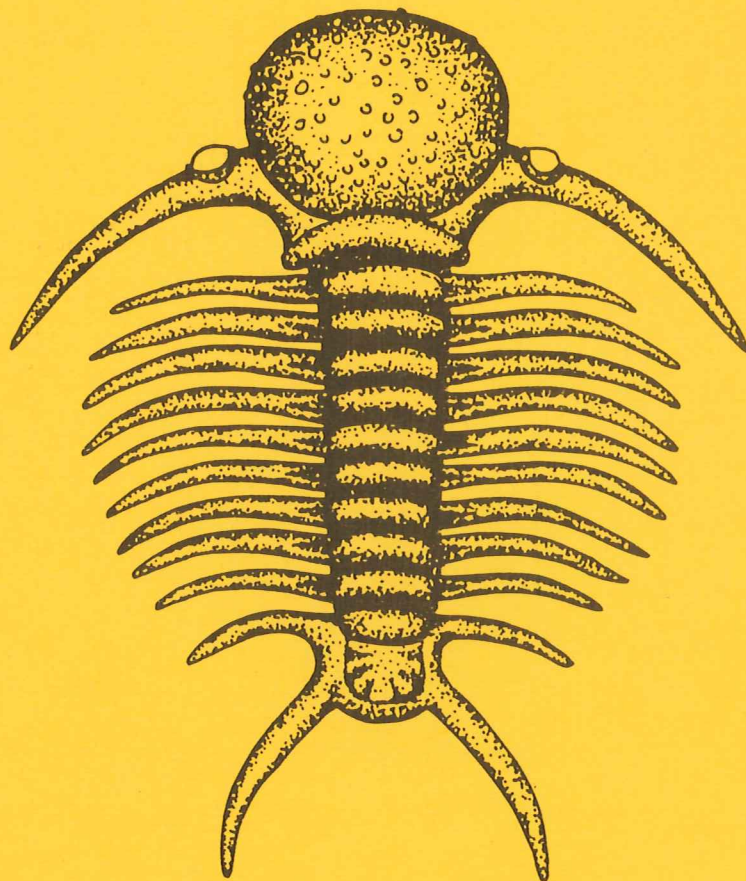


# EXAMENSARBETEN I GEOLOGI VID LUNDS UNIVERSITET

Historisk geologi och paleontologi

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DEPOSITIONAL AND PETROGRAPHIC RESPONSE  
OF CLIMATIC CHANGES IN THE TRIASSIC OF  
HÖLLVIKEN-II, SOUTHERN SWEDEN

MIKAEL JACOBSSON

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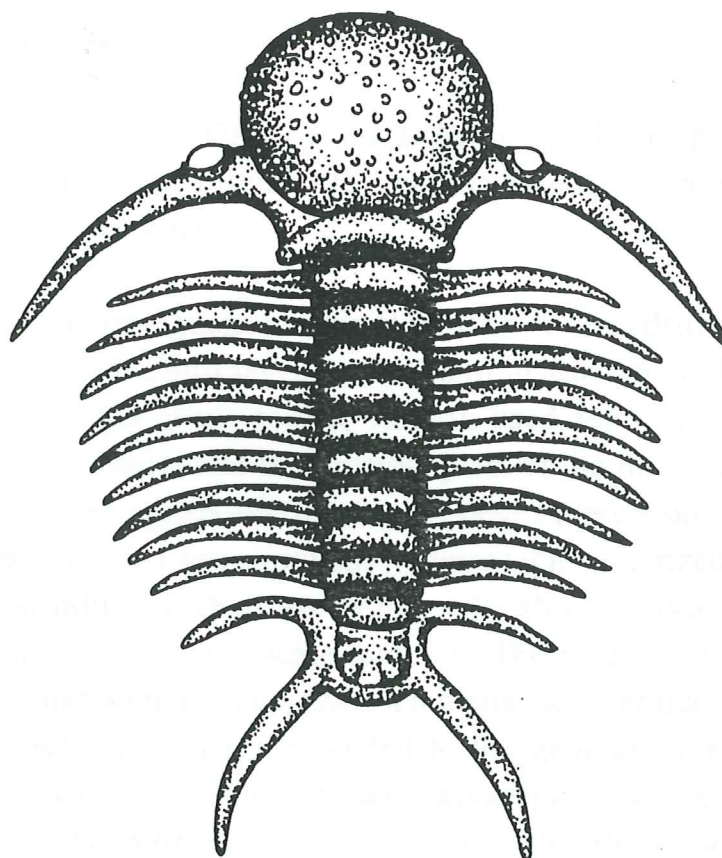
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LUND 1993

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GEOLOGISKA INSTITUTIONEN LUNDS UNIVERSITET

## Depositional and petrographic response of climatic changes in the Triassic of Höllviken-II, southern Sweden

MIKAEL JACOBSSON

Jacobsson, M., 1993 02 17: Depositional and petrographic response of climatic changes in the Triassic of Höllviken-II, southern Sweden. 10 p. *Examensarbete i Geologi, Lunds Universitet.*

A 180 meter long core sequence of the Höllviken-II deep drilling project was investigated and divided into seven subfacies from a sedimentological point of view. Special attention were paid to criteria used for interpretation of the palaeoclimate. The lowest and the topmost parts of the investigated sequence were interpreted as being deposited during hot, desert-like conditions. Intervening parts were deposited in a terrestrial environment, characterized by seasonally dry and humid conditions. There are evidence for short periods of instability in the climate just before a large scale turnover. The results were applied on a climatic model, and were thereby given a tentative stratigraphical assignment. The climatic fluctuations may be related to the geographic shiftings of the monsoonal belt, caused by the repeated expansions and regressions of the Tethys. □ *Tethys, Danish-Polish Trough, Scania, Triassic, Scythian, Ladinian, Anisian, Carnian, desert, monsoonal belt, kaolinite, smectite, calcrete, dolomite.*

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In 1945, Brotzen published his first report on the geology exposed during the drilling operations at Höllviken. The core hole Höllviken-I was sunk to the depth of 1415 m and Höllviken-II to 1201 m. None of the holes penetrated anything but the Cretaceous. Continued drilling during 1947 deepened Höllviken-II to 1923.76 m. Lundblad (1949a, 1949b, 1959) studied and described the plant-remains and Ödum (1953) examined the macro fossils of the cores. Unfortunately, there has not been made any reliable biostratigraphical determination of this core sequence yet. The intention of this essay is to update and complete the work of Brotzen (1949) and adapt the results to a climatological model.

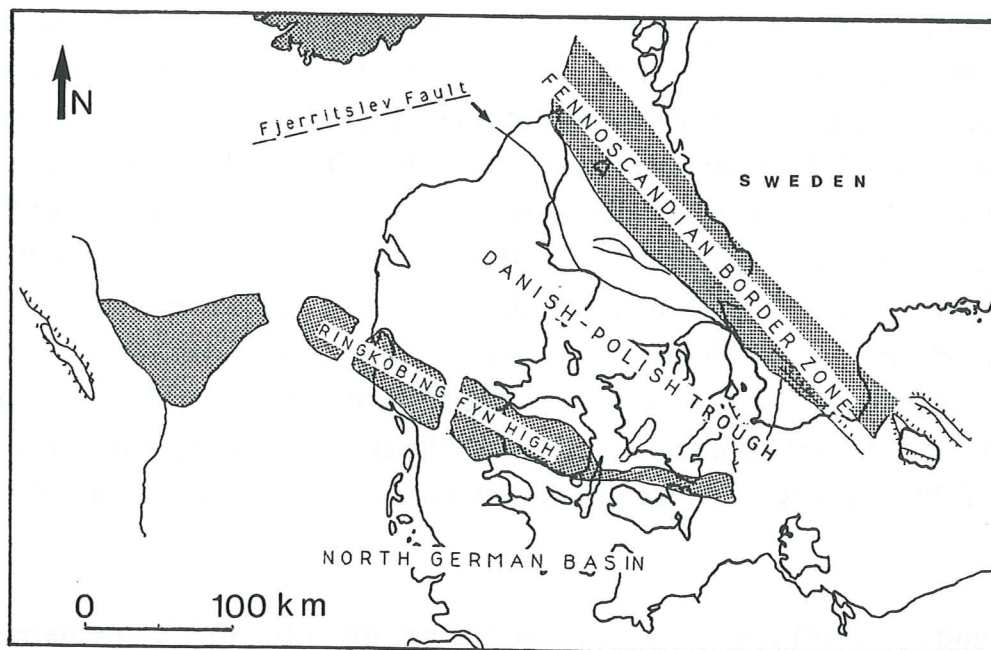


Fig. 1. Structural map of the Danish-Polish Basin (from Bertelsen 1978).

### Geological setting

The Fennoscandian Border Zone (Fig. 1) is the southern margin of the Baltic Shield and it forms the northeastern limit of the Tornquist-Teisseyre Lineament. This lineament separates the stable Baltic Shield from the more mobile Danish-Polish Trough. The highly complex block-faulted Fennoscandian Border Zone is 50 to 75 km wide and strikes approximately northwest to southeast from northern Jutland over Scania and Bornholm to Poland (Norling & Bergström 1982). In Scania and Bornholm the Fennoscandian Border Zone is defined by series of large basement blocks, tilting towards the southwest. According to

Kornfelt & Larsson (1987) these horsts have been exposed along the northeastern limit of the Border Zone and have therefore been one of the major sediment producers to the eastern part of the Danish Polish Trough. In the Fennoscandian Border Zone the Triassic deposits rest directly upon the Precambrian crystalline basement (Fig. 2) or onlap Palaeozoic rocks (Norling & Bergström 1987).

A rapid subsidence of the Danish-Polish Trough during the late Permian reactivated the Tornquist-Teisseyre Lineament (Wagner *et al.* 1978). This might have been related to the early phases of crustal extension in the Tethys realm (Ziegler 1982). In the Triassic, the tectogenesis was caused by left lateral wrench faulting and tension along the Tornquist Zone (Norling & Bergström 1987). According to Norling & Bergström (1987) and Norling & Skoglund (1977) these transtensional tectonics induced subsidence of the faultbounded basins in the Danish-Polish Trough. The Höllviken deposits were deposited in a shallow part of the deep Danish-Polish Trough (Norling and Bergström 1987). This relatively small basin appears to be delimited by the synsedimentary Svedala Fault in the east, the Malmö Fault in the north and the Öresund Fault in the west (Fig. 3). In this graben shaped basin, Lower Triassic strata attain a thickness of 135 to 220 m and Middle to Lower Upper Triassic deposits 65 to 190 m (Norling & Bergström 1987). The uppermost Triassic series are around 300 m thick and have a much wider geographic distribution. This illustrates that the older basin margins became gradually overstepped (Norling and Bergström 1987).

### **Sediments deposited during the Triassic in the Danish Polish Trough**

Periodic marine incursions reached the rapidly subsiding Danish-Polish Trough from the Tethys in the southeast (Peryt 1975, Fuglewicz 1980). Along its margins, the Scythian series are predominantly represented by fluvial sandstones. The Scythian redbeds were deposited in continental to shallow-lacustrine settings and basinward these are interfingering with fluvial mudstones, containing cyclical sandstone and siltstone intercalations (Ziegler 1982). An arid climate combined with periodic tectonally and/or eustatically controlled sea level fluctuations caused repeated drainages and floodings (Ziegler 1982). By late Scythian (Fig. 4), as a result of the Pangean break-up, the Tethys transgressed into the southern Permo-Triassic Basin and gave rise to the accumulation of Röt halites and their associated mudstones in the Danish-Polish Trough (Ziegler 1982).

During Early Anisian (Fig.4) the sea level rose again and renewed the free

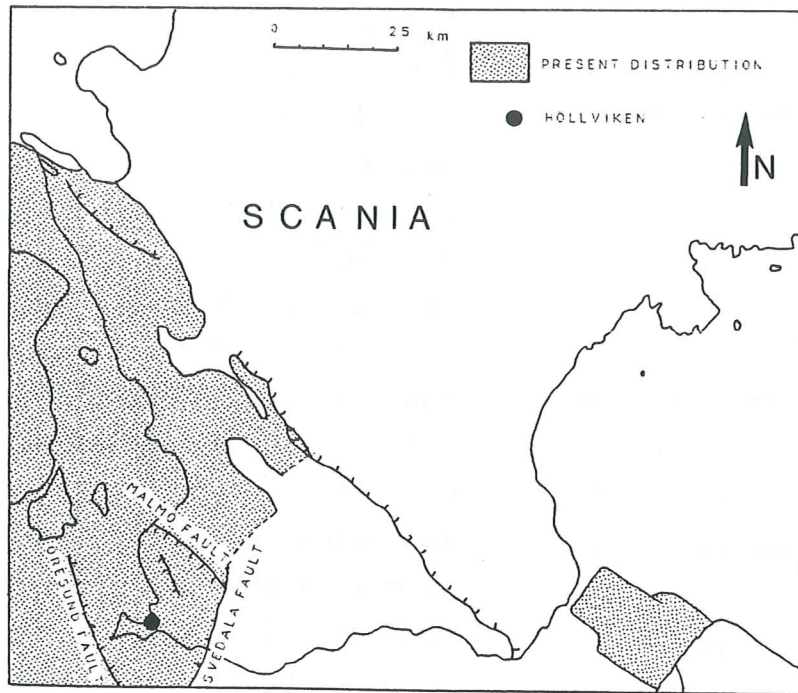


Fig. 2. Present distribution of Triassic sediments (except for the Rhaetian) in Scania and surrounding areas (Bergström *et al.* 1982).

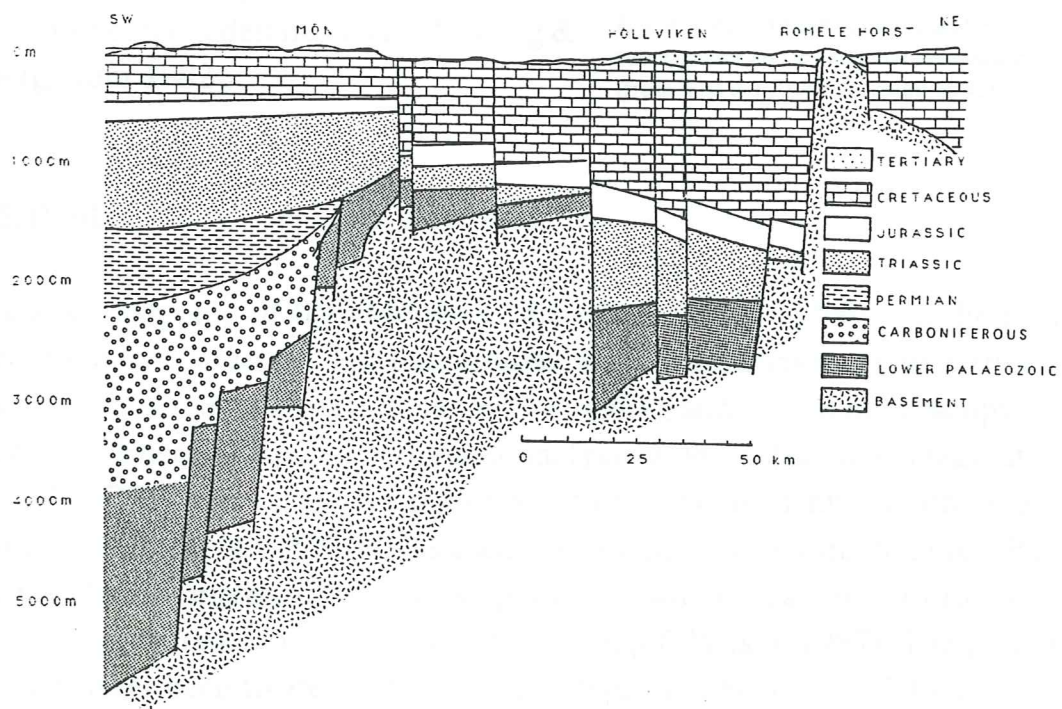


Fig. 3. Schematic cross section through the southwestern part of Scania, Danish-Polish Basin and the Ringköbing-Fyn High (from Kornfelt & Larsson 1987).

communication between the Tethys and the southern Permo-Triassic Basin (Ziegler 1982). In northern Denmark, dolomitic and evaporitic shales grade northwards into alluvial fan deposits (Jakobsson *et al.* 1980). The Anisian and Ladinian transgressions may have reached some distance north of the Mid North Sea-Ringköbing-Fyn High through the rapidly subsiding Central Graben (Ziegler 1982).

According to Ziegler (1982) and Pergum (1984) the Early Kimmerian tectonic phase affected wide areas in the northwestern and central Europe. This tectonic pulse was of major importance in the structural history of Scania. In the Rhaetian predominantly dark greyish and brownish sediments were deposited. The Triassic-Jurassic transition comprise clay, silt, sand, coal and plant bearing sediments of continental to deltaic origin (Norling & Bergström 1982).

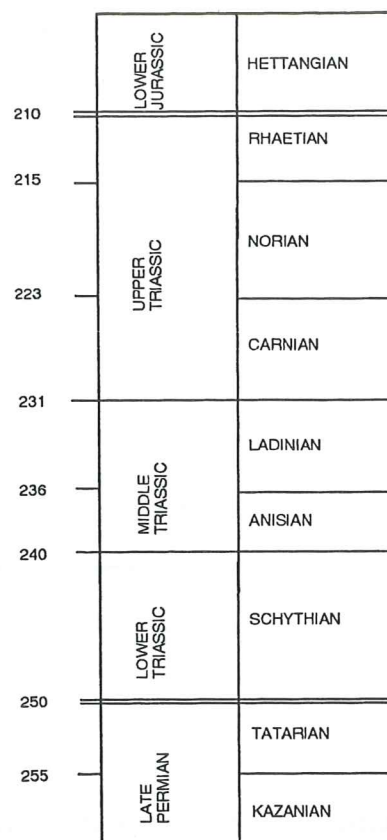


Fig. 4. Late Permian, Triassic and Early Jurassic subdivisions and the absolute time scale to the left (from Van der Zwan & Spaak 1992).

## Methods

Detailed mapping of the core were carried out with emphasis on the primary sedimentary characters. The petrographical investigations was carried out using standard methods such as mineral point counting and optical microscopy of thin sections. Energy dispersive element analysis with backscatter image analysis (EDAX/BSE) were used for high resolution mineral identification. Scanning electron microscopy (SEM) was used to scrutinize the textural features. Powder X-ray diffractometry (XRD) was applied on wholerock and on oriented clay fraction preparates for mineral identification (cf. Wilson 1987). The preparates have further been treated with ethylene glycol and heated to 550°C.

The classification of sandstones and graywackes (Fig. 5) follows the system made up by Pettijohn (1954). Powers (1953) six classes for roundness determination of sand grains were used and they are as follow: very angular,

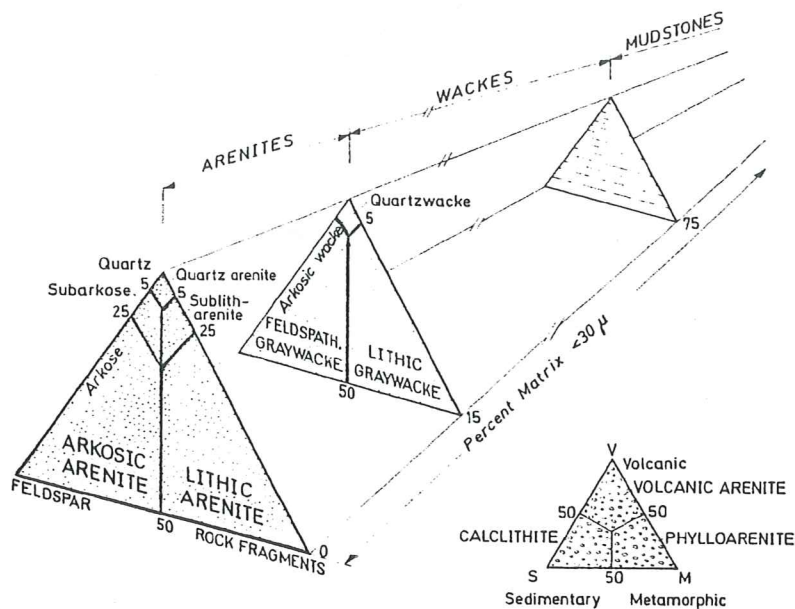


Fig. 5. Classification of terrigenous rocks (from Pettijohn *et al.* 1954).

angular, subangular, subrounded, rounded and well rounded. The sorting images very well sorted, well sorted, moderately sorted, poorly sorted and very poorly sorted are adopted from Compton (1962).

## Material

The Höllviken-II core has been divided into seven subfacies according to their primary lithological and textural characters (Fig. 6). Subfacies I is the deepest lying subfacies and extends from 1924 up to 1889 m. The six other subfacies follow in an advanced order and extend as follows. Subfacies II: 1889-1879 m, Subfacies III: 1879-1858 m, Subfacies IV: 1858-1800 m, Subfacies V: 1800-1780 m, Subfacies VI: 1780-1762 m and Subfacies VII: 1762-1745 m.

## Description of strata

The results are presented in a table (Tab. 1) and in the following description of the core sequence divided in to the seven subfacies.



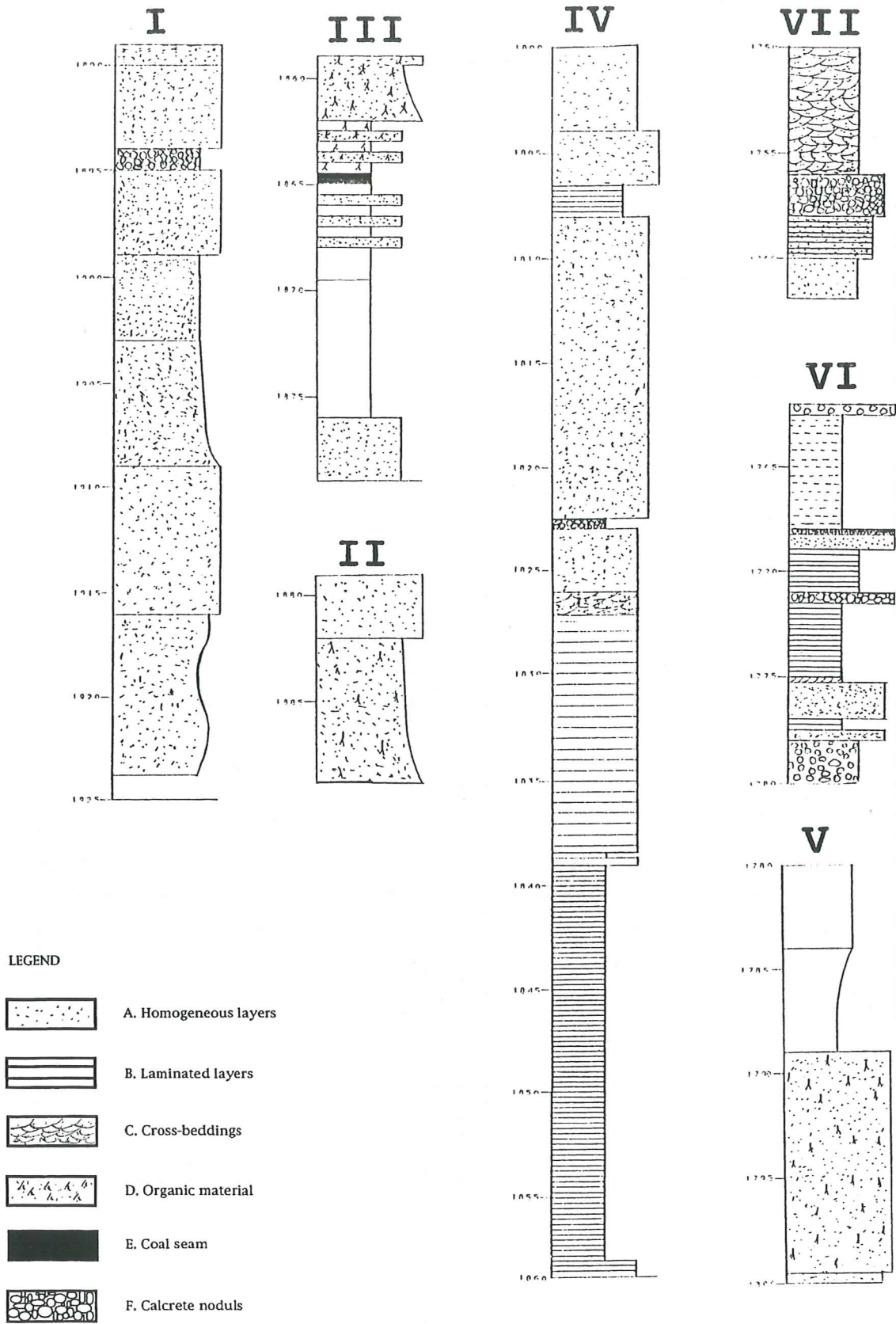


Fig. 7. The Höllviken-II core section divided into subfacies.



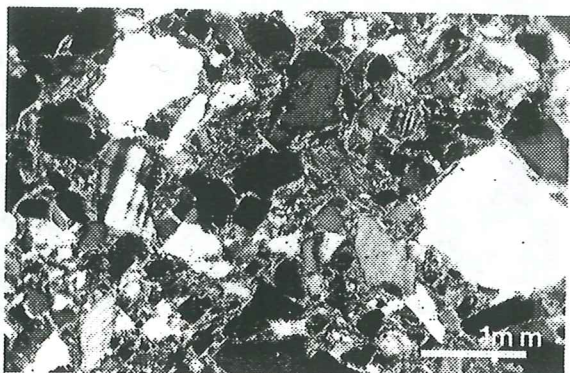


Fig. 7. Thin-section of a typical light red and light green graywacke within the Subfacies I. The sample was located at the 1906 m level.

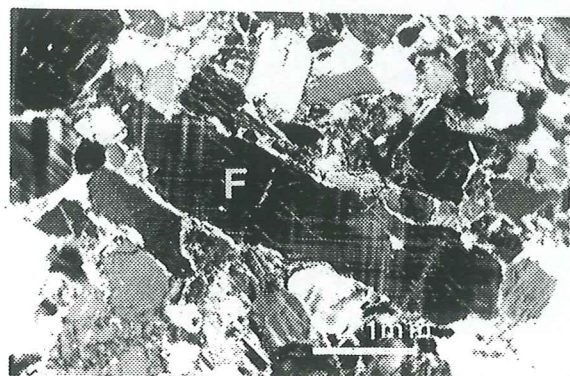


Fig. 8. Thin-section of dark red arkose in Subfacies I. The sample was located at the 1893 m level. Notice the large feldspar grain.

### *Subfacies I: 1924-1889 m*

The subfacies consists of light red and light green graywackes with fine grain size, they are interbedded with dark red arkoses containing by coarser grains. The sorting is generally poor and the grains are mostly subangular to angular (Figs. 7, 8). Illite and chlorite are the dominating clay minerals. Some of the units contain calcrete nodules and some have a dolomitic matrix. The light red and light green colours create an irregular patchy pattern. The dark red units contain abundant large angular feldspar grains (Fig. 9), as well as high contents of accessory minerals i.e. muscovite, hornblende, apatite and zircon. There is no occurrence of fossils or plant-debris in this subfacies.

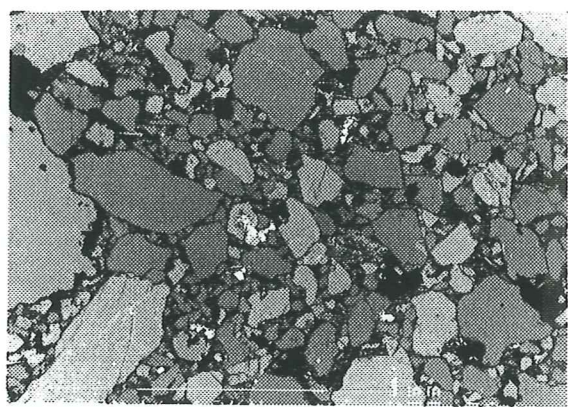


Fig. 9. Dark red arkose in Subfacies I (EDAX). Poor sorting and angular shape provide the climatological interpretation. The sample was located at the 1893 m level.

### *Subfacies II: 1889-1879 m*

In the lower part, this subfacies consists of a light red and light green graywacke and in the upper part of a dark red arkose. The light red and light green graywacke is very well sorted and the grains are rounded to subrounded in shape (Fig. 10). The dark red arkose comprise of poorly sorted, very coarse and angular grains. Small amounts of smectite are present but illite and kaolinite are the dominant clay minerals through the whole subfacies. In the upper parts traces of chlorite

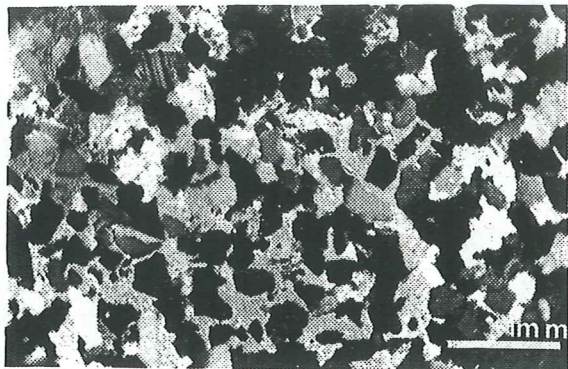


Fig. 10. Thin-section of light red and light green graywacke in Subfacies II. The sample was located at the 1885 m level.

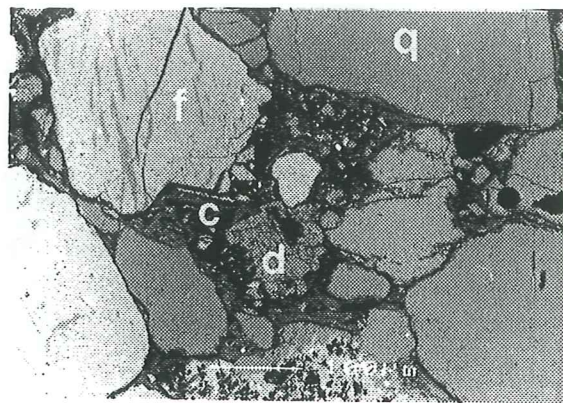


Fig. 11. Light red and light green graywacke in Subfacies II (EDAX). Note the dolomite and clay matrix. The sample was located at the 1885 m level.

appears. The matrix is dolomitic (Fig. 11) and there is organic material to be found in the entire subfacies.

#### *Subfacies III :1879-1858 m*

Light red and light green mudstones are interbedded with siltstones and sandstones in the same faint colors. The grains are subrounded to rounded and the sorting is good (Fig. 12). In the upper part, there is a large amount of organic material. Kaolinite and illite are the dominating clay minerals in the lower part of the subfacies. In the upper part smectite emerges and kaolinite decreases and finally disappears. There is still some traces of clorite, but not as frequent as in Subfacies II. The matrix is alternately calcitic or dolomitic. The uppermost unit forms a coarsening upward sequence and ends in a planar laminated sandstone.

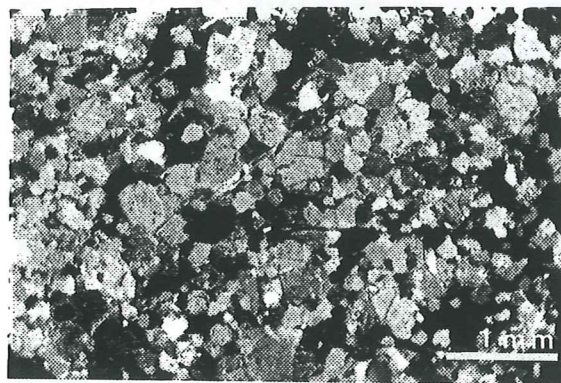


Fig. 12. Thin-section of light red and light green mudstone in Subfacies III. The sample was located at the 1875 m level.

#### *Subfacies IV: 1858-1800 m*

Grey laminated, muddy to silty quartz arenites interbedded with grey laminated subarkoses. The sorting is very good and the grains are rounded to well rounded (Figs. 13, 14). The coarser upper half of this subfacies is rich in organic material, while the lowermost mudstones do not contain any organic material at all. In the middle of Subfacies IV a coarse dark red sandstone occurs, with well sorted and well rounded calcrete noduls in a angular matrix (Fig. 15). Pyrite was found in

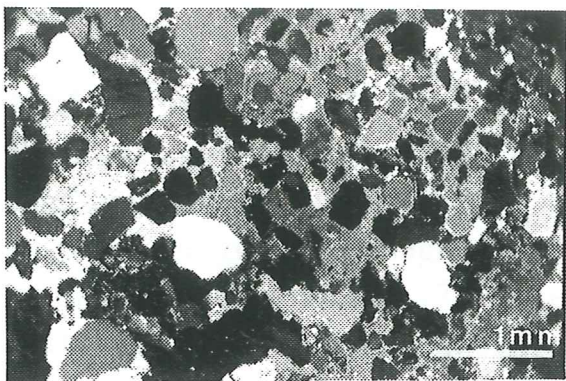


Fig. 13. Thin-section of grey laminated quartz arenite in Subfacies IV. The sample was located at the 1855 m level.

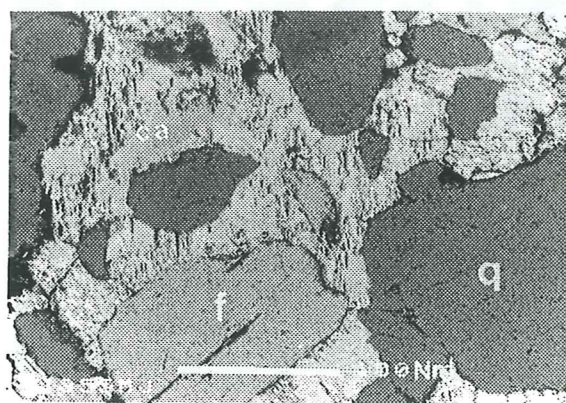


Fig. 14. Grey laminated quartz arenite in Subfacies IV (EDAX). Quartz and feldspar grains in calcite cement. The sample was located at the 1855 m level.

a coal seam in this coarse grained red sandstone. The dominant clay minerals in the lower part of the subfacies are smectite and illite, while in the upper part, the amount of illite decreases and finally disappears. In the topmost unit chlorite, calcrete nodules and flakes of mica appear.

#### *Subfacies V: 1800-1780 m*

A light grey to light red muddy graywacke overlying fine grained brownish red arkose. The shape of the grains are angular and the sorting is poor. There is plenty of organic material and muscovite in most of the units in this subfacies.

#### *Subfacies VI: 1780-1762 m*

This subfacies consists of laminated grey silty and sandy graywackes. They are well to very well sorted and the grains are rounded to well rounded (Fig. 16). There are frequent amounts of calcrete nodules and organic material through most of the subfacies. Smectite is clearly the dominating clay mineral and a small amount of kaolinite is present.

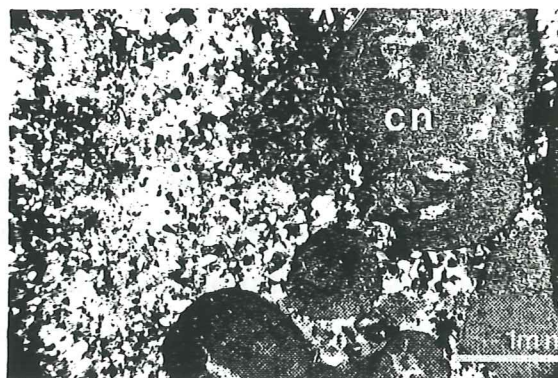


Fig. 15. Coarse-grained dark red sandstone with well sorted, well rounded calcrete nodules in a more angular matrix. The sample was located at the 1827.4 m level in Subfacies IV.

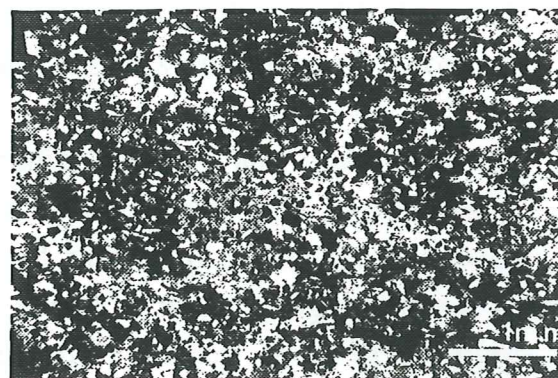


Fig. 16. Thin-section of grey laminated silty graywacke in Subfacies VI. The sample was located at the 1771 m level.

### *Subfacies VII: 1762-1745 m*

Partly cross-laminated red and green sandstones with dolomitic matrix. The shape of the grains are angular and the sorting is mostly poor (Fig. 17). There has not been any organic material found in this subfacies. Calcrete and mica flakes are present in the lower grey units.

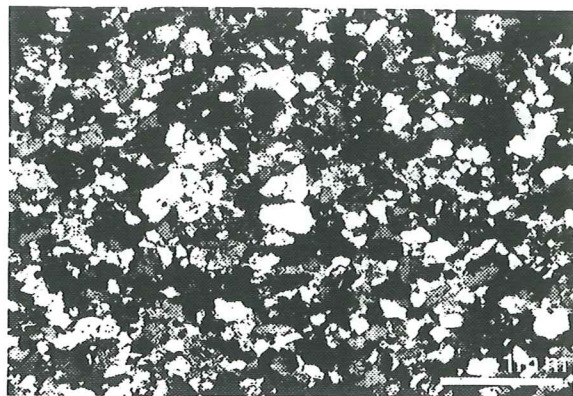


Fig. 17. Thin-section of red and green cross-laminated sandstone in Subfacies VII. The sample was located at the 1745 m level.

### **Interpretation of the results**

Subfacies I and VII may have been deposited during hot and dry conditions. Among the main evidence for a hot and arid climate are the colours of the red and green sandstones. According to Walker (1975) the red colour is derived through hematite pigmentation. Hematite would have been developed above the water table and where the groundwater was oxidizing. Secondary alternation of the red colour probably took place where reducing solutions penetrated the sediment. The red colour was then changed into a green and grey patchy pattern and even in to white, where the leaching was intense enough (Tucker 1981).

Further strong evidence in support of an arid regime are the calcrete nodules and the dolomitic matrix. According to Chamley (1989), there is today developing calcretes in areas where a hot and arid climate is prevailing. Dolomitic matrix is usually associated with evaporites (Tucker 1981). The absence of evaporites in these two subfacies can be explained by a recent example. Continental groundwater discharges into shallow lakes and then precipitates. According to Müller *et al.* (1972) this is happening in a series of coastal lagoons and lakes in Coorong, Australia.

The large and angular feldspar grains indicate short water transport and a low rate of chemical weathering. This can be compared with recent desert environments, where the absence or rarity of rainfall prevents the chemical weathering. The hydrolytic processes are very low and mostly restricted to removal and precipitation of iron and manganese oxides. Most of the clay minerals proceed from physical weathering and therefore reflect the composition of the parent rock. This may be one of the main explanations for the frequent abundance of illitic and chloritic minerals in the sediments of Subfacies I. According to Chamley (1989) many modern deserts are developed in old and

stable cratonic areas, made of crystalline rocks. Further support for the desert interpretation, is a comparison between the relatively high content of rock fragments in this subfacies (Fig. 18) with the QFR ternary plot (Fig. 19) in Suttner *et al.* (1981).

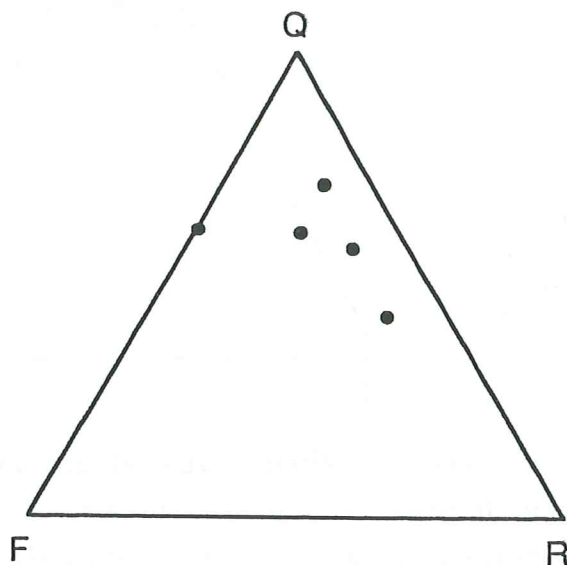


Fig. 18. QFR ternary plot of the composition in Subfacies I. Notice the similarity with the QFR ternary plot by Suttner *et al.* (Fig. 19 here in).

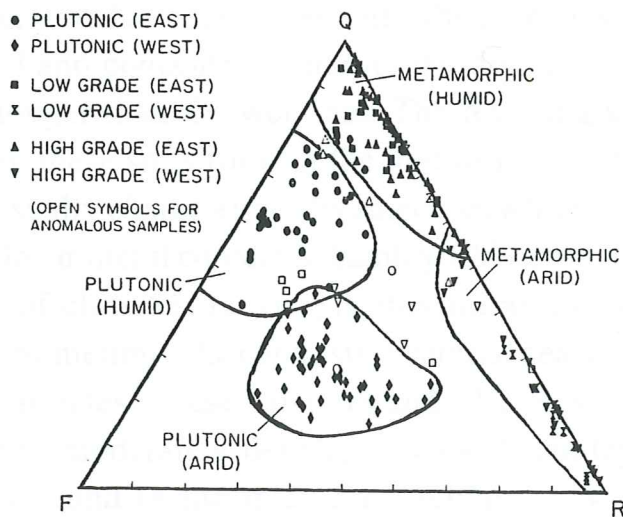


Fig. 19. QFR ternary plot of the composition of Holocene fluvial sands (from Suttner *et al.* 1981).

The mature mudstones, siltstones and sandstones with distinctly laminated sedimentary structures in Subfacies IV may signify the action of substantial quantities of running water, alternating with dry periods. Further support for

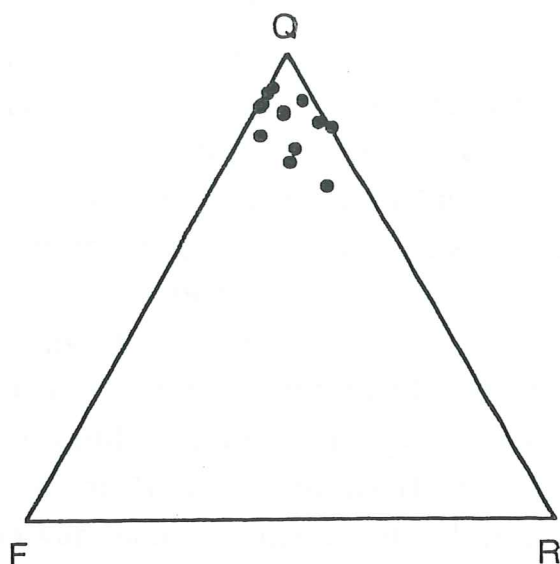


Fig. 20. QFR ternary plot of the composition in Subfacies IV. Notice the similarities between the Höllviken-II results and the QFR ternary plot by Suttner *et al.* (Fig. 19 here in).

water deposited sediments, is a comparison between the QFR ternary plot for this subfacies (Fig. 20) with a relatively high content of quartz grains, with the QFR ternary plot (Fig. 19) of Suttner *et al.* (1981). The dominance of smectite in the clay fraction may, according to Chamley (1979) be related to moderately hot and only periodically humid conditions. The area must have been submitted to a strong alternation of wet and dry seasons characterized by interrupted weathering processes. Hydrolysis has intervened actively during the wet seasons, especially when the temperature has been rather high. Then the ions were released from the minerals, stored and concentrated during the dry seasons, particularly if these seasons were longer than the wet ones. The resulting soils are interpreted as vertisols. Today these soils form in the mid to low latitude regions. The clay mineralogy is usually characterized by smectites which commonly constitute 60 to 90 % of the clay mineral content (Chamley 1989). Smectite forms today under a great variety of climates, ranging from semi arid to sub tropical (Dudal & Bramao 1965). Sometimes the contrasts in rainfall seasonality may have created silcretes and calcretes. These calcretes and silcretes may be associated with strong lateritic to moderately developed soils (Chamley 1989). The rounded calcrete nodules found in the middle of Subfacies IV can be interpreted as redeposited elements eroded from older sediments. The nodules have been incorporated into the bottom lag and due to water transport they have been rounded (Fig. 15). Because they are less resistant they have been more rounded than the harder surrounding grains. Furthermore the abundance of plant-rich mudrocks are very good criteria for regional humidity. Due to the results discussed above, Subfacies IV and VI are interpreted to have been deposited



during a hot semiarid climate with dry and wet seasons.

Subfacies II and III are suggested to have been deposited during a warmer humid climate. However, not as humid as the Raethian but more wet than the other periods described and discussed above. The major criteria supporting the hypothesis of shorter periods of more humid conditions within the longer time of hot semi-arid climate are kaolinite in association with the well rounded clastic grains (Figs. 10, 12) and the abundance of organic material. Kaolinite is the most typical pedogenic mineral issued from weathering under hot and wet conditions. It is mostly formed by laterization, associated with this type of climate. Laterites are soils formed in an intertropical environment characterized by high rainfall, active drainage and oxidizing conditions and may reach a thickness of 10 to 30 meters (Chamley 1989). Illite/smectite mixed layer minerals and smectite may also develop in the first weathering stages of a laterite (Chamley 1989).

Subfacies V was probably formed during a short period of relatively arid conditions, within the period of seasonally hot and humid conditions (Subfacies IV and VI), yet not as dry as the periods Subfacies I and VII represents. This assumption is primarily based on the very angular grains, the poor sorting and the brownish red colour (compare with the discussion of Subfacies I and VII).

Subfacies II, V and VI display relatively rapid changes in the climatic pattern. The climate trend curve (Tab. 1) seems to aim in the opposite direction just before a large scale turnover in any direction. According to Van der Zwan & Spaak (1992) such variations in the climatic pattern are typical for the Middle and Late Triassic.

### **Aspects on the Triassic climate in general**

During the Triassic the temperature characteristics of today's tropical climate, extended from mid-latitudes to polar regions (Barnard 1973, Colbert 1964, Frakes 1979, Habicht 1979, Hallam 1975). Triassic ferns and gymnosperms signifying subtropical to warm temperate conditions extended up to 60° palaeolatitude, with rich floras in Greenland and Antarctica (Barnard 1973, Wesley 1973). The wide distribution during this period of terrestrial tetrapods (Colbert 1964, Cox 1974) and invertebrates sensitive to temperature fluctuations, such as reef corals, provide strong supporting evidence. Furthermore there is generally no great diversity dispersal from palaeoequatorial regions to the palaeopoles (Hallam 1975). It has been widely assumed that the surface

temperature gradient from the equator to the pole, was appreciably less than today and the atmospheric circulation would have been relatively slow (Hallam 1985).

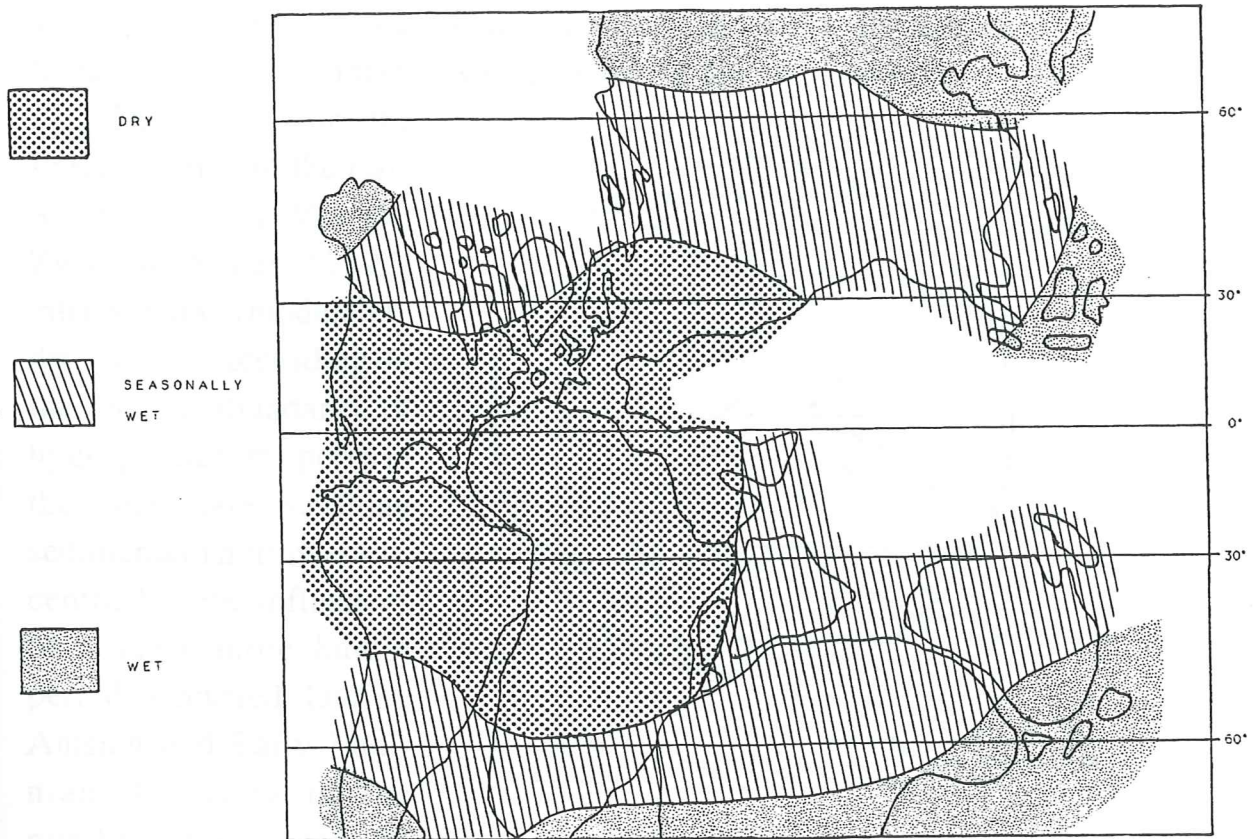


Fig. 21. Schematic presentation of continental humid and arid belts for the Early Triassic (Robinson 1970).

Robinson (1970) pointed out, because of very different palaeogeography, the pattern of continental precipitation in the Triassic bore only a limited correspondence to that of today. The most striking differences were the lack of an equatorial humid zone and the general dominance of a monsoonal effect (Parrish *et al.* 1982). This is primarily the consequence of the major continental areas gathered together in Pangea, more or less symmetrically distributed about the equator. The only humid regions in Robinson's model (Fig. 21) are in high latitudes and on westerly or northerly coasts.

## The Höllviken area in a wider perspective

Van der Zwan & Spaak (1992) have presented a model for the sequence stratigraphy and climatology of the Netherlands during the Lower to Middle Triassic. This model expresses the climatic changes as a shifting of the monsoonal belt northwards, due to the break-up of Pangea. This model can of course not be applied with absolute certainty on the Höllviken results, due to the geographical distance, the absence of biostratigraphical information and the limited nature of a study of an one-cored sequence. However, the major climatic changes ought to have been approximately simultaneous in the two areas.

The period from the Early Tatarian to the Late Scythian, is by Van der Zwan & Spaak (1992) interpreted as a moderately dry period. According to the relative abundance of hygrophytic fern spores in the very Late Scythian sediments of northwestern central Europe, influences of slightly more humid periods occurred. During Anisian and Early Ladinian, the flora in the northwestern central Europe changed completely. The conifer pollen-grains dominates the

sediments and indicate a very dry climate. Today this climate prevails in the zone between the latitudes  $20^{\circ}$  and  $35^{\circ}$ , where the crowding of air is sufficient to raise the pressure, and thereby it descends to the surface. This zone is commonly known as the high pressure subtropical calm belt (Fig. 22). The winds blow from  $30^{\circ}$  westwards toward the equator, bringing no rainfall. They become increasingly arid, blowing over extensive landmasses (Hallam 1985).

There would have been no connection between the Danish-Polish Trough and the Tethys during eustatic sea level lowstands (Fig. 23). Due to precipitation, evaporites developed in the dried-out parts of the Danish-Polish Trough (Hallam

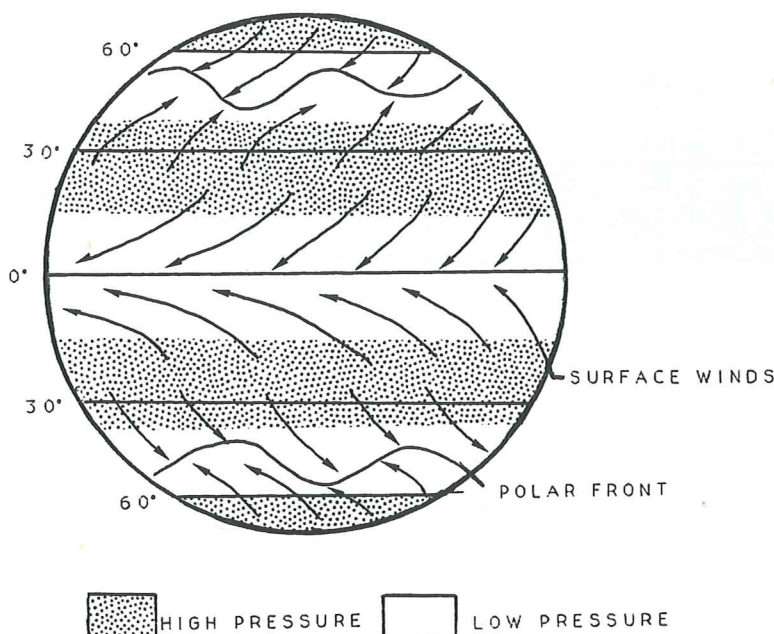


Fig. 22. Schematic diagram of circulation on an Earth with a homogeneous surface showing the zonal distribution of the surface-winds and pressures (from Parrish 1982).

1985). During such conditions in the Anisian and Early Ladinian, a desert environment may have been developed in the Höllviken area. No high areas cooling down the winds and the absence of high mountains in the path, would further enhance the development of a hot desert climate. In comparison between the results of this study and the model discussed above, Subfacies I in the Höllviken-II core may correspond with the late Early Ladinian.

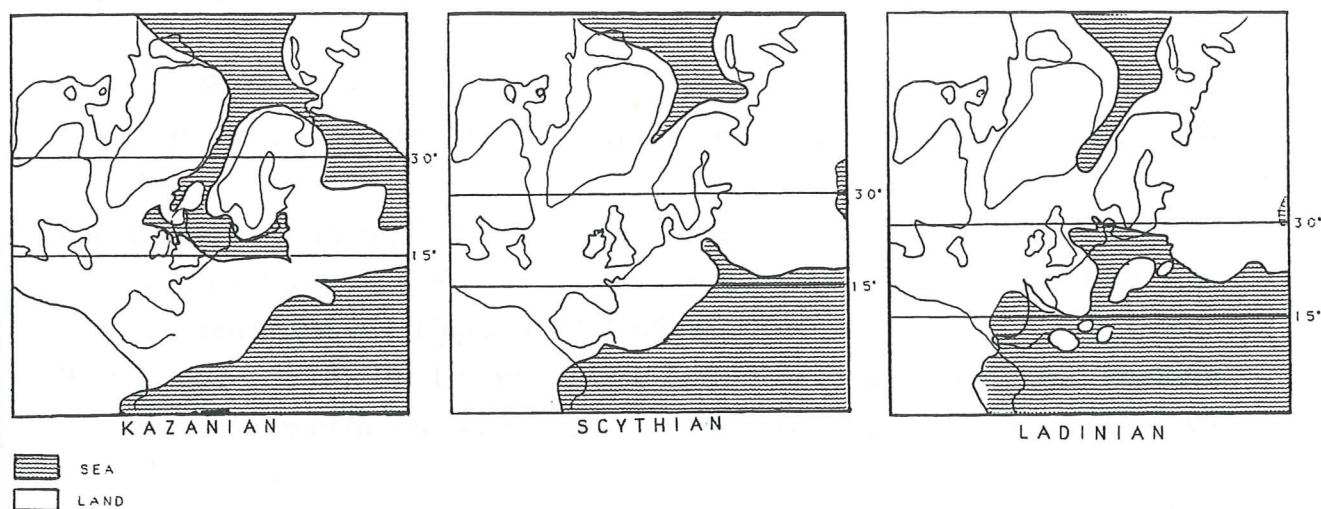


Fig. 23. Palaeogeographic maps for the Late Permian, Early Triassic and the Middle Triassic (from Van der Zwan & Spaak 1992).

The floras from Late Ladinian (Van Buggenum, 1985), mid Carnian (Senkowicza & Szperko-Sliwczynska 1975) and from the Rhaetian (Schuurman 1977) yield many hygrophytic (wet) flora elements, indicating a moderate humid to humid climate. These periods are, according to Van der Zwan & Spaak (1992), separated by intervals characterised by floras with a generally drier character.

If this assumption is correct, the tradewinds would have followed the tropical Tethys expanding westwards due to the break-up of Pangea (Fig. 23). The eastern monsoon belt (Robinson 1970; Visscher & Van der Zwan 1981; Parrish *et al.* 1982; Simms & Ruffel 1990) may have reached as far as the southern Scania and with its warm and seasonally humid climate affected this area.

Referring to the earlier discussion, Subfacies II, III and IV may match with the Late Ladinian and Subfacies V with the Carnian.

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