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Silurian 'hot shales' in North Africa: Mapping anoxia in time and space

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Lower Silurian organic-rich ('hot') shales are the origin of approximately 90% of the Palaeozoic-sourced hydrocarbons in North Africa. They contain up to 17% TOC, however, their organic-richness and thickness varies strongly across the region, whereby maximum values are generally reached in palaeodepressional areas, mostly in central North Africa (E-Algeria, S-Tunisia, W- Libya) (Lüning et al. 1999, 2000, in press). Early Silurian palaeohigh areas in the region lack the Silurian hot shale and instead were dominated by nondeposition or deposition of shallow marine/continental siltstones and sandstones.

Sedimentation of the Silurian organic-rich shales occurred during a major second-order sea-level rise following the melting of the late Ordovician glacial ice in North Africa/Arabia. Several mechanisms in combination with this transgression exist that might have triggered and supported early Silurian anoxia. This includes upwelling along the northern Gondwanan coast, restricted water circulation on the wide northern Gondwanan shelf due to a strong palaeorelief, postglacial fresh-water stratification, and retrogradation of deltaic sand bodies during transgression that resulted in less dilution of the shales. Detailed estimations of the relative significance of these parameters do not exist.

The exact temporal-spatial distribution of the early Silurian anoxia is still unclear. While in many parts of North Africa and Arabia the organic-rich phase is restricted to the earliest Silurian stage (Rhuddanian), the hot shale in parts of Algeria appears younger, with the older phase probably being absent. An important area in this respect is the Ghadames / Berkine Basin where in some of the Libyan and Algerian exploration wells a 'double hot shale' can be found. In these wells, the Rhuddanian hot shale is often separated from a younger, Telychian/Wenlockian hot shale by several 10s meters of organically lean shale. A reliable depositional model is needed to explain diachroneity and synchroneity observed within the Silurian 'hot shale' system.

The Silurian 'hot shale' can be best studied in fresh core or cutting subsurface material. In well logs they are marked by high gamma-ray radiation due to their relatively high content in uranium, which is usually enriched at or near the base of the shale succession. Nevertheless, outcrop studies of these black shales at the undrilled basin margins are important to better understand the larger-scale, interbasinal trends in source quality and to perform high-resolution biostratigraphic analyses based on macrofossils which cannot be easily retrieved from subsurface samples. Identification of the Silurian (and Upper Devonian) source rock units at outcrop is usually complicated because arid Saharan weathering resulted in the organic matter to be largely oxidised and rock colours to be altered. "Black shales" cropping out on the Saharan Platform, therefore, often appear in red/green colours and are organically lean.

Two new techniques have recently been successfully employed in the field that help with differentiating between pre-weathering organically rich and lean shales. Extensive tests at Saharan outcrops have demonstrated that the uranium originally enriched in the Silurian (and Devonian) black shales at least in part survives desert weathering and, detected by means of a handheld gamma-ray spectrometer, can potentially be used to identify weathered source rocks. Furthermore, quantitative grain size and abundance analyses of pyrite framboids carried out on weathered and unweathered shale samples have proven useful to determine the degree of water column oxygenation, and, therefore, represent another technique for the identification of source facies in Palaeozoic Saharan outcrop samples. This technique is based on the formation of framboidal pyrites in oxygen-depleted watercolumns, with diameters decreasing with decreasing oxygen-levels / increasing TOC in the sea water (Wilkin 1996, 1997). Furthermore, the abundance of framboids increases markedly with increasing TOC. Once a standard correlation between TOC/framboid mean grain size/abundance has been established (Lüning et al. submitted), the framboid data from outcrop samples can be used to calculate the approximate original TOC.

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