MARINE CALCARENITES FROM THE RINGERIKE GROUP ('STAGE' 10) OF SOUTHERN NORWAY

PETER TURNER

Turner, Peter: Marine calcarenites from the Ringerike Group ('Stage' 10) of southern Norway. *Norsk Geologisk Tidsskrift,* Vol. 54, pp. 1–12. Oslo 1974.

Calcarenites occur at several horizons in the lower part of the Ringerike Group (Sundvollen Formation) at Ringerike. Analysis of cross-stratification, composition and grain-size distribution enables the calcarenites to be interpreted as shallow marine deposits which formed near the mouths of large tidal estuaries. It is suggested that sedimentation in 'Stage' 9 was taking place to the south of these estuaries and that the calcarenites were derived from previously lithified carbonates in that area.

P. Turner, Department of Geophysics and Planetary Physics, School of Physics, The University, Newcastle-upon-Tyne NE1 7RU, England.

The Ringerike Group (formerly the Ringerike Sandstone) of southern Norway is well-known for both its vertebrate (Kiær 1911, 1924, Heintz 1969) and arthropod faunas (Störmer 1934). The greater part of the succession, however, is unfossiliferous and consists of fine-grained sandstones and siltstones similar in character to the Old Red Sandstone of Spitsbergen and the Welsh Borderlands of Great Britain. Although the succession is almost wholly non-marine it contains a wide variety of facies and at least two distinct sedimentary provinces within the Oslo Graben (Turner 1973). The only marine sediments to occur within the Ringerike Group are several thin limestones which occur in the lowest 500 m at Ringerike and the purpose of this paper is to describe them.

Stratigraphically the Ringerike Group (probably Ludlovian) lies conformably on the carbonate succession of 'Stage' 9 (probably mostly Wenlockian) and its base marks the point in the Norwegian Palaeozoic when marine carbonate deposition gave way to non-marine clastic deposition. This change took place gradually and the sediments in 'Stage' 9 consist of sub-tidal fossiliferous marine limestones, inter-tidal crinoidal and peloidal limestones and shales and supra-tidal finely laminated dolomitic shales with mud-cracked algal mat structures. The sediments at the boundary of 'Stage' 9 and the Ringerike Group also consist of inter-tidal and supratidal limestones and shales both at Ringerike and at Kolsås (Spjeldnæs 1966). The occurrence of marine limestones within the Ringerike Group thus forms a link between the sedimentation of 'Stages' 9 and 10 and lends support to Spjeldnæs's (1966) conclusion that the boundary between them is diachronous.

Sedimentation of the Ringerike Group

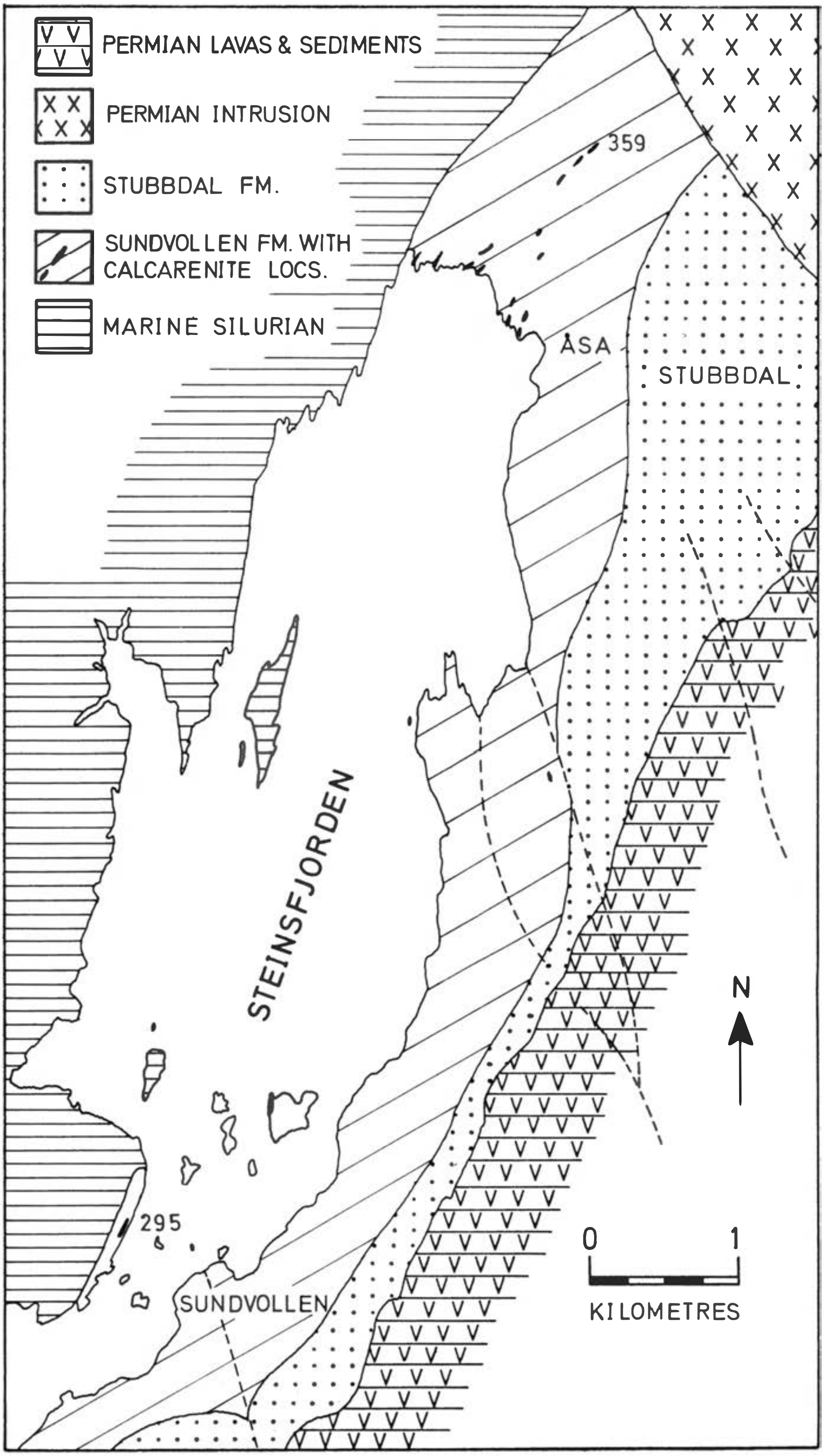
In the type area of Ringerike (30 km NW of Oslo) the Ringerike Group can be divided into two mappable formations of distinct sedimentary type. The lowermost of these, the Sundvollen Formation (500 m) consists of grey and red fine and very-fine grained sandstones and red micaceous and argillaceous siltstones with minor red shales and mudstones. There is a wide range of sedimentary structures most of which are characteristic of shallow, fresh-water deposition. The facies show a systematic vertical arrangement, repeated many times throughout the Sundvollen Formation in units 2–25 m in thickness and averaging 5.6 m. Each unit commences with an erosional surface overlain by a coarse member of flat-bedded and cross-stratified sandstones, often with intra-formational conglomerate towards the base. This is overlain gradationally by a fine member of siltstones and mudrocks with cross-lamination, ripple-marks and mud-cracks. Nodular concretionary horizons (cornstones) are common in many of the siltstones. Fining-upwards cyclothems of this type have been described from many geological formations, particularly from the Old Red Sandstone (Allen 1965, Friend 1965). By analogy with Recent examples they have been interpreted as the deposits of meandering rivers. The sands are deposited on point bars and in the river channel and the siltstones and mudrocks are deposited on levees and the river flood-plain.

The overlying Stubbdal Formation (750 m) consists mainly of unfossiliferous fine-grained sandstones with mud-flake intra-formational conglomerate. Erosional scoured surfaces and channels are common and filled with flat and cross-stratified sandstones. Unlike the Sundvollen Formation siltstones and mudrocks are scarce. This arrangement is very similar to that found in present-day braided rivers (Doeglas 1962, Williams & Rust 1969). The absence of coarser sand grades and extra-formational conglomerate suggests a similarity to large alluvial braided rivers such as the Yellow River (Chien 1961) or the Brahmaputra (Coleman 1969).

Occurrence and geometry of the calcarenites

The calcarenites at Ringerike were first discovered by Kiær (1924, p. 8) who suggested that they resulted from the erosion of Silurian limestones in a terrestrial source area. They occur at several horizons (Fig. 1) and are restricted entirely to the Sundvollen Formation. Owing to differential weathering they contrast sharply with the associated sandstones and siltstones. In the northern part of the area they are grey in colour, but elsewhere they are red, reddish-green or grey. They are always interbedded within the coarse members of cyclothems and their thickness varies from

Fig. 1. Geological sketch map of the area around Steinsfjorden, Ringerike showing important calcarenite localities (Nos. 295 and 359).


PERMIAN LAVAS & SEDIMENTS
PERMIAN INTRUSION
STUBBDAL FM.
SUNDVOLLEN FM. WITH CALCARENITE LOCS.
MARINE SILURIAN
359
ÅSA
STUBBDAL
STEINSFJORDEN
N
295
SUNDVOLLEN
0
1
KILOMETRES

0.25 m to 1.0 m, averaging 0.5 m. As far as can be seen there are only slight thickness variations along strike; some individual beds have been traced for distances up to 1 km parallel to the strike. Typically a basal zone with green mud-flake conglomerate is overlain by cross-stratified medium or coarse-grained calcarenite. The base of the calcarenite bed may lie directly on an erosional scoured surface, or on cross-stratified or flat-bedded sandstones which in turn lie on a scoured surface. The transition to overlying sediment, usually fine-grained sandstone is abrupt but non-erosional. Thin lenses of fine-grained sandstone, up to 0.25 m thick, occur in some of the thicker calcarenite beds. Fig. 2 shows measured sections of two calcarenite localities.

Petrology

Thin sections of calcarenite were cut perpendicular to the bedding and half of each was stained following the method outlined by Dixon (1965). Using an automatic point counter, 500 determinations were made for compositional analysis of each thin section using the grain-bulk method (Jaanusson 1972). For grain size analysis the longest axes of 200 grains were measured. Results of the compositional analysis are given in Fig. 3 and a photomicrograph of calcarenite is shown in Fig. 4. The dominant constituents are well-rounded grains of micritic carbonate sand. Sparry calcite lithoclasts and lithoclasts containing fossil fragments are also common. Most of the clasts are in contact and the fabric of the calcarenites is thus grain-supported. The fabric is also anisotropic as the clasts show a strong preferred orientation. Other allochemical constituents, ooids and peloids, comprise only a very small proportion (less than 1 %) of any thin section. Discrete fossil fragments never exceed 10 % of any thin section but are very conspicuous and include: bryozoa, ostracodes, echinoderms, trilobites, algae and thelodont fish scales.

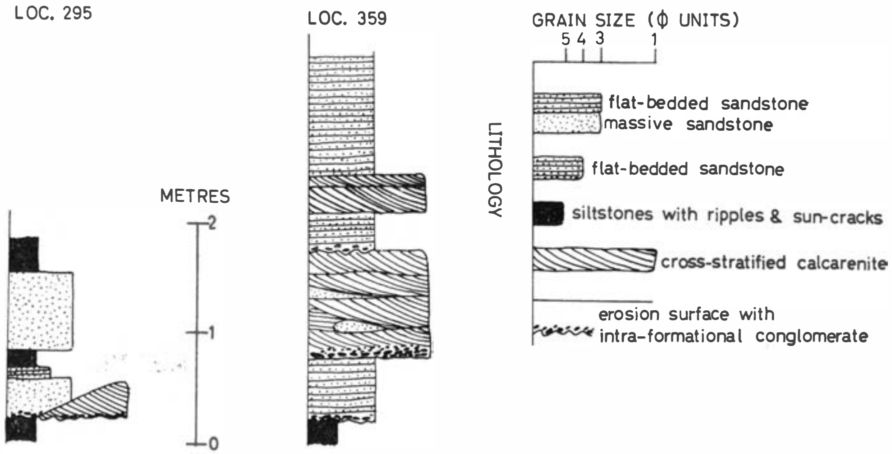
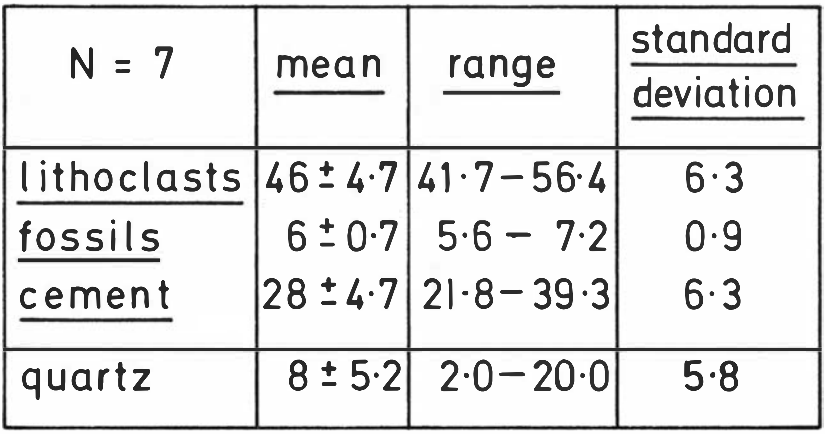


Fig. 2. Measured sections of calcarenite beds at localities 295 and 359.



N = 7	mean	range	standard deviation
lithoclasts	46 ± 4·7	41·7 – 56·4	6·3
fossils	6 ± 0·7	5·6 – 7·2	0·9
cement	28 ± 4·7	21·8 – 39·3	6·3
quartz	8 ± 5·2	2·0 – 20·0	5·8

Fig. 3. The main constituents of calcarenites based on results of point count analysis expressed in per cent. Confidence intervals are at the 95 % level.

Despite the irregular shape of many of the fossil fragments they are frequently well-rounded. A large number of grains, particularly sparry lithoclasts, show micrite envelopes similar to those described by Bathurst (1966). These micrite envelopes are formed by the boring of the surface of carbonate grains by endolithic algae. When the bores are vacated they become filled with micrite and the carbonate grains are thus gradually and centripetally replaced with micrite.

A small amount of angular to sub-angular quartz sand is present in most

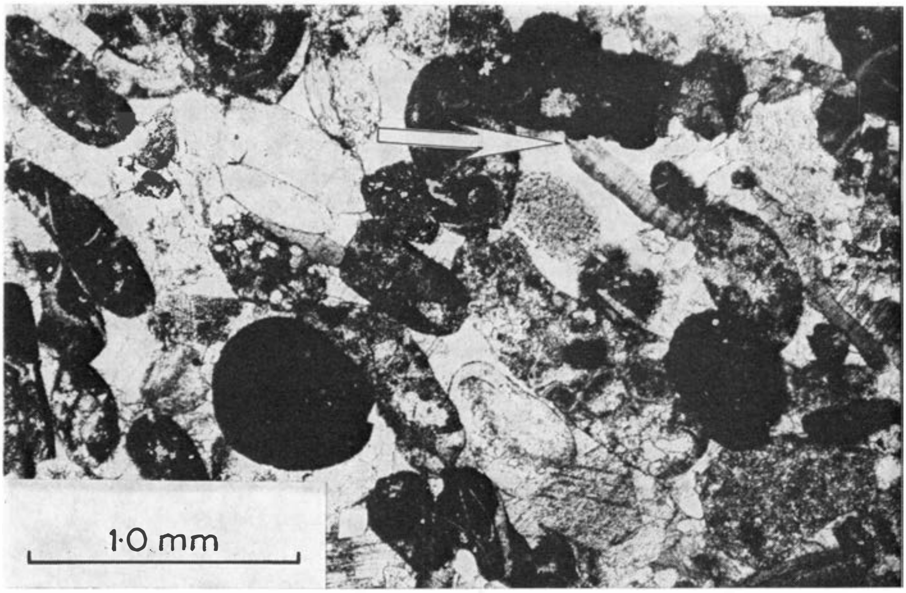
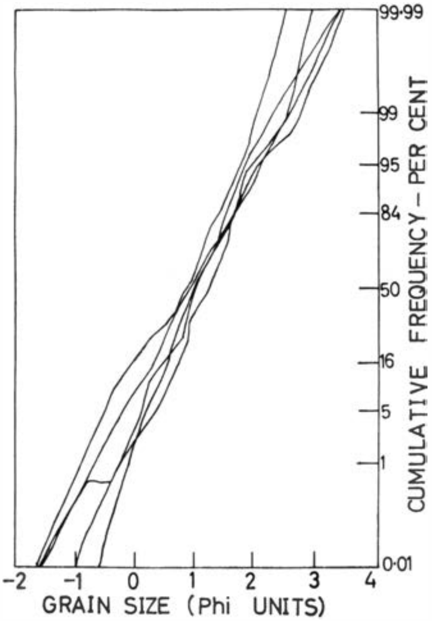


Fig. 4. Coarse calcarenite with well-rounded lithoclasts and skeletal fragments. Note trilobite fragments in top right-hand corner (arrowed) and large areas of calcite cement.



Mz	0·85ϕ	1·10ϕ	1·15ϕ	1·08ϕ	0·80ϕ
SI	0·95ϕ	0·55ϕ	0·53ϕ	0·55ϕ	0·55ϕ
SkI	−0·13	−0·06	−0·12	+0·17	−0·03
KG	0·93	1·17	1·13	0·97	1·55

Fig. 5. Grain size distributions plotted on a normal probability scale. Graphic statistics are tabulated.

thin sections. Occasionally more than 20 % of the calcarenite is quartz sand but in such cases it forms thin distinct laminae alternating with quite pure calcarenite.

The open framework of well-rounded carbonate sand grains is cemented by a mosaic of coarse sparry calcite. Radiaxial fibrous mosaic (Bathurst 1971, p. 426) has not been recognized and most of the cementing crystals have an equant rhombohedral form. Many grains, particularly echinoderm fragments, have syntaxial overgrowths and some are completely 'ghosted' by the calcite cement so that only a faint outline of their original boundary remains. Only one generation of cement has been recognized and staining indicates that this is ferroan calcite. Most of the allochemical constituents are also composed of ferroan calcite although a few grains composed of dolomite or ferroan dolomite do occur. No rhombs of secondary dolomite have been seen although there are a few thin veinlets of later ferroan dolomite. In composition, therefore, the calcarenites may be classed as intrasparites and fossiliferous intrasparites (Folk 1968).

The grain size analyses are shown in Fig. 5. They are plotted as cumulative frequency % (probability scale) against grain size (ϕ). For comparison between samples, grain size parameters were computed graphically (Folk 1968). The calcarenites are medium to coarse grained ($M_Z=0.80\phi$–1.15ϕ), well sorted to moderately sorted ($\sigma_I=0.53\phi$–0.95ϕ), fine skewed to coarse skewed ($Sk_I=-0.13$–$+0.17$) and mesokurtic to very leptokurtic ($K_G=$ 0.93–1.55). Grain size analyses have long been used as environmental indicators (Friedman 1961). Their application to carbonate sands, however, is particularly difficult because of the irregular shape and size of many skeletal particles (Jindrich 1969). In Recent carbonate sands these skeletal fragments often cause negatively skewed grain size distributions particularly in tidal channel and shelf environments. The dominance of negatively skewed distributions in the Ringerike calcarenites is also due largely to skeletal grains, particularly those of trilobites (Fig. 4). On the whole, the composition and grain size distributions of the calcarenites compare closely with those of Recent carbonate sands which are known to be of shallow marine origin, despite the difficulties of comparing data from sieving and thin sections. They also compare well with other ancient carbonate sands which have been analysed in a similar way (e.g. Knewtson & Hubert 1969).

Sedimentary structures

Cross-stratification in single or grouped sets is the dominant sedimentary structure of the calcarenites. Set thickness ranges from 0.05 m to 0.40 m with a mean of 0.17 m and corrected foreset inclination ranges from 8° to 33° with a mean of 18°. Commonly, grouped sets of cross-strata are similar to Allen's (1963) pi and omikron types which are produced by linguoid and straight crested megaripples respectively. At some localities set thickness tends to decrease upwards accompanied, in some cases, by a corresponding decrease in grain size (Fig. 6). The cross-beds were deposited in the lower flow regime (Simons et al. 1965) and the mean angle of inclination (18°) suggests, by analogy with Recent carbonate sands, that the sand waves built

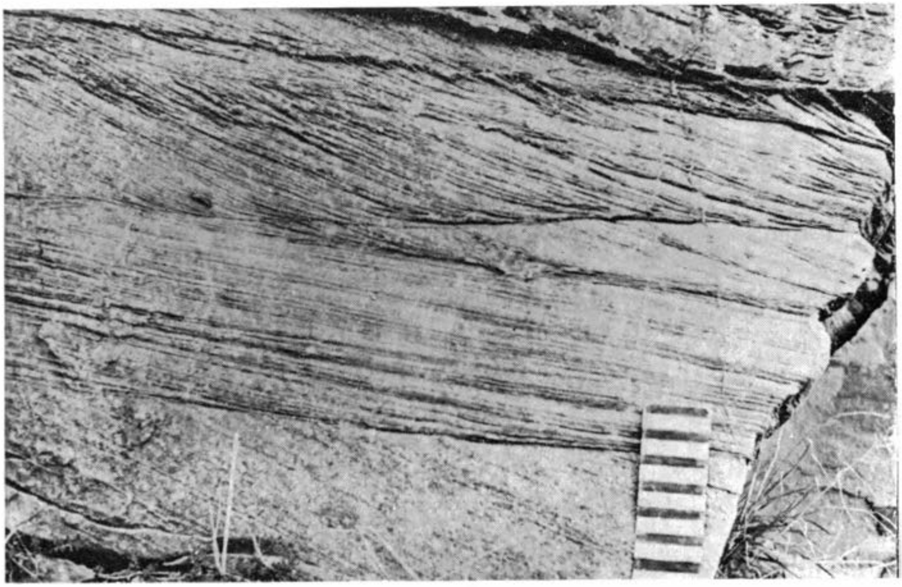


Fig. 6. Cross-stratified coarse calcarenite. Note the tendency for set thickness to decrease upwards. Scale is in centimetres.

forward by accretionary rather than avalanching processes (Imbrie & Buchanan 1965, p. 157). A minimum water depth for the formation of the calcarenites was estimated using the formula: $H=0.086d^{1.19}$ where $0.1 \leqslant d \leqslant 100$ metres, for the relationship between dune height (H) and water depth (d) given by Allen (1970, p. 78). The mean set thickness for cross-stratification of 0.17 m gives a water depth of 0.90 m, which coincides approximately with the maximum thickness of the calcarenites. Megaripples in Recent carbonate sands are common in tidal channels and areas with strong tidal flow. Jindrich (1969) described examples from the mouth of the Bluefish tidal channel in the Lower Florida Keys. They were dominantly straight crested with amplitudes from 0.15 to 0.35 m and wavelengths from 2 to 5 m, and must have been very similar to the megaripples which produced the cross-stratification in the calcarenites.

The dispersal pattern of the calcarenites has been inferred from the direction of maximum foreset inclination of cross-beds. One reading was made for each set, with a maximum of four readings for any one locality. The indifferent exposure of the calcarenites and the abundance of two-dimensional exposures has meant that only a limited number of readings (27) are available. Although only a small number of readings are available Hrabar et al. (1971) suggested as few as 24 readings per 7½ minute quadrangle may be sufficient when sampling a bimodal or variable current system. The most important feature of the results is the bimodality, both at individual outcrop

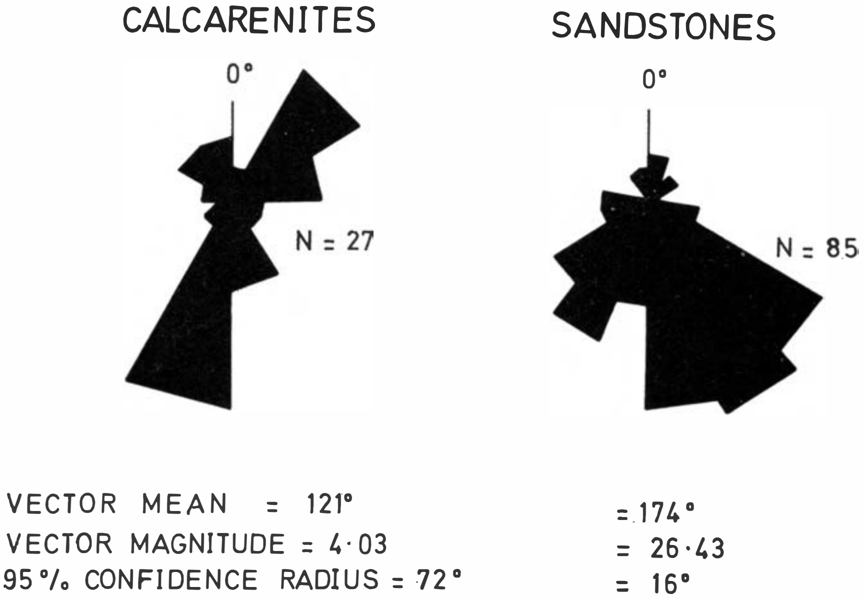


Fig. 7. Comparison of cross-stratification of the sandstones and calcarenites of the Sundvollen Formation. Note that the calcarenites have important modes indicating both northward and southward flowing currents whereas the two important modes in the sandstones indicate currents flowing southwards only.

level, and in the regional analysis. Polar histograms of cross-stratification azimuths for both calcarenites and sandstones in the Sundvollen Formation are shown in Fig. 7. The bimodal nature of the calcarenite azimuths contrasts sharply with the essentially unimodal pattern shown by the sandstones. The vector mean, vector magnitude and the 95 % spherical radius of confidence were calculated using the computer program described by Fox (1967). The vector magnitude is a measure of concentration of the azimuths. If all the azimuths have the same value then the vector magnitude would be equal to the number of azimuths. The very low vector magnitude of 4.03 (14.9 %) emphasizes the great variability of the calcarenite azimuths. Similarly the 95 % spherical radius of confidence indicates a 5 % probability that the true vector mean varies from the calculated one by 72°. This variability is in contrast to that found in the sandstones. These have a unidirectional pattern with relatively low variability characteristic of fluviatile deposits.

Variable or bimodal current systems are not uncommon in the stratigraphic record and have been described from both clastic and carbonate sequences. Examples from carbonate successions include the Great Oolite Series (Jurassic) of England (Klein 1965) and the Tanglewood Limestone Member of the Lexington Limestone (Ordovician) of the U.S.A. (Hrabar et al. 1971). By analogy with Recent examples these sequences have been interpreted as having formed under the influence of strong tidal currents which flowed both on-shore and off-shore. The Ringerike calcarenites are interpreted in the same way.

Palaeontological evidence

Although the fossils in the calcarenites are mostly fragmentary they have a distinctly marine aspect. Bryozoa, echinoderms and trilobites are characteristic of shallow marine deposits and are common in the calcarenites. The absence of well-preserved body fossils is not surprising. Modern carbonate sands contain little evidence of the rich fauna and flora which they support. Newall et al. (1959, p. 200) estimated that commonly less than 5 % of a local biota secretes hard parts that can survive as fossils in the ultimate sediment. The best preserved fossils in the calcarenites are thelodont fish scales. Extraction of the thelodonts by dissolving the limestones in 20 % acetic acid and separating the residue in heavy liquids produced many well-preserved scales. These are unlikely to have been transported far and certainly could not have been derived from a terrestrial source area as suggested by Kiær (1924). Further evidence of the marine nature of the calcarenites is provided by the occurrence of trace fossils. At locality SF212 flat-bedded calcarenite has an irregular, burrowed upper surface. The burrows are v-shaped and between 1 and 4 cm deep. The burrowed surface is overlain by bio-turbated calcarenite. Such intense biotic activity as this is only likely to have taken place in a shallow marine environment.

Depositional environment and source of the carbonate sand

The calcarenites with their typically shallow marine fauna, albeit fragmentary, and trace fossils, were probably deposited in a well-oxygenated shallow marine environment. The evidence from cross-stratification suggests that they were deposited by strong tidal currents in relatively shallow water, probably less than 1 m deep. In all they are similar to Recent carbonate sands deposited in or at the mouths of tidal channels (Jindrich 1969). The close association of the calcarenites with apparently normal fluviatile sand-

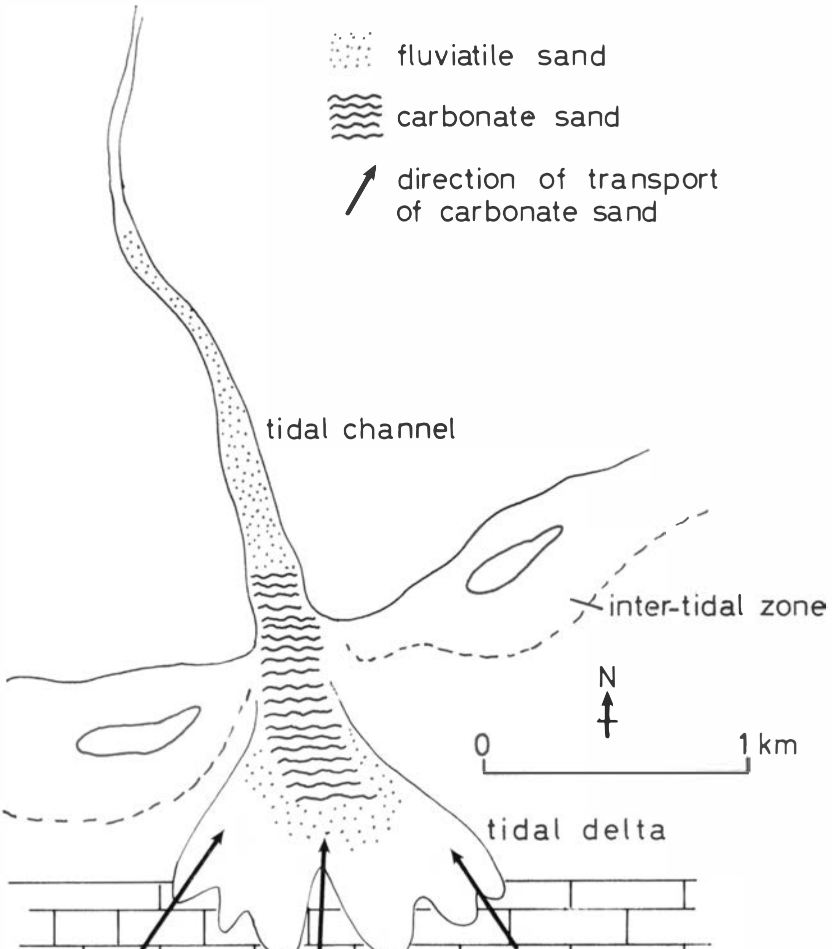


Fig. 8. Sketch showing the suggested depositional environments within the Sundvollen Formation and the possible source of the calcarenites.

stones suggests that they were deposited in tidal estuaries where there was a continual oscillation of tidal and fluvial currents. The occurrence of the calcarenites throughout the Sundvollen Formation indicates that coastal or near coastal conditions prevailed throughout this time. This is supported by the fine-grained nature of the Sundvollen Formation clastics and the occurrence of other evidence of shoreline conditions in the Sundvollen Formation. However, no evidence of other types of shoreline sediments associated with the calcarenites has been found.

The source of the carbonate sand could not have been in a terrestrial source area as suggested by Kiær (1924). In view of the palaeocurrent evidence it was probably derived from an area south of the coastal alluvial plain and transported north by tidal currents. In this area carbonate sedimentation must have not long ceased and it may even have been continuing. These carbonate sediments are most likely to be those now represented in 'Stage' 9. As noted earlier they consist of sub-tidal, inter-tidal and supratidal carbonates, shales and dolomitic shales. Erosion of these previously lithified sediments is thought to have taken place and been responsible for the production of the carbonate sand which formed the calcarenites. A diagrammatic summary of the source and depositional environment of the calcarenite is given in Fig. 8.

Conclusions

Calcarenites occur at several horizons in the Sundvollen Formation at Ringerike. They are associated with fluviatile sandstones and have an average thickness of 0.5 m. The calcarenites are medium to coarse-grained, well-rounded and of intrasparite or fossiliferous intrasparite composition. Cross-stratification is the most common sedimentary structure and the bipolar distribution of azimuths suggests deposition by strong tidal currents. This is supported by the presence of a fragmentary shallow marine fauna and the occurrence of burrowed and bio-turbated calcarenites.

The calcarenites are thought to have been deposited at or near the mouths of large tidal estuaries which penetrated the coastal alluvial plain of the Sundvollen Formation. The carbonate sand was probably derived from previously lithified carbonates in 'Stage' 9 which lay to the south of the coastal plain. This supports the conclusion made by Spjeldnæs (1966) that the boundary between 'Stage' 9 and 10 is diachronous.

September 1972

REFERENCES

Allen, J. R. L. 1963: The classification of cross-stratified units, with notes on their origin. *Sedimentology 2,* 93–114.

Allen, J. R. L. 1965: A review of the origin and characteristics of Recent alluvial sediments. *Sedimentology 5,* No. 2 (spec. publ.), 89–191.

Allen, J. R. L. 1970: *Physical Processes of Sedimentation,* Allen and Unwin, London, 248 pp.

Bathurst, R. G. C. 1966: Boring algae, micrite envelopes and lithification of molluscan biosparites. *Geol. J. 5,* 15–32.

Bathurst, R. G. C. 1971: *Carbonate Sediments and their Diagenesis.* Elsevier, Amsterdam, 620 pp.

Chien, N. 1961: The braided stream of the lower Yellow River. *Sci. Sin. X,* 734–754.

Coleman, J. M. 1969: Brahmaputra River: Channel processes and sedimentation. *Sediment. Geol. 8,* 129–239.

Dixon, J. A. D. 1965: A modified staining technique for carbonates in thin section. *Nature 205,* 587.

Doeglas, D. J. 1962: The structure of sedimentary deposits of braided rivers. *Sedimentology 1,* 167–190.

Fox, W. T. 1967: Fortran IV program for vector trend analysis of directional data. *Kans. Geol. Surv.* Computer Contribution 28, 31 pp.

Friend, P. F. 1965: Fluviatile sedimentary structures in the Wood Bay Series (Devonian) of Spitsbergen. *Sedimentology 5,* 39–68.

Heintz, A. 1969: New agnaths from the Ringerike Sandstone. *Skr. Nor. Vidensk.-Akad. i Oslo, Mat.-Naturvidensk. Kl.,* No. 26, 1–28.

Hrabar, S. V., Cressman, E. R. & Potter, P. E. 1971: Cross-bedding of the Tanglewood Limestone Member of the Lexington Limestone (Ordovician) of the Blue Grass Region of Kentucky. *Brigham Young Univ., Geol. Studies, 18,* 99–114.

Imbrie, J. & Buchanan, H. 1965: Sedimentary structures in modern carbonate sands of the Bahamas. *Soc. Econ. Palaeontol. Mineral.* (spec. publ. 12), 149–172.

Jaanusson, V. 1972: Constituent analysis of an Ordovician limestone from Sweden. *Lethaia 5,* 217–237.

Jindrich, V. 1969: Recent carbonate sedimentation by tidal channels in the Lower Florida Keys. *J. Sediment. Petrol. 39,* 531–553.

Kiær, J. 1911: A new Downtonian fauna in the Sandstone Series of the Kristiania area, a preliminary report. *Skr. Nor. Vidensk.-Akad. i Oslo, Mat.-Naturvidensk. Kl.,* No. 7, 1–22.

Kiær, J. 1924: The Downtonian fauna of Norway. 1. Anaspida with a geological introduction. *Skr. Nor. Vidensk.-Akad. i Oslo, Mat.-Naturvidensk. Kl.,* No. 6, 1–139.

Klein, G. De V. 1965: Dynamic significance of primary sedimentary structures in the Middle Jurassic Great Oolite Series, southern England. *Soc. Econ. Palaeontol. Mineral.,* (spec. publ. 12), 173–191.

Newall, N. D., Rigby, J. K., Whiteman, A. J. & Bradley, J. S. 1959: Organism communities and bottom facies, Great Bahama Bank. *Bull. Am. Mus. Nat. Hist. 97,* 1–29.

Simons, D. B., Richardson, E. V. & Nordin, C. F. 1965: Sedimentary structures generated by flow in alluvial channels. *Soc. Econ. Palaeontol. Mineral.,* (spec. publ. 12), 34–52.

Spjeldnæs, N. 1966: Silurian tidal sediments from the base of the Ringerike Formation, Oslo Region, Norway. *Nor. Geol. Tidsskr. 46,* 497–509.

Störmer, L. 1934: Merostomata from the Downtonian sandstone of Ringerike, Norway. *Skr. Nor. Vidensk.-Akad. i Oslo, Mat.-Naturvidensk. Kl.,* No. 10, 1–125.

Turner, P. 1973: *The Stratigraphy and Sedimentology of the Ringerike Group of Norway.* Unpublished thesis, University of Leicester.

Williams, P. F. & Rust, B. R. 1969: The sedimentology of a braided river. *J. Sediment. Petrol. 39,* 649–679.