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## ABSTRACT


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The Upper Cretaceous rocks exposed at Ignaberga are mainly composed of skeletal grainstones and packstones of marine origin and Early Campanian age. An approximately 20 m thick sequence of strata is exposed in the New and Old Quarries. The sequence is dominated by grainstones in the lower and middle part while the grainstones give way to packstones in the upper part. At the bottom of the New Quarry the top of an up to 30 m thick calcareous glauconitic sandstone is exposed. Interbeds of pebble conglomerates are frequent in the section. Two glauconite coated hardgrounds are found, one in the basal part on top of the calcareous glauconitic sandstone and one in the middle of the investigated section. The conglomerates are commonly associated with erosion surfaces and graded bedding sequences with variably developed hummocky and swaley cross stratification and undulating bedding planes. Truncated beds and incomplete bedding sequences are commonly associated with the conglomerates. Large bag shaped scour and fill structures are also frequent along the basal erosion surfaces of the conglomerates. The pebbles are mainly composed of Precambrian crystalline rocks and are frequently encrusted by an epifauna of oysters, serpulids and bryozoans. Enrichment of heavy minerals is mainly found in association with the conglomerates in the basal part of the sequence and shoal-like depositional structures oriented parallel to the Nävlingeåsen horst. Megaripples and orientation of belemnites give a NW–SE palaeocurrent. The micro- and macrofaunas with dominantly sedentary species are characteristic for a high-energy nearshore environment. The depositional environment is interpreted as being wave dominated nearshore and the deposits formed mainly within the storm wave base and the breaker zone.



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## Introduction and geological setting

The sedimentary sequence in the Kristianstad Basin is the result of a world wide transgressive nature of the Cretaceous seas due to increased rate of sea-floor spreading and compressional movements in the crust (Hays & Pitman 1973). Numerous transgressive pulses are recognized in the deposits (Christensen 1975, 1984; Bergström & Sundquist 1978; Lidmar-Bergström 1982, Lidmar-Bergström & Bergström 1984a, b; Gabrielson & Holland, 1984). Major pulses occurred during the pre-Cenomanian, Cenomanian, Early Santonian, mid-Campanian and Early Maastrichtian ages (Christensen 1975). The transgressing Cretaceous seas invaded a previously irregularly weathered basement of Precambrian crystalline rocks. This resulted in the development of an archipelago and irregular coast-line morphology. The basal portion of the sedimentary sequence is consequently dominated by kaolin and quartz-rich sediments, occasionally of fluviatile origin (e.g. the deposits at Åsen and Axeltorp). The oldest sediments in the Basin consist of calcareous glauconitic sands of Barremian, Aptian-Albian and Cenomanian age (Norling & Skoglund 1977; Norling *in* Kornfält et al. 1978; Norling 1981). Aptian-Albian strata have also been verified in the Sixtorp boring (Guy-Ohlson 1984). Mixed siliciclastic and bioclastic sediments of marine origin constitute, however, the main part of the succeeding sedimentary sequence. The major part of the sequence was deposited during mid-Campanian times when a major transgressive pulse occurred. Most outcrops expose strata of late Early Campanian – early Late Campanian age. Early Maastrichtian strata are only found in three areas (Ballingslöv, Bjärnum and Balsvik; Siverson pers. com.). In total the Cretaceous is at least 250 m thick in the central parts of the Kristianstad Basin (O. Gustavsson pers. com.).

The fossil fauna in the outcrops gives a shallow marine composition characteristic of an inner shelf community. Descriptions of the sedimentary sequence have not been conclusive in the same way concerning the depositional environment. This is largely due to the fact that the fossils have been given more attention in previous works and that the sediments look apparently structureless and homogeneous in composition. The sediments are, however, on the contrary relatively rich in structures and bedding sequences that give valuable information about the depositional conditions. The interbedding conglomerates and the associated structures are the most important environmental indicators apart from the fossil fauna.

Outcropping conglomerates have been described by Hadding (1927) and Voigt (1929). The locations and main characteristics of the the known outcropping conglomerates are compiled in Fig. 1. The conglomerates are mainly found along a marginal zone of the Cretaceous sedimentary cover in the Kristianstad Basin. Today, many of the localities described by Lundegren (1934) are inaccessible due to overgrowth and debris. The limited number of outcropping conglomerates are almost exclusively of late Early Campanian to early Late Campanian age with the exception of a conglomerate of Santonian age at Ringeleslätt.

The conglomerates have been characterized as either of basal or marginal type (Lundegren 1934). The basal conglomerates were according to Hadding (1927) of regressional intraformational origin, while Lundegren (1934) interpreted a transgressional origin. The marginal conglomerates at Ignaberga have been considered as lag deposit due to decreased bioclastic sedimentation (Hadding, 1927). Voigt (1929) considered the conglomerates as being the result of numerous tectonically induced regressional events and subsequent transgressions. These interpretations are, however, not based on recent knowledge about the sedimentology of the nearshore inner shelf region. Recent studies conclude that storms generate a wide spectra of structures and depositional sequences, similar to the ones frequently occurring in the Kristianstad Basin. These features include coarse-grained clastic deposits with pebbly conglomerates, fining upward cycles and erosional basal surfaces, scour and fill structures, hummocky cross stratification and amalgamated sedimentary sequences (cf. Kumar & Sanders 1976; Einsele & Seilacher 1982; Allen 1982, 1984; Dott & Bourgeois 1982; Goldring & Aigner 1982; Leckie & Walker 1982; Mount 1984; Leithold & Bourgeois 1984; Robertson Handford 1986; Greenwood & Mittler 1985; McCrory & Walker 1986; Brenchley 1989).

The deposits at Ignaberga and several of the studied outcrops exhibit many of these features. It is therefore most likely that storms played an important role in the depositional process (cf. Erlström 1986; Erlström & Gabrielson 1986). Increased quarrying in the Ignaberga New Quarry has led to good exposures of the sedimentary sequence and thus given good conditions for mapping separate units over larger distances. The locality also exposes the most continuous section of the strata in the basin. This gives an opportunity to make a sedimentological description of the Ignaberga deposits and interprete the palaeodepositional environment in which these deposits were formed, taking into consideration features which indicate storm influenced depositional conditions.

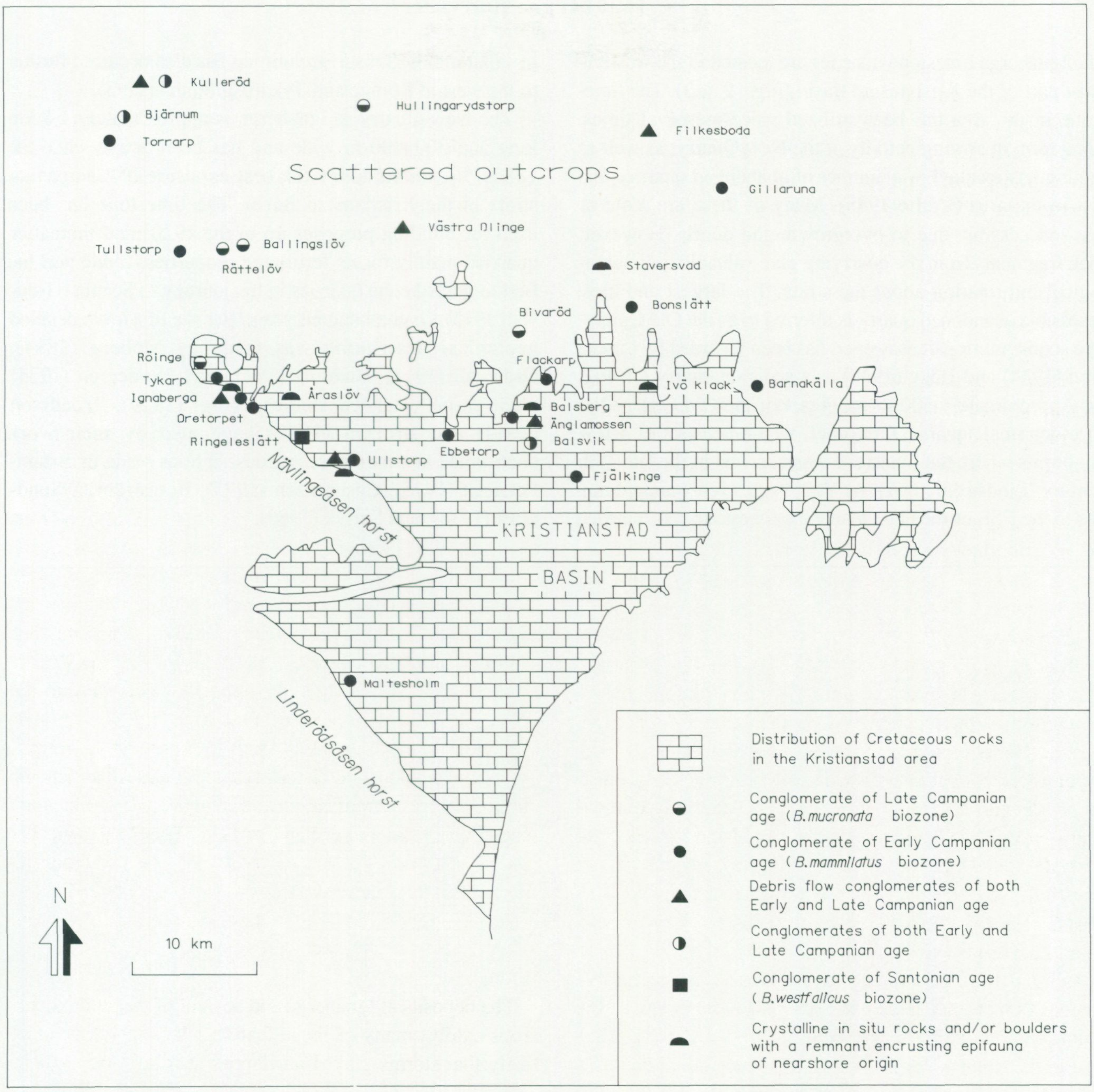


Fig. 1. General map of the Kristianstad Basin showing the distribution, age, and main characteristics of known conglomerate outcrops in the area.

## The Ignaberga quarries

The Ignaberga limestone quarries are located in the westernmost part of the Kristianstad Basin (Figs. 2 & 3). The limestone in the area has been utilized since medieval times. Long term quarrying activity at the New Quarry, as well as mining has resulted in a number of abandoned quarries and pits in the area (Carlie 1985). Many of these are more or less inaccessible due to overgrowth and debris. However, rock fragments from the quarrying give valuable sedimentological information about the strata. The largest and most accessible abandoned quarry is referred to as the Old Quarry. The southeastern part, however, has been regarded by Lundegren (1934) and Hägg (1947) as a separate quarry (cf. Fig. 2). Approximately 500 m southeast of the Old Quarry lies an older small quarry, Oretorpet, which consists of a few minor pits where the limestone was quarried in the late 19th century (Lindström 1877). At Vedhygge a few hundred metres to the ESE of the Old Quarry the limestone was quarried in small mines. Subsurface mining has also occurred further to the west at Röinge and Tykarpsgrottan (Fig. 3).

The New Quarry at Ignaberga is approximately 1.5 km long and 300–400 m wide and has been active since the 1880s. It exhibits today the best exposure of Campanian strata in the Kristianstad Basin. The limestone has been used for building purposes up to the 1920s and thereafter quarried mainly for its fertilizing properties. Linné was the first to describe the quarries in his journey to Scania (Grönwall 1915). Over a hundred years later the first more detailed geological description was made by Moberg (1884). Grönwall (1915), Hadding (1927) and Lundegren (1934) made more extended studies. Voigt (1929), Troedsson (1954) and Brotzen (1960) have also by their work contributed to the more recent descriptions made by Bruun-Petersen (1975), Christensen (1975), Bergström & Sundquist (1978), and Surlyk (1980).

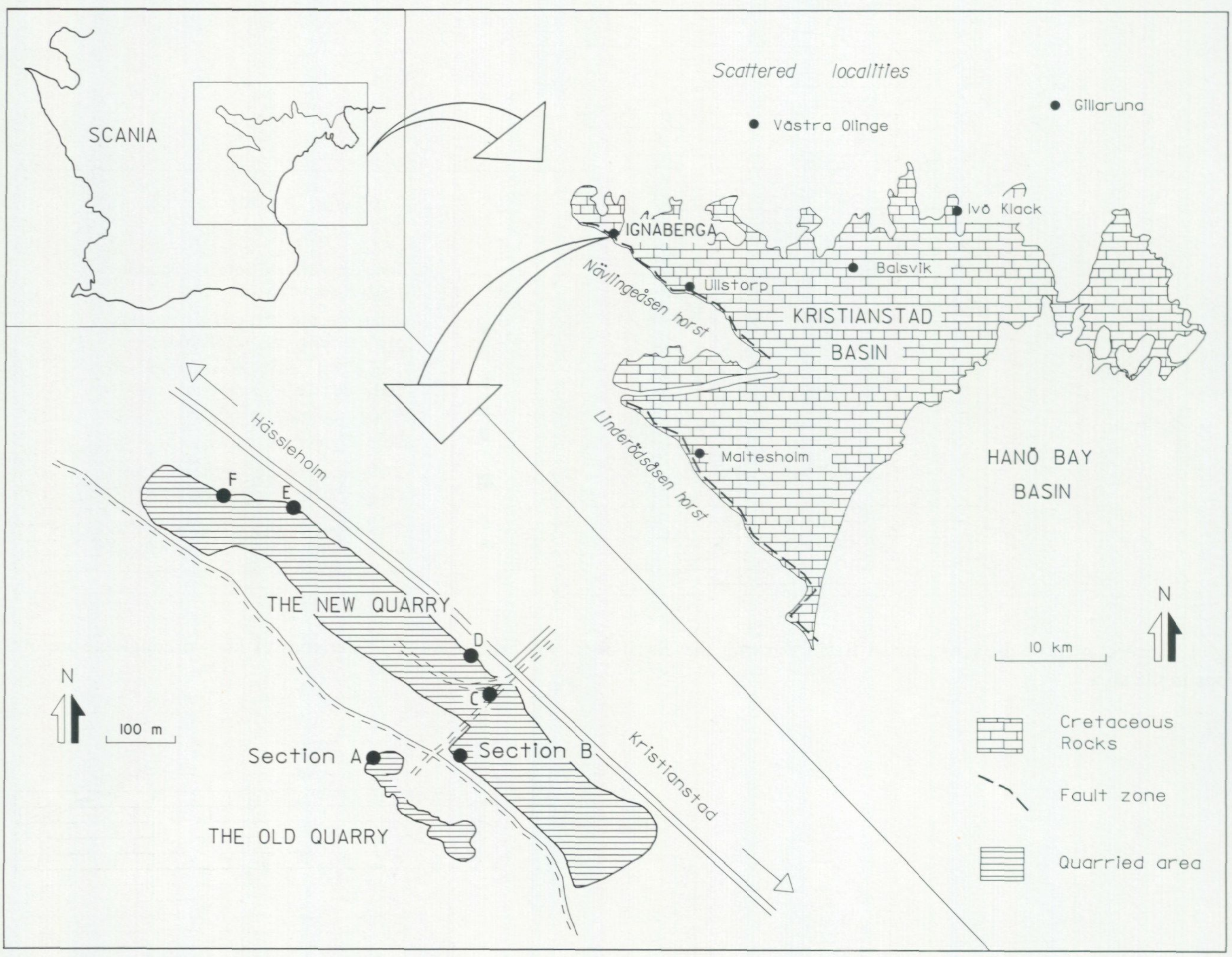


Fig. 2. General map of the Kristianstad Basin showing the present distribution of Cretaceous strata and the location of the Ignaberga quarries. The outlines of the Old and New Quarries are illustrated together with the location of sections A and B presented in figure 4. C–F refers to location of additional sampled sections concerning the foraminiferal composition (cf. Table 4).

The exposed part of the limestone in the area consists of variably lithified packstones and grainstones interbedded by thin conglomeratic layers. Two hardground levels are also found in the sedimentary sequence, the lower one at the bottom of the New Quarry (25–28 m.a.s.l.) and the upper one at approximately 35 m.a.s.l. The bed thickness varies between 0.2 m and 1.5 m. The beds dip 5–10° in a N40–50°E direction. The sequence is overall increasingly sandy towards the base. At approximately 5 m (20 m.a.s.l.), below the lower hardground in the central part of the New Quarry the sediments are composed of a calcareous, glauconitic quartzose sandstone. The up to 30 m thick sandstone unit lies directly on top of the weathered Precambrian basement. To the east and west the top of this unit is found at much shallower depth (28–30 m.a.s.l) and thus found more or less directly beneath the quarry floor. The above lying limestone with on average 85–95% $CaCO_3$ is approximately 20 m thick and has a lens shaped outline in a NE–SE direction. The shape and distribution of the limestone is probably related to the relief of the underlying Precambrian basement. Borings performed by Ignaberga Kalksten AB confirm the existence of Precambrian ridges beneath the sedimentary cover to the east and west of the New Quarry. These ridges played most likely an important role to the Cretaceous depositional pattern in the area.

Biostratigraphical investigations (belemnites) give a late Early Campanian age (*Belemnellocamax mamillatus* biozone) of the exposed biocalcarenitic strata (Christensen 1975). Finding of an ammonite (*Hauericeras* cf. *pseudogardeni*) below the lower hardground at approximately 26

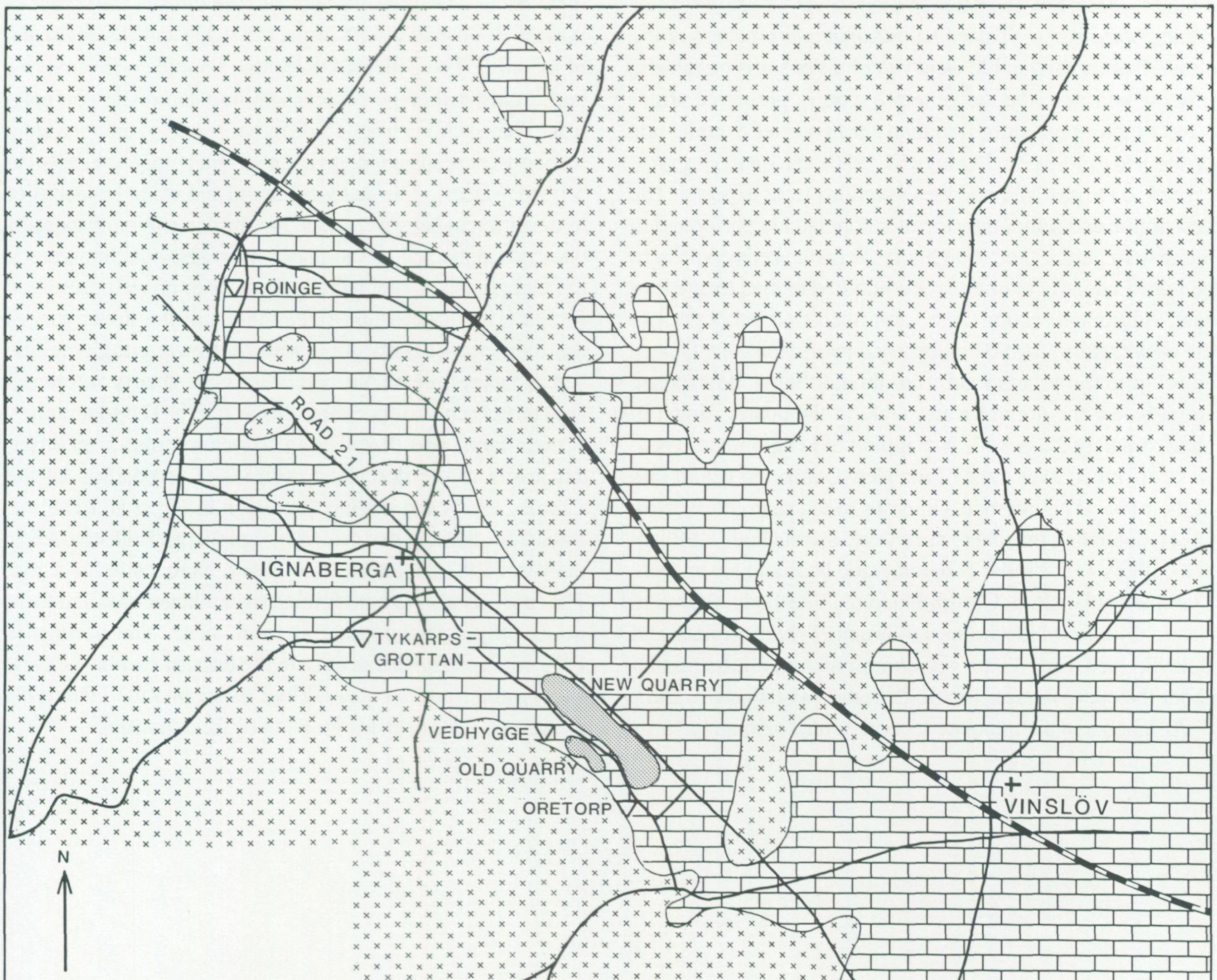


Fig. 3. Schematic illustration of the local distribution of the Cretaceous strata in the Ignaberga area and location of outcrops and small quarries mentioned in the text.

m.a.s.l. in the western part of the New Quarry indicates prescence of lower Lower Campanian or Upper Santonian deposits below the hardground (Birkelund & Bromley 1979). The shark teeth assemblage in the sandstone is to a large extent composed of redeposited Cenomanian specimens. This confirms that at least some of the previous Cretaceous transgressions reached into the Ignaberga area. A Santonian age of the basal sandstone is also confirmed by the findings of the belemnite species *Gonioteuthis westfalica* (Christensen pers. com.). Thus, these data imply the occurrence of a significant hiatus, including much of the middle Early Campanian, in the sequence at the hardground.

## Material and methods

The choice of field work strategy was largely governed by the aim to get an overall view of the sedimentary sequence and sedimentology in the Ignaberga area. The work was also aimed to locate and characterize sedimentary structures which could contribute to a palaeodepositional interpretation of the strata. During favourable weather conditions it is possible to observe and describe the generally poorly preserved structures which occur more frequently than a brief examination of the beds indicates. During the 1980s the quarrying proceeded to the east and new fresh sections were exposed. The description and sampling were therefore mainly performed in the eastern part of the New Quarry. Separate beds could here be traced laterally over a several hundred metres long exposure. Additional sections were described from other parts of the New Quarry. In 1991 a deepened part in the New Quarry adjacent to the access road from the northern side exposed strata below the normal water table in the quarry, down to approximately 22 m.a.s.l. A mapping of conglomeratic beds was performed over most of the New Quarry to get an idea of their lateral persistence. Outcrops to the south of the New Quarry including the Old Quarry were also studied. Additional localities with similar conglomeratic beds and layers were examined at Ullstorp, Ugnsmunnarna, Filkesboda, Bjärnum, Västra Olinge, Maltesholm, Gillaruna, Tykarpsgrottan and Balsvik (see Fig. 1) to get complementary information about the conglomerate lithology in the Kristianstad Basin.

At Ignaberga a composite section of approximately 15 m was measured and described in the south part of the New Quarry and the Old Quarry (Fig. 4). The basal part of the section includes two distinct conglomeratic levels in which there occur several scour and fill structures. Twentyfour of these were described with respect to shape and characteristics of the infill. The collected limestone samples were analysed concerning carbonate content and non-carbonate composition. Thin sections from 15 different levels in the measured section were prepared, point counted and petrographically described. Macrofossils that were found and could be identified in the different beds were added to the description. Especially one bed connected to the upper intraclast conglomerate in the Old Quarry contained a high number of well preserved fossils. The orientation of belemnites in the lower part of the sequence in connection with the lower conglomeratic bed and a layer in the NE-part of the New Quarry was measured on 100 and 50 specimens respectively. The foraminiferal microfauna was described in sixteen samples from different levels in the described sections. The position of the sampled levels and sections are given in Fig. 2 and Table 4. Data from borings performed by Ignaberga Kalksten AB in the years 1983–84 and 1991 was also included in the study. The first borings were performed over a larger area and there exists only cuttings material from these. The borings in 1991 were performed mainly in the eastern part of the New Quarry and from the quarry floor down into the underlying sandstone. Cores exist from most of these borings.

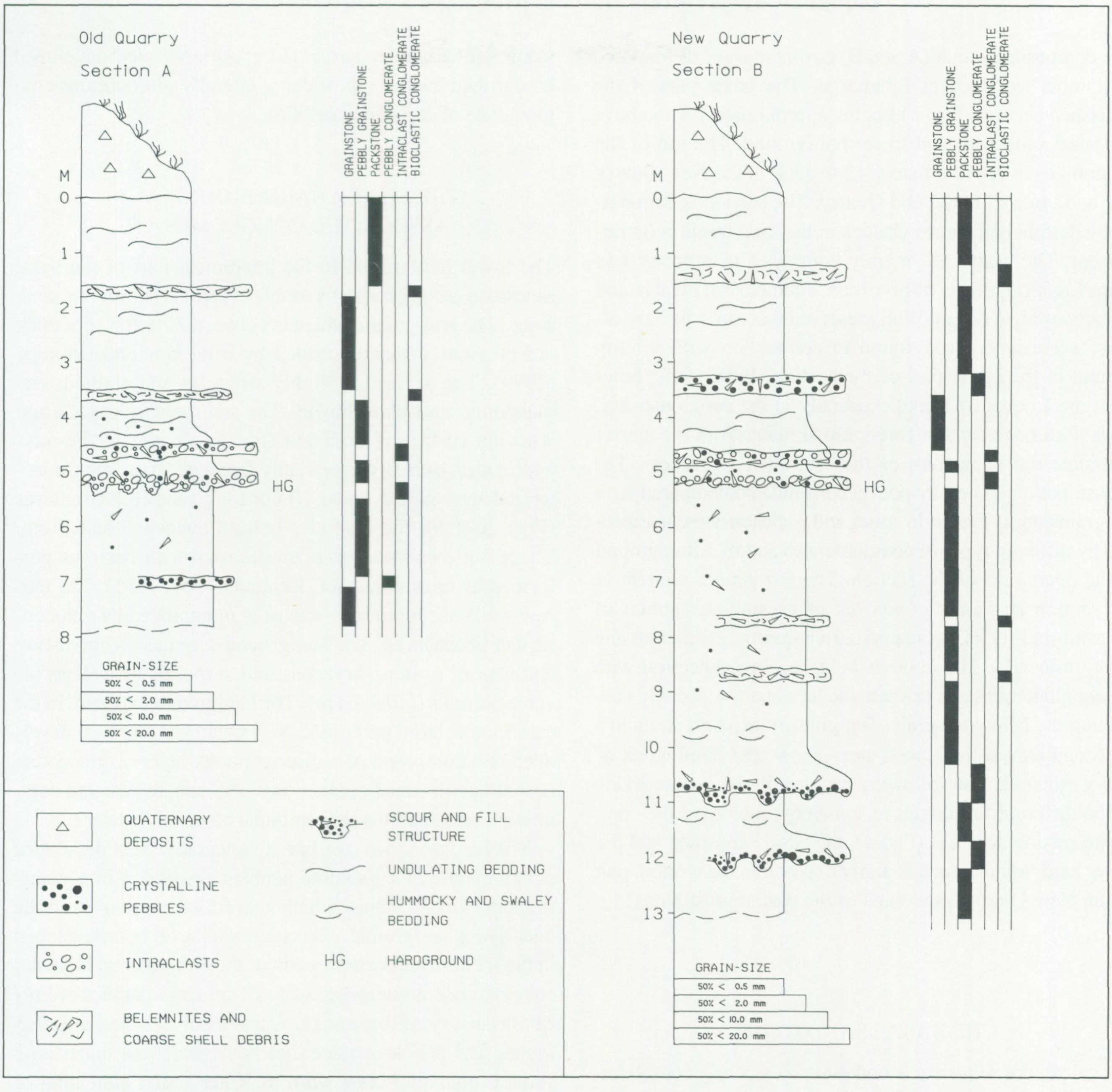


Fig. 4. Sedimentologic logs of the Ignaberga limestone. Section A is located in the western wall of the Old Quarry and section B in the south wall of the New Quarry (cf Fig. 2).

## General description of the lithological sequence

The composite section (A and B) covers most of the exposed limestone sequence at Ignaberga. The basal part of the described section (Fig. 4) begins approximately 4 m above the basal sandstone and lower hardground. The top of the section lies at approximately 42 m.a.s.l. in the New Quarry and at 52 m.a.s.l in the Old Quarry. The section is dominated by detrital calcareous clastics in the sand fraction (grainstones). The grains are mainly composed of more or less worn fossil fragments of bryozoan, echinoderm, bivalve and calcareous algal origin. Well preserved macrofossils have almost exclusively been found in connection with a hardground in the upper part of the section. Belemnites, however, are frequently found especially in the conglomerates. Beds with considerable fine-grained material in the matrix dominate the upper part of the section (packstones). The packstones are generally poorly consolidated compared with the grainstones. The grainstones and packstones are interbedded by different types of conglomerates and by a hardground in the upper part of the section. The terrigenous content in the section is mainly composed of crystalline pebbles of Precambrian rocks, monocrystalline quartz, glauconite and heavy minerals. The content is higher in connection with the conglomerates and towards the basal part, especially concerning the heavy minerals. Temporarily exposed strata in a deepened part of the New Quarry show clear lamination of heavy minerals. The following pages will give a description of the different lithologies at Ignaberga including the composite section A and B (Fig. 4), the basal sandstone and the lower hardground which is partly exposed in the western part of the New Quarry as well as in the easternmost part (Fig. 11).

### THE BASAL SANDSTONE

The calcareous sequence is underlain by a poorly consolidated sandstone, the upper part of which is exposed in the basal part of the quarried sequece in the western and eastern parts of the New Quarry. The sandstone is according to borings up to 30 m thick and rests directly on top of the weathered Precambrian basement. The sandstone is thicker in basement depressions, thus partly levelling out the pre-Cretaceous relief in the area. The sandstone is characterized as a medium-grained calcareous quartz-arenite. Granular glauconite occurs frequently and gives the sand a slight greenish colour. Feldspars and crystalline rock fragments are also relatively common. The carbonate content varies between 20 and 40% being significantly lower in the basal parts. The calcareous component occurs mainly as fine-grained matrix and poorly developed cement. Fossil fragments are rare and strongly abraded. Shark teeth, however, are quite common. The sandstone is overlain by an irregular, variably well developed hardground and on top of that a laterally discontinuos conglomerate of crystalline pebbles.

### THE LOWER HARDGROUND AND ASSOCIATED CONGLOMERATE

The lower hardground in the uppermost part of the basal sandstone is composed of variably cemented calcareous sandstone. The hardground which is between 20 and 30 cm thick has previously been described by Birkelund and Bromley (1979). The surface is highly irregular and stained with glauconite and phosphorite. The sediment in association with the surface is occasionally discoloured by Fe-oxy-hydroxides. Burrows are variably frequent. These are characterized by winding up to 20 cm long tube-like structures (Figs. 5 & 6), the diameter being between 1 and 2 cm. These burrows show great similarities with burrows performed by crustaceans (cf. Kennedy 1967, 1975). The burrow-walls are commonly intensely mineralized by glauconite and phosphorite. The hardground contains an encrusting epifauna of oysters, bryzoans and serpulids as well as bivalve burrows (*Lithophaga*). The hardground exposure in the easternmost basal part of the New Quarry is less well developed and composed of a discontinuous layer of glauconite coated cobble-sized concretions. The concretions are commonly encrusted by a rich epifauna of mainly oysters.

The hardground is overlain by a variably well developed conglomerate of crystalline pebbles embedded in a grainstone-packstone matrix which also fills the burrrows in the underlying hardground. The conglomerate is best developed in the western and eastern parts of the New quarry. Here the conglomerate is composed of 5–20 cm large pebbles of Precambrian crystalline rocks. Occasional cobbles are also found. The pebble surface that lies against the underlying strata is commonly less worn by water action indicating *in situ* position of most pebbles. The pebble crests and sides are also frequently encrusted by an epifauna of serpulids, bryozoans and oysters. Shark teeth and belemnite rostra are commonly found in the conglomerate, especially in the eastern part where the pebble size is slightly smaller.

### GRAINSTONE

The exposed sequence is dominated by grainstones which are dominantly massive and structureless. However, preserved bedding structures occur, especially in the basal part in association with the pebble conglomerates (Fig. 7). These structures consist of alterations of concave (troughs or swales) and convex (hummocks) laminations, and numerous undu-

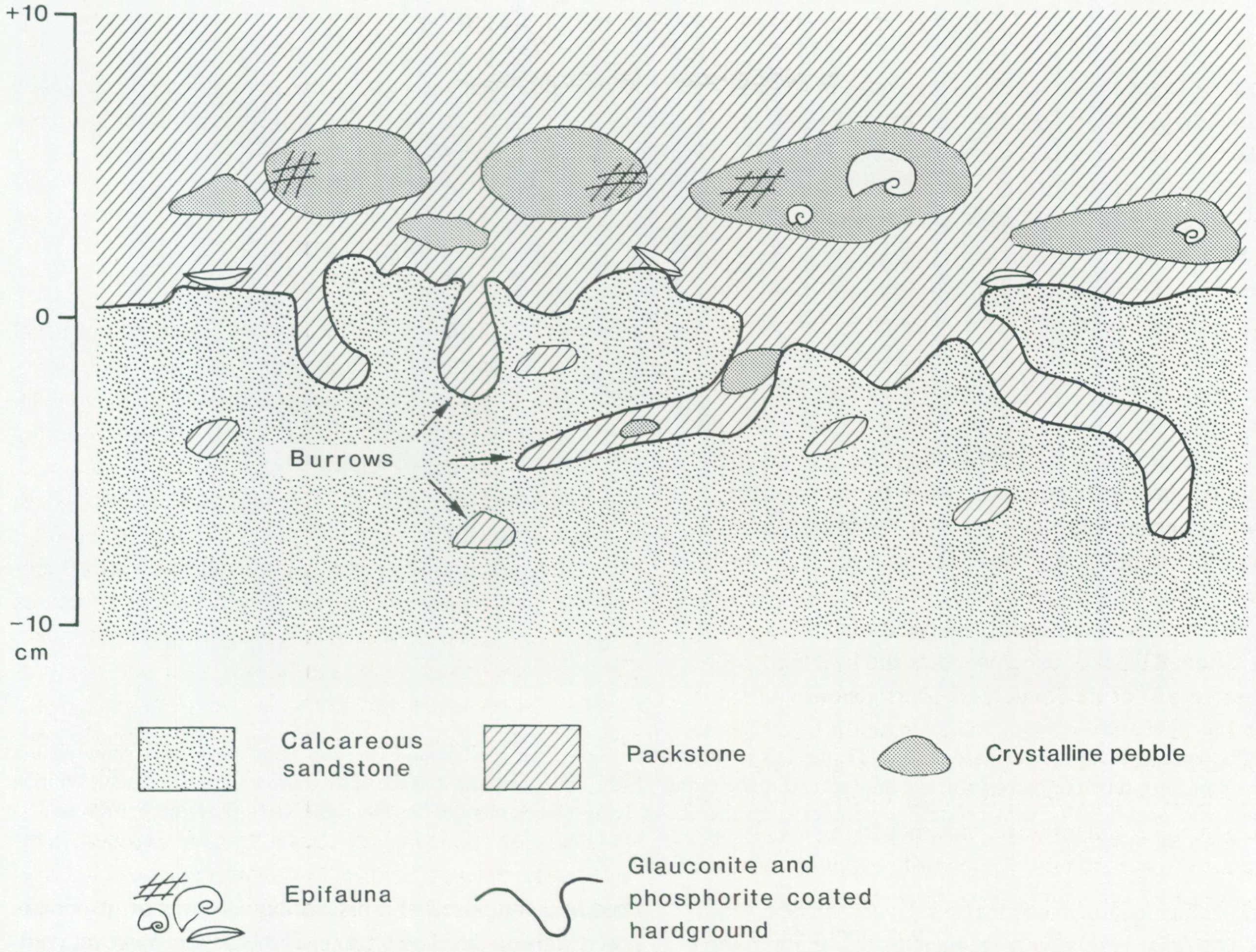


Fig. 5. Schematic illustration of the lower burrowed hardground and associated conglomerate from the western basal parts of the New Quarry.

lating erosion surfaces. The laminae dip generally less than 10° and there is generally a distance of more than one metre between the swales. Large scale trough cross-bedding and mega-ripples are occasionally found slightly higher up in the sequence (cf. Surlyk 1980). The lithology comprises moderately sorted yellowish-white medium- to coarse-grained more or less clean-washed shell fragment limestone. The bioclastic components are mainly composed of broken, abraded and partly micritized echinoderm, bivalve, coralline algae and bryozoan fragments (Fig. 8A). Subrounded, fine- to medium-grained quartz grains comprise up to 15% of the sediment. Heavy minerals (ilmenite, zircon and garnet) also occur especially in the basal parts of the section in association with the pebble conglomerates. The pores in the rock are variably filled with micritic mud of varying origin, probably from both internal and external sedimentation. The grainstone is bound together by tangential, meniscus, syntaxial cement and to some extent by micritic mud (Figs. 8A & 8B). Scattered pebbles of Precambrian rocks are common in some beds. The pebbles are generally >5 cm in diameter, however, a few decimeter-large pebbles are also found. The pebbles are commonly coated with glauconite and encrusted by an epifauna of oysters, bryozoans and serpulids. The surface is generally strongly worn and abraded indicating long exposure to water action. The micritic mud content increases overall upwards in the section and the grainstones give way to packstones.

## PACKSTONE

Packstones are mainly found in the upper part of the section, beside a few packstone beds in the lower part. The packstone lithology is composed of micritized strongly abraded fossil fragments of mainly echinoderm origin in a micritic matrix (Figs. 8B & 8C–F). The micritic mud content is between 10–30%. Occasionally the packstones are on the limit of being characterized as wackestones due to intense micritization of the grain-supported fabric. The packstones are generally poorly consolidated (Fig. 8E). Some beds are, however, relatively indurated by a microsparitic cement (Fig. 8C). The terrigenous content is generally less than 10%, usually around 5%, and composed of fine-grained

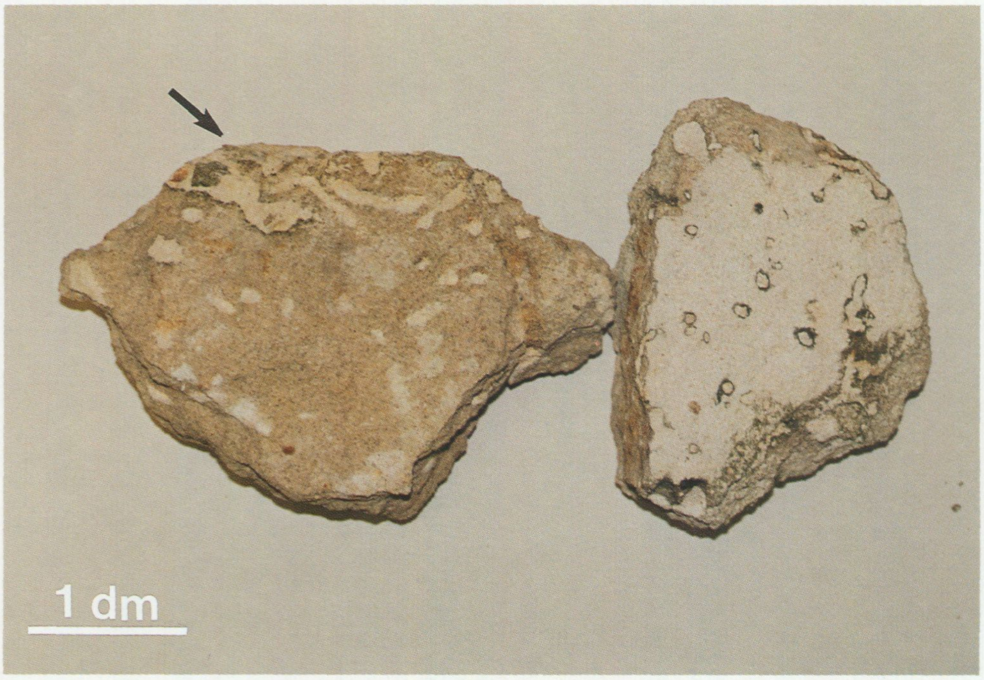


Fig. 6. Photograph of the lower hardground. To the left a vertical section of the hardground (the top is at the arrow) showing the occurrence of long tubelike burrows in the hardground, penetrating 15–20 cm below the surface. The burrows are filled with whitish grainstone and occasionally with crystalline pebbles from the above lying conglomerate. To the right the top of the hardground is shown. Photo M. Erlström.

monocrystalline quartz, some feldspar grains and heavy minerals. Glauconite is relatively frequent as 0.2–0.5 mm large grains.

## CONGLOMERATES

The exposed sequence at Ignaberga displays several conglomerates and conglomeratic layers interbedded in the grainstones and packstones. Beside the basal conglomerate on top of the lower hardground there exist at least 8 different conglomerates in the investigated sections. Their lateral extension and character varies and it is difficult to correlate individual beds exactly between the south and north side of the New Quarry due to discontinuous exposures. Further, there are also local variations in dip of the layers, most likely related to the subsurface relief of the Precambrian crystalline basement, which makes it diffcult to correlate. The conglomerates are of three different types. The most common variety is the pebble conglomerate. Shell fragment conglomerates and intraclast conglomerates are less frequent. In the investigated section and over most parts of the southern wall in the New Quarry and in the Old Quarry there is one significant composite bed beginning with a hardground overlain by an intraclast and pebble conglomerate which occasionally becomes divided into two beds as in the described section. This level is referred as the upper hardground and associated conglomerate by Surlyk (1980).

*Pebble conglomerate:* This variety is common in all exposed walls in the New Quarry. The beds are, however, variably well developed and could occasionally be characterized as a very pebbly grainstone. The relation between pebbles and fossil fragments (mainly belemnites) in the beds vary, however, pebbles of crystalline origin are in majority. The pebbles are on average between 2 and 5 cm in diameter and mainly composed of Precambrian crystalline rocks (gneiss, granite and dolerite). Sedimentary rocks such as sandstones, limestones, and phosphorite and limonite nodules are also found. The sandstone pebbles are composed of a silica cemented medium to coarse-grained quartzarenite, occasionally with some mudclasts. This lithology is very like sandstones of Jurassic age (Höör sandstone), today outcropping approximately 30 km to the SSW of Ignaberga. Belemnites and thick-shelled bivalves and occasional vertebrate fragments are also found in the beds. The pebbles are generally rounded and worn by water action. Glauconite is found as coatings on most pebbles. An encrusting epifauna occur on a few pebbles. An enrichment of medium-grained quartz and heavy mineral grains (ilmenite, rutile and zircon) is often found in association with the beds. The pebble conglomerates are mainly normally graded and associated with bag-like excavations along the erosive basal surface. These are filled with pebbles and fossil fragments (Fig. 9 & Table 1). The structures were already observed by Moberg (1884, 1888) but have since then not been given any further notice. Hadding

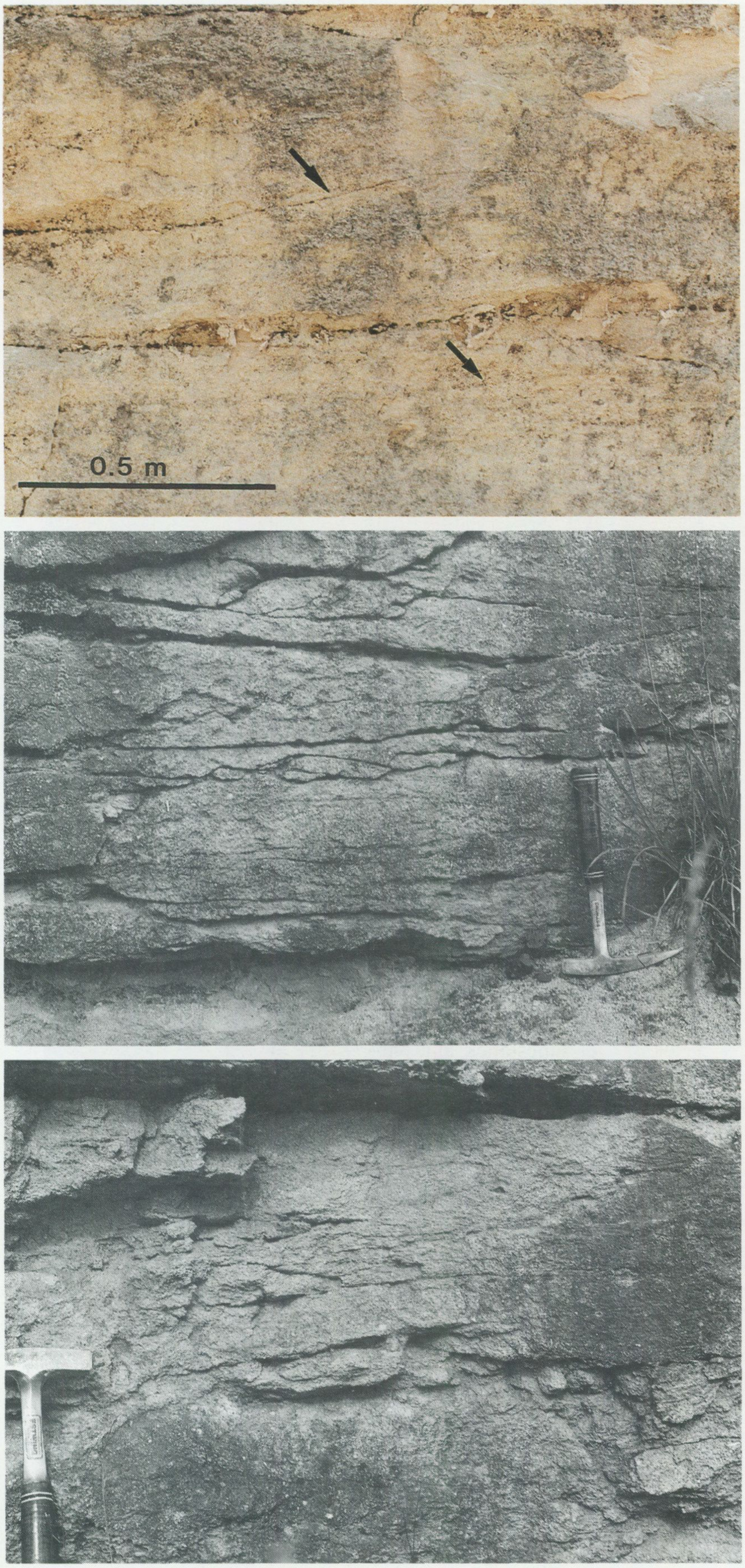


Fig. 7. Photographs showing swaley and hummocky cross stratified layers in the lower grainstone-packstone unit (cf. Fig 11). Photographs are taken in the southern wall of the New Quarry in connection with section B. Photo M. Erlström. Photo M. Erlström.

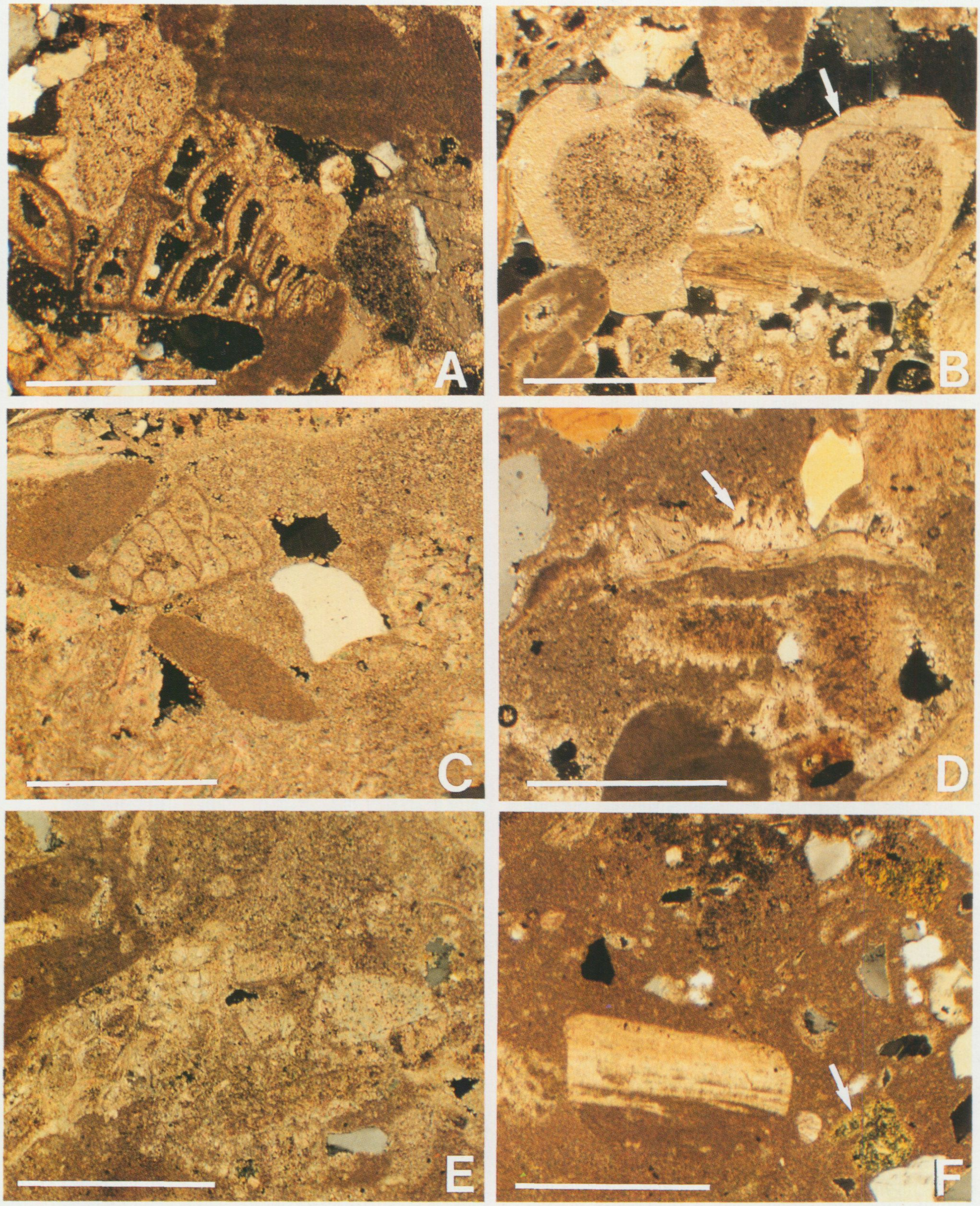


Fig. 8. Thin section micrographs. A: Grainstone dominated by bioclastic grains of bryozoan, coralline algae, bivalve, gastropod and echinoderm origin. B: Overgrowth cement (arrows) on partly micritized echinoderm fragments in the grainstone lithology. C: Packstone with microsparite and micrite filling the intergranular space. D: Circumgranular drusy microsparitic cement (arrow) fringing bioclastic grains in the packstone lithology. E: Packstone dominated by more or less micritized bioclastic fragments and micrite. F: Dense biomicritic packstone texture with quartz grains and glauconite (arrow). Scale bar 0.1 mm. Photo M. Erlström.

Table 1. Characteristics of 24 bag-shaped scour and fill structures in the basal part of the New Quarry.

| Character | Frequency |
|---|---|
| **Shape** | |
| Symmetric | 13 |
| Asymmetric | 11 |
| **Type of fill** | |
| Pebbles | 1 |
| Pebbles>fossils | 6 |
| Pebbles=fossils | 5 |
| Pebbles<fossils | 6 |
| Fossils | 6 |
| **Distribution of fill** | |
| Uniform | 7 |
| Graded | 1 |
| Heterogeneous | 16 |
| **Size** (width/depth) | |
| <1.0 | 1 |
| 1.0-3.0 | 15 |
| 3.0-5.0 | 5 |
| >5.0 | 3 |

(1927) cites Moberg's findings and descriptions since he was unable to find any at the time of his investigation of the Ignaberga conglomerate and limestone. In the southern wall in association to the investigated section in the lower two conglomerates there are several of these structures present. They are on average 40–60 cm deep and about equally wide (Fig. 9). An assymmetric outline is about equally frequent as a symmetric one. The pebbles in the bag-like structure are mainly concentrated against the sides of the structure (Table 1). The pebble conglomerates are generally overlain by a variably thick (0.5–1.0 m) interval with undulating laminations succeded by swaley and hummocky cross bedded grainstones with scattered pebbles.

*Shell fragment conglomerate:* These conglomerates are mainly found in the upper part of the studied section and corresponding levels in other parts of the Old and New Quarry. The 10–20 cm thick beds are laterally discontinuous, variably well developed and commonly associated with a basal erosion surface. The conglomerates are dominated by cm-large fossil fragment and belemnites. The terrigenous content is generally low apart from some scattered crystalline pebbles. The matrix is composed of a coarse grainstone cemented by epitaxial sparite.

*Intraclast conglomerate and associated (upper) hardground:* Intraclasts of relatively well indurated packstone and wackestone are found in most of the investigated conglomerates. One composite bed, however, in the section at the 5 m level is dominantly composed of intraclasts. The bed is especially well developed in the southern wall of the Old Quarry (Fig. 10). The bed is locally divided into two separate layers and interbedded by a pebbly coarse grainstone. The clasts are between 5–10 cm in diameter and composed of a packstone lithology similar to the underlying hardground. The clasts are frequently coated with phosphorite and glauconite. The intraclast bed which overlays a variably well developed hardground can be followed over most parts of the New Quarry as well as the Old Quarry. The underlying hardground is best developed in the Old Quarry where it is composed of a relatively well indurated packstone. It is also found in the New Quarry and has been referred as the upper hardground by Surlyk (1980). The hardground surface is highly irregular with numerous cavities. Loose fist sized fragments of the

Fig. 9. Photographs showing the characteristics of the pebble conglomerates and associated bag shaped scour and fill structures. The photographs are taken from the basal part of section B in the southern wall of the New Quarry. Photo M. Erlström.

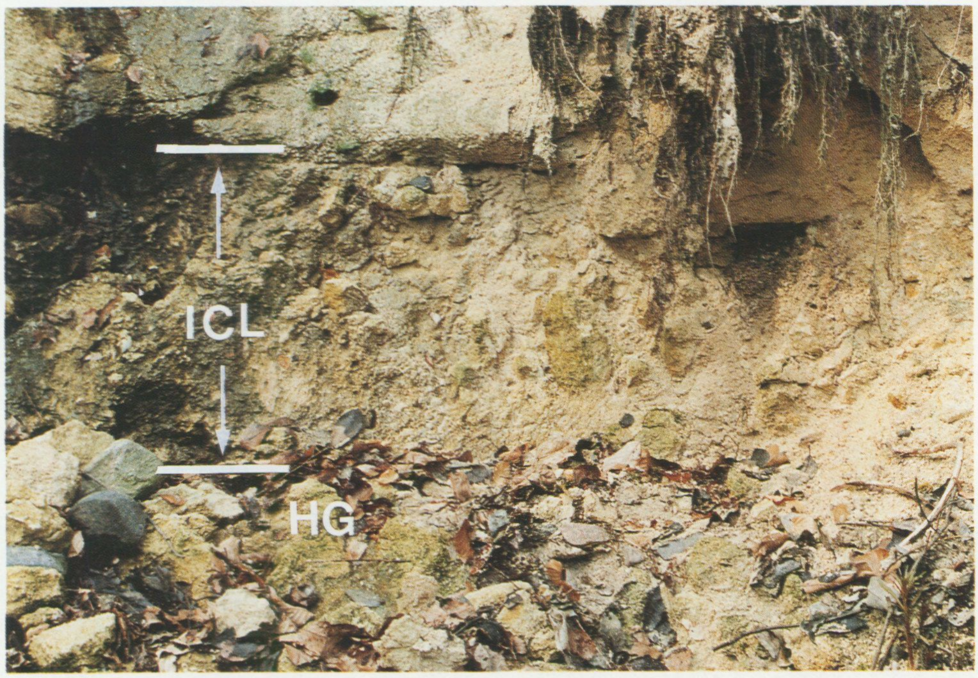


Fig. 10. Photograph of the intraclast conglomerate in the southern part of the Old Quarry. The bed is approximately 0.5 m thick and in this part of the quarry composed of firm packstone intraclasts embedded in a soft grainstone matrix. The clasts are commonly coated with glauconite. ICL: Intraclast layer, HG: hardground. Photo M. Erlström.

hardground are found resting on the surface. These fragments were probably formed as a result of broken overhangs produced by undermining cavities. The surface is coated by glauconite and phosphorite, and partly colonized by an encrusting epifauna of mainly oysters. Burrows have not been found. The above laying conglomerate is in majority composed of intraclasts. A thin layer with numerous relatively well preserved macrofossils occurs in the basal part of the intraclast conglomerate. The fossils include mainly thickshelled bivalve and brachiopod species apart from numerous belemnites. In the upper part of the composite bed intraclasts still constitute a major component but pebbles of crystalline origin are also fairly abundant especially in the New Quarry to the north. The intraclast conglomerate is embedded with an unlithified coarse grainstone.

## Geochemistry

Beside analytical data received from Ignaberga Kalksten AB a multicomponent analysis has been performed on eight samples from different levels in sections A and B. The sample positions are given in Table 2. The carbonate content in samples from the quarried part of the sequence varies between 85 and 95% according to analyses performed by Ignaberga Kalksten AB. The carbonates are composed of high magnesium calcites containing between 0.1 and 3% $MgCO_3$ (Bruun-Petersen 1975). The $FeCO_3$ content is below 1%. The terrigenous related elements varies between a few % up to slightly less than 15% in the investigated samples. Apart from $SiO_2$ there are only minor amounts of the other analyzed elements (Table 2). These constitute generally less than 2% of the samples and are mainly related to the occurrence of glauconite and heavy minerals. Relatively high amounts of $TiO_2$, $Fe_2O_3$ and Zr are found in the basal samples which is related to the occurrence of heavy minerals of ilmentie, rutile and zircon. The intraclast sample from the intraclast conglomerate shows a relatively high $P_2O_5$ content which probably relates to the phosphorite clast coatings. Of 19 trace elements analyzed only six of these (Sr, Ba, Zr, Zn, Cr and Y) occur in detectable amounts. Apart from Sr which increases slightly upwards in the section the trace elements do not indicate any major change in the depositional environment. The Sr/Ca ratio in skeletal carbonates is to some extent related to the palaeoenvironmental temperature, the higher the Sr content the lower the temperature (Kinsman 1969). Deviations in the Sr/Ca ratio in the inves-

Table 2. Chemical composition of eight samples from section A and B. The given levels are related to the intraclast level.

| | Old Quarry (OQ:9) +4 m | Old Quarry (OQ:8) +2 m | Matrix in intra-clast cgl. | Intra-clast | Hard-ground below intra-clast cgl. | Old Quarry (OQ:1) -1 m | New Quarry (NQ:11) -6 m | New Quarry (NQ:13) -8 m |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 5.24 | 8.92 | 6.11 | 5.21 | 4.32 | 2.36 | 5.11 | 11.80 |
| $Al_2O_3$ | 0.362 | 0.622 | 0.461 | 0.395 | 0.358 | 0.216 | 0.312 | 0.743 |
| $Fe_2O_3$ | 0.250 | 0.250 | 0.431 | 0.343 | 0.309 | 0.143 | 0.183 | 0.749 |
| $K_2O$ | 0.142 | 0.241 | 0.132 | 0.125 | 0.094 | 0.058 | 0.123 | 0.317 |
| $Na_2O$ | 0.071 | 0.129 | 0.096 | 0.060 | 0.053 | 0.035 | 0.047 | 0.116 |
| MgO | 0.417 | 0.397 | 0.478 | 0.556 | 0.561 | 0.463 | 0.470 | 0.452 |
| MnO | 0.060 | 0.045 | 0.053 | 0.055 | 0.050 | 0.063 | 0.035 | 0.049 |
| CaO | 52.6 | 48.0 | 52.7 | 52.5 | 53.5 | 54.5 | 52.9 | 49.5 |
| $P_2O_5$ | 0.059 | 0.065 | 0.102 | 0.405 | 0.171 | 0.040 | 0.053 | 0.129 |
| $TiO_2$ | 0.028 | 0.045 | 0.075 | 0.114 | 0.109 | 0.016 | 0.022 | 0.473 |
| $CO_2$ | 39.8 | 37.2 | 39.5 | 40.8 | 40.5 | 41.3 | 40.1 | 35.4 |
| Sum (%) | 99.0 | 95.9 | 100.1 | 100.6 | 100.3 | 99.2 | 99.4 | 99.7 |
| Sr (ppm) | 265 | 346 | 300 | 254 | 259 | 232 | 233 | 249 |
| Ba | 32 | 56 | 33 | 31 | 29 | 20 | 31 | 63 |
| Zr | 42 | 75 | 123 | 261 | 205 | 62 | 42 | 818 |
| Zn | 8 | 10 | 12 | 15 | 14 | 15 | 21 | 19 |
| Cr | 4 | 14 | 11 | 12 | 26 | 8 | 16 | 37 |
| Y | 2.5 | 3.4 | 4.6 | 7.7 | 5.8 | 2.6 | 3.4 | 14 |

tigated section is most significant above the upper hardground. If this change could be related to a change in temperature is uncertain, even if there are an increased amount of fine-grained carbonates in the beds indicating slightly deeper conditions and perhaps also a corresponding change in water temperature. A similar change is also found above the hardground and associated conglomerate at Ullstorp, described by Erlström & Gabrielson (1986). Below the hardground the Sr content is 200–250 ppm while it is 300–350 ppm in above lying carbonates.

## Fossil assemblage and palaeoecology

### MACROFAUNA

Several studies have been performed on different fossil groups from the Ignaberga quarries. The preserved fauna is dominated by molluscs, bryozoans and brachiopods.

Lundgren (*in* Lindström 1877) was the first to describe the fossil composition of the limestone at Ignaberga. Moberg (1884) and Lundgren (1894) compiled a comprehensive listing of the macrofaunal species. Lundgren (1894) also made estimations concerning the relative frequency of different mollusc species. Lundegren (1934) and Troedsson (1954) made a similar and somewhat extended listing of the most common species.

Beside these studies there are several monograph papers on different fossils groups from the Kristianstad Basin. These contributions also give valuable information concerning the composition of the fauna at Ignaberga.

Carlsson (1938) described the bivalves from the Malm collection including *Trigonia buchi* which mainly inhabited coarse-grained bottoms. Lundgren (1876) also noted the presence of numerous inoceramid fragments in the sediments, probably of at least two different species. Inoceramid fragments are especially frequent in association with the upper conglomeratic levels in the northeastern part of the New Quarry. Moberg (1884), Lundgren (1894) and Lundegren (1934) found that the bivalve fauna is dominated by oyster species and free-living pectinids. The fauna is conspiciously free of infaunal species which could be related to an unsuitable living enviroment or selective preservation of these different groups.

The cephalopods have been described in detail by Moberg (1884, 1885) and by Christensen (1975). *Belemnellocamax mammillatus* is the most common species especially in connection the conglomerate levels. *Belemnitella mucronata* and *Gonioteuthis quadrata scaniensis* are also present in the deposits. Additional belemnite species of the genus *Gonioteuthis* are found in the uppermost part of the basal sandstone unit (pers. com. M. Siverson; W. K. Christensen 1991). Only two ammonite species have been described from Ignaberga, *Ammonites stobaei* (Moberg 1884, 1885) and *Hauericeras* cf. *pseudogardeni* (Birkelund & Bromley 1979), the latter coming from the uppermost part of the basal sandstone unit.

The gastropods are few and are generally found as very small fragments or internal moulds. Two individuals representing two different species have been described by Carlsson (1938).

Lundgren (1885) made a comprehensive listing of 20 brachiopod species found at Ignaberga. Later Hägg (1947) made a similar slightly revised listing of the brachiopod fauna. Carlsson (1938, 1958) revised the genus *Crania* and mentioned the occurrences at Ignaberga. Hadding (1919) investigated and revised the genus *Terebratula*, however, without any specific data concerning the occurrences. In 1938 Carlsson made a description of the brachiopods from the Malm collection. Surlyk (1973) described the frequently occurring inarticulate brachiopod *Isocrania egnabergensisas*. The later investigation together with previous contributions show that the brachiopod fossil assemblage is dominated by rather thick shelled species characteristic of a high energy inner shelf environment, e.g. current swept shoals.

The bryozoans were described by Hennig (1892, 1894). His listing included six Cheilostomataceans and eleven *Cyclostomatous* species from Ignaberga. Brood (1972) improved the knowledge concerning the *Cyclostomatous* bryozoan fauna. He concluded that the bryozoan fauna at Ignaberga indicates a shallow to moderately deep and agitated living environment. The bryozoans were also mainly characteristic of a firm substrate such as shells and stones. Only a small part of the fauna seems to have been living attached to algae (cf. the foraminiferal microfauna).

The echinoderm fauna is mainly found as spine and plate fragments. Lundgren (1880) identified two fragments as belonging to the genus *Hemipneustes*. Spines and plates from the genus *Cidaris* occur frequently as well as fragments of Ophiruids. Beside the fragmented echinoderms there is a relatively well preserved fauna of small *Salenia areolata* echinoid specimens.

The fauna at Ignaberga also includes significant numbers of sponges, corals, serpulids, and arthropods. These faunas are unfortunately not as well documented. Most of these fossils were, however, more or less adapted to a firm or at least stable substrate.

Fragments of coralline algae constitute up to 10% of the sediment (Bruun-Petersen 1975). The occurrence of other algae is indirectly verified by presence of epifaunal microfossils, e.g. foraminifers (cf. Gabrielson 1991) and bryozoans (Brood 1972).

Shark teeth are relatively common in the sediments. Evidences of a marine reptile fauna are scarce but vertebrae and limb-bones from Pleisosaurians and teeth from Mosasaurians have been identified (Persson 1959).

The above mentioned contributions have all added to the understanding of the fossil palaeocommunity. An additional important contribution is given by Bruun-Petersen (1975) who describes the shell-fragment composition of the grainstones. His results show a fauna dominated by molluscs and brachiopods (17–34%), echinoderms (10–27%), bryozoans (8–25%), and also coralline algae (5–10%). By this he concludes that the fossil fauna resembles an inner shelf community. Surlyk (1980) describes the shell-bearing fossil assemblage as partly resembling a diluted fauna present in a rocky coast line environment similar to the environment at Ivö Klack (Surlyk & Christensen 1974).

The fossils found in connection with this investigation all fit into the palaeoenvironmental pattern implied by previous authors. The fossils in the described section include mainly fragments of thick-shelled bivalves, brachiopods, bryozoans, regular echinoids, corals, coralline algae, ophiruids and belemnites. Especially one layer immediately above the upper hardground in the Old Quarry contains a high number of relatively well preserved macrofossils (Table. 3). The fossil assemblage in this layer is significantly enriched in sedentary species. The fossils could either been living on the underlying lithified hardground or derive from a nearby rocky coast habitat. The scarcity of a shelly infaunal species in the macrofauna is conspicious. This is probably a result of a rapidly changing character of the environment, thus numerous events of reworking and deposition of the bottom strongly affected the infaunal habitat. It

Table 3. Major faunal components found in connection with the intraclast layer in section A, in the Old Quarry, and their implication of living environment.

| Faunal element | Substrate | Way of living |
|---|---|---|
| Oysters (Ostrea) | Lithified | Epifauna |
| *Magas* sp. | -"- | -"- |
| *Chlamys* sp. | -"- | Free-living |
| Craniaceans | Firm | Epifauna |
| Terebratulids. | -"- | -"- |
| Regular echinoids. | -"- | Free-living |
| Ophiruids | Various | -"- |
| Corals | Lithified | Epifauna |
| Bryozoans | Firm | Epifauna |

should not however be forgotten that crustaceans (*Calianassa* sp.) were most likely quite numerous, even if they are not preserved as fossils. Their burrows are occasionally found in association with hardgrounds. Especially the lower hardground contains frequent evidence of their presence in the fossil community. Their burrowing activity would most likely give a more or less totally bio-turbated sediment. The preservation of the burrows was however poor due to the dominantly loose character of the bottom sediments.

The environment was furthermore probably inhabited by faunal elements about which unfortunately very little is known because their poor state of preservation.

## MICROFAUNA

The calcareous microfauna has been investigated in 16 different samples (each 200 g). The fauna is dominated by foraminifers and ostracodes. The samples were collected both in the investigated sections A and B and at different positions within the Old and New quarry (sections C–F) to get an overall idea about microfaunal distribution in the area. In the basal central western part of the New Quarry samples were taken in connection with a preserved shoal structure. The sampled levels are related to the intraclast conglomerate which is considered as a reference bed within the Ignaberga area (Table 4).

The samples contained on average 100 foraminifers and 5–10 ostracodes. The highest frequencies, 250–300 foraminifers and 40–50 ostracodes, were encountered in samples taken in connection with shoal structures in the basal central part of the New Quarry. The number of foraminifer species varies between 11 and 34. Again the most diverse fauna was found in the samples from the shoal structures. The diversity of the foraminifer fauna was measured by the use of Fisher $\alpha$-values (cf. Fig. 4 in Murray 1973). The values for the Ignaberga samples show that there is a correlation with distance to the paleoshore to the south as well as the vertical position in the lithological sequence. The lowest values are thus related to the proximal samples close to the paleoshore, i.e. Nävlingeåsen horst, and in the basal parts of the lithological sequence. The highest values are found in the samples from the shoal structures and some levels in the above lying beds. The values show however a large spreading which most likely reflects temporary variation in paleoenvironment and depositional conditions. In general the Fisher $\alpha$-values indicate an inner neritic to nearshore environment (cf. values for the Gulf of California, Bandy 1961). Interesting to note is the discrepancy in number of specimens and diversity of the fauna between the Ignaberga and Ullstorp localities. At Ullstorp the foraminiferal fauna is much richer and on average several thousand specimens were found in each grainstone sample (Erlström & Gabrielson 1986). This could be explained by more open marine conditions at Ullstorp compared with Ignaberga.

The foraminiferal fauna at Ignaberga is divided into 12 groups, i.e. agglutinated, planktic, benthic biserials, Polymorphinids, Nodosariaceans, *Praebulimina*, other Buliminaceans, attached forms, low trochospirals, compact built Rotaliids, *Stensioeina-Osangularia* and finally a group of miscellaneous species (Others). The groups are based on work by Gabrielson (1991).

The attached foraminifers and the Polymorphinids constitute the most important groups in the samples from Ignaberga. The attached forms are the dominant species in most samples although Polymorphinids predominate in connection with the shoal structures. The remaining groups are only represented by a few species and never constitute more than a few percent of the fauna. Representatives of the other Buliminaceans have not been found. The miscellaneous species constitute approximately 5–10% of the fauna.

The attached group which comprises as much as 40% of the fauna in some samples is represented by two species *Cibicides ribbingi* and *C. excavatus*. Both species have a typical planoconvex morphology. Their shape and way of living (attached) reflects the adaption to their living environment which most likely was dominated by high energy currents and wave action (Gabrielson 1991).

The Polymorphinids comprise up to 10% of the fauna. Common species in the group are *Guttulina trigonula*, *G. problema*, *Globulina lacrima*, species of the genus *Polymorphina* and a few specimens of the genus *Webbinella*. Specimens with ultimate fistuolose chambers are also found especially in samples from the shoal-structures. The fistuolose chambers vary in shape, from simple to test surronding forms. Pozaryska & Voigt (1985) concluded that adult

Table 4. Compilation of data concerning the foraminiferal investigation.
Positions of the named sections A–F are given in Fig. 2.

| Sample number and position in relation to intraclast layer | Number of specimens | Fishervalue and Number of. species | Dominant groups |
|---|---|---|---|
| A1: +5.5 m in section A | 77 | 6/15 | Agglut.>Attach.-Low Troch. |
| A2: +2 m in section A | 106 | 9/21 | Attach.>Polymorphs.>Nodosar |
| A3: +0.5 m in section A | 117 | 5/16 | Attach.>Nodosar.- C. B. Rotal. |
| A4: -2 m in section A | 289 | 8/29 | C. B. Rotal.>Others - Attach. |
| A5: -5 m in section A | 95 | 8/21 | Attach.>Agglut.>Polymorphs. |
| B1: -7.5 m in section B | 60 | 4/11 | Attach.>Low Troch.>Agglut. |
| B2: -8 m in section B | 116 | 6/18 | C. B. Rotal.-Attach.-Low Troch. |
| B3: -10.5 m in section B | 131 | 5/18 | Attach.>Others-Polymorphs. |
| C1: 0 m in section C | 304 | 8/29 | C. B. Rotal.>Low Troch.>Praeb. |
| C2. -1 m in section C | 124 | 9/23 | Attach.>Low Troch.-Nodosar. |
| D1: +4 m in section D | 80 | 6/17 | Attach.>Nodosar.-Low Troch. |
| D2: +2 m in section D | 119 | 10/25 | Others>Low Troch.-C. B. Rotal. |
| E1: +3 m in section E | 128 | 8/21 | Polymorph.>Nodosar.-Others |
| F1: +8.5 m in section F | 254 | 10/34 | Polymorph.>Attach.>Praebul. |
| F2: +5.5 m in section F | 171 | 11/30 | Polymorph.>Nodosar.-Attach. |
| F3: +2 m in section F | 199 | 10/30 | Polymorph.-Attach.>Nodosar. |

Polymorphinids develop large fistuolose chambes in sheltered microenvironments within high energy living environments in the littoral to sublittoral zone. At Ignaberga, however, the specimens are generally small which most likely relates to a relatively unsheltered living environment and exposure to currents and waves.

Planctic foraminifers are found in most samples. They are, however, generally small and fragmented. They are dominated by *Hedbergella* spp., while *Globigerinelloides multispina* and *Heterohelix globulosa* are less frequent. A few *Archaeo-globigerina cretacea* specimens are also found. Their presence in the sample material indicates at least temporary water communication with more open marine conditions. The poor state of preservation and dominance of small specimens indicate that they were transported into the depositional area. During this process the larger relatively fragile specimens were more easily fragmented compared with the smaller ones.

The benthic biserial foraminifers occur only sporadically in the samples. The recognized species include, *Bolininoides granulatus*, *B. decoratus*, *B. laevigatus* and *Loxostoma eleyi*.

Agglutinated species constitute up to 10% of the fauna which is relatively high compared with other parts of the Kristianstad Basin (Gabrielson 1991). Common species are *Spiroplectammina baudouiniana*, *Marssonella trochus* and *Textularia conula*.

The group of compact built Rotaliids consists mainly of the species *Alabamina dorsoplana* and *Gyroidinoides octocamerata*. Gabrielson (1991) concluded that the group favours environments with fine-grained substrates and medium to low energy conditions. The specimens found consist in the majority of juveniles.

The Nodosariaceans and *Praebulimina* groups are variably represented in the samples. There is a somewhat higher diversity of the Nodosariacean fauna in the samples from the shoal structures. The low trochospiral forms seem to be under-represented in all samples.

Ostracodes are generally uncommon in the biocalcarenitic strata, however, being relatively common in connection to the shoal structures. The species found are both represented by ornamented and smooth varieties in about equal numbers. The ornamented species show great similarities with the fauna at Malen and river Stensån in the Båstad area (Sivhed 1983). The Ignaberga species are thick-shelled and therefore identified as near-shore, coarse substrate dwellers (cf. Brasier 1980). Similar conclusions have been drawn by Sivhed (1983) for the Malen and Stensån fauna. As the specimens are generally found as whole carapaces the sedimentation rate must have been high (Oertlie in Brasier 1980).

## Palaeogeographic setting

The Kristianstad Basin is situated within the marginal zone of block faulted bedrock units which constitute the transition between the stable Fennoscandian Shield and the tectonic unstable Europe. In Scania the bedrock was affected by inversion movements in the Cretaceous which led to a subsidence of the Kristianstad area north of the Nävlingeåsen and Linderödsåsen fault zones (Bergström 1981). The bedrock surface north of the fault zones subsided and tilted to the southwest. The same pattern occurs in the offshore continuation of the Kristianstad Basin the Hanö Bay Basin (Kumpas 1980). The major episodes of subsidence took place in the Campanian (Bergström & Sundquist 1978; Norling & Bergström 1987). More extensive deposition of sediments commenced during late Early Cretaceous times in the Kristianstad basin. The depositional pattern during the Cretaceous was indirectly governed by large scale tectonic features such as increased seafloor spreading with the opening of the Atlantic, and Alpine orogenic movements in southern Central Europe (Hays & Pitman 1973; Ziegler 1982). Major transgressive pulses in Scania occurred most likely in the Albian-Aptian, Cenomanian, Early Santonian, Middle Campanian and in the Early Maastrichtian (Christensen 1975). The Late Cretaceous transgressing marginal seas invaded large parts of the continents and estimations have indicated that only 18% of the Earth´s surface was land compared with 28% today (Hancock & Kauffman 1979). The relative increase of oceanic to continental areas led to a stable climate during much of the Late Cretaceous (Hays & Pitman 1973; Hallam 1984).

Scania was as a part of the marginal zone to the Fennoscandian shield largely affected by these eustatic changes of the sea level. During the most extensive transgressions in the Campanian, most of Scania was covered by an epicontinental sea. Land was found only in the central parts of Scania in connection to the rising horsts and in the northern parts. Indications from scattered outliers and flints indicate a periodic communicating sea-link between the Båstad area and the Kristianstad Basin (Bergström 1981; Lidmar-Bergström 1982). During the Campanian or possibly the earliest Maastrichtian, areas 110–120 metres above present sea level existed as land during the maximum extension of the sea (Bergström 1981). Topographic irregularities due to pre-Cretaceous weathering resulted in the development of an irregular coastline and archipelago in the north-northeastern part of the Kristianstad Basin.

The extension and morphology of the different basins in Scania were strongly related to the inversion movements of the block-faulted bedrock (Norling & Bergström, 1987). Uplift and subsidence in connection with the major fault zones, i.e. Nävlingeåsen, Linderödsåsen and Romeleåsen fault zones, led to local variations of the depositional conditions especially reflected in the Cretaceous deposits. Findings of Silurian shale, Cambrian quartzite and Jurassic ferruginous sandstone together with Precambrian crystalline rock fragments in Campanian strata in the SW part of Scania indicate a source area quite similar in composition to what is today found to the north-northeast of the Romeleåsen fault zone (Erlström 1990). In addition, similar evidence of a mid-Scanian source area for the clastics during the Campanian is found in the deposits in the Vomb Trough. Here the conglomerates, e.g. Tosterup conglomerate, contain numerous Silurian Colonus shale fragments (Hadding 1927; Gravesen 1977; Chatziemannouil 1982; Christensen 1986). The Campanian sediments in the Kristianstad Basin display similiar evidences of a mid-Scanian source area. Conglomerates at Ignaberga contain pebbles composed of rock types characteristic of the Nävlingeåsen horst to the south (cf. Hadding 1927). The extension of this mid-Scanian land mass is not known in detail.The same is true of its duration. There are, however, indications that a land mass existed immediately northeast of the Romeleåsen fault zone in late Middle Maastrichtian time. This is evidenced by a 5–55 m thick coarse clastic deposit of deltaic origin in the Lund area of the Danish subbasin (Hansa sandstone; Erlström pers. obs.) with numerous rock fragments characteristic of the Romeleåsen horst area.

The Campanian sedimentary sequences in the Scanian depositional basins (Danish Subbasin, Vomb Trough, Kristianstad Basin, Hanö Bay Basin and Båstad Basin) exhibit quite different depositional conditions which most likely were related to some dividing land mass or barrier between the areas. In SW Scania the Campanian is composed of thick coarse-grained terrigenous clastic deposits of deltaic origin close to the Romeleåsen horst (Erlström 1990). Further out into the Danish Subbasin the deposits are dominated by argillaceous limestones. The Kristianstad Basin, Båstad Basin and the Hanö Bay Basin are on the contrary dominated by bioclastic sediments with only minor amount of terrigenous material. The explanation for this significant difference between synchronous neighbouring depositional areas, less than 100 km apart, could be related to several factors. Relatively increased uplift of the Romeleåsen horst and related areas compared with the Nävlingeåsen and Linderödsåsen horsts played most likely an important role. There is evidence that there existed a significant subsidence of the area immediately SW of the Romeleåsen fault zone as well as an uplift of the Romeleåsen horst during a much longer period than in the Kristianstad Basin where the movements along the horsts probably terminated by the end of the Early Campanian (Norling & Bergström 1987). This would naturally lead to relative stable depositional conditions during much of the Campanian in the Kristianstad Basin. There was consequently a relative small amount of terrigenous material entering the basin. The palaeocurrent pattern in the marginal basins could also contribute to the development of diffferent depositional environments. The bioclastic sedimentation in the Kristianstad Basin most likely took place in a protected shallow inner carbonate shelf bay with comparatively warm water and limited mixing with other water bodies. Occasional mixing with relatively colder waters resulted in phosphate mineralizations and omission surfaces in association with decreased carbonate production. In contrast, the Campanian strata in the SW part of Scania were deposited in connection with more open marine conditions and likely more influenced by regional current systems. This could further decrease the possibility of developing a typical carbonate shelf depositional environment in SW Scania contemporary with deposition in the Kristianstad Basin. Local variations in precipitation could also be an explanation of the difference between the two areas. A significant ridge system in the SW could result in a higher rainfall and associated erosion of the slopes bordering the Danish Subbasin in the northeast.

## Palaeodepositional environment at Ignaberga

*Previous work:* Only brief descriptions and interpretations of the depositional environment have been included in previous work and merely concluded that the limestone was deposited in a shallow water environment (Moberg 1884; Lundegren 1934; Surlyk 1973; Bruun-Petersen 1975). The apparent lack of sedimentary structures was suggested to be the result of intense reworking by burrowing organisms destroying primary structures (Surlyk 1980). However, bag shaped scour and fill structures were obviously already observed at Tykarpsgrottan (Fig. 3) by Moberg (1884) and Voigt (1929). Moberg (1884) concluded that the structures must have been formed during a short timespan. Voigt (1929) found similar structures in connection with conglomerate beds at Ignaberga, but he suggested that these were the result of sea urchins burrowing. Voigt also noted that the same levels contain oriented belemnite rostra. The intraclast conglomerate was first described by Lundegren (1934) as a glauconitic layer above a pebble conglomerate in the NW part of the Old Quarry. The same level was described by Christensen (1975) and Birkelund & Bromley (1979) as an omission surface in the western parts of the New Quarry. Surlyk (1980) described it as a second "upper" glauconitic hardground. Mörner (1983) described the same bed as a regressive sequence.

*This study:* The Ignaberga deposits were probably formed in a marginal area where the irregular Precambrian relief resulted in the development of islands and peninsulas along the northern margins of the Cretaceous sea which transgressed the area. To the south the rising Nävlingeåsen horst constituted the southern coast line. Local variations in water depth and exposure to currents and waves resulted in variations in sediment characteristics at Ignaberga. Surlyk (1973) deduced an environment largely composed of shallow water current swept shoals partly influenced by high energy nearshore conditions. A recent study by Gabrielson (1991) has indicated that the sediments were deposited in a nearshore environment within less than 20 metres water depth.

The sedimentary sequence at Ignaberga can be divided into five units (Fig. 11). These are from the bottom: the basal sandstone, the lower hardground, the lower grainstone-packstone unit, the intraclast unit and finally the upper grainstone-packstone unit. The subdivision is mainly based on the occurrence of sedimentary structures and petrological characteristics.

The basal sandstone is characterized by a high content of minerogene constituents derived from the crystalline bedrock surface. The deposit is found immediately on top of the crystalline bedrock surface and reflects the first major in-

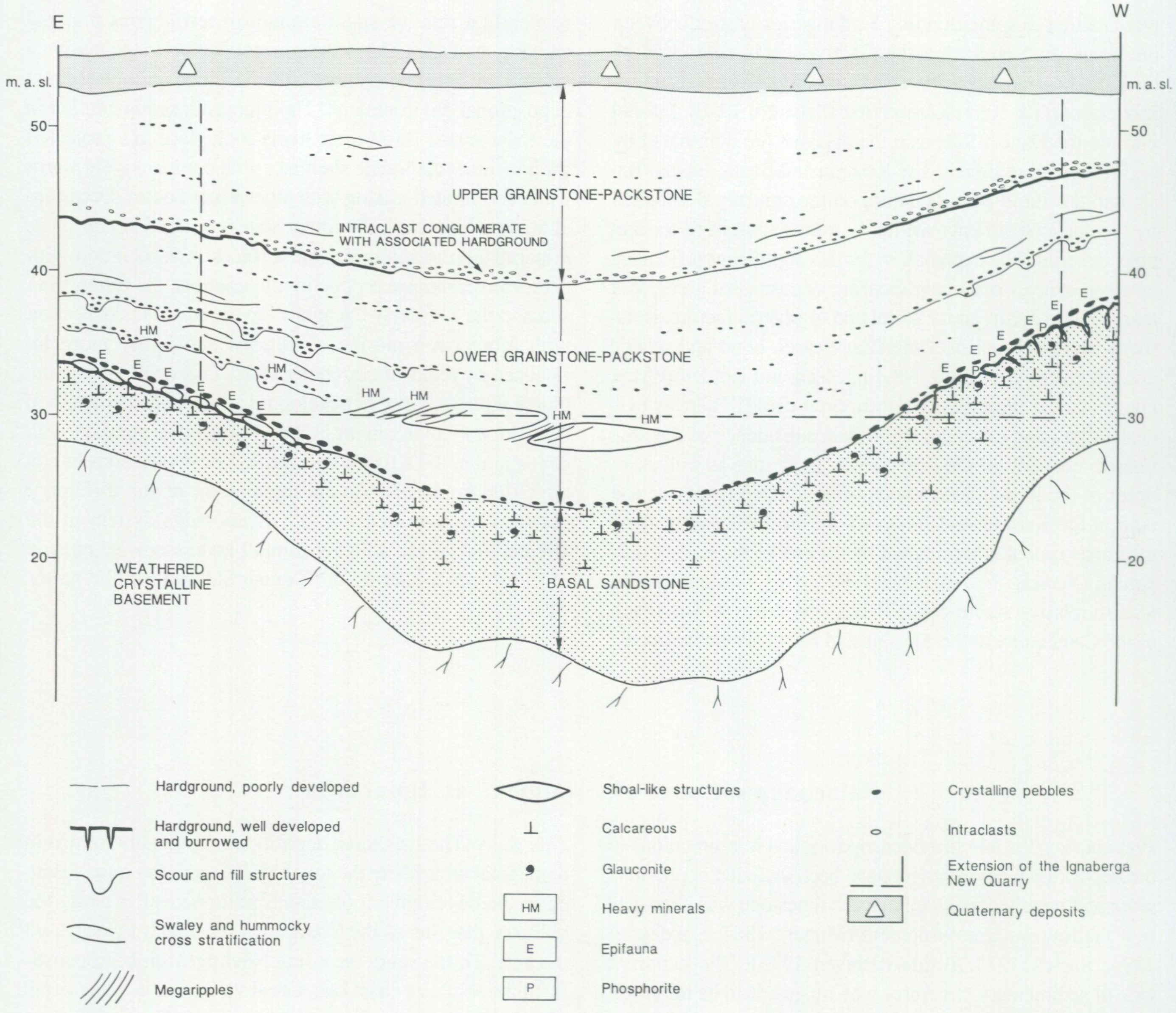


Fig. 11. Schematic illustration describing a cross-section from east to west across the New Quarry. An approximate outline of the quarry is given by the dashed line.

fluence of marine conditions in the area. The presence of Middle Santonian – early Early Campanian fossils (belemnites, ammonites) indicates that the deposit was formed during the Santonian transgression. Hence, the sea invaded areas which yielded a plentiful source of clastic material (mainly quartz) as a result of Late Jurassic weathering of the crystalline bedrock surface. The sandstone is according to borings in the area increasingly calcareous and glauconitic towards the top which indicates that the deposit was formed during a gradual transgression and that primary shoreline sands were overlain by slightly deeper seaward deposits. The lateral thickness variation of the sandstone is related to preservation of topographic depressions in the underlying crystalline basement. The presence of Cenomanian strata in the area is indicated by findings of reworked Cenomanian shark teeth in the sandstone (Siverson pers. com.).

The basal sandstone is topped by an irregular hardground which is exposed in the western- and easternmost basal parts of the New Quarry. It is variably well developed and not known to exist in the central part of the New Quarry. This local variation in hardground morphology and formation reflects most likely variations of the submarine relief, exposure to waves and currents and the paleobathymetry in the area. The formation of the lower hardground seems also to have been strongly influenced by the relief of the underlying crystalline basement. Topographic highs are verified, by data from borings, immediately below the hardground in the western and eastern parts of the New Quarry. The sub-

Cretaceous relief, approximately 20 metres (25–5 m.a.sl.), constituted most likely a major feature which influenced the paleodepositional conditions. The initial sedimentation in the area, i.e. the basal sandstone, partly levelled out the irregularities but the topographic highs continued to influece the palaeoenvironment. The exposure to currents and waves and low rate of sedimentation or non-deposition favoured the hardground formation on the submarine highs. The hardground was probably developed in slightly deeper environments compared with the basal sandstone. This is indicated by the gradual increase of carbonates and glauconite in the sandstone and phosphorite/glauconite mineralization of the hardground. The paleoenvironmental conditions prevailed long enough to enable the formation of the characteristic hardground. Intense burrowing and mechanical erosion enlarged the burrows and cavities, overhangs and hardground intraclasts were formed. In the easternmost part of the New Quarry the hardground is heavily eroded and mainly composed of a stationary intraclast lag, produced by bioturbation and mechanical erosion of the hardground. A variably well developed conglomerate occurrs on top of the lower hardground, both in the western and eastern part of the New Quarry.

The conglomerate was probably deposited in a wave dominated beach to shoreface setting based on the predominance of disc-shaped pebbles and cobbles, and the occurrence of a well developed epifauna on all pebble sides except on the one towards the underlying substrate. The epifauna of oysters, bryozoans and serpulids is similar to the fauna described by Surlyk & Christensen (1974) at Ivö Klack. The pebbles and cobbles are devoid of glauconite and phosphorite mineralizations which indicate quite different palaeodepositional conditions compared with the those prevailing during the hardground formation. Biostratigraphical evidence (ammonites, belemnites) indicates a major hiatus between the hardground and the overlying grainstone and conglomerate. Findings of *B. mammillatus* in the grainstone filling the hardground burrows gives a late Early Campanian age for the overlying grainstone. Findings of the belemnite *G. westfalicagranulata* (Christensen pers. com.), the ammonite *H.* cf. *pseudogardeni* (Birkelund & Bromley 1979) in the underlying hardground and sandstone indicate a Santonian to early Early Campanian age of these deposits. The hiatus could thus comprise much of the Early Campanian and may be related to the regressive nature of the north-european seas during this period (Hancock & Kauffman 1979; Christensen 1984). Thus, the recommenced marine sedimentation in the area began with the formation of the conglomerate layer. There must have existed a nearby positioned source of crystalline rocks based on the predominance of relatively large pebbles and cobbles in the conglomerate. Large pebbles and cobbles are mainly found in the eastern and western parts of the New quarry indicating nearby located sources, e.g. rocky coast. The conglomerate is overlain by the lower grainstone-packstone unit (Fig. 11).

The lower grainstone-packstone unit contains several bedding structures which are characteristic for nearshore deposits formed in the shoreface region between fair weather and storm wave base depths. The erosional character of basal bed planes, truncated beds and fining upward sequences with swaley and hummocky cross stratification are diagnostic features of wave induced processes (cf. Nemec & Steel 1984; Brenchley 1989). The variable distribution of these structures in the described section reflects most likely variations in water depth, wave base and position of the depositonal area in relation to exposure to waves and currents.

The large scale cross-bedding indicates the influence of current related processes in the area. Palaeocurrent measurements on mega-ripples as well as orientation of belemnite rostra give a dominant palaeocurrent direction parallel to the Nävlingeåsen horst (Fig. 12). The presence of scattered large pebbles and cobbles in the grainstone could indicate that these were brought into the depositional area by algae or seaweed and thereby more easily dragged along the bottom by the currents. The otherwise day-to-day current velocities would not be capable of transporting these pebbles.

The scour and fill structures associated with some of the pebbly conglomerates in this unit (cf. Fig. 9 & Table 1) constitute the most conspicuous depositional structures in these beds. The structures are irregularly spaced from one to several metres apart along variably well defined erosion surfaces. The three dimensional geometry is difficult to discern but the structures seem to resemble pit-like rather than gutter-like excavations. The structures are filled with a mixture

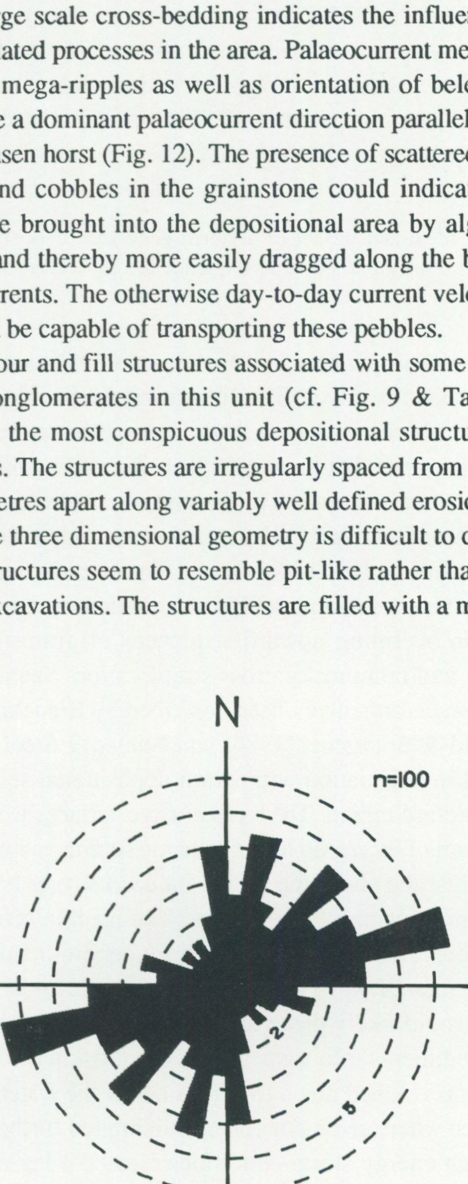


Fig. 12. Orientation of belemnite rostra in the basal conglomerates of section B.

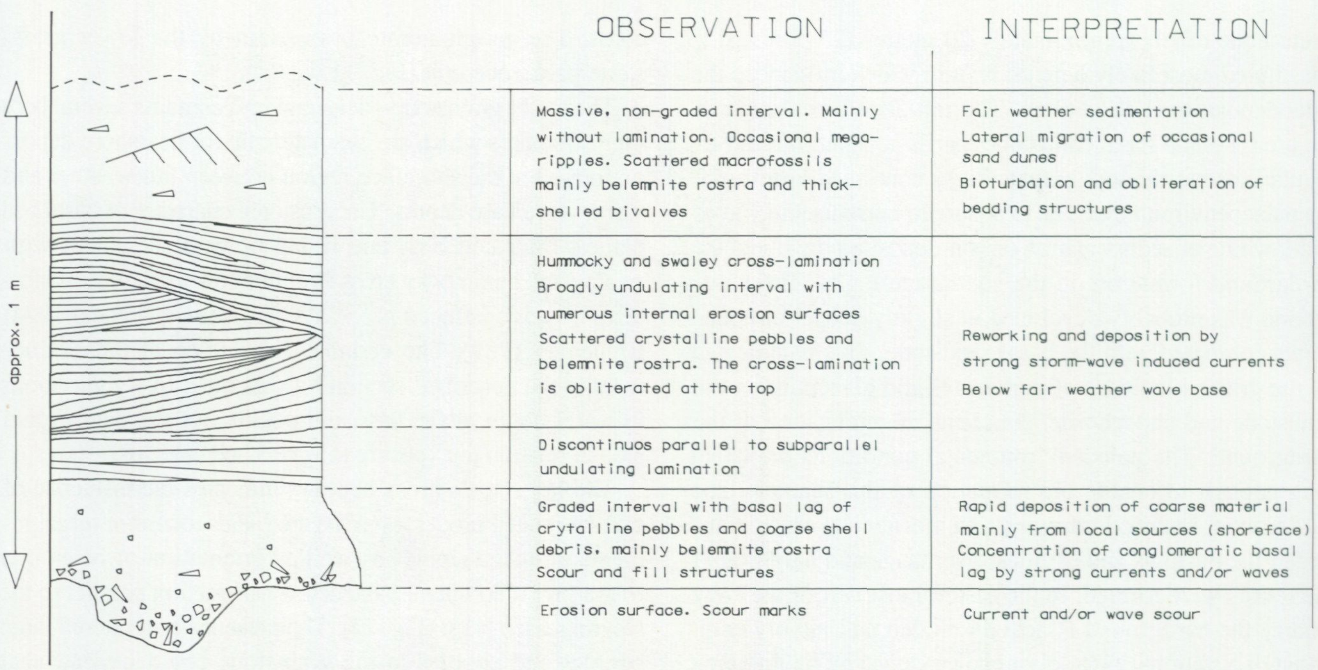


Fig 13. Idealized model of a storm generated depositional sequence in the nearshore environment (modified after Brenchley 1989). In general only parts of this sequence are preserved in the sedimentary record at Ignaberga.

of crystalline pebbles and fossils, mainly belemnites and thick shelled bivalves. The fill is most frequently asymmetric and concentrated against one side of the scour (Table 1) which suggests that the scours were formed by more or less unidirectional currents. The amount of pebbles on top of the scoured surface varies greatly and commonly there are only pebbles filling the pit-like scours. The erosion surfaces with pit-like structures and pebbly conglomerates are generally overlain by fining upward sequences of grainstones with swaley and hummocky cross stratification. Sequences like this have among others been described by Brenchley (1989), Leithold & Bourgeois (1984) and Nemec & Steel (1984) as formed in association with storm depositional sequences in the shoreface region. The basal erosive surfaces were formed as a result of increased hydrodynamic setting and wave build up against the shoreline which induced strong bottom currents and erosion of the bottom. The pit-like scours could have been created by higher energy conditions due to e.g. combination of wave induced currents and rip-currents. The storm would likely place much of the friable surface sand-sized sediments into suspension. The erosion of the bottom sediments reached down to depths below the water/sediment interface where sediment cohesion inhibited further erosion. The high energy storm conditions created a lag of pebbles and fossil fragments along the scoured surfaces and in the pit-like excavations. As the storm waned the lag deposit became covered by a sequence of fining upward grainstone with swaley and hummocky cross stratification. A major part of these sequences agrees well with an idealized model of storm generated depositional sequences (Fig. 13).

The lower grainstone-packstone unit contains beside the charcteristic storm deposited sequences also megaripples, low-angle cross-stratification with heavy mineral accumulation along the bedplanes and shoal-like structures (Figs. 11 & 14). These features verifies the interpretation that the lower grainstone-packstone unit was formed in a wave-dominated shoreface environment (cf. Heward 1981).

The lower grainstone-packstone unit is separated from the upper grainstone-packstone unit by a distinct intraclast conglomerate bed underlain by a variably well developed hardground (Fig. 11). This hardground resembles the lower one, on top of the sandstone. It is likely that suitable conditions for hardground formation existed repeatedly, although their formation seems to have been strictly local. The hardgrounds were frequently eroded which resulted in the formation of intraclasts. The intraclast conglomerate was probably formed by intense reworking of the hardground by currents and waves. In the Old Quarry the hardground is well preserved beneath the intraclast conglomerate indicating an outside source of the intraclasts in this part. The high number of thick-shelled fossils, mainly of epifaunal affinity (Table 3) and the enrichment of crystalline pebbles, heavy minerals and quartz in the bed indicate that most of the sediment derived from a more proximal nearshore area. The heterogeneous bedding and fabric indicate a more or less synchronous deposition of the intraclast conglomerate corresponding to debris flow or storm generated processes.

The upper grainstone-packstone unit is similar in characteristics to the lower unit below the intraclast conglomerate. The packstone, however, predominates slightly over the

Fig. 14. Laminations of heavy minerals in connection with the shoal structures in the basal central parts of the New Quarry.

grainstone lithology. The unit includes a few thin beds of pebbly and bioclastic conglomerates of varying lateral continuity. The conglomerates are overlain by crossbedded fining upward deposits indicating a storm origin of these deposits. The unit is overall more homogeneous which may indicate slightly deeper depositional conditions.

## CONCLUSIONS

The main part of the Ignaberga limestone was deposited during the late Early Campanian transgression. The basal sandstone below the lower hardground were, however, most likely deposited during a Santonian to early Early Campanian transgression. Cenomanian deposits have not been verified at Ignaberga but findings of reworked fossils indicate nearby located deposits. The Ignaberga limestone was deposited in a nearshore environment, mainly between storm and fair weather wave base. Most of the sediments were deposited within water depths of 20–50 metres. A submarine relief affected the local depositional pattern. Favourable conditions on the submarine highs led to the formation of laterally discontinuous glauconite and phosphorite coated hardgrounds. The depositional pattern was frequently interupted by storms which generated conglomeratic beds associated with erosion surfaces, fining upward sequences and cross-stratification. Shoals or barshaped bodies of sediment were frequently developed and constituted probably important features in the environment. The calcareous fossil fauna was dominated by epifaunal and free-living species characteristic of a nearshore high energy environment. The number of infaunal species was low as a consequence of a shifting living environment with repeated lateral redeposition of surface sediments.

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