flints but other erratics of local Cretaceous rock.

If the map is checked against Table 7 it can be seen that all localities along the coast with dark flint contain flint of type E. This means that it is fairly certain that they contain Senonian flints. The flints may be of local origin. Thus the solid circles on the map are intended to give a picture of the distribution of possible local Senonian rock types.

During field work along the west coast I did not use any specific method. Instead, I tried to observe overall conditions in order to obtain ideas of good methods to discriminate between local and transported flint. In the study area and to the southwest of its central part all flints found have been counted. At Hallandsåsen and at most localities along the coast I mostly counted 1000 stones and calculated the relative frequencies of flint (counts based on less than 500 stones are in brackets). Along the coast (area south of Halmstad to northern Halland, Table 7) the figure for total amounts of Cretaceous rock mainly represents the number of collected stones. The determinations of flint types have been made mainly on the collected material. In Table 7 the localities are listed from south to north.

Results of field investigations — From Figs. 32a and b it can be seen that local flints occur just southwest of the central part of the study area and of course southwest of the Båstad area. No flints have ever been found northeast of the study area (see also Lundegren 1934, p. 171).

Northwest of the study area there are firstly five localities with supposed local flints and belemnites. One just outside the area and one north of Halmstad have been

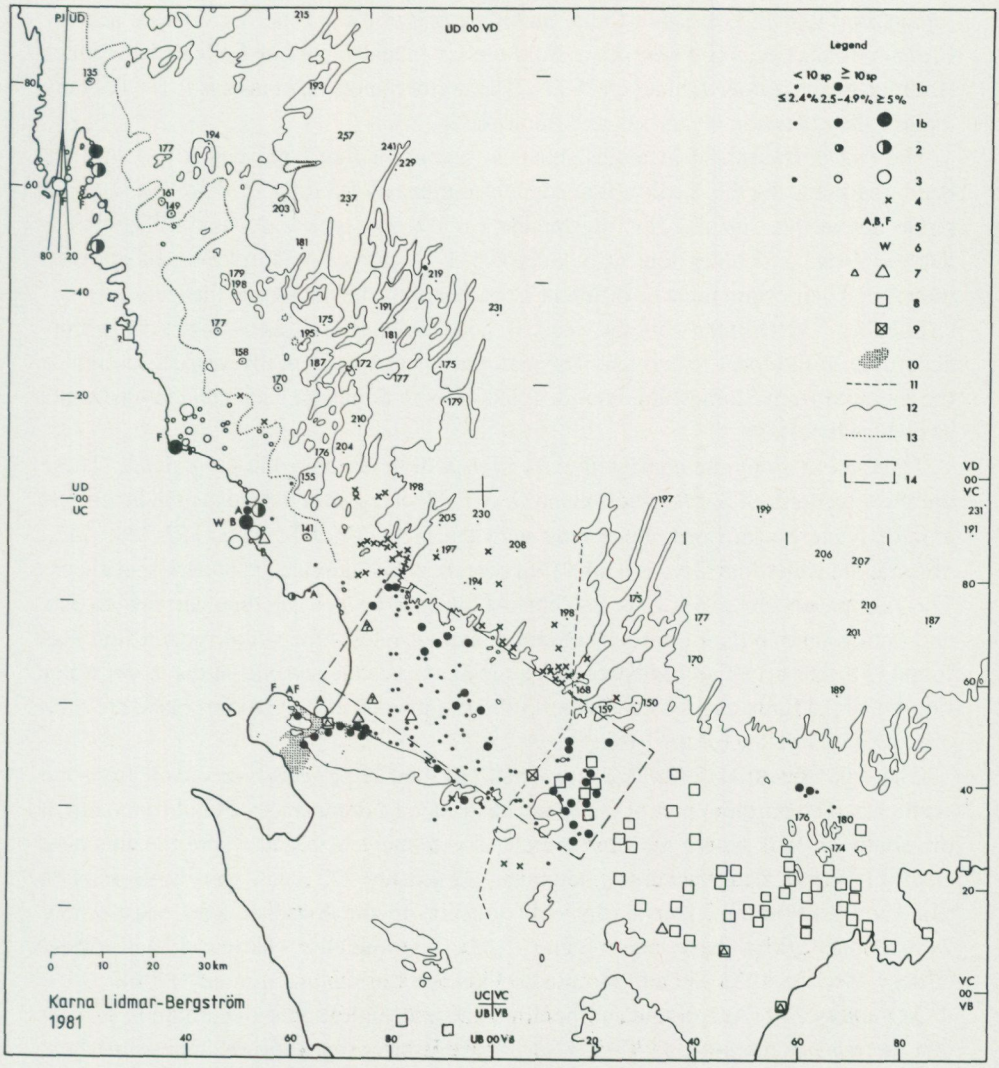


Fig. 32a Erratic flints (and belemites) and Upper Cretaceous rock *in situ* in southwestern Sweden. 1a. Flint of types A–D or Upper Cretaceous fossils; inland localities. 1b. Dark flints predominate; coastal localities. 2. Mixture of flint types with many dark flints. 3. Mixture of flint types or predominance of light flints. 4. No flints found. 5. Flints of types A, B or F. 6. "Wallsteine" (well rounded flints). 7. Cretaceous rocks *in situ:* Aptian–Santonian. 8. Cretaceous rocks *in situ:* Campanian–Maastrichtian. 9. Limestone breccia. 10. Till with Cretaceous boulders. 11. Extension of the profile in Fig. 39. 12. 133 m contour line. 13. Flint limit (mostly from Werner 1974). 14. The study area. Figures show top heights. The UTM grid reference system is indicated.

reported previously (Lidmar-Bergström & Johansson 1971). These localities are of the same character as those within the study area. The northernmost locality with local flint material at a height of 40 m was not included in the study of Lidmar-Bergström &

Johansson (1971). Two small flints, including one of the B type, were found here by Christer Johansson. The two other solid circles inland represent finds of belemnites (Lidmar-Bergström & Johansson 1971). The northernmost belemnite is from Skintaby in the valley between Nyårsåsen and Bårarpsåsen.

The rest of the inland localities shows a mixture of flint types which have not yet been analysed. At the locality immediately northeast of Särdal (275 Högen, a small circle above the triangle) five big boulders of Danian type were found. They were derived from a boulder line at a level 0.5–1 m below the surface in redeposited material. Their origin must be different from that of the belemnites in the vicinity.

Locality 332 (Flinten) off the coast is noticeable. It is a shoal covered by flints according to the local fishermen. The material is knotty and in this respect resembles the material from Stora Middelgrund. Flints of both Senonian and Danian type occur, as well as limestone.

Three areas along the coast with dark flints will be described in more detail. These are the area north of Särdal, the area north of Falkenberg, and the area in the innermost part of Kungsbacka fiord. Beginning with the localities at Stensjö (157–159, 162–164), at the water line there is a high flint content with a dominance of dark specimens. The flint pieces are small, only 2–6 cm. At the storm water line there are fewer flints and both light and dark ones are present at similar rates. One white spotted flint was found. Further up on an old beach ridge the amount is the same as at the storm water line but light flints clearly dominate. Further uppwards at the parking place the dark ones again dominate (cf. p. 102).

Glassvik (localities 269–272) is a small bay that is protected very well from the northeast. The northern part of the beach has yielded a dominance of light flints, but in the southern part, where the flint content is extremely high and where the flints are small (1–5 cm), dark specimens dominate. At locality 272 small, very well-rounded flints are also found. This is the only locality on the Swedish west coast where well-rounded flints have been found. They resemble the German ''Wallsteine'' (Hucke 1967, p. 103). Such flints are also found on Bornholm (Grönwall 1900).

At locality 249 (Agerörsmalen) the flint content is high and the overall impression is that there are numerous dark flint. Many type E flints occur. Several appear as whole nodules with an undamaged uneven original surface. At locality 257 south of Agerörsmalen a test was made in the beach gravel as the beach did not contain many pebbles in the ordinary flint sizes 2–10 cm. This test showed 3.6% of mainly dark flints in the size range 0.2–3.6 cm.

At many of the localities in northernmost Halland there is a great amount of dark flint, but they rarely dominate. One of the localities (304 at Ulvsbäck) suggests a pattern very like that at Glassvik. Ulvsbäck is a well protected small bay with a great number of small dark flints. Typical type E flints with undamaged surface occur as well as knotty undamaged original flint concretions (cf. Stora Middelgrund p. 107 and Flinten, above). The other beach material seems to be of local origin, with contributions of erratic Kinne Diabase from Västergötland (from the northeast). Other

localities with local material in the vicinity are Nos 298 (Draget) and 300 (Stora Utholmen). The flints are of different types.

On the southeastern shore of Lake Fegen, west of Kätabo, a dark, speckled flint with a silicified crust (cf. Werner 1974, No. 658; p. 102 this paper) was found in till by Tommy Carlsson, Smålands Burseryd, and forwarded to me by Christer Johansson. The locality is 133–135 m a.s.l. I visited the locality in October 1979 but was unable to find additional flints in the small road cut. In my opinion the flint was found in its original position in till and it has not been brought there by man, although more finds are desirable to confirm this view.

Summarizing the distribution (see Fig. 32b), A (Båstad) and B (Hishult) types of flint are found as far north as at locality 159 (Stensjö) along the coast, while inland they are found as far north as at CJ9 Börsingagård. The C (Lycke) type is found along the northeastern end of Hallandsåsen and around Källshult in the study area. The D (Kristianstad) type is found as far west as in the Örkelljunga area (M1, M2, M5). The E types begin to appear at the shores of Hallandsåsen and occur along the whole Halland coast. The F type is known from six localities, viz. two north of Hallandsåsen (204a, Table 7; Lidmar 1965a, b), Glommen, Getterön (Lidmar 1965a, b), Hållsundsudde (299, Table 7) and Ölmanäs (318, Table 7).

SUMMARY OF EVIDENCE OF LOCAL CRETACEOUS FLINTS IN THE SOUTHERN PART OF THE WEST COAST

The summary is based mainly on informations in Figs. 30 and 32. The area on Hallandsåsen has yielded a high content of local Cretaceous material. Along the southern shores of Laholm Bay local material occurs, but not very frequently. Along the northern shores of Laholm Bay the amount of dark flint is higher than on the southern shores, and flint of the A type has been found, indicating flint of local provenance. A soil sample from the Kattegat offshore from Halmstad had more than 30% flint in the 8–16 mm size fraction.

Upper Cretaceous rocks occur *in situ* at Särdal, north of Halmstad. North of Särdal are situated the localities with many dark flints and flints of types A and B (Stensjö – also in the vicinity a limestone block of supposed Santonian age, see p. 105; and Glassvik). To the northeast is locality CJ9 (Börsingagård) with flint of type B. The existence of Cretaceous *in situ* and localities with Halland flint support the opinion of small local remnants with Cretaceous rocks and the existence of local residual flints.

The material at locality 249 (Agerörsmalen) and localities to the south also indicate local flint remnants. Northeast of Falkenberg is one locality, which has yielded more than 30% flint in the 8–16 mm size fraction. It is not impossible that the flints found by Åberg (p. 102) are of local origin. In my opinion the flint from Fegen may also be of local origin. It is possibly derived from a protected position in the bottom of the lake.

Dark and white-spotted flints, as well as Campanian fossils have been found in the

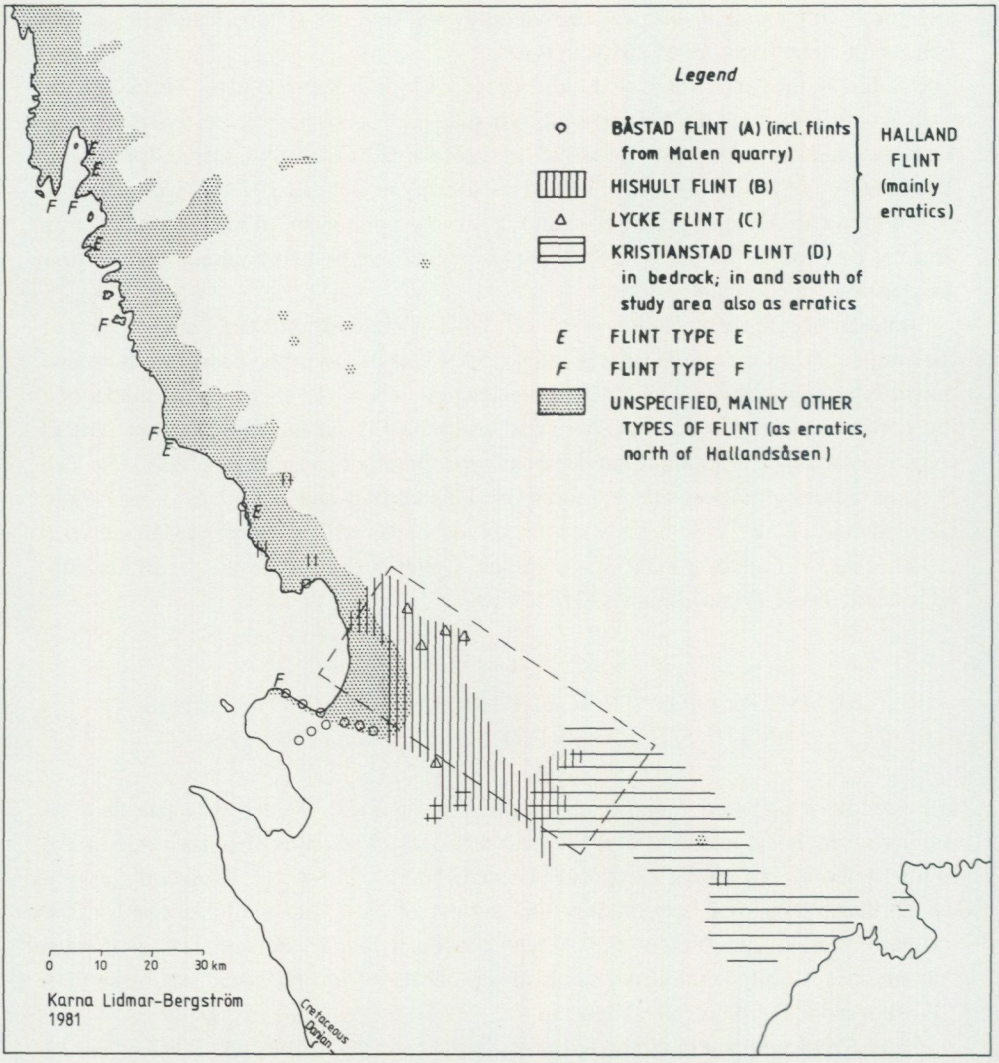


Fig. 32b. Distribution of flint types. The distribution of the characteristic types of Halland flint is very strong evidence for a local origin as there is no other possible source area. The distribution of typical Kristianstad flint shows very little overlap (but this type is common as erratics further south in Skåne). Along the Swedish west coast there is a wider spectrum of flint types, apparently with Upper Cretaceous and Danian flints transported into the area and locally with more concentrated occurrences of local flints (A, B, E).

Varberg area. As yet it is impossible to draw any conclusions from the flint find by Eichstädt (1909) from Öxabäck. Local limestone remnants may have occurred late and may still occur in the Varberg area.

The dark flints at Ulvsbäck in Kungsbacka fiord also indicate local remnants there of sedimentary rocks. The black and white-spotted flints reported from this area support

this interpretation, and so does the high flint amount in a soil sample (p. 102). The dark flint reported by Werner (1974, loc. 658; see p. 102) is situated at the figure 5 in 135 (UD 278849), Fig. 32a. I interpret it as a local flint.

A good criterion for the local provenance of some of the flints is the occurrence of undamaged knotty flints with an original nodule surface. Such flints have been reported from Stora Middelgrund (p. 107), Flinten (p. 120), locality 249 (Agerörsmalen) and 304 (Ulvsbäck). Also the ''Wallsteine'' from locality 272 (Glassvik) point to a local provenance. However, the well-rounded small flints may indicate a Tertiary deposit with redeposited Cretaceous flints.

Thus, it seems probable that until lately the entire Halland coast region has had or still has outliers of Upper Cretaceous limestone. Where the limestone has been dissolved there may still be concentrations of residual flints. The contributions of local Upper Cretaceous flints must be less than that of predominating Danian flints transported into the area. The occurrence of knotty flints of Danian type at Flinten (p. 120) may also indicate that Danian deposits occurred close to the Swedish west coast.

The appearance of dark and light flints at separate levels (pp. 102, 120) may indicate (if not due to size sorting) a different source for the flints at different times. In certain periods flints from distant sources may have dominated, while in others flints from neighbouring sources may have been brought to the shores during strong winds or by ice pushing.

CONCLUDING REMARKS

The problems discussed here also apply in Scotland. Loose Upper Cretaceous flints occur along both the eastern and western shores of Scotland (Gemmell & Kesel 1979) as well as in a small inland area in Buchan (cf. p. 53). The two possibilities discussed for the provenance of the Buchan flints are that ''either the flint is a lag deposit formed during the weathering of the chalk or that the flint has been transported to its present position by some geomorphological agency. The bedding displayed in various pits suggests that the latter is the case'' (Gemmel & Kesel 1979, p. 71). The question as to whether the flints have been transported over a short or a long distance cannot yet be answered satisfactorily.

There are several arguments to suggest that flints along the Swedish west coast were transported into the area. I have tried to point out arguments which support the idea that some flints are of local origin.

Age determinations of the flints will hopefully help to solve the provenance problem in the future. Finds of unworked Cretaceous flints above the ML in Halland and Västergötland would provide proof of a local provenance of some of the flints. The most convincing argument for a local provenance of flints along the shores seems to be the undamaged and knotty appearance of some flints at particular localities.

CRETACEOUS TRANSGRESSIONS AND MORPHOLOGY RELATED TO A FORMER CRETACEOUS COVER

CRETACEOUS TRANSGRESSIONS AND ROCKS

One current interpretation of the distribution of Cretaceous deposits in the Kristianstad and Båstad areas is shown in Fig. 1 (from *Karta över Sveriges berggrund* 1958). Different maps show different distributions of the deposits in the Laholm plain (*e.g.* Sahlström 1948 with a map of the bedrock by Kindberg; Hjelmqvist & Kulling 1953; Eklund 1957; Eklund 1944, reproduced here as Fig. 15; Wiman 1916). Several of the supposed outliers with Cretaceous rocks in the study area were obviously based on the discovery of erratics, and not on *in situ* material (Figs. 2, folded map after text, and 32a).

The Geological Survey of Sweden has started work on new bedrock maps in the Kristianstad and Båstad areas. The first map from the Kristianstad area is published (Kornfält *et al.* 1978). The following account is based mainly on the results of this work, on articles by Christensen (1975), Bergström *et al.* (1973), and also on some information from Regnéll in Magnusson *et al.* (1963).

Most information about the west coast is old, and therefore the dating of the sediments is rather uncertain (indicated by dashed lines in Fig. 33). With regard to references for Tormarp see Table 3 (34) and for Gräseryd Table 7 (southwest of the study area). The following authors have dealt with Båstad (including Malen and Gropemöllan): Fischerström (1761), Hummel (1871 and 1877a), Moberg (1886), Lundgren (1889), Svedmark (1893), Wiman (1916), De Geer (1918, 1920), Hadding (1927), Stolley (1930), Bexell (1938), Hägg (1954), Christensen (1970), and Brood (1972). Erik Norling has provided me with unpublished information on the biostratigraphy and lithology of the boring at Skottorps kvarn.

In the Kristianstad area there is evidence from the boring at Härlöv of a transgression in the Early Cretaceous, and perhaps also from the boring at Åhus (Fig. 33). Tormarp and Skottorps kvarn in southern Halland on the west coast also seem to have sediments of this early age. In the Cenomanian the sea flooded the central part of the Kristianstad basin and also at least the southern part of the west coast. Turonian strata occur in southern Halland but as a whole the Turonian is characterized by regression of the sea, and so is the Coniacian. In the Kristianstad area the Santonian transgression reached further northwest than the Cenomanian sea. On the west coast the sea reached as far as the Båstad area (Gräseryd) and Särdal. This transgression was followed by a regression. A new transgression that reached higher levels than before followed in the Campanian. This transgression flooded the Båstad Basin on the west coast and probably also reached the Varberg area (Hägg 1946, Fig. 32a). In the Kristianstad area both the middle Early Campanian and the latest Campanian were periods of regression at least in the peripheral regions, while the earliest Maastrichtian was characterized by

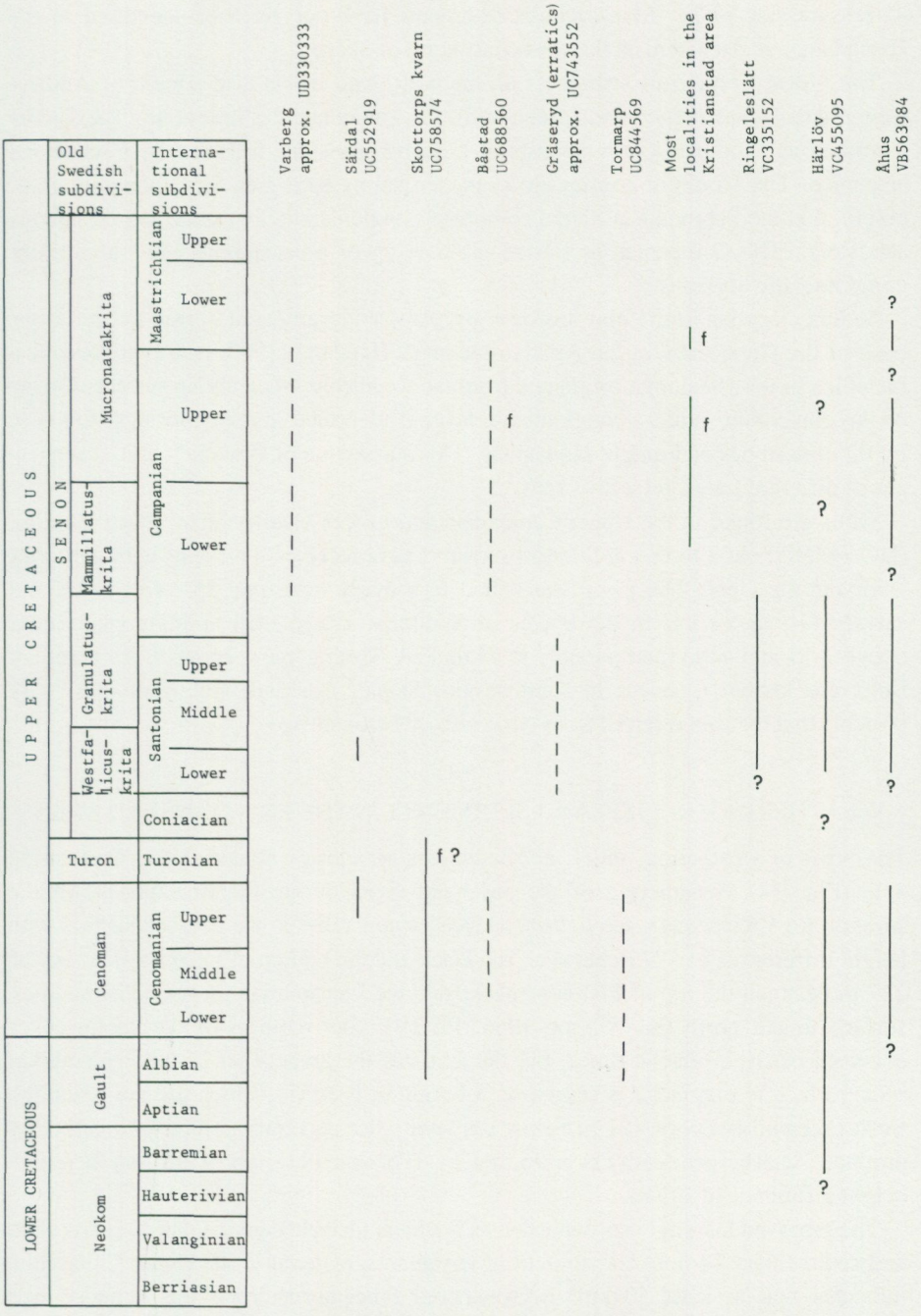


Fig. 33. Cretaceous transgressions in the Kristianstad and Båstad areas and on the Swedish west coast. Dashed lines indicate uncertainty of time span of sedimentation, f means flint.

a transgressive pulse. Maastrichtian sediments have not yet been identified in the Båstad area or elsewhere on the west coast north of Skåne.

The oldest Cretaceous sediments on the west coast of Halland consist of Albian–Cenomanian glauconitic sand (greensand) and conglomeratic limestone. The Lower Turonian at Skottorps kvarn consists of a quartz sandstone followed by a limestone sequence. The Gräseryd erratics are characterized by hard grey limestone with glauconite, and the Santonian at Särdal comprises conglomeratic limestone and calcareous sandstone. The Campanian at Båstad is made up of a calcarenite with subordinate conglomeratic horizons.

Sedimentary kaolinitic clay overlain by glauconitic greensand often occurs at the base of the Cretaceous in the Kristianstad area. Hessland (1950, p. 97) believes that the silica in the glauconite originated from the weathered Precambrian surface. On top of the glauconitic sand, a conglomerate layer is identified in many borings, followed by the limestones and quartz sandstones. This succession of strata is found in sequences of different Late Cretaceous ages.

Flints are found in the Upper Campanian and Lower Maastrichtian. From a boring (UC 747585) close to that at Skottorps kvarn I have received a piece of light grey flint from Jan De Geer. The piece was found in a marly limestone 55–59 m below the surface (10 m a.s.l.). In the boring at Skottorps kvarn, there are Turonian strata between 31 and 44 m (and possibly to 54 m; Erik Norling, pers. comm.). As Turonian flints are known to occur in southwestern Skåne, Denmark and Bornholm, it is possible that the flint referred to above is also of Turonian age.

WEATHERING, RELIEF, AND SEDIMENTS IN THE KRISTIANSTAD AREA

The types of weathering, relief, and sediments are closely related in the Kristianstad area (Fig. 34). Weathering of the basement rocks during the Rhaetian to Middle Jurassic (to Cretaceous?; see p. 96) produced a new relief in the bedrock surface with height differences of 177 m between Ivö klack and the bottom of Lake Ivösjön, and of 227 m between the top of Fjälkinge backe and the Precambrian unweathered bedrock surface to the north (K. Nilsson 1966, Pl. IV). The removal of the kaolin cover occurred partly in glacial times, but the fact that the great relief of the Precambrian rock surface is preglacial is shown by a boring at Råbelöv, which did not reach the fresh Precambrian until 121 m below sea level after penetrating 40 m of weathering products. Balsberget nearby is at 96 m a.s.l. (Persson 1932, pp. 9, 18), so there is a height difference of 217 m.

The removed material was deposited as boulders (detached core-stones), quartz sand and sedimentary kaolin. The amount of terrigenous material in the Upper Cretaceous indicates that at least 50 km^3 of weathered Precambrian rock was denuded and transported into the Kristianstad area (Bergström in Kornfält *et al.* 1978, p. 61). To this can be added the volume of terrigenous sediments in Hanö Bay and further away (Kumpas 1980).

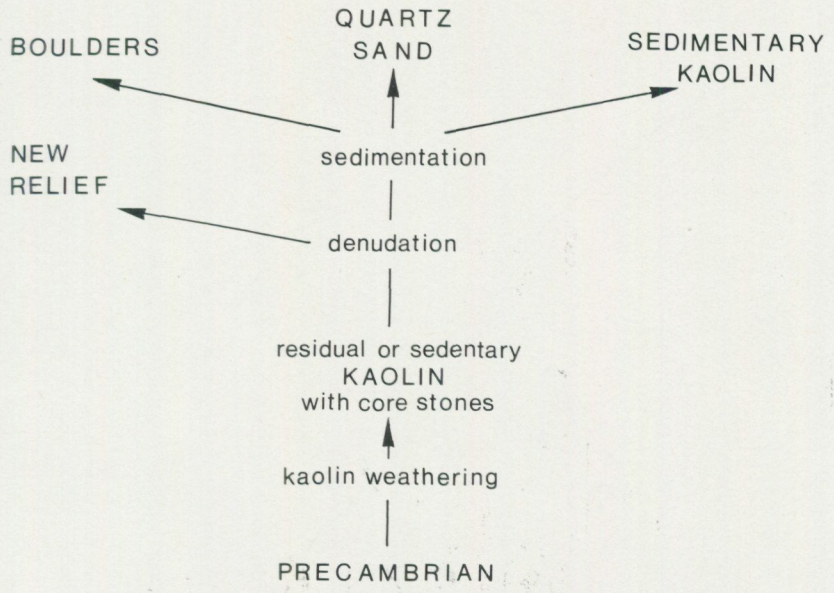


Fig. 34. Interconnection between weathering, relief and sediments in Precambrian areas during the Late Triassic–Late Cretaceous (redrawn from Bergström in Kornfält *et al.* 1978).

At Ivö klack the residual kaolin (p. 69) before quarrying was covered by Campanian strata (Christensen 1975). Further up-slope the Campanian rested directly on the fresh Precambrian bedrock. The Precambrian surface has been uncovered by quarrying. Here is a unique possibility to study the sub-Campanian surface (Mattsson 1962; Bergsten 1972; Lidmar-Bergström 1981). Fossil oysters can still be seen sitting on the exhumed granite. Tors and Campanian littoral boulders have been exposed.

FORMER EXTENT OF UPPER CRETACEOUS DEPOSITS

The highest locality with Cretaceous rocks *in situ* is Kulleröd (142, Table 3) at 120 m a.s.l., situated in the southeastern part of the study area. Another locality, a fissure with calcite, is found where the bedrock surface is at about 130 m a.s.l. (98). The highest localities are at 120 m and in the middle part they are at 110 m a.s.l. In many cases the flints seem to have been moved upwards from valleys.

The regenerated sub-Cretaceous relief in the northwestern part of the study area is found as high as 125 m a.s.l. The reason why this relief has survived is probably because the protective cover of Upper Cretaceous rocks has been removed fairly recently.

The lowest points of the water divide between the Båstad and Kristianstad areas are around 115 m a.s.l. (p. 24). Together with this fact and the level of the highest

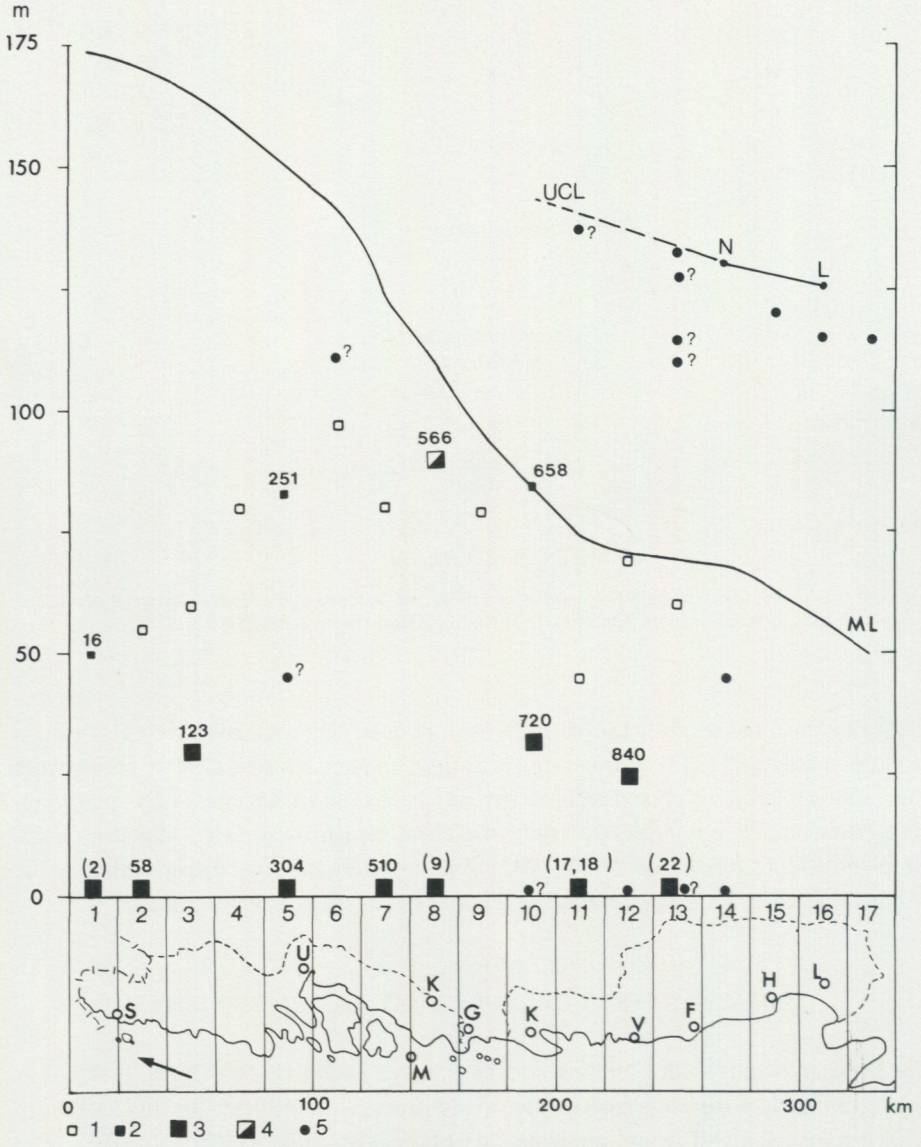


Fig. 35. Height of certain flint localities compared with the post-glacial marine limit (ML) and with the hypothetical upper limit for remnants of Upper Cretaceous sedimentary rocks (UCL). For each zone the level of the highest flint locality is given together with the highest locality with local kind of flint, and of certain other localities with local kinds of flint. The diagram is partly redrawn from Werner (1974, Figs. 42 and 60). For the square symbols, the information is extracted from Werner's (1974) appendices: figures indicate locality numbers as given in her appendix 1, while figures in brackets indicate locality numbers as given in her appendix 2.
1. Highest locality with flint. 2. Highest locality with black flints only. 3. Locality with at least 5 pieces and 19% of black flint (cf. Fig. 30:6). 4. Rich flint locality with many dark flints. 5. Localities with local types of flint (from various sources, see the text), in zones 15–17 including only the highest localities.

Knickpoints of the rivers Lagan (L) and Nissan (N) are indicated. Cities on the map are, from the north, S = Strömstad, U = Uddevalla, M = Marstrand, K = Kungälv, G = Göteborg, K = Kungsbacka, V = Varberg, F = Falkenberg, H = Halmstad, and L = Laholm.

Cretaceous localities, the observations of fully marine conditions in the northwestern part of the Kristianstad area in late Early Campanian (Jens Bruun Petersen in Kornfält *et al.* 1978, p. 90) makes a marine connection between the two areas very probable.

The various factors referred to above clearly indicate that Upper Cretaceous deposits reached a height of at least 120–130 m above present sea level within the area concerned. The transgressing sea seems to have been of Campanian (cf. above) and perhaps also of Maastrichtian age considering the conditions in the Båstad and Kristianstad areas (pp. 124–126). Hopefully, dating of the flints in the future will date the transgressions exactly.

Fossils in the Cenomanian strata at Särdal indicate that the sea temporarily reached at least some 100 m above the present sea level (Bergström *et al.* 1973, p. 147).

Fig. 35 is redrawn from Werner 1974, fig. 60, with some information added. For her flint studies the Swedish west coast was divided into 17 zones perpendicular to the coast. Werner constructed the curve for the marine limit (ML) and plotted the highest flint localities in each zone. For zones 1–13 I have taken the localities from Werner and used a special symbol for those which contain only dark flints and another symbol for one locality (566) with many flints of the colour classes 3–5 (dark to medium grey) in the rock colour chart (p. 100).

Locality 566 is especially interesting as it is one of the highest containing many flints, including dark types. The flints were found 1.5 m from the surface in a washed till. Local flint may have contributed to the high content. Locality 658 obviously contains local flint (cf. pp. 102, 123).

Fig. 35 also shows those localities in Fig. 30 that contained more than 5 pieces or more than 19% of black flint (from Werner 1974). In her zones 15–17 which fall within my study area I have also plotted my highest localities. In zone 14 my localities outside the study area with reliable local flint are also plotted. In zones 10 and 13 I have localities with supposed local flint at about sea level. The locality at Varberg with Late Cretaceous fossils is in zone 12.

The locality at 133 m a.s.l. in zone 13 (p. 121) is most interesting because of its height and distance from the coast. The flint may originate from a lower level on the lake bottom. The deepest part of the lake, at 37 m (*i.e.* the bottom is about 95 m a.s.l.), is situated just off the shore at the place of discovery. The outflow from the present lake is through Lake Kalvsjön to the west and then northwards through Lillån to the River Ätran. It seems likely that Lake Fegen or the valley it occupies had a pre-Weichselian outlet to the southwest in bedrock at a level lower than 133 m.

The three other localities in zone 13 are taken from Åberg (1963; cf. p. 102). The flints may have been brought to the localities by man, but it is not fully excluded that they are of local origin. The localities are indicated by dotted lines in Fig. 32a, as are the flints reported by Eichstädt (1909) from Öxabäck (p. 105) at 140 m a.s.l. A flint from Lake Vristulven (p. 105) is also plotted on the diagram (zone 6), even though it is about 150 km from the coast. The flints reported by Eichstädt (1909) are from the shore of Lake Vänern in zone 5.

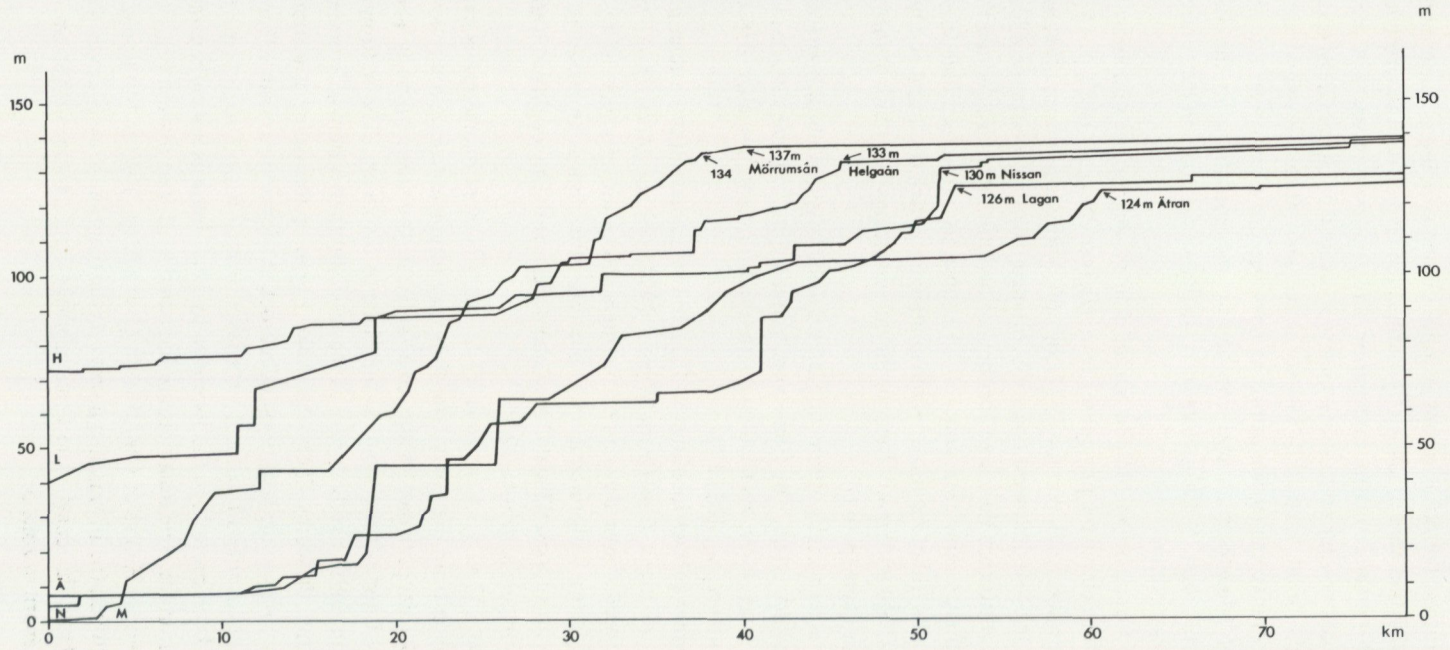


Fig. 36. Profiles along the rivers Ätran, Nissan, Lagan, and Mörrumsån (from *Förteckning över Sveriges vattenfall* /List of Swedish waterfalls, 1945). Arrows mark the border of the south Småland peneplain (except for Ätran, see the text).

In zone 16 Werner has a locality at 155 m a.s.l. which I have omitted. This locality is situated on Hallandsåsen and the flint was brought there from the Båstad area by Pleistocene ice.

Thus it seems probable that Upper Cretaceous deposits once reached at least 120–130 m a.s.l. in the study area and perhaps 130–140 m in the inland part of the southern west coast.

POSSIBLE CORRELATION BETWEEN MORPHOLOGY AND THE DISTRIBUTION OF FLINTS

I have not found signs of any possible Cretaceous shorelines within the study area. Asklund's (1928) suggestion of the presence of a terrace in the bedrock must be rejected (see p. 11) since there is no indication in the area of such a feature.

PROFILES ALONG THE MAIN RIVERS IN SOUTHWEST SWEDEN

Profiles along the main rivers have been redrawn from *''Förteckning över Sveriges vattenfall III''* (1945; see Fig. 36). These profiles show that the main rivers have knickpoints at heights between 124 and 137 m a.s.l. In all the rivers except the Ätran the knickpoints mark the edge of the south Småland peneplain. The vertical range of the knickpoints is only 13 m (11 m if the Ätran is not included). The height of the knickpoints, combined with the similar maximum height of the flint localities gave me the idea that the south Småland peneplain was a surface that might have developed with a Cretaceous sea as an initial base level. (This idea was later modified, see p. 136). In all the rivers except Nissan there is also a marked level at about 100 m a.s.l.

As a means of relating the south Småland peneplain to the highest remnants of Upper Cretaceous deposits, Fig. 35 shows a plot of the values for the knickpoints in the Lagan and Nissan rivers and a hypothetical upper limit for the relict Upper Cretaceous (UCL). The knickpoints in the rivers are localized in Fig. 38. It is my working hypothesis that flints occur up to this level and never on the peneplain surface.

The area between the ML (postglacial marine limit) and the hypothetical upper limit of Upper Cretaceous remnants (UCL) is interesting. To me it seems probable that more flint occurs at these levels than has been found hitherto.

THE SOUTH SMÅLAND PENEPLAIN

Profiles based on the Mean Height Map of Sweden — The distribution of peneplains in Sweden was outlined by Rudberg (1970a). Here, I attempt to delimit the south Småland peneplain with the aid of the Mean Height Map of Sweden (1963). The mean

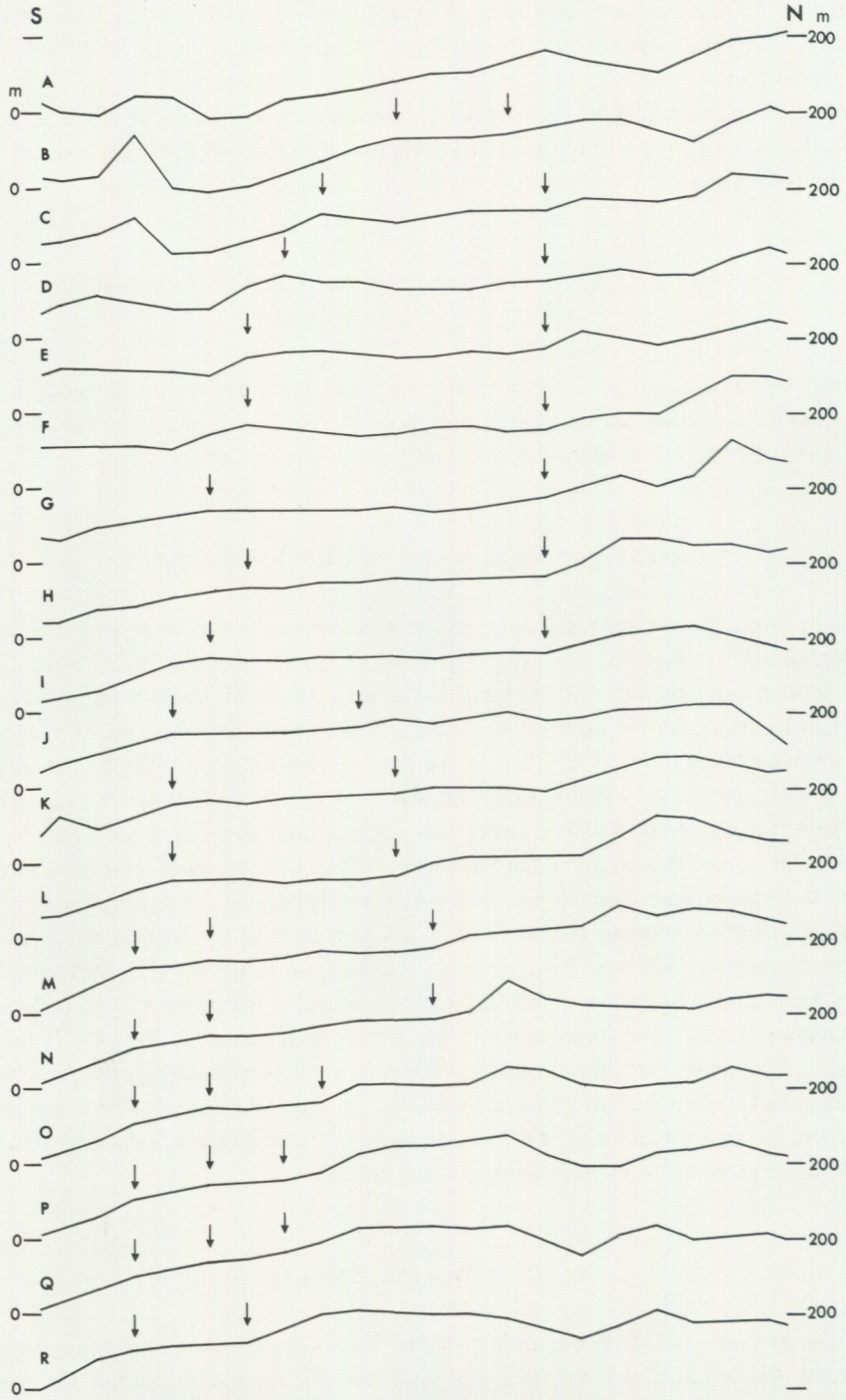


Fig. 37. North–south profiles based on the Mean Height Map of Sweden (1963). For location see Fig. 38. Arrows mark the limits for the south Småland peneplain and, in profiles M–R, also for a lower peneplain. Horizontal scale 1:2 mill.

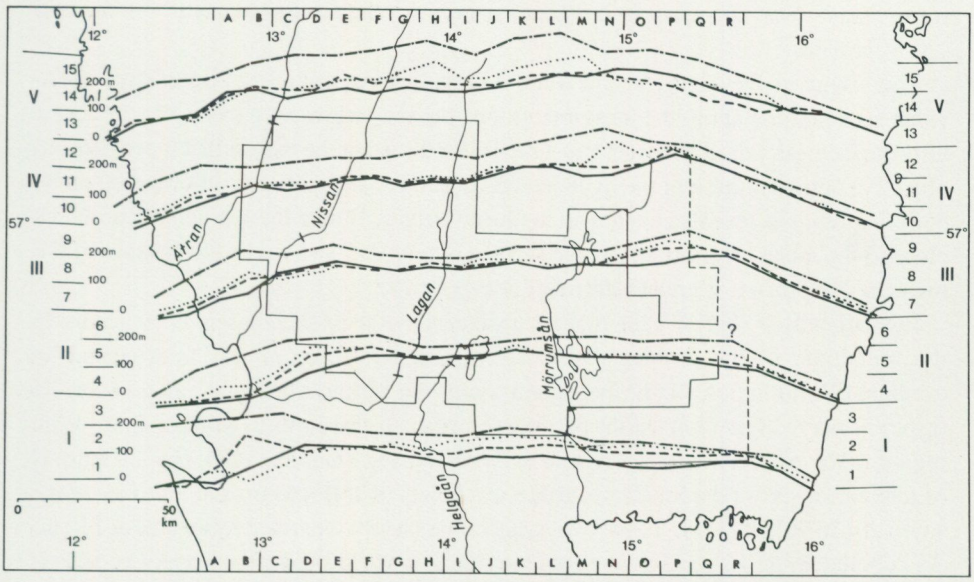


Fig. 38. East–west profiles across southern Sweden. The profiles are based on the Mean Height Map of Sweden (1963). Profiles from three successive narrow belts (continous line for southernmost belt, dotted line for northernmost belt) drawn from common base line to facilitate comparison. Fourth profile (marked with dots and lines) shows elevation of top heights for whole zone (three belts). The south Småland peneplain is delimited with the aid of the mean height profiles of Figs. 37 and 38. Small cross strokes on rivers mark positions where rivers begin to descend from the south Småland peneplain (except for Ätran; cf. Fig. 36). A lower surface is delimited in the southeast. The tilted sub-Cambrian peneplain is clearly visible to the east. Scale 1:2.5 mill.

heights on this map have been obtained mainly by estimation from the base maps for the Hypsometric Map of Sweden (scale 1:500 000). (The mean heights were estimated for compartments measuring 1' × 2'. From these figures, average values were then calculated for compartments measuring 5' × 10'.) Based on this map Figs. 37 and 38 show profiles drawn in N–S and E–W directions respectively. The E–W profiles were grouped in threes on a map of south Sweden. Each group is supplemented with a profile for the top heights for all three profiles. The top heights were taken from the 15' × 15' compartments (Georef system) of *Provisorisk Översiktskarta över Sverige, flygversionen*. Unfortunately this map is not quite reliable, and some of the values had to be corrected. It can not be excluded that there are additional errors.

Delimitation of the peneplain — In the N–S profiles (Fig. 37) changes in inclination possibly relevant for the delimitation of the south Småland peneplain are marked with arrows. In the southeast a change in inclination within the peneplain was noted and resulted in three arrows in several profiles. This partition was taken to indicate the existence in the southeast of a somewhat lower peneplain surface. The E–W profiles were treated in the same way. The peneplain delimitation was made directly on the Mean Height Map of Sweden (hence the angular delimitation on the map, Fig. 38). In

some cases it was necessary to compromise between the results obtained from the two sets of profiles.

This usage of the Mean Height Map is open to some criticism. A particular mean value says nothing about the local topography but may represent either a flat surface, a hilly surface, or a dissected surface. The reason for using the map is that it provides an objective demonstration of the main peneplain surface and adds new information on its delimitation as it reveals changes in the mean height. Where the top height curve lies close to the mean height profiles, the surface is very flat, and where the distance to the mean height profiles is greater the relief is also greater.

In profiles B–F (Fig. 37) the main peneplain shows a distinct margin in the south. In the remainder of the profiles the southern limit is a more or less faint change in gradient. Delimitation of the peneplain along the northern margin can be made in different ways. The limit might be drawn further to the north in profiles J–M. With regard to the N–S profiles, the profile of Sjöstrand and Stanfors (1975; Fig. 39 here) is of interest. It shows the Småland surface at a height of 150–160 m, and a surface in the south at 120–125 m a.s.l. These two surfaces are clearly separated by an area at 110 m. As concluded before (p. 32), the southern block was elevated after Upper Cretaceous sediments were deposited in the area. Thus, the southern block originally had a lower elevation. The profile is situated in the zones of profiles E and F (Fig. 38).

A lower surface is distinguished in the southeast corner of the area covered by profiles (M–R). It is indicated by a faint change in gradient. From the E–W profiles it can be judged that this area is extremely flat and devoid of high hills (Fig. 38, profiles 2–4). The whole area is below 140 m, with a mean height between 100 and 130 m a.s.l.

For the morphological interpretation (Fig. 38) part of south Sweden was divided into five zones (p. 133). Zone I lies partly outside the south Småland peneplain but includes the lower surface in the southeast. Zone II clearly shows the south Småland peneplain, and is cut in the east by the sub-Cambrian peneplain. The western rim seems to be slightly elevated, with the highest point at 208 m. Zone III also shows the peneplain very well. In the east the sub-Cambrian peneplain reaches a higher level and there is no direct contact between the two peneplains. In the west there are isolated hills that reach high levels. In zone IV the peneplain is still present, but the top curve has a greater distance to the peneplain than in zones II and III. In zones II–IV the three curves for the mean height are smooth and follow each other very well. In zone V the divergence is greater and the top curve is at a still higher level. In this hilly landscape other methods must be used to delimit small parts of the peneplain that may follow the rivers, as Rudberg (1970a) showed on his map.

Northwest of the south Småland peneplain, as delimited here, there seem to be isolated fragments of the plain between the deep valleys. A field trip in the area between the Högvadsån (a tributary of the Ätran) and Viskan rivers has confirmed that flat top surfaces exist there. To delimit the peneplain in this area it is necessary to examine detailed topographical maps in conjunction with field work.

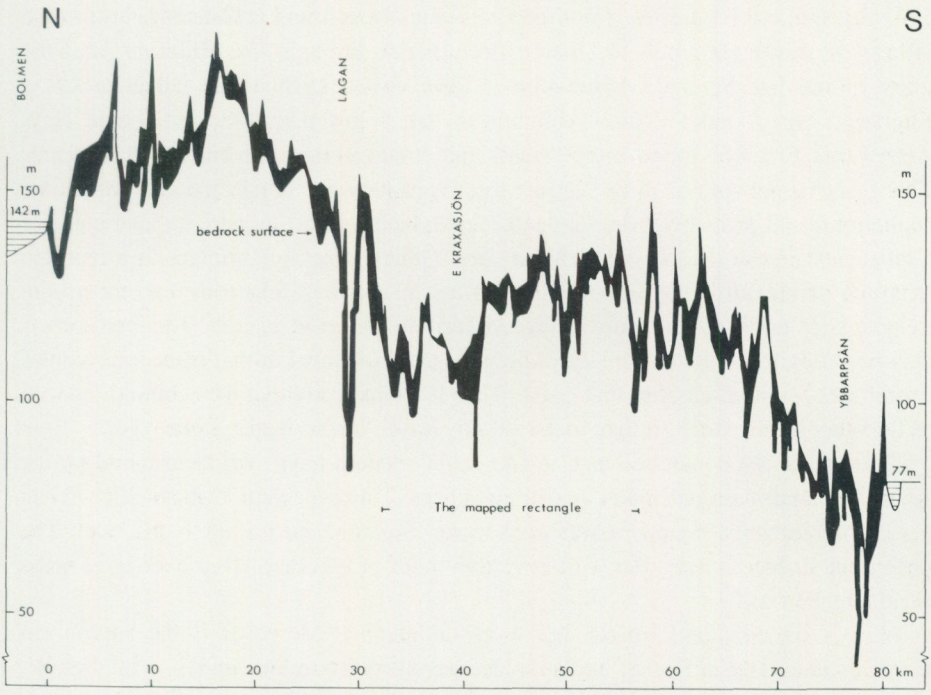


Fig. 39. Profile from Lake Bolmen on the south Småland peneplain across the mapped area (from Sjöstrand & Stanfors 1975; for location see Fig. 32a). Note the height difference between the peneplain at about 150–160 m and the surface in Skåne to the south at 120–125 m. The intermediate area is situated at about 110 m. Deep-weathered bedrock occurs below Lagan and east of Kraxasjön. The study area is crossed between 32 and 57 km, where it is represented by a tectonic block tilted to the northeast. The block is delimited by a tectonic zone in the south (55–57 km). The fracture in the middle (50 km) of the block is the E–W lineament seen in Fig. 8.

Discussion and conclusions — There are clear similarities between my map (Fig. 38) and that of Rudberg (1970a). However, they differ on one important point. Rudberg connects the south Småland peneplain with plain surfaces in Skåne, and profiles G and H may be interpreted to support this idea. In the profiles, however, there is a change in the gradient indicating a shift from one surface to another.

In the Bjärnum area (southeastern part of the study area) the Cretaceous remnants are situated on a plateau between 100 and 120 m a.s.l. and partly at lower levels. It has often been argued that the Cretaceous remnants here rest on the south Småland peneplain and that this therefore must be a surface of Mesozoic age. However, if my delimitation of the peneplain is correct, the Cretaceous remnants are always situated below the main peneplain.

The only report of presumed Cretaceous remnants on the peneplain, as delimited here, comes from Urshult (VC 885655; Fig. 32a), from where Moberg (1884) mentioned a *Belemnitella mucronata* (stored at the Department of Geology in Lund). In

1941 an echinoid (*Galerites*, from the Cretaceous) was found at Österäng farm in the village of Räveboda south of Urshult (information through Åke Hillefors from the diary of the late Samuel Mårtensson). I have visited Urshult and talked to Arvid Engberg, who found the fossil echinoid 82 cm below the surface in a blue clay. Afterwards Engberg found more remarkable stones among the excavated material. This material consists of three Silurian fossils, namely two corals and one orthoconic cephalopod, all probably from Gotland (determined by Jan Bergström), one piece of Cretaceous limestone and one flint artefact. Other Stone Age artefacts are reported from the neighbourhood. Both the Silurian fossils and the Cretaceous limestone seem to have been polished and more or less abraded by the sea at a shore. The limestone is also bored by a marine worm *(Polydora)* and a bivalve, and in that respect resembles limestones found along the west coast. Thus it seems likely that the echinoid, as well as the other items, were brought to the sites by travellers during the Stone Age.

Thus, it can be concluded that no Mesozoic residues have ever been found on the south Småland main peneplain as delimited here. This peneplain is above 126–137 m a.s.l. and remnants of Upper Cretaceous rocks seem to occur just up to this level. The peneplain surface is very flat with a relative relief of less than 20 m over large areas (Rudberg 1970a).

Why is the Småland surface not more undulating? Moreover if the kaolin was formed subaerially in Skåne, it should also have been so in Småland — why then has virtually nothing been found? Has a protective Cretaceous cover ever existed?

One hypothesis which may answer these questions is based on the assumption that the south Småland peneplain evolved with the Late Cretaceous sea as an initial base level. In this case the first parts of the peneplain to be produced acted as a base level for its further development during the Tertiary. The kaolin was removed before the present surface was formed and Cretaceous sediments were never deposited on it. However, this hypothesis does not explain why flints can be found very close to the peneplain level (Fig. 35). An alternative hypothesis which appears to satisfy more questions may be formulated as follows: The Cretaceous sea may have transgressed to an unknown height over an uneven, kaolin weathered surface in Småland. In the Tertiary the Cretaceous deposits and the kaolin saprolite were completely stripped away and the surface levelled in Småland and adjacent areas. Thus originally, the south Småland erosion surface would have been cut through both Upper Cretaceous (in Halland, Skåne and Blekinge) and Precambrian (in Småland) rocks. The age of the south Småland peneplain thus must be post-Cretaceous, that is Tertiary. This hypothesis satisfies the fundamental observation that exhumed sub-Upper Cretaceous relief occurs below the peneplain level, while no Cretaceous remnants and no kaolin have been found on the peneplain.

The plateau between 100 and 120 m a.s.l. in the study area may be classed in the same category as the lower surface at the southeastern corner of the south Småland peneplain. These surfaces may have been formed after the formation of the south Småland main surface and may be correlated to a lower base level. The levelling

agents have cut across both Precambrian and Cretaceous rocks. This levelling may also explain the 100 m level in the river profiles (Fig. 36 and p. 131).

SUPPOSED EXTENT OF AN UPPER CRETACEOUS COVER IN THE EARLY TERTIARY AND THE EXTENT AND ORIGIN OF AN EXHUMED SUB-CRETACEOUS RELIEF

In order to present a picture of the supposed extent of an Upper Cretaceous cover in the Early Tertiary, the contour line for 133 m is plotted on Fig. 32a. This level is chosen because the knickpoints in the river profiles lie between 126 and 137 m and the 133 m isohypse was the only contour line available in an appropriate scale close to these levels, when the map was drawn. On the basis of the evidence in the study area an Upper Cretaceous cover extended up to at least 120–130 m a.s.l. The flints along the west coast are found almost exclusively below this level (Fig. 35 and p. 131). Exhumed sub-Cretaceous relief can be expected to occur below this level, though it may have been destroyed in part by later erosion.

Some localities with such relief were identified within the study area (p. 56). In addition the marked relief north of the Kristianstad plain in the area around Lake Ivösjön has been interpreted as exhumed pre-Senonian relief (Rudberg 1954, p. 26; 1970a). The locality on Ivö island provides strong evidence for this interpretation (p. 127).

Deep weathering and erosion may not be the only causes of the relative relief of more than 200 m in northeastern Skåne (p. 126). In the study area the relative relief reaches a maximum of only 90 m in areas that have not been affected by late tectonic movements. Thus the strong relief in the northeastern part of the Kristianstad area also seems to be due to a higher elevation of the area during the time of weathering (p. 31). Much of the weathered material was therefore removed by erosion before the Late Cretaceous transgressions, and the weathering penetrated deeper. The Cretaceous sediments were then deposited in the depressions (Bergström in Kornfält *et al.*, 1978). The maximum height differences occur in areas with granites (cf. Lundegren 1931, pp. 299–300).

The morphology along the west coast has also been interpreted as partly exhumed pre-Senonian relief (Rudberg 1954, p. 26; 1970a). The morphology in the Viskan valley and around lakes Tolken and Öresjön in Västergötland (UD 500-600/600-700; Fig. 32a) is spectacular, with residual hills reaching high levels; *e.g.* Seatons kulle, on a neck on the middle of Lake Öresjön at 58 m a.s.l. and with a maximum depth of 24 m, reaches 146 m. Thus, there is a local relative relief of 112 m.

Borings in the area around Halmstad (p. 113) show that clay weathering (supposed kaolin, but without analytical confirmation) also occurs there. It seems probable that kaolin weathering has contributed to the shape of a sub-Cretaceous bedrock surface in Halland. Pre-Late Cretaceous erosion probably carried away most of the saprolite

before the Late Cretaceous transgressions (cf. p. 125). The interpretation of the relief in Halland partly as a regenerated sub-Upper Cretaceous feature seems reasonable.

A generally high position of the entire Halland coast and adjoining parts of Västergötland in relation to the sea during the kaolin weathering period may have contributed to a high relative relief (cf. the Kristianstad area p. 137). Periods of more intense weathering may have alternated with periods of more intense stripping related to lower sea levels (Middle Jurassic, Early Cretaceous). Petrographical and structural differences in the Precambrian rocks in different parts of the area with exhumed relief probably caused differences in the topography.

EROSION SURFACES IN SOUTHERN SWEDEN AND ADJACENT AREAS OF EUROPE

EROSION SURFACES IN SOUTHERN SWEDEN

Fig. 40 depicts the erosion surfaces that can be recognized in southern Sweden, with their limits based on Figs. 32, 37 and 38, the map by Norlindh (1924), topographical map sheets north and northeast of Växjö, Rudberg (1970a), and *Karta över Sveriges berggrund* (1958). The map is a combination of schematic sketches of the periphery of the south Småland peneplain and of more detailed maps over central Småland by Norlindh (1924) and Rudberg (1970a).

The oldest erosion surface of importance in south Sweden is the sub-Cambrian peneplain (Rudberg 1970a), which is situated along the east coast and continues off the coast west of outcropping Lower Cambrian sandstone (Flodén 1980). For the major part it is an extremely flat bedrock surface with a relative relief of less than 20 m where intact (Rudberg 1970a; Flodén 1980). The northwestern part of the peneplain (as delimited in Fig. 40) is dissected to a certain degree. Recently, Samuelsson (1975, 1978) argued that a sub-Middle Cambrian undulating surface exists in the Göteborg area on the west coast. Another view is held by Rudberg (1954, 1970a) who considers the sub-Cambrian peneplain in west Sweden as a dissected surface found only on the tops of the plateaux. This idea originates from Ljungner (1927, pp. 231–242).

The next surface that I discern is the sub-Jurassic surface (cf. Troedsson 1932, p. 223), on which there are remnants of Rhaetian–Jurassic strata (Fig. 1). Recent surveys by the Geological Survey of Sweden reveal that large quantities of residual kaolin rest on this surface (p. 69). To the southwest this surface is bounded by Rhaetian–Jurassic strata and by faults. The northeastern limit is along the fault line along the northern sides of Hallandsåsen and Nävlingeåsen. The surface is characterized by bedrock knolls, tor socles and loose boulders. On the Hallandsåsen and Linderödsåsen horsts this surface is probably cut by younger surfaces (not investigated here).

Northeast of the Hallandsåsen–Nävlingeåsen fault line a sub-Cretaceous surface is discerned. It occupies the Precambrian bedrock from where it emerges out of the Cretaceous cover to about 125–135 m a.s.l. Where best preserved this surface is characterized by bedrock knolls, tor socles, boulders and kaolin occurrences. It is identified by the presence of Cretaceous outliers and erratic flints.

South Småland forms a flat surface with a relative relief of less than 20 m over large areas. This surface is at 125–185 m a.s.l. The highest residual hills reach 230 m (Fig. 32a). The surface is interpreted to be of Tertiary age (p. 136).

Analyses of four topographical map sheets north and northeast of Växjö revealed a higher peneplain level at 200–230 m. This level was also discerned by Norlindh (1924), and is also clearly visible in the profiles (F, K, L, M, and O in Fig. 37). Moding also (1970, p. 136) noted the distinctness of the level. I have used Norlindh's

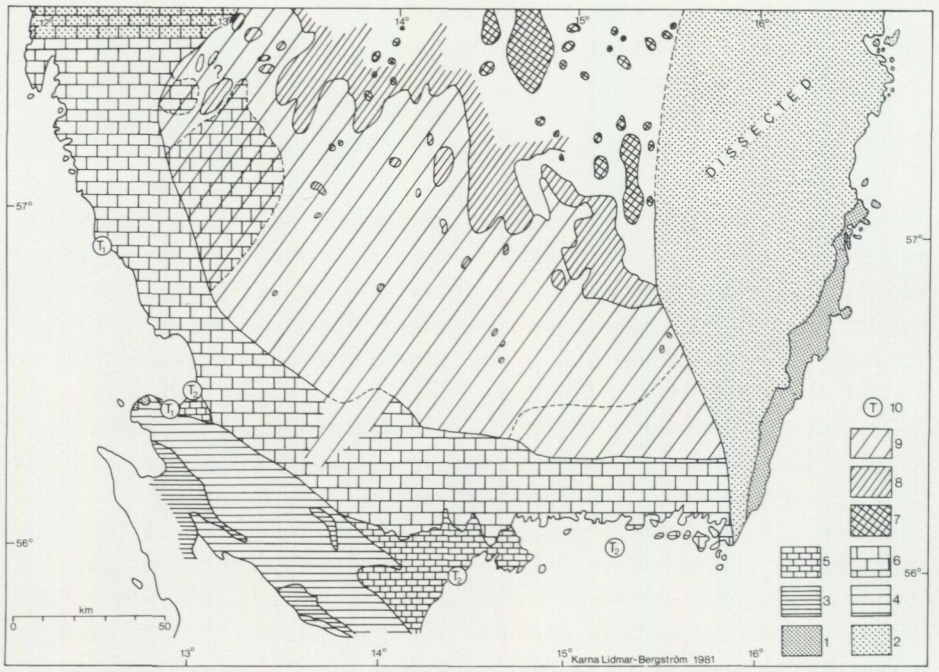


Fig. 40. Erosion surfaces and cover rocks in southern Sweden. 1. Cambrian strata. 2. Sub-Cambrian erosion surface. 3. Rhaetian–Jurassic strata. 4. Sub-Jurassic erosion surface (later remodelled particularly in the northwest and southeast). 5. Upper Cretaceous strata. 6. Sub-Upper Cretaceous erosion surface, partly later remodelled (see point 10 below). 7–10. Tertiary erosion surfaces with a tentative dating of the initiation of the different surfaces: 7. Level 1, initiated in the Coniacian. 8. Level 2, initiated in the Paleocene. 9. Levels 3 and 4, initiated in the Eocene–Oligocene. 10. Levels 5 and 6 (T_1 and T_2), initiated in the Miocene–Pliocene. The Late Tertiary surfaces probably have a much wider extent than indicated by T_1 and T_2.

southern boundary to delimit the 200 m-surface on Fig. 40. The remnants of a higher surface, the post-Silurian peneplain as delimited by Rudberg (1970a), is also represented on the map, situated at 280–300 m a.s.l. in the Växjö area.

The detailed interpretation of the northwestern part of the Tertiary erosion surface requires a closer examination (cf. p. 134). An area with supposed sub-Upper Cretaceous relief (cf. Fig. 32a) modified by Tertiary hill summit planation is marked with double symbols in Fig. 40. In this area tectonics also seem to have played an important part in producing the morphology.

At the southern margin of the south Småland peneplain there are remnants of a slightly lower erosion surface. It is best preserved in the southeast corner of the peneplain but also present in part of the study area between 100 and 120 m (the plateau and part of the area without flints). The same level is indicated by the 100 m level in the rivers. Apparently this surface must have been cut mainly in Cretaceous rocks, later removed by erosion (cf. Fig. 3).

As a summary the southern parts of the profiles in Fig. 41 can be studied. The

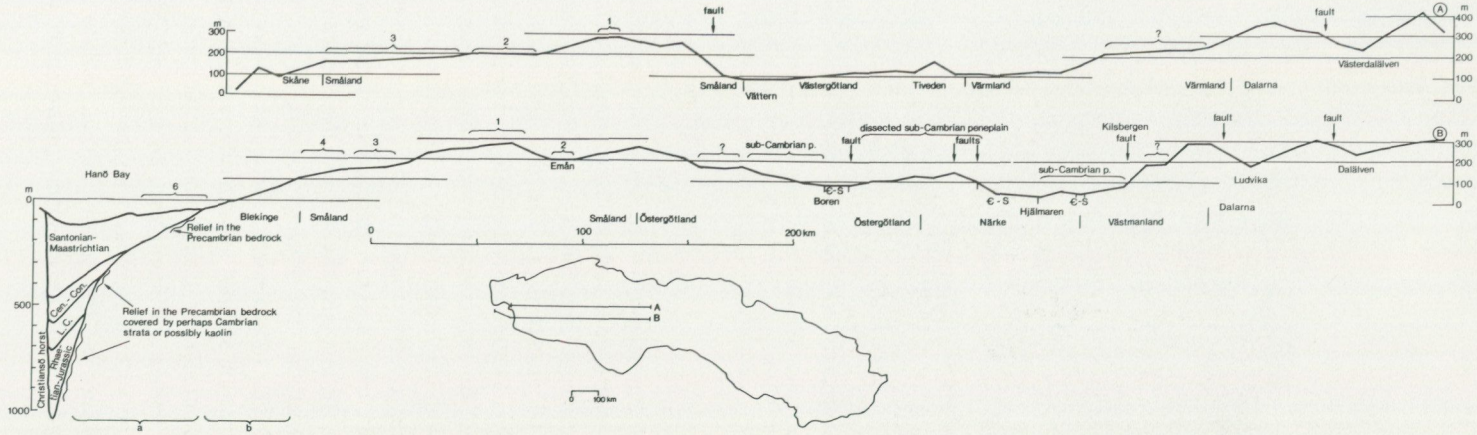


Fig. 41. North–south profiles through southern Sweden, showing some characteristic morphological features (see the text). For the numbered levels see Table 9 and Fig. 40. Letter 'a' means buried sub-Mesozoic erosion surfaces, 'b' an exhumed sub-Upper Cretaceous erosion surface. The profiles are based on data from the Mean Height Map of Sweden (1963) and Kumpas (1980).



Fig. 42. Hunnsberget, a residual hill reaching 230 m a.s.l., on the south Småland peneplain, which here is at about 170 m a.s.l. The hill is an amphibolite body within a gneiss area. Grid reference UC 996938; the hill is shown on maps Figs. 32a and 40.

profiles are based on mean heights for the land areas and seismic depths for the sea areas, and have been constructed from Hanö Bay through Småland to Dalarna (see also p. 145). The information from Hanö Bay is taken from Kumpas (1980). The following erosion surfaces can be discerned: a. The first surface Kumpas called the sub-Mesozoic peneplain. The average relief is 30–50 m but in places it reaches 60–80 m and 150 m around Hanö. An area covered by supposedly Cambrian sandstone exhibits a more rugged relief, with height differences of more than 100 m, if the interpretation of seismic velocities and reflectors is correct. As there are no borings in this area, the interpretation is not conclusive and the supposed sandstone may, for instance, just as well be a kaolin cover. In that case the relief in the Precambrian would be smaller. (Discussed by Jan Bergström and Michael Kumpas at the public presentation of Kumpas' dissertation.) The sub-Mesozoic surface is composed of a number of sections, the evolution of which stopped at such different times as the Rhaetian for the oldest part and the Santonian or Campanian for the most recent. Thus, an age difference of 120 Ma between different parts of the ''sub-Mesozoic peneplain'' is obvious. Sections of the surface correlate with the sub-Jurassic and sub-Cretaceous erosion surfaces in Skåne. b. The second erosion surface is a regenerated sub-Campanian surface and is thus an exhumed prolongation of the sub-Cretaceous



Fig. 43. Small residual hill (Berget at Boberg) rising from 15 to 40 m on the coastal plain in Halland. The gross morphology of the bedrock surface was initiated by deep weathering in the Mesozoic. An uneven erosion surface was formed in the Early and early Late Cretaceous, buried in the Late Cretaceous, and exhumed and remodelled in the Neogene.

surface. Surfaces a and b (Fig. 41) are buried or regenerated features in contrast to the surfaces to be discussed below.

If the profiles are studied from the highest part of Småland southwards, the following surfaces can be discerned: 1, the remnants of Rudberg's post-Silurian peneplain (at 280–300 m a.s.l. in the Växjö area), 2, the level discerned by Norlindh (1924) and myself at 200–230 m, 3, the south Småland main peneplain at 125–185 m as delimited by me in Fig. 38 (Norlindh 1924 noted two levels, one with the lakes at 130–145 m and another with the lakes at 165 m), 4, the lower surface in the southeast corner of the peneplain (Fig. 38) at 100–125 m, and 6, the bottom of Hanö Bay down to 75 m below sea level (T_2 Fig. 40). The latter surface lies on top of the Cretaceous deposits. It can also be studied on the map of the Kristianstad plain by K. Nilsson (1966). A surface at -70 to -80 m is also noted in the Baltic by Fromm (1943, p. 158).

In connection with work on the new geological map sheet 4C Halmstad SV, the Geological Survey of Sweden has run a seismic profile along the southern shore of Laholm Bay. It shows a mixed Cretaceous and Precambrian levelled surface below the Quaternary at 50–70 m below the present sea level (Bergström & Lidmar-Bergström 1980, Fig. 3). Thus, a younger Tertiary surface can also be discerned here (T_2 Fig. 40).

There are indications that still more erosion levels exist in this area. Geological

Survey of Sweden archives contain old manuscript profiles (made by Gerhard De Geer, supplied by Jan De Geer) indicating that a level at 0–30 m (level No. 5 in the above sequence) at the northern slope of Hallandsåsen cuts across Precambrian and Cretaceous rocks. Flat bedrock in the Falkenberg area on the west coast could be assigned to approximately the same level (T_1 Fig. 40). The profiles in Fig. 4 (III–VI and the projected profiles) might imply a surface at about 0–40 m (5) in the study area.

In summary a distinction can be made between the exhumed surfaces, the sub-Cambrian surface, the sub-Jurassic surface, and the sub-Upper Cretaceous surface on the one hand, and the mainly Tertiary surfaces 1–6 on the other. The Early Eocene transgression may have reached very high levels (cf. p. 162). Marine Eocene diatomaceans reported by Cleve-Euler (1941) were found at 195–215 m a.s.l. in the Emån valley. This level corresponds to surface 2, although there is a possibility that the diatomaceans have been brought down from the higher level 1. Thus, there is a possibility that a Palaeogene surface was covered by Lower Eocene sediments for some period of time and then later exhumed.

It is important to note that Fig. 40 shows the oldest elements in the actual landscape. Along the coasts, areas with a sub-Cretaceous relief coincide partly with areas with a Neogene relief. Detailed studies are needed for a distinction between the sub-Cretaceous and Neogene features.

EROSION SURFACES IN NORTHERN SWEDEN

With the hypothesis that the south Småland peneplain is a Tertiary surface and Rudberg's view (1954) on the inland plains in northern Sweden as developed during the same time a correlation between northern and southern Sweden should be possible. Therefore a survey of the erosion surfaces in northern Sweden can be appropriate.

Rudberg (1954) gives a detailed account of the literature on northern Sweden. The account by Wråk (1908) is the most interesting old reference, describing work on both the Swedish and Norwegian sides of the mountains. He discerned six levels of erosion surfaces. The most important are the Tuipal level at 900–1100 m, the Borsu level at 650–850 m, and the Muddus level at 300–550 m. One higher and two lower levels were also discerned. He made the observations that the higher surfaces have an inclination to the southeast while the Muddus and lower levels have a southeasterly inclination in the east and a northwesterly inclination in the west. The observation of the tilt may have potentials for the interpretation of landform development and tectonic evolution, but reconfirmation is needed.

The thorough investigation by Rudberg (1954) in Västerbotten revealed that Wråk's levels represent a simplified picture of the conditions. Rudberg mapped 13 successively lower erosion generations from the mountains in the west to the Bothnian Bay in the east. A small sub-Cambrian facet was also discerned at the foot of the mountains at about 500 m a.s.l., and larger sub-Cambrian surfaces were mapped at 0–200 m in the

vicinity of the Bothnian Bay. Only a few of the surfaces were thought to have been complete peneplains. The largest surfaces are the inland plains at 200–450 m a.s.l. (generations 4–6). Rudberg suggested that these vast plains may have developed during the Tertiary in a tropical climate with alternating seasons, analogous with the conditions in Central Europe. The most important of the higher generations are generations 7 (475–550 m) and 10 (750–800m). The highest important level is generation 12 (950–1000 m).

The erosion surfaces of different generations are parallel to one another. This condition forced Rudberg to conclude that Scandinavia cannot represent an inclined block but instead must have experienced a ''concordant'' development, ''where the continental surface rises without change of the inclination, and where the rejuvenation of the relief is caused by peripherally placed faults and flexures'' (Rudberg 1954, pp. 103, 428).

Ängeby (1955) discerned only a few surfaces in Jämtland. The study was based on peak heights along profiles and cannot be compared to the thorough areal analyses of Rudberg further north.

IS IT POSSIBLE TO CORRELATE THE EROSION SURFACES IN SOUTHERN AND NORTHERN SWEDEN?

I have found it reasonable to attempt a correlation between the main inland surface in northern Sweden, generation 4 of Rudberg (1954), and the main Småland surface (Table 8). The other surfaces can then be placed as shown in the table. Surfaces at other levels in parts of Norrland that are not yet investigated in detail may be larger than generation 4 (Sten Rudberg, pers. comm.). Thus other correlations might be better. For the time being, however, the best available possibility is to correlate with the well investigated Västerbotten county.

In addition to those from Småland (p. 144), Early Eocene marine diatomaceans have been described from Västerbotten (Cleve-Euler 1941). The exact height of the localities is not known but one of them seems to be at 375–425 m a.s.l., which is the level of generation 5 or 6. As the diatomaceans are not found in their original positions, they may very well have a provenance in surfaces other than those in which they were found. Thus, their value for dating the surfaces is limited but there are no obvious alternative means of dating. Therefore, I have used the diatomaceans and tentatively placed generation 5 and surface 2 in the Paleocene (Table 8).

Profiles based on the Mean Height Map of Sweden have revealed important morphological features of well known parts of southern Sweden (pp. 131–137). It has been tempting to continue some of the profiles northwards to try to correlate with northern Sweden. In Fig. 41 profiles K and P from Fig. 37 have been prolonged to Dalarna in south central Sweden. The Precambrian surface rises in a flexure from 1000 m b.s.l. in Hanö Bay to about 300 m a.s.l. in northern Småland. In Västergötland,

TABLE 8. An attempt to correlate erosion surfaces in southern and northern Sweden, and a tentative dating of the surfaces/levels. Smål. main p. = Småland main peneplain.

Northern Sweden (Rudberg 1954)	Southern Sweden	Tentative ages
(gen. 13) (1150 - 1200 m)		
gen. 12 950 - 1000 m	Central Skåne sub-Jurassic	Early Triassic
gen. 9 - 10 - 11 675 - 775 - 900 m		Middle Jurassic
(gen. 8) (550 - 650 m)		
gen. 7 475 - 550 m	sub-Cretaceous	Early Cretaceous
gen. 6 400 - 450 m	1. 280 - 300 m	Coniacian
gen. 5 300 - 400 m	2. 200 - 230 m	Paleocene
gen. 4 200 - 300 m	3. Smål. main p. 125 - 185 m	Middle Eocene - Oligocene
gen. 3 100 - 200 m	4. 100 - 125 m	Oligocene
gen. 2 25 m - 100 m	5. T_1 0 - 40 m	Miocene
gen. 1 <0 - 25 m	6. T_2 -75 - -50 m	Pliocene

Värmland (A), Östergötland, Närke, and Västmanland (B) there is a depression covered partly by Cambro-Silurian strata. In this area there are exhumed parts of the sub-Cambrian peneplain (cf. Rudberg 1970a). Striking features in the profiles are the indications of erosion surfaces north of Småland, viz. in Östergötland at 160–170 m a.s.l. (B) and north of the depression at 180 m (B) and at 215–240 m (A) a.s.l. The profiles suggest that it might be valuable to make morphological investigations in these areas. As faults occur in the depression, at its borders, and in southern Dalarna (Frödin 1910), it seems impossible to correlate the supposed erosion surfaces and continue the correlation northwards without further studies. However, the preliminary profile studies indicate the possibility that erosion surfaces may have cut across Precambrian and Cambro-Silurian rocks over the south central Swedish lowlands (the depression in Fig. 41). The profile study also gives the impression that the south Swedish Precambrian surface is slightly arched.

Large vertical movements of the Fennoscandian Shield have been reported by Mörner (1980a and b). He claims that there is evidence of a minor uplift at the Eocene/Oligocene transition and a major uplift at the Oligocene/Miocene transition (p. 161). Marked subsidence is said to have occurred in the Pleistocene, followed by postglacial uplift to the present level. It seems unlikely that the shield was uplifted in a continuous bulge, but it is more probable that earthquakes and faults accompanied the movements. The faults shown by Rudberg (1970a, see also Fig. 41) and the earthquake maps by Sahlström (in Magnusson *et al.* 1963, p. 267), Huseby *et al.* (1976) and Båth (1979) indicate where these movements may have occurred. In this context the idea put forward by Norlindh (1924, p. 244) of faults delimiting the Norrland terrian should not be forgotten (cf. *Marin geologi och oceanografi 1979*, p. 32).

In studying the profiles in Fig. 41, it must be borne in mind that the height scale is 100 times the length scale. The slope gradient of the south Småland peneplain is very small (0.05–0.1%, Rudberg 1970c). By uplift and subsidence the gradient of the surface has changed with time, as is the case with other surfaces in Sweden. However, it should be noted that if the northern end of profile A (Fig. 41) is elevated 600 m and the southern end of surface No. 3 is raised 200 m (figures calculated from the maximum uplift of central Scandinavia of 1100 m estimated by Mörner 1980 Figs. 5 and 23) the slope gradient for surface 3 will only increase from 0.07% to 0.14% (calculated from profile A Fig. 41). Thus it can be noted that uplifts and subsidences have not influenced the gradients of the surfaces to any great degree. The surfaces in the county of Västerbotten have a steeper gradient than the south Småland peneplain (Rudberg 1970c). However, as they have been tilted in an opposite direction to their inclination (according to Mörner 1980a) their original slope gradient may have been less than today.

An interesting observation that can be made from the paper by Rudberg (1970c, p. 165) is that the sub-Cambrian peneplain does not show any evidence of dissection until the slope gradient reaches 0.4%. A comparable figure (0.5%) for undissected planation surfaces is found by Spönemann (1979) in East Africa. Thus much larger crustal tilting seems to be needed to destroy the south Småland peneplain than is thought to have occurred since the Early Tertiary.

EROSION SURFACES AND THEIR ORIGIN IN ADJACENT AREAS OF EUROPE

Ziegler (1975) presented a map of the presumed extent of sea and land in the Late Cretaceous. The map is useful for the understanding of erosion surfaces and is therefore redrawn here (Fig. 44). In my opinion (p. 136), part of Sweden covered by the dotted land symbol was remodelled in the Tertiary, and it is very likely that the Late Cretaceous sea had a wider maximum extent than supposed by Ziegler. The map can therefore be regarded as a sketch of the extent of a Cretaceous rock cover remaining at the end of the Palaeogene. As a result, the white areas indicate where

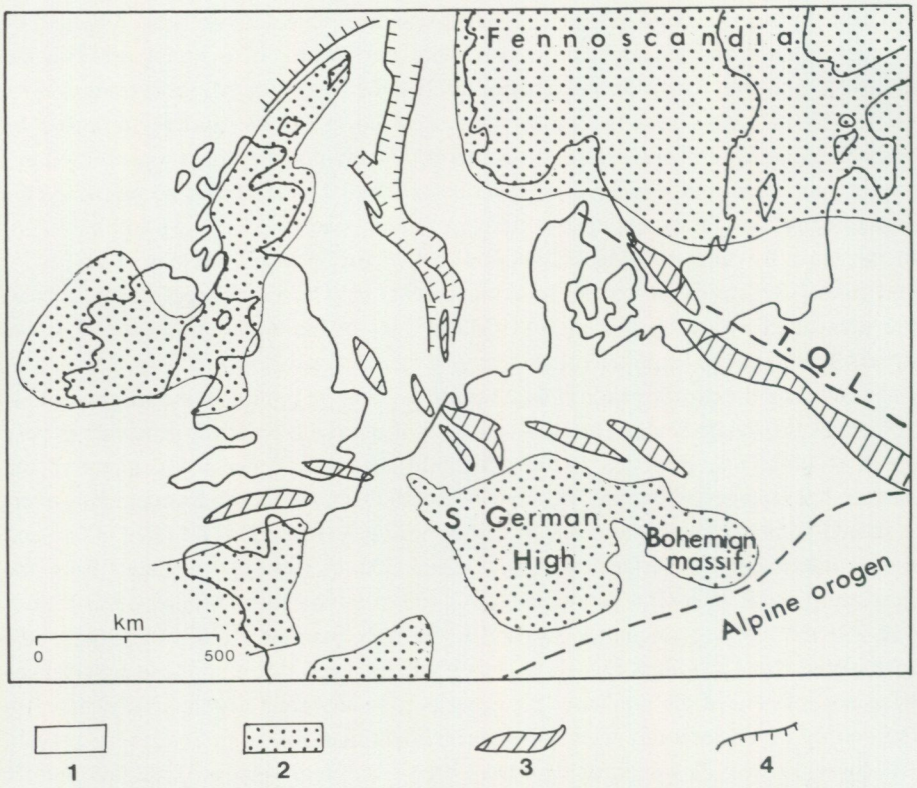


Fig. 44. Palaeogeography of northwestern Europe during the Late Cretaceous according to Ziegler (1975; the map is a simplification from his map, Fig. 17, p. 1090). The map does not take later landsurface remodelling into account, and in my opinion it rather shows the extension of a preserved Upper Cretaceous cover at the end of the Palaeogene. 1. Upper Cretaceous rocks. 2. Positive area. 3. Inversion axis. 4. Fault.

exhumed sub-Upper Cretaceous relief may be expected to occur in pre-Late Cretaceous rocks together with Neogene relief, and Tertiary relief in Upper Cretaceous rocks, while the dotted areas indicate where the relief is partly imprinted by the Early Tertiary. The following section summarizes the development of erosion surfaces in Norway, Finland, Poland, Germany, Belgium, and Great Britain.

NORWAY

Discussion of the ''paleic'' surface in Norway was summarized by Gjessing (1967). The wide upland areas with forms distinct from the young ones were named the ''paleic'' surface by Reusch in 1901. In the Oslo region, Reusch (1903a) suggested deep weathering and subsequent stripping as the cause of the landscape with hills and depressions. Gjessing compared this area with the Lake Ivösjön area in northeast

Skåne. It can also be noted that Reusch (1903b) suggested that the Oslo region has been covered by Cretaceous rocks (superimposed drainage, flints on the coast). The idea that the ''paleic'' surface consists of two parallel surfaces at different altitudes was put forward by several researchers such as Reusch (1903b), Machaček (1908), and Strøm (1948). Evers (1941), among others, argued for a ''Piedmonttreppe'', with denudation surfaces arranged as a series of steps. Rudberg (1966) was critical of the latter reconstruction even if he did not reject completely the view of a regular, polycyclical relief. He thought that more evidence is needed to confirm this idea.

Many opinions exist about the origin of the ''paleic'' surface (see Rudberg 1954, pp. 57–58, 63–65, 75–81 and Gjessing 1967). Gjessing (1967, p. 124) reached the following conclusion: ''As the paleic land forms probably developed within a wide range in height above and distance from the general base level, the development of the paleic surface type of forms was not due to particular tectonic movements or to particular positions of land in relation to the base level, even though the general form of the paleic surface must have been influenced by them. In the development of the specific character of the paleic land forms, the particular — probably climatically determined — processes involved seem to have been of the most vital importance''. Further: ''However, the similarity between the forms seems so striking, that the actual processes in the present arid or semiarid warm climates undoubtedly help to explain the development of the forms of Norway's paleic surface'' (Gjessing 1967, p. 113). He suggests ''that the history of denudation which finally resulted in the paleic forms . . . may have taken place, not only in the Tertiary, but in part also in the Mesozoic or even earlier'' (Gjessing 1967, p. 118) as indicated by the kaolin weathered sub-Jurassic–Cretaceous surface on Andøya island and by evidence of deep weathering from other Scandinavian countries.

In a study by Schipull (1974) on the Hardangervidda it is said that the surface of Norway was probably sculptured simultaneously at many different altitudes, predominantly independent of height above sea level. Two main levels were discerned viz. at 1100–1300 m and at 1800 m. The sub-Cambrian peneplain was thought to exist only on minor surfaces at 1250–1300 m.

Another view is held by Peulvast (1978), who interpreted Hardangervidda as the sub-Cambrian peneplain (a view put forward earlier by Ahlmann 1919 and Holtedahl 1953). Moreover, he interpreted the ''paleic'' surface in Norway as consisting of an upper peneplain of supposed Palaeogene age and a lower peneplain supposedly of Neogene age. He considered Norway as an inclined block with the greatest uplift in the northwest (referring to Torske 1972). The two peneplain surfaces were considered as curved and inclined to the southeast. He ascribed the main uplift to the Neogene and the successive incision of the long deep valleys to the Pliocene.

NORTHERN FINLAND AND NORTHERN NORWAY

Kaitanen (1969) studied an area in northern Finland and northern Norway. He came to the following conclusion: ''In the landforms of the investigated area, there are two clearly distinguished main types; the upper relief, which curves rather gently over the whole of its area, and the lower relief, which is more or less ''sunk'' into it and is almost completely independent of its composition, consisting of steeply sloping valleys. Such a twopart division of the relief can hardly be considered a consequence of different stages of evolution caused by similar erosional events, but must be seen as a result of different erosional events caused by climatic changes. The upper relief developed, in essence, during the early and middle periods of the Tertiary era as a result of erosional action primarily comparable with pediplanation conditions which might be defined as moderately semi-arid. The lower relief formed after that during the Pliocene and also during the interglacial phases of the Pleistocene, mainly as a result of fluvial incision, in conditions largely resembling the present climate, although maybe slightly warmer. Since there was relative lowering of the base level at approximately the same time, the advance of fluvial incision was intense and rapid'' (Kaitanen 1969, pp. 77–78). The upper relief seems to be equivalent to the concept of the ''paleic'' surface.

FINLAND

Tanner (1938, p. 120) described the relief in Finland as made up of ''unterschiedliche Erosionsfazetten'' and ''subparallele Peneplainflächen in verschiedenen Niveaus''. Inselbergs are described from several areas (Tanner 1938, pp. 125, 146–147; Hausen 1933, p. 142; Schrepfer 1933).

In southern Finland, exhumed sub-Cambrian surfaces are recognized, cut by a younger surface, the Finnish sea plateau at 100–150 m. The latter has inselbergs present (Hausen 1933, p. 143; Tanner 1938, pp. 64–65). Tanner (1936, 1938, p. 355) tentatively interpreted the Finnish sea plateau as a Late Paleozoic surface, but an Early Tertiary age was also suggested as an alternative (Tanner 1938, p. 423). Most of the surfaces in northern Finland were assigned by Tanner to the Neogene (1938, pp. 370–382).

POLAND

A Palaeogene surface is recognized in the Polish Sudetic Mountains of the Bohemian massif. This surface was separated by faults in the Mid-Oligocene into a higher and a lower part. The present flats of the higher level seem to be the stripped basal weathering surface. The lower level in the Sudetic Foreland bears thick kaolin and

laterite covers. Below the Palaeogene surface there is a surface thought to have developed under periodically semi-arid conditions during the Late Oligocene–Early Miocene. The lowest planation surface is of Late Miocene–Early Pliocene age. (Baumgart-Kotarba *et al.* 1976). The concept of the three planation surfaces originates from Jahn (1953), who later (1980) stressed that the morphogenesis of the Sudetes has been influenced by processes at work in an intertropical climate during the Tertiary.

GERMANY

In Germany the peneplanation of the Variscan Mountains was terminated with the formation of ''der Permische Rumpf'', on which the Zechstein and Mesozoic sediments were deposited. Where the sediments have been removed by erosion, ''der Permische Rumpf'' is exposed. Rifting during the Jurassic and later periods lifted the South German High and the Bohemian Massif into a high position, with continued weathering and erosion. The highest and oldest identified surfaces are of Late Cretaceous to Mid-Eocene ages. (Gellert 1958; Störr 1975; Büdel 1977, pp. 204 ff.). Below the older ''Rumpftreppen'' in the Rheinische Schiefergebirge, Late Pliocene–Early Pleistocene ''Breitterassen'' can be discerned, below which are young Pleistocene deeply incised valleys (Büdel 1977, pp. 208 ff.).

Apart from ''der Permische Rumpf'' exhumed surfaces occur north of Erzgebirge, where residual hills protude through Oligocene and Eocene sediments. The Kuppenalb in Frankenalb is analogous to the hillocky landscape in northeast Skåne. It is developed in Jurassic limestone. Kaolin occurs in the depressions and the whole area has been covered by Upper Cretaceous deposits (Büdel 1977, pp. 101–102).

BELGIUM

A detailed map of erosion surfaces in Belgium was made by Lefèvre (1950). The highest surface is an exhumed sub-Cretaceous surface at about 550–700 m a.s.l., below which there are surfaces identified at 480–500 m, 380–400 m, 280–300 m, and at 50–180 m. The latter is the Plio-Pleistocene glacis.

WALES

The Welsh tableland has been interpreted in many different ways, ranging from a sub-Triassic peneplain, a sub-Chalk peneplain, to an Early Tertiary planation surface. Brown (1960) mapped several surfaces (the high plateau at 515–600 m, the middle peneplain at 360–485 m, the low peneplain at 245–330 m) that he considered to be of Late Tertiary age. A coastal platform at 180 m was also recognized. (From Small 1978).

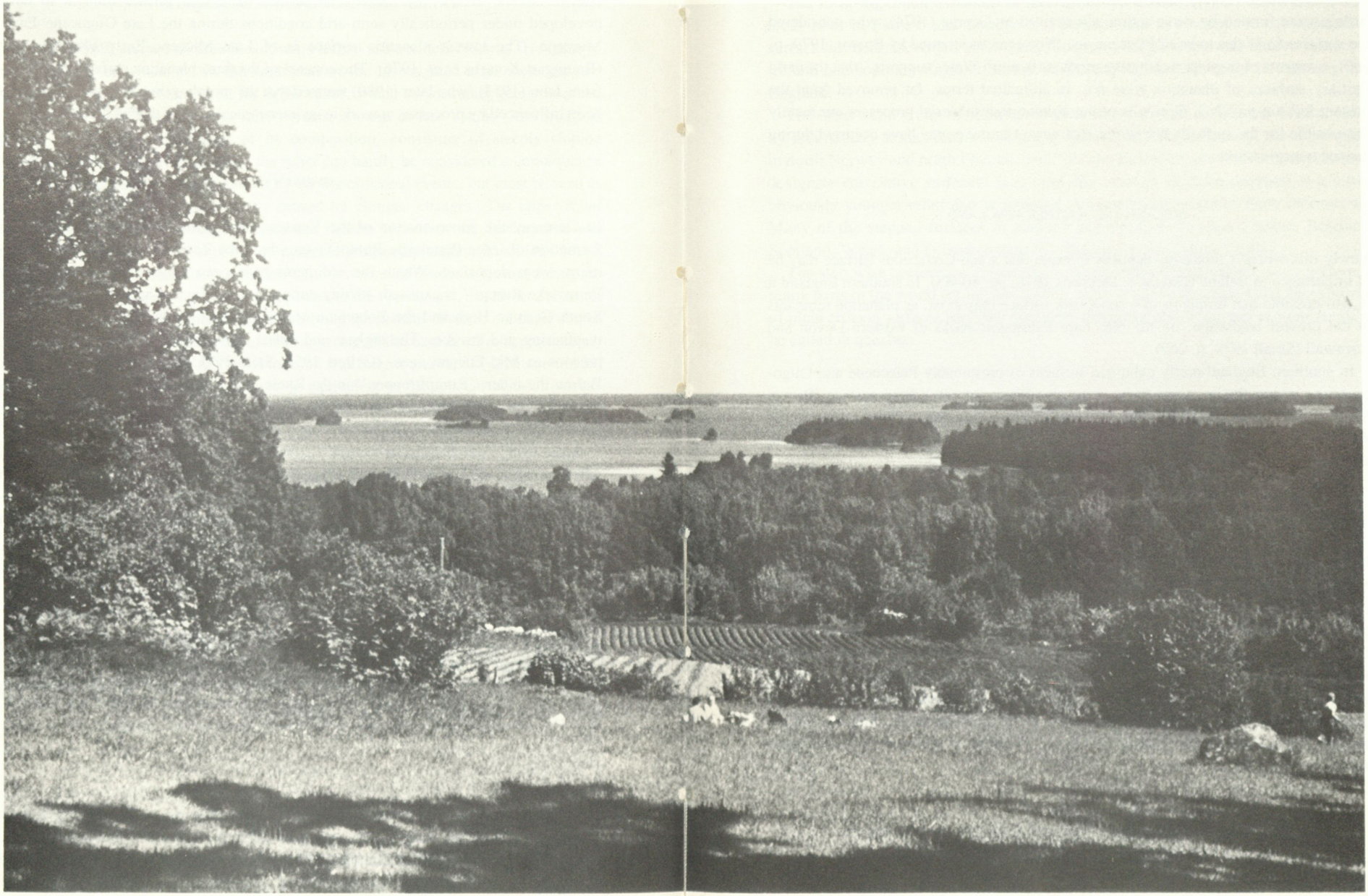


Fig. 45. The south Småland peneplain with Lake Åsnen (140 m a.s.l.) from Lunna backe (187 m a.s.l., point marked in Fig. 32; grid reference VC 877716) to the north. The horizon is perfectly straight.

The nineteenth century idea of British geologists that the erosion surfaces of Great Britain were formed by wave action was revived by George (1974), who considered the surfaces in Wales to be of Pliocene age. However, as stressed by Brown (1979, p. 460), remnants of tropical weathering products in north Wales suggests ''that the early Tertiary surfaces of planation were not, in altitudinal terms, far removed from the present hill top profile''. Brown is of the opinion that subaerial processes are mainly responsible for the surfaces but admits that wave trimming may have occurred during marine transgressions.

IRELAND AND SOUTHERN ENGLAND

Newly discovered Cretaceous deposits indicate that a sub-Cretaceous surface may be of importance in Ireland (Davies & Stephens 1978, pp. 80–83). In southern England it is also possible that remnants of a sub-Chalk surface may exist, as planation remnants in the present landscape, on the old, hard Palaeozoic rocks of western Devon and Cornwall (Small 1978, p. 262).

In southern England partly exhumed surfaces of presumably Paleocene and Oligocene age, respectively, seem to be more significant for the hilltop surface (Brown 1979, p. 460; Isaac 1981) than the Miocene-Pliocene planation surface postulated by Wooldridge & Linton (cf. p. 51). For further information on the erosion surfaces in southern England see pp. 51–52.

SCOTLAND

In Scotland planation surfaces occur at approximately the following levels: 1070–1220 m, 700–940 m (Grampian main surface), 400–640 m (Grampian lower surface), 180–300 m, and 90–180 m (Sissons 1976). Linton (1951) suggested that the highest peaks in Scotland are remnants of a sub-Cenomanian surface. He interpreted the Grampian main surface as the result of an Early Tertiary erosion cycle. George (1966) argued that the Scottish scenery is essentially of Neogene origin as the identified surfaces cut Palaeogene igneous masses and are younger than mid-Tertiary folds and faults in the Hebrides. He also argued that the surfaces are wave cut. Minor exhumed surfaces are mentioned by Sissons (1976, pp. 21–22), for instance a sub-Devonian surface.

EROSION SURFACES IN THE DIFFERENT COUNTRIES — COMPARISON AND CONCLUSIONS

Two kinds of erosion surfaces occur, viz. exhumed surfaces (mainly old) and surfaces arranged in stepped sequences on which the Tertiary conditions have put its imprint.

The most important exhumed surface is the sub-Cambrian one, which covers vast areas both in Finland and Sweden and perhaps also in Norway. A sub-Cretaceous surface has been identified in Sweden, Germany, Belgium and may also be present in Ireland and southern England. Exhumed Palaeogene surfaces occur in Germany and England.

The other main group of surfaces never or only for short periods has been covered by sedimentary strata. Terms such as the ''paleic'' surface in Norway, the upper relief in north Norway and north Finland, and ''die alte Rumpftreppen'' in Germany seem to designate correlative surfaces. Sunk into this relief in all three countries is a lower obviously younger relief that is regarded as latest Pliocene and/or Early Pleistocene. Many of the stepped surfaces in northern and southern Sweden, Finland, Belgium, Scotland, Wales, and Poland seem to be eqivalents of the ''paleic'' relief.

The step-wise occurrence of surfaces is not an isolated phenomenon but is present in many parts of the world (cf. pp. 167–169). Thus, it can be concluded that the existence of plain erosion surfaces and their step-wise arrangement is a fact that no more needs to be called in question.

DEVONIAN TO TERTIARY CONTINENTAL DRIFT, PALAEOGEOGRAPHY AND PALAEOCLIMATES IN NORTH AND CENTRAL EUROPE

For the discussion of the age and mode of formation of the European erosion surfaces it seems necessary to summarize the tectonic, geographic and climatic events in Europe from the Devonian to the Tertiary. As the oldest periods have less significance for the actual erosion surfaces the treatment of them is less thorough than of the younger ones.

Discussion of this topic here is based on the reconstructions of continental positions published by Scotese (1975) and on the palaeogeographic maps of Northwest Europe by Ziegler (1975). Supporting comments are based mainly on Brinkmann (1969) and Ziegler (1975). The evidence is summarized in Table 11.

DEVONIAN

In Devonian times Caledonian folding came to an end and North America had fused with Greenland and Fennosarmatia to form the Old Red continent. This block became the northern frame of the Variscan geosyncline. The Caledonian Mountains in Scandinavia remained an area of uplift. At the same time the Swedish-Finnish foreland was elevated, to form what is now Fennoscandia.

In Middle Devonian time the equator passed through south Sweden, in a NW–SE direction. An unbroken plant cover, which would hinder erosion and transport as in later periods, was still lacking. Therefore one may not consider the poorly fossiliferous, brightly coloured Old Red in Great Britain as a normal desert deposit. However, Schwarzbach (1961, 1974) believes that the Old Red facies is evidence of aridity. In any case, south Sweden belonged to the equatorial zone at this time.

CARBONIFEROUS

During the Carboniferous the formation of the Variscan mountains took place. The seaway between North America and North Europe on the one side and South America, southeastern North America, Africa, and South Europe on the other was almost closed at the end of the Carboniferous. By about middle Carboniferous times the continental blocks had moved northwards, with an equatorial position immediately south of Sweden and through Scotland. Plants ultimately formed a more coherent cover on the continents and large amounts of coal were formed during the Late Carboniferous. In Europe a warm, humid climate prevailed (Schwarzbach 1961), which continued into the Early Permian in Central Europe (Störr *et al.* 1977, p. 14).

PERMIAN

Major changes in the structure of the bedrock took place in Central Europe during Permian times. The Variscan foreland was then subjected to uplift, tilting and erosion, followed by differential subsidence along predominantly NW–SE striking normal faults (Hercynian strike). In addition to the strike of Variscan folds, new lineaments were developed, especially in E–W and NNE–SSW directions. This revolution had already begun in the Early Permian, and it accelerated at the beginning of the Late Permian. Two large intracratonic basins were formed: a northern one including the northern North Sea and the Danish Embayment, and a southern one including the southern North Sea, northern Germany and Poland. Between these areas the Mid-North Sea–Ringkøbing–Fyn High developed as a major positive element. Early Permian eruptions in Central Europe were probably connected with the formation of the Oslo Graben. The ''Tornquist Line'' existed as a major lineament during the Permian. Recent geological and geophysical data have revealed a pattern of linear sedimentary troughs crossing the continental shelf of Northwest Europe. This system of troughs is thought to represent a number of wholly or partially failed spreading systems which were initiated as early as in the Late Palaeozoic and which remained active until the Late Mesozoic, or in some instances into the Tertiary (Pegrum *et al.* 1975, pp. 13–15).

The Variscan mountain building was accompanied by further marine regression, which began in the Late Carboniferous and reached its climax in the Late Permian–Early Triassic time. However, continued subsidence of the Early Permian basins finally resulted in the ingression of the Zechstein sea, probably from the ocean north of Greenland and Scandinavia and between Norway and Scotland. At the beginning of the Mesozoic the sea was almost completely restricted to the large sea basins. The Tethys formed a large bay between Southeast Europe and Northeast Africa and expanded into an ocean in the east.

During the Permian a large landmass was centered around the equator, which extended through Southern Europe. This large landmass, the Hercynian continent, produced a very dry climate (Robinsson 1973). Studies of borehole data have proved that the Lower Permian sediments in the North Sea area were laid down in an arid desert environment. ''The desert extended from the newly uplifted Hercynian Mountains to the south, northwards to the highlands or bare rock pediments of the Mid-North Sea and Fyn–Ringkøbing Platforms. A second desert basin lay to the north of these platforms.'' (Pegrum *et al.* 1975, p. 35). In the middle Permian south Sweden was situated at about latitude 15°N.

TRIASSIC

In Triassic times a continental regime predominated in Northwest Europe. The Graben systems, initiated during the Permian, developed in connection with early rifting

movements along the Arctic–North Atlantic rift zone. The Viking-Central Graben system of the North Sea subsided rapidly as did the Danish-Polish Furrow bounded to the northeast by the ''Tornquist Line''. Progressive downwarping and widening of the northern and southern Permian-Triassic basins resulted in the gradual burial of the Mid-North Sea–Ringkøbing–Fyn High.

From the Tethys sea in the southeast the Triassic, marine transgressions entered into the North European basin. Land areas included most of Fennoscandia, Scotland, Ireland, Wales, Cornwall, and parts of Devon, the London-Brabant Massif and parts of the Mid-North Sea–Ringkøbing–Fyn High.

The Permian warm and dry climate continued through most of the Triassic, and only at the end of the Triassic it was generally moister. South Sweden was then situated at about 35°N (see also p. 96).

JURASSIC

The early Kimmerian (Rhaetian) movements that affected Northwest Europe marked the transition from the Triassic terrestrial framework to the Jurassic marine pattern. With the Liassic transgressions, marine conditions returned to large parts of Northwest Europe. Marine ingressions into the North Sea area originated chiefly from the newly established North Atlantic seaway through the northern North Sea, but also from the Tethys. Early Liassic transgressions were followed by regressions in the Middle Jurassic. A new period of transgression started in the late Middle Jurassic, which resulted in a maximum extension of the Jurassic sea.

Northwest Europe as a whole appears to have been subject to extensional stresses during the Jurassic. This led to a progressive fragmentation of Northwest Europe, a process that had been initiated already during the Permian. During the Jurassic the Viking-Central North Sea graben system and the Danish-Polish Furrow developed into the dominant fracture zones in the Alpine foreland. Marginal troughs developed to flank the London-Brabant, the Rhenish and the Bohemian massifs. Mid-Kimmerian movements also took place in the North Sea (including volcanism), the marginal troughs and the Danish-Polish Furrow. The volcanism in Skåne probably started during the transition from Early to Middle Jurassic (p. 68). Late Kimmerian (Late Jurassic–Early Cretaceous) movements in the form of fault-folds were wide-spread in the foreland plateau of Central and Western Europe (cf. p. 30 concerning Skåne). The London-Brabant, the Rhenish and the Bohemian massifs were consolidated into a continuous positive area extending from England to Poland. The Fyn–Ringkøbing platform was uplifted together with parts of northern Germany and the southern North Sea.

In the Jurassic, south Sweden was still situated at about 35° north. The Lias, like the Rhaetian, was a relatively humid interval. Jurassic sea temperatures in Europe have

been calculated to about 10°C higher than now (Lowenstein & Epstein 1954). According to Frakes (1979, p. 168) and Hallam (1975, pp. 191–196), however, this figure may be too high. The Late Jurassic produced a drier climate according to Brinkman (1969). This is also the opinion of Störr (1975, p. 38). Hallam (1975, pp. 188–191), however, questioned this statement. In any case the fossil record indicates a warm climate during the Jurassic (Hallam 1975, pp. 179–181, 188). With regard to the areas bordering the Danish Embayment, Larsen (1966, p. 110) believed that the Late Jurassic climate could be regarded as humid as indicated by the presence of considerable amounts of local plant material. However, the kaolinite content in the Upper Jurassic of the northern part of East Germany decreases, indicating a somewhat drier climate than before (cf. p. 95).

CRETACEOUS

Rifting in the Arctic North Atlantic continued during Cretaceous times. In the Early Cretaceous, subsidence resumed in the marginal troughs as well as in the Polish-Danish Furrow, leading to the deposition of thick clastic sequences in initially narrow basins. These sediment masses were largely the products of post-Kimmerian erosion, the sediments being stripped from the elevated areas (Pegrum *et al.* 1975, p. 78). During the Subhercynian tectonic phase (early Late Cretaceous), the first inversion movements occurred in the Central European marginal troughs, as well as in the Polish lowland, leading to the uplift of the axial zones of the basins and the development of secondary depocentres flanking the uplifted basin centres. Large-scale inversion involving also the southern part of the central North Sea Graben took place during the Maastrichtian to Late Paleocene (Laramide phase), resulting in the uplift of the basin fill. In the Polish-Danish Trough the inversion tectonics die out in the area of Skåne. The inversion axis in Skåne from Hallandsåsen southeastwards must be noted (Fig. 44). The Kristianstad and Båstad areas may be regarded as secondary depocentres.

With the Albian, one of the largest transgressions in earth history began and reached a first climax in the Cenomanian-Turonian, with a second in the Maastrichtian. This world-wide transgression and subsequent regression may have been caused by a contemporaneous pulse of rapid spreading at most of the mid-oceanic ridges between 110 and 85 Ma (Aptian–Coniacian). The rapid spreading caused the ridges to expand and hence reduced the volumetric capacity of the basins. The subsequent regression was caused by a reduction in spreading rates beginning at 85 Ma (Hays & Pitman 1973).

During the Mesozoic, large areas of the world, which are today above sea-level, were submerged beneath relatively shallow seas. The increase in the ratio of oceanic to continental area moderated and stabilized the climate (Hays & Pitman 1973). The climate was rather uniform over a wide latitudinal range and the tropical region extended much further north and south than it does today. During the Cretaceous,

south Sweden was situated 35°–45° north of the equator. Palaeotemperature studies on the Upper Cretaceous of Western Europe indicate a low in the Aptian, a high in the Albian, a low in the Cenomanian, followed by a gradual increase until the Coniacian-Santonian, and then a decline in the Campanian (Bowen 1961). The absolute temperature values may be incorrect (cf. p. 159) and therefore they are omitted here. The temperature changes based on isotopic studies correspond well with the results from studies of the carbonate compensation depth (CCD) in the Atlantic and the Caribbean. In part the CCD is thought to reflect surface temperatures (Frakes 1979, pp. 183–184). As a whole the Cretaceous must be recognized as a time of great warmth. Tropical to subtropical conditions extended to at least 45°N (Frakes 1979, p. 178).

Large quantities of sediment from shallow marine environments containing iron minerals indicate a well vegetated hinterland with a warm humid climate (Hallam 1975, p. 184). This is supported by evidence from the Liassic sediments in Skåne and on Bornholm (Fig. 29). Also in the Early Cretaceous (Neocomian) clay ironstone was formed on Bornholm. Ironstone is also known in the Neocomian of Lincolnshire in England (Pegrum *et al.* 1975, p. 82). Coal beds occur in the Lower Cretaceous in the Netherlands (Pegrum *et al.* 1975, p. 84). In the Saxon-Bohemian Upper Chalk basin, the kaolinitic weathering crust is overlain by Cenomanian strata (Störr *et al.* 1977, p. 9) and the sediments of the southern part of East Germany contain fairly high amounts of kaolin in the Lower Cretaceous (Störr 1975, p. 54). The Lower Cretaceous sediments of the Kome Formation (Barremian-Aptian?) of western Greenland rest on a deeply kaolin weathered gneiss surface (Pulvertaft 1979). The Gault clay (Albian) in southern England contains kaolin (p. 71). All these facts indicate warm, humid climates during the Early Cretaceous.

Lithologically, the Upper Cretaceous Chalk is an exceedingly pure carbonate rock, which is remarkably free from land derived clastic material. The general absence of muds and sands is largely due to the wide extent of the Late Cretaceous transgression which submerged the potential supply area. Where it approaches the Late Cretaceous shore line, the Chalk (including coarser limestone) is interbedded with land derived clays and sandstones. Such terrigenous sediments have been encountered in Skåne (pp. 124–126), they fringe the East Shetland Platform, and are known from outcrops in west Dorset, Bretagne, and on the fringes of the Ardennes and the Bohemian Massif. The sands do not extend far into the Chalk basin. (Pegrum *et al.* 1975, pp. 90, 92.)

Thus, like the Jurassic, the Cretaceous consists of two petrographically different facies: a lower, predominantly terrigenous and an upper, mostly calcareous facies. The differences in rock types may also have been determined climatically. Brinkmann (1969) believes that even if temperatures and aridity increased during the Cretaceous, it was not to such an extent as in the Jurassic. He arrived at the concept of a subtropical climate with marked zonal arrangement in the Late Cretaceous. Bakker & Levelt (1964) consider that a type of Mediterranean Csa climate (the Köppen system: subtropical climate with warm and dry summer; mean temperature for warmest month $> +22°C$) is most probable. They base their opinion on the illite-montmorillonite clay

association in samples from the Campanian and Maastrichtian in the Netherlands. The same clay mineral association occurs in Denmark in the Maastrichtian and the Danian (Fig. 29, cf. discussion about the significance of montmorillonite in chalk, p. 96). Whether the Late Cretaceous was an epoch with a humid climate (as suggested by Montford 1970) or with a dry climate (which Pegrum *et al.* regard as possible) is not yet settled. The ages with cooler sea temperatures (Aptian, Cenomanian, Campanian, Maastrichtian) may have produced more arid conditions on the adjacent lands as seems be the case for the Tertiary (Table 9). The results of Störr (1975) and Kužwart & Konta (1968) may support the idea of a somewhat drier Late Cretaceous interval (cf. Table 11).

TERTIARY

Active spreading in the Mid-Atlantic shifted from the Mid-Labrador Sea ridge to the Reykjanes ridge about 60 Ma ago (Paleocene), which resulted in a separation of Greenland and Scandinavia and the opening and deepening of the Norwegian and Greenland Seas. The final fragmentation of Laurasia was achieved about 50 Ma ago (Eocene) with the separation of Greenland and Svalbard (Harland 1969; Johnson & Heezen 1967; Vine & Hess 1971; Pitman & Talwani 1972; all in Berggren & Hollister 1974). Torske (1972) considered the Tertiary uplift of Fennoscandia to have bee largely a side effect of the opening of the North Atlantic Ocean and its northern continuation, the Norwegian Sea. He considered that the corresponding uplift of Scandinavia started some time during the Eocene and was either contemporaneous with or immediately preceded the final rifting of the Laurasian continent. Contemporaneous volcanism occurred in the Skagerrak, Scotland, the Färö Islands, and Greenland. Spjeldnæs (1975, p. 308) suggested that uplift of Fennoscandia started in the Oligocene and reached its maximum after the Late Miocene. This interpretation was made from the sediments which, however, at least partly may reflect the climatic changes (cf. p. 97, 164). Mörner (1980a, p. 161, and 1980b) noted a smaller uplift at the Eocene/Oligocene transition and a main uplift at the Oligocene/Miocene transition. Uplift and fracturing of the Variscan massifs led to widespread volcanism during the Miocene and Pliocene.

According to Pegrum *et al.* (1975, p. 93), the long period of Late Cretaceous deposition was brought to an end by the Laramide tectonic phase. The North Sea is regarded to have suffered a gentle regional uplift which forced the Cretaceous sea to retreat. However, in the Central Graben and its extension eastwards to northern Denmark, a restricted sea remained and there was continuous marine deposition from the Cretaceous into the Tertiary. Here the Danian Chalk was formed. In other areas erosion is said to have been widespread.

After the withdrawal of the Danian sea the whole of Central Europe was land. Next Paleocene inundation came from the north and flooded the Danish islands and the

western part of north Germany. During Eocene to Holocene times the North Sea was dominated by regional subsidence that resulted in the formation of a symmetrical, saucer-shaped intracratonic basin. There was a first maximum of flooding in the Early Eocene. A high rate of sea-floor spreading (Melhorn & Edgar 1976, from different sources) caused the volumetric capacity of the Atlantic ocean to decrease, which caused a eustatic rise of sea level comparable to the Late Cretaceous transgression (Rona 1973). The London Clay in England indicates a considerable deepening of the sea (Brinkmann 1969, p. 121) as do the Eocene sediments in Denmark (p. 94). Bonde (1973) suggested distance from the coast (p. 163) as one cause to explain these fine-grained sediments.

In this context the Eocene diatomaceans from southern Lappland and northern Småland, Sweden, are interesting. They were reported by Cleve-Euler (1941), but many geologists mistrusted the determinations because they did not believe in such an extensive Eocene marine transgression as this would imply. However, Brotzen (1960, pp. 124–125) gave credit to the finds and interpretations. Recently marine Early Tertiary deposits have been found in northern Finland (Hirvas & Tynni 1976). Redeposited Palaeogene diatomaceans also occur on the Kola Peninsula in the Soviet Union (Kiselev 1979). Thus there is no longer particular reasons to mistrust Cleve-Euler's interpretation.

After a regression, the Oligocene sea flooded Jylland (Denmark) and was connected with the Tethys in the southeast through northern Germany and Eastern Europe. The later Tertiary seas were confined to the North Sea Basin and immediately adjacent areas. In East Germany and Poland a basin existed in the Miocene and Pliocene in which non-marine sediments were deposited. In contrast to Mesozoic sediments, Tertiary sediments in Central Europe are mostly unconsolidated and predominantly clastic.

Palaeotemperatures calculated from the oxygen isotope composition of shells from benthic organisms from the North Sea Tertiary have given the following results for sea temperatures (Table 9): After lower temperatures in the Early Paleocene (minimum of 12°C on the mean temperature curve), temperatures became high and remained relatively constant through the Paleocene and Eocene (max. 27°C). A sharp drop in temperature in the Early Oligocene (min. 7°C) was followed by a gradual increase which culminated in the Middle Miocene (max. 17°C). The Late Miocene was a cool interval (min. 9°C), while somewhat warmer conditions prevailed in the middle Pliocene (max. 13°C). At the end of the Pliocene the temperature dropped again (Buchardt 1978).

According to Berggren & Hollister (1974, p. 160) the Eocene marine tropical zone extended to about 60°N (recent latitude) on the west coast of Europe. ''The relatively warm climate of Europe during the Palaeogene was due to the continued, if somewhat reduced presence of the extensive Tethys Sea which connected with the Pacific Ocean in the west. The gradual restriction of this seaway in the Miocene concomitant with the rise of the Alpine mountain chain and the general cooling of the earth resulted in a

distinct climatic zonation in Europe as well as in the marine environment'' (Berggren & Hollister 1974, p. 161).

The Tertiary palaeotemperatures for the North Sea area given by Buchardt show a rapid decline in the Early Oligocene. Buchardt (1978, p. 122) thinks that this decline could reflect the onset of cold-water circulation in the Norwegian-Greenlandic Sea initiated by the formation of a strait between Greenland and Svalbard at 37–38 Ma ago. However, as he also states, there is convincing evidence from other parts of the world to indicate a drastic global cooling event at the beginning of the Oligocene, probably triggered by the development of the cryosphere in Antarctia. In accordance with these results the frequency of palaeotropical elements in European fossil floras is shown to be very low in the Oligocene (Mai 1965).

It is more difficult to ascertain conditions of precipitation than temperature conditions during the Tertiary, although some data are available, as follows (see also pp. 96–97): The high smectite (montmorillonite) content in the Paleocene sediments (Fig. 29 and below) may be explained partly by production in a dry climate (cf. pp. 76–77).

Palaeobotanical evidence indicates a warm, humid climate during the Early and Middle Eocene (Frakes & Kemp 1973). A kaolinitic weathering crust on the Iceland-Färö Ridge is overlain by Middle Eocene sediments (Nilsen & Kerr 1978), and the same relationships are known from East Germany (Störr 1975).

Peculiar faunal and sedimentological characteristics in the Early Eocene of Denmark indicate cold water (Spjeldnæs 1975, p. 298). For the Early Eocene, Bonde (1973) presents a model embracing palaeogeography, oceanography, climate and marine life. The North Sea was a bay with a connection to the Atlantic between Norway and Great Britain. An active volcanic area lay south of Norway. Northerly winds dominated. Cold water upwelled along the coast of Norway and in northwestern Denmark close to the Fennoscandian coast. The climate seems to have been subtropical. The upwelling cold water may have produced arid conditions on the adjacent land, which together with low relief and distance to the coast may explain the very fine-grained sediments.

Schwarzbach (1961, 1974) concluded that there were two intervals of high humidity during the Tertiary in Europe, namely Middle Eocene and Early Miocene. He further concluded that the Late Eocene to Early Oligocene was generally arid and that the Late Miocene was markedly so. The middle Oligocene transgression in East Germany only exceptionally covered kaolinitic weathering crusts (Störr 1975, pp. 71–72). The Upper Oligocene and Lower to Middle Miocene on the contrary cover thick weathering crusts. The volcanic rocks of Late Oligocene to Early Miocene age in the Berzdorf Basin are also deeply kaolinized and overlain by Lower Miocene sediments (Störr 1975, p. 73).

The Paleocene in a North Sea boring (Karlsson *et al.* 1979) contains very high amounts of smectite (montmorillonite). In the Eocene the smectite content decreases somewhat, but remains rather high until the Upper Miocene where it decreases drastically. Throughout the core there is a small amount of kaolinite with somewhat higher amounts in the upper Lower Eocene and Middle Miocene sediments. The illite

TABLE 9. Precipitation conditions in Europe during the Tertiary Period as abstracted from different sources (see the text) and correlated with sea temperatures. GDR means East Germany.

Paleocene		Eocene			Oligocene		Miocene			Pliocene			
Early	Late	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late		
Cool min. 12°C	Very warm, max. 27°C				Cool min. 7°C	Fairly warm		Warm max. 17°C	Cool min. 9°C	Cool	Less cool, max. 13° C	Cool min. 7°C	North Sea temperatures, Buchardt 1978
		Humid, altern. wet and dry seasons; tropical			Semi-arid	Humid, altern. wet and dry seasons; subtropical							Climate in Europe, Jessen 1938
			Max. coal form.	Salt dep.				Max. coal form.		Salt dep.			Climate-controlled sed., Brinkmann 1969
			Humid	Arid				Humid		Arid			Precip. climate in Europe, Schwarzbach 1974
		? Kaolinitic weathering ?				? Kaolinitic weathering ?				? ? Lateritization			Weathering in GDR, background inform. in Störr 1975
Very high smectite content		Kaolinite increase	High smectite content					Kaolinite increase		Kaolinite and smectite decrease; illite increase; chlorite			North Sea clay minerals, Karlsson et al. 1979
Low		Fairly high		Low			Fairly high	Very high		High	Very High		Sedim. accum. rate in the Atlantic, Davies et al. 1977
Arid (?)		Humid			Arid		Humid			Arid	Humid		Central Europe
Arid (?)		?	Humid		Arid		Humid			Arid	Humid		Northern Europe

Conclusions for precipitation climate, this paper

content is fairly low at the bottom of the profile, but increases sharply in the Upper Miocene where chlorite also begins to occur. Karlsson *et al.* (1979) interpreted the high amounts of smectite in the Lower Tertiary strata as a result of transformation of volcanic glass. They interpreted the changes of clay mineralogy in the Upper Miocene as a response to a colder climate and to higher rates of erosion.

Davies *et al.* (1977, p. 53) stated that estimations of average Cenozoic sedimentation rates for the Atlantic, Indian and Pacific oceans indicate global synchronous fluctuations. The same general trends for total sedimentation and carbonate sedimentation was thought to imply gross fluctuations of the river input. As their curves diverge from what they expected with respect to continental area exposed and the average elevation of the continents, and as these curves have the same trends for all three oceans, their explanation of the fluctuations was climatic. They stated that Paleocene to Early Eocene and Late Eocene to Early Miocene sedimentation rates were only a fraction of Middle Eocene and Middle Miocene to Recent rates. This was thought to reflect significantly different modes of continental weathering, possibly due to changes in global precipitation. They compared the denudation of large parts of the continents during the Oligocene and Paleocene with the denudation of present-day Australia (Davies *et al.* 1977, p. 54). As the high peaks of sedimentation mainly coincide with other indices of humidity (Table 9) their interpretation of arid conditions during the Oligocene and Paleocene is followed in the conclusions concerning the European precipitation climate. However, the idea of stripping as a consequence of climatic change should favour an interpretation of the high sedimentation rates as due to the onset of arid conditions following a period of deep weathering. This would alter

the conclusions in the following section and in Table 9 in such a way that a period with climatic change should be introduced between the humid periods of the Early Eocene and Early Miocene and the following arid periods.

Table 9 summarizes the data on conditions of precipitation discussed above. From these data the following conclusions can be drawn. The Paleocene was possibly arid (cf. p. 96), while the Eocene, especially the Early and Middle Eocene, was humid in Central Europe. Close to the Fennoscandian coast the Early Eocene climate can have been arid (cf. Bonde 1973, p. 142). The humidity decreased during the Late Eocene, and the Early Oligocene was arid. Humidity returned during the Late Oligocene, and prevailed throughout the Early and Middle Miocene. The Late Miocene was characterized by arid conditions, whereas the Pliocene was again humid. During the Tertiary until some time in the Pliocene the climate was characterized by alternating annual wet and dry seasons (Jessen 1938; Brinkmann 1969, p. 128). Thus, during the more arid intervals the dry seasons lasted longer, and vice-versa.

SUMMARY OF TERTIARY CLIMATIC AND PALAEOGEOGRAPHIC CONDITIONS IN SOUTHERN FENNOSCANDIA

Following the Danian regression the later Paleocene and Eocene seas transgressed to a point where the coastlines were situated approximately along the present coastline of west Sweden (Spjeldnæs 1975). The Early Eocene transgression, however, may have reached much further (p. 162). The climate during the Early Tertiary was subtropical with probably arid conditions in the Paleocene and possibly Early Eocene, becoming more humid in the Middle and Late Eocene (cf. p. 97). The sea then regressed. Uplift of Fennoscandia may have occurred in connection with the final rifting of the Atlantic during the Eocene and/or at the Eocene/Oligocene transition.

The Early Oligocene was a cool, arid interval. The Oligocene transgression probably did not reach so far towards the Swedish coast as the earlier transgressions. Uplift of Fennoscandia is indicated at the Oligocene/Miocene transition.

In Late Miocene times the climatic conditions seem to have changed drastically. The temperature dropped and the weathering conditions changed as indicated by the clay minerals from the North Sea.

CONCLUSIONS WITH REGARD TO EUROPEAN WEATHERING CRUSTS

From the above review and in accord with conditions in the Soviet Union (Kiselev 1979), European weathering crusts (pp. 67–74) may be classified into two groups, namely an older one consisting of clays and a younger one comprising ''growan'' (p. 71) and equivalent sandy saprolites. The older one formed during the Mesozoic and Early Tertiary into the Middle Miocene. The younger one was formed from the Late Miocene onwards. The weathering at Boarpa backe (pp. 57–66) belongs to this latter interval.

EROSION SURFACES: AGE AND MODE OF FORMATION

The literature on planation surfaces is rather confusing. One reason may be that two different phenomena must be explained, namely the existence of plain surfaces, and the distribution of erosion surfaces in stepped sequences.

In the early studies only a few surfaces were identified, while in most cases later investigations based on improved maps result in the recognition of many (cf. Rudberg 1954, p. 87 referring to Macar 1949). The concept of the cycle of erosion introduced by Davis (1899) gave better support to the early opinions. Twidale (1976a, p. 82) stated the following with regard to Davis' theory: ''Theoretically peneplanation and the lowering of interfluves it implies are inimical to the development of multicycle landscapes and to the survival of paleoforms.'' Yet the model has been in general use for half a century to explain concordant summit levels as remnants of earlier erosion cycles.

Penck (1924) stressed that it is important to study the interaction between endogenic and exogenic forces when analyzing the landscape. For the observed phenomenon that erosion surfaces are arranged in a stepped fashion he created the term ''Piedmont-treppe'', and argued that it could be explained by a continuous rise of the landmass.

Hack (1960) argued that the concept of dynamic equilibrium provides a more reasonable basis for the interpretation of topographical forms in an erosionally graded landscape. Schumm & Lichty (1965, p. 262) stated that ''depending on the temporal and spatial dimensions of the system under consideration, landforms can be considered as either a stage in a cycle of erosion or as a system in dynamic equilibrium''. They said that ''although landforms are physical systems and can be studied for the information they afford during the present moment of geologic time, they are also analogous to organisms because they are systems influenced by history''. According to Howard (1965, p. 302), ''landform features may be considered as open systems of complex behaviour. Equilibria in geomorphology may arise in several types of system-environment relationships, and all adjustments of landforms to changes in the environment may be regarded as tending toward an equilibrium state. The influence of a past process having acted upon a geomorphic system is proportional to the intensity and duration of its action but inversely proportional to the elapsed time since its action. That is to say, the amount of information within landforms about their historical changes decreases the more remote the past''. Brown (1979) used this retrospective approach for the analysis of landforms in Britain.

However, Davis' cycle of erosion is thought to work on the whole surface in question, and the theory of dynamic equilibrium ''implies continuous and equal erosion of the entire land surface, once the system is in adjustment. This is contrary to the field evidence of the widespread survival of old land surfaces. Even if it were argued that such survivals denote temporary maladjustments of the system, it is reasonable to ask how long, in view of the great age of some of the palaeoforms, can maladjustment prevail before it is considered the norm?'' (Twidale 1976a, p. 82).

These views are particularly relevant to the discussion.

There are three main concepts in Davis' theory, the concept of cycles, the concept of peneplains, and the concept of reduction of slopes. The above discussion covers the concept of cycles. Criticism against Davis' concept of peneplains has sometimes gone so far that peneplains have been regarded as ''lines in the sky''. This kind of criticism may be a result of the search for peneplains in the wrong places. In fact almost plain surfaces do exist. For example, in south Sweden the south Småland peneplain is an extremely flat bedrock surface. I have used and will use the term peneplain only in the sense of an almost level erosional plain irrespective of the mode of formation. I follow here the opinion of Fairbridge & Finkl (1980, pp. 77–78), that it would be desirable to return to Davis' original definition of the peneplain as ''an almost featureless plain showing little sympathy to structure, and controlled by a close approach to base level'' (Davis 1889, p. 340). However, base level does not always have to be the sea level. The term peneplain is a good one which should not be abandoned. It is useful to be able to describe existing forms without regard to their exact mode of formation. The major question is how these surfaces evolve (cf. Ahlmann 1939, p. 64). This question actualizes two problems: How are the surfaces related to different base levels, and how do slopes and surfaces evolve? These questions are as yet unanswered.

ATTEMPTS AT A WORLD WIDE RECOGNITION OF SYNCHRONOUS SURFACES

The recognition that many erosion surfaces in the world are arranged in a step-wise pattern led to several commissions of the International Geographical Union being established to study the subject. In 1925 the ''Commission pour l'étude des terrasses pliocène et pléistocène'' was created, in 1931 the ''Commission pour la cartographie des surfaces d'aplanissement tertiaires'', and in 1952 the ''Commission pour l'étude des corrélations des niveaux d'érosion et des surfaces d'aplanissement autour de l'Atlantique'' (Lefèvre 1960). An attempt to correlate the surfaces in England with those of the eastern United States was made by Brown (1961).

Chorley (1963) gave an excellent review of the eustatic theory and the difficulties the increasing awareness of continental instability has given to it. In an article entitled ''Geophysical speculations on the origin of stepped erosion surfaces'' Geyl (1960), inspired by Baulig (1935) and Du Toit (1937), put forward a hypothesis that stepped erosion surfaces are ultimately caused by continental ''shift'' (see Geyl 1960) induced by deep convection currents. The speculations in the article on geophysical mechanisms are now outdated. However, the main idea that stepped erosion surfaces correlate with world wide rises and falls of sea level, now regarded as resulting from differences in sea floor spreading rates (Rona 1973), is similar to the ideas put forward by Melhorn & Edgar (1976, see p. 168).

Already in 1948 Wegmann suggested a comparison between surfaces in Scandi-

navia, Greenland and the Arctic islands as a means of checking the hypothesis of continental drift. King (1951) related historical geomorphology to structural and tectonic evolution and the drifting of continents. He established a world-wide system for erosion surfaces (1962, 1976). The surfaces in Africa, which he thinks may well serve as a standard for the whole globe, were dated in part with the aid of overlying sediments and correlative sediments in the marine sequences (Table 10).

In the Soviet Union a map of erosion surfaces has been constructed at a scale of 1:2 500 000 (Gerasimov & Sidorenko 1971). The authors distinguished between exhumed surfaces and others which in turn are divided into ancient denudational surfaces, denudational–depositional surfaces evolved mainly during the Cenozoic, and Pleistocene depositional surfaces. The exhumed surfaces are dated to the following time intervals: Precambrian–Cambrian, Late Triassic–Early Jurassic, Late Jurassic–Cretaceous, Cretaceous–Palaeogene (particularly Late Cretaceous–middle Palaeogene), Palaeogene, Miocene.

With a growing knowledge of contemporaneous world-wide continental drift events and of eustatic and climatic changes, it seems increasingly probable that erosion surfaces in different parts of the world are correlative. A great problem is that there is little agreement both as to the extent of different surfaces and especially their age.

Melhorn & Edgar (1976) pointed to six unconformities in the geological record in North America which coincide with periods of world-wide marine regression. Unconformities in the sediments of the Atlantic coastal plain were correlated with curves for relative sea-floor spreading, transgressions and regressions, and relative rate of sediment accumulation. They suggested that ''during and following times of cratonal uplift and marine regressions, continental freeboard and overall elevation of the continent above near sea level is increased. Therefore, these should be optimum times for extensive landsurface erosion with climatic variation either tempering or enhancing this condition. During times of transgression and cratonal subsidence, net erosion rates should be reduced as effective base level rises and the geomorphic regime moves towards a depositional stage. Although this could have the same effect of landscape planation, producing a landscape of very low relief, the landsurface would result predominantly from the shift to depositional conditions. Production of a degradational or denudational landsurface would be retarded'' (Melhorn & Edgar 1976, p. 264).

The different erosion surfaces of the Appalachians in the eastern United States were referred by Melhorn & Edgar to the regressive periods. During the Mesozoic and Cenozoic, four periods were discerned with optimum conditions for the production of major, continental-scale erosion surfaces (Table 10). The Appalachian surfaces were correlated with those in Africa. The Miocene-Pleistocene interval is the most difficult to interpret and Melhorn & Edgar made no correlation with Africa for this interval.

The most serious attempts to explain the step-wise occurrence of erosion surfaces are those by Penck (1924), Baulig (1935), Geyl (1960), and King (1962). Melhorn & Edgar (1976a, p. 27) stated that their reasoning required the assumption of uplift followed by extended tectonic stability as erosion progresses.

TABLE 10. Continental-scale erosion surfaces accordning to Melhorn & Edgar (1976), with additional information from King (1976).

Time intervals	Eastern United States	South Africa (dating by King)
Late Jurassic-Early Cretaceous 135 - 110 Ma	Fall Zone surface	Gondwana planation (Jurassic)
Very Late Cretaceous through Paleocene 85 - 50 Ma	Schooley surface	Post-Gondwana planation (Early - Mid Cretaceous)
Latest Eocene through Oligocene from about 45 Ma	Harrisburg surface	African planation (Late Cret. - Mid Cen.)
		Rolling landsurface (Miocene)
Late Miocene - Early Pleistocene 12 - 2 Ma	Sommerville - Parker straths	Widespread landscape (Pliocene)
		Youngest cycle (Quaternary)

That higher erosion surfaces continue to develop with themselves as base levels is a common view. The consequence that a surface may be young even if the level (originally controlled by sea level) is old, was stressed by Geyl (1960). However, the old erosion surfaces in Australia show that it is even possible for surfaces (not only levels) to remain for a long time in suitable positions and climates (Twidale 1976a, 82–89).

MODE OF FORMATION

Climatic geomorphology has contributed greatly to the understanding of the formation of plain erosion surfaces. Already Davis (1927 in King & Schumm 1980, pp. 34–49) realized that erosion in arid climates differed from that in humid climates. King (1962, pp. 135–165) developed the pediplanation theory inspired by the study of processes in semiarid–arid climates, involving pediment formation and slope retreat with constant declivity. King also widened this concept to be valid in all climates. The pediplanation theory includes the maintenance of the higher surface and thus may explain the so-called polycyclic landscapes, which Davis' theory failed to explain (cf. the statement by Twidale p. 166, this paper). King's theory seems to have been influenced mainly by the views of Penck (*e.g.* 1924) and Baulig (*e.g.* 1935).

Wayland (1933), Büdel (1957), Ollier (1960), and Thomas (1966, 1974) stressed the significance of deep weathering in the humid tropics, and all contributed to the concept of an etchplain (see pp. 74–75 and below).

The present day climatomorphic zones, as distinguished by Büdel (1977), display a good model for understanding the pattern of forms and processes. Even if the model is not completely correct and is oversimplified, it introduces new ideas. One of Büdel's ideas is that deeply incised valleys may represent not only a response to base level change but also to the drastic climatic change, when an area is transferred into the subpolar and taiga zones of valley formation. However, Rudberg (1972, p. 228) stressed the importance of the type of bedrock in valley formation. Büdel (1963, 1977, 1980) has explained the morphology of Central Europe by claiming that the high peneplain surfaces were formed during the Late Cretaceous–middle Pliocene in a tropical climate oscillating between permanently and seasonally humid conditions. He interpreted the deep valleys as having been cut during the Pleistocene periglacial phases (cf. also Kaitanen 1969, pp. 29–40). With regard to Northwest and Central Europe, Büdel considers that Holocene processes are minor with only weak valley incision.

There is evidence of older tropical climates in the temperate zone. The world

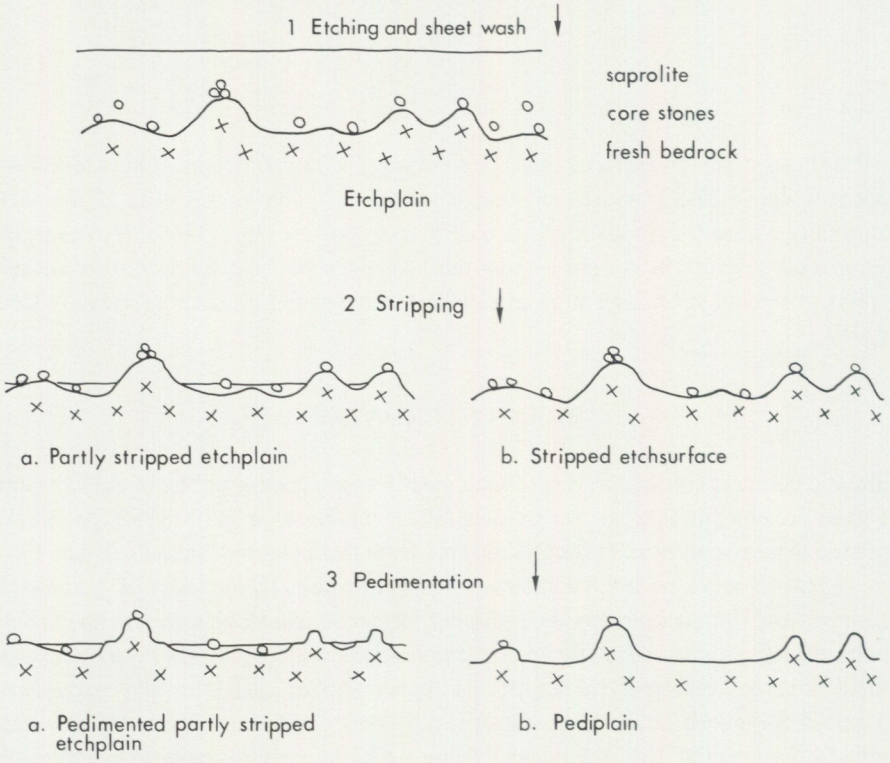


Fig. 46. Mode of origin of erosion surfaces in the tropics. A generalized sketch.

climate during the Late Cenozoic is considered to have been comparatively abnormal (Donn & Shaw 1977; Frakes 1979, p. 261). As could be seen from the account above of continental drift and climate Northwest and Central Europe were situated in tropical and subtropical zones continuously from the Devonian to the Middle or Late Tertiary. Thus, it is important for the interpretation of the evolution of erosion surfaces in Northwest and Central Europe to understand conditions in the present tropical and subtropical zones.

The most useful classification of tropical planation surfaces that I have found is that by Thomas (see pp. 74–75). I have partly used his scheme, but with more stress on the modelling processes in order to sketch a mode of formation for erosion surfaces (Fig. 46). Three main processes are distinguished. 1. *Etching* (differential groundwater weathering; Thomas 1968, p. 332) occurs during warm and humid time intervals. In semihumid to semiarid climates a plain surface (etchplain) is produced on top of the saprolite by sheet wash (Büdel 1957). Ollier (1969, p. 212) criticized Thomas for his use of the term etchplain as applied to subaerial surfaces cut mainly in saprolite. Ollier prefers to restrict the term etchplain to the stripped hardrock surface below the saprolite. However, I believe that Thomas' use of the term is acceptable because the etched surface below the saprolite need not be a plain, while the subaerial surface on top of the saprolite is. 2. *Stripping* of weathered saprolite occurs in connection with tectonic upheaval/lowering of base levels or climatic change (Thomas 1974, p. 237). The result is a stripped etchsurface. 3. *Pedimentation*. In an appropriate climate, the stripped uneven etchsurface, or the partially stripped etchplain, may be pedimented and converted to a pediplain. Pedimented surfaces evolve in arid and semiarid zones (Büdel 1970, pp. 11–16, 29–44; Young 1972, pp. 204–213, 230–233). Mensching (1970, p.21) described this process: ''Hangabtragung, Fussflächenbildung und flächenhafter Sedimenttransport bilden den nach physikalischen Gesetzen ablaufenden morphodynamischen Komplex der Flächenbildung unter ariden und semiariden Klimabedingungen''.

The optimum conditions for plain bedrock surfaces to evolve seem to be a succession of events in tropical to subtropical climates involving a humid period with etching followed by a period with stripping caused by a lower base level and/or a climatic change and then an arid period with pedimentation. Much the same opinion is expessed by Fairbridge & Finkl (1980, pp. 71–73). The process change with time in any area. An etchplain may be stripped, pedimented and converted to a pediplain, or a pediplain may be etched and converted to an etchplain. As time goes by the surfaces are successively lowered.

A fourth process that can have played a role is *duricrusting,* which according to Brückner (1976) and Finkel (1979) is thought to be a response to intensified aridification (desiccation). In many cases in Australia duricrusts have helped to preserve old erosion surfaces (Twidale 1976a, 1976b, p. 504). The sarsens of southern England (Dury 1971; Summerfield 1979) seem to be relicts of an old duricrust. Silcretes also cap the kaolin deposits in western and northwestern Bohemia (Kral 1976).

Ma			Tectonic events	Sea movements	Climate	Kaolinization 1 2 3 4 5	Erosional events. Europe North	Erosional events. Europe Central
2	TERTIARY	Pliocene		Regression	Drop in temp.		INCISION	
7			Volcanism. Uplifting and tilting of Variscan massifs	Transgress.	Warmer, humid		STRIPPING ETCHING	
		Miocene			Cool, arid		PEDIMENTATION	
26			Uplift of Fennoscandia	Regression	Drop in temp. Warm, humid	maximum	ETCH. STRIP.	ETCH-ING
		Oligocene	Alpine folding	Transgress.	Cool, arid		STR. PED.	STRIP. PED.
38			Subsidence of the North Sea		Sharp drop in temp.			
			Final rifting of Laurasia				ETCH-ING	STRIP. PED.
		Eocene	Uplift of Fennoscandia. Volcanism	Regression	Very warm Humid			
54				Climax	Dry close to Fennosc. coast		ETCH-ING	ETCH-ING
		Pale. Danian		Transgress.	Very warm			
			Laramide deformation phase: inversion axes arose in the southern North sea and Skåne. The Variscan massifs were tilted and uplifted	Regression Danian Sea	Cool Arid?		STRIP. PEDIM. (?)	STRIP. PED. (?)
65	CRETACEOUS	Late C. Maastricht.		Regression			ETCHING, STRIPPING	ETCHING, STRIPPING
		Campanian		Climax	Cool			
		Santonian		Transgress.	Drier			
		Coniacian	Subhercynian deformation phase: inversion movements in Poland and central European marginal troughs	Regression	Warm			
		Turonian		Climax	Tropical to subtropical			
		Cenomanian	Rapid spreading in mid-oceanic ridges		Cool			
100		Early C. Albian		Transgress.	Warm			
		Aptian	Austrian deformation phase					
		Barremian	Subsidence of the troughs	Sea restricted to North Sea basin	Humid			
		Neocomian	Rifting in the Arctic North Atlantic	and troughs	Warm			
136	JURASSIC	Late	Late Kimmerian movements	Transgress.	Drier. Humid close to Danish Embayment?		ETCHING	STRIPPING PEDIMENT.
		Middle	Development of marginal troughs with a Hercynian (NW-SE) strike	Regression				
			Volcanism in the North Sea and Skåne. Establishment of the North	Transgress.				
		Early (Lias)	Sea Central graben systems and the Danish Polish furrow	Opening of Arctic North	Warm, humid			ETCH.
195	TRIASSIC	Late Rhaetian	Early Kimmerian movements	Atlantic	More humid		STRIPPING, PEDIMENTATION	STRIPPING, PEDIMENTATION
		Middle	Danish-Polish furrow subsided	Transgress.				
		Early	Development of grabens in the North Sea area	Regression	Warm, arid			
225	PERMIAN	Late	Tornquist line became a major lineament	Transgress.				
			Emplacement of North Atlantic rift system		Warm, arid			
		Early	Volcanism. Oslo graben formed					
280			Intracratonic basins formed	Regression				
	CARBONIF.	Late	Hercynian continent formed		Warm, humid	m m lm	ETCHING	ETCHING
		Early	Variscan folding (Compressive period)		Increasing plant cover			
345	DEVONIAN	Late	Fennoscandia originated	Variscan geosyncline	Warm		STRIPPING	STRIPPING
		Middle	Old Red continent formed		Vegetation			
		Early	Caledonian folding		sparse			
400								

In glaciated countries the last stripping agent was the ice, which was also able to strip below earlier base levels and thus depressions (now filled with lakes) were formed. It is worth noting that the significance of deep weathering was discussed already by Nathorst (1879), who gave an explanation that seems quite modern today for the lakes and small bedrock knolls that are so common in Sweden: ''. . . thus both the abundance of lakes as the relict forms of the surface in a large part of our country depends firstly on weathering through several geological periods, and secondly on the carrying away of the weathering remnants by erosion of water and ice. The influence of the ice on the solid bedrock, where it consists of basement rocks, however, for the most part ought to be comparatively insignificant, consisting only of rounding off, polishing and scratching of the surface'' (Nathorst 1879, p. 289, my translation).

EROSIONAL HISTORY OF NORTH AND CENTRAL EUROPE

By integrating the data for the formation and deposition of kaolin with tectonic events, sea movements, and climate (pp. 156–165) it is possible to propose a scheme for erosional events in North and Central Europe (Table 11). Information on kaolin and quartz sand in sediments from Sweden and Denmark was summarized in Fig. 29. Additional information from the Kristianstad area is taken from Kornfält *et al.* (1978). The information on kaolin in sediments in the northern and southern parts of East Germany comes from Störr (1975; cf. p. 95). Störr's diagram shows kaolinite in the sediments throughout the whole Tertiary. However, it has to be noted that the diagram is divided only into the Palaeogene and Neogene. As Paleocene sediments are mostly absent and since the middle Oligocene transgression only exceptionally covered kaolinitic weathering crusts (p. 163), my interpretation of the weathering conditions does not wholly follow that of Störr. The last column in Table 11 depicts the occurrence frequency of kaolins and laterites with bauxites of various geological ages in Europe (Kužvart & Konta 1968). This curve is not reliable in detail as the dating of many deposits is uncertain. For example, Kužvart & Konta (1968) assigned the kaolin deposits on Bornholm to the Carboniferous. A Rhaetian–Jurassic age seems more probable and in agreement with conditions in nearby Skåne (Fig. 29; cf. p. 95). Furthermore, these authors removed the Ural kaolins from the Jurassic as this age did not fit into their scheme.

TABLE 11. Summary of tectonic, regressive-transgressive, climatic, weathering, and erosional events in Northern and Central Europe. The information of tectonic events, sea movements and climate is extracted from the literature, mainly Brinkmann (1969) and Ziegler (1975). Kaolinization: 1. Kaolinite in sediments in Sweden and Denmark (from Fig. 29 and Kornfält *et al.* 1978). 2. Quartz sand in sediments in Sweden and Denmark (from Fig. 29 and Kornfält *et al.* 1978). 3. Kaolin in sediments in the northern part of East Germany (from Störr 1975.) 4. Kaolin in sediments in the southern part of East Germany (from Störr 1975). 5. Occurrence frequency of kaolin and laterite with bauxite in Europe (from Kužvart & Konta 1968). m = maximum, lm = lower maximum, l = lower part of general maximum. The column for erosional events summarizes the conclusions reached in this paper regarding the types of landscape forming processes.

The erosional events suggested in Table 11 (p. 172) are separated into two columns, one for Central and one for North Europe. Most of the used information concerns Central Europe. Thus the two columns do not differ greatly. However, more and more information about the Norwegian sea is produced and greater differences may be revealed. No serious attempt has been made to extract information from Greenland and Spitsbergen. For a thorough interpretation of the conditions in northern Scandinavia more information from the Arctic is desirable.

In the Devonian the climate was warm and the vegetation sparse. Therefore, if deep weathering occurred, the material could be stripped rather effectively. In the Carboniferous warm, humid conditions prevailed in Europe and the bedrock was deeply weathered. The Permian and Triassic were dry periods. In Germany the Zechstein sea transgressed over a plain surface, ''der Permische Rumpf'' (Gellert 1958). Trümpy (1971, p. 302) stated that Western Europe had an extremely low relief during the Triassic. It seems reasonable to regard stripping and pedimentation as responsible for the flat surfaces.

Humid conditions returned to Europe in the late Rhaetian and kaolin was deposited in the sediments in northern Germany, Denmark and south Sweden. Deep weathering (etching) must have been the dominant process in neighbouring areas. In the Middle and Late Jurassic drier conditions prevailed at least in Central Europe. Stripping and pedimentation may have been the dominant processes there, while deep weathering conditions possibly continued further north. The Late Kimmerian movements (Late Jurassic) elevated large parts of North and Central Europe and in the Early Cretaceous the sea was restricted to the north Sea Basin, the Danish-Polish Furrow and to marginal troughs. The Early Cretaceous should have been a period of stripping but also of deep weathering as seen in columns 4 and 5 (Table 11). The Late Cretaceous was probably a somewhat drier period. The kaolin and quartz sand in the Kristianstad area (east Skåne) probably originated from the stripping of the surface over Småland. A similar relationship in sediments of similar age has been noticed close to other land areas (p. 160).

The drier conditions in the Late Cretaceous were probably accentuated in the Paleocene. At this time the sea had regressed. Accordingly, the dominant processes should have been stripping and pedimentation. The Early Eocene (perhaps it was dry close to the Fennoscandian coast, see p. 163) and the Middle Eocene were hot and humid. Etching seems to have been the dominant process with a maximum formation of kaolin crusts in Europe. The Late Eocene (Central Europe) and Early Oligocene had an arid and cool (Early Oligocene) climate, which continued into the Late Oligocene. The arid interval started in southern regions and moved northwards. Stripping and pedimentation should have prevailed. The latest Oligocene, Early and Middle Miocene had a warm, humid climate, presumably with etching. Redeposited kaolin occurs in sediments of this age in the East Germany (Störr 1975, p. 72). Uplift of Fennoscandia at the Oligocene/Miocene transition probably caused stripping of the regolith. The Late Miocene was a cool, arid interval. Pedimentation should have been the dominant

process. The humid and temporarily somewhat warmer climate in the Pliocene may have caused some etching. Stripping of the regolith probably occurred in connection with lower sea levels and a changing climate. The temperature fall can be suggested as a cause of river incision (in accord with the ideas of Büdel and Kaitanen, see p. 170). The process of incision may have advanced southwards from the north and may have produced different results in areas with different bedrock (cf. Rudberg p. 170, this paper).

OPTIMUM TIME INTERVALS FOR EROSION SURFACES TO EVOLVE

If the theory of Melhorn & Edgar (1976; this paper p. 168) is accepted (that periods with low sea levels are optimum times for erosion surfaces to evolve) and is combined with the optimum conditions for plain erosion surfaces to evolve (p. 171), three optimum time intervals for North and Central Europe can be calculated from the preceding account of erosional history. These optimum intervals are the Permian–Triassic (with two regressive minima), the Paleocene(?), and the Eocene–Oligocene. The produced surfaces were pediplains.

The Middle Jurassic, Early Cretaceous, and Coniacian were three further periods of marine regression over North and Central Europe. The climate during these periods was warm and humid, and part of the exhumed surfaces in south Sweden from these time intervals are dominantly stripped etchsurfaces.

Table 10 indicates that in the Early Cretaceous, the Paleocene and the Eocene–Oligocene erosion surfaces were produced all over the world. The Permian–Triassic, the Middle Jurassic and the Coniacian produced erosion surfaces in North and Central Europe (cf. pp. 149–155, 157, 174). Local epeirogenic movements in Fennoscandia caused further steps in the erosional succession. The supposed main uplift at the Oligocene/Miocene transition (p. 161) was followed by climates causing firstly etching and then pedimentation. Still lower sea levels occurred in the Pliocene causing erosion surfaces that are now situated below present sea level. In summary, the following periods may have produced erosion surfaces in Fennoscandia: Early Permian, Early Triassic, Middle Jurassic, Early Cretaceous, Coniacian, Paleocene, Eocene–Oligocene, Miocene, and Pliocene.

Duricrusts also seem to have existed in Europe (p. 171). Optimum conditions for duricrusting with a change from humid to arid conditions may have existed in the Oligocene and Late Miocene.

TENTATIVE DATING OF EROSION SURFACES/LEVELS IN SWEDEN

There are two divergent opinions as to the age of most erosion surfaces in the world. The first and most widely accepted is that many surfaces are old (King 1962, 1976;

Melhorn & Edgar 1976; authors in Soviet see p. 168, Germany see p. 151, Poland see p. 150, most authors regarding the ''paleic'' surface in Norway see p. 148). According to the second view few surfaces are older than the Neogene (for new ideas in Great Britain see p. 151, Strøm 1948 for Norway; Tanner 1938 for north Finland). When trying to date the erosion surfaces in south Sweden, the exhumed surfaces do not present any great problems as they have remains of datable sediments, but the other surfaces are problematical.

Data obtained and reviewed in this study have made possible an attempt to date the Swedish stepped (subaerially preserved) erosion surfaces as follows (Table 8). Firstly, I conclude that the south Småland surface is a Tertiary surface (p. 136). Secondly, surface 2 (Figs. 40, 41) and generation 5 (north Sweden) can be interpreted tentatively as Paleocene in origin (pp. 144–145). With this dating in mind the alleged optimum time intervals for erosion surfaces to evolve (p. 175) indicate that the successive south Småland surfaces (3 and 4) may have developed in the Middle Eocene–Oligocene interval. This interval had optimum conditions for producing plain bedrock surfaces, with a period of etching followed by stripping and pedimentation. Possible minor uplift at the Eocene/Oligocene transition (p. 161) may have caused the step between the two surfaces. Generation 6 and surface 1 would then fall into the Coniacian interval. A correlation with the earlier periods regarded as suitable for developing erosion surfaces is made tentatively for the higher surfaces in north Sweden. Only the more peneplain-like higher surfaces of Rudberg, viz. generations 7, 10, and 12, are correlated with the alleged main erosional periods.

The exhumation of the areas below the 100 m level is assumed to have occurred as a response to the main uplift at the Oligocene/Miocene transition. The weathered flints in the study area as well as the gravelly weathering at Boarpa backe (pp. 69, 165) seem to be traces of Miocene/Pliocene weathering. The indications for level T_2 (5) might imply that a surface was initiated in the Miocene at about 0–40 m (p. 144). Surface T_1 (6) might correspond to a still lower level in the Pliocene. The Neogene fluviatile flint conglomerate in the Skagerrak (Ødum 1968; Spjelnæs 1975, p. 306; Fig. 30 this paper) supports the concept of low surfaces in the Neogene.

The exact dating of the surfaces/levels is not particular important for the interpretation of their mode of formation. However, this dating of the surfaces in Sweden suggests that Scandinavia has been an area of intermittent uplift throughout at least the Mesozoic and Tertiary.

TOWARDS A NEW MODEL FOR THE EVOLUTION OF STEPPED EROSION SURFACES

Recent research has shown that it is more likely that plain erosion surfaces are formed in cratonic areas by surface processes in tropical to subtropical climates than by fluviatile mechanisms in temperate climates as argued by Davis.

Davis' model failed to explain the step-wise occurrence of erosion surfaces. It is therefore necessary to find a new model to replace that of Davis. Various observations and ideas have to be taken into consideration in such a model. The model presented here is based firstly on the geodynamic model of Melhorn & Edgar (1976), supplemented with ideas from Penck (1924), Baulig (1935), Geyl (1960), King (1962), and Fairbridge & Finkl (1980), and secondly on ideas on surface modelling agents. The ideas on surface development are influenced mainly by Thomas (1966, 1979) and Büdel (1957, 1977, 1980) and coincide to a certain extent with those of Fairbridge & Finkl (1980).

In unstable (orogenic) zones the disparity between present rates of denudation and uplift is too great to afford enough time for the formation of erosion surfaces (Schumm 1963) and thus those areas are not considered here. A model is presented concerning the cratonic areas (cf. Fairbridge & Finkl 1980, p. 70) as follows. During times of high activity in the mid-oceanic ridges, the volumetric capacity of the oceans is reduced. The continents are at relatively lower elevations and the sea transgresses. During periods of low activity in the mid-oceanic ridges, the ocean basins can store more water. The continental areas and their overall elevation above sea level increase with higher denudational rates as a consequence. Stepped topographies are thought to be caused by intermittent lowering of the initiating base levels due to uplift of the cratons. (Epeirogenic rise and subsidence of the relatively stable cratons is a quite distinct phenomenon. Cratonal areas covered by thick sedimentary sequences and/or shallow seas are proofs for subsidence of certain areas. Other parts of the cratons are not denuded to immediate proximity of sea level, which they should have been if they were not rising.) If the mechanism of cratonal rise is caused by isostatic adjustment or something else is not a task for geomorphologists to analyse. The eustatic regressive sea phases are thus thought to cause erosion surfaces of global extent.

Erosion surfaces originally related to the same base level (sea level) in different parts of the world cannot be expected to occur at equal heights today. Differences in regional epeirogenic movements and local tectonics should have given different heights in different areas to surfaces with the same initial age and also caused steps in the erosional succession of only regional and local importance.

Suppose that an erosion surface is developed with the sea as the base level during a regressive stage (Fig. 47). During next regressive phase a new erosion surface begins to develop at a level below the earlier formed erosion surface since the landmass has reached a relatively higher position. The higher surface continues to develop simultaneously with itself as base level. On the higher steps of an erosional succession it only has to be the level (step) that is old, as the original surface may have been consumed by lower steps and/or continously lowered (cf. Brown 1979, p. 460, and p. 154 in this paper). A critical point in the discussion is the slope between the two surfaces and its development. The question of slope development is not reviewed here but is of critical importance to an improvement of the model. It also rises the question of the relative importance of downwearing *versus* backwearing.

The detailed geomorphological features of erosion surfaces are determined by climate. Plain erosion surfaces form in the tropical to subtropical zones by the alternating processes of etching, occasionally duricrusting, stripping, and pedimentation. The stepped surfaces are either fossilized (p. 169) or continue to evolve (which includes both downwearing and backwearing) after having been elevated. The shape of the surface adjusts continuously to the prevailing climate. Buried surfaces retain their shape and can be studied today and give information of past processes. A produced and uplifted surface exposed to a cool, wet climate becomes dissected from the edge. Tilting of surfaces causes more rapid dissection over the whole surface, while nearly horizontal surfaces survive subaerially for long times even in climates that do not favour the production of plain surfaces.

It should be noted that young extrusions of igneous rocks can be bevelled to levels that were initiated long before the time of extrusion. This might be an explanation of the conditions in Scotland (p. 154), where Eocene extrusions have been cut by surfaces for which an older initiation has been advocated (Sissons 1976, p. 26; cf. Fig. 47 herein). Thus it can be concluded that levels (steps) can be old even if the actual surfaces are young due to continued development.

Dating of the surfaces can be done by analysing their regoliths and occasional remnants of sedimentary covers. Some of the Tertiary transgressions reached very far. The Early to Middle Eocene far-reaching transgression was a global event. As the Tertiary sediments are mainly unconsolidated they are easily erodible and only small fragments can be expected to occur in uplifted regions. Correlation of surfaces can be made by comparison of their areal extent as some periods are thought to have been more effective in producing surfaces than others. Optimum time intervals for erosion surfaces to evolve can be calculated for any area from the geologic history. Thus, a relative relief chronology can be constructed. The possible existence of local structural base levels must always be controlled. In glacially eroded countries most of the regolith, but not all of it, have been stripped. The survey of weathering in granitoid

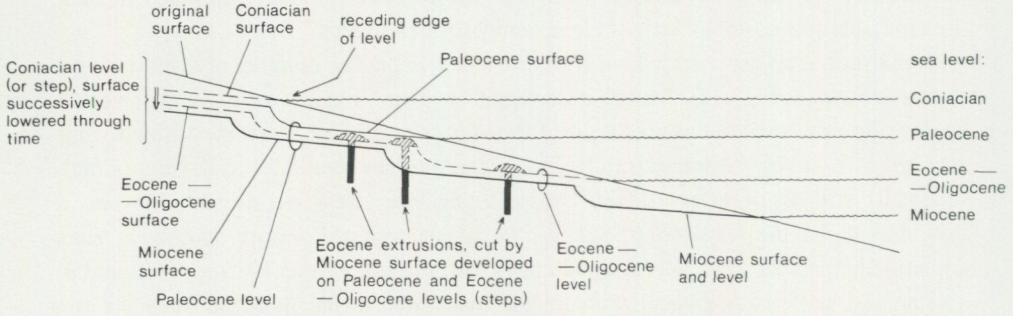


Fig. 47. Generalized model for the evolution of stepped erosion surfaces. Sea levels are shown for four time intervals with optimum conditions for producing erosion surfaces in Fennoscandia. Notice the difference between a level (step) and a surface. The relative importance of backwearing *versus* downwearing is not known.

rocks has shown that more has escaped the stripping ice than is generally thought.

Previous views on the evolution of erosion surfaces seem to conflict with one another and with some of the existing evidence. The model outlined here satisfies the competing ideas that surfaces are predominantly old and that surfaces are predominantly young. The model also embraces the idea of simultaneous development of surfaces at different levels independent of sea level in a tropical to subtropical climate. The model does not solve all the problems involved in the formation of stepped plain erosion surfaces. It should be seen as a working hypothesis, which will require modification in the future to fit in with the landscape observed and the mechanism of plate tectonics.

PRE-QUATERNARY GEOMORPHOLOGICAL EVOLUTION IN SOUTHERN FENNOSCANDIA — A GENERALIZED SKETCH

The geomorphological evolution is summarized in six schematic profiles (Fig. 48) extending from the Kattegat to the northeast over Halland and Småland

PERMIAN — TRIASSIC

If any Cambro-Silurian strata were left at the beginning of the Permian they were removed and nothing remained at the end of the Triassic. The climate was warm and arid, the base levels low and the active processes were stripping and pedimentation. During the previous period, the Carboniferous, deep weathering was the dominant process. Together these periods with first etching of the bedrock surface and then stripping and pedimentation produced very plain surfaces in Europe. At the end of the Triassic the basement surface can be regarded as having been a pediplain.

In the Permian or even earlier a flexure originated in the west. In this context dolerites were intruded and extruded in Västergötland and Skåne. Fractures originated in a dinaric (''Tornquist Line'') direction (NW), as well as in N–S and E–W alignments (cf. p. 31). During the Permian and Triassic the drainage of southwestern Fennoscandia was to the southwest and the sediments with denudation products are found in Denmark and Skåne.

RHAETIAN — JURASSIC

The climate changed in the Rhaetian and became moister. The Triassic pediplain was etched. In central Skåne the evolution of the surface was ended by deposition of Rhaetian and Liassic strata. In central Skåne the surface was exhumed recently and can be regarded as a partly–dominantly stripped etchsurface with residual kaolin on the hardrock surface. On this surface volcanoes erupted in the Early Jurassic, some remnants of which are prominent landscape features today.

EARLY — MIDDLE CRETACEOUS

The Late Kimmerian movements caused faulting and flexuring in central Skåne. In the Early Cretaceous the Båstad and Kristianstad areas began to sink in connection with the Austrian deformation phase that can be traced in the Danish Embayment and the North Sea. The drainage pattern changed (Troedsson 1932, pp. 224–225) and the erosional products from Halland, south Småland and northeast Skåne can be expected to be found on the bottom of the Kattegat and Hanö Bay.

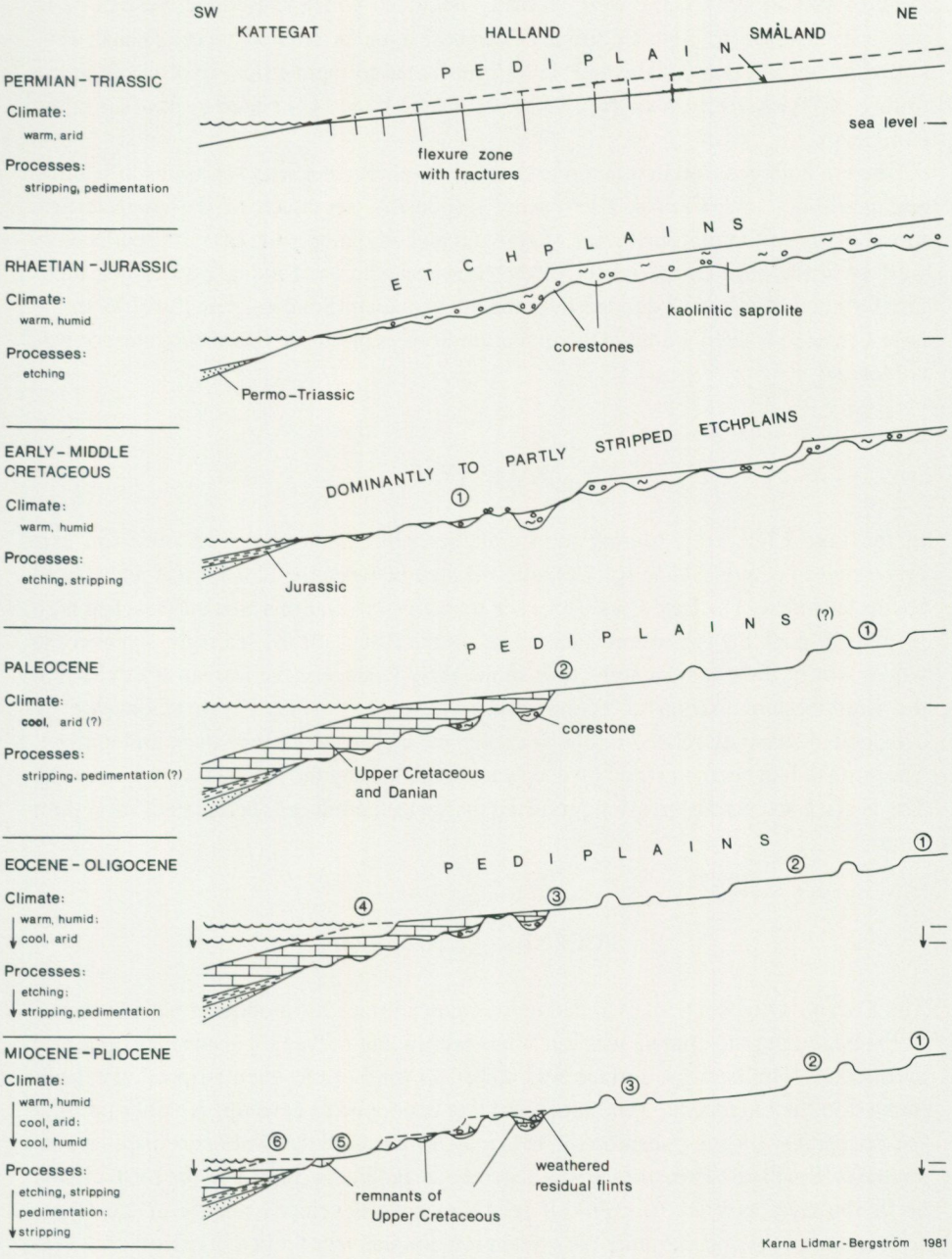


Fig. 48. Pre-Quaternary geomorphological evolution on the southwestern margin of Fennoscandia. A generalized sketch.

The climate was warm. The Neocomian and the Barremian seem to have been humid periods, as may the Albian and the Santonian (pp. 160–161, Table 11). Parts of the area in northeast Skåne were probably upfaulted which caused the weathering to penetrate deeply (p. 31). Uplifting of Fennoscandia in relation to the Danish Embayment and lowering of the base level contributed to rapid stripping of the saprolite during the Early Cretaceous (pp. 93, 159). Level 1 (p. 143) began to develop in the Coniacian.

Thus, a high position in relation to the base level together with variations in jointing and petrology (cf. Thomas 1966) were responsible for much of the characteristic morphology in the marginal zone of Halland and adjoining parts of Västergötland, as well as in the northern periphery of the Kristianstad area. Undulating bedrock topography must also have extended over the present south Småland peneplain. With the Late Cretaceous sedimentation the evolution of the sub-Upper Cretaceous surface was completed.

PALEOCENE

In the Late Cretaceous (during the Laramide deformation phase) an inversion axis originated in central Skåne (p. 159) and the area between the Kristianstad and Båstad basins subsided. The Late Cretaceous sea transgressed over this area and reached high levels, although the full extent is unknown. In the Paleocene the sea regressed over the whole world, although for some time in the early Paleocene the Danian sea existed at the southwestern margin of Fennoscandia. Level 2 (p. 143) began to develop by accelerated stripping related to low sea level and a probable change to an arid climate. The surface had been prepared by deep weathering during the preceding time intervals. The Early Eocene transgression protected the surface produced (pediplain?) for a short time.

EOCENE — OLIGOCENE

The Eocene–Oligocene interval had optimum conditions for producing plain surfaces. In the beginning the climate was warm and humid, but in the Oligocene it became arid and cooler. The bedrock surface was etched in the Eocene, then stripped and pedimented in the Oligocene. The higher surfaces continued to develop. A minor uplift at the Eocene/Oligocene transition (p. 161) may have caused the lower peneplain level in southeast Småland. This surface was also recognized in the study area (p. 136), as well as in the river profiles (p. 136). It seems to have developed mainly in the Upper Cretaceous rocks and therefore the present remains are very limited in extent.

MIOCENE — PLIOCENE

During this interval the ultimate preglacial land surface of south Sweden was formed. Uplift of Fennoscandia and regression of the sea (pp. 161–162) caused erosion surfaces at least at two levels, viz. 0–40 m a.s.l. and 50–70 m below sea level. A period of deep weathering and stripping was followed in the late Miocene by a period of pedimentation. The sub-Upper Cretaceous surface was remodelled in Halland and in the Kristianstad area. During the Pliocene, cool humid conditions caused intense stripping and dissolution of the remnants of the Cretaceous limestone, and a residue of flints was left. The flints were weathered brown. The clay weathering conditions that had prevailed were replaced by the gravelly weathering type as seen for example at Boarpa backe.

In the late Pliocene and in the Pleistocene an intensified river incision began in the unweathered bedrock. The plain surfaces in Småland acted as local base levels for further valley incision in higher levels.

III. FINAL REMARKS

COMPARISON WITH EARLIER IDEAS ON THE GROSS MORPHOLOGY OF SOUTHERN SWEDEN

Table 2 lists earlier ideas on the origin and age of erosion surfaces in southern Sweden. In this study I have come to much the same conclusions as Ahlmann (1920) and Eklund (1961). However, the interpretation of the coastal plain and the marginal zone as exhumed sub-Upper Cretaceous relief as argued by Asklund (1928) and Rudberg (1954, 1970a) has also proved to be partly true. Thus, for the interpretation of the coastal plain and the marginal zone, it is important to realize that there are features of both a sub-Upper Cretaceous and a Neogene relief.

GEOMORPHOLOGICAL PROBLEMS IN SOUTH SWEDEN

The four main problems posed at the initiation of this study (p. 14) have been solved as follows. 1. The south Småland peneplain is dated tentatively to the Eocene–Oligocene. It is thought to have evolved in a tropical–sub-tropical climate mainly with the sea as a base level. The surface seems first to have been etched during warm, humid conditions in the Eocene and later stripped and pedimented in the Oligocene. A further development has occurred during the Neogene. 2. The relief on the coastal plain of the west coast seems to be a mixture of an uneven sub-Cretaceous erosion surface and a more plain erosion surface of Miocene and later ages. 3. Much of the marked relief east of the coastal plain and north of the Kristianstad plain seems to be a sub-Cretaceous erosion surface. In the middle and northern parts of Halland and adjoining parts of Västergötland in particular, structural control seems to be of importance. 4. The south Småland peneplain cannot be traced to the horsts in Skåne, as the area in between (incl. the study area) was lowered in the Late Cretaceous and probably did not reach its present position until after the Oligocene. The surfaces of the horsts are primarily sub-Jurassic, but have been remodelled later.

FLINT AS A KEY TO UNDERSTANDING GEOMORPHOLOGICAL EVOLUTION

This study, that from the beginning was devoted to the occurrence of erratic flints, has demonstrated the potential of flint for revealing landscape history. The Late Cretaceous transgression was of wide extent over large parts of the world. In many areas the Cretaceous includes chalk and limestone with flint. As the flints have a comparatively strong power of resistance to weathering they remain in the landscape long after

the carrying rock has been eroded away. Thus in areas of uplift they help to localize exhumed sub-Cretaceous surfaces. The upper limit of their occurrence marks the lower boundary of Palaeogene and older relief in Northwest Europe. Below the boundary a Neogene relief can be expected to occur mixed with sub-Cretaceous relief. The importance of even very limited numbers of local flints in the landscape is shown in this study.

IV. SUMMARY

The morphology of southern Fennoscandia is studied from the point of view of four main problems: 1, the age and mode of formation of the south Småland peneplain, 2, the origin and shape of the bedrock surface on the Swedish west coast, 3, the origin and shape of the marked relief east of this coastal plain and north of the Kristianstad plain in Skåne, and 4, the relation between the peneplain and the horst region in Skåne (Fig. 1).

In order to study these problems, an area was chosen at the southwestern border of the south Småland peneplain. This rectangular study area is located between Laholm Bay on the west coast and the town of Hässleholm in the southeast. It extends over parts of the west coast with unknown bedrock relief, parts with marked relief in the bedrock, part of a fairly flat surface that was previously supposed to belong to the south Småland peneplain, and into an area with numerous Upper Cretaceous remnants northwest of the Kristianstad region.

Morphometric studies were undertaken and data from borings compiled in order to obtain an accurate picture of the relief. The tectonics of the study area are discussed. Field investigations were undertaken of Cretaceous erratics, mainly flints, and a compilation of data on Cretaceous rocks in the study area was made. Weathering phenomena were investigated in the study area and weathering in granitoid rocks in adjacent areas of Europe are surveyed from the literature. Reports on the surrounding sediments are examined for a better understanding of the preglacial morphogenesis.

In order to place the study area into its context, erosion surfaces in southern Sweden are analysed in part two of the text. Literature on erosion surfaces in adjacent areas is surveyed. For a better understanding of the gemorphological evolution a compilation of data is made on the evolution of continents, seas and climate in Northwest and Central Europe from the Devonian to the Tertiary. Models for the evolution of stepped topographies and plain erosion surfaces are surveyed.

The main results of the study can be summarized as follows:

1. Conclusions concerning morphology in the study area (Fig. 2, folded map after text):
   a. For vast areas the relief is low. In the southeastern half 45% of the study area is situated between 100 and 120 m. The northwestern half contrasts in having a high relative relief with a maximum of 100 m.
   b. The area consists of tectonic blocks that were tilted in connection with Late Cretaceous sedimentation. The central part has been affected by a later rise, probably post-Oligocene.
   c. Erratic flints occur over most of the area. Because of their specific nature and local appearence it is concluded that the flints are from former Cretaceous deposits in the area. In the northwest in particular the flints are not associated

with other Cretaceous erratics and are often weathered brown. Based on this condition and a comparison with neighbouring parts of Europe it is concluded that these flints can be regarded as Tertiary weathering residuals.

d. Minor occurrences of kaolin exist in the area. In parts the topography is characterized by small knolls and an uneven surface often in combination with a great many boulders in the terrain. This morphology is considered to represent an old weathering front preserved by a cover of Upper Cretaceous rocks during much of the Tertiary.

e. A locality is described with sandy weathering, that is suggested to be of Late Tertiary or perhaps interglacial age.

f. The sequence of events experienced by the study area has been dated as follows: Kaolinitic weathering started in the Rhaetian and continued at least into the Middle Jurassic. Stripping accompanied the weathering and accelerated in the Early Cretaceous in connection with an uplift of Fennoscandia. Kaolinitic weathering conditions probably existed during parts of the Late Jurassic and Early Cretaceous and continued into the Late Cretaceous. Upper Cretaceous deposits then protected the area until the Late Tertiary.

2. Most flints along the west coast of Sweden are thought to have been transported to the coast from elsewhere. However, along the entire Halland coast there also occur locally derived Upper Cretaceous flints. Cretaceous rocks covered the basement in Halland at a comparatively late date and sites with Cretaceous rocks still occur.

3. Two sets of erosion surfaces are recognized in southern Sweden (Fig. 40). These are the exhumed sub-Cambrian, sub-Jurassic, and sub-Upper Cretaceous surfaces on the one hand, and surfaces moulded mainly during the Tertiary on the other. The latter surfaces form steps with the oldest around 300 m a.s.l., and the youngest around 75 m below sea level. Areas with a sub-Cretaceous relief partly coincide with areas with a Neogene relief. A tentative correlation is made with Tertiary erosion surfaces in northern Sweden (Table 8) mainly on the basis of the size of the surfaces.

4. Flat erosion surfaces are found to occur in a step-wise arrangement in most of the European countries surveyed. From Germany and Norway deep valleys are reported as ''sunk'' into this ''paleic'' relief. Among the exhumed surfaces the sub-Cambrian surface is particularly important in Fennoscandia. Sub-Cretaceous surfaces occur in many of the countries surveyed. Exhumed Palaeogene surfaces are identified to a lesser extent.

5. Climate is important for the interpretation of the mode of formation of erosion surfaces. The climate in Europe was warm, tropical to subtropical continuously from the Devonian to the Late Tertiary. Humid periods alternated with arid intervals. Deep clayey saprolites were produced during the humid intervals until the Miocene. From the Late Miocene onwards, conditions favouring a sandy weathering type seem to have been prevalent.

6. Davis' cycle of erosion has not proved to be relevant for the explanation of stepped plain erosion surfaces.
7. Davis' term ''peneplain'' still seems to be useful with his original definition (p. 167). However, it should not be used as a genetic term for a stage in a cycle of erosion, but instead as a descriptive term for a plain erosion surface.
8. A few papers in recent years again actualize the question of synchronous erosion surfaces all over the world, now with the mechanism of plate tectonics as a means of explanation.
9. The evolution of plain erosion surfaces in the tropics is examined from the literature. Such surfaces seem to evolve in the following way. Warm, humid intervals promote etching (deep weathering), while uplift and climatic change promote stripping of the saprolite, and arid intervals induce pedimentation. A succession of a warm humid interval followed by an arid interval produces optimum conditions for the formation of level surfaces.
10. An account is given of the erosional history in North and Central Europe from the Devonian to the Tertiary (Table 11). Nine optimum intervals for the evolution of erosion surfaces in Fennoscandia are inferred. They are: Early Permian, Early Triassic, Middle Jurassic, Early Cretaceous, Coniacian, Paleocene, Eocene–Oligocene, Miocene, and Pliocene.
11. A model for the evolution of stepped erosion surfaces is tentatively proposed with the geodynamic model of Melhorn & Edgar (1976) and results of climatic geomorphology as a base. It is as follows. The main erosion surfaces are produced during regressive stages of the oceans. In times and areas with cratonal uplift the surfaces are initiated at successively lower levels. The plain surfaces are produced by a sequence of processes comprising etching, stripping and pedimentation. The levelling procedes simultaneously in a stepped fashion with both downwearing and backwearing. Thus, a surface may be relatively young even if the initiation of the level (step) is old. However, in suitable positions and climates non-stripped duricrusted surfaces can survive for long. In Pliocene and Quaternary times cool to cold climates promoted valley incision in the older surfaces in Europe. The old steps act as base levels for the present rivers.
12. A geomorphological model is presented for southern Scandinavia. The south Småland surface is regarded as Palaeogene in origin and the coastal surface as Miocene. Features of a sub-Cretaceous relief occur on the coastal plain and in the marginal zone. This interpretation turns out to combine a selection of various earlier ideas (Table 2). The flint has been one important key in the disclosure of the geomorphological history.

APPENDIX

FIELDS OF GEOMORPHOLOGY

Geomorphology can be approached in many ways (Table 12). The oldest approach to the subject within the fields of geography is the regional approach. Influenced by the thoughts of Darwin, Davis adopted an evolutionary point of view. Davis regarded his field of work as explanatory geomorphology, using the three concepts of structure, process and stage to explain landforms (King & Schumm 1980, p. XX). This approach brought geomorphology closer to geology. Strahler (1952) argued for a dynamic approach to geomorphology, which almost separated geomorphology from geography and placed it in the general field of geosciences.

Parallel to these changes in approach, research was carried out in two basic fields of geomorphology, viz. structural and climatic geomorphology. Structural geomorphology has been a field of particular interest in East and Central Europe, the Soviet Union and Australia. Also in Lund, Sweden, several works have been performed in this field, viz. by Björnsson (1937), Sandell (1941), Nordenskjöld (1944), Behrens (1953), and Larsson (1954). Pioneers of climatic geomorphology include Peltier (1950), Büdel (1957 etc.), Birot (1960), and Tricart & Cailleux (1965).

The most recent trends in geomorphology have been focused on the environment and the impact of man on the landscape and the interaction of man and active processes. This seems again to link geomorphology with geography.

However, all these branches of geomorphology continue to develop side by side. The kind of geomorphology dealt with in this contribution is historical or evolutionary geomorphology (Ollier 1979; Brown 1980). As the study of recent processes is

TABLE 12. Fields of geomorphology.

	Dynamic geomorphology	Evolutionary geomorphology	Regional geomorphology
Structural geomorphology	active endogenic processes	structural-genetic evolution	morphostructural regions present and past geomorphological maps
Climatic geomorphology	active exogenic processes	climato-genetic evolution	morphoclimatic regions present and past geomorphological maps
Environmental geomorphology	man and active processes monitoring of environment	man and existing forms (and material) management of resources	applied geomorphology

important for the understanding of the evolution of landforms, the study of the history of landforms can give valuable information of the intensity and duration of past processes (cf. Strahler 1952, p. 925).

Evolutionary and dynamic approaches to geomorphology do not seem to be of equal value everywhere. ''Vorzeitformen'' are very common in some parts of the world, while in others landscape very much bears the impress of processes active today. Thus some parts of the world can be regarded as nature's laboratories and others rather as ''museums''. Process studies are best performed in the natural laboratories, while historical geomorphology is best studied in ''museum'' areas.

Ollier wisely stated that geomorphology has an historical aspect which is difficult to understand from studies of processes in unique recent climatic environments: ''. . . process studies alone are insufficient to explain how landscapes are formed, and without the parallel study of geomorphic history may lead to only partial or even incorrect interpretations'' (Ollier 1978, p. 175). The present is not a clue to the past unless we have learnt from the past which processes and features are relevant.

FUTURE TASKS FOR EVOLUTIONARY GEOMORPHOLOGY IN FENNOSCANDIA

In this kind of study the side-tracks are too numerous to be followed up in detail, and the relevant information is not generally available. I have mentioned a number of subjects that should be worked through more thoroughly. One such interesting field is the deep weathering in various parts of Fennoscandia. Another is the study of tors and tor socles which seem to be present in northeast and central Skåne, the first of which have been recognized and described only recently. The landscape on the exhumed Mesozoic surfaces with tors, boulders and small hills ought to be thoroughly mapped.

Geologists and geomorphologists should devote attention to finding Cretaceous flint erratics which may occur very sparsely above the marine limit on the Swedish west coast. A comparison of the flint types (including their age) and their shape along the coasts of Denmark and southwest Sweden might provide firmer evidence for conclusions as to the provenance of flints on the Swedish west coast.

Isolated Tertiary deposits should be more numerous than is known. It is remarkable that most of the published records are very old. In this context some recent finds of Paleocene and Eocene deposits should be mentioned (p. 90).

More exact mapping is required of the surfaces in Småland and of erosion surfaces north and south of the south central Swedish lowlands as well as more detailed investigations of the sub-Cambrian peneplain and the further evolution of the areas with exhumed sub-Cambrian surfaces. The complicated relief in Skåne, Halland and Blekinge with interference between Mesozoic and Neogene erosion surfaces needs a closer examination.

The awareness of the importance of stepped topography would make mapping of the paleic surfaces in Norway very interesting as well as of surfaces in Finland.

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DGU = Danmarks geologiske undersøgelse
GFF = Geologiska föreningens i Stockholm förhandlingar
IBG = Institute of British geographers
SGU = Sveriges geologiska undersökning
SGÅ = Svensk geografisk årsbok

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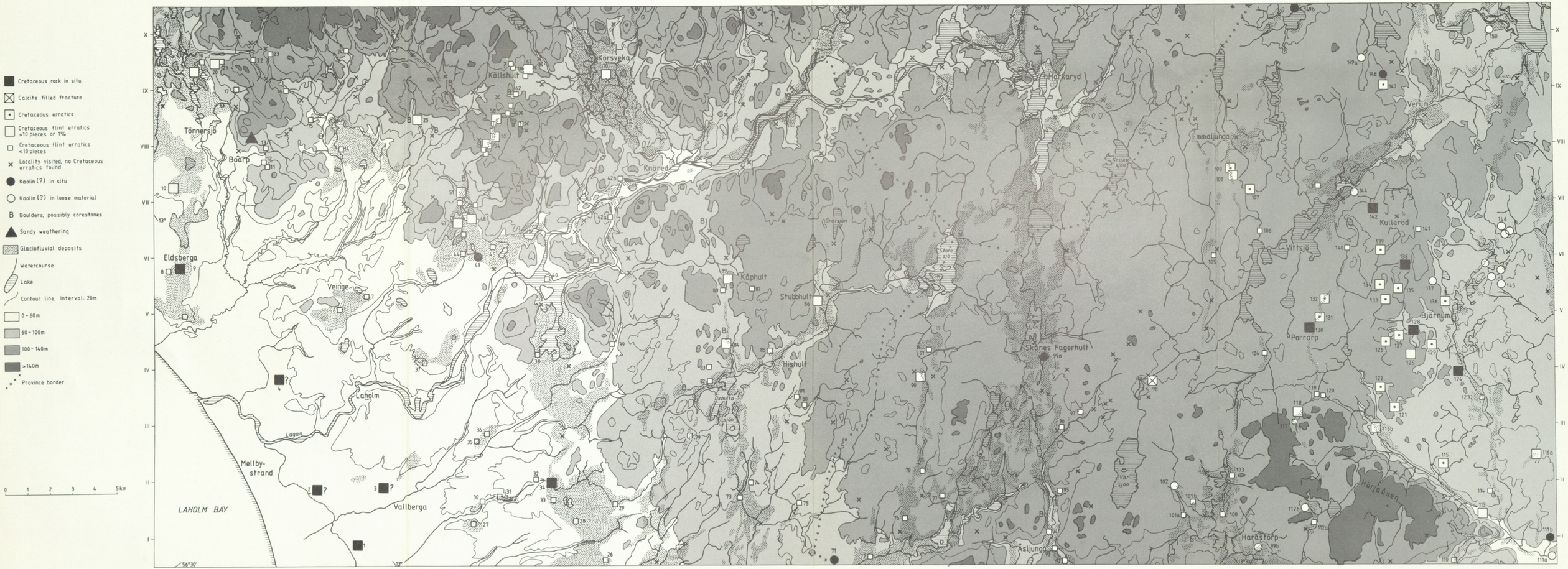
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Cretaceous rock in situ
Calcite filled fracture
Cretaceous erratics
Cretaceous flint erratics >10 pieces or 1%
Cretaceous flint erratics <10 pieces
Locality visited, no Cretaceous erratics found
Kaolin (?) in situ
Kaolin (?) in loose material
B Boulders, possibly corestones
Sandy weathering
Glaciofluvial deposits
Watercourse
Lake
Contour line. Interval: 20m
0 - 60m
60 - 100m
100 - 140m
>140m
Province border
0 1 2 3 4 5km
Tönnersjö
Eldsberga
Veinge
Laholm
Lagan
Mellby-strand
LAHOLM BAY
Vallberga
Båarp
Källshult
Körsveka
Knäred
Käphult
Stubbhult
Hishult
Harkaryd
Emmaljunga
Skånes Fagerhult
Åsljunga
Vittsjö
Verum
Kullerød
Porrarp
Bjärnum
Harjaåsen
Haråstorp
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13°

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