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THE STRUCTURE, STRATIGRAPHY AND PETROLEUM GEOLOGY OF THE MURZUK BASIN, SOUTHWEST LIBYA

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ABSTRACT

The Murzuk Basin covers an area in excess of 350,000km^2, and is one of several intra-cratonic sag basins located on the Saharan Platform of North Africa. Compared with some of these basins, the Murzuk Basin has a relatively simple structure and stratigraphy, probably as a result of it's location on a the East Saharan Craton. The basin contains a sedimentary fill which reaches a thickness of about 4,000m in the basin centre. This fill can be divided into a predominantly marine Paleozoic section, and a continental Mesozoic section.

The principal hydrocarbon play consists of a glacial-marine sandstone reservoir of Cambro-Ordovician age, sourced and sealed by overlying Silurian shales. The present day borders of the basin are defined by tectonic uplifts, each of multi-phase generation, and the present day basin geometry bears little relation to the more extensive Early Palaeozoic sedimentary basin within which the reservoir and source rocks were deposited.

The key to the understanding of the Cambro-Ordovician play is the relative timing of oil generation compared to the Cretaceous and Tertiary inversion tectonics which influenced source burial depth, reactivated faults and reorganised migration pathways. At the present day only a limited area of the basin centre remains within the oil generating window. Modelling of the timing and distribution of source rock maturity uses input data from AFTA and fluid inclusion studies to define palaeo temperatures, shale velocity work to estimate maximum burial depth and source rock geochemistry to define kinetics and pseudo-Ro. Migration pathways are investigated through structural analysis.

The majority of the discovered fields and identified exploration prospects in the Murzuk Basin involve traps associated with high angle reverse faults. Extensional faulting occurred in the Cambro-Ordovician and this was followed by repeated compressional movements during Late Silurian, Late Carboniferous, Mid Cretaceous and

Tertiary, each associated with regional uplift and erosion.

REGIONAL TECTONIC EVOLUTION

The Murzuk Basin is one of several intra-cratonic sag basins located on the Saharan Platform of North Africa (Fig. 1). Compared with some of these basins (for example, the neighbouring Illizi Basin of Algeria), the Murzuk Basin is relatively simple, both in terms of structure and stratigraphy. This difference probably results from the location of the basin on the East Saharan Craton, rather than on a Pan-African mobile belt.

The eastern and western margins of the Murzuk Basin are formed by the Tibesti and Tihemboka Highs respectively (Fig. 2). These highs are related to north-south trending Pan-African basement fault systems. Substantial strike-slip movement has probably occurred along these fault systems, and it is likely that throughout the basin's long history, the faults have been used to accommodate stresses generated by the relative movements of the African plate. The northern margin of the basin is formed by the east-west trending Gargaf Arch whereas the southern part of the basin extends into Niger.

Tectonic movements affected the Murzuk Basin during late Precambrian times (Pan-African), Cambro-Ordovician, late Ordovician to early Devonian times (Caledonian), Carboniferous times (Hercynian) and late Cretaceous to early Tertiary times (Alpine).

BASIN STRATIGRAPHY

A stratigraphic column for the Murzuk Basin is shown in Figure 3. The traditional stratigraphic scheme is mainly based on field work, which was carried out along the margins of the basin in connection with the preparation of geological maps. Some of the basin margin sequences do not appear to be present in the basin centre, possibly due to lateral facies change and/or non-deposition, and there is a tendency for the basin centre sediments to be finer grained.

The sedimentary deposits in the Murzuk Basin range from Cambrian to Cretaceous in age, and can be divided into four major sedimentary cycles:

Cambro-Ordovician Cycle

The oldest sediments preserved in the basin are early Cambrian in age, and belong to the Mourizidie Formation. These coarse clastic sediments filled topographic lows as the Pan-African surface was being peneplaned.

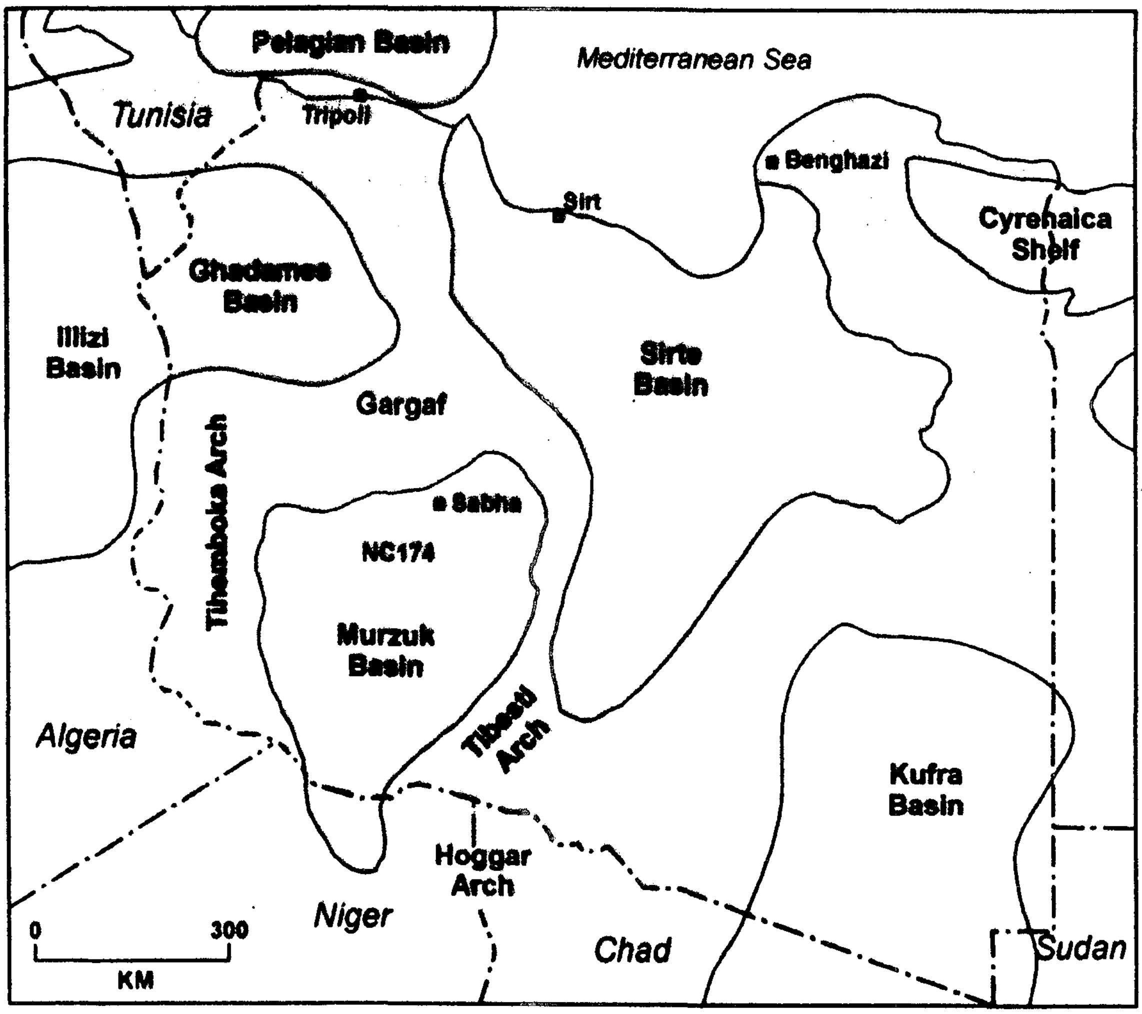
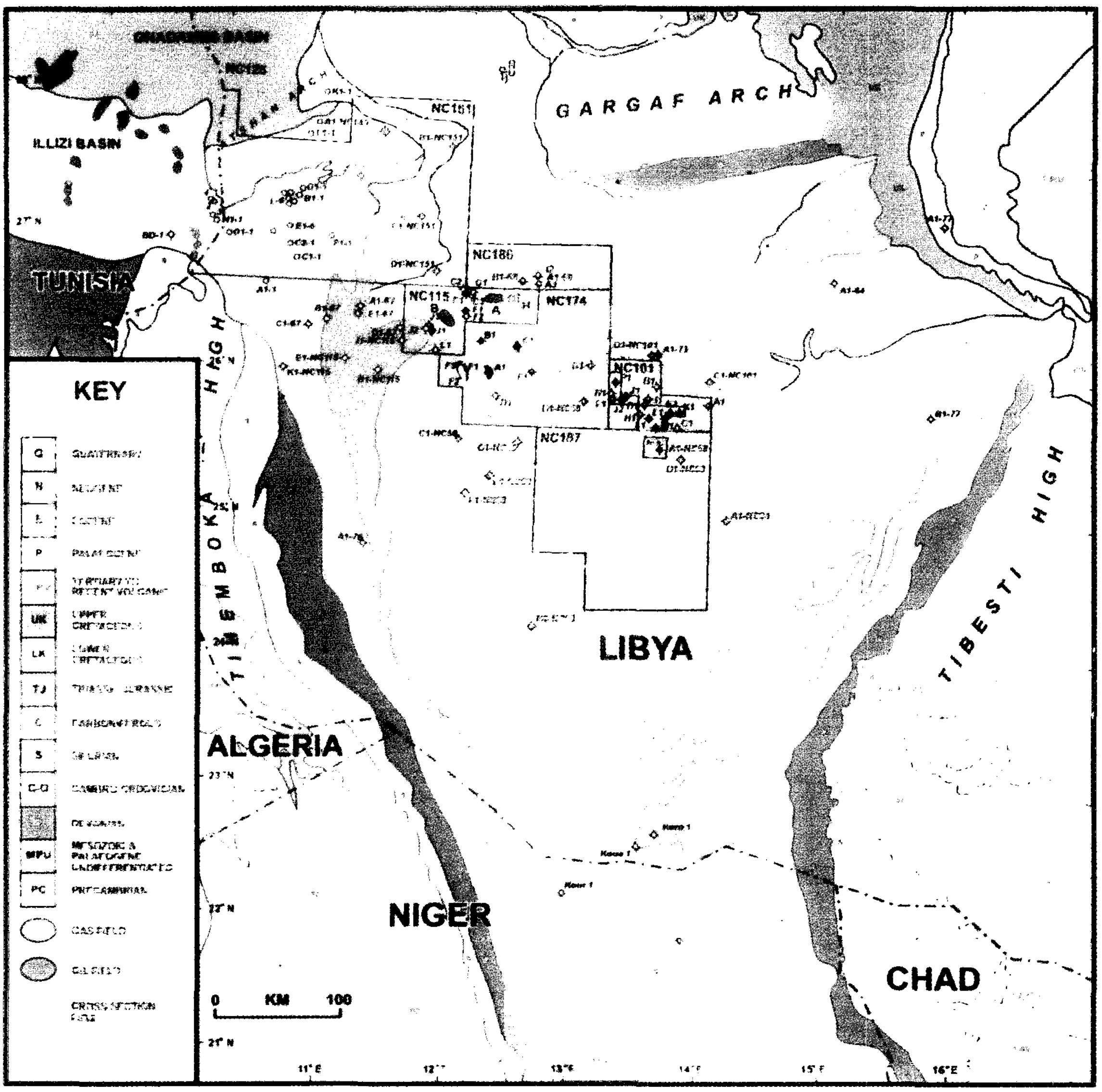


Figure 1. Locatin map of the Murzuk Basin



From : Geological map of Libya, Industrial Research Centre, 1985 and other sources
International Boundary from NOC Concession map 1994

Fig. 2. Simplified geological map of the Murzuk Basin.

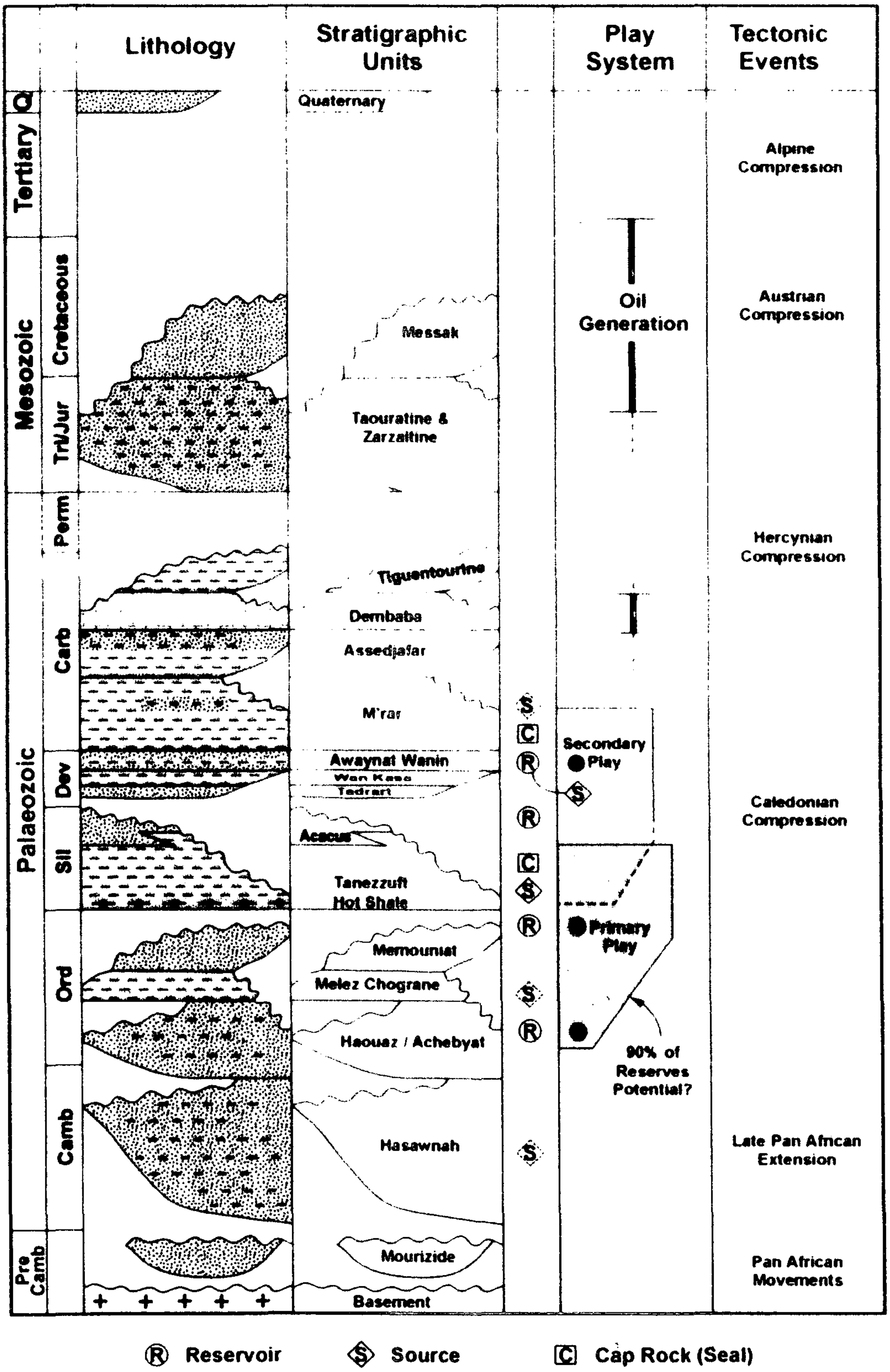


Fig. 3. A summary of the stratigraphy, hydrocarbon play systems and chronology of tectonic events in the Murzuk Basin.

The first sediments to be deposited throughout the basin belong to the Cambrian Hasawnah Formation. A basal conglomerate has been recorded, although the bulk of the formation comprises medium to very coarse grained, quartzitic sandstone. The environment of deposition passed from fluvial at the base of the formation to shallow marine at the top. Sediment supply was from the south, with the sea transgressing from the north.

An unconformity separates the Hasawnah Formation from the overlying middle Ordovician Haouaz Formation. The type area for the Haouaz Formation is located on the Gargaf Arch, where the section comprises fine to medium grained sandstone, with subordinate siltstone and shale. This section has been described by Vos (1981), who suggested that the sediments were deposited in a fan delta complex which prograded across the Gargaf Arch in a northerly direction.

In the northwestern part of the basin, the Haouaz Formation is overlain by shale of the late Ordovician Melez Chograne Formation. This shale forms a fairly distinctive unit with uniform wireline log responses, and has been dated as Ashgill in age (Abugares and Ramaekers, 1993). The shale was probably deposited in a relatively shallow marine environment, and a predominantly green colour points to reducing conditions, suggesting restricted marine circulation.

The Memouniat Formation mainly comprises sandstone with subordinate siltstone and shale beds which have been dated as Ashgill in age. The sandstone forms the reservoir of the primary play in the basin, and is typically quartzitic, fine to medium grained, and fairly well sorted. Several different facies can be recognised in the Memouniat Formation, although most can be assigned to a relatively high energy, shallow marine environment of deposition. Braided fluvial deposits also occur within the formation, and may be more dominant in the southern part of the basin.

The Memouniat Formation was deposited at a time of glaciation over North Africa, which lay along the margin of Gondwanaland. It is possible that an ice sheet extended as far north as the Murzuk Basin. Glaciation was important in releasing vast quantities of sediment, which were initially transported in high energy braided fluvial systems, and then reworked in the shallow marine environment. The glaciation may have also resulted in short lived sea level changes, connected with the growth and retreat of the ice cap..

Silurian to Devonian Cycle

The Silurian to Devonian cycle began with a major marine transgression, which spread from the north, and reached across much of the North African margin. At the base of the cycle, an unconformity separates the Memouniat Formation from the

overlying shale of the Silurian Tanezzuft Formation. A organic rich hot shale with patchy areal distribution occurs at the basal part of the Tanezzuft Formation, and is the main source rock within the basin. and has been dated as mainly late Llandovery (Telychian) in age. The shale becomes gradually siltier up through the section, although the sandy, shallow marine late Silurian Akakus Formation, which occurs at the basin margins, appears to be absent in the basin centre. A hot shale can occur at the base of the Tanezzuft Formation, and is the main source rock within the basin.
An unconformity separates the Tanezzuft Formation from the overlying mid to late Devonian Awaynat Wanin Formation. Sediments of early Devonian age appear to be absent in the basin centre, probably as a result of non-deposition, rather than erosion. The Awaynat Wanin Formation comprises shale and subordinate sandstone, often rich in iron, deposited in a littoral to shallow marine environment. The sandstone of the Awaynat Wanin Formation forms the reservoir for the secondary play.

Early to Mid Carboniferous Cycle

The early to mid Carboniferous cycle also began with a transgression. The Awaynat Wanin Formation is overlain by the M'rar Formation, which is in turn overlain by the Assedjefar Formation. Both of these formations are early Carboniferous in age, and comprise shale with subordinate sandstone. Several minor coarsening-up cycles can be traced across the basin, suggesting deposition in a relatively low energy shallow marine environment with periodic shoaling. The overlying mid Carboniferous Dembaba Formation comprises shallow marine limestone, sandstone and grey shale in the northern part of the basin, and lagoonal limestone and red shale in the southern part. This formation represents a transition from the marine conditions which occurred throughout much of the Paleozoic, to the continental conditions which have prevailed since.

Late Carboniferous to Cretaceous Cycle

The late Carboniferous to Cretaceous sediments were deposited in continental conditions. The section can be divided into the red lacustrine mudstone of the late Carboniferous to Permian Tiguentourine Formation, the fluvial sandstone and red mudstone of the Triassic to Jurassic Zarzaitine/Taouratine Formation, and the fluvial sandstone, conglomerate and mudstone of the Cretaceous Messak Formation. These formations appear to be conformable, and are separated by periods of non-deposition.

THE CAMBRO-ORDOVICIAN PLAY

The Cambro-Ordovician play has proved very successful, and accounts for all of the estimated 800 to 1,500 million barrels of recoverable oil discovered in the Murzuk Basin so far. An important factor in the success of the play is its simplicity. Oil is expelled from a rich, oil-prone source rock at the base of the Silurian section directly into the underlying sandstone rich Cambro-Ordovician section, within which the relative simple structure of the basin allows the oil to migrate long distances until it is either trapped, or lost along the migration pathway.

Source Model

Oil-prone source rocks at the base of the Silurian section occur throughout much of North Africa. These source rocks have generated and expelled considerable volumes of hydrocarbons, not only in the Murzuk Basin, but also in the nearby Illizi, Ghadames and Triassic Basins of Algeria. Geochemical data indicate that in the Murzuk Basin, the best source potential is provided by an impersistent uranium rich hot shale unit occurring at the very base of the Silurian section.

The base Silurian hot shale can be treated as a distinct stratigraphic unit and knowledge of its distribution is of prime importance in understanding the Cambro - Ordovician play (Fig. 4). In some areas calibration to drilling results shows, that where the hot shale unit is present it gives rise to a strong base Silurian seismic reflector, but this reflector dims significantly where the hot shale is absent (Fig. 5). This relationship allows the areal distribution of hot shale to be mapped using horizon keyed seismic amplitudes (Fig. 6). Using this technique, the hot shale which can be seen to onlap some early Caledonian structures where the hot shale is absent, but pass straight over other structures where fault movement was later or the structural crest had been peneplaned by erosion.late Caledonian structures where the hot shale is present.

A thermal modelling of the basal Tanezzuft hot shale source rock in the Murzuk Basin wells was carried using the BasinMod program. Some results are illustrated in Fig. 7. The timing and amount of uplift during phases of compressional tectonics are also key inputs to the model, and these parameters are being refined by studies on basin tectonics combined with shale velocity work.

The results of the maturity model show that the hot shale might have entered the mid-mature window and started to generate significant quantities of oil at about mid to late Cretaceous times, approximately 80mmy bp, and continued to do so until mid-Tertiary, about 50mmy bp, when uplift and erosion caused sufficient cooling of the source rock to remove it from the oil window. At the present day the hot shale

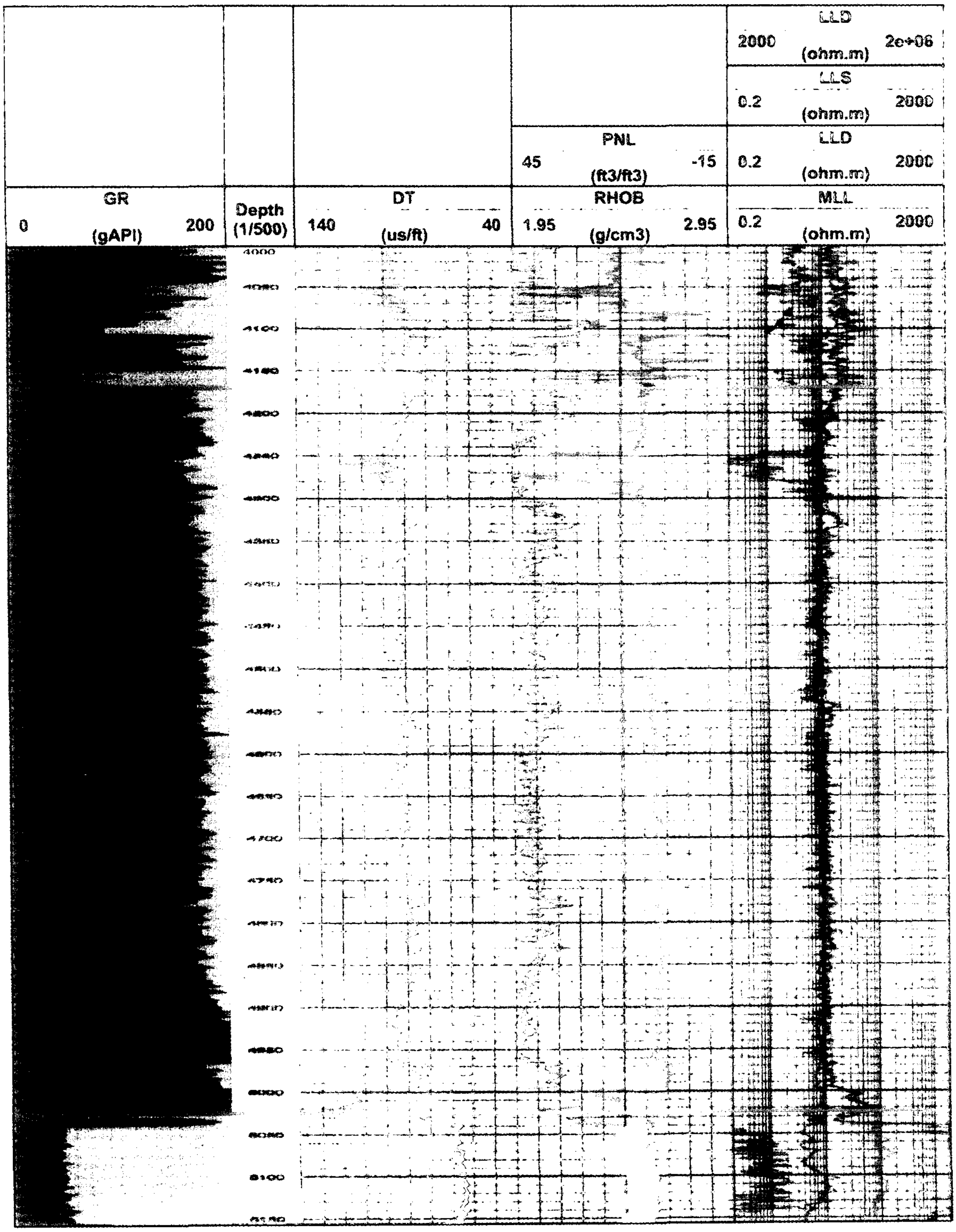


Fig. 4. Typical logs through the Silurian Tanezzuft Formation including the hot shale interval.

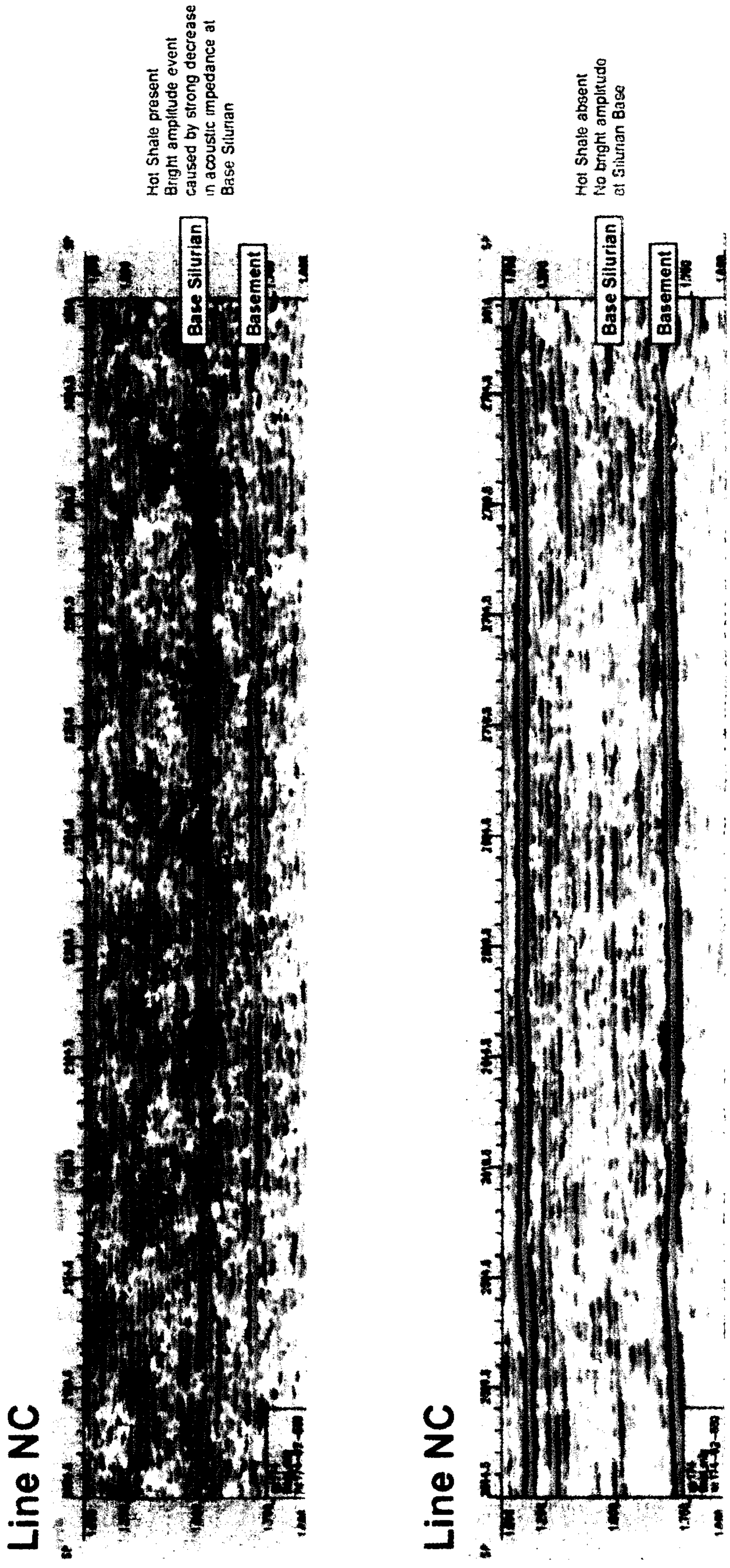
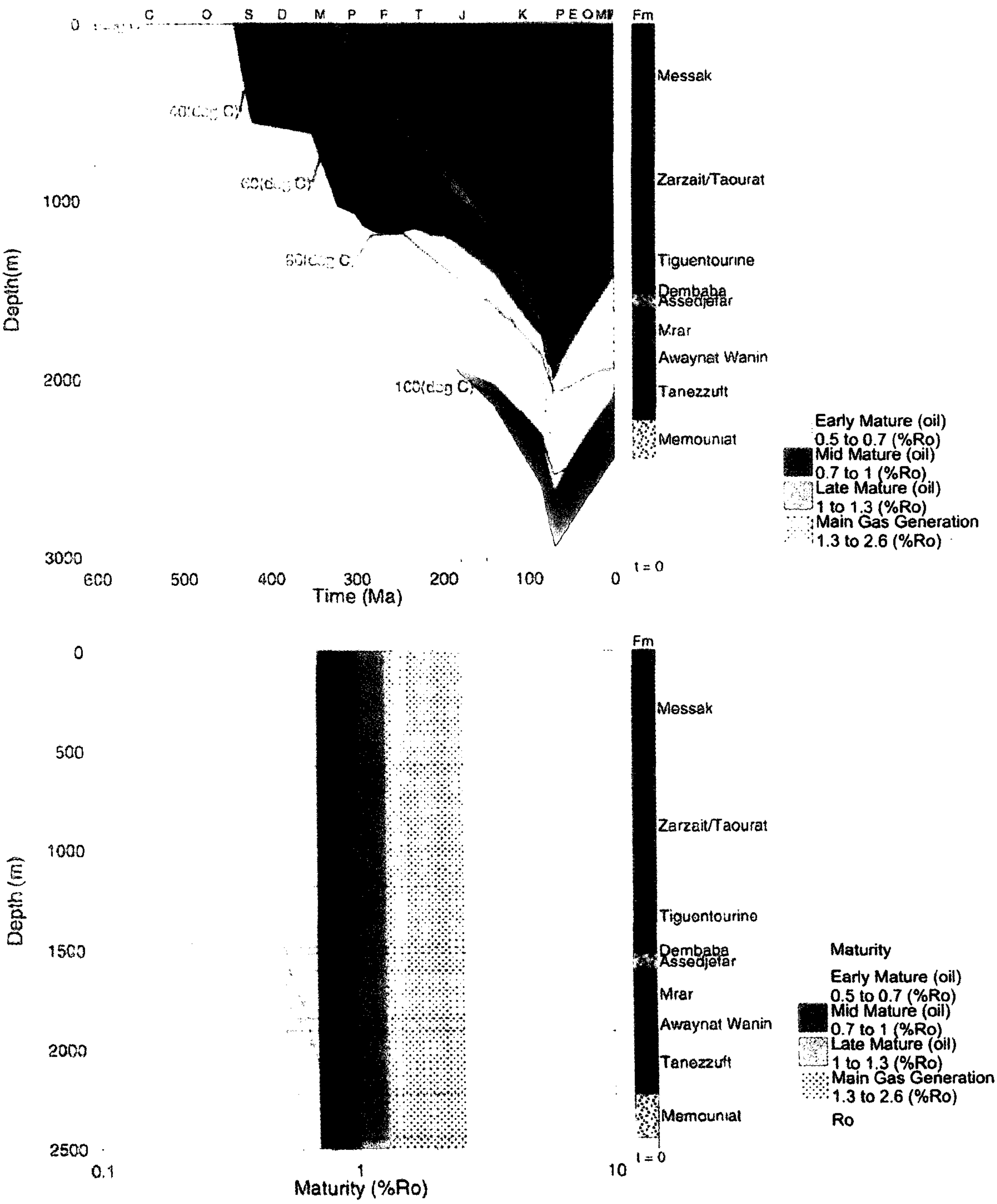

Hot Shale present
Bright amplitude event
caused by strong decrease
in acoustic impedance at
Base Silurian
Base Silurian
Basement
Line NC
Hot Shale absent
No bright amplitude
at Silurian Base
Base Silurian
Basement
Line NC

Fig. 6. Map showing distribution of the hot shale source rock within the Silurian Tanezzuft shale.



(500m Cretaceous Erosion)

Fig. 7. Thermal modelling results of the basal Tanezzuft hot shale using the BasinMod programme.

in the Murzuk Basin is not generating any oil, and will remain in this "frozen" state unless its temperature is elevated by further burial or increased heat flow.

Oil generated from the base Silurian source rock will be expelled directly into the underlying normally pressured Cambro-Ordovician sandstone. Once in the sandstone, the oil migrates up dip until it is either trapped, or lost as residual saturation along the migration pathway.

Reservoir Model

Sandstone in the upper part of the Cambro-Ordovician section forms the reservoir for the primary play in the Murzuk Basin. The success of the play is in part a result of the sandstone rich nature of the Cambro-Ordovician section, which not only acts as the reservoir, but also as the carrier bed for long distance oil migration from the source kitchen.

The Cambro-Ordovician section can be divided into three main units; the Cambrian Hasawnah Formation, the middle Ordovician Haouaz (or Achebyat) Formation, and the late Ordovician Memouniat Formation (and Melez Chograne Formation). These units were probably deposited during periods of tectonically controlled regional subsidence, separated by relatively long hiatuses. The reservoir for the Cambro-Ordovician play comprises the sandstone at the top of the section. Seismic and well data indicate that although the exact age of the sediments at the top of the Cambro-Ordovician section might vary, there is little evidence to suggest that the Memouniat Formation is not present throughout much of the Murzuk Basin (Beswetherick, 1996).

The Memouniat Formation was deposited at a time of glaciation over North Africa, which lay along the margin of Gondwanaland. It is possible that at its maximum extent, the ice sheet extended across the whole of the Murzuk Basin. However, unlike the neighbouring Illizi Basin of Algeria, there is very little evidence for either erosion or deposits resulting directly from the actions of glaciation. This difference is probably a consequence of the long distance between the basin and any upland areas. Glaciation was important in generating vast quantities of sediment. The glaciation may have also resulted in short lived sea level changes, connected with the growth and retreat of the ice cap.

The depositional model for the Memouniat Formation is based on a combination of outcrop and well data. On the southeastern margin of the basin (the Tibesti High), the sediments appear to have been deposited in high energy glacial outwash fans, which spread out from the edge of the ice sheet (Beswetherick, 1992a). The proximal parts of these fans include matrix supported conglomerates containing boulder sized clasts, whereas the distal parts are dominated by poorly sorted, coarse grained sandstones deposited in braided fluvial conditions.

On the northern and western margins of the basin (the Gargaf Arch and Tihemboka High respectively), the Memouniat Formation is dominated by moderate to well sorted, fine to medium grained, quartzitic sandstone, which tends to be both texturally and mineralogically mature. The bulk of the sandstone appears to have been deposited in shallow marine conditions, although there is also some evidence for braided fluvial deposits.

There is no simple depositional model for the Memouniat Formation in the Murzuk Basin, mainly as a result of changes in the lateral and vertical facies related to three main factors: i) regional and local structuration, which means that the section in one area may not be exactly the same age as the section in another area; ii) the depositional environment, with the interaction of fluvial and marine systems, and the building, abandonment, and reworking of different parts of the braid delta systems, and iii) glacially driven sea level changes, which although relatively small and short lived, may have strongly influenced the depositional systems on the wide, shallow shelf covering the basin.

The reservoir quality of a particular Cambro-Ordovician sandstone depends on a combination of primary, textural factors, and secondary, compactional and diagenetic factors. Reservoir quality tends to increase with increasing grain size and sorting, and decreasing detrital clay content (depositional fabric and the abundance of detrital feldspar, lithic fragments and mica are also important). These primary factors can be strongly over-printed by the secondary factors, which tend to reduce the porosity and permeability of the sandstone (for example, through compaction, precipitation of authigenic cement, and clay mineral authigenesis). One exception to this reduction in reservoir quality is that of feldspar dissolution, which can increase the porosity and permeability.

The key to predicting the reservoir potential will be an understanding of the facies distribution. Unfortunately, it has not yet proved possible to constrain the distribution of the facies with the available data.

Seal Model

The sandstone reservoir of the Cambro-Ordovician play is sealed by shale of the overlying Silurian Tanezzuft Formation. This shale is present throughout the Murzuk Basin, except on the Brak-Ganimah High northeastern part of the basin, where the Silurian section is absent, and on the southern margin of the basin, where the Silurian section becomes sand.

Trap Types

The majority of the prospects identified at the top Cambro-Ordovician level in the Murzuk Basin involve structural traps, which are probably typical of the traps occurring in the Murzuk Basin. These traps occur on the hanging wall side of high angle reverse faults, and can be divided into two types. Firstly, there are traps developed within the actual hanging wall of the faults. These traps require cross-fault seal, usually against the Silurian shale in the footwall. Secondly, there are traps with four-way dip closure formed by the tip-line folds above the faults.

CONCLUSIONS

The Murzuk Basin is a fairly underexplored basin in which reserves in excess of one billion barrels of recoverable oil have already been discovered. The primary play in the basin comprises a Cambro-Ordovician sandstone reservoir, sourced and sealed by overlying Silurian shales. The success of the play is in part a result of it's simplicity. Oil is generated from an extremely rich source rock at the base of a thick Silurian shale section, and expelled directly into the underlying sandstone-rich Cambro-Ordovician reservoir section. The relatively simple regional structure of the basin allows the long distance migration of oil., whereas the occurrence of closures related to high angle reverse faults, provides an opportunity for the oil to be trapped.

The Cambro-Ordovician play has only met with a limited amount of success elsewhere along the North African margin. In some basins, this lack of success can be attributed to the distribution of the source rock. However, in other basins such as the neighbouring Illizi Basin of Algeria, the limited success of the play is mainly the result of a different tectonic history. The Murzuk Basin lies on a stable craton, and has had a relatively quiet tectonic evolution. This means that the Cambro-Ordovician sandstone reservoir has not been buried to great depths, and that the Silurian source rock only entered the oil window from late Palaeozoic times. In contrast, the Illizi Basin lies on a tectonically active Pan-African mobile belt, and there has been much greater subsidence and structuration. This means that the reservoir quality of the Cambro-Ordovician sandstone tends to be poor due to deep burial, and that much of the oil was generated in Paleozoic times, prior to Hercynian deformation.

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