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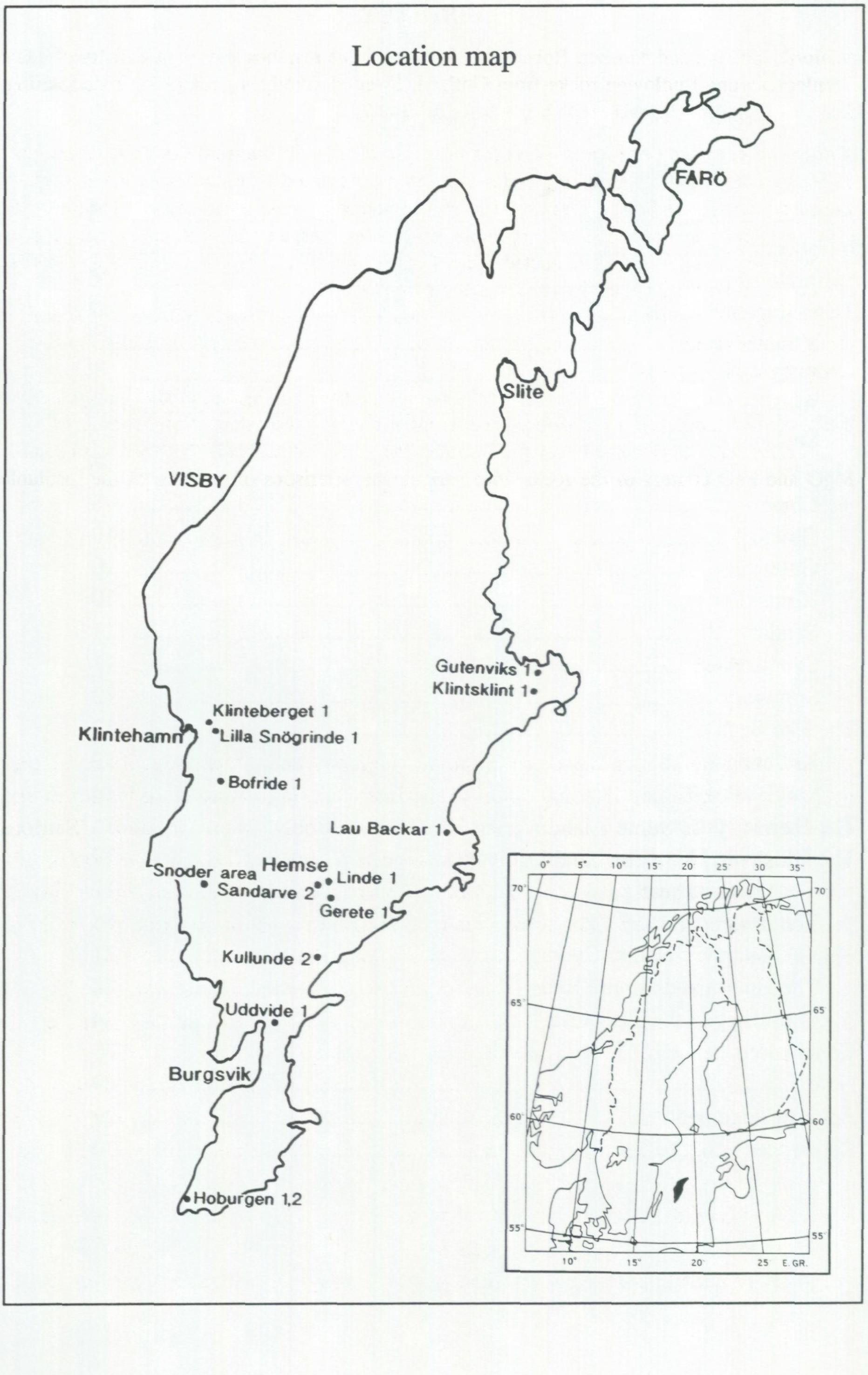
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## ABSTRACT

Sanford, John T., and Mosher, Robert E., 1994: Insoluble residues and geochemistry of some Wenlockian and Ludlovian rocks from Gotland, Sweden. Sveriges geologiska undersökning. Ser. C 827, 30 pp. Uppsala 1994. ISBN 91-7158-542-7.

This is the second of two papers and continues a presentation of the results of detailed analyses of sedimentary rocks of Gotland. The area of study presented here continues the Klinteberg Beds up through the Sundre Beds, which are the youngest rocks exposed. In addition to the previously described chemical and insoluble residue analyses, a number of sand grain parameters were measured on rocks collected at Hoburgen 2 and Uddvide 1 in an attempt to clarify and compare depositional environments at these two localities.

Further discussions are presented on the continuing trends in the relative deposition of clastic materials and chemical precipitates. This is discussed in relationship to diagenesis and environmental changes.

Detailed analyses were made at 0.5 cm intervals over the Eke/Hemse contact at Nyan 2 and the Burgsvik/Hamra contact at Hoburgen 2 in order to clarify the nature of these contacts.

Further data is presented which illustrates the direct relationship between acid-soluble MgO and FeO content of the rocks with various characteristics of portions of the insoluble residues.

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## INTRODUCTION

Our approach to the problems of Gotland stratigraphy and our analytical methodology has been explained in some detail in the Introduction to "Insoluble Residues and Geochemistry of Some Llandoverian Wenlockian Rocks From Gotland." (Sanford and Mosher 1985). The sandstones have required some additional attention as explained below. There has been no difference in our thinking between the writing of the two reports and reference is also made to the first paper for an explanation of our objectives.

For the reader to obtain a better understanding of the basic data, compare Table I of this paper with Table I of the former reference. For practical purposes, these two tables comprise one table summarizing the data for all of the Gotland sections.

There appears to be no well delineated lithological break between the rocks discussed previously (Sanford and Mosher 1985) and those discussed herein. The lower Klinteberg Beds do have a much lower clastic content than many of the older beds. There is, however, no greater change between those older Wenlock rocks and the Klinteberg Beds than occurs several times within the older Wenlock sequence alone. There appears to be a repeated tendency for beds with high silt/clay content to be gradually replaced upward by pure limestones, sometimes with attendant reef building. It is also true that there are a few beds in the Ludlow, which contain the fine clastics so numerous in the Wenlock. However, of the beds we have sampled it is apparent that the fine silts and clays so prominent in the Mulde Beds and older stratigraphic units are less conspicuous in those studied here. This difference does not seem to reflect a profound change in the general paleogeography. Whatever changes took place appear to have been gradual and to reflect a general evolutionary trend with what might be termed a cleaning up of the sediments in the Ludlow section. Although the Burgsvik sands represent some increase in the general character of the mechanical energy, they are fine sands not much coarser than silt and are not burdened with the real "fine" clastics so apparent in the lower beds.

## METHODOLOGY

In addition to the standard analysis, 0.5 to 1.0 gram aliquots of sandstone samples of the Hoburgen 2 and Uddvide 1 sections of Gotland were placed in 50 ml beakers and treated with 1 normal hydrochloric acid to remove carbonate cement. When reaction seemed complete, the beakers were heated just to a boil and the aggregates crushed gently with a plastic stirring rod. Due to slight silica cementation, further treatment with dilute hydrofluoric acid was required. The sands were transferred to plastic beakers after washing and draining and treated with 10% hydrofluoric acid for 20 minutes. This was adequate to disaggregate all of the samples except R72584, which was given an additional 30 minutes. The mixtures were stirred gently throughout using a plastic stirring rod. The process described produced satisfactory disaggregation of all samples. The residues were then washed, rinsed with distilled water and dried at 105° C.

Portions of the dried sands were transferred to microscope slides, several drops of monobrombenzene were added and the preparations were covered with 22 x 40 mm cover glasses. Monobrombenzene was used as the immersion fluid since its refractive index (1.5581) simplifies differentiating mica and silica due to differences in relief, refractive index, and birefringence.

The mean of the major and minor axis of each grain (Martin's Diameter) was then determined for 500 particles in the sand size range, chosen at random and distributed over the entire area of the slide. A Leitz SM-Lux-POL monocular microscope with 10X objective and 10X wide field ocular containing a micrometer reticle were used. This reticle was calibrated with a Leitz stage micrometer.

Moments measures were computed manually from the raw grouped frequency data using a calculator. Martin's Diameter was chosen because of the ease of its determination and because it is a recognized measurement. All linear measures of diameter were converted to phi ($\phi$) units (Krumbein 1936).

Mica particles were not counted in the total because their shape is so different from that of the other mineral grains. No grains smaller than 25 micrometers were measured since we were interested primarily in the sand-size grain distribution and because the silt content as determined by standard methods was very small.

## THE KLINTEBERG BEDS

In 1960 the official Wenlock–Ludlow Boundary was drawn below the *M. vulgaris* zone. Today it is drawn above that zone. Thereby Klinteberg is now Wenlock. Hede (Hede 1960, p. 76) has described the general characteristics and lithologies of the various units of the Klinteberg Group. At least the main part of the Klinteberg Group is Late Wenlock in age (Jeppsson 1983). Manten (1971) discussed the Klinteberg Group with sketches and photographs from the Klinteberget area. The papers by Laufeld (1974a, 1974b) have been helpful, particularly his "Reference Localities" which is essential to any work on Gotland stratigraphy. The reader is referred to these for coverage of the field relationships.

**Klinteberget 1** (CJ 3391 6340). The thickest of three exposures of the Klinteberg Beds studied occurs at this section, where 10.35 m of stratified limestone are exposed. Fourteen representative specimens were collected at this locality. Its position in the upper part of the Wenlock Series is well established. Hede (1960, p. 76) concluded that the Mulde Beds most likely occur not far below the exposure.

The insoluble residues of the rocks at the Klinteberget section are low, averaging only 1.6 percent of clay and silt. Traces of sand are present with a few grains up to 0.5 mm in greatest dimension. The average percent of clastics in the upper five samples at Klinteberget, above a more phosphatic zone at approximately 4 meters, is 2.0% and the range from 1.1% to 2.8%, while the lower seven samples of that locality average 1.1% and range from 0.8% to 1.4%. Nonclastic insoluble materials are present in very small amounts throughout the section at 0.1% and traces of secondary silica are always present. Traces of sulfides are scattered throughout much of the section, including a mineral whose grains were too small for positive identification but which is probably sphalerite. Many of the residues contain arenaceous foraminifers (cf. *Psammosphaera*) or fragments of some arenaceous foraminifera, and scolecodonts are present in a few residues.

Chemically, the samples are all relatively pure limestones, averaging a CaO content of 53.98% and a MgO content of 1.28%. Only the topmost specimen has a CaO/MgO ratio as low as 10. The other samples have ratios ranging from 27 to 190 and only three of these are lower than 40. Iron is low, averaging 0.08%. Of the 42 Gotland averages, only seven are as low or lower than this, and these all occur in relatively pure limestones similar to the ones under discussion.

The zone of higher phosphorus content referred to above is indicated by two analyses, one from a sample at 3.95 meters and another at 4.05 meters above the base of the section. The first sample contains 0.020% (200 ppm) and the second 0.016% (160 ppm). The average for the samples below this zone is 0.005% (50 ppm) and for those above 0.009% (90 ppm). The sample from 4.05 meters also has the highest percentage of FeO in the section (0.18%) with the mean from the remaining 13 samples being 0.07%. As both middle and lower Klinteberg Beds are reported from this section (Laufeld 1974a, 1974b), it seems possible that this horizon may represent a transition zone.

**Lilla Snögrinde 1** (CJ 3421 6315). This locality has been placed in the lower to middle part of the Klinteberg Beds (Laufeld 1974a, 1975a) and so may overlap with or lie stratigraphically near the Klinteberget 1 section. The average percent of clastics from the Lilla Snögrinde 1 samples is 3.3% and ranges from 0.9% to 5.7%. The residues at the two localities have similar characteristics. Those at Lilla Snögrinde 1 are predominantly silty clays with small amounts of fine to very fine sand, weathered sulfides and fragmentary arenaceous foraminifera (cf. *Psammosphaera*). There are small amounts of secondary silica in some samples.

The limestones are quite pure with an average CaO content of 50.40%. One sample near the middle of the section has relatively high values in both MgO (9.75%) and FeO (0.36%), with a CaO/MgO ratio of 4. The other six samples have a mean CaO/MgO ratio of 58, ranging from 16 to 170 and a mean value for FeO of 0.10%. Phosphorus has a mean value of 0.008% (80 ppm) and a range from 0.002% to 0.020% (10 to 40 ppm). The values tend to be higher near the top of the section.

**Bofride 1** (CJ 3509 5837). The third section sampled was at Bofride 1, where 5.3 m of beds are exposed and 8 specimens were collected for study. Laufeld (1974a, 1974b) indicates that this section is in the upper part of the Klinteberg Beds. The lower beds (1.6 to 2.0 m thick) are thinly bedded, predominantly light tan, very finely to medium crystalline limestones. The upper beds present a complex of small biohermal and interbiohermal beds, which is difficult to decipher. These limestones are variably crystalline, although both dense and finely crystalline rocks are present. They contain a macro fauna, including pink pelmatozoan columnals, reworked fossil fragments. One sample had pebbles of finely crystalline, grey limestone.

The percentages of clastics in the residues are small, averaging 1.7%. Clays and silts predominate with only traces of sand. There are traces of nonclastic insoluble materials, including secondary amorphous silica and sulfides. One residue included a scolecodont.

These limestones are quite pure with an average CaO content of 53.40%. FeO is low with a mean value of 0.06% and phosphorus very low averaging only 0.002%

(20 ppm) and ranging from 0.001% to 0.004% (10 to 40 ppm) for the eight samples.

The combination of incipient reef building with evidence for reworking suggests an environment conducive to biohermal development, but without sufficient depth of water for major reef formation. There is no intended inference as to the distance from shore.

**Summary.** The Klinteberg Beds as analyzed exhibit a marked contrast to the Wenlock rocks below them. They contain much lower percentages of clastic materials and do not exhibit the marked evolutionary trends from higher to lower clastic values frequently climaxing in well developed bioherms. The influx of fine pyroclastics must have been negligible or absent during Klinteberg time as contrasted to the presence of bentonites exhibiting strong evidence for volcanic influence during the deposition of the older beds. It would appear that there was some change in the general milieu between Wenlock and Ludlow times.

## THE HEMSE BEDS

The Hemse Beds include high calcium limestones with only small percentages of clastics as well as some strata with appreciable clastics and higher percentages of MgO. Seven exposures were sampled although most of them were too small to give an adequate picture of the rocks. The section at Botvide-1 is included in the discussion of the Hemse-Eke contact.

**Linde 1** (CJ 4201 5181). This is the best section of the Hemse Beds. Eleven samples were obtained from 10.51 meters of stratified section and four samples from what appears to be biohermal rocks approximately 100 meters away, but which were equivalent horizontally to at least the stratified part of the section. This section has been placed in the upper part of the Hemse Beds (Laufeld 1974b, p. 96).

The stratified rocks are low in insoluble clastic materials with a mean of 2.7% and range in values from 0.5 to 6.9%. These clastics are predominantly silts, some of which are slightly argillaceous, and a few contain fine to very fine grained sand. The nonclastic insolubles average 0.6% ranging from 0 to 2.6%. They consist of secondary silica, which in the lower part of the section is composed partly of fragmentary fossils. Pyrite is prominent in the residue from 4.73 meters above the base. Arenaceous foraminifers are scattered through the section.

The four samples from the rocks of biohermal appearance average 8.5% of clastics and 1% of insoluble nonclastics. The clastics are predominantly silt with a little very fine sand and clay. One sample contains mica. The nonclastics included white amorphous silica and in some places considerable pyrite. Traces of glauconite and arenaceous foraminifers were present. The high percentage of clastics might raise some question about the biohermal genesis of these rocks, although it does not demonstrate that they did not have a biohermal origin.

Both the stratified and biohermal facies at Linde 1 are relatively pure limestones. The stratified limestones are variably crystalline with coarse pelmatozoan debris, some of which is pink. The biohermal rocks tend to be somewhat more finely crystalline, ranging for the most part from fine to medium, but they do contain the coarser pelmatozoan debris.

The biohermal rocks tend to be on average slightly higher in magnesium, iron and phosphorus. Relatively high values of these three elements for the samples at the top of the stratified section suggest the possibility of contamination. The abundant pyrite in sample R72313 coupled with the normal value for iron in the solubles from the same sample, suggests that there was no stripping of iron from the pyrite during solution of the sample in 1 normal hydrochloric acid.

**Gerete 1** (CJ 4115 4907). In overall appearance, this rock is best described as a grey, blocky, lime clay rock with a few large calcite crystals, fossils and a trace of pyrite. The insolubles assayed 22.2% of clastics, predominantly in the fine range and consisting of somewhat micaceous silt, a little clay and a few fine sand grains. As in the case with most rocks high in fine, insoluble clastics, it has a low CaO/MgO ratio of 5.9 and although it would still be considered a limestone, technically it is approaching the dolomite range. Iron at 0.32% is somewhat higher than most limestones, but phosphorus at 0.011% (110) ppm falls within an ordinary range.

**Gutenviks 1** (CJ 7046 6697). According to Laufeld (1974, p. 52), units "c" and "d" of the Hemse Beds are exposed here. The one sample available appears to have had a stromatoporoidal origin with some interleaved clay, but it may be atypical. The carbonate varies between grey, very finely crystalline and brown, medium crystalline limestone. The analysis indicated 0.9% of argillaceous silt and 1.8% of insoluble nonclastics consisting of white rounded spongy siliceous masses of unknown origin mostly ranging up to 1 mm. There were several masses of pyrite up to 3 to 4 mm in size. Chemically, the rock is a rather pure limestone with low iron and phosphorus.

**Klintsklint 1** (CJ 6952 6459). Four samples from the 3.85 m of relatively massive limestones at Klintsklint 1 consist of light brown, fine to medium and variably crystalline limestone. Traces of pink, ferruginous pelmatozoan debris and columnals are apparent in several samples. Small rounded limestone pebbles are present at the top and bottom of the section and are not as coarsely crystalline as the matrix. Two beds of soft material, approximately 65 cm apart and probably bentonitic, occur near the middle of the section. Under the low power stereoscopic microscope, this material has the appearance of a soft, greenish grey, calcareous shale. It breaks down readily in water and has the gross characteristics of a clay.

The residues from the limestone are extremely small, varying from traces of both clastic and nonclastic material to a maximum of 1.0% of silt and very fine sand. Fragments of arenaceous foraminifera are present and small amounts of pyrite occur at the top of the section. The limestones are quite pure chemically with only nominal amounts of magnesium, iron and phosphorus.

One soft shale sample is 41.6% soluble in hydrochloric acid and the residue consists of fine bits of silica with traces of clay. It is relatively high in both magnesium ($CaO/MgO = 2.7$) and iron (1.00%).

The chemical purity of the limestones, coupled with the small amount of insoluble clastics and the presence of small, rounded, limestone pebbles and pelmatozoan debris suggests reworking by wave and current action in reasonably shallow water, but not near the shore. This environment could have been a preliminary to biohermal development provided the subsequent situation was favourable.

The fine character of the thin, shaly beds and their radical differences from the limestones indicates a strong possibility that they were originally deposited as fine windblown tephra, and therefore clastics, which accumulated rapidly in an environment conducive to carbonate deposition. The silicious tephra may have been reorganized during epigenesis and we have interpreted them as reorganized silica, and therefore authigenic, although their syngenetic history must have been allogenic. At the magnifications at which residues are studied with the stereoscopic microscope, this interpretation is at best a reasonable supposition.

**Sandarve 2** (CJ 3989 5116). According to Laufeld (Laufeld 1974b, p. 119), this locality presents the upper part of the Hemse Beds. The rocks are poorly exposed and we collected only two grab samples. These gave similar analytical results and are probably representative of these rocks. They are light grey to brownish and pink variably crystalline rocks with some pelmatozoan debris and other fossils.

The insoluble residues average 3.3% clastics, consisting of light grey clay and silt, and 0.2% of non-clastics, consisting of fine, white silica with traces of quartz and a few small chitin fragments. Chemically, the rock is a pure limestone with a $CaO/MgO$ ratio of 81, only 0.16% of iron and 50 ppm of phosphorus as mean values for the two samples. A comparison of these rocks, with the thicker section exposed at Linde, shows that they are typical of the upper part of the Hemse Beds.

**Snoder Area.** Three samples of very finely crystalline, fossiliferous, argillaceous limestone were collected from a short section along the banks of the Snoder Kanal. Approximately 125 cm of rock were exposed above the water level. Only the hard beds were collected in place, although the hard and soft beds were present in about the same proportions. These specimens were very impure carbonates with insoluble residues averaging 31.2% clastics, largely silt and argillaceous silt. Except for scolecodont and arenaceous fragments of foraminifera and a small amount of sulfide, there were no insoluble nonclastic materials in the residues.

Loose pieces of shale were also collected at the outcrop and analysis of one sample showed 73.1% of clastic material. This residue consisted of slightly argillaceous, micaceous silt with a few small black chitin fragments scattered through it. Chemically, the solubles are close to dolomite composition with a CaO/MgO oxide ratio of 4.5 and a MgO/FeO ratio of 2.3. The high magnesium and iron contents, as in other cases, are associated with the large amounts of silt present. It is probable that a more adequate exposure would have exhibited a series of limestone and argillaceous or shaly limestone beds alternating in a sequence similar to that of the Visby Beds at Ireviken 3.

**Summary.** Hede (1960) and Laufeld (1974a, p. 11–12) indicate that the northeastern exposures are mostly limestones, but they use the term "Hemse Marl" for those beds farther south. The limited size of most of the exposures sampled does not allow an adequate summarization of the overall lithological character of the Hemse Beds. The analytical data do demonstrate, however, that relatively pure limestones with a low content of mostly fine clastics appear to predominate. Argillaceous limestones and shales with high percentages of silts and clays are also present and these are higher in magnesium content although they are not true dolomites. The Hemse Beds are in some respects intermediate between the Wenlock and the younger Ludlow rocks.

## THE EKE BEDS

The Eke Beds are not sufficiently represented in our samples to permit us to give an adequate characterization of these strata. Four localities are represented altogether, but two of them will be discussed in another section dealing with the Hemse–Eke contact. The two localities discussed in this section are represented by a total of only three samples. These are carbonates, but it seems probable that "marl" beds are present in these sections.

**Kullunde 2** (CJ 4412 3799). The two samples from Kullunde 2 are predominantly fine to very fine crystalline, fossiliferous limestones. Some of the fossils and fossil fragments are surrounded by fine laminae of limestone which tends to be more finely crystalline, exhibits accretionary growth around the fossils and is possibly due to the activities of algae. The rocks are brown to greyish. Clastic materials in the residues average 6.1% and are primarily silty, grey clay, although there are appreciable

TABLE I. Summary of mean values of analytical data.

| Formation | Location | Insolubles % C* | %** | % Sol. | % CaO | % MgO | % FeO | % P | No. Samples | Interval | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SUNDRE** | Hoburgen 3 | 0.4 | 0.1 | 99.6 | 54.93 | 0.52 | 0.08 | 0.012 | 4 | 10 m | |
| **HAMRA** | Hoburgen 3 | 0.8 | 0.4 | 98.7 | 54.25 | 0.66 | 0.14 | 0.014 | 7 | 19.9 m | Not divided into (b) & (c)[1] |
| | Uddvide 1 (above spergenite) | 5.8 | 0.2 | 94.0 | 49.64 | 1.37 | 0.17 | 0.014 | 2 | 0.8 m | |
| | Hoburgen 2 (above spergenite) | 3.7 | 0.2 | 96.1 | 52.57 | 0.99 | 0.17 | 0.017 | 6 | 5.95 m | |
| Hamra Spergenite | Hoburgen 2 | 8.3 | - | 91.7 | 49.89 | 0.57 | 0.26 | 0.019 | 4 | 1.4 m | |
| | Uddvide 1 | 7.7 | Trace | 92.3 | 49.42 | 0.93 | 0.29 | 0.012 | 4 | 0.75 m? | |
| **BURGSVIK** | | | | | | | | | | | |
| Upper | Hoburgen 2 | 88.4 | - | 11.6 | 3.76 | 1.04 | 0.67 | 0.021 | 6 | 4.10 m | |
| Upper | Uddvide 1 | 85.3 | - | 14.7 | 4.30 | 1.30 | 0.60 | 0.029 | 5 | 1.25 m? | |
| **EKE** | | | | | | | | | | | |
| Upper | Lau Backar 1 | 4.4 | Trace | 95.5 | 51.49 | 083 | 0.48 | 0.013 | 1 | - | |
| Upper Middle | Kullunde 2 | 6.1 | - | 94.0 | 51.15 | 0.77 | 0.34 | 0.010 | 2 | Loose | |
| Lower | Botvide 1 | 0.8 | 0.3 | 98.9 | 54.46 | 0.68 | 0.11 | 0.010 | 4 | 64 cm | |
| **HEMSE** | | | | | | | | | | | |
| Uppermost | Botvide 1 | 4.6 | 0.1 | 95.2 | 46.15 | 4.53 | 0.36 | 0.014 | 1 | | |
| Upper Part | Sandarve 2 | 3.3 | 0.2 | 96.6 | 52.50 | 0.66 | 0.16 | 0.005 | 2 | Grab | |
| Undiff. Upper | Linde 1 | 2.7 | 0.5 | 96.7 | 53.28 | 0.51 | 0.17 | 0.006 | 11 | 11.51 m | Stratified |
| | Linde 1 | 7.0 | 0.5 | 92.6 | 49.86 | 0.98 | 0.28 | 0.008 | 4 | - | Biohermal,upper part |
| Units d & c | Klintsklint 1 | 0.3 | Trace | 99.7 | 54.63 | 0.65 | 0.08 | 0.005 | 4 | 3.85 m | |
| Unit, undiff. | Gutenviks 1 | 0.9 | 1.8 | 97.3 | 51.59 | 1.02 | 0.05 | 0.005 | 1 | - | |
| Northwest Part | Gerete 1 | 22.2 | 0.0 | 77.8 | 16.25 | 2.76 | 0.32 | 0.011 | 1 | | |
| | Snoder Area | 41.7 | - | 58.4 | 30.63 | 2.30 | 0.83 | 0.014 | 4 | - | |
| **KLINTEBERG** | | | | | | | | | | | |
| Upper Part | Bofride 1 | 1.7 | Trace | 98.3 | 53.40 | 0.77 | 0.06 | 0.002 | 8 | 5.30 m | |
| Undiff., Low-mid. | Lilla Snögrinde | 3.3 | Trace | 96.7 | 50.40 | 2.77 | 0.13 | 0.008 | 7 | 4.00 m | |
| Undiff., Low-mid. | Klinteberget 1 | 1.6 | 0.1 | 98.4 | 53.98 | 1.28 | 0.01 | 0.008 | 14 | 10.35 m | |

[1] as in Laufeld. * % C = % Clastics ** % NC = % Nonclastics

amounts of very fine, angular, somewhat micaceous sand. Scolecodont fragments and arenaceous foraminifera are also present.

The carbonate fractions are quite similar chemically and are relatively pure limestones with an average CaO/MgO ratio of 69. Phosphorus and iron oxide are present in normal amounts (Table I).

**Lau Backar 1** (CJ 5775 5209). This is the type locality for the *Rhizophyllum Limestone*. The limestone is light brown, dense to finely crystalline and fossiliferous. It exhibits rusty weathering and has argillaceous-appearing patches and a little secondary crystallization. Two residues from the single sample average 4.4% of clastics with a trace of nonclastics. Clastics are predominantly light grey, argillaceous silt with a few very fine grains of quartz sand. The nonclastics consist of white silica, a little rusty weathered sulfide and arenaceous foraminifera. The silica is partly silicified fossils. The rock is a typical limestone with a CaO/MgO ratio of 62, FeO content of 0.48% and 0.013% (130 ppm) of phosphorus.

## THE HEMSE–EKE CONTACT

This contact is exposed in a short section at locality Botvide 1 (CJ 5851 5295) and, in addition, we have a single specimen which includes this contact from the locality at Nyan 2 (CJ 6168 5057). The latter specimen was kindly furnished by Dr. Sven Laufeld, at that time of the Geological Survey of Sweden. The section at Botvide 1 has been described in some detail by Hede (Hede 1960:80,81). He described about 2.5 m of section and indicated that a thin conglomerate, up to 10 cm thick in places, appears at the contact between the Hemse Marl and the Eke Group. It contains pebbles of a lithology of the Hemse group and various fossils. These pebbles and fossils are imbedded in "marlstones" and argillaceous limestone. He cites this as evidence for a "discontinuity" between the Hemse and Eke Beds and this conclusion is undoubtedly correct.

Apparently the quality of the exposure has deteriorated since Hede described it, as the section which we studied consisted of less than a meter stratigraphically exposed. The "conglomerate" was not seen in the studied section. The lower, 17 cm of the exposed rocks can definitely be referred to the Hemse beds. Above this there are 5 cm of very calcareous shale which also seem to belong to the same unit. The beds exposed above this are Eke. We have referred our zero reference plane to the top of the 5 cm of calcareous shale. A sample 11 cm below the zero horizon is probably the only really typical Hemse sample from this locality. It consists of light tan-grey, predominately finely crystalline, fossiliferous limestone with a few coarser crystals and some secondary crystallization. It is reasonably pure and contains only 4.7% of insolubles of which 4.6% are clastics. The clastics are slightly argillaceous and somewhat micaceous silts and the nonclastics include a few siliceous fossil fragments, arenaceous foraminifera and thin films of pyrite, some of which were formed after fossils. The MgO content is relatively high, 4.53%, giving a CaO/MgO ratio of 10, which means that the rock is a magnesian limestone. The percentage of FeO is 0.36% and the phosphorus 0.014% (140 ppm). Although the iron content is somewhat higher than in the covering Eke Beds, these latter figures excite no particular interest.

A specimen from just below the 5 cm of calcareous shale is a very finely crystalline, rusty-grey, impure limestone. It contains 26.3% of clastics which are primarily light grey, slightly micaceous, slightly argillaceous silt. The nonclastic insolubles consist primarily of white, flaky silica and make up 4.9% of the sample. There are a few fossils which are referred to as *Tasmanites*. In the upper part of this specimen, there are a number of fine, argillaceous, greenish streaks of material which appear to be burrow fillings. These might be compared to similar burrow fillings in the Kettle Pointe Shales of Ontario, Canada, which are middle Devonian in age and contain numerous *Tasmanites*. Although less soluble than the limestone below, this rock contains a high percentage of magnesium oxide, 6.47%, and is certainly in the magnesian limestone category even though it is very impure. It has 0.1% of FeO, and 0.019% (190 ppm) of phosphorus which is a relatively large amount.

The 5 cm of calcareous shale which might be considered a contact zone, consists of greenish-grey, blocky, calcareous shale which is quite uniform in character. It has 36.1% of insoluble clastic material which consists of slightly argillaceous silt. 19.4% of the rock is made up of nonclastic insolubles, primarily white, flaky silica with a few *Tasmanites* and metallic-appearing fragments of indefinite character. A little mica is scattered through the insolubles. This rock has a magnesium content of 10.48% giving it a CaO/MgO ratio of 2.3, which puts it within the dolomite range as far as the solubles are concerned. Technically, the analysis indicates a silty, siliceous, dolomitic rock as it has less than 50% of any of these constituents.

An Eke sample taken immediately above the contact is atypical of the Eke Beds exposed here. It undoubtedly was influenced by the close proximity to the underlying shale. It contains 7.7% of clastic material and no appreciable amount of nonclastics. It is composed primarily of micaceous, slightly argillaceous silt and a little micaceous, very fine sand. Traces of pyrite, scolecodonts, *Tasmanites* and an arenaceous foraminifer (cf. *Psammosphaera*) are present. It would be difficult to say whether or not these fossils are characteristic of the Eke or are reworked from the underlying shales and may in a small way represent a lag deposit developed during a period of nondeposition.

The remaining four samples of Eke Beds taken from a thickness of about 70 cm are quite uniform and differ from the lower samples. They consist of grey, light brown, variably crystalline, fossiliferous limestones with some secondary recrystallization. The insolubles are very meager, averaging only 0.85% of clastics and 0.3%

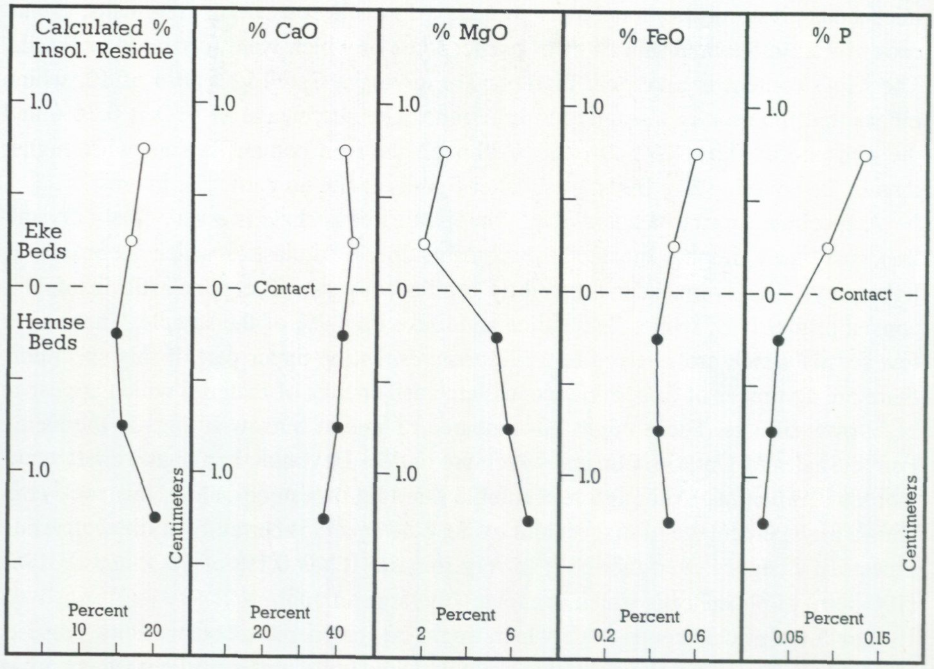

Fig. 1. Variations in composition of rock across the Hemse–Eke unconformity at Nyan 2.

of nonclastics. The clastics range from very fine sand to somewhat argillaceous silt. The nonclastics are principally secondary silica with a little pyrite and traces of glauconite, although one sample did have a considerably greater amount of pyrite. Arenaceous foraminifera are scattered through the section. Chemically, these limestones are quite pure with only 0.68% of MgO, 0.11% of FeO and 0.010% (100 ppm) of phosphorus. Although the Hemse Beds are inadequately represented, this does show a marked contrast in all of the various factors between the Eke and the Hemse Beds. The Hemse Beds contain more insolubles and more FeO and MgO than the Eke Beds. Although based on an entirely different set of data our interpretation seems to check very well with that made by previous workers.

The single specimen we have from locality Nyan 2 extends over only 2 or 3 cm of vertical section, but even in so small a sample the characteristics of a definite unconformable contact are amply displayed. The Hemse unit is a very finely crystalline limestone with a mean of 16.8% of calculated insolubles, largely silt as determined from three half centimeter samples (Fig. 1). It contains very thin, but largely undamaged, brachipod shells distributed parallel to the bedding. Calcium oxide makes up about 40% of the rock and there is a mean value of 5.93% of magnesium oxide. Iron oxide averages 0.444% and phosphorus 310 ppm.

Fig. 2. Photograph of Hemse–Eke unconformity at Nyan 2. Scale in millimeters.

The contact of the Hemse with the Eke Beds at Nyan 2 is relatively sharp and slightly irregular. Pyrite occurs along the surface of the Hemse and in the overlying Eke Beds. The Eke Beds are made up of reworked fossil debris with a finely crystalline, calcium carbonate matrix and about the same insoluble residue content as the underlying Hemse. In the small hand specimen we have collected there are clasts of Hemse type in the lower part of the Eke. One of these clasts is approximately 12 x 7 mm and another about 4 x 4 mm. They are irregularly shaped and do not show evidence of wear (Fig. 2). The Eke beds also contain much reworked pelmatozoan debris. They have 17.6% of insolubles, primarily silt, as shown by studies of residues with the petrographic microscope, although there is some very fine sand. Rare grains of feldspar occur in both Hemse and Eke residues.

The considerable differences in the gross lithologies, with a sharp contact between the two, and the presence of pyrite in proximity to the contact are sufficient evidence in themselves to warrant postulating an unconformity. A striking feature is the ample evidence for hydroturbation in the rocks above the contact and the absence of it in the rocks below. Both stratigraphic units are magnesian limestones, but differ in CaO/MgO values with a ratio of 18 for the Eke and 6.7 for the Hemse Beds.

## THE BURGSVIK, HAMRA AND SUNDRE BEDS

**General Comment.** The section at Hoburgen includes the Burgsvik, Hamra and Sundre Beds in ascending order, which were sampled at Hoburgen 2 (CJ 2517 1252) and Hoburgen 3 (CJ 2620 1252). The rocks are exposed at sea level and can be sampled upward for eleven meters at Hoburgen 2. Above this, approximately ten meters are under cover but about 22 meters of Hamra and Sundre Beds are exposed in the upper part of the cliff (Hoburgen 3). The terrain is difficult and while the lower part of the section could be carefully measured using sea level as a zero point, the measurements in the higher parts of the section are in part estimates. The analytical data indicate a broad trend in the development of the section so that small discrepancies in measurement would not affect the interpretation of the stratigraphy.

The units exposed at this locality have been placed in the Ludlovian by Hede (1960) and they represent the youngest formations of the Gotland sequence. Hede has described this locality and reference should be made to his report for details of the exposure and its fossil content. The fine-grained upper Burgsvik sandstones represent the only truly arenaceous beds which we have seen on the island and contrast with the clastic fractions of the older formations, which are predominantly silts and clays. The spergenitic (extremely fossiliferous) strata above the sandstone, which we include in the Hamra, have usually been included in the Burgsvik (Hede 1960, Laufeld 1974). Manten (1971, p. 409) suggested placing the boundary below the "upper oölitic horizon".

The Hamra beds are a complex of bioherms and fossiliferous interbiohermal rocks, the latter containing considerable reef detritus. Their contact with the overlying Sundre crinoidal beds is gradational and the upper beds of the Hamra contain some of the pink pelmatozoan columnals characteristic of the Sundre. Manten (1971, p. 408) did not find a suitable boundary between the Hamra and Sundre Beds and suggested the term Hamra–Sundre Beds; he does however discuss them under separate headings. Although this stratigraphic boundary is a transitional one we prefer to separate the two sets of beds. The differences between the lithologies are demonstrated from the analytical data as well as by gross characteristics. The occurrence of a transitional boundary is not a sufficient reason for combining two stratigraphic units. The upper beds (Sundre) are unique enough to have been used commercially as the Gotland or Hoburg Marble (Hede 1960).

A small exposure in a quarry at Uddvide 1 (CJ 3737 3225), approximately 22 kilometers NNE of Hoburgen, includes beds from upper Burgsvik through the lower Hamra. It is of interest for correlation with the stratigraphic sequence at Hoburgen and for comparison of the statistical parameters of the Burgsvik sandstone at the two localities.

**The Burgsvik Beds.** The Burgsvik sandstone has a thickness of 4.1 m exposed above the sea at Hoburgen 2. It is a very fine to fine, angular, micaceous sandstone containing small amounts of silt and at the very top a little argillaceous material. A sample 50 cm above the zero point contained 35.9% of solubles, but this is an atypical calcareous nodule. The top sample may have had carbonate introduced from the overlying limestones and is 19.2% solubles, but the remaining 5 samples average approximately 10% soluble. The micas are light in color (muscovite) and more numerous in the lower than in the upper portion of the exposure.

The Burgsvik section exposed in the small quarry at Uddvide 1 is very similar to that at Hoburgen 2, with 128 cm available above the water in the quarry. There is a dolomitic shale within the sandstone sequence from 110 to 114 cm above the base of the exposure and analysis shows the clastic content (86.6% of the rock) to be slightly argillaceous silt with a little light mica. The sands throughout the section are very fine to fine and predominantly angular with some subangular grains with a small silt content and some light mica. The 4 cm of sandstone at the top has a higher carbonate content (26.4% soluble) and a higher CaO/MgO ratio (6.1) than the beds below which average 11.6% of solubles and have a CaO/MgO ratio of 4.0. As at Hoburgen 2, it probably has been enriched by circulating water from the overlying limestone. It also contains abundant pyrite.

Textural parameters of sandstones may reflect some elements of their environment of deposition provided the rate of burial is slow enough to allow them to become compatible with that environment. They also can inherit some characteristics from the conditions in the source area or during transportation. The phi-moment parameters from the Burgsvik sandstones exposed at localities Uddvide 1 and Hoburgen 2 illustrate the uniformity of these sandstones (Figs. 3 and 4 and Table II) and allow some speculation regarding their history. Phi is the negative logarithm of the diameter of a particle in millimeters. When expressed in phi units the grain-size distribution of sands can be plotted as a frequency curve having normal Gaussian characteristics which is useful statistically.

The plot of phi standard deviation versus phi mean grain size describes extremely uniform, very fine, well-sorted sands at both of these localities (Fig. 3). Friedman (1961) notes that for the most part the phi grain size distribution of dune sands is positively skewed, while that of beach sands is skewed negatively. Krumbein and Sloss (1963, p. 104–105) indicate that these two environments produce sands with "very similar size distribution". The skewness of the sands from the two localities is slightly positive and only two samples, one at each locality show very small negative or positive values. Both of these samples are atypical and are not included in the plot. The Uddvide 1 sample represents a shale bed and the Hoburgen 2 sample the contact with the Hamra.

The relatively uniform moment data suggest that the Burgsvik sandstone was deposited in a relatively shallow marine environment. Hede (1960, p. 84) in his description of the Hoburgen locality says "the sandstone is sporadically richly fossiliferous" and notes irregular stratifications and some cross-bedding. In consideration of the field relationships, particularly the proximity to the unconformity described below, it is possible that both marine and nonmarine influences played a part in the genesis of the sandstone. The limited exposures place some restrictions on further interpretation.

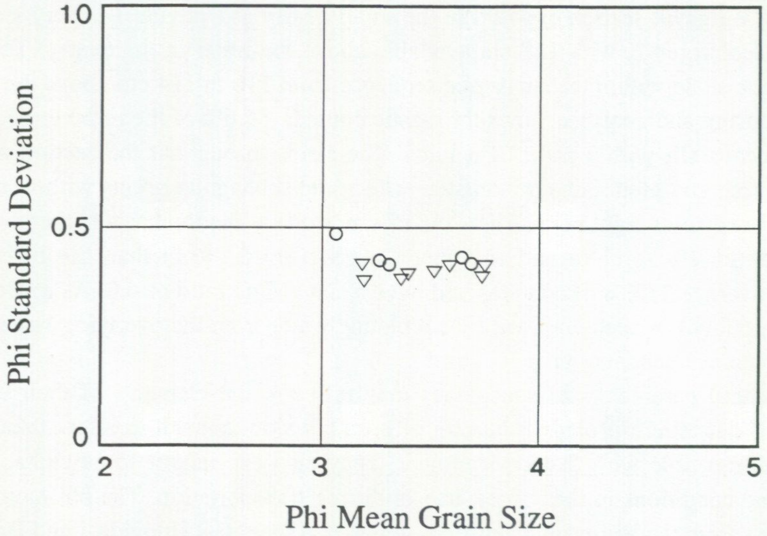

Fig. 3. Burgsvik sandstone at Hoburgen 2 (▽) and Uddvide 1 ( o ). Plot of phi mean grain size versus phi standard deviation.

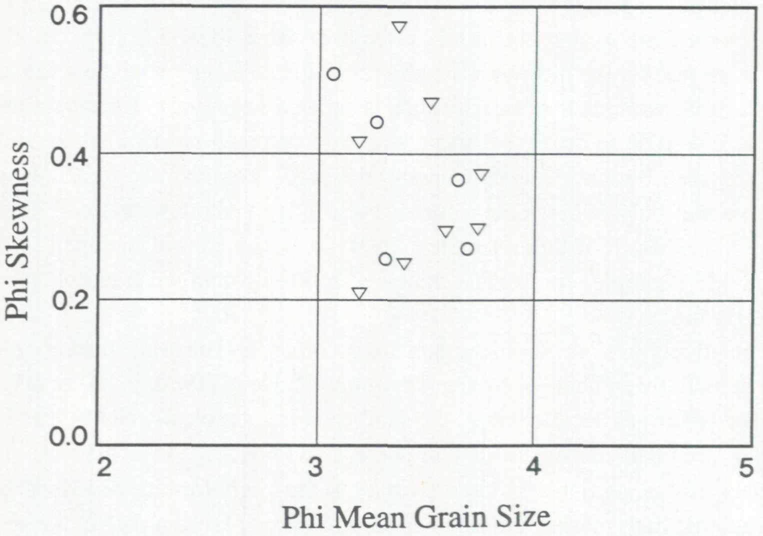

Fig. 4. Burgsvik sandstone at Hoburgen 2 (▽) and Uddvide 1 ( o ). Plot of phi mean grain size versus phi skewness.

TABLE II. Burgsvik Sandstone moment measures in Phi units.

| Sample | Level | $x_\phi$ | $\sigma_\phi$ | $\alpha_{3\phi}$ | $\alpha_{4\phi}$ | Notes |
|---|---|---|---|---|---|---|
| Hoburgen 2 | | | | | | |
| R72588 | 4.11 m | 3.186 | 0.416 | 0.416 | 3.76 | Hamra spergenite |
| R72587 | 4.09 m | 3.194 | 0.378 | 0.209 | 3.53 | |
| R72586 | 3.40 m | 3.367 | 0.383 | 0.575 | 3.78 | |
| R72585 | 2.40 m | 3.519 | 0.401 | 0.447 | 3.64 | |
| R72584 | 1.50 m | 3.401 | 0.394 | 0.250 | 3.30 | |
| R72583 | 0.50 m | 3.754 | 0.413 | 0.372 | 3.49 | |
| R72582 | 0.50 m | 3.739 | 0.388 | 0.298 | 3.41 | Atypical nodule |
| R72581 | 0 m | 3.592 | 0.415 | 0.295 | 3.36 | Base (water level) |
| Uddvide 1 | | | | | | |
| R72427 | 1.28 m | 3.065 | 0.484 | 0.509 | 3.12 | Hamra spergenite |
| R72426 | 1.26 m | 3.646 | 0.431 | 0.364 | 3.82 | |
| R72424 | 1.10 m | 3.692 | 0.417 | 0.270 | 3.37 | |
| R72425 | 0.95 m | 3.311 | 0.414 | 0.255 | 3.73 | |
| R72433 | 0 | 3.267 | 0.423 | 0.443 | 3.74 | Base (water level) |

$x_\phi$ = Phi mean grain size.
$\sigma_\phi$ = Phi standard deviation.
$\alpha_{3\phi}$ = Phi skewness.
$\alpha_{4\phi}$ = Phi kurtosis.

**The Burgsvik–Hamra Contact.** Both physical and chemical evidence indicate the presence of an unconformity between the top of the Burgsvik sandstone and the overlying Hamra spergenite, although the latter has usually been included in the Burgsvik Beds. The presence of oölitic (probably spergenitic) strata lower in the Burgsvik sandstones does not indicate a stratigraphic relationship as repetition of lithology does not necessarily imply stratigraphic continuity.

The lithologic break between the sandstone and the "spergenite" at Hoburgen 2 is sharp, a definite change from sandstone to limestone (Figs. 5 and 6). Sand grains in the "spergenite" are at least in part reworked from the Burgsvik. The contact is apparently also abrupt at Uddvide 1. The presence of abundant pyrite in the residue from the top of the Burgsvik sandstone at Uddvide indicates the probability of a time lapse.

The Hamra Beds above the spergenite, adequately represented at Hoburgen 2, do contain less FeO and fewer clastics than the spergenite, but there is no apparent evidence of a marked break between these two sets of beds.

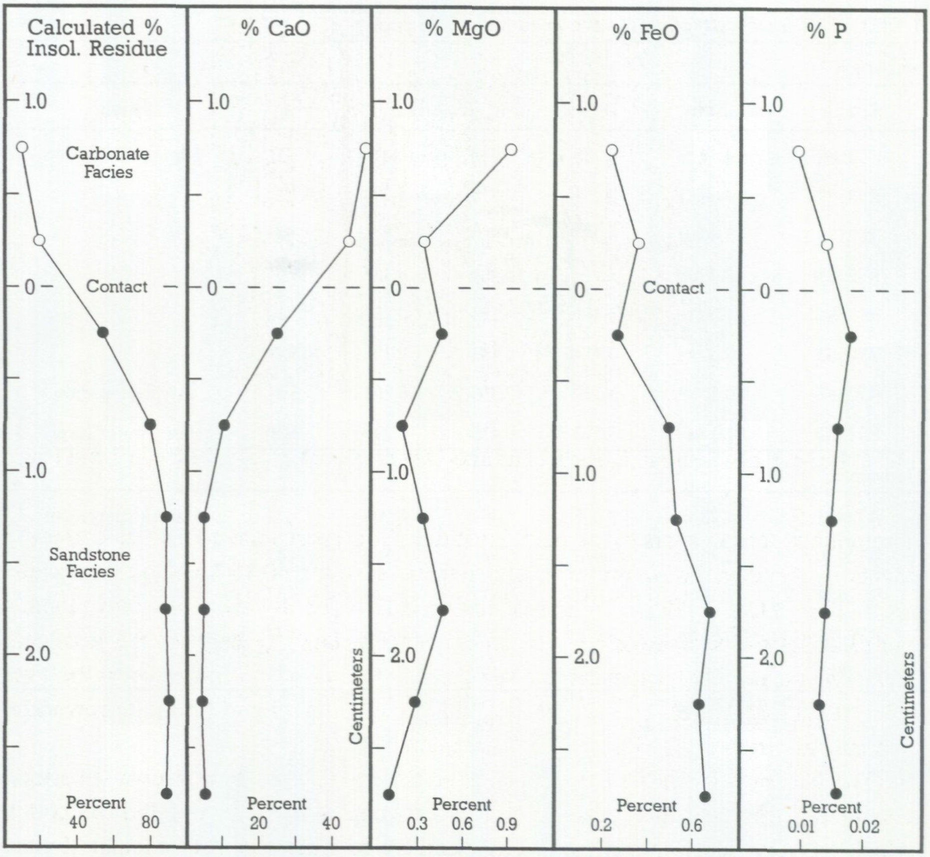

Fig. 5. Variations in composition of rock across the Burgsvik–Hamra unconformity at Hoburgen 2.

**The Hamra and Sundre Beds.** The Hamra Beds are discussed as three separate units. The spergenite strata form a natural subdivision and the strata at Hoburgen 3 are separated from those at Hoburgen 2 by a covered interval. They are discussed separately not for stratigraphical reasons, but because it is convenient to do so as the differences between them illustrate the trend of Hamra lithologies.

The spergenite beds (oölite beds of the authors) are similar in both sections, and approximately 90 cm thick. These light brown limestones contain small fossil fragments with calcareous coatings mostly in the 1 to 5 mm range and some oölites. There are also secondary calcite crystals. Analysis indicates a clastic content of 7.7% at Uddvide 1 and 8.3% at Hoburgen 2. The insolubles consist of very fine to fine, angular sands with some brownish grey, silty clay and contain a little mica. Arenaceous

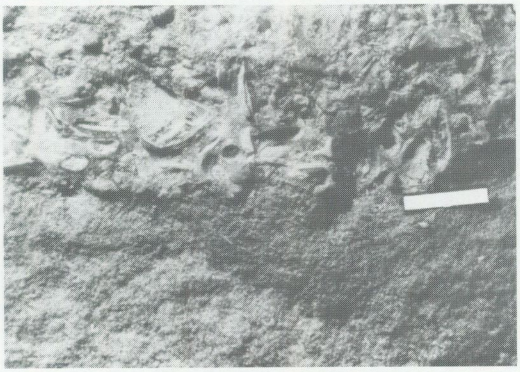

Fig. 6. Photograph of Burgsvik–Hamra unconformity at Hoburgen 2. White bar is 5 mm long.

foraminifera occur sparsely at both localities. The spergenite rocks are somewhat higher in iron than the Hamra strata above them, averaging 0.26% FeO at Hoburgen 2 and 0.29% FeO at Uddvide 1, as compared to 0.17% FeO for the rocks above them at both localities. There are no significant chemical differences between the two localities. The greater FeO content in the spergenitic carbonates, as compared to the overlying strata may be related to slower deposition with more opportunity for reworking and may also reflect the slightly greater amount of clastics.

The Hamra beds above the spergenite at Hoburgen 2 are light brown limestones containing pelmatozoan fragments, except the samples from the top and the bottom which are very finely crystalline or dense and are fossiliferous. Any interstitial material in the pelmatozoan beds tends to be finely or finely to medium crystalline and there are a few patches of light greenish, argillaceous material. Pelmatozoan columnals in one sample exhibit rounding and it seems probable that all the fossil materials may have been reworked with some sorting.

Only a fraction of a meter of postspergenitic Hamra occurs at Uddvide 1. These are light brown, finely crystalline, fossiliferous limestones which contain some coarse, secondary calcite crystals.

Very fine to fine, angular sand grains are present in small quantities in the residues from both localities, usually a small fraction of a percent although the lowest sample at Hoburgen 2 did have over 2% percent. A little white to rusty silica, usually not more than 0.1%, is present except in one sample which contained 0.7%. The fine clastics predominating in the residues from both localities consisted principally of silts and clays, ranging from brown to greys, and varying from silty clay to argillaceous silt. Pyrite was present in several residues. Total clastics averaged 3.9% at Hoburgen-2 and 5.8% from the two samples from Uddvide 1 (See Table I). Arenaceous foraminifera (cf. *Psammosphaera*) occur commonly and one scolecodont was found in a sample from Uddvide-1.

The Hamra beds at Hoburgen 3 occur above the 10 meters separating Hoburgen 2 and Hoburgen 3. These upper Hamra Beds are dominated by light brown, crinoidal limestones although there are traces of pink in the upper part suggesting a transition into the overlying Sundre Beds. The lower samples show obvious reworking with rounded limestone pebbles and fossil fragments covered with calcareous coatings. Although no oölites were noted, these rocks are certainly related genetically to the spergenite at the base of the Hamra Beds. In places there are small argillaceous patches. Microcavernous porosity and a little secondary recrystallization are evidence of epigenetic processes.

The residues are small, averaging only 1.3%. The clastics average 0.8% of the sample and are composed of rusty grey, silty clays and argillaceous silts with traces of angular sand ranging from very fine to medium in size. The nonclastics are principally secondary silica with arenaceous foraminifera (cf. *Psammosphaera*) in most of the residues. One residue contained a scolecodont. The chemistry of the carbonates at Hoburgen 3 is discussed below.

Approximately 8 meters of Sundre Beds occur at the top of the Hoburgen section. They consist of light brown pelmatozoan limestones in which some of the columnals are pink, giving the quarried stone its attractive appearance. Although the contact with the underlying Hamra Beds is transitional, the lowest sample did contain abundant rosettes of pyrite in the small residue (0.6% of the sample). The residues averaged 0.5%, mostly clastics consisting of silty clays with traces of very fine sand. The non-clastic materials were silica and pyrite.

**Chemistry of the Carbonates.** The solubles throughout the carbonate section (Hoburgen 2 and Hoburgen 3) are best understood on a comparative basis and the discussion will assume frequent reference to Table I, which shows mean values. Small percentage differences between various parameters, which might otherwise appear insignificant, assume importance when they follow a reasonably definite pattern of either increasing or decreasing values throughout the section. These tendencies, although less regular, can also be recognized when the majority of the parameters are examined on an individual sample basis. (Figs. 7 and 8).

The CaO-MgO and MgO-FeO stratigraphic relationships are of interest as ratios. The increases in the amounts of iron combined in the carbonates accompanying greater amounts of included clastics is apparent in the MgO/FeO ratios for both the spergenites and the sandstones (Table III). The greater amount of dolomitization in the carbonates included in the sandstones is indicated by the low CaO/MgO ratios of 4.4 at Hoburgen 2 and 4.5 at Uddvide 1. A ratio of 3.95 indicates a mixture of equal parts of limestone and dolomite. Similar relationships exist between the clastic and

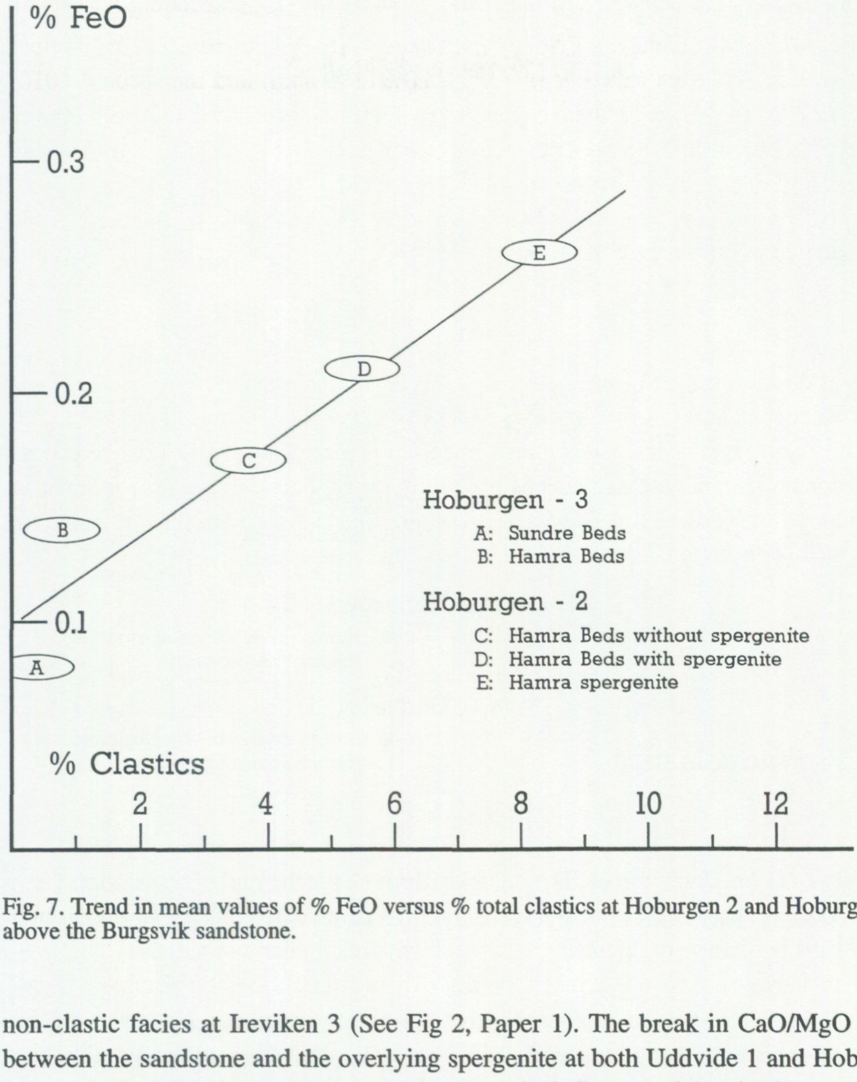

Fig. 7. Trend in mean values of % FeO versus % total clastics at Hoburgen 2 and Hoburgen 3 above the Burgsvik sandstone.

non-clastic facies at Ireviken 3 (See Fig 2, Paper 1). The break in CaO/MgO ratios between the sandstone and the overlying spergenite at both Uddvide 1 and Hoburgen 2 is so marked that there can be no doubt about the influence of the clastics.

There is a trend, within the sequence at Hoburgen, of decreasing clastics and increasing CaO/MgO ratios upward, although the ratio of the spergenite is an exception (See Table III). The percentages of clastics above the spergenite are small and whether or not the latter serve as a control might be debated. It may be that both were responding to some evolving factor in the general palaeogeographical environment. The erratic CaO/MgO value for the spergenite is rather surprising, although the sand content may be reworked material from the underlying beds. The MgO/FeO ratios also tend to increase upward although the relative values of the Hamra Beds at Ho-

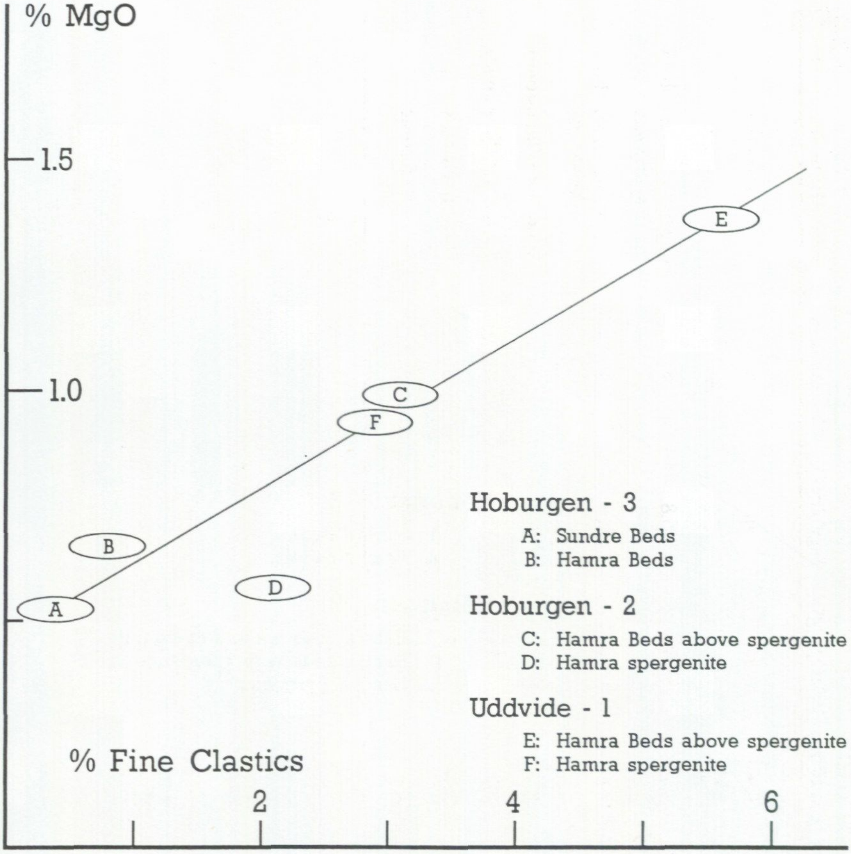

Fig. 8. Trends in mean values of % MgO versus % fine clastics at Hoburgen 2, Hoburgen 3 and Uddvide 1.

burgen 2 and Hoburgen 3 are reversed from the orderly sequence. However, the differences between the two is so small, 0.6 of one point, that they are for practical purposes equivalent, indicating a reasonably uniform value for the Hamra Beds above the spergenite.

When the means of the percentages of FeO for the various stratigraphical units above the Burgsvik sandstone are compared with the means for the percentages of clastics, a direct relationship can be seen between the two (Fig. 7). However, if a similar comparison is made between MgO and the clastics, only the fine clastics, silts and clays, can be included if such a relationship is maintained. (Fig. 8). This demonstrates that the grain size of the clastics, and possibly also the mineralogy, has an effect on the MgO concentration which is not apparent in the FeO values at this local-

TABLE III. Mean values of analyses of samples.

| Stratum | Locality | % Coarse Clastics | % Fine Clastics | % Total Clastics | CaO/MgO | MgO/FeO | No. Samples | Remarks |
|---|---|---|---|---|---|---|---|---|
| Sundre Beds | Hoburgen 3 | Trace | 0.4 | 0.4 | 107 | 6.5 | 4 | Limestone |
| Hamra Beds | Hoburgen 3 | Trace | 0.8 | 0.8 | 85 | 5.2 | 7 | Limestone |
| Hamra Beds | Hoburgen 2 | 0.6 | 3.1 | 3.7 | 58 | 5.8 | 6 | Limestone Strata above spergenite |
| Hamra Beds | Uddvide 1 | 0.2 | 5.6 | 5.8 | 36 | 8.4 | 2 | Limestone strata above spergenite |
| Hamra Beds | Hoburgen 2 | 6.2 | 2.1 | 8.3 | 89 | 2.3 | 4 | Spergenite (limestone) |
| Hamra Beds | Uddvide 1 | 4.8 | 2.9 | 7.7 | 53 | 3.8 | 4 | Spergenite (limestone) |
| Burgsvik Beds | Hoburgen 1 | 86.9 | 1.5 | 88.4 | 4.4 | 1.7 | 6 | Sandstone |
| Burgsvik Beds | Uddvide 1 | 83.1 | 1.9 | 85.0 | 4.5 | 4.3 | 4 | Sandstone |

ity. The data are not sufficient to permit generalizations. However, the influence of even small amounts of clastics on the chemistry of the lithologies cannot be discounted.

Both FeO and P decrease from the Burgsvik upward in the section and although the amounts are small and the relative differences slight, the trend is definite and consistent. This reflects the relationships discussed above. The most marked shift in values is the drop from an average of 0.68% FeO in the solubles of the Burgsvik to 0.26% in the spergenite. The range in FeO percentages between the spergenite and the Sundre is only 0.18% and in phosphorus from the Burgsvik to the Sundre is only 0.009% (90 ppm), but in view of the distribution these differences may have a meaning in terms of environmental evolution.

The observations cited above become more convincing when the data are compared with those from Uddvide 1, although the latter section by itself is too thin to allow any conclusive results. If it is divided into three units, Burgsvik, spergenite and post-spergenite Hamra, the values can be compared (See Tables I and III). As at Hoburgen 2 the CaO/MgO ratio for the spergenite is higher than it should be for an orderly sequence, but with this exception and a slightly high value for phosphorus in the post-spergenitic Hamra the trend is similar and the order of magnitude of these values is comparable to those at Hoburgen 2.

## CONCLUSIONS

Although definitive correlations cannot be substantiated by lithostratigraphical data alone, they offer convincing evidence which can be helpful in corroborating or evaluating biostratigraphical conclusions. As fossils are facies followers more often than not, there is a natural bias in favor of similar conclusions being drawn from each of the two types of evidence. This circumstance casts some doubt regarding the validity of too precise biostratigraphical correlations, particularly long range ones.

It is impractical to correlate all of our findings with those of other workers. However, the lithostratigraphical data appear to fit the generally established pattern of the Gotland stratigraphy and in some instances contribute substantiating evidence. Although incomplete as regards the total section, we hope that the formations are well enough represented to furnish essential data to various specialists, who have various approaches to stratigraphical problems.

The analyses of the Gotland rocks raise some fundamental questions regarding the problems of dolomitization. Unlike many of the dolomites of the Great Lakes area in North America, increasing dolomitization of the Gotland carbonates is related to relatively greater content of fine clastics, silts and clays (Sanford and Mosher 1985). The question arises as to paucity of dolomitization in the relatively pure carbonates of the

Gotland area when it is so prevalent in many of the massive and biohermal carbonates of the United States and Canada.

The two unconformities described in this writing, as well as that at Galgberget 1 previously analyzed (Sanford and Mosher 1985), are recognizable from the analytical data and perhaps more surely demonstrated in this manner than by their appearances in the exposures. Although indicating definite breaks in the sequence, they do not appear to represent lengthy periods of time during which profound changes in the general paleogeography were accomplished.

In general, the uppermost Ludlow rocks do not appear to have the large amounts of fine clastics which are characteristic of the strata below them and which are particularly noticeable in the Visby, Slite and Mulde Beds. The only true sandstone bodies visible on Gotland are the Burgsvik Beds. Their occurrence and the relative purity of the limestones above them indicates a marked contrast with the lower part of the Gotland section resulting from the gradual but consistent evolution of the general paleogeography of the area.

## NOTE

Complete analytical data are on file at Allekvia, Gotland, at the Geological Survey of Sweden, and at Wayne State University.

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