The presence of oil within the Ordovician limestone mounds of the Siljan district, central Sweden

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The distribution and chemical composition of oil occurring within the Ordovician limestone mounds of the Siljan district is discussed. The oil is concentrated in the core facies *Stromatactis* and coquinoid limestones of the larger, least tectonically disturbed, mounds. Analysis has shown the oil to be an immature crude, of hybrid paraffinic-naphthenic type.

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Introduction

The Kullsberg Limestone and Boda Limestone are carbonate-mud mounds of Middle and Upper Ordovician age respectively. They are lenticular in plan and cross-section and form positive topographic features within the ring of highly disturbed Lower Palaeozoic sediments of the Siljan district.

The Boda Limestone has an average stratigraphic thickness of approximately 100 m. It is separated from the underlying Kullsberg Limestone by a sequence of nodular bioclastic calcilutites and green shales, the Skålberget limestone (Jaanusson 1972, p. 20, fig. 3), the Slandrom Limestone and the Fjäcka Shale, a black bituminous shale (Jaanusson 1963). The Kullsberg Limestone has an average stratigraphic thickness of approximately 40 m according to Thorslund (in Thorslund & Jaanusson 1960).

The main lithology of the core facies of the mounds is a poorly stratified biomicrite containing the enigmatic cavity structures known as *Stromatactis*, which are partially or completely filled with radiaxial fibrous calcite (Bathurst 1959, Kendal & Tucker 1973). Discontinuous beds, or lenticular pockets, of coarsely crystalline bioclastic coquina limestone are also a major component of the mound cores.

The surrounding flank facies consist of bioclastic sparites formed largely of comminuted echinoderm debris, intercalated with red and green marly shales which represent tongues of the "off mound" or normal facies.

Distribution of oil

The presence of asphaltite within the Boda Limestone at Osmundsberget was noted by Thorslund (in Thorslund & Jaanusson op. cit., p. 33). However, recent quarrying within several of the

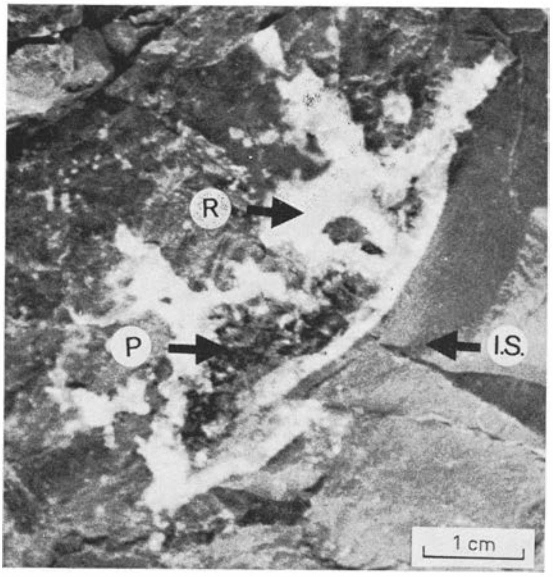

Fig. 1. A small *Stromatactis* from the core facies of the Boda Limestone at Osmundsberget showing oil and asphaltite concentrated in the residual porosity of the cavity. R: Early generations of radiaxial fibrous calcite. P: Paraxial calcite cement with asphaltite inclusions and coating of oil. I.S.: Internal sediment lining the bottom of the *Stromatactis* cavity.

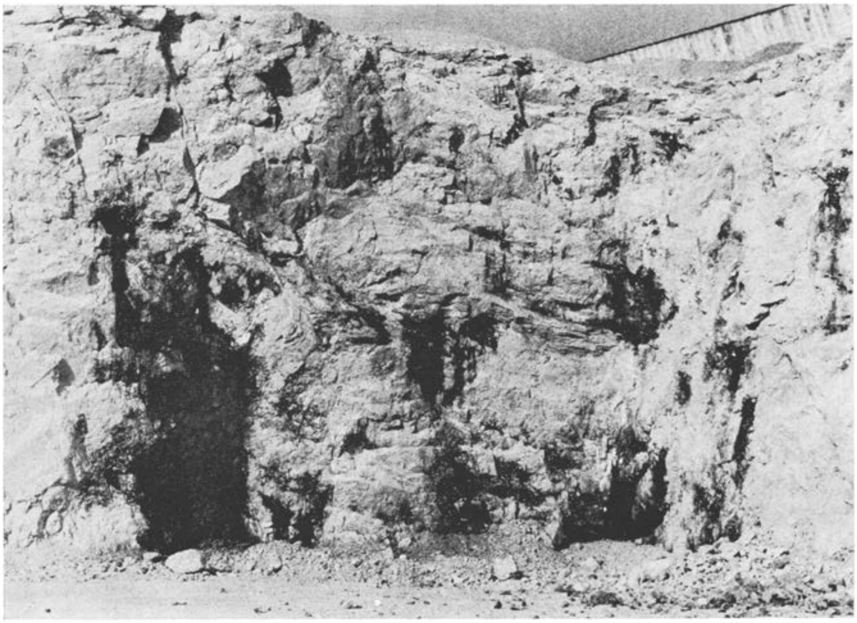

Fig. 2. Oil seeps in the upper core facies of the Boda Limestone in the south-west face of the lower quarry level at Osmundsberget in 1976. Quarry face approximately 15 m high.

larger limestone masses has revealed certain facts regarding the distribution of liquid oil within them.

The main oil-bearing strata are the coquinoid and *Stromatactis* limestones of the core facies, especially those within the top 30 m of the Boda Limestone at Osmundsberget. The oil is concentrated along bedding, joint and fault planes and in the intragranular porosity of shells within the coquinas. It also occurs as the latest stage of infilling of *Stromatactis* cavities (Fig. 1). In the last two instances, much of the oil postdates the latest identifiable cement phase of coarsely crystalline paraxial calcite, though many of the paraxial crystals contain asphaltite inclusions.

The amount of oil within each mound is dependent on the size of the mound and its tectonic situation. Small masses, such as those at Kullsberg, Amtjärn and Sätra, contain little oil. Larger masses, such as those at Osmundsberget and Solberga contain many metres of oil-stained rock.

A study of geopetal structures within the Boda and Kullsberg Limestones indicates that the mounds possessed an original outward radial dip, varying from 18° to 28°. The present dip of the mounds varies: near vertical or overturned at Unskarsheden, Amtjärn, Skålberget; 45° to 50° at Osmundsberget and Östbjörka; and near to their original dip at Kallholn (28°) and Solberga (24°). The amount of oil is greatest in the large limestone mounds which dip at or near their original amount, i.e. at Solberga and Kallholn. Large oil seeps also occur along bedding and fault planes at Osmundsberget (Fig. 2) and Kallholn. The permeability of the limestone at these localities is increased by the shattered nature of the core facies, especially in the upper part of the Boda Limestone. This shattering is thought to be, in part, a result of shock from the impact of a large meteorite which was responsible for the formation of the ring structure itself (Svensson 1973, Rondot 1975, Thorslund & Auton 1975, Hjelmqvist 1977). Shattering is most intense where the limestone masses are least displaced. Where mounds are overturned or vertical, e.g. Unskarsheden, brecciation is less obvious and only an asphaltite residue remains, indicating that the oil has largely seeped out of the rock. The source of the oil is thought to be the black bituminous Fjäcka Shale.

Analyses of oil from the Solberga borehole

A small sample (25 cc) of oil from a borehole within the Boda Limestone at Solberga was subjected to C15+ liquid-gas chromatography, C4—

Table 1. Detailed C4—C7 analysis of gasoline range hydrocarbons from the Solberga borehole.

COMPONENT	%	TYPE	COMPONENT	%	TYPE
isobutane	1,62	isoparaffin	2,2,3-trimethyl B.	22,75	isoparaffin
butane (B)	1,20	n-paraffin	cyclohexane	5,46	naphthene
isopentane	4,04	isoparaffin	3,3-dimethyl P.	0,02	isoparaffin
pentane (P)	1,58	n-paraffin	1,1-dimethyl CP.	5,38	naphthene
2,2-dimethyl B.	1,03	isoparaffin	2-methyl H.	0,51	isoparaffin
cyclopentane (CP)	1,05	naphthene	2,3-dimethyl P.	2,66	„
2,3-dimethyl B.	0,65	isoparaffin	cis-1,3-dimethyl CP.	—	naphthene
2-methyl P.	3,60	„	3-methyl H.	2,77	isoparaffin
3-methyl P.	1,71	„			
			trans-1,3-dimethyl CP.	—	naphthene
hexane (H)	0,06	n-paraffin	trans-1,2-dimethyl CP.	8,66	„
methyl CP. (MCP)	9,65	naphthene	3-ethyl P.	0,05	isoparaffin
2,2-dimethyl P.	1,20	isoparaffin			
benzene	7,10	aromatic	heptane	0,19	n-paraffin
			cis-1,2-dimethyl CP.	2,88	naphthene
2,4-dimethyl P.	0,60	isoparaffin	methyl CH. (MCH)	10,88	„
			toluene	2,71	aromatic

Abundance (p.p.m.)

MCP/benzene	1,36
MCP/MCH	0,89
CH/MCP	0,56
isoparaffin/n-paraffin	2,56

% n-paraffins	3,03
% isoparaffins	43,21
% naphthenes	43,95
% aromatics	9,81

C7 gasoline range analysis and C15+ paraffin-naphthene chromatography to determine its composition.

The C15+ liquid-gas chromatography showed the bulk composition of the oil to be:

Paraffin-naphthenes	25,81 %
Aromatics	16,53 %
Asphaltenes	47,98 %
Nitrogen, sulphur and oxygen compounds	9,68 %

The proportion of hydrocarbons was found to be anomalously low. A detailed C4—C7 analysis of the gasoline range of hydrocarbons is given in Table 1. This analysis is characterised by a moderately high abundance of isoparaffins and naphthenes, low abundance of aromatics and a very low abundance of normal paraffins.

The C15+ chromatogram (Fig. 3) of the paraffin-naphthene hydrocarbon series is characterised by normal paraffins, which do not decrease regularly and which show an even carbon preference index, an anomalously high phytane peak and a high C16 peak. These results indicate that the sample represents a relatively immature crude oil derived from amorphous organic matter.

Crude oils have been classified according to the proportions of the different hydrocarbon series they contain (Sachanen 1945, Russel 1960, pp. 17—31). Thus a predominance of naphthenic hydrocarbons classes the oil as naphthenic, while a large concentration of paraffins classes it as paraffinic. As is the case with most crude oils, this sample is a hybrid and is classed as of paraffinic-naphthenic type, with a large percentage of asphaltic material.

Conclusions

Recent geophysical investigations in the southern Baltic (Flodén 1975, Hessland 1976), and cores from Gotland have proved the existence of many carbonate mounds of Boda Limestone type and possibly also of Kullsberg Limestone type in the subsurface Ordovician sequence. A similar study in the south Bothnian submarine district, by Winterhalter (1972), has indicated the probable presence of Kullsberg mounds in that area. In both instances the mounds are of smaller dimensions than those of the Siljan district. Small quantities of oil and gas have been produced in test drillings in the southern Baltic but not as yet in economic amounts.

In the Siljan district the absence of a suitable cap rock and the low permeability of the limestone

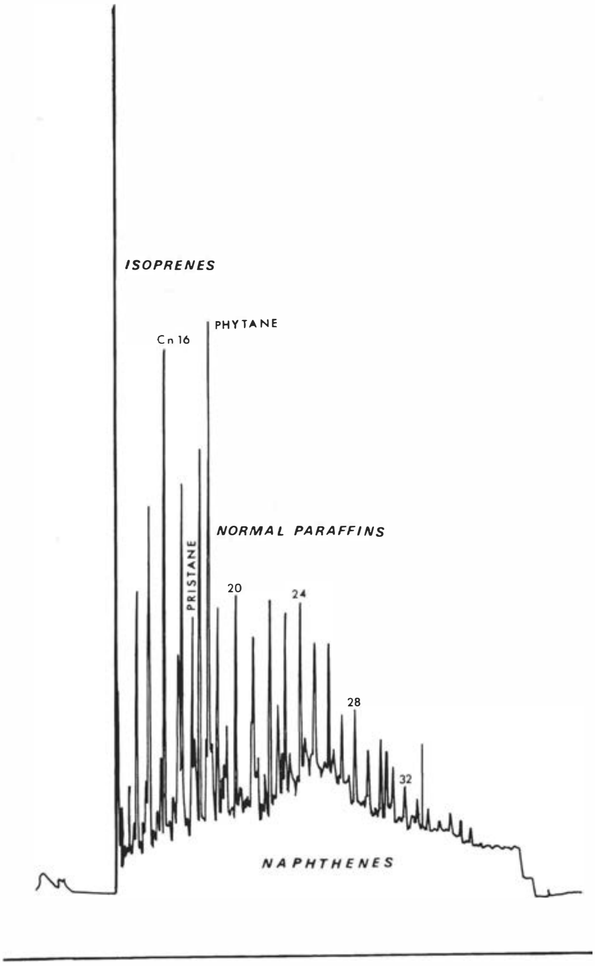

Fig. 3. C15+ chromatogram of the paraffin-naphthene hydrocarbon series from the Solberga borehole oil sample.

precludes the extraction of oil from the localities known at present. If, however, seismic investigations in the north-western part of the Siljan structure reveal large limestone masses, suitably capped by Silurian shale overlain by Orsa Sandstone, oil may be present in large amounts. The low permeability of the rock and the low hydrocarbon content of the oil, however, makes economic exploitation unlikely.

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