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The Dandaragan Trough, northern Perth Basin. New thinking in a mature basin delivers multi-Tcf gas discoveries, new play opportunities, a prolific geothermal fairway and promising CCS opportunities.

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Summary

Multiple large gas discoveries have recently been made in the deep, axial part of the northern Perth Basin, Western Australia. These are primarily hosted in Early Permian sandstones of the Kingia Formation but also include discoveries in the basal Triassic/Late Permian sandstones of the Dongara/Wagina Formations and Jurassic Cattamarra Coal Measures. Gas is hosted in linked, reactivated fault blocks. The Kingia Formation contains thick, excellent quality reservoir in a regionally continuous, sandstone penetrated at depths between 2,800-5,000m. Despite deep burial, porosity was retained by syndepositional clay coatings and early burial gas-charge. Well tests have achieved rates over 100 MMscfd. Excellent reservoir quality is also encountered in water-wet Kingia sandstones off-structure. Coupled with high temperatures of 160-180^{o}C this opens up the possibility of coupled gas/geothermal development. Shallower Jurassic reservoirs have excellent potential for CCS storage in the same area as well as the possibility for regional basin-centered gas accumulations.

Geological Background

The onshore northern Perth Basin is an approximately N-S oriented, narrow, elongate (250 x 90 km) basin with maximum sedimentary thickness estimated at > 12 km. It is underlain by Precambrian basement rocks and originally formed in the early Silurian along the suture between the Australian, Antarctic and Indian tectonic plates. The onshore part of the Basin is characterized by series of N-S trending troughs located between structurally elevated horst blocks. Fault terraces cascade from the elevated horst blocks into the deep axial parts of the Basin. The deepest part of the basin, the Dandaragan Trough comprises several deep grabens separated by reactivated basin axial fault terraces. The complex tectonic history of the basin involves multiple phases of early extension with intervening periods of uplift, followed by reactivation, strike-slip movement and erosion. Sedimentation occurred from the Silurian to the Pleistocene, with

sedimentation rates and depositional environments closely linked to tectonic events and isostatic.response.

Exploration History

Early commercial discoveries in the Basin were largely hosted in basal Triassic to late Permian sandstones and limestones in structural closures within elevated fault terraces along the west margin of the Dandaragan Trough. Beyond a few stratigraphic tests drilled in the 1960s-1970s, the Permian stratigraphy of the deepest parts of the basin remained untested. Wells in the Dandaragan Trough focused on shallower Jurassic sandstones. As more well data was obtained, a paradigm developed that the floor for preservation of effective conventional porosity in the basin was around 2,800m. More recent drilling in the 1990s and early 2000s demonstrated the potential for tight gas accumulations in the basal Triassic to late Permian section as well as small hydrocarbons accumulations in the lower Permian section. In 2014, the deepening of a well into the lower Permian section led to the serendipitous discovery of the Waitsia field. The presence of clay-coated sandstones with conventional porosities at relatively great depths in the lower Permian Kingia member and High Cliff Formations upset the earlier paradigm regarding a porosity floor. Follow-up exploration from 2019 to the present has tested deeper (up to 5km) structures within the Dandaragan Trough and resulted in the discovery of several large (100's Bcf to >1 Tcf) gas accumulations in the lower Permian with extremely prolific flow rates (exceeding 50-100 Mmscfd).

Kingia Formation – Evolving Conventional Gas and Geothermal Fairway Potential

Regional correlations indicate that thick (>50m), sheet-like porous and permeable upper shoreface to marginal marine sheet sands are present within the informally named Kingia member in all deep wells in the northern Perth Basin. These sandstones were deposited as a sheet-like unit in estuarine to shallow marine environments during a period of relatively rapid sea-level fall. This sheet of sandstones is seen to thicken into the northern part of the Dandaragan Trough where the recent discoveries are located. This wedge of sand then appears to taper to the south and west into the deepest parts of the Dandaragan Trough. Syndepositional clay coatings on quartz grains in this interval have been converted to chlorite and illite-smectite. These coatings preclude quartz cementation and preserve porosity to great depths. Early bitumen coatings on sand grains may also suggest early hydrocarbon charge played a role in preserving porosity.in some areas. Seismic data indicates the presence of numerous additional closures within the Dandaragan Trough that could contain additional large hydrocarbon accumulations at depths ranging from 3-6km. These will be the target of systematic exploration over the next few years.

In a few wells where water-wet Kingia has been penetrated, clay-coated sandstones with conventional grade porosity identical to those in the gas reservoirs are present. A well test of one zone with mixed water and gas resulted in production of approximately 35 MMscfd and 2,000 bwpd from just 10m of water-wet sandstones. Coupled with extremely high temperatures of 160-180^{o}C, this opens up the possibility of exploitation of the Kingia for its geothermal resource

potential as well as its hydrocarbon potential. If commerciality is confirmed by appraisal, this geothermal resource could contribute to decarbonizing industrial operations in the region, as well as providing reliable, on-demand power.

Early Permian under-explored Tight Gas and Shale Gas Potential

Overpressured, gas-charged shales of the Carynginia Formation overlie the Kingia member and are ubiquitously present across the Dandaragan Trough. Prolific gas flows from sand stringers within these shales during drilling suggest the potential for a regional shale gas development. Production from these shales following stimulation has already been demonstrated in one trial area. Very thick (>150m) Basal Triassic to late Permian sandstones immediately overlying these shales are also ubiquitously present and ubiquitously gas-charged in the Dandaragan Trough. These sandstones exhibit heterogeneous reservoir development but have flowed gas at rates up to 35 MMscfd during unstimulated well tests.

Jurassic Cattamarra Coal Measures under-explored BCG and CCS Potential

Tight Jurassic sandstones in other parts of the Deep basin contain diagnostic characteristics of a regional basin-centered gas accumulation (BCGA): The vertical extent of gross gas-charged sandstones penetrated in Jurassic structures can be hundreds of meters in vertical extent and greatly exceeds mapped structural closures. These thick gross gas columns underlie 100s of meters of water-wet sands, lack a distinct top seal and top of gas does not occur in exactly the same stratigraphic level in each well or in each accumulation. Pressure gradients are unusual. Gas sands appear near normally pressured, or even underpressured at the top of the gross gas column, but pressure in the gross gas column increases at a rate much higher than normal – the sands in the lowest parts of the thick gross gas column are overpressured. There are sealing beds distributed vertically throughout the reservoir complex, which is consistent a gross gas column comprising of multiple stacked pay sands in a BCGA rather than forming one continuous gas column. Charge into these fields is from rock sequences that have experienced a hotter thermal history than currently observed; peak gas generation and reservoir charging was accomplished during an earlier, hotter temperature event.

These vertically extensive stacked reservoir seals pairs in the Jurassic are also regionally present across the basin. This opens up the possibility for carbon capture and storage (CCS) in shallower parts of the Basin where structures are in compressive tectonic settings. This is currently being evaluated.

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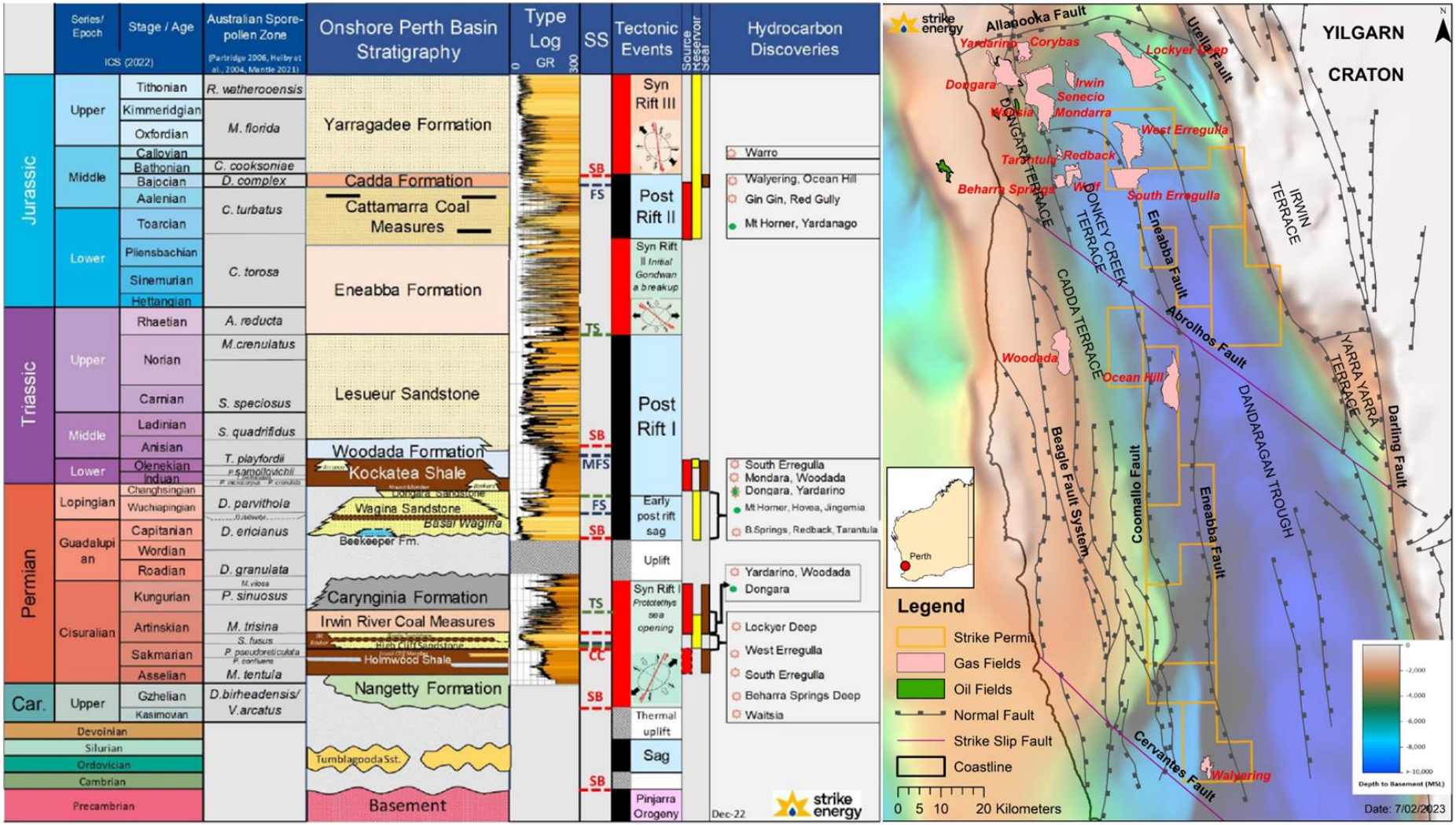

Onshore northern Perth Basin:
Stratigraphic column, Tectonic events, hydrocarbon habitat and key Structural Elements