GEOLOGY AND RESOURCE POTENTIAL OF THE SOUTHERN GEORGINA BASIN EXTENDED ABSTRACT

JN Dunster, PD Kruse, ML Duffett and GJ Ambrose

This multidisciplinary study of the southern Georgina Basin draws together lithostratigraphic revision, geophysical and structural interpretation, petroleum studies, studies of thermal maturity and Pb isotopes, mineral prospect descriptions, new assays of prospective horizons and surface geochemistry. Targets for a range of commodities are mapped.

The Georgina Basin is a 330 000 km^2 erosional remnant of a series of originally interconnected central Australian intracratonic basins that range from Neoproterozoic to Palaeozoic. In excess of 1.5 km of Neoproterozoic sedimentary rocks are preserved in downfaulted blocks and half-grabens on the southern margin of the Georgina Basin in the NT. Depocentres and synclines contain up to 2.2 km of Cambrian to Devonian section. Previous estimates of as much as 9 km total thickness, based on magnetic depth modelling, did not recognise low-magnetic intensity granites and hence have overestimated the thickness of the sedimentary basin. Seismic basement south of 21˚S can be divided into western Dulcie and eastern Altjawarra Domains. The former is dominated by folded and faulted Palaeoproterozoic felsic gneiss, intruded by syn- to post-tectonic granitoids. The Altjawarra Domain is relatively undeformed and consists of late Palaeoproterozoic (and possibly older) mafic-intermediate intrusive bodies and younger non-magnetic granitoids. SHRIMP U-Pb zircon ages of basement rocks range from 1846 ± 6 Ma to 1749 ± 8 Ma.

The southern Georgina Basin (south of 21˚S) in the NT (primarily ALCOOTA[1], BARROW CREEK, ELKEDRA, HAY RIVER, HUCKITTA, SANDOVER RIVER and TOBERMORY) is a semi-desert area prospective for a range of commodities including petroleum, base metals, diamonds, manganese, phosphate and turquoise. Lithostratigraphy has been revised based on second edition mapping, relogging of drillcore, stratigraphic drilling and correlations of petrophysical logs. Nomenclature has been simplified and new group names established. SRK Consultancy and NTGS undertook geophysical interpretations of basin thickness, basement composition and fault kinematics incorporating NTGS aeromagnetics, limited company seismic data, additional ground gravity and a database of 500 density and magnetic susceptibility measurements of core. All existing petroleum data have been collated and new thermal maturity and source rock studies undertaken. Existing surface geochemistry and known base metal prospects and occurrences have been documented and are complemented by new multi-element geochemical and isotopic data. Spatial data, covering the 78 000 km^2 study area, have been compiled into a MapInfo GIS. An NTGS Report, incorporating all this new work, will be released later in 2003.

BASIN HISTORY

The Georgina Basin is a polyphase basin. Its complex evolutionary history began during the Neoproterozoic breakup of the Rodinia supercontinent when a northwest-trending transcontinental rift system developed. Sag sedimentation extended over surrounding, competent, Archaean-Palaeoproterozoic cratonic nuclei and deposition occurred in several interconnected basins that collectively constituted the Centralian Superbasin. In the southern Georgina Basin, siliciclastic rocks were deposited in small grabens and half-grabens and on rift shoulders. The Neoproterozoic (early Cryogenian) Plenty Group is dominated by fluvial siliciclastic rocks (lower Yackah beds and Amesbury Quartzite), but also includes intertidal to shallow marine stromatolitic carbonate and an emergent, hypersaline, lacustrine to anoxic deep marine succession (upper Yackah beds). Collectively, these units are up to 350 m thick. The succeeding Aroota Group contains late Cryogenian glacigene units; these include the Yardida Tillite (in excess of 650 m thick) and several hundred metres of diamictite of the Mount Cornish Formation. These are probable correlatives of Sturtian glacial deposits in the Adelaide Rift.

Uplift associated with the Rinkabeena Movement preceded deposition of the Keepera Group. This group contains basal glacial outwash (Sun Hill, Black Stump and Oorabra Arkoses, which individually range up to 800 m thick) and glacial till (Boko Formation, Little Burke Tillite) that are tentatively correlated with Marinoan glacial units in the Adelaide Rift. These are overlain by, and are probably partly laterally equivalent to the 450 m-thick intertidal to deeper marine Wonnadinna Dolostone. Post-glacial Mopunga Group sediments deposited following the Toomba Movement include the Elkera Formation and the marine siliciclastic Gnallan-a-Gea Arkose, Elyuah Formation and Grant Bluff Formation. The terminal Neoproterozoic Central Mount Stuart Formation is a partial lateral equivalent of the Elkera Formation and consists of 800 m of basal polymictic conglomerate and succeeding sandstone, siltstone and minor dolostone. The Central Mount Stuart Formation was deposited at a time of mild tectonism, broadly coincident with the beginning of the Petermann Orogeny. Sediments were shed into southeast-trending fault troughs. The overlying Andagera Formation contains high-energy fluvial and possibly shallow marine sandstone and conglomerate.

By about 550 Ma, a major dextral strike-slip zone developed between the northern and southern blocks in central Australia. This tectonism, of which the Petermann Orogeny and Huckitta Movement were part, uplifted what is now the Musgrave Province and inverted the deepest parts of the Centralian Superbasin. In the southern Georgina Basin, up to 360 m of Early Cambrian sediments (lower Shadow Group) were deposited in a distal foreland–sag basin. After the Petermann

[1] Names of 1:250 000 and 1:100 000 map sheets are shown in large and small capitals respectively, eg ELKEDRA, AMMAROO.

Orogeny strike-slip faults locked, more stable conditions led to deposition of the Red Heart Dolostone (upper Shadow Group) on a carbonate platform. This unit is typically <20 m thick but ranges up to 92 m.

After a brief hiatus and erosion, carbonate platform deposition resumed in the early Middle Cambrian (Narpa and Cockroach Groups). The Thorntonia Limestone was deposited on a carbonate platform that extended over most of the basin. It is typically <100 m thick in the southern basin, but is known to be considerably thicker elsewhere. Localised shale interbeds in the southern basin may represent minor relative subsidence. More-widespread subsidence resulted in starved, low-energy marine anoxic shale in the lower Arthur Creek Formation. Carbonate deposition then resumed for the remainder of the Arthur Creek Formation and most of the Arrinthrunga Formation. Deposition of the Steamboat Sandstone and Eurowie Sandstone Member and a hiatus between the Arrinthrunga and Tomahawk Formations reflect localised relative uplift corresponding to the Cambro-Ordovician Delamerian Orogeny that deformed and metamorphosed areas to the east and southeast. The Narpa and Cockroach Groups comprise several laterally-equivalent formations, reflecting contrasting deposition across the southern basin.

The Ordovician Larapinta Event exposed a basement core complex south of the Georgina Basin and opened a rift basin that transected the Australian part of Gondwana. The Larapinta Seaway formed in this rift. Sedimentation in the southern Georgina Basin was dominated by Early and Middle Ordovician marine siliciclastic rocks (Toko Group). Synsedimentary normal faulting occurred in what are now the Toko and Dulcie Synclines, but north of these, the overall environment was probably a siliciclastic platform.

Ordovician extension was terminated at 450 Ma by the onset of convergent subduction at Australia's eastern margin. During the Alice Springs Orogeny, which spans the Late Ordovician to Late Carboniferous, basement was thrust over Neoproterozoic-Ordovician rocks to form the present southern margin of the Georgina Basin. Most north- and northwest-trending structures within the basin were reactivated in a reverse sense. Devonian synorogenic sedimentation occurred in a siliciclastic foreland with deposition of the Dulcie Sandstone and Cravens Peak beds. The total thickness of sediment deposited at this time is not known due to subsequent erosion, but in excess of 650 m is preserved.

The Georgina Basin is overlain in the northwest by Cretaceous sandstone of the Dunmarra Basin. Eastern and southeastern margins are obscured by Jurassic-Cretaceous sedimentary rocks of the Eromanga Basin. Minor Cenozoic fault activity and localised subsidence accompanied deposition in the overlying Ti Tree and Waite Basins. Other Cenozoic formations include the Poodyea Formation and Austral Downs and Brunette Downs Limestones.

Alginite reflectivity, Tmax and PI data, indices of aromatic maturity based on methylphenanthrene (MPI) and other measures of thermal maturity, indicate several palaeothermal anomalies in the southern Georgina Basin. These are not simply related to 'hot' granites, as supposed by some previous workers, but probably result from a combination of causes including lateral migration of hot fluids under a lower Arthur Creek Formation shale blanket. Limited conventional fluid inclusion studies show areas of highest uncorrected fluid temperature at Boat Hill (av 190˚C) and in the central basin (NTGS01/1; av 211˚C). Inclusions in sphalerite from the southernmost basin average 117˚C and testify to the fluid temperatures responsible for this mineralisation. Barite, intimately associated with galena at Box Hole, has an average fluid inclusion temperature of 90˚C. Temperatures of 495-520˚C, as previously reported in the literature, could not be corroborated. Timing has been constrained by apatite fission track studies that indicate cooling from major heating events during the Alice Springs Orogeny with possible overprints (locally up to 105˚C) in the Late Triassic–Early Jurassic, mid-Cretaceous and Cenozoic. Four petroleum wells have present geothermal gradients >35˚C/km, which are significantly above world average.

PETROLEUM

The southern Georgina Basin is prospective for oil and gas, but exploration is still at the frontier stage, with little seismic data available. The first significant hydrocarbon show was a gas explosion in a waterbore in 1956 and a dry gas flow in Ethabuka 1 in Queensland remains the most significant show of any kind in the basin to date. Numerous and widespread oil and bitumen shows have been reported from the Red Heart Dolostone, Thorntonia Limestone, Arthur Creek Formation, Chabalowe Formation and Arrinthrunga Formation in the NT portion of the southern Georgina Basin. Potential source rocks occur in the Thorntonia Limestone [maximum 8.6%, average 1.46% total organic carbon (TOC)] and Arthur Creek Formation. In particular, TOCs of selected samples of pyritic carbonaceous shale in the lower Arthur Creek Formation are in the range 0.11-14.2% and average 3.3%). Thin shales in the Arrinthrunga Formation and Hagen Member of the Chabalowe Formation are also viable source rocks, averaging over 1% TOC. Hydrocarbon yields in the Thorntonia Limestone and Arthur Creek Formation range up to 50.7 kg/t and 35.8 kg/t, respectively. Biomarker geochemistry indicates that each formation has generated genetically distinct oil. An uncorroborated Russian study calculated that, overall, $40x10^9$ tonnes of oil have migrated (not generated) in the southern Georgina Basin. Middle Cambrian source rocks grade from immature in the north to overmature near the present southern margin of the basin. In addition, gas-prone to overmature rocks occur in a northwest-trending zone from the basin margin to the vicinity of the gas show in Discovery Bore (ELKEDRA). Some of the best visible porosity in the southern Georgina Basin occurs in fractured and vuggy dolostone. Potential reservoir exists in the Red Heart Dolostone (Hacking 1), medial and upper Thorntonia Limestone (Owen 2, Ross 1), upper Arthur Creek Formation (MacIntyre 1) and Hagen Member of the Chabalowe Formation (Randall 1). Intraformational rocks with >1000 psi capillary pressure for 10% Hg saturation and, locally, anhydrite provide seals.

Surface hydrocarbon surveys using both direct and indirect experimental methods have previously been conducted over 1340 km^2 and the results are reviewed. Structural leads have been mapped from existing seismic lines. Conceptual structural targets invoke: proximity to early-mature troughs; the presence of structures associated with Ordovician faults; a lack of deformation during later phases of the Alice Springs Orogeny; and suitable reservoir-seal combinations at drillable depths. This highlights an area of Red Heart Dolostone ideally situated to be charged from the Dulcie and Marqua Troughs. The Thorntonia Limestone and Arthur Creek Formation contain potential reservoirs in a structurally favourable setting overlying the basement Altjawarra Domain. Conceptual stratigraphic traps include an updip pinchout of the Red Heart Dolostone in HUCKITTA and the wedging out of the Thorntonia Limestone on the southern basin margin. Siliciclastic wedges, developed downflank of palaeohighs, may enhance the reservoir potential of the Mount Baldwin Formation and its equivalents in the same area.

BASE METALS

Known base metal prospects and occurrences have been documented and additional studies undertaken. All available mineralised intercepts have been reassayed using a standardised technique. The best Cu occurrences are in Neoproterozoic siliciclastic rocks. Known Pb-Zn prospects and occurrences are widespread and throughout the succession from Neoproterozoic siliciclastic rocks to Lower Ordovician carbonate and mixed carbonate-siliciclastic rocks. There is a wide range of mineralisation styles. At the Box Hole Mine, galena and barite occur along 6.5 km of strike in the Late Cambrian Arrinthrunga Formation. About 15 t of ore, averaging 65-70% Pb and 60 g/t Ag, has been handpicked. Mineralisation is stratabound epigenetic replacement and vug-fill in a stromatolitic dolostone, possibly localised by proximity to a feeder fault. Similar surface galena and minor pyrite occur at the Trackrider Prospect. Host rocks are vuggy siliceous and manganiferous dolostone of the Late Cambrian Arrinthrunga Formation, just below the contact with the overlying Tomahawk Formation. Mineralisation at both Box Hole and Trackrider is similar to Mississippi Valley-type (MVT) orebodies. Visible Zn-Pb mineralisation (up to 1.2% Zn) occurs in association with hydrocarbons in and just below a shale cap at the contact of the Arthur Creek Formation and Thorntonia Limestone in Baldwin 1 and may have affinities to Century-type, stratiform, shale-hosted base metal mineralisation. A fault breccia at the Boat Hill Prospect contains two intervals with percent levels of Zn. NTGS drilling also intersected percent levels of Zn and visible galena in the Thorntonia Limestone in this area, which considerably extends the area of known mineralisation. Previously undocumented visible galena has also been recognised in the Neoproterozoic Elyuah Formation at the Mount Skinner Prospect in ALCOOTA. This core contains 2.44 m assayed at 0.3 m intervals, all of which are >2000 ppm Pb.

Lead isotope data have been acquired for galena in host rocks ranging from Neoproterozoic to Late Cambrian–Early Ordovician. These, together with previously published data from Queensland, show a close correlation to a single isochron indicating a single mineralising event with an initial ratio close to crustal Pb (no mixing). This is interpreted as a 1840-1780 Ma Pb source and a 420-280 Ma mineralisation age, corresponding to the Alice Springs Orogeny.

Bureau of Mineral Resources (BMR, now Geoscience Australia) and exploration company surface geochemical data have been compiled into an Explorer 3 database. These data are log normalised and are presented as colour-contour maps. However scavenging by the regolith complicates their interpretation. Contouring of rock chip Pb highlights Box Hole and Zn anomalies are centred on Box Hole and Boat Hill. Cu in soils was considered unreliable by previous explorers, but there are clearly anomalies within the Neoproterozoic Central Mount Stuart Formation.

Previously, Cambrian carbonate rocks of the southern Georgina Basin have been considered potential hosts for MVT base metal mineralisation. Exploration for copper has focused on Neoproterozoic sedimentary rocks. New genetic models are proposed for base metal mineralisation and prospectivity maps have been generated by applying selected criteria for each model using GIS. A generalised sediment-hosted Cu model targets syn-rift to early sag phase Neoproterozoic formations, containing permeable siliciclastic rocks and redox boundaries in close proximity to a suitable fault feeder. The Mount Skinner Cu Prospect falls within the target areas generated. A more specific analogy is drawn with the Zambian Cu belt. Global correlation of glacial rocks indicates that the Plenty Group in the southern Georgina Basin would be analogous to the Roan Supergroup that contains the Zambian Ore Shale. The lowermost shale in the Plenty Group would therefore be a target. Potential hosts for epigenetic, stratiform, sediment-hosted Pb-Zn include the Adam Shale, basal Arthur Creek Formation and intra-Thorntonia Limestone. Suitable fault feeders mark a fundamental change in basement composition and were active during the Alice Springs Orogeny. Very localised targets exist in ELKEDRA and HUCKITTA. Classic syngenetic exhalative models have been developed for the same target formations. Electromagnetic survey is seen as a suitable technique to locate host rocks. All available data support the validity of an MVT model. Targets have been modelled using Cambrian or Cambro-Ordovician carbonates on the shelf break, which are cut by postdepositional faults that tap basement. Box Hole falls within the target areas generated. Irish-style and Manto orebodies form at a higher temperature than MVT and have a stockwork feeder. If orebodies of this type are to be found, they will be in Cambrian carbonate rocks in areas of highest thermal maturity and would have been fed by a suitable dilational fault. Such targets are present in ELKEDRA, SANDOVER RIVER and TOBERMORY. Epigenetic sandstone-hosted Pb, such as at Jinding in China, is hosted in the first transgressive sandstone or arkose at the start of a basin phase. In this case, targets include basal Neoproterozoic siliciclastic rocks, near the depositional or structural basin edge, <100 m above basement and cut by a suitable fault feeder. This constrains drillable targets to the southern basin margin and includes a newly reported galena occurrence in the Elyuah Formation at Mount Skinner.

OTHER COMMODITIES

Manganese occurrences are widespread throughout the Georgina Basin. Many of these are surficial manganocrete related to recent weathering. The Ninmaroo, Tomahawk and Kelly Creek Formations contain such occurrences in the southern basin. However, a recently located occurrence (Lucy Creek 2 Prospect), within Tomahawk Formation dolomitic siltstone in TOBERMORY, has been interpreted as a stratabound, possibly hydrothermal deposit.

In 1985, BMR reported economic levels of 1.5 ppm Pt and 0.8 ppm Pd in separate samples of shale from what is now regarded as medial Thorntonia Limestone in cored stratigraphic drillhole BMR Hay River 11A in HAY RIVER. Several companies explored unsuccessfully in the southern Georgina Basin for Platinum Group Elements using a Zechstein shale model. These BMR assays are now regarded as dubious.

The central Georgina Basin contains world-class phosphorite deposits. Minor occurrences in Middle Cambrian carbonate shelf areas in the southern basin indicate that this area is also prospective, but it has not been systematically explored.

Much of the southern Georgina Basin is currently under tenure for diamond exploration. Prior to work by Elkedra Diamonds NL, the area had yielded one macrodiamond, 13 microdiamonds and numerous diamond indicator minerals. To date, Elkedra has located four additional microdiamonds, including two from their Wanda target, and hundreds of high-Cr chromites. A U-Pb crystallisation age of 390 Ma for a niobian rutile collected during stream sediment sampling for diamond exploration is taken as evidence of an early Devonian mafic igneous event of similar age to the Merlin diamond pipes.

The lowermost Arthur Creek Formation in ELKEDRA contains Australia's only turquoise mine. About 20 t of poor to average quality turquoise was produced between 1971 and 1980 from the Tosca open cut. Other occurrences are known in the Arthur Creek Formation in ELKEDRA, and associated with a fault between the Mount Baldwin Formation and Red Heart Dolostone in HUCKITTA.