Oils and hydrocarbon source rocks of the Baltic syneclise

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Prolific source rock horizons of varying thickness, having considerable areal extent, occur over the Baltic syneclise.

These source sediments are rich and have excellent petroleum generation potential. Their state of thermal maturity varies from immature in the northeastern part of the syneclise to peak generation maturity in the southwestern part of the region—the main kitchen area.

These maturity variations are manifest in petroleum composition in the region. Hence, mature oils occur in the Polish and Kaliningrad areas, immature oils in small accumulations in Latvian and central Lithuanian onshore areas, and intermediate oils in areas between these extremes.

The oil accumulations probably result from pooling of petroleum generated from a number of different source rocks at varying levels of thermal maturity. Hence, no single source for petroleum occurrences in the Baltic syneclise may be identified.

Regional maturity trend was formed under the influence of late Paleozoic paleostructure, differing considerably from the modern one. Hence peak generation area, alongside with the deeply subsided part of the Baltic syneclise, incorporates its western uplifted areas as well and is close to the offshore part of the Liepaja-Saldus high, which can be a prospective oil accumulation area.

Besides, significant petroleum generation has probably occurred in local kitchen in the Liepaja depression, allowing updip migration of early generated petroleum filling shallow Ordovician and Cambrian traps in the northern part of the region.

Baltic syneclise

The platform cover of the Baltic syneclise incorporates four structural complexes: the Baikalian, the Caledonian, the Hercynian, and the Alpine, characterized by various spatial development.[1]

The Caledonian complex is predominant and widespread. All known hydrocarbon accumulations in the area are associated with it as well as the source rock intervals.

The most important reservoir rocks for hydrocarbon accumulations are middle Cambrian sandstones. In both Polish, Kaliningrad, and Lithuanian onshore and offshore areas, as well as in Latvian onshore area, a significant number of hydrocarbon accumulations of varying size are known, all occurring in Cambrian reservoirs (Fig. 1).

Other reservoirs are constituted by Ordovician carbonates/reefs, mainly in Latvia and on the island of Gotland (Sweden), and by Silurian reefs in the central part of Lithuania. Fields reservoired in Ordovician and Silurian deposits are generally small.

Several prolific hydrocarbon source rock intervals occur within the lower Paleozoic sequence. Deposits corresponding to Scandinavian Alum shales, with excellent source properties, occur on a limited scale in the area under discussion.

Two other source rock intervals, having the same excellent quality, are associated with deepwater argillites in the Ordovician and Silurian sections. These were deposited during the episodes of overall subsidence of the syneclise and occur practically everywhere.

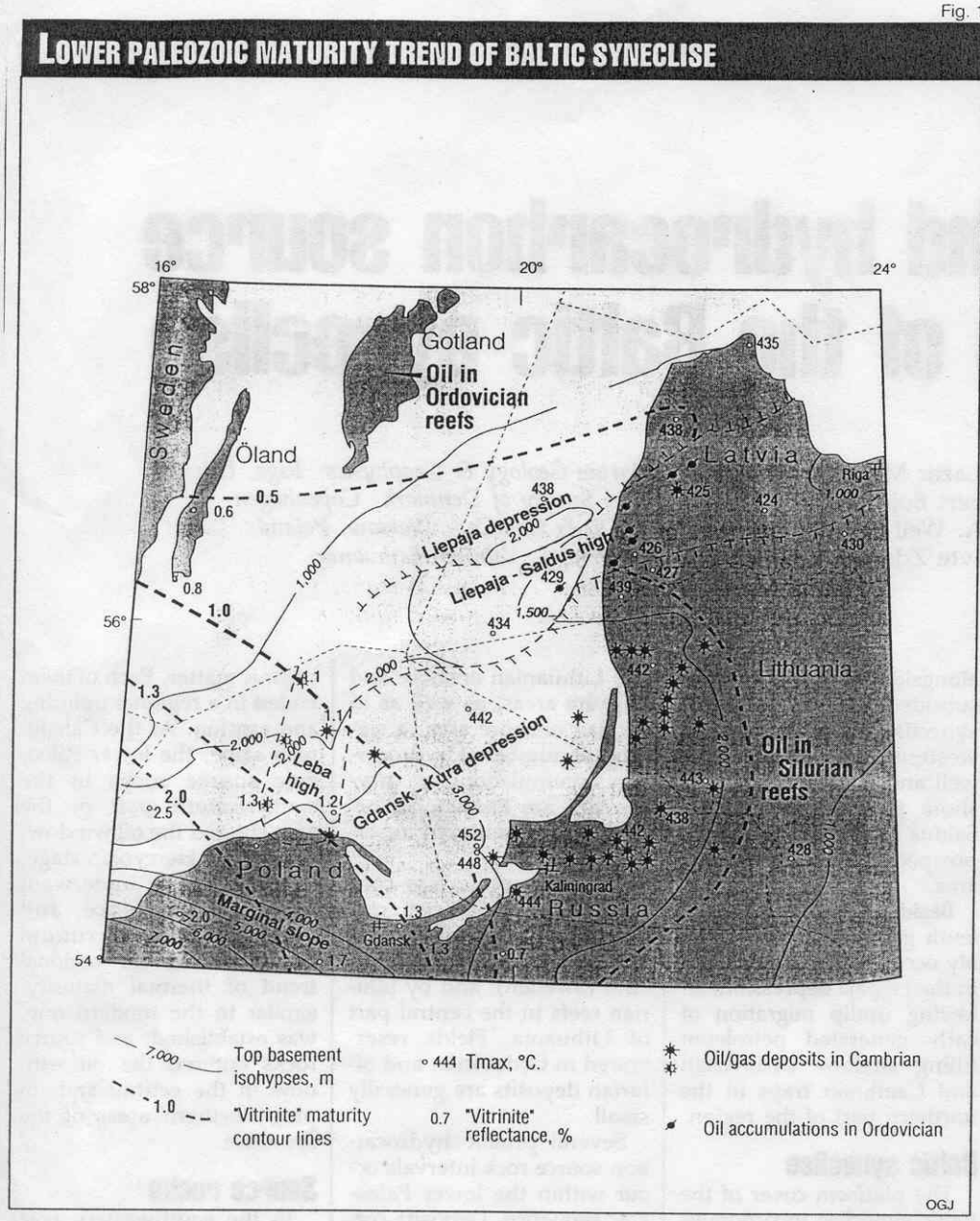
Two stages of subsidence, Caledonian and Hercynian, have greatly influenced the thermal maturation of the organic matter. Each of them ended in a regional uplifting and erosion. At the Caledonian stage, the lower Paleozoic source rocks in the southwestern part of the area entered the oil window. During the Hercynian stage, the sediments underwent further subsidence and reached their maximum depths of burial; regional trend of thermal maturity, similar to the modern one, was established, and source rocks entered the oil window in the central and, in part, northern areas of the syneclise.

Source rocks

In the southwestern part of the basin, Upper Cambrian-Tremadoc deposits, equivalent to the Cambro-Ordovician Alum shales of Bornholm and Scania, constitute excellent hydrocarbon source rocks. The sequence may reach a thickness of about 20 m, dominated by dark grey and black shales.

Total organic carbon (TOC) contents may reach 12%, with pyrolysis yields of hydrocarbons of up to 9 kg/ton (RockEval S2), despite

Fig. 1



high levels of thermal maturity, corresponding to the stage of peak or late oil generation (RockEval Tmax: 440-460° C.).

These sediments have been eroded in the area to the east of the line Kaliningrad-N. Oland. Hence in Latvia and Lithuania as well as in Kaliningrad onshore area the Cambrian-Lower Ordovician sequence does not seem to comprise sediments having appreciable hydrocarbon potential.

Within the Caradoc stage of the Ordovician, deepwater black shales referred to as the Fjacka and Mossen formations constitute excellent hydrocarbon source rocks. The sequence is rather thin in the bulk of the syneclise, the total thickness amounting to 5-10 m, reaching 30-40 m in the edge platform zone.

In the southwestern part of the basin the sediments are thermally mature, with values of TOC occasionally exceeding 5-6% and pyrolysis hydrocarbon yield of up to 14 kg/ton. In the northeastern parts in Latvian onshore and offshore areas in which the deposits are immature, TOC may reach 15% and pyrolysis hydrocarbon yields of 65-70 kg/ton are observed.

Also within the Silurian sequence prolific hydrocarbon source rocks are found. A 5-25 m thick sequence of black and dark grey deepwater shales of Lower Silurian (Llandoverian) age, displaying excellent quantities of oil-prone organic matter, occur over the region. Thermally mature sediments from Polish and Kaliningrad areas shows TOC contents up to 10%, with pyrolysis hydrocarbon yields of up to 18 kg/ton. In the immature areas, TOC may reach 16%, with pyrolysis yields of up to 70 kg/ton.

Based on the RockEval screening data, the type of organic matter in these various hydrocarbon source rock sequences is rather similar, irrespective of geologic age. The kerogen may be classified as typical marine Type II, the variations observed being ascribable to original richness and maturity variation only (Fig. 2A, 2B).

Thermal maturity

Prolific source rocks of different ages mentioned above are concentrated in a rather thin (up to 100 m) interval of the section. During the subsidence, they underwent roughly similar temperature influence and are characterized by similar levels of thermal maturity in each section. Hence, Fig. 1 shows tentative maturity trend established for that interval as a whole, using a combination of RockEval Tmax and reflectance measurements data.

In the eastern (larger) part of the area, the configuration of the maturity trend coincides with the modern structures and, mostly, follows the configurations of larger tectonic elements. Hence, the Liepaja-Saldus high, crossing the axial zone of the syneclise, is an immature area with respect to oil generation. To the north, in the Liepaja depression, marginally/early mature source rocks have been observed. Considerably higher states of thermal maturity prevail to the south, in the Gdansk-Kura depression, where the level of thermal maturity increases approximately parallel to the present-day increase in depth of burial, reaching peak oil generation ("vitrinite" maturity approximately 1.0%) in Kaliningrad and Polish offshore areas.

The situation is different in the western part of the syneclise, starting with the Leba high where the maturity level, corresponding to the peak oil generation, has been observed at about half the depth than in the Gdansk-Kura depression. Further to the west, the discrepancy between the thermal maturity and present

depths is even more marked. Judging by the data from Polish offshore wells, as well as Alum shale maturity in outcrops on Oland and Bornholm,[2] in the whole of that area there exists a northeast-southwest maturity trend, independent of the modern structural trend, formed under the influence of the maximum subsidence of the area in the late Paleozoic.

Oils and extracts

Oil compositions display spatial variation, roughly paralleling the regional trend of thermal maturity. In general, thermally mature oils, characterized by 70-85% of saturated components, a pronounced dominance of light n-alkanes, and a virtual absence of sterane and terpane biomarker compounds are found in the southwestern parts of the basin, i.e. in Poland, Kaliningrad, and western Lithuania.

In the northeastern/eastern parts of the syneclise, in Latvian and central Lithuanian onshore areas, less mature oils are found, characterized by 50-60% saturated components, less pronounced dominance of light n-alkanes, and low contents of sterane and terpane biomarker compounds.

Minor biodegradation may be hinted by slight enrichment in linear isoprenoids, and slightly elevated proportions of unresolved components in saturated GC-traces. Sterane and bihomohopane isomerization ratios may be slightly below equilibrium, indicating early generation. Oils in Latvian and Lithuanian offshore areas occupy an intermediate position (Fig. 3A).

Overall, the oils are characterized by pronounced unimodal, light-end skewed, smooth n-alkane distributions, low contents of waxy components, and pristane/phytane ratios close to 2.

When biomarkers are present, other general features include high proportions of tricyclic terpanes in the m/z 191 ion trace, forming a homologous series reaching at least C_{30};[3] pentacyclic triterpanes dominated by hopane (occasionally Norhopane); extended hopanes low in abundance; and occasional prominence of the "Compound X" of Philp and Gilbert.[4]

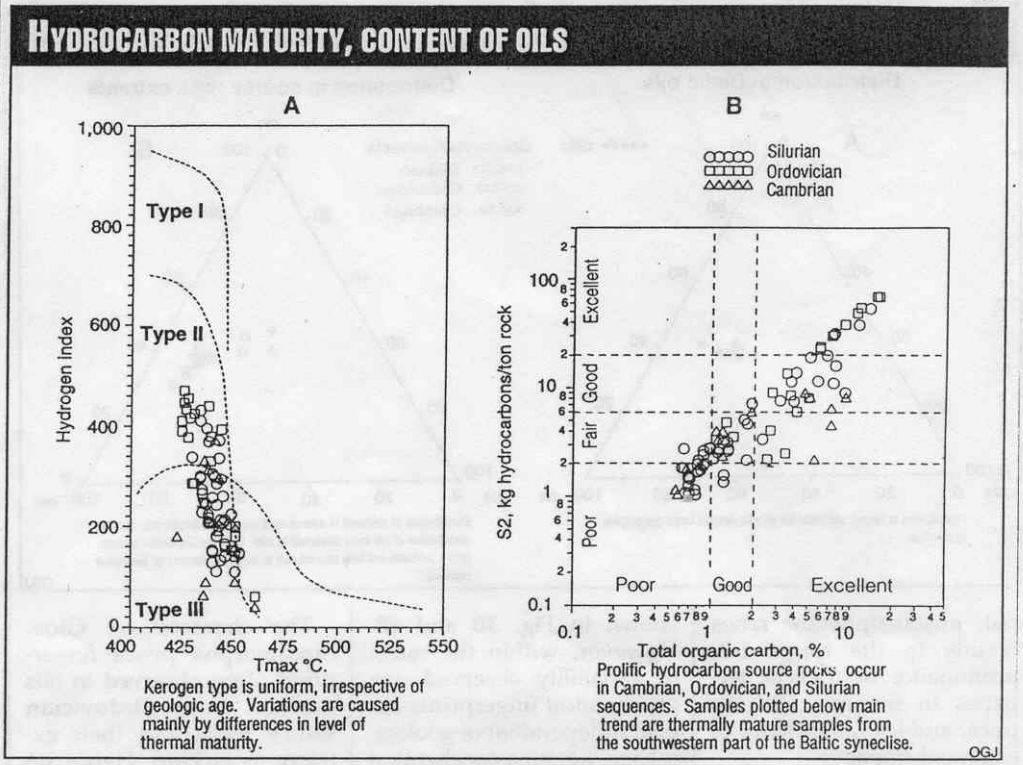
The distribution of regular steranes is very similar for all samples analyzed, featuring roughly equal proportions of C_{27} and C_{29} sterane species, and subordinate proportions of C_{28} species, conformable with the observations of Grantham and Wakefield[5] (Fig. 4A).

The abundance of rearranged steranes roughly follows the regional maturity trend. Overall the oil compositions are very similar to the ones observed in other Paleozoic oils in the region, e.g. on the island of Gotland and near Lake Siljan in central Sweden.[6,7]

Solvent extracts, prepared from samples of various source rocks, in all respects display a somewhat wider compositional scatter than do the oils, although a number of general features are mutual to all samples as well as to the oils.

Sediment extracts display unimodal, light-end skewed, smooth n-alkane distributions, variable proportions of unresolved mate-

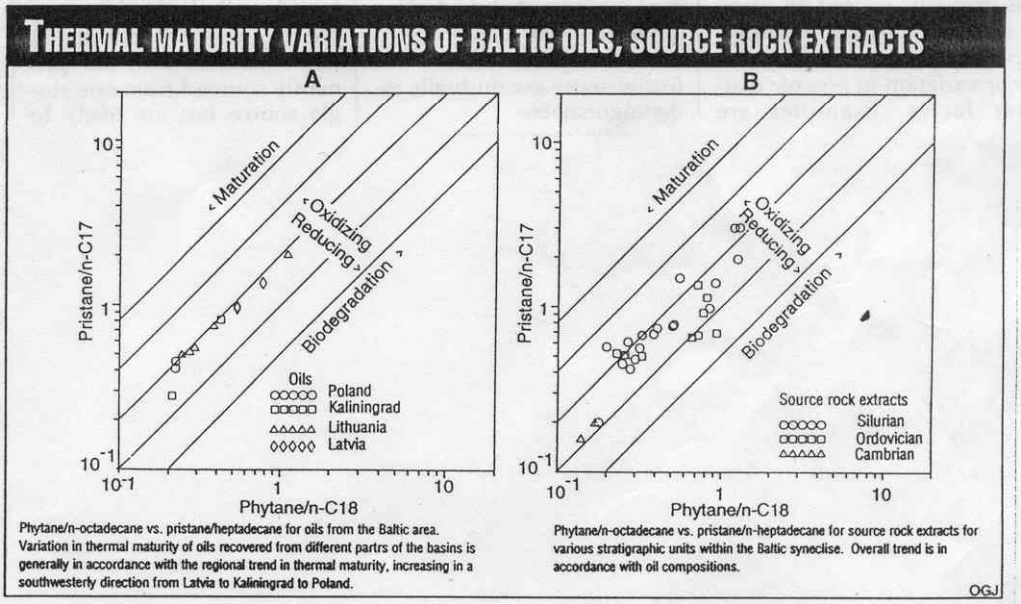
Fig. 2



Kerogen type is uniform, irrespective of geologic age. Variations are caused mainly by differences in level of thermal maturity.

Prolific hydrocarbon source rocks occur in Cambrian, Ordovician, and Silurian sequences. Samples plotted below main trend are thermally mature samples from the southwestern part of the Baltic syneclise.

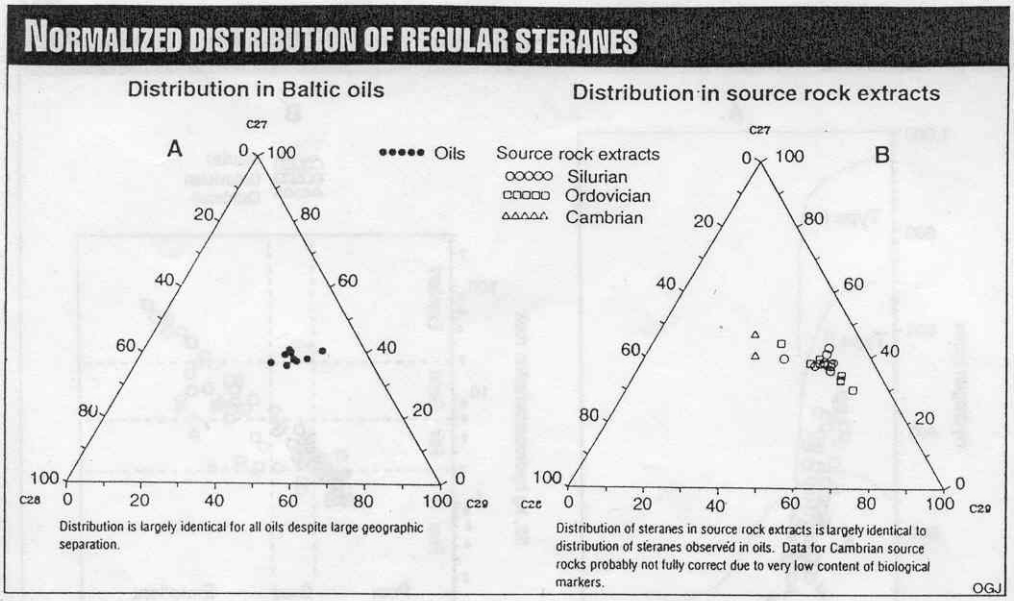
Fig. 3



Phytane/n-octadecane vs. pristane/heptadecane for oils from the Baltic area. Variation in thermal maturity of oils recovered from different partrs of the basins is generally in accordance with the regional trend in thermal maturity, increasing in a southwesterly direction from Latvia to Kaliningrad to Poland.

Phytane/n-octadecane vs. pristane/n-heptadecane for source rock extracts for various stratigraphic units within the Baltic syneclise. Overall trend is in accordance with oil compositions.

Fig. 4



rial, pristane/phytane ratios mainly in the range 1-3, prominence of tricyclic terpanes in the m/z 191 ion trace, and low abundance of extended hopanes.

The compositional scatter is primarily caused by variations in thermal maturity, perhaps overprinted by minor variation in organic matter facies. Examples are shown in Fig. 3B and 4B. However, within the range of variability observed, the geochemical fingerprints appear independent of geological age, i.e. on a geochemical basis Ordovician source rocks cannot be distinguished from Cambrian or Silurian source rocks, which furthermore are mutually indistinguishable.

The characteristic Gloecapsamorpha prisca fingerprint[8] often observed in oils derived from Ordovician source rocks and their extracts, is lacking. Hence no single source for the oils can be identified. Within any one geographical area the oil accumulations may be primarily sourced from one single source but are likely to result from pooling of contributions from several sources at slightly different levels of thermal maturity.

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