CANNING BASIN AND GLOBAL PALAEOZOIC PETROLEUM SYSTEMS—A REVIEW

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ABSTRACT

There are more than 131 giant and super-giant oil and gas fields with Palaeozoic source and reservoir that are similar to the Canning Basin. These include Palaeozoic basins of North America, North Africa, and the North Caspian Basin of Kazakhstan and Russia.

The productivity of these Palaeozoic petroleum systems depends on timing of generation and preservation of charge. Thick Ordovician, Permian, and Triassic evaporite deposits played a very important role in creating and preserving the North American, north Caspian, and north African giant oil and gas fields, respectively.

The Mesozoic–Tertiary charged Palaeozoic systems are typically more productive than the Palaeozoic charged systems as exemplified by the north African basins.

The Ordovician sourced and reservoired giant oil fields of the North American Mid-Continent are also highly productive. Within the Canning Basin, Ordovician sourced oil has been recovered on the Barbwire Terrace (in Dodonea–1, Percival–1 and Solanum–1) on the Dampier Terrace (in Edgar Range–1 and Pictor–1) and along the Admiral Bay Fault Zone (in Cudalgarra–1, Great Sandy–1, and Leo–1).

The Canning Basin may be the least explored of the known Palaeozoic basins with proven petroleum systems. The Palaeozoic basins of North America are the most explored with 500-wells/10,000 km^2 compared to the Canning Basin with only 4-wells/10,000 km^2.

The presence of five oil fields, numerous oil and gas shows and the well density in the Canning Basin (200 wells in 530,000 km^2) suggests that further exploration is warranted. Critical analysis of the distribution of source rock, reservoir, seal, timing of generation versus trap formation and post accumulation modification for each tectonic unit of the Canning Basin is required.

KEYWORDS

Canning Basin, Palaeozoic, petroleum system, giant and super-giant fields, productivity, charge timing, subsalt, suprasalt, plays.

INTRODUCTION

According to Duncan S. Macgregor, BP, 1996, 'The best remaining frontier prospects lie in young basins where oil generation has occurred recently or in older basins with a high preservation potential, e.g. intracratonic basins with evaporite seals.' This paper will examine if the conditions are present for high preservation potential for untested prospects in the Canning Basin.

More than 90% of original recoverable oil and gas reserves in the world have been generated from source rocks at six stratigraphic intervals:

- Silurian (generated 9% of the world reserves);
- Upper Devonian–Tournaisian (8% of world reserves);
- Pennsylvanian–Lower Permian (8% of world reserves);
- Upper Jurassic (25% of world reserves);
- Middle Cretaceous (29% of world reserves), and;
- Oligocene–Miocene (12.5% of world reserves).

Platforms open to the oceans controlled the deposition of effective source rocks during the Early and Middle Palaeozoic (Klemme and Ulmishek, 1991). Palaeozoic source rocks of the Canning Basin were deposited on platforms and sub-basins open to the Paleo-Tethys Ocean.

This study reviews Palaeozoic petroleum systems that have similar age source rocks and reservoirs to the Canning Basin of Western Australia (Fig. 1). The Canning Basin has three main sequences: the Ordovician–Silurian; Devonian–Lower Carboniferous; and Upper Carboniferous–Permian (Fig. 2). The Canning Basin has been producing oil since 1983 from the Upper Devonian–Lower Carboniferous sequence (the Blina oil field), and Upper Carboniferous–Lower Permian sequence (the Boundary, Lloyd, Sundown, West Kora and West Terrace oil fields). Within the Ordovician–Silurian sequence, oil and gas has been found in Dodonea–1 and Pictor–1 (Cadman et al, 1993).

Globally, Ordovician–Silurian, Devonian–Lower Carboniferous, and Upper Carboniferous–Permian sequences are very important in generating and hosting giant and super-giant oil and gas fields. The prolific Palaeozoic (Ordovician–Permian) petroleum systems are present within the:

- Illizi-Berkine Basin (Algeria);
- Alberta Basin (Canada);
- Jianghan and Shanganning-Ordos Basins (China);
- North Caspian Basin (Kazakhstan);
- Ghadâmis and Murzuk Basins (Libya);
- Ghaba Salt Basin (Oman);
- Siberian and Volga-Ural Basins (Russia);
- Shetland Basin (UK); and,
- Anadarko, Appalachian, Illinois and Permian Basins of the USA (Klemme and Ulmishek, 1991; Mann et al, 2003; Fig. 3).

These prolific petroleum systems encourage a review of the under-explored Palaeozoic sequences of the onshore Canning Basin. The sedimentary fill of the northwest-trending Fitzroy Trough and Gregory Sub-basin in the north is up to 15,000 m thick with predominantly Devonian–Permian

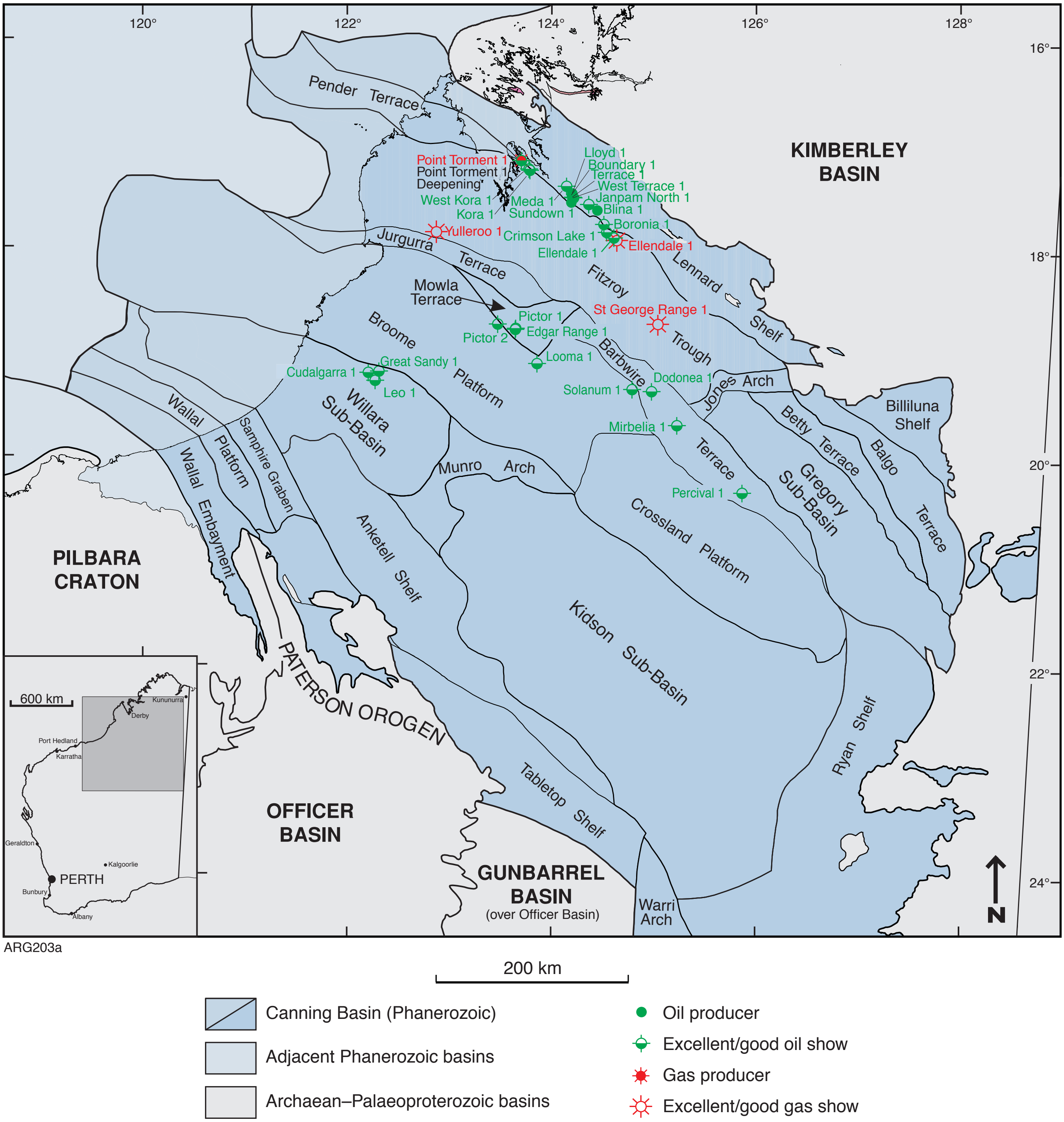

Figure 1. Canning Basin tectonic units and wells with oil and gas occurrences (modified from Tyler and Hocking, 2002).

sediments. Within the Willara and Kidson Sub-basins in the south, the fill is thinner with up to 5,000 m of predominantly Ordovician–Silurian sediments (Fig. 2).

The main aim of this review is to compare and contrast the Canning Basin with prolific Palaeozoic petroleum systems elsewhere in the world. Petroleum exploration in the Canning Basin using these Palaeozoic analogue fields should help in the critical analysis and understanding of the relationships between source rock, reservoir, seal, development of stratigraphic and structural traps, timing of petroleum generation, migration and accumulation, and the subsequent preservation of hydrocarbons.

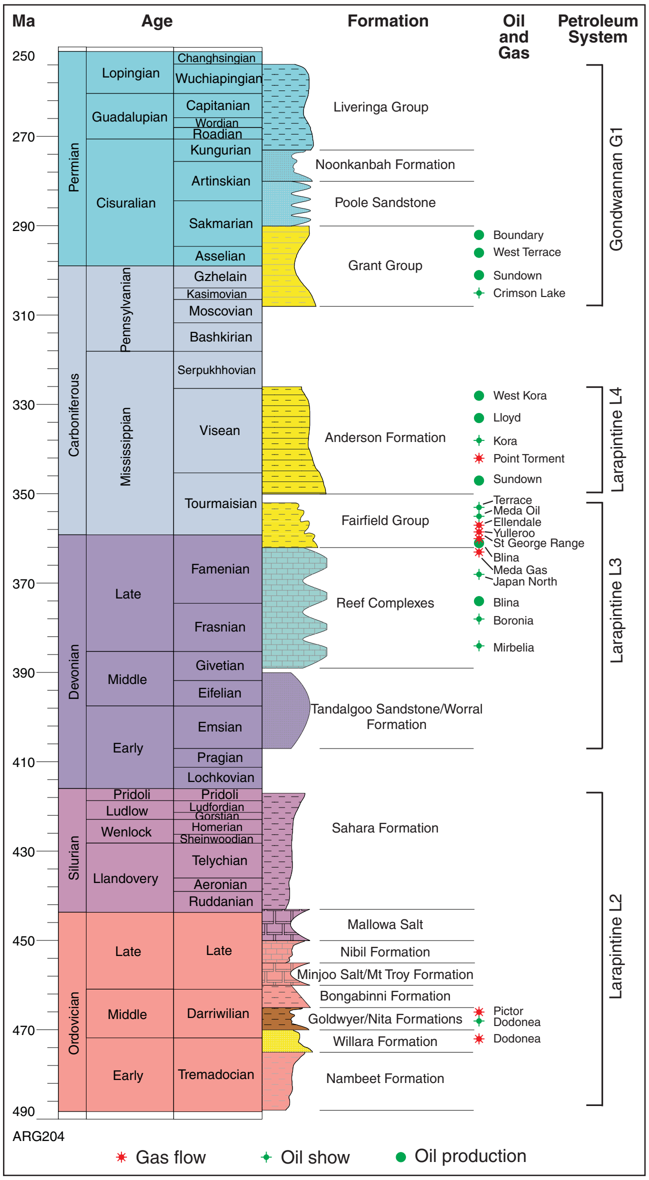

Figure 2. Canning Basin generalised time-stratigraphy with oil and gas occurrences (timescale after Gradstein et al, 2004).

PALAEOZOIC PETROLEUM SYSTEMS

There are more than 131 giant and super-giant oil and gas fields within Palaeozoic petroleum systems (Fig. 3). The Ghaba Salt Basin Province and Fahud Salt Basin Province of Oman provide the best example for the oldest sourced petroleum from Precambrian–Cambrian source rocks of the Huqf Group (Fig. 4; Pollastro, 1999).

The productivity of Palaeozoic petroleum systems depends on charge timing, which may vary from Palaeozoic to Mesozoic–Tertiary. The giant clusters of Palaeozoic petroleum 'lockbox' (Mann et al, 2003) or high preservation oil system (Macgregor, 1996) fields of the Permian Basin of the United States, the Illizi Basin of Algeria, the Siberian Platform of Russia and North Caspian Basin of Kazakhstan and Russia are good examples of proven Palaeozoic petroleum potential (Mann et al, 2003).

Macgregor (1996) defines high, medium, and low preservation oil systems, 'based primarily on evidence for long-term preservation or for partial or complete destruction of giant light oilfields', and provides case studies for each type.

The most explored Palaeozoic basins are in North America with 500-wells/10,000 km^2 compared to the Illizi Basin of Algeria with 29-wells/10,000 km^2 (Macgregor, 1998). The Canning Basin of Australia with only 4-wells/10,000 km^2 and the stable Palaeozoic Platform of the former Soviet Union are the least explored. The most prolific Palaeozoic petroleum systems of the worlds are briefly reviewed below with references for further studies.

USA Palaeozoic Basins

Mann et al (2003) discussed 29 giant fields within the Palaeozoic sourced and reservoired petroleum system of the Permian and Anadarko basins of Texas and Oklahoma (Fig. 5). According to their basin classification these basins are related to the Palaeozoic continent-to-continent collision between North America and South America during the Pennsylvanian–Lower Triassic. Source rocks and reservoirs are mainly deepwater Palaeozoic rocks deposited in basinal areas. The estimated timing of charge was during the Late Permian–Early Jurassic. The Permian Basin provides an excellent example for the preservation of light oil due to excellent thick Permian evaporite sealing giant oil and gas fields.

The Woodford Shale of the Anadarko Basin and Chattanooga Shale of the Appalachian Basin are good examples of source rocks that reached principal maturation stage during the Palaeozoic (Pennsylvanian–Early Permian) and sourced many giant oil and gas fields of the United States (Klemme and Ulmishek, 1991).

Longman and Palmer (1987) describe the geochemistry of oil generated and preserved in Middle to Late Ordovician rocks. The resultant oils have unique geochemical features to distinguish them from oil generated from younger rocks. The Ordovician rocks are economically important for generating and hosting nine giant (>100 million bbl) oil fields in North American basins including the Michigan, Cincinnati Arch and Illinois, Kansas, Southern Oklahoma, Delaware and Williston basins (Fig. 5). The great volume of Upper Ordovician carbonate reservoir rocks and transgressive shale source rocks were the result of widespread marine transgression across the North American continent during the Palaeozoic. The correlation of these units across several basins is shown in Figure 6. Foster et al (1986) correlated the Ordovician Goldwyer Formation source rocks of the Canning Basin with source rocks in the Baltic, Michigan, Illinois, Williston, and Amadeus Basins on the basis of presence of *Gloeocapsamorpha prisca*. *G. prisca*-bearing source rocks are claimed to be responsible for commercial accumulations of hydrocarbons in the Amadeus, Baltic, Michigan–Illinois, and Williston Basins, each of which, including the Canning Basin, lay within 5°

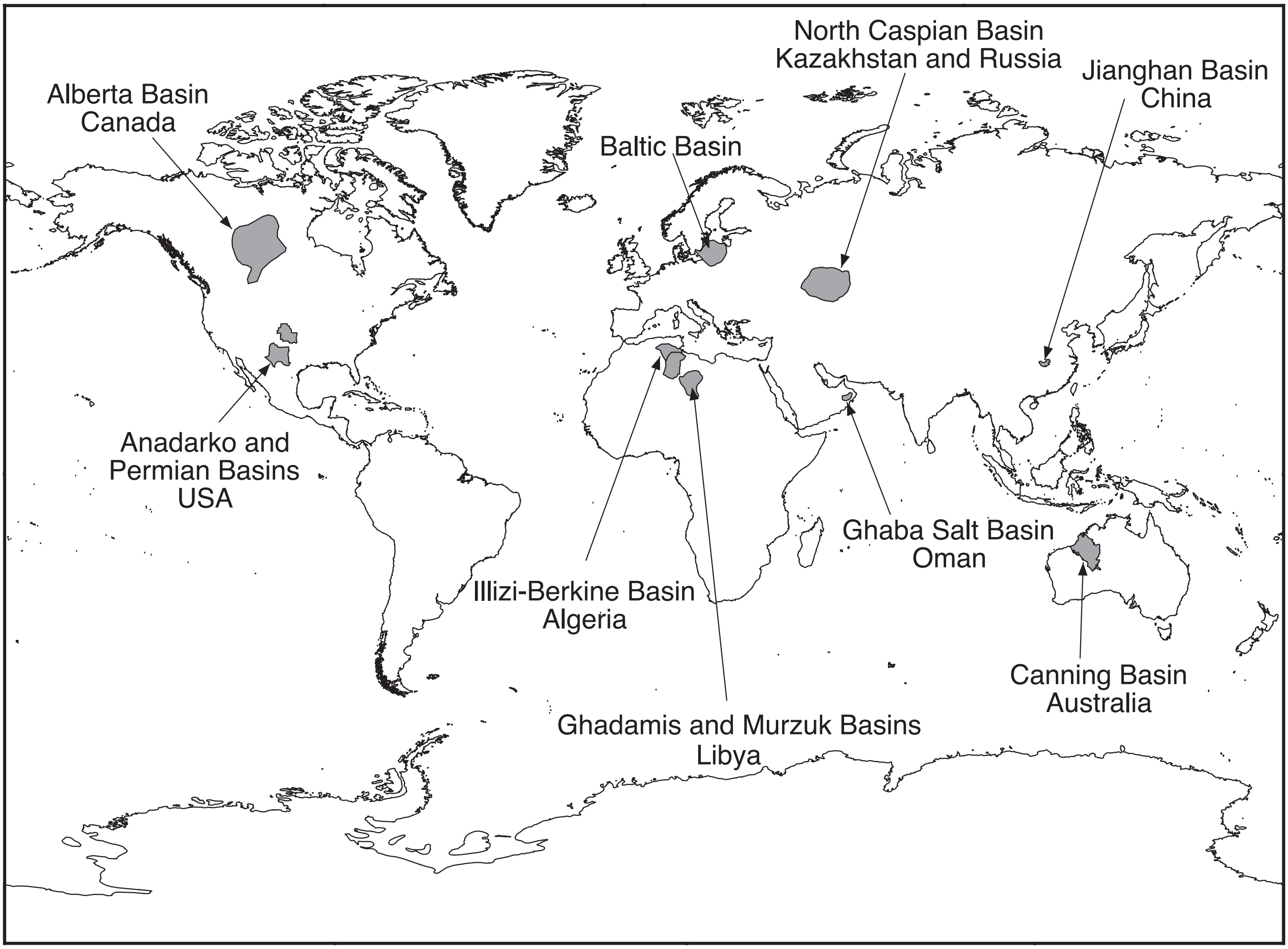

Figure 3. Location of countries with prolific Palaeozoic petroleum systems.

of the equator during the Ordovician (Foster et al, 1986). The Horn Valley Siltstone (source rock) of the Amadeus Basin is Arenigian (485–470 Ma). Chronostratigraphy is based largely on conodonts, with the Goldwyer Formation ranging from the upper Histiodella holodentata Zone to the lower Phragmodus–Plectodina Zone, indicating an early Llanvirn (470–465 Ma) age (Nicoll, 1993; Nicoll et al, 1993; Jones et al, 1998) during which period the first land plants evolved.

North African Palaeozoic Basins

Echikh (1998) describes Palaeozoic petroleum occurrences of Algeria, Tunisia, and Libya; Boote et al (1998) and Klett (2000a, b, c) discussed the Palaeozoic petroleum systems of north Africa; Ghori and Mohammed (2000) describe petroleum system modelling of the Ghadâmis Basin, NW Libya; Lüning et al (2000) discussed the distribution of the main Silurian source rocks in Africa and Arabia; and Mann et al (2003) discussed the tectonic setting of giant oil and gas fields of the Palaeozoic Saharan Platform (Fig. 7).

The recoverable reserves in the North African Palaeozoic petroleum systems are more than 46 billion barrels of oil equivalent including the reserves discovered in 29 giant oil and gas fields. The petroleum accumulations were mainly charged from the Lower Silurian Rhuddanian shales (Tanezzuft Formation) that source up to 80–90% of reserves (Fig. 8). The remaining reserves are sourced from Upper Devonian Frasnian shales (Boote et al, 1998). The organic-rich, graptolitic Silurian source interval is widely distributed in the North African and Arabian basins and thickly developed within the Algerian, Tunisian and western Libyan basins (Lüning et al, 2002).

Palaeozoic oil and gas are trapped in various reservoir sandstones ranging in age from Cambrian–Ordovician to basal Triassic with hydrocarbon charge occurring during the Palaeozoic and Mesozoic–Tertiary. The Mesozoic to Early Tertiary charged systems are most productive within the Mesozoic sag or Triassic Basin of the Northern Saharan Platform, where Triassic shales and evaporite provide the seal. About 78% of the total discovered reserves in the Northern Saharan Platform as well as the Hassi R'Mel and Hassi Messaoud super-giant fields are part of this

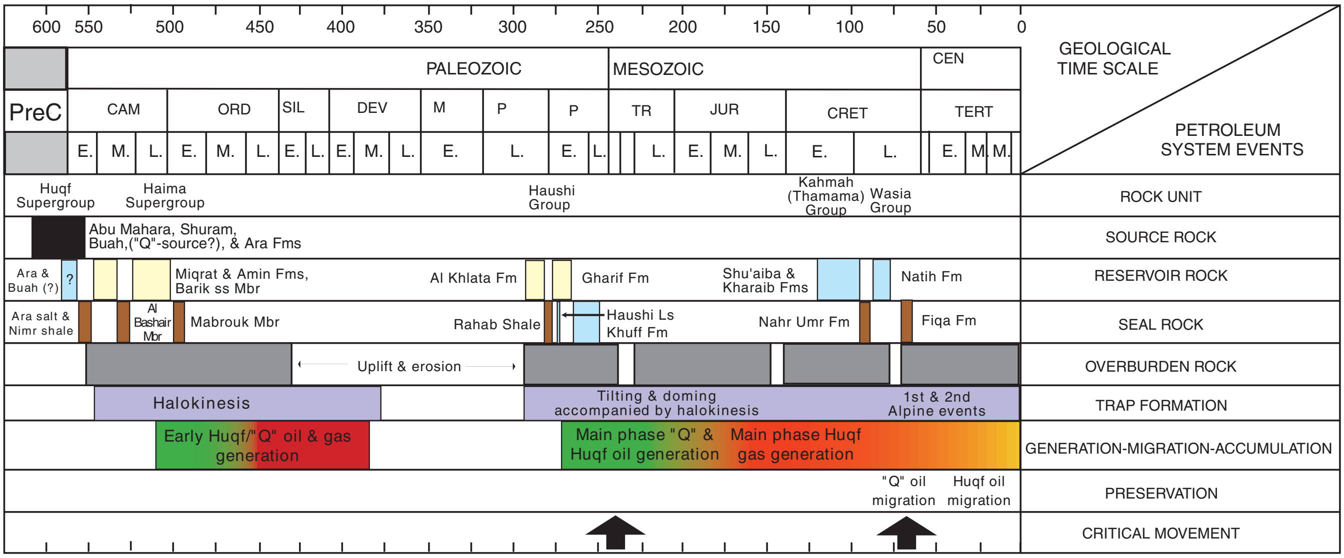

Figure 4. Petroleum system events chart of the oldest sourced petroleum system for Ghaba Salt Basin, Oman (after Pollastro, 1999).

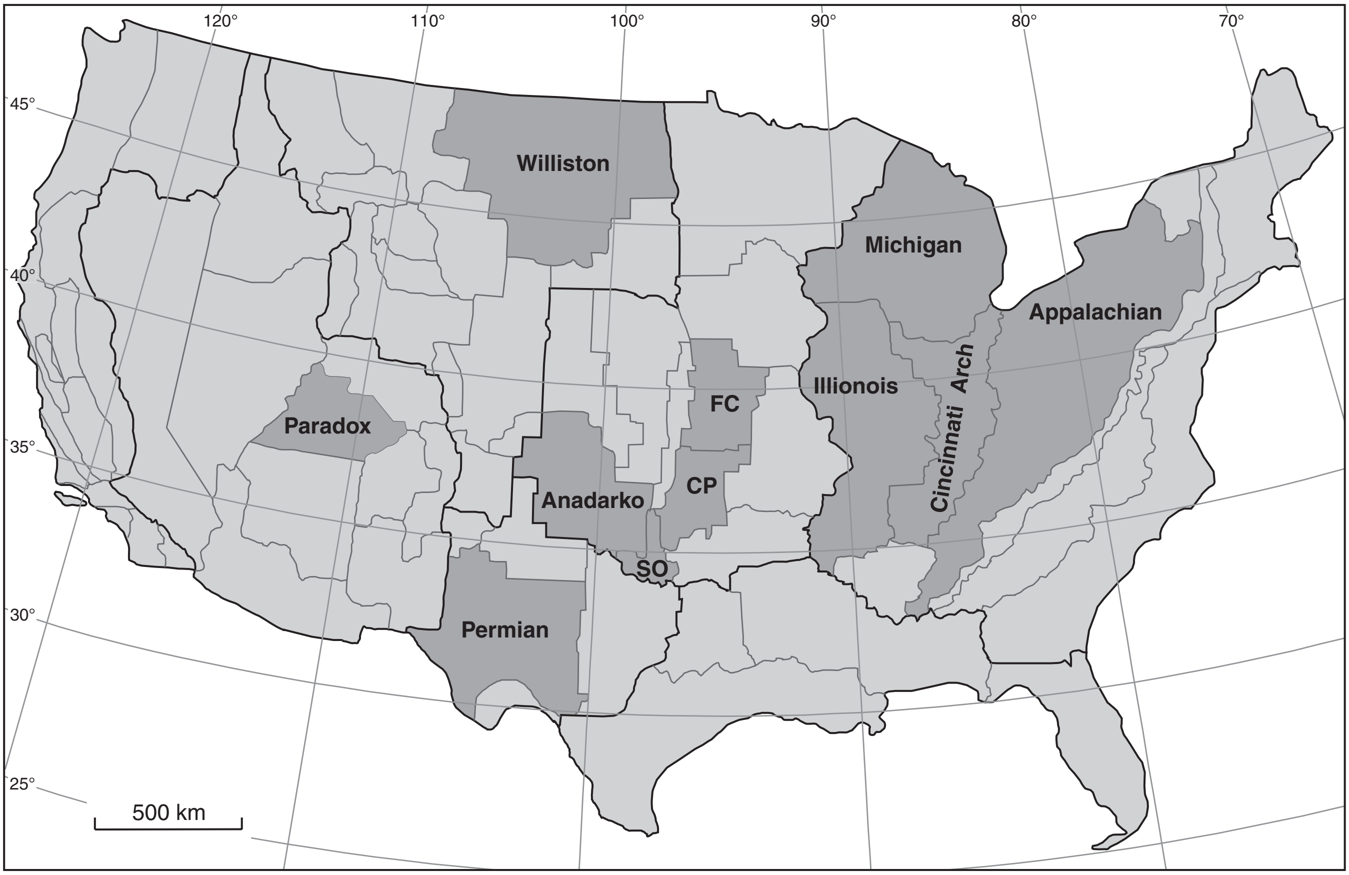

Figure 5. Palaeozoic basins of the United States with giant oil and gas fields. Outlines represent USGS oil and gas assessment units. The Permian Basin includes the Delaware Basin of Figure 6. FC is Forest City Basin, CP is Cherokee Platform, and SO is Southern Oklahoma.

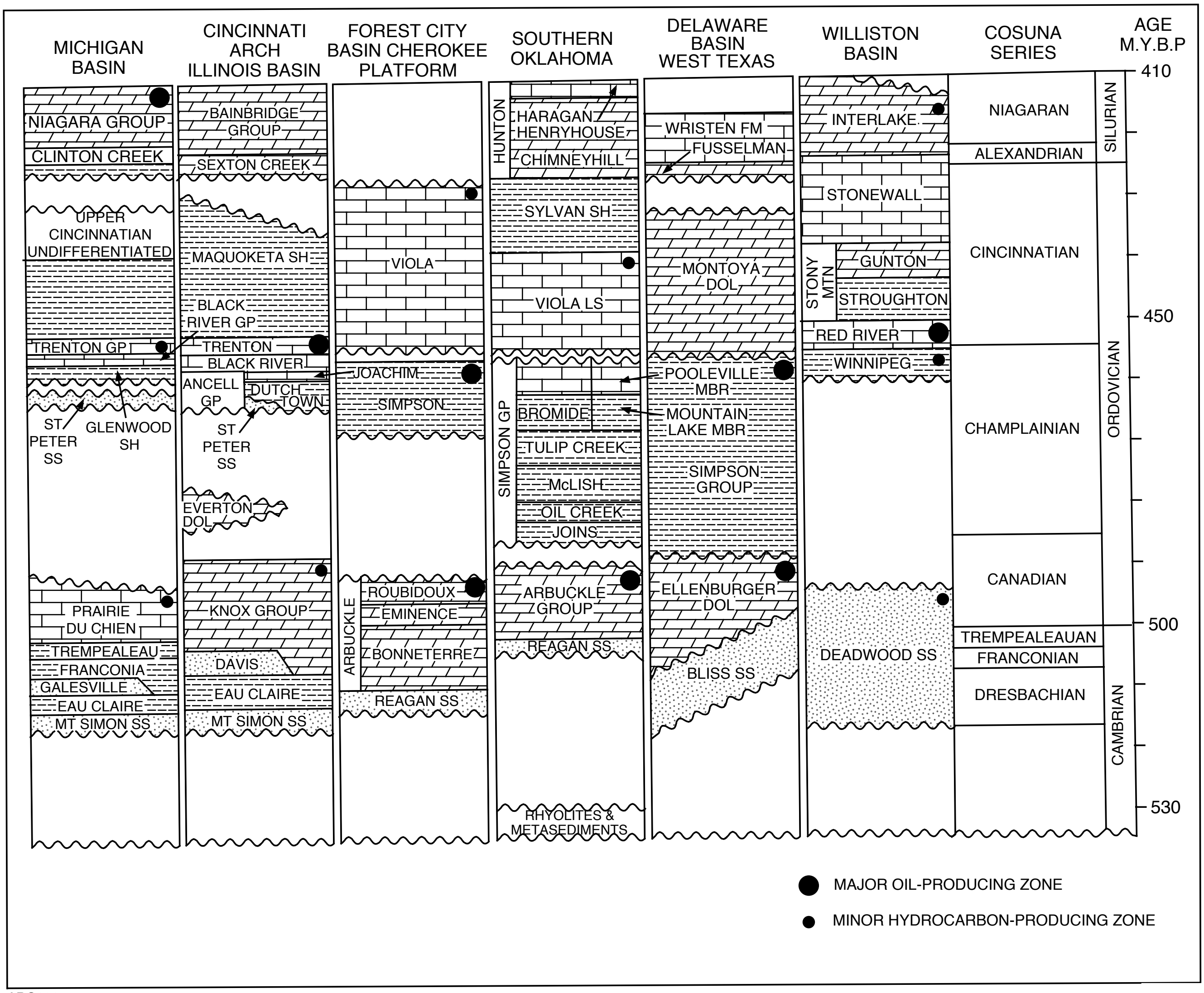

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Figure 6. Ordovician sequences with giant oil and gas fields of the United States mid-continent (modified from Longman and Palmer, 1987).

charge system. Those fields with intra-Palaeozoic seals to the south and east of the Triassic Basin include more than 18% of the total discovered reserves of the Northern Saharan Platform and are mostly in the prolific Illizi Basin. Palaeozoic charged systems with intra-Palaeozoic seals are the least productive. These occur within southwest Algeria and Morocco and account for only 3% of the total discovered reserves of the Northern Saharan Platform. The productivity of the Palaeozoic systems depends on several factors, including charge timing, seal type, and structural modification during the Hercynian Variscan, Austrian Oregonian, and mid-Tertiary uplift tectonic phases.

Most of the prolific Palaeozoic basins of north Africa (Illizi, Ghadâmis and Murzuk) began as Cambrian–Ordovician rifts with overlying sag basins. The late Carboniferous Hercynian Unconformity separates folded Cambrian–Ordovician rocks from relatively undeformed Permian–Triassic clastic sedimentary and volcanic rocks. This unconformity played a very important role in both the accumulation and destruction of oil and gas fields.

North Caspian Basin

Ulmishek (2001) provides petroleum geology of the North Caspian Basin of Kazakhstan and Russia; O'Hearn et al (2003) provides information on the giant Karachaganak Field, which is one of the largest gas-condensate-oil field developments of the 1990s (Mann et al, 2003).

The North Caspian is one of the deepest basins in the world (Fig. 9), containing sedimentary strata more than 20 km thick with about 19.7 billion barrels of oil and natural gas liquids and 157 trillion cubic feet of gas. The thick Permian Kungurian salt, separating the Palaeozoic subsalt oil field reservoirs and younger suprasalt oil field

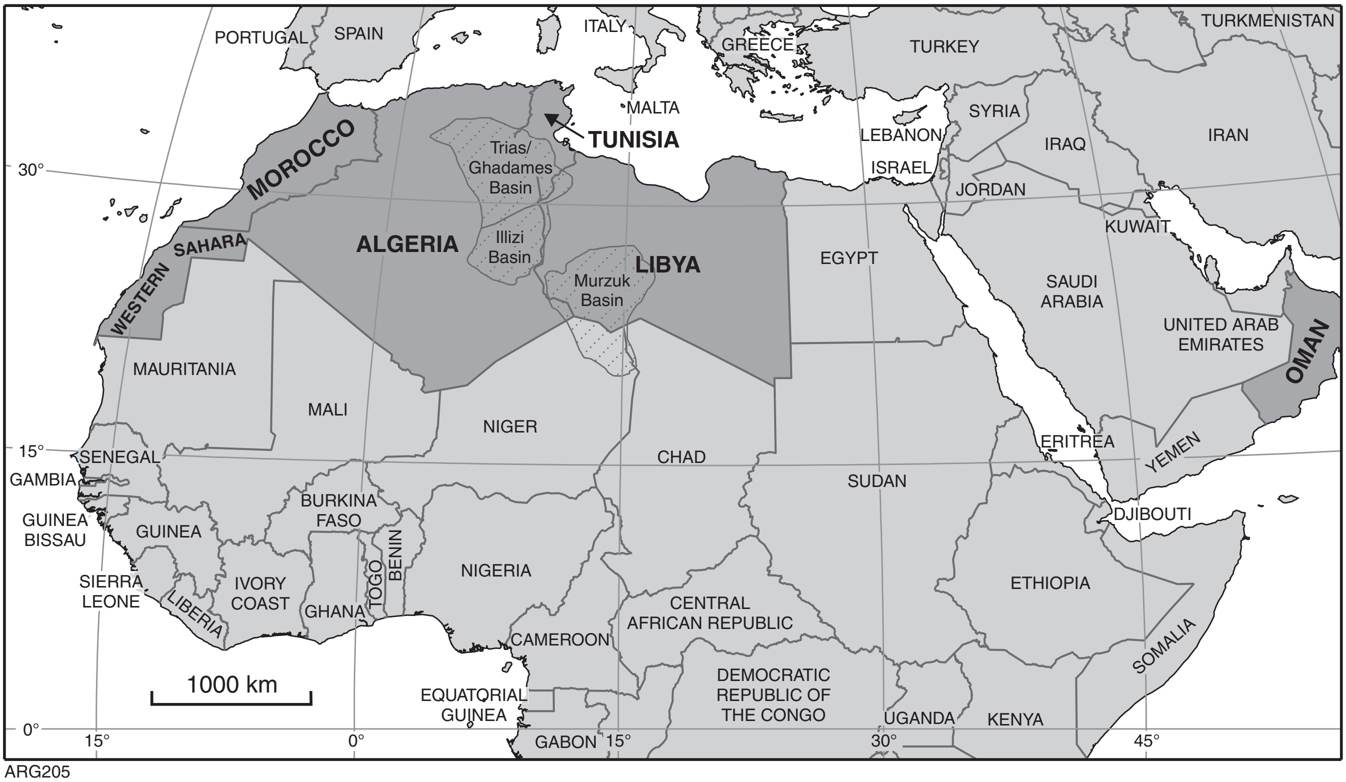

Figure 7. North Africa and Middle East location of prolific Palaeozoic petroleum systems.

reservoirs, played an important role in the formation of the current oil and gas fields.

The major oil and gas fields are within the Palaeozoic subsalt reefs and structural traps whereas numerous smaller oil and gas fields are located within the Mesozoic suprasalt sequence in shallow Jurassic and Cretaceous clastic reservoirs related to salt dome traps.

The source rocks of these oil and gas fields have not been recognised from geochemical analyses but geological interpretation suggests that the principal source rocks are the Upper Devonian to Lower Permian deepwater black-shale facies and an upper Paleozoic source rock. Thick orogenic clastics deposited during the Late Permian–Triassic were the most likely mechanism for source rock maturation. Petroleum migrated laterally into adjacent subsalt reservoirs and vertically into suprasalt clastic reservoirs, through depressions between Kungurian salt domes where the salt is thin or absent. The thick Permian salt basins played an important role in the location of suprasalt fields and the preservation of subsalt fields.

Canning Basin

Information on the Canning Basin is available from numerous published and unpublished reports archived in the Department of Industry and Resources library, Perth. Purcell (1984) edited the first comprehensive symposium on the petroleum geology of the Canning Basin. Bradshaw et al (1994), Kennard et al (1994), Romine et al (1994), and Edwards et al (1997) provide information on petroleum systems; Cadman et al (1993), and Crostella (1998) provide information on petroleum occurrences; and SRK Consulting (1998), and D'Ercole et al (2003) provide information on prospectivity.

The Canning Basin may be the least explored of Palaeozoic basins of the world with proven petroleum systems. Lack of information continues to contribute to the perception of low prospectivity in the Canning Basin.

Three Palaeozoic petroleum systems are recognised within the onshore Canning Basin with source rocks in the Ordovician Goldwyer and Bongabinni Formations, Devonian Gogo Formation, and Early Carboniferous Laurel and Anderson Formations (Fig. 10). Hydrocarbons from these petroleum systems are identified from isotopic and biomarker data (Edwards et al, 1997). They are part of the Australia-wide Larapintine 2 (Ordovician), 3 (Devonian), and 4 (Early Carboniferous) and Larapintine–Gondwanan Transition petroleum supersystems (Bradshaw et al, 1994; Kennard et al, 1994; Romine et al, 1994). The Pictor–1 hydrocarbon accumulation (subsalt) and Blina oil field (suprasalt) are representative of Larapintine 2 and 3 supersystems, respectively. Boundary, Lloyd, Sundown, West Kora, and West Terrace oil fields (suprasalt) are representative of the Larapintine–Gondwanan Transition petroleum supersystem.

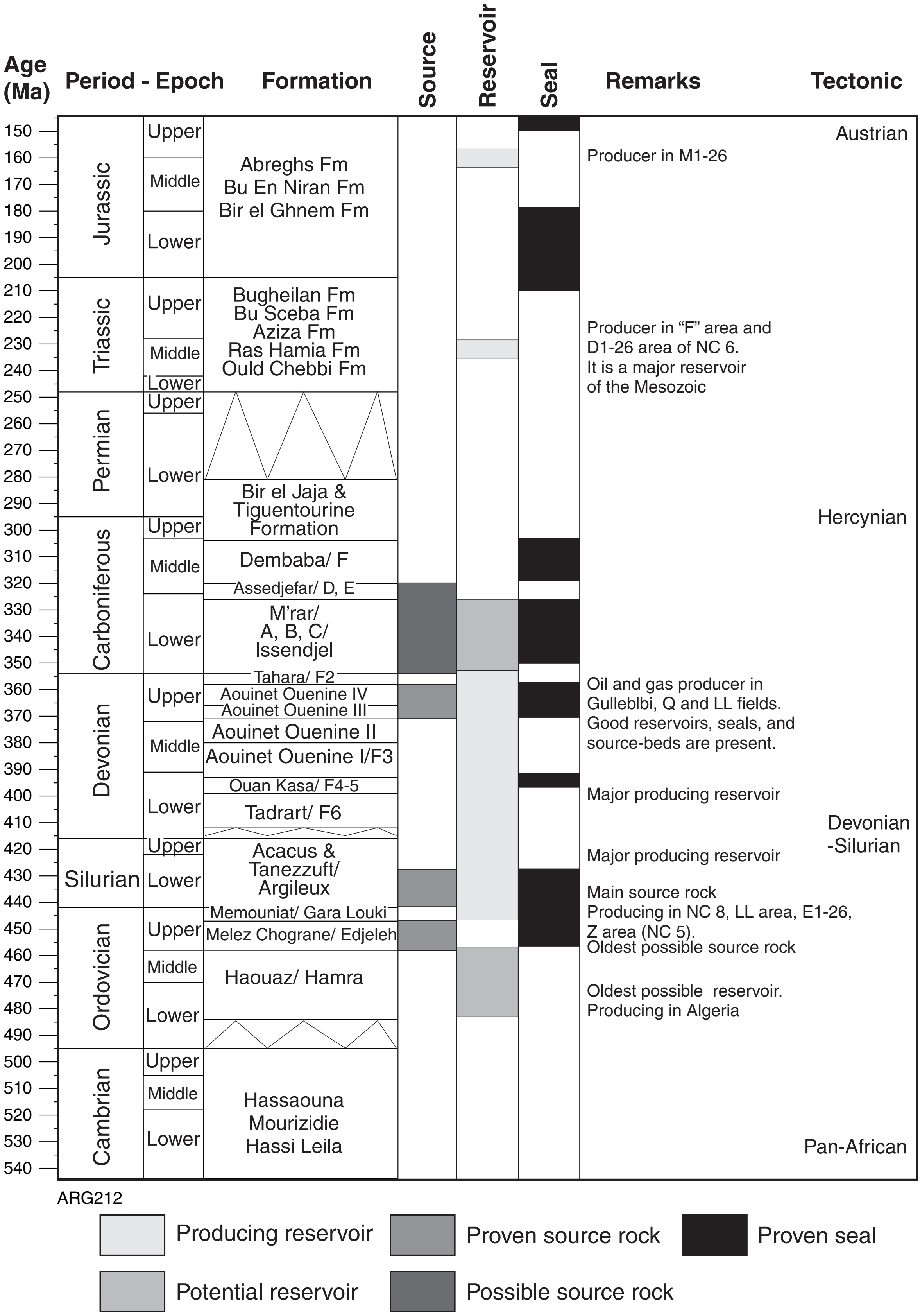

Figure 8. Generalised time-stratigraphy of North African basins with Palaeozoic oil and gas (modified from Ghori and Mohammed, 2000).

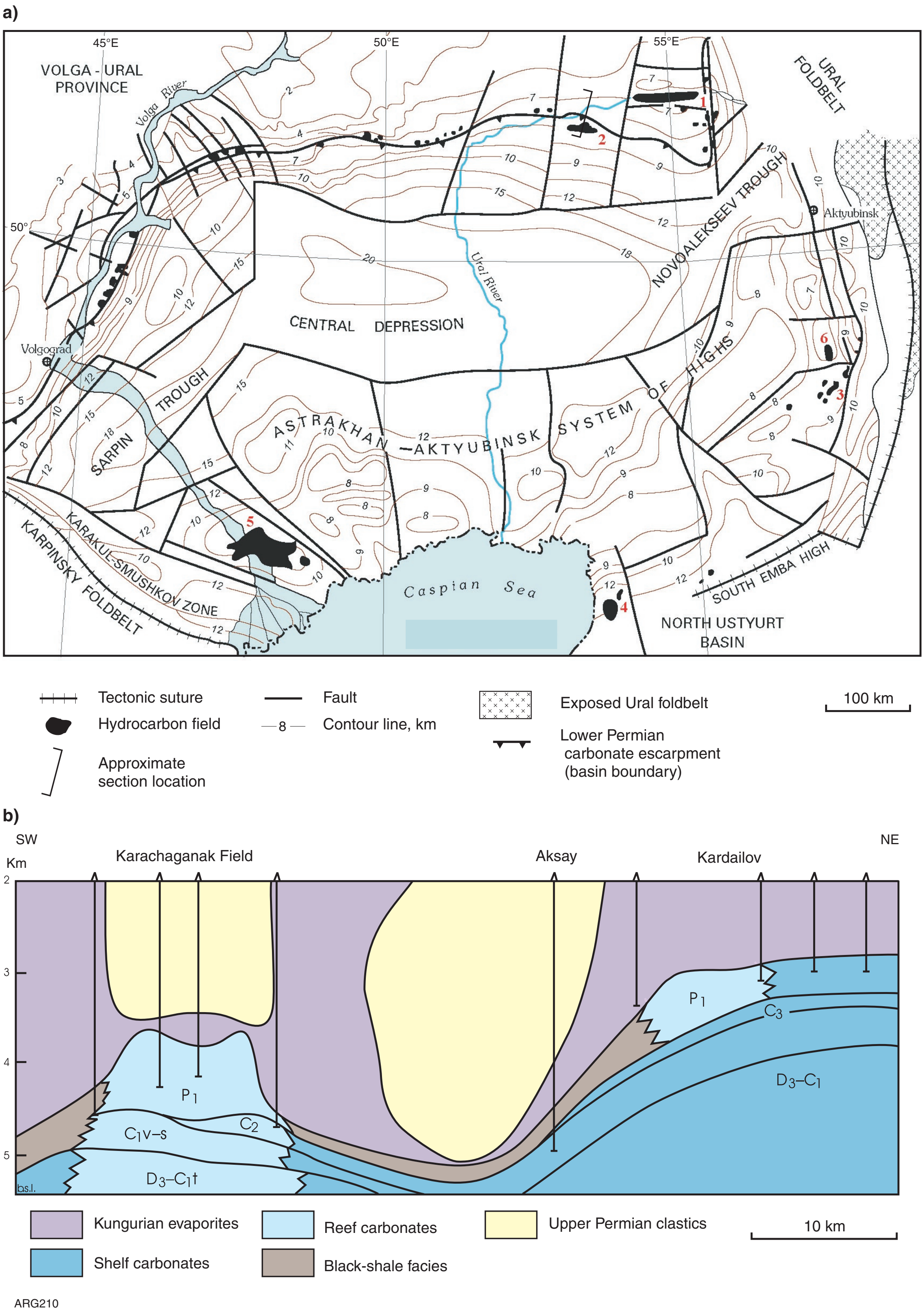

Figure 9. North Caspian Basin: **a.** structural map and petroleum fields; **b.** stratigraphy of giant Karachaganak Field (modified from Ulmishek, 2001).

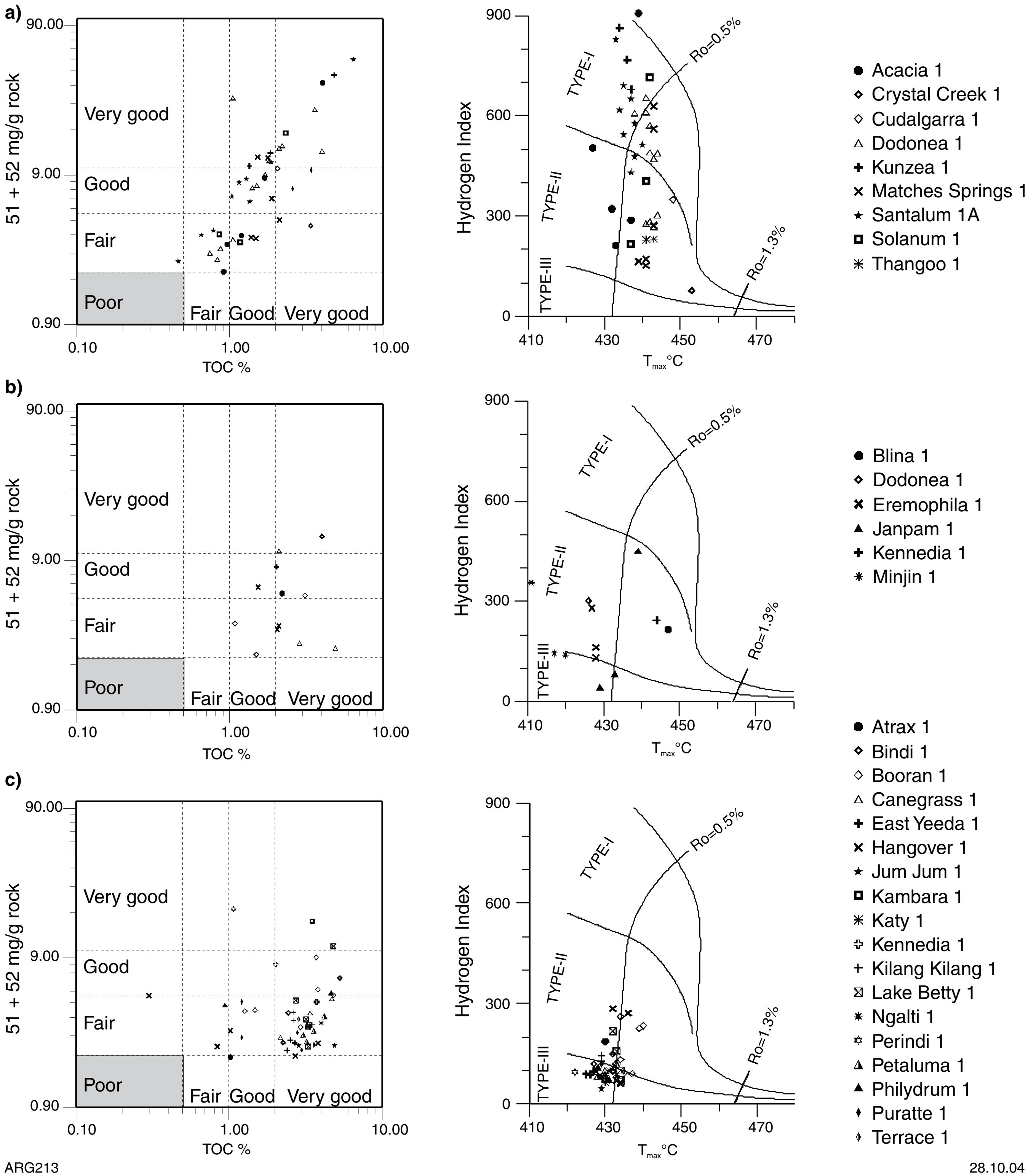

Figure 10. Canning Basin source potential within the: **a.** Ordovician–Silurian; **b.** Devonian–Lower Carboniferous; **c.** Upper Carboniferous—Lower Permian sequences.

The best source rock identified in the Canning Basin Ordovician–Silurian sequence is the Ordovician Goldwyer Formation. The Goldwyer Formation can be equated with global Cambrian–Ordovician source rocks (Foster et al, 1986; Taylor, 1992) and regionally with source rocks of the Mereenie oil field of the Amadeus Basin. Within the Canning Basin, Ordovician sourced oil has been recovered on the Barbwire Terrace (in Dodonea–1, Percival–1 and Solanum–1) on the Dampier Terrace (in Edgar Range–1 and Pictor–1) and along the Admiral Bay Fault Zone in (Cudalgarra–1, Great Sandy–1, and Leo–1). Globally, the Cambrian–Ordovician source rocks have generated only 1% of the original world petroleum reserves although basins such as the Permian Basin of Texas demonstrate capacity to charge giant oil fields.

Intra-salt 'lockbox' plays of the Canning Basin are based on an Ordovician–Silurian petroleum system sourced by the Goldwyer Formation and sealed by the Carribuddy Group (Fig. 11a). The Ordovician–Silurian Carribuddy Group consists of shale, impermeable carbonate, and evaporite facies including shale within the Nibil Formation and Bongabinni Formation (with excellent source and seal potential), and evaporite facies within the Mallowa and Minjoo Salt. The Carribuddy Group can be up to 1,500 m thick, of which around one-third is massive evaporate facies.

Suprasalt plays of the Canning Basin may also be sourced from the Upper Carboniferous Laurel Formation or the Upper Devonian Gogo Formation with the best source rocks equivalent to global black shale source facies of Upper Devonian–Tournaisian with type II kerogen. This global source interval accounts for about 8% of the original world petroleum reserves with 80% of those reserves as oil (Klemme and Ulmishek, 1991). Within the Canning Basin, Upper Devonian sourced oil has been produced from the Upper Devonian Nullara Limestone and the Yellow Drum Formation of the Fairfield Group in the Blina oil field and oil shows have been recorded in Boronia–1, Ellendale–1, and Janpam–1 on the Lennard Shelf.

Lower Carboniferous (Laurel Formation) sourced oil is produced from the Lower Carboniferous Anderson Formation at Lloyd and West Kora fields and from the Lower Permian Grant Group at the Boundary, Sundown and West Terrace fields. These source rocks have also generated the gas accumulation at Point Torment–1 (producing 4.3 MMCFD on test).

No source rocks from the Upper Carboniferous–Lower Permian source (Gondwanan G1 of Bradshaw et al (1994) are recognised in the Canning Basin.

The Upper Devonian Gogo Formation is considered the most likely source rock for the Blina Field, and the Lower Carboniferous Laurel Formation is considered the most likely source rock for the Boundary, Lloyd, Sundown, and West Terrace oil fields (Alexander et al, 1984; Cadman et al, 1993; Edwards et al, 1997; Crostella, 1998). A series of play types with potential Devonian to Carboniferous source rocks is illustrated in Figure 11b.

The trap at the Blina oil field is a Carboniferous faulted anticline. At the Boundary oil field the trap is formed by a Carboniferous–Permian gentle drape closure overlying a Carboniferous flower structure. The trap at the Lloyd oil field is a Carboniferous four-way dip structure while the Sundown and West Kora oil fields are mid-Jurassic fault controlled anticlines with pinch-out or permeability barriers (Crostella, 1998). None of these accumulations are in high preservation petroleum systems.

A high preservation oil system is most likely to exist, within the Canning Basin, beneath the Carribuddy Group Seal. Seals in the Carribuddy Group include mobile salt, thick-bedded salt, kerogenous shale (world class seals), shale, and carbonate.

Reservoirs in the sub-salt play include Nita Formation carbonates and clastics (e.g. Pictor–1 and –2), and the Acacia Sandstone (e.g. Looma–1). Other local reservoir facies have also been noted in previous exploration wells. Most reservoir intersections to date have been of poor to fair porosity and permeability.

The best source rocks for the sub-salt play are the Goldwyer Formation and the Bongabinni Formation (lowest formation in the Carribuddy Group)—both have excellent source rock characteristics in parts. Source rock maturation and timing of charge vary across the basin from immature to overmature and therefore critical moment must be analysed for each prospect individually.

CONCLUSIONS

The productivity of Palaeozoic petroleum systems depends on tectonostratigraphic basin developments that favour deposition of excellent source rock, good reservoir, and world-class seal. Synchronous timing of trap formation with petroleum generation, migration, accumulation and preservation, often over significant geologic time, also play a major role in forming giant fields.

The Ordovician sourced and reservoired giant oil fields of the North American Mid-Continent are a good example of prolific Palaeozoic basins and may be used as analogues for the Canning Basin. Other analogues may exist in the Northern Saharan Platform. The Canning Basin Goldwyer Formation source rocks can be equated with the worldwide Ordovician source rock interval and regionally with the marginally older source rocks of the Mereenie Oil Field of the Amadeus Basin. Within the Canning Basin, Ordovician sourced oil has been recovered on the Barbwire Terrace (in Dodonea–1, Percival–1 and Solanum–1), on the Dampier Terrace (in Edgar Range–1 and Pictor–1 and along the Admiral Bay Fault Zone (in Cudalgarra–1, Great Sandy–1 and Leo–1). This has proved the Ordovician petroleum system for the Canning Basin. The key exploration target here is the intra-salt 'lockbox' play sourced by the Goldwyer Formation and sealed by the Carribuddy Group. Exploration should focus on identifying, mapping, and naming the hydrocarbon fluid systems of the subsalt Canning Basin and then identifying potential large traps. In the past the reverse has been true—large traps were identified and drilled without a full assessment of the potential petroleum system the trap depended on.

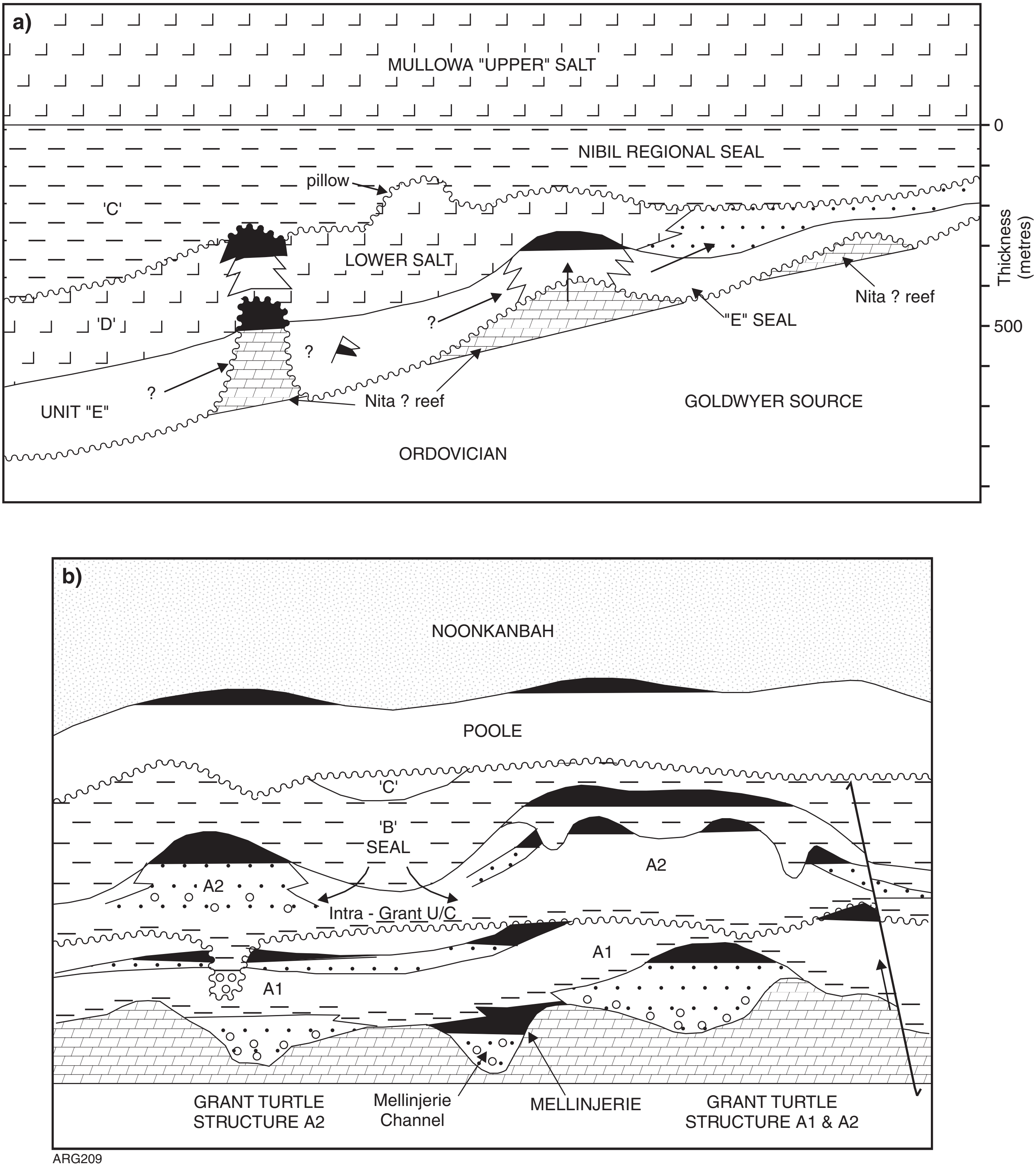

Figure 11. Diagram showing some Canning Basin plays: **a.** subsalt; **b.** suprasalt. Models apply to various areas of the Canning Basin.

The second play type for the Canning Basin is based on the Devonian Gogo Formation as the source rock. Within the Canning Basin, Upper Devonian sourced oil has been produced from the Upper Devonian Nullara Limestone and the Yellow Drum Formation of the Fairfield Group in the Blina oil field and oil shows have been recorded in Boronia–1, Ellendale–1, and Janpam–1 on the Lennard Shelf. Analogues to the Devonian source rocks may be found in the Woodford Shale of the Anadarko Basin and Chattanooga Shale of the Appalachian Basin, which are good examples of source rocks that reached principal maturation stage during the Palaeozoic (Pennsylvanian–Early Permian) and sourced many giant oil and gas fields of the United States (Klemme and Ulmishek, 1991). This is a proved play within the Canning Basin. Exploration should focus on identifying, mapping, and naming the hydrocarbon fluid systems of the Devonian source rocks and then identifying potential large traps. In the past the reverse has been true—reef traps were identified and drilled without a full assessment of the potential petroleum system the trap depended on.

The third play type relies on the Early Carboniferous Laurel and Anderson Formations as the source rock. Lower Carboniferous (Laurel Formation) sourced oil is produced from the Lower Carboniferous Anderson Formation at Lloyd and West Kora fields and from the Lower Permian Grant Group at the Boundary, Sundown and West Terrace fields. These source rocks have also generated the gas accumulation at Point Torment–1 (producing 4.3 MMCFD on test). Analogues for source rocks in this play may be found in the North Caspian Basin. This is a proved play within the Canning Basin. Exploration should focus on identifying, mapping, and naming the hydrocarbon fluid systems of the Carboniferous source rocks and then identifying potential large traps. In the past the reverse has been true—drape traps were identified and drilled without a full assessment of the potential petroleum system the trap depended on.

The Canning Basin may be the least explored of Palaeozoic basins of the world with proven petroleum systems. Lack of information continues to contribute to the perception of low prospectivity in the Canning Basin. The Palaeozoic basins of North America are the most explored with 500-wells/10,000 km^2 and the Canning Basin is least explored with only 4-wells/10,000 km^2.

The presence of five oil fields and numerous oil and gas shows, in the Canning Basin suggests further exploration is required. New oil and gas discoveries are likely to be made in sub-salt plays with good reservoirs, and in supra-salt plays with good preservation potential. Both these plays are most likely to be developed in a deliberate search for the subtle trap.

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REFERENCES

ALEXANDER, R., CUMBERS, M. AND KAGI, R.I., 1984—Geochemistry of some Canning Basin crude oils. In: Purcell P.G. (ed), The Canning Basin, WA. Proceedings, GSA/PESA Symposium, Perth, 1984, 353–8.

BOOTE, D.R.D., CLARK-LOWES, D.D. AND TRAUT, M.W., 1998—Palaeozoic petroleum systems of north Africa. In: Macgregor, D.S., Moody, R.T.J. and Clark-Lowes, D.D. (eds), Petroleum geology of north Africa, GSL, Special Publication 132, 7–68.

BRADSHAW, M.T., BRADSHAW, J., MURRAY, A.P., NEEDHAM, L., SPENCER, L., SUMMONS, R.E., WILMOT, J. AND WINN, S., 1994—Petroleum systems in West Australian basins. In: Purcell, P.G and R.R. (eds). The sedimentary basins of Western Australia. Proceedings, Western Australian Basins Symposium, Perth, Western Australia, 93–118.

CADMAN, S.J., PAIN, L., VUCKOVIC, V. AND LE POIDEVIN, S.R., 1993—Canning Basin, WA. BRS, Canberra, Australian Petroleum Accumulation Report 9, 80.

CROSTELLA, A., 1998—A review of oil occurrences within the Lennard Shelf, Canning Basin, Western Australia. GSWA Report 56, 40.

D'ERCOLE, C., GIBBSON, L. AND GHORI, K.A.R. (compilers), 2003—Prospects and leads, central Canning Basin, Western Australia, GSWA Record 2003/14, 89.

ECHIKH, K., 1998—Geology and hydrocarbon occurrences in the Ghadames Basin, Algeria, Tunisia, Libya. In: Macgregor, D.S., Moody, R.T.J. and Clark-Lowes, D.D. (eds), Petroleum Geology of north Africa, GSL, Special Publication 132, 109–29.

EDWARDS, D.S., SUMMONS, R.E., KENNARD, J.M., NICOLL, R.S., BRADSHAW, J., BRADSHAW, M., FOSTER, C.B., O.BRIEN, G.W. AND ZUMBERGE, J.E., 1997—Geochemical characteristics of Palaeozoic petroleum systems in northwestern Australia. The APPEA Journal, 37 (1), 351–79.

FOSTER, C.B., O'BRIEN, G.W. AND WATSON, S.T., 1986—Hydrocarbon source potential of the Goldwyer Formation, Barbwire Terrace, Canning Basin, Western Australia. The APEA Journal, 26 (1), 142–56.

GHORI, K.A.R. AND MOHAMMED, R.A, 2000—Petroleum system modelling in Ghadâmis Basin of NW Libya. In: Salem, M.J. and Khaled, M. Oun (eds). The geology of northwest Libya, Sedimentary Basins of Libya–Second Symposium, November 6–8, Tripoli, Libya, GSPLAJ, 245–59.

GRADSTEIN, F. M., OGG, J. G., SMITH, A.G., BLEEKER, W. AND LUCAS, L. J., 2004—A new geologic time scale, with special reference to Precambrian and Neogene. Episodes 27 (2), 83–100.

JONES, P. J., NICOLL, R. S., EDWARDS, D. S., KENNARD, J. M. AND GLENN, K. C., 1998—Canning Basin biozonation and stratigraphy, 1998. AGSO, Chart 2.

KENNARD, J.M., JACKSON, M.J., ROMINE, K.K., SHAW, R.D. AND SOUTHGATE, P.N., 1994—Depositional sequences and associated petroleum systems of the Canning Basin, WA. In: Purcell, P.G. and R.R. (eds). The sedimentary basins of Western Australia. Proceedings, Western Australian Basins Symposium, Perth, Western Australia, 657–76.

KLEMME, H.D. AND ULMISHEK, G.F., 1991—Effective petroleum source rocks of the world: stratigraphic distribution and controlling depositional factors. AAPG Bulletin, 1,809–51.

KLETT, T.R., 2000a—Total petroleum systems of the Illizi Province, Algeria and Libya—Tanezzuft-Illizi. USGS Bulletin 2202-A, 79.

KLETT, T.R., 2000b—Total petroleum systems of the Grand Erg/Ahnet Province, Algeria and Morocco—The Tanezzuft-Timimoun, Tanezzuft-Ahnet, Tanezzuft-Sbaa, Tanezzuft-Mouydir, Tanezzuft-Benoud and Tanezzuft-Béchar/Abadla. USGS Bulletin 2202-B, 144.

KLETT, T.R., 2000c—Total petroleum systems of the Trias/Ghadames Province, Algeria, Tunisia, and Libya—The Tanezzuft-Oued Mya, Tanezzuft-Melrhir, and Tanezzuft-Ghadames. USGS Bulletin 2202-C, 118.

LONGMAN, M.W. AND PALMER, S.E., 1987—Organic geochemistry of mid-continent Middle and Late Ordovician oils. AAPG Bulletin, 938–50.

LÜNING, S., CRAIG, J., LOYDELL, D.K., STORCH, P. AND FITCHES, B., 2000—Lower Silurian 'hot shales' in north Africa and Arabia: regional distribution and depositional model. Elsevier, Earth-Science Reviews 49, 121–200.

MANN, P., GAHAGAN, L. AND GORDON, B.M., 2003—Karachaganak Field, Northern Pre-Caspian Basin, Northwestern Kazakhstan. In: Halbouty, M.T. (ed), Giant oil and gas fields of the decade 1990–1999. AAPG Memoir 78, 15–105.

MACGREGOR, D.S., 1996—Factors controlling the destruction or preservation of giant light oilfields. Petroleum Geoscience, Vol.2, 197–217.

MACGREGOR, D.S., 1998—Introduction. In Macgregor, D.S., Moody, R.T.J. and Clark-Lowes, D.D. (eds), Petroleum geology of north Africa. GSL, Special Publication 132, 1–6.

NICOLL, R. S., 1984, Conodont studies in the Canning Basin—a review and update. In: Purcell P.G. (ed), The Canning Basin, WA. Proceedings, GSA/PESA Canning Basin Symposium, Perth, 1984, 179–86.

NICOLL, R. S., 1993—Ordovician conodont distribution in selected petroleum exploration wells, Canning Basin, Western Australia. AGSO Record 1993/17, 136.

NICOLL, R. S., LAURIE, J. R. and ROCHE, M. T., 1993—Revised stratigraphy of the Ordovician (Late Tremadoc–Arenig) Prices Creek Group and Devonian Poulton Formation, Lennard Shelf, Canning Basin, Western Australia. AGSO Journal of Australian Geology and Geophysics, v. 14, 65–76.

O'HEARN, T., ELLIOTT, S. AND SAMSONOV, A., 2003—Karachaganak Field, Northern Pre-Caspian Basin, Northwestern Kazakhstan. In: Halbouty, M.T. (ed), Giant oil and gas fields of the Decade 1990–1999. AAPG Memoir 78, 237–50.

POLLASTRO, R.M., 1999—Ghaba Salt Basin Province and Fahud Salt Basin Province, Oman—Geological overview and total petroleum systems. USGS Bulletin 2167, 41.

PURCELL, P.G. (ed), 1984—The Canning Basin, WA. Proceedings, GSA/PESA Canning Basin Symposium, Perth, 1984, 582.

ROMINE, K.K., SOUTHGATE, P.N., KENNARD, J.M. AND JACKSON, M.J., 1994—The Ordovician to Silurian Phase of the Canning Basin, WA: Structure and sequence evolution. In: Purcell, P.G and R.R. (eds). The sedimentary basins of Western Australia. Proceedings, Western Australian Basins Symposium, Perth, Western Australia, 677–96.

SRK CONSULTING, 1998—Canning Basin Project. GSWA, Statutory petroleum exploration report, S-6353 R1 A5 unpublished.

TAYLOR, D., 1992—A review of Ordovician source rocks, Canning Basin, Western Australia. BMR Record 1992/43, 148.

TYLER, I.M. AND HOCKING, R.M., 2002—A revision of the tectonic units of Western Australia. GSWA, Annual Review 2000–01, 33–44.

ULMISHEK, G.F., 2001—Petroleum geology and resources of the north Caspian Basin, Kazakhstan and Russia. USGS Bulletin 2201-B, 25.

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