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Nutrients from sediments

Implications for algal blooms in Myall Lakes

D Palmer, DJ Fredericks, C Smith & DT Heggie

During April and October 1999, the Myall Lakes experienced blue green algae blooms that persisted until August 2000.[1] The bloom conditions had considerable impact on the local tourism and fishing industry. In response to community outcry and political pressure to find solutions to the problem, the managing authorities developed monitoring and assessment programs in an attempt to discover the cause of the algal blooms. An important component of the assessment was to understand the nutrient dynamics and sediment–water interactions within the Bombah Broadwater.

AGSO conducted an 11-day survey in Bombah Broadwater within the Myall Lakes system, measuring fluxes of nutrients from the sediments using benthic chamber instrumentation. The results showed that denitrification, a natural microbial process which removes nitrogen from estuaries as nitrogen gas, was operating inefficiently. As a consequence, a high proportion of the nitrogen recycled in the sediments was being returned to the water column as biologically available ammonia, potentially enhancing algal growth in the water column.

The Myall Lakes region is on the central coast of New South Wales approximately 280 kilometres north of Sydney. The Myall Lakes drain a catchment approximately 780 square kilometres in area, of which about 25 per cent is cleared and under agricultural production; the remainder is relatively undisturbed vegetation within state forest, national park or uncleared private land holdings.[2]

Bombah Broadwater (figure 1) is the southern most lake within the Myall Lake system. It is a relatively shallow, flat-bottomed lagoon, approximately 22 square kilometres in size. Bombah Broadwater receives the main freshwater input to the lake system (Myall and Crawford Rivers and Boolambayte Creek via Boolambayte Lake) and drains out via the lower Myall River which flows south, approximately 20 kilometres into Port Stephens. There is very little tidal flushing of the Myall Lakes as marine water only moves up the lower Myall River into Bombah Broadwater during extended periods of low rainfall.[2]

The distribution of sediment facies within the lake corresponds closely with water depth. The outer margins and a broad shoal in the centre of the lake consist of medium to coarse sand, dominantly quartzose in composition. Areas greater than two metres in water depth are dominated by mud with a total organic carbon content of around five to seven per cent.[3]

Benthic flux measurements

The flux of nutrients and metabolites between the sediments and the overlying water was measured using benthic chambers.[4] The chambers were deployed on the sediments of the lake and captured approximately nine litres of seawater. Data loggers recorded dissolved oxygen concentrations both within the confined chamber waters and in bottom waters outside the

Map: AUSLIG

Figure 1. Bombah Broadwater site map

chamber. Samples were drawn from within the chamber at predetermined intervals and analysed for dissolved inorganic nutrients (NO_x^-, NH_4^+, HPO_4^{2-}, SiO_4^{2-}), pH, TCO_2, alkalinity, N_2 and Cs concentrations. The flux of nutrients and metabolites across the sediment water interface was determined from the rate of change in concentration within the chamber, during the course of each incubation.

Benthic chambers were deployed at three sites as selected by the New South Wales Department of Land and Water Conservation (figure 1). One site was located on the sand facies (site 3); the other two were on the mud facies (sites 1 and 2).

Sediment denitrification

Nitrogen is delivered to coastal lake and estuarine environments in dissolved and particulate forms. Nitrogen added to the estuary is either captured by primary producers—including phytoplankton, various seagrass species and mangroves—or is flushed out to the sea. In most Australian barrier estuaries (those separated from the ocean by a sand barrier) most nitrogen is trapped or/and recycled within the coastal lake or estuary. The dominant, naturally occurring, self-cleansing mechanism for these lakes and estuaries is denitrification. Denitrification is a bacterially-mediated process that occurs within sediments. It converts nitrates, and nitrites generated from the breakdown of organic matter, into nitrogen gas, which is subsequently lost to the atmosphere. The identification of this denitrification process and the efficiency to which it is occurring are key sedimentary indicators of environmental condition.

Denitrifying bacteria are ubiquitous in nature and require an organic substrate, a supply of nitrate, and a sub-oxic to anoxic environment or niche within the sediments for metabolism. When denitrifying bacteria are operating efficiently, the majority of dissolved inorganic nitrogen (DIN) generated via the breakdown of organic matter is converted to gaseous N_2. However, when denitrification is operating inefficiently, most DIN is returned to the water column, thus remaining available for plant growth.

Denitrification efficiency, expressed as a percentage, was calculated using

$$\textit{Denitrification Efficiency} = \frac{(\text{N Predicted} - \text{DIN Measured})}{\text{N Predicted}} * 100$$

N Predicted is the calculated flux of DIN from the measured Total CO_2 flux assuming a Redfield stoichiometry of 106C:16N.

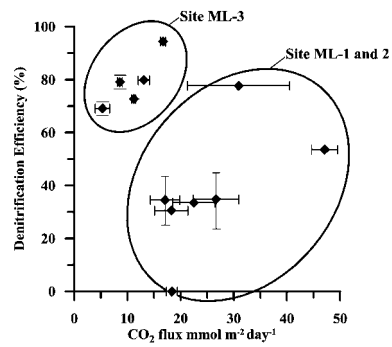

Figure 2. Calculated denitrification efficiency

Calculated denitrification efficiencies were greatest at site ML-3 (average 79% ± 4%) (figure 2). This suggests that the sand facies at ML-3 is very efficient at converting nitrogen from degrading organic matter into N_2. Calculated denitrification efficiencies for mud facies sites, ML-1 and 2 (figure 2) varied over a wider range (30% to 78%), yet had a considerably lower average (38% ± 9%). These efficiencies are low by comparison to muddy sites within other Australian estuaries such as the central portion of Port Philip Bay (~60% to 100%) and Wilson Inlet (~50% to 80%).

In Myall Lakes, the majority of nitrogen recycled from organic matter is being returned to the water column as ammonia at sites 1 and 2. In contrast, the small amount of organic matter being recycled at site 3 is

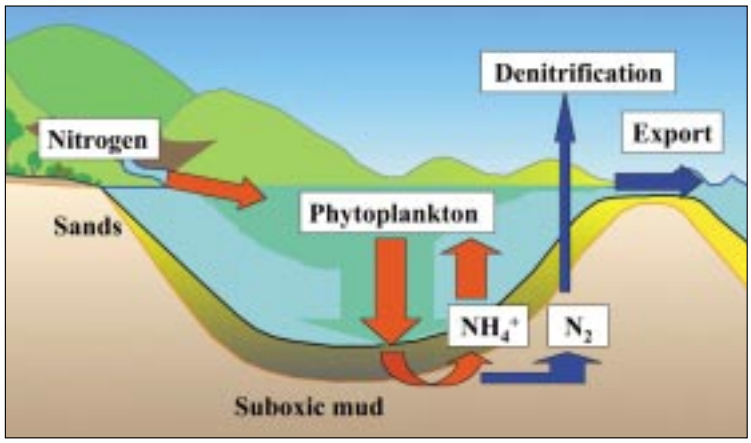

Figure 3. Schematic of nitrogen cycling in Bombah water

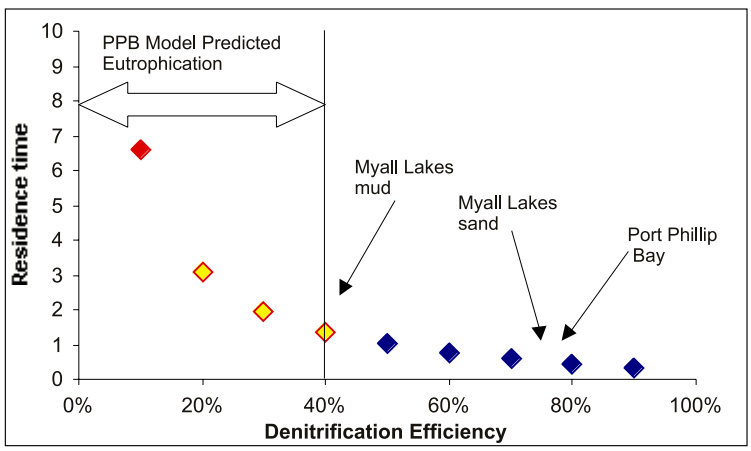

Figure 4. Relationship between residence time of nitrogen in an ideal estuary and sediment denitrification. In this figure, residence time is defined as the number of times added nitrogen is recycled between sediments and the overlying water column before 50% of it is lost as nitrogen gas.

efficiently converting organic nitrogen into nitrogen gas (figure 3).

It is important to consider the significance of low denitrification efficiency. Recycling of nitrogen from sediments is known to have a non-linear impact on productivity[5]— that is, a small decrease in denitrification efficiency may have a disproportionately large impact on primary production.

The impact of denitrification efficiency on the residence time of nitrogen in an estuary with limited flushing is illustrated in figure 4. It shows that the residence time of nitrogen in the estuary increases rapidly when the denitrification efficiency decreases below about 40 per cent. A similar effect was found in the Port Phillip Bay Environmental Study where primary production was predicted to increase rapidly when denitrification effeciencies fell below about 40% (equivalent to a doubling of the N load).[5,6]

Conclusion

It is difficult to assess the system-wide denitrification rate from the data available for Myall Lakes. However, the limited measurements of sediment denitrification in Myall Lakes indicate that denitrification efficiency is low, at least during the winter month of June at the mud sites. Furthermore, the data suggest that Bombah Broadwater may be close to a state in which feedback of labile nitrogen from the sediments may fuel plant growth. It is possible that the extended cyanobacteria bloom experienced in Myall Lakes over the summer of 1999–2000 was sustained by poor sediment denitrification. Any further decline in sediment denitrification is likely to result in more extensive phytoplankton production, though not necessarily cyanobacteria.

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More sources for gas and oil in Perth Basin

Study highlights potential for multiple petroleum systems

CJ Boreham, JM Hope, B Hartung-Kagi & BJK van Aarssen

Perth Basin has been intermittently explored for the last few decades, resulting in the production of gas and oil from several onshore fields. The bulk of known hydrocarbon reserves has been produced, however, and new ideas are needed for Perth Basin to contribute to Australia's petroleum stock in the future. Notwithstanding this long exploration history, the accepted sources for gas have been based on minimal geochemical data; even the generally accepted major Early Triassic Kockatea Shale source for oil has been questioned recently.[1] To improve understanding, carbon isotopic and biomarker analyses of gases, condensates and oils have been analysed as part of AGSO's South and South-west Regional Project. The study has documented numerous oil families from Permian, Triassic and Jurassic sources and positively identified, for the first time, both Permian and Triassic sources for gas in the Perth Basin.

Perth Basin is a deep, linear north–south trending trough extending more than 1000 kilometres from Geraldton in the north to the south coast of Western Australia (figure 1). The basin covers an area of approximately 45 000 square kilometres onshore and 98 000 square kilometres offshore and contains sediments of Permian to Cainozoic age. A generalised stratigraphy for Perth Basin is shown in figure 1.

The basin is bounded to the east by the north–south trending Darling Fault and this has been downthrown on its western side.[2,3] The main depocentre is the Dandaragan Trough, where up to 15 kilometres of Permian and Mesozoic sediments were deposited. The succession shallows to the north and west, where it is bounded by Beagle Ridge. To the south, Dandaragan Trough is separated from Bunbury Trough by Harvey Ridge. Offshore and to the north, the Abrolhos Sub-basin contains sediments of Early Permian to Late Cretaceous age. Offshore and to the south and west of the city of Perth, the Vlaming Sub-basin contains about 10 kilometres of Cretaceous and Tertiary sediments.

The structural history of the basin is recognised as being very complex with none of the existing models giving completely satisfactory explanations for all tectonic elements.[4] There are considerable problems in accurately dating the Permian sections and this adds to the difficulties in reconstructing the basin history. Mory and Iasky recognise two major phases in the structural evolution of Perth Basin related to the breakup of Australia and India.[5] The first of these began with north–south extension in the Early Permian resulting in east–west trending normal faults and probable sinistral strike-slip faults along the Darling Fault. The Late Jurassic extension and subsequent Early Cretaceous separation of Greater India from Australia caused reactivation of these faults and major uplift and erosion. This second event was probably associated with increased heatflow.

Petroleum systems

The onshore Perth Basin has yielded volumes of 4.2 billion barrels, 1.4 billion barrels and 0.7 trillion cubic feet of oil, condensate and gas, respectively.[6] The bulk of these reserves have already been produced. The Dongara field contains more than half the oil and gas reserves, while approximately 85 per cent of the condensate is found in the Beharra Springs field.

Sources

Petroleum accumulations in the Perth Basin are believed to originate from sources within the terrestrial source rocks of the Early Permian Irwin River Coal Measures and some marine mudstone source rocks of the Early Permian Carynginia Formation, Permian Wagina Sandstone and Early Triassic Kockatea Shale.[1,7,8] Organic matter in these sediments is considered to be the source of gas, condensate and oil in the Beharra Springs, Mondarra, Woodada, Dongara, Mount Horner and Whicher Range fields of the onshore Perth Basin.[8–11] In contrast, oil in offshore Gage Roads-1 is thought to originate from Late Jurassic rift-related sediments of the Yarragadee and/or Parmelia Formations.[8,12–14] Liquids from the Gingin and Walyering Gas fields of the onshore Dandaragan Trough were probably sourced from the Cattamarra Coal Measures.[8]

Reservoirs

Lithostratigraphic units with reservoir potential are widespread throughout the entire sedimentary succession.[15,16] The Lower Permian sandstones of the Irwin River Coal Measures produce gas of economic significance in the Dongara field. Discontinuous thin sandstones in the Carynginia Formation reservoir gas in the Dongara field and on Beagle Ridge, while the Woodada gas field is found in thick carbonates of the Carynginia Formation. The Wagina Sandstone produces gas in the Dongara and Mondarra fields. The best reservoir potential is present in the Upper Permian Dongara Sandstone and Beekeeper Formation. These reservoirs, together with the high-grade reservoirs in the basal Triassic sandstone of the Kockatea Shale, contain the bulk of hydrocarbons discovered in the basin. There are minor accumulations in the sandstones of the Lower Triassic Arranoo Member (gas and oil in Dongara and oil in Mount Horner). Several thin sandstone horizons of the Lower to Middle Jurassic Cattamarra Coal Measures produce oil from the Mount Horner field.

Seals

Regional seals are provided by the Cadda Formation and by some intervals within the Cattamarra Coal Measures, but mainly by the thick and laterally extensive Kockatea Shale.[15,16] Shales in the Carynginia Formation may provide a seal to the Irwin River Coal Measures, or juxtaposition of Kockatea Shale and intra-formational seals of the Carynginia Formation across fault boundaries can provide compartmentalisation of hydrocarbon.[16,17] Seals for the sandstone reservoirs within the Cattamarra Coal Measures/Eneabba Formation are either intra-formational or provided by the regional Cadda Formation, while the Yarragadee Formation is sealed by the Parmelia Formation in the Dandaragan Trough.

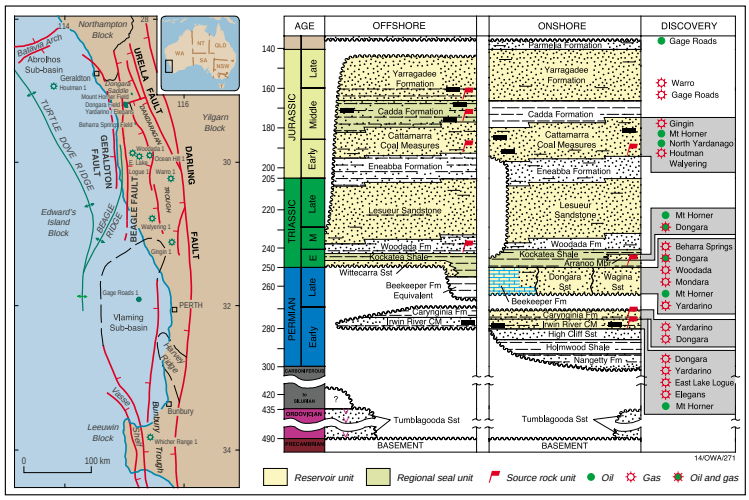

Figure 1. Tectonic elements, selected well locations and generalised stratigraphy in the Perth Basin. Note: stratigraphy modified after Owad-Jones and Ellis[15] and Crostella[25].

Present investigation

Gas composition

The highest CO_2 content is seven per cent in gas from Houtman-1 in the offshore Northern Perth Basin, which is similar to the average composition of Australian natural gas,[18] whereas Whicher Range-1 and Yardarino-3 have only trace amounts (figure 2a). A much better appreciation of the origin of CO_2 is seen using the relationship between CO_2 content and carbon isotopic composition of the CO_2 (figure 2b). The strong relationship between increasing CO_2 content and enrichment in ^{13}C is governed by the degree of mixing of isotopically light thermogenic, organic-derived and isotopically heavy inorganic (mantle and/or igneous)-derived CO_2. Very high N_2 content is found in Yardarino-3 while all other wells (figure 2a) are below the average of 3.2 per cent for Australian natural gases.[18]

Maturity is the principal control on the composition of the gaseous hydrocarbons and is reflected in the strong relationship between the ratio $\%C_1/\%C_1–C_5$ and the ratio $\%C_2/\%C_3$ (figure 3a). The bulk of the gases have high ratios suggesting relatively high maturities. This is supported by the carbon isotopic composition of individual gaseous hydrocarbons (figure 3b), which suggests gas generation at vitrinite reflectance (VR) >1.1 per cent. The considerable 'scatter' around the predicted maturity trend indicates that the isotopic composition is also governed by source effects.[18] Figure 3c shows the carbon isotopic composition of individual $C_1–C_5$ gaseous hydrocarbons in relation to the range in carbon isotopes of Australian natural gases.[18]

Oil geochemistry

Of the 10 oils analysed for C33-alkylcyclohexane (C33ACH; table 1), a characteristic biomarker of the organic matter in the Kockatea Shale, relatively high amounts were found in North Erregulla-1, Woodada-3 and Mt Horner-1, and in somewhat lower abundance in Erregulla-1. Although its presence confirms a major contribution from the Early Triassic Kockatea Shale, its absence is equivocal. On the other hand, carbon isotopes are one of the most diagnostic indicators of source in the Perth Basin (see below).

The results of the analysis of aromatic hydrocarbons for methylated naphthalenes, methylated benzenes and higher plant-derived biomarkers are listed in table 1. The naphthalene parameters TMNr, TeMNr and PMNr for all oils fall in or close to the centre when plotted in a ternary diagram (figure 4).19 Since none of the samples deviates appreciably from the 'maturity centre' there is no positive indication, within the limitations of the technique, of any significant in-reservoir mixing of oils of different maturities, biodegradation or migration contamination.

The oils from Dongara-4, East Lake Logue-1, Erregulla-1 and Mount Horner-1, sourced predominantly from the Kockatea Shale, have relatively low abundances of the land-plant markers retene and *i*p-iHMN.[20,21] The high HPI for the oil from Woodada-3 suggests an additional input from allochthonous terrestrial organic matter to the extensively marine depositional environment of the Kockatea Shale.

The oils from Gage Roads-1 and Gingin-1 contain relatively abundant conifer-derived retene, consistent with a source from the Late Jurassic Yarragadee Formation and Early Jurassic Cattamarra Coal Measures, respectively.[8]

The HPF for Whicher Range-1 is unexpectedly weak for oil derived from a Permian land-plant source. The HPF for Walyering-2 is similar to marine-sourced oil from North Erregulla-4 but its high TeMBr may indicate an additional input from a terrestrial source biased towards the low molecular weight components (see below).

Gas-to-oil-to-source correlation

The most reliable approach for assigning source rocks for the various natural gases firstly involves defining gas-to-oil correlations and secondly, by using better understood oil-to-source correlations, extrapolating to the desired gas-to-source correlations. The critical step relies on the utility of the *n*-alkane carbon isotope profile of oil as a good diagnostic tool in oil-oil and oil-to-source correlations.[8,22] The $>C_{7+}$ *n*-alkane carbon isotopic ratios for representative oils from Perth Basin are shown in figure 5. A range in $\delta^{13}C$ of <2 ‰ for *n*-alkanes of the same carbon number but from different oils is typical for variations in organic facies from essentially the same source rock interval. To unravel the source of the gas, the position and shape of an extended *n*-alkane carbon isotope profile is used, involving the combination of the carbon isotopic data for gas (C_1, C_2 C_3, *n*-C_4, *n*-C_5) components and the $>C_{7+}$ *n*-alkane carbon isotopes from accompanying oils and condensates (figure 5).

For East Lake Logue-1 and Dongara field gas and oil there is a fairly smooth trend (i.e. continuity) across the carbon number range C_4 to C_9, which defines the gas to oil transition zone (figure 5). This trend supports the idea that the gas and oil are genetically related, both generated from the Early Triassic Kockatea Shale. Gases from the Beharra Springs field, Indoon-1 and Woodada-6 are also thought to have a major contribution from Early Triassic rocks. Oils from Mount Horner-1 (figure 5), North Erregulla-1 and Yardarino-1 are extremely isotopically light (depleted in ^{13}C) compared with oils from older Permian (Whicher Range-1) and younger Jurassic sources (Gage Roads-1 and Gingin-1).[8] The rather

flat (constant carbon isotopes) profile for the C_{15+} *n*-alkanes is typical of marine-sourced oil.[23] A flat profile is also characteristic of the lacustrine source (Gage Roads-1), while increasing isotopic lightness with increasing carbon number is typical of a land plant source.[8,23]

The oils from Erregulla-1, Woodada-3 and Walyering-2 show 'intermediate' *n*-alkane carbon isotope profiles (figure 5).[8] The first two oils are isotopically similar and most likely from the same source. Summons et al. suggest an Early Triassic Kockatea Shale source, albeit from slightly different organic facies.[8]

The Woodada-3 oil was described as a 'vagrant'—that is, it stood alone compared with the other Perth Basin oils using statistical principal component cluster analysis based on biomarker ratios and bulk carbon iotopes.[24] The additional biomarker data in table 1 also support the unusual composition of this oil. If this interpretation is correct, then the Kockatea Shale source can give rise to a wide isotopic variability in the same *n*-alkane (e.g. 3.5 ‰ for *n*-C_{15}).

The gas isotope data for Woodada-6 indicate that the gas is from the more common organic facies of the Kockatea Shale source, indicating a rather complex charge history.

It is apparent that the carbon isotopic composition of the wet gas components in Elegans-1 (a later re-entry of Yardarino-1) is heavier (enriched in ^{13}C) compared to the other Perth Basin gases as well as to the shallower oil from the original well on the same site (Yardarino-1). This enrichment in ^{13}C is attributed to a source effect and is consistent with either a Jurassic or Permian source. The geological setting and regional maturation profiles indicate a Permian source for the gas.[15]

Table 1. Results from biomarker analyses

HPF

Sample	HPI	% ret	% cad	% iHMN	TMNr	TeMNr	PMNr	136/ 137	TeMBr	DBT/ 1367	C33ACH
Dongara-4	0.27	3	96	1	0.82	0.75	0.60	1.10	0.64	0.10	
East Lake Logue-1	0.12	0	100	0	0.91	0.86	0.59	1.29	0.78	0.45	
Erregulla-1	0.07	0	100	0	0.75	0.80	0.70	1.45	0.49	0.15	+
Gage Roads-1	0.67	70	25	5	0.53	0.56	0.41	1.23	0.74	0.14	
Gingin-1	0.18	38	62	1	0.74	0.71	0.63	1.16	0.75	0.12	
Mt Horner-1	0.10	0	100	0	0.76	0.75	0.61	1.42	0.48	0.20	++
North Erregulla-1	0.12	30	70	0	0.72	0.70	0.52	1.49	0.47	0.05	++
Walyering-2	0.13	32	68	0	0.83	0.85	0.74	1.26	0.73	0.28	
Whicher Range-1	0.13	9	90	1	0.67	0.65	0.58	1.10	0.70	0.30	
Woodada-3	0.72	12	85	3	0.67	0.70	0.55	1.37	0.51	1.07	++

HPI : Higher plant index = (retene + cadalene + *i*p-iHMN) /1,3,6,7-TeMN
HPF: Higher plant fingerprint
%ret = retene / (retene + cadalene + *i*p-iHMN); % cad = cadalene / (retene + cadalene + *i*p-iHMN); %iHMN = *i*p-iHMN / (retene + cadalene + *i*p-iHMN)
TMNr = 1,3,7-TMN / (1,3,7-TMN + 1,2,5-TMN)
TeMNr = 1,3,6,7-TeMN / (1,3,6,7-TeMN + 1,2,5,6-TeMN)
PMNr = 1,2,4,6,7-PMN / (1,2,4,6,7-PMN + 1,2,3,5,6-PMN)
136/137 = 1,3,6-TMN / 1,3,7-TMN
TeMBr = 1,2,3,5-TeMB / (1,2,3,5-TeMB + 1,2,3,4-TeMB)
DBT/1367 = DBT / 1,3,6,7-TeMN
C_{33}ACH = C_{33} alkylcyclohexane

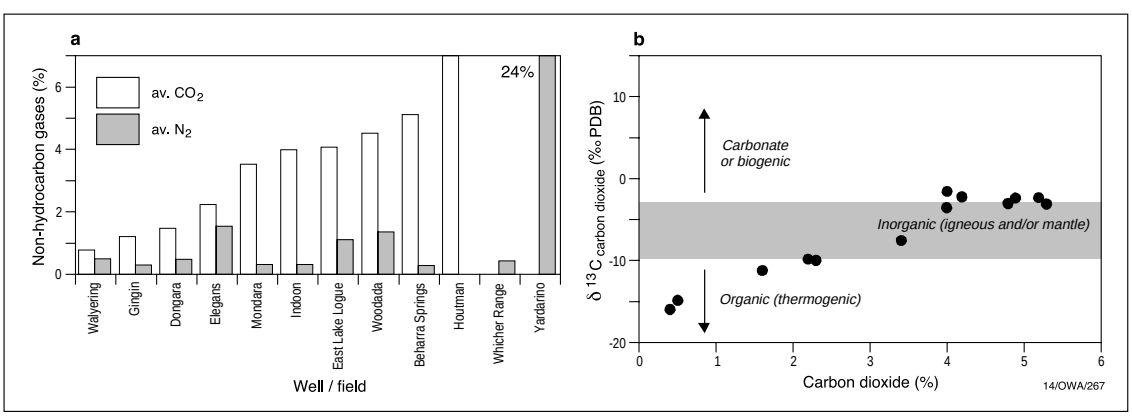

Figure 2. Plots showing **a.** average molecular percentage of CO_2 and N_2 and **b.** carbon isotopic composition of CO_2 versus molecular percentage of CO_2 for natural gases from Perth Basin.

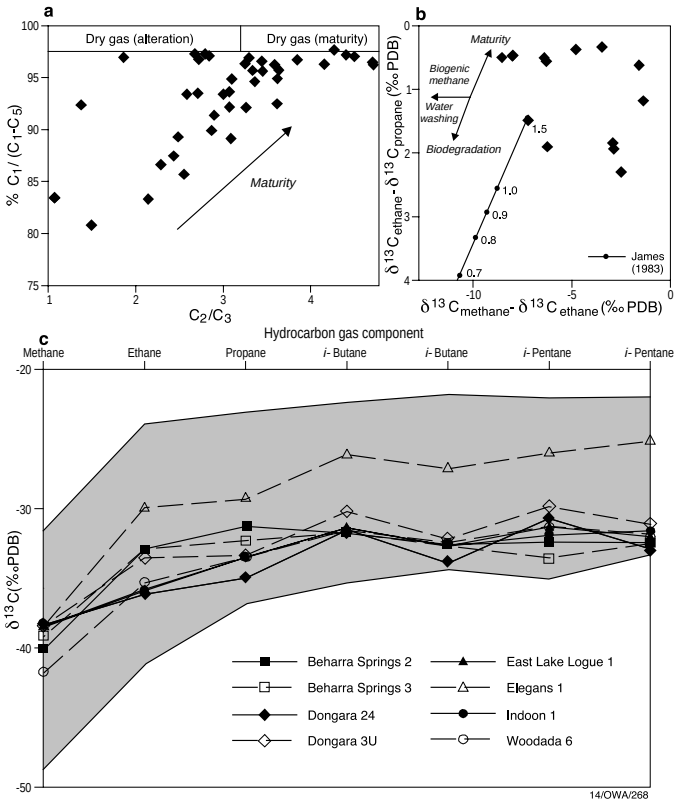

Figure 3. Plots of
a. Percentage methane%/(methane% + ethane% + propane% + *iso*- & *n*-butane% + iso & n- pentane%) versus ethane%/propane%; (%C_1/C_1–C_5 vs C_2/C_3)
b. $\delta^{13}C_{methane}$ minus $\delta^{13}C_{ethane}$ versus $\delta^{13}C_{ethane}$ minus $\delta^{13}C_{propane}$ (the predicted evolution of carbon isotopic difference[26])
c. $\delta^{13}C$ of individual C_1–C_5 gaseous hydrocarbons for natural gases from the Perth Basin (the shaded area is the range in carbon isotopes for unaltered Australian gases[18]).

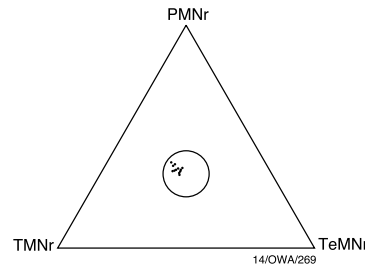

Figure 4. Triangular plot of TNMr, TeMNr and PMNr. The circle defines the 'maturity centre' representing a 10 % variability in the ratios.[19]

Implications for exploration

This study identified numerous oil families and petroleum systems in Perth Basin. It also positively identified, for the first time, both Permian and Triassic sources for gas in Perth Basin.

The Early Triassic Kockatea Shale is the principal source for oil, and it is of the highest quality in the onshore Northern Perth Basin. Carbon isotopic evidence for gas indicates that the Kockatea Shale is also the major source for gas onshore. Gas generation should still have occurred offshore, even though the Kockatea Shale has diminished potential for oil.[24] The Permian, and to a lesser extent, Jurassic sediments are also gas sources in Perth Basin. The existence of leaky Permian seals for gas leads to a large scale 'gas flush' in the subsurface, compounding the widespread gas-stripping of oil in Perth Basin.[17] However, this re-mobilisation of hydrocarbons should result in long-range migration and a mechanism for emplacement of petroleum higher in the section.

In summary, the identification of Permian and Triassic sources for gas in the onshore Perth Basin, coupled with recognised oil and gas potential in the Mesozoic sediments offshore,[25] highlight the potential for multiple petroleum systems active in the region and points to new exploration opportunities.

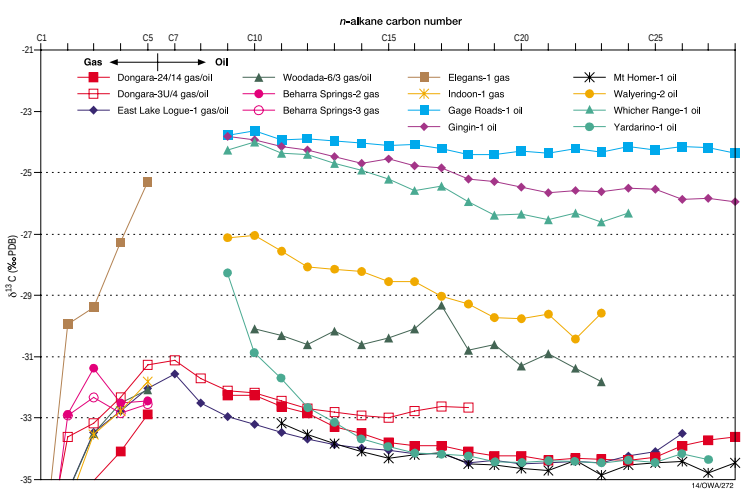

Figure 5. Carbon isotope profile for *n*-alkanes from gases and oil in the Perth Basin

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The importance of the 'backend' to online delivery of geoscience information

RJ Ryburn

The love affair geoscientists have had with their PCs leads many to think that a do-it-yourself approach can carry us into the 'dotcom' era. However, the secret to the success of major online businesses is their mastery of the 'backend'—the logical, physical and human infrastructure that is the foundation of web sites. These businesses know that in the long run their customers are best served by building a solid backend. Attractive web pages get customers in, but what keeps them returning is the quality, quantity and timeliness of the content behind the web site. Most successful dotcom companies have restructured, or built from the ground up, to provide the best possible backends. Geological surveys must do likewise to survive in the information age.

'Backend' is a term commonly used for the combination of people, hardware, software and data that lies behind corporate information systems. In this article I apply the term particularly to the corporate database component of the backend conglomerate. The 'front end' refers to the part the user sees—the forms, client software or browser pages that are used to access the backend. The front end is like a butterfly: eye catching but with a short life span, soon to be replaced by better, brighter interfaces. The backend, particularly the data and their logical structure, is made of sterner stuff. Good backends take time and effort to construct, but when done properly should survive for decades, outlasting any number of front ends. The hardware and system software aspects of the backend evolve over time, but data and their logical structure should be made to last.

Geological surveys such as AGSO are very much a part of the dotcom scene as we strive to deliver more and more geoscience information via the internet and web.[1] We are presently constrained by narrow communication channels, but these limitations will be largely overcome in just a few years. Although part of AGSO's output will always be in the form of electronic documents, images, GIS datasets and other project-related datasets, enhanced band-widths will increase demand for integrated, seamless national datasets that can be automatically subsetted and delivered online for specified areas of the Australian lithosphere (figure 1). These standardised national datasets replace the map series that were traditionally one of the main outputs of most geological surveys. They will come with added dimensions, greatly enhanced usefulness, and methods of presentation that are limited largely by the imagination.

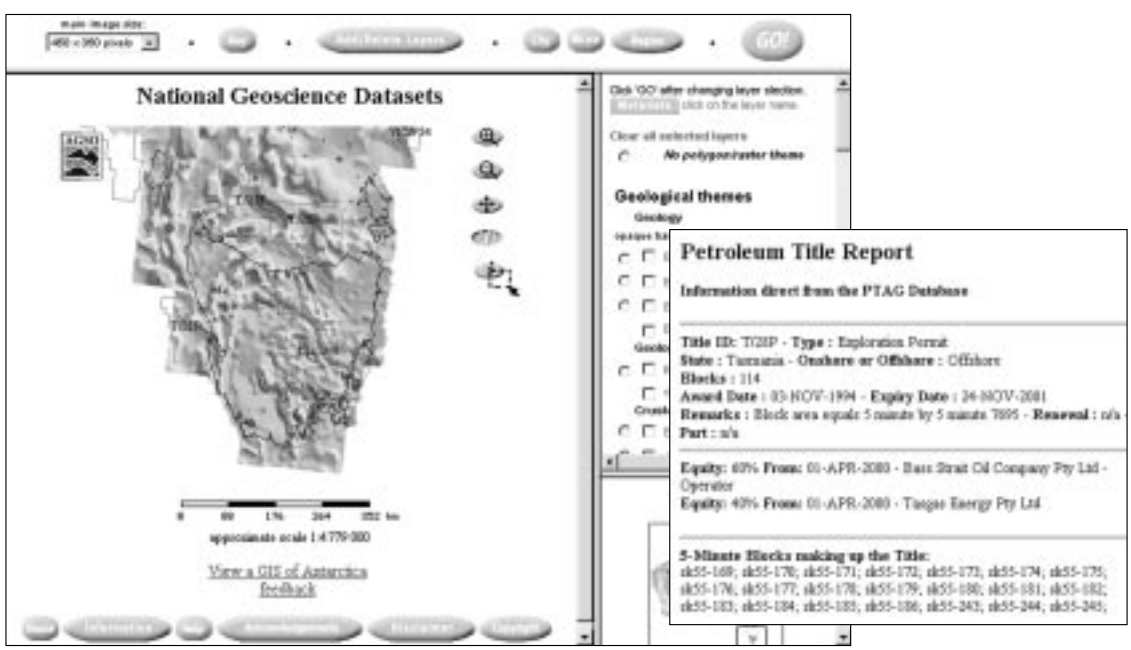


Figure 1. A recent example of integrated online delivery of geoscience information via the web—in this case petroleum exploration titles. The titles layer has been zoomed to the Tasmanian region, and the T/28P title polygon clicked to obtain a report on that title from three tables in the PTAG petroleum accumulations database.
See http://www.agso.gov.au/map/national

Limitations of hierarchical directories

Every PC user is familiar with hierarchical, or tree-structured, computer disk directories. They have been around as long as random-access storage devices—that is, almost as long as the computer itself. Every PC and workstation, and most servers, are organised around tree-structured directory systems. For personal- and project-scale management of information, hierarchical directory systems are still very useful and entirely appropriate.

For large-scale data management, however, tree-structured filing systems are cumbersome, as they permit just one way of classifying and locating files. In corporate computing networks, files can easily be lost in a maze of directories, and file searches are slow and inefficient. Duplication of data is rife, and there is often no way of knowing which version of a file is the most up to date. Other problems concern frequent changes to directory structures, leading to isolation of files relying on pathnames for access. These limitations may not seem serious on a PC, but on the computer networks of large organisations they are major headaches. Similarly, web sites organised around tree-structured filing systems can become difficult to manage once they grow beyond a certain size. Applications become difficult to write, requiring many changes to keep up with fast-changing directory structures.

The evolving backend Relational database management systems (and their forerunners) arose partly to overcome the problems encountered with traditional filing systems. With a relational database the user has many ways of finding data that are efficiently indexed, obviating system-wide file-by-file searches. Similarly, the problem of duplicated data can be largely overcome in a properly designed corporate database system by rejection of inadvertent attempts to re-enter the same information, and clear version control. In reality there are many reasons for using relational database management systems—such as transaction management, business rules, concurrency, security and automatic backup.

Corporate databases have existed almost as long as the computer itself, and as relational databases for the past 20 years. Corporate databases, albeit in a simpler form, were certainly to the fore in the days of corporate mainframe computers with dumb terminal access.

With the rise of the minicomputer in the seventies, and the PC in the eighties, databases were able to migrate to the department, the project and the person. At the same time the idea of distributed computing gained currency, and people liked the relative freedom of being able to do their own thing on their own machine (if at some cost).

The advent of the web in the early nineties gave rise to 'thin-client' computing in which the web browser became the graphical equivalent of the old character terminal, and the bulk of the computing power was put back into the server. Suddenly there was the potential for thousands of terminals anywhere in the world to be connected to your server at little cost.

You could upgrade your system software and applications in the one place, without the need to upgrade all those client systems. The efficiencies to be gained were astounding—the backend was back with a vengeance. The net result has been the reunification of the corporate backend into one integrated system, albeit spread over a number of CPUs. Oracle Corporation, fed up with the inefficiencies of dispersed systems, recently consolidated thousands of their business servers spread around the world into what is effectively one corporate backend at their headquarters in Redwood Shores, California.[2] In so doing they claim they will save a billion dollars.

The rise of object-relational databases

In the early nineties there were predictions that object-oriented databases would take over completely from relational databases. This has not happened, and pure object database systems now form only a small, specialised part of the current database scene. What has happened, though, is that the main relational database systems have gradually taken on some of the more useful qualities of the object-oriented world. A variety of different object types may now be conveniently handled in what are known as universal, or object-relational database management systems. For example, Oracle has acquired the technology for handling images in the database, to the extent that it can now deal with commands like 'get me all pictures that look a bit like this one'—and that is without recourse to textual metadata. In AGSO's case, the ability to handle GIS datasets in Oracle 8i (with or without ESRI's Spatial Data Engine) and to store documents in the database will undoubtedly prove to be very valuable. Images, too, will be increasingly placed inside the database.

At the same time the database is expanding to accommodate a greater variety of data types, the application software that allows one to easily handle these new forms of data is maturing. With Oracle's latest application development tools, one can rapidly construct a web site that includes text, images, documents, video, sound and 'XML' extracts—all from within the corporate database. Once the corporate database includes all these new forms of information in a well-organised and accessible manner, constructing an attractive, highly functional web site becomes an easy and relatively quick exercise. Furthermore, multimedia front ends such as these are now easily modified or expanded to meet client expectations. 'Portals' for use on other web sites can also be projected.

Burgeoning database administration

A consequence of the rapidly expanding backend is that database administration (DBA) is a more complex and critical job than it was a few years ago. The software needed to place corporate information on the web has grown enormously in volume and sophistication, and the variety of information types being stored in the backend for presentation on the web is increasing in leaps and bounds. New products, such as Oracle's WebDB 3.0, allow the contents of the entire web site to be brought within the database. Control of content can then be distributed to the appropriate areas of the organisation with security handled by the database management system. GIS datasets are also moving into the database, as in ESRI's Spatial Data Engine now used in AGSO. We will soon be required to use a document management system, in which all documents and communications are stored within the corporate database system and accessed via the intranet and web. Information can now be supplied via the web encapsulated in the XML data definition language.

Efficient management of a corporate web site requires people with at least three types of expertise. First you need people who are competent with hardware, operating systems, communications,

➥ *Continued page 20*

Minerals laboratory staff develops new ICP–MS preparation method

J Pyke

AGSO's Minerals Division laboratory staff has developed a new method of sample preparation for ICP–MS analysis that replaces the time-consuming, multi-step acid dissolution technique used to date.

The new method involves digesting pieces of the 12:22 lithium tetraborate/lithium metaborate fusions that have been prepared and run for XRF major element analysis.

To date sample preparation for ICP–MS analysis at AGSO has been based on a method outlined by Jenner et al.[1] The method involves a series of acid digestion and drying stages over a period of four days. Comparisons between XRF Zr results and Zr results from the ICP–MS indicated that for many samples the method was not achieving total digestion of the zircon present. Subsequent replicates of problem samples also showed large variations in Zr results. Hot or cold spots on the hotplate surfaces, affecting digestion, may have been the reason for these variations.

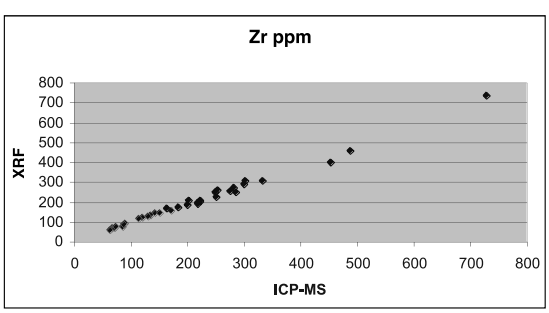
Comparison of XRF and ICP–MS Cr results for those samples with significant Cr values suggests that similar problems are present for the dissolution of the refactory mineral chromite. Other elements present in refactory minerals generally tend to be at levels approaching or below the detection limit of the XRF method making comparisons meaningless.

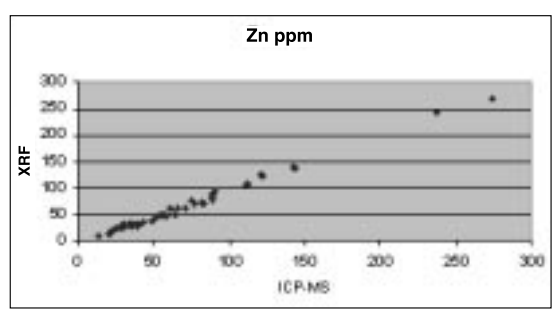
To overcome these problems laboratory staff first experimented with Parr bomb and microwave digestions. Little or no improvement was found with the microwave and only slight improvement with the Parr bombs. Steve Eggins from the Australian National University's School of Geology was using laser ablation on XRF fusions to do trace element analyses. His work led Minerals laboratory staff to the idea of digesting pieces of XRF fusions. Digesting the fusions proved straightforward.

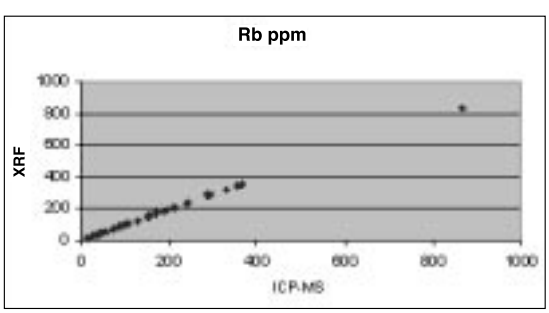
The only problems encountered arose from contamination of the digest by the platinum ware used to produce the fusions. All platinum crucibles contained some rhodium and palladium, even the recently purchased 95% Pt/5% Au crucibles. Rhodium is the most commonly used internal standard used in ICP–MS because of its position in the mass range.

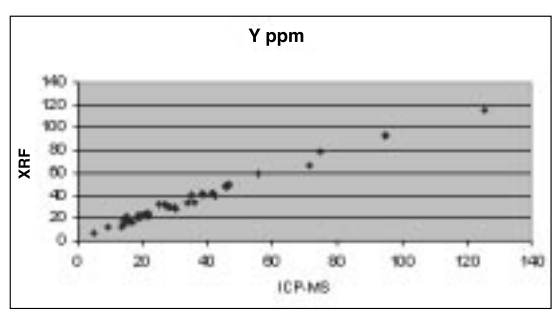
Introducing it into the sample obviously precluded its use as an internal standard. Fortunately the elements for which Rh had been used as an internal standard were successfully divided between Ni 61 and Sm 147. Lanthanum was also present in many older crucibles—most probably residual from the Norrish and Hutton flux that the laboratory had used for many years. The La was removed successfully with a number of dummy fusions. One crucible that was highly contaminated with zinc is no longer used.

During the development of this method, the cause of an intermittent Ba and Pb contamination problem with the ICP–MS analysis was identified. One of a number of glass pipettes that could be used in the preparation of the internal standard was having these elements leached out of the glass by the 1% HF used in the preparation. No glassware is used in the ICP–MS laboratory now.









Method

Approximately 100 micrograms of chips from the smashed discs are weighed accurately into Savillex teflon vessels. Five millilitres of internal standard, one millilitre of HF and five millilitres of HNO_3 are then added.

The vessels are sealed and heated for 12 hours overnight at 200 degrees centigrade on a timed hotplate, such that cooled samples are ready the following morning. The digests are then transferred to volumetric flasks and made up to volume ready for the ICP–MS.

Occupational health and safety

There are substantial benefits from an occupational health and safety perspective. The digests take place in a sealed vessel. If the fume cupboard system failed, dangerous acid fumes would not leak (unlike the present situation). The use of acids, particularly HF, is substantially reduced. With this method one millilitre of HF is used instead of six, and five millilitres of HNO_3 are used instead of 18. This greatly reduces staff handling of acids, with less acid needing to be distilled and stored in the laboratory.

Table 1. Zr results obtained on some international standards

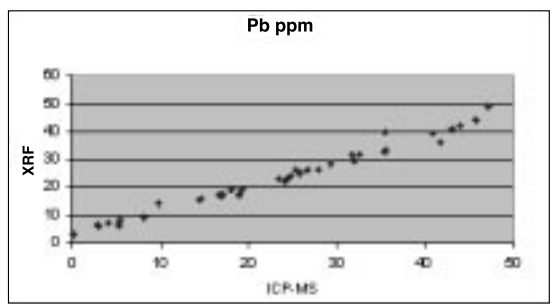
Standard	ICP–MS Old	ICP–MS New	AGSO XRF	Recommended value[2]
W-2	78 ppm	95 ppm	93 ppm	94 ppm
BIR-1	15	15	15	15.5
DNC-1	36	37	36	41
QLO-1	171	189	188	185
BHVO-1	151	176	175	179
AGV-1	205	235	235	227

Sample digestion

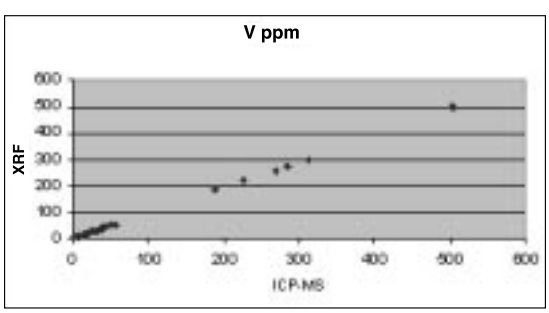
The sample is totally digested. Any undissolved sample in the glass disc creates stress points and the disc shatters. Because the discs have survived XRF analysis and a few days stored in a plastic bag, laboratory staff can be confident that dissolution in the glass is complete.

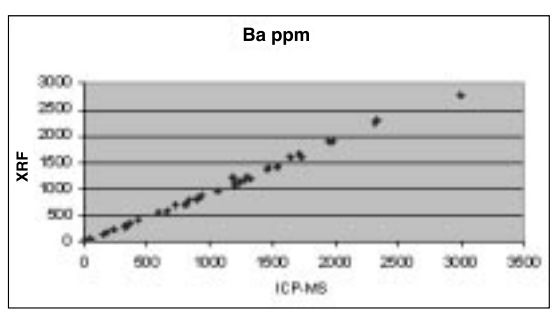
Disregarding the fusion process, which is standard practice for the XRF, this method is a one-step 24-hour preparation compared to a multi-step four-day procedure. The time could be cut even further by using a microwave for small lots of 'specials'.

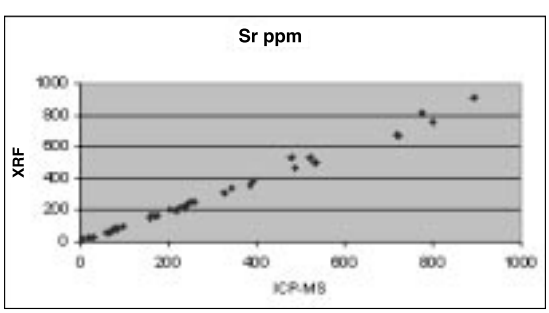
Contamination of samples should be effectively eliminated since the digestion takes place in a sealed container. There are no drying stages as in the current method where samples spend many hours in open vessels. Because the sample is totally in solution, laboratory staff can now confidently analyse for those elements associated with the refractory minerals—elements such as Zr (see table 1), Hf, Cr and the REE likely to be tied up in zircons.

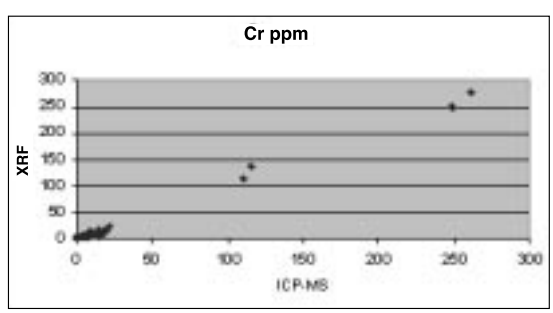


Figures 1–9. XRF vs ICP–MS: Result comparisons for a number of elements from a recent suite of samples









The distribution of zircon, if present, in a powdered sample is an excellent indicator of sample homogeneity. Any major discrepancy in Zr results from the XRF and the ICP–MS will now suggest problems with the sample grinding rather than analytical problems. Results, particularly trace results, could be then treated with appropriate caution or the sample(s) reground and reanalysed.

The laboratory will be able to report both results for those elements that can now be equally well determined by XRF and ICP–MS. These elements will probably be Ba, V, Cr, Ni, Cu, Zn, Rb, Sr, Y, Zr and Pb because they are generally present in silicates at levels significantly above the detection limit of the less-sensitive XRF (see figures 1 to 9).

Although the effective sample weight in the final solution is smaller than presently used, the weight used to make the fused disc is approximately three times larger than at present. The end result is that laboratory staff is now using what should be a more representative aliquot of the sample.

Because discrete chips of glass are used, there are no problems with electrostatic charges that cause segregation in some sample powders. One chip digests as easily as a dozen smaller pieces.

Similar rock standards will routinely be run with each batch of both XRF and ICP–MS. Collection and storage of this data will continually monitor the performance of both techniques.

Disadvantage

Lithium and boron analyses will no longer be available from the Minerals Division laboratory because of the Li and B present in the flux and their memory effect within the spectrometer.

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Bonaparte Basin

Geochemical characteristics of hydrocarbon families and petroleum systems

DS Edwards, JM Kennard, JC Preston, RE Summons, CJ Boreham & JE Zumberge

The Bonaparte Basin has been actively explored for more than 20 years, with oil production from several fields (Jabiru, Challis–Cassini, Laminaria–Corallina, Elang and the depleted Skua field) and proposed production from giant gas/condensate fields (Bayu–Undan, Sunrise–Loxton Shoals–Troubadour and Petrel–Tern). Despite this focused exploration and appraisal, to date geoscientists have had a relatively poor understanding of the region's petroleum systems.

To improve this understanding, isotopic and biomarker analyses of numerous oils, condensates and gases have been undertaken to geochemically characterise the hydrocarbon families in the Bonaparte Basin, and to correlate them with likely source rocks. Preliminary results of this study show that two Palaeozoic and seven Mesozoic oil families can be identified in the Bonaparte Basin. Details of the petroleum systems active in this basin were presented at the recent AAPG International Conference in Bali (October 15–18, 2000) by Dianne Edwards and John Kennard, and continue to be investigated by AGSO's North-north-west Regional Project.

The Bonaparte Basin lies between north-western Australia and the island of Timor (figure 1). It has a complex tectonic history involving two phases of Palaeozoic extension and Late Triassic compression prior to the onset of Mesozoic extension.

Initial rifting occurred in the Late Devonian to form the north-west-trending Petrel Sub-basin in the south-east. The resultant thick Late Devonian–Carboniferous rift and sag succession was orthogonally overprinted in the Late Carboniferous to Early Permian by north-east-trending rift basins to form a proto-Malita and possible proto-Vulcan Sub-basin. Late Jurassic extension resulted in a series of linked, north-west-trending (Vulcan Sub-basin and Malita Graben) and south-east-trending (Sahul and Flamingo Synclines) intracontinental grabens. Thick marine mudstones accumulated within these grabens, and passed laterally to fan delta sandstones on the adjacent horst blocks and terraces. These Mesozoic depocentres are surrounded by structural highs (Ashmore Platform, Londonderry High, Sahul Platform and Darwin Shelf; figure 1) which have relatively thin Jurassic–Cretaceous sediments across an uplifted and eroded Triassic–Palaeozoic section.

Most of the commercial and soon to be developed oil and gas accumulations are reservoired in Middle and Upper Jurassic sandstones (Plover and Montara/Elang Formation, respectively; figure 2). Commercial accumulations also occur in Upper Triassic and Upper Cretaceous sands in the Vulcan Sub-basin. In the Petrel Sub-basin, gas and gas/condensate accumulations occur in the Upper Permian Hyland Bay Formation (Petrel and Tern Fields, Fishburn-1 and Penguin-1), and gas discoveries on the Londonderry High (Prometheus-1, Ascalon-1A) and Sahul Platform (Kelp Deep-1) also occur within this unit (figure 2).

Hydrocarbon families

Oil–oil comparisons were made using cluster and principal component analysis—the results of which are displayed as a dendrogram in figure 3. The GeoMark protocol was adhered to which utilises 16 geochemical parameters (two bulk carbon isotopic values, 13 source-specific terpane

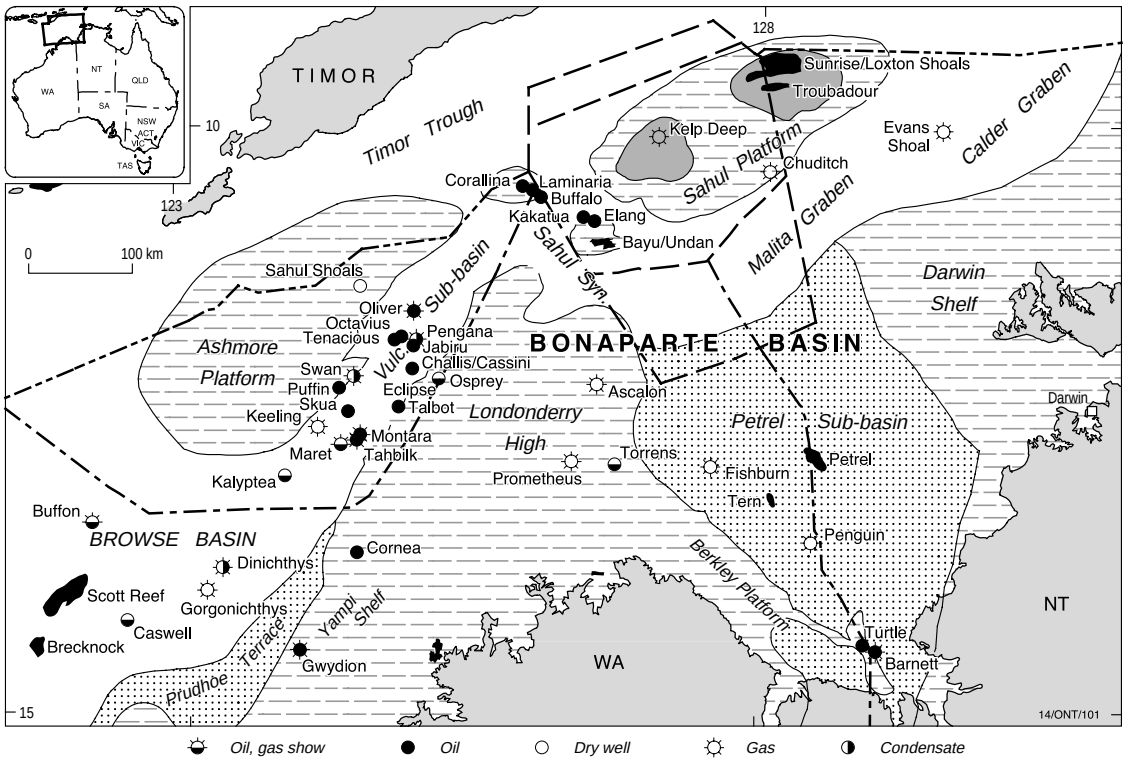

Figure 1. Location of petroleum exploration wells in the Bonaparte Basin

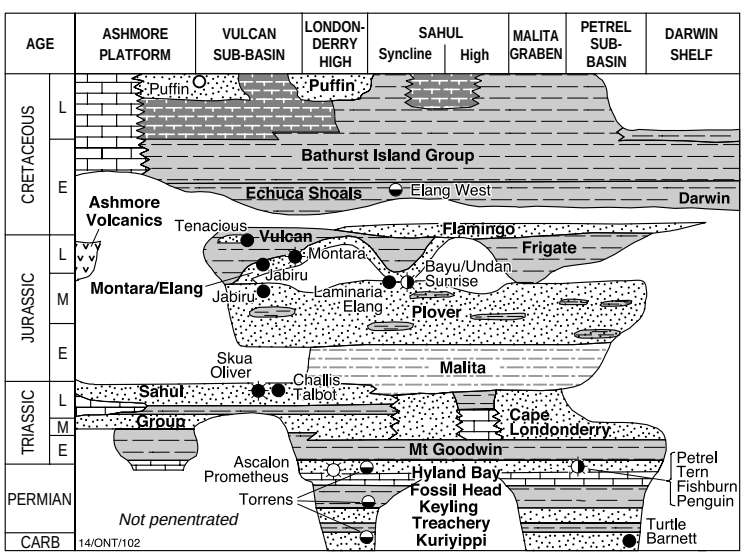

Figure 2. Generalised stratigraphy of the Bonaparte Basin

and sterane biomarker ratios, and pristane/phytane ratio).[1] Two Palaeozoic oil families are recognised in the Petrel Sub-basin, interpreted to be sourced by Carboniferous and Permian sediments. Seven Mesozoic oil families are currently recognised from the Bonaparte Basin, three of which are present in the Vulcan Sub-basin, and four in the northern part of the basin, in and adjacent to the Timor Gap Zone of Co-operation. The two oil families in the adjacent Browse Basin identified by Blevin et al. plot separately to those of the Bonaparte Basin.[2] It is apparent from the number of discrete oil families that there are many effective source units in the Bonaparte Basin.

Palaeozoic hydrocarbon families

Oils interpreted to be derived from the Lower Carboniferous Milligans Formation in the Petrel Sub-basin (Barnett, Turtle and Waggon Creek wells) are isotopically light ($\delta^{13}C$ values for the *n*-alkanes between -28 to -29 ‰) and have a slightly negative trend with increasing *n*-alkane number (figure 4). Their biomarker signatures are characterised by low pristane/phytane

ratios (Pr/Ph = 1.2), an abundance of rearranged hopane and steranes, and high sterane/hopane and tricyclic terpane/hopane ratios, which indicate generation from marine, anoxic, clay-rich source rocks.[3]

In contrast, the condensates from the Petrel and Tern Fields have heavy isotopic signatures (δ^{13}Csat = -24 ‰) and their *n*-alkane isotopic profiles exhibit a strong negative-slope. The *n*-alkane isotopic trends of the Tern-5 gases (C_1–C_5) are generally continuous with the *n*-alkane trends of the condensates, suggesting that the gases have the same source as the liquids. These heavy ^{13}C enriched isotopic values of the gas/condensates are consistent with derivation from land-plant material, and this interpretation is supported by the high abundance of C_{29} diasteranes. Geologically, the most likely source of these hydrocarbons are the Permian sediments of the Keyling and Hyland Bay Formations which are rich in land-plant remains and were deposited in coastal plain and deltaic environments, respectively.[3]

Dry gas from the Upper Permian Hyland Bay Formation in Kelp Deep-1 is extremely enriched in ^{13}C, which is in keeping with generation from a land-plant-rich source rock that is now overmature. Its stratigraphic and structural position on the Sahul Platform also suggests a Permian origin.

The gas discoveries at Penguin-1 and Fishburn-1 in the Petrel Sub-basin, as well as Ascalon-1A and, most recently, Prometheus-1 on the Londonderry High (all reservoired within the Upper Permian Hyland Bay Formation; figure 1), are also attributed to this Permian system.

Analysis of oil-bearing fluid inclusions in the Torrens-1 well on the Londonderry High indicates an interpreted 42-metre gross palaeo-oil column within the Permian Fossil Head Formation.[4] Isotopic and biomarker profiles of a residual oil from this palaeo column (Core 2, Permian Fossil Head Formation) are comparable to the Petrel and Tern condensates (figure 4). This oil is thus also attributed to a Permian source.[5–7] In contrast, the residual oil in Core 3 at Torrens-1 (Upper Carboniferous Kuriyippi Formation) has an isotopic signature similar to the Barnett and Turtle oils, and is interpreted to be derived from a Carboniferous source.

Oil-bearing fluid inclusions have also been interpreted to indicate a palaeo-oil column in the Upper Permian Hyland Bay Formation in Osprey-1 on the western margin of the Londonderry High.[8] The stratigraphic and structural setting of the Osprey-1 and Torrens-1 wells also supports the interpretation that these prior-oil accumulations were sourced from Permian sediments. This finding is significant because it indicates that a viable Permian oil play may be present across much of the Londonderry High.

Additional evidence of a viable Permian oil play in the Bonaparte Basin is suggested by the occurrence of clusters of interpreted oil slicks on Synthetic Aperture Radar (SAR) satellite scenes on the Ashmore Platform.[9] These slicks overlie areas where Jurassic and Cretaceous source rock are known to be absent or immature. Based on the current state of knowledge of potential Triassic and Palaeozoic source rocks, these slicks most probably indicate an active, oil-prone Permian petroleum system.

New gas isotopic data indicate that the Permian system also extends into the eastern Browse Basin.[10]

Mesozoic hydrocarbon families in the Vulcan Sub-basin

In the Vulcan Sub-basin, two major oil families are recognised: one with a dominant marine source signature and the other with a dominant terrestrial source signature (figure 5). A third oil family comprises condensates with variable geochemical composition.

The Vulcan Sub-basin marine oil family comprises oils from the Puffin, Skua, Cassini, Challis, Talbot, Jabiru and Tenacious wells (figure 5). They have light isotopic signatures (δ^{13}Csat = -27.5 ‰) with the *n*-alkanes displaying a 'lazy-S' profile (figure 4). This type of isotopic profile is seen in many Upper Jurassic sourced oils on the North West Shelf and is characteristic of mixing low molecular weight *n*-alkanes of the oil fraction with the higher molecular weight components of a more mature gas.[10] Whole oil chromatograms show that these oils have a unimodal *n*-alkane distribution with a maximum between C_{10} and C_{13} and intermediate Pr/Ph ratios (mean = 2.8), which are indicative of marine organic matter deposited in a sub oxic environment. Other source-dependent characteristics include a slight predominance of the C_{29} homologue among the regular and rearranged steranes ($C_{29} > C_{27} > C_{28}$). A siliciclastic source lithology is indicated by the abundance of rearranged steranes and hopanes. Preliminary oil–source correlations indicate that these oils are derived from the Upper Jurassic Lower Vulcan Formation.

The Vulcan Sub-basin terrestrial-influenced oil family includes oils from Maret-1, Bilyara-1, Montara-1 and Oliver-1, all of which have relatively heavy isotopic signatures (δ^{13}Csat = -25.5 ‰). Whole oil chromatograms show that these oils have moderately high Pr/Ph ratios (2.4–6.2) and high wax contents, consistent with their derivation from land-plant organic matter. Diagnostic biomarker features include an abundance of C_{29} sterane in comparison to the C_{27} and C_{28} homologues; diasteranes are more abundant than steranes. Rearranged hopanes are present, but in different relative amounts (e.g. C_{29}Ts/C_{29} hopane ratio is lower) compared with the aforementioned marine oil family. The lower correlation co-efficient between the Oliver, Montara-Bilyara and Maret oils (figure 5) indicates derivation from several localised source units. The most likely source of these oils is the Lower–Middle Jurassic Plover Formation.

Condensates in the Vulcan Sub-basin—including those at Tahbilk-1, Eclipse-2 and Swan-1—show some variation in their geochemistry, and plot together as a separate family in figure 5. Data for these condensates were not used in the generation of the Bonaparte dendrogram (figure 3), because it is believed that their present composition is more reflective of reservoir alteration effects (such as leakage and gas flushing) rather than the type of organic matter in their source rocks.

Mesozoic hydrocarbon families in the northern Bonaparte Basin

The oils and condensates from the northern Bonaparte Basin fall into four families. The condensates from the Bayu–Undan Field and oils from the Elang and Kakatua Fields have a dominant marine signature, but plot as a separate family to the Vulcan Sub-basin marine oil family (figure 3). This is probably due to these oils originating from multiple marine-influenced source facies within the Middle Jurassic Plover Formation and Upper Jurassic Elang and Flamingo Formations.[11]

The terrestrial-influenced oils from the Laminaria, Corallina, Buffalo and Jahal Fields make up a second oil family in the northern Bonaparte Basin. These oils probably also arise from several Jurassic source rocks, rich in land-plant remains.[11]

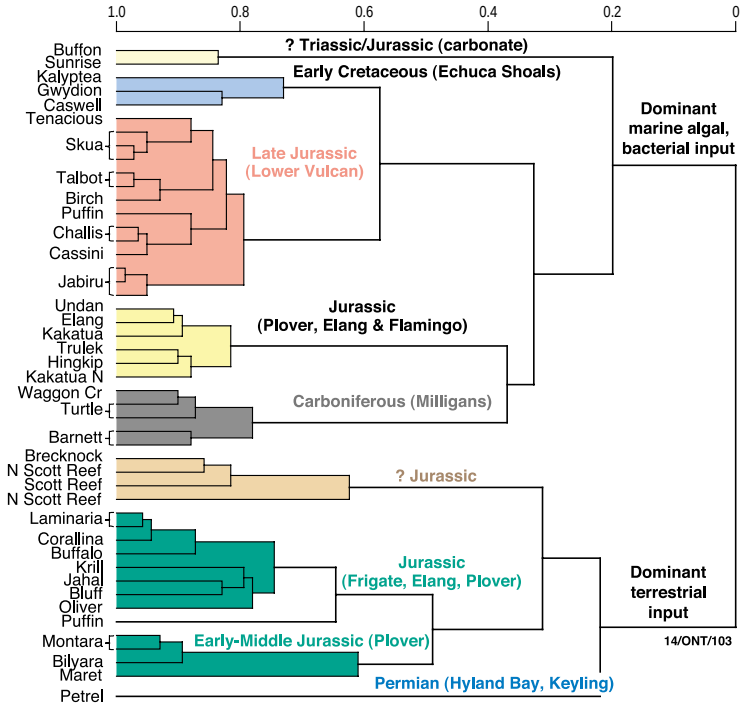

Figure 3. Oil family dendrogram showing the degree of compositional similarity between the oils/condensate of the Bonaparte and Browse Basins

The third oil family comprises condensate from the Sunrise Field. This condensate has a biomarker signature that is atypical of North West Shelf hydrocarbon accumulations in that it appears to have a marine carbonate origin, as demonstrated by the abundance of 30-norhopanes, with C_{29} hopane being the dominant hopane. The only other known condensate in this region with similar composition is from Buffon-1 in the Browse Basin. These hydrocarbons are reservoired within the Lower–Middle Jurassic Plover Formation, and may originate from pre-Jurassic source rocks. Alternatively, the carbonate signature in these condensates may originate from diesel contamination in the drilling muds; further work is required to resolve this issue of possible contamination.

A fourth oil family (not shown in figure 3), comprising the Elang West-1, Kakatua North-1 and Layang-1 oils (all reservoired in the Lower Cretaceous Darwin Formation), was recognised in the northern Bonaparte Basin by Preston and Edwards.[11] These oils have a marine clastic signature and have been correlated to the underlying Echuca Shoals Formation. Some similarity is seen between these oils and the Early Cretaceous oil family (Caswell-2 and Gwydion-1; figure 3) identified by Blevin and co-workers in the Browse Basin.[2]

Regional implications

These studies have identified numerous oil families and petroleum systems in the Bonaparte Basin, and highlight the fact that both Palaeozoic and Mesozoic source units are effective in the region.

The Permian system, previously known only as a gas/condensate system in the Petrel Sub-basin, has been shown to be more widespread and extends across the Londonderry High to the Sahul Platform and eastern Browse Basin. Fluid inclusion data indicates that this system has generated substantial palaeo-oil accumulations on the Londonderry High. Source rock data and

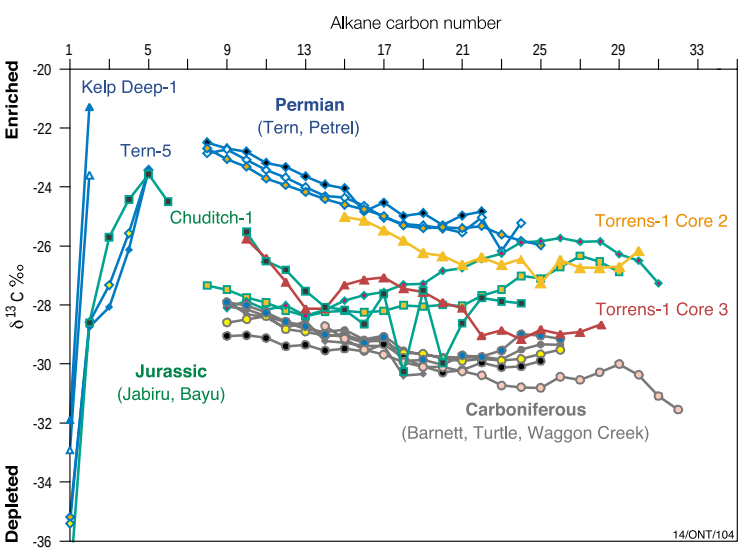

Figure 4. Plot of $\delta^{13}C$ versus carbon number for *n*-alkanes from selected Bonaparte gases, condensates and oils

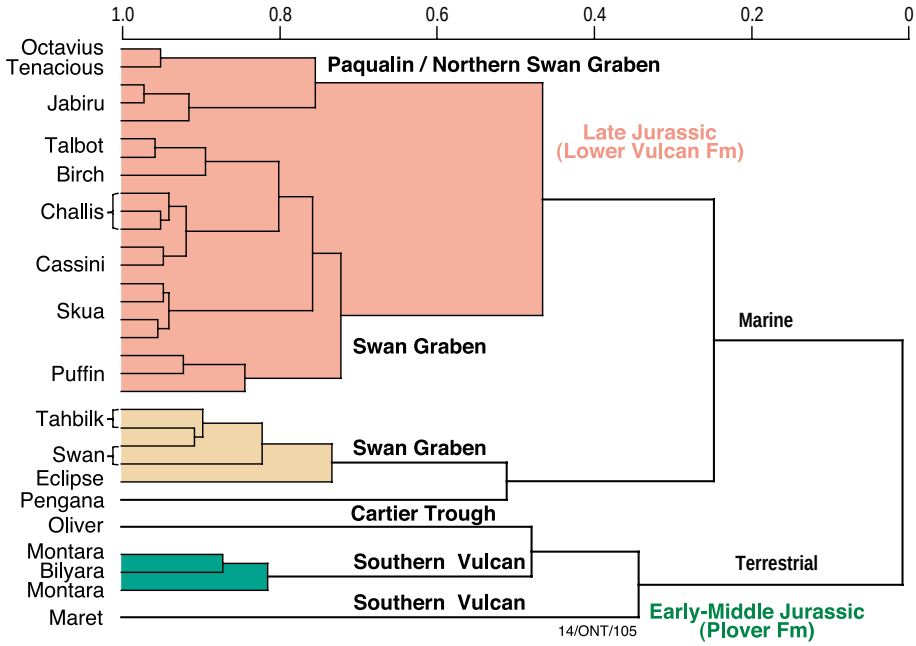

Figure 5. Dendrogram of the Vulcan Sub-basin oils and condensates

palaeogeographic facies maps suggest that oil-prone coaly shales of the Lower Permian Keyling Formation probably extend across the Londonderry High and around the southern and north-eastern margin of the Petrel Sub-basin. The Permian system is untested on the Ashmore Platform, but oil potential here is suggested by the presence of interpreted SAR oil slicks.

Previous studies focusing on Mesozoic plays in the Bonaparte Basin have made the somewhat simplistic assumption that most hydrocarbon accumulations in the western and northern Bonaparte Basin have been charged from Upper Jurassic source rocks. Although this is true for the producing fields in the Vulcan Sub-basin, it is now apparent that there has been a significant contribution to hydrocarbon reserves in both the northern Bonaparte Basin and southernmost Vulcan Sub-basin from the Lower–Middle Jurassic Plover Formation. If plays can be identified where the timing of hydrocarbon generation and trap formation is more favourable to preserve Early–Middle Jurassic-derived liquids, then this system could add significant reserves to the region. Furthermore, non-Jurassic, oil-prone petroleum systems have now been identifed in the Browse Basin (Gwydion-1, Caswell-2 and Cornea Field[2]) and northern Bonaparte Basin (Elang West-1), both of which are sourced from Lower Cretaceous marine mudstones.

An additional (?)Early Mesozoic petroleum system may be indicated by the condensates at the Sunrise Field and Buffon-1 near the outer margins of the Australian plate. These condensates have a distinctive, marine carbonate biomarker signature, and may form part of the oil-prone Late Triassic–Early Jurassic carbonate system known in the Australian–Banda boundary complex to the north.[12] This carbonate system includes oils from the islands of Buton, Buru, Seram and Timor, and may also be prospective along the outer margin of the Bonaparte–Browse Basins.

In summary, the Bonaparte Basin has greater hydrocarbon potential than is currently recognised since several other source units besides the well-known Upper Jurassic marine mudstones are also capable of generating liquid hydrocarbons.

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Hydrocarbon seepage in Carnarvon Basin subject of major study

AGSO and its partners, Signalworks Pty Ltd and Nigel Press & Associates are investigating hydrocarbon leakage and seepage in the Carnarvon Basin (figure 1). The study is using several independent remote-sensing technologies, namely:

- double-coverage RadarSat Synthetic Aperture Radar (SAR). SAR is effective for mapping oil-prone leakage and seepage;
- 20 000 kilometres of reprocessed Mark III Airborne Laser Fluorosensor (ALF) data. ALF effectively maps oil and condensate leakage and seepage. Interpretations from reprocessing BP regional legacy Mark II ALF data through the area are also being used, as are BP's original interpretations from the Mark II ALF surveys;
- more than 2000 kilometres of water column geochemical sniffer (WaSi) data, which detects oil, condensate and gas leakage and seepage; and
- Landsat data.

The interpretations derived from these technologies (i.e. SAR, WaSi, ALF and Landsat) are being been compared and contrasted, and then integrated with regional seismic data, isopach maps of key reservoir, source and sealing units, and fault maps.

The goals of the study are to:

1. provide a soundly based understanding of the relative responses of these technologies to different types and rates of hydrocarbon seepage; and
2. determine the nature of, and principal controls on, hydrocarbon seepage within the Carnarvon Basin.

Lessons learnt in the Carnarvon Basin, and from a recently completed similar study in the Timor Sea, will be applied to evaluations of frontier exploration areas around Australia.

For more information about the study phone Dr Geoff O'Brien on +61 2 6249 9342 or e-mail geoff.obrien@agso.gov.au

Figure 1. Study area of seepage investigation, Carnarvon Basin, North West Shelf. Area covered by BP ALF data (now reprocessed) is shown in red; area covered by Fugro ALF survey (now reprocessed) is shown in blue. Water column geochemical sniffer data covers parts of the basin.

Continued from page 11

networking, computer security and web servers. You then need good webmasters, database administrators, and application developers. Finally you need people to supply the content—the information to go in the databases and on the web. In organisations of any size it is impossible for one person to be across all these skills; a team is generally needed to run web sites of dotcom organisations. Increasingly, though, it is the database administrator who occupies the pivotal position, and has the most demanding job. In organisations that float on seas of information, the database administrator is the pilot. One must look after the DBA role carefully, or risk disorganisation.

Web delivery of geoscience data

In organisations like AGSO there is a clear distinction to be made between standard national databases and the more ad-hoc datasets and documents produced particularly by research projects. However, both types of information have to be adequately managed as we move towards an era in which online delivery of geoscience information is the norm. Both information types demand that attention be given to the backend part of the total information management environment.

In regard to ad-hoc types of information, I include all traditional documents, papers and publications, most of which will soon be routinely available on AGSO's intranet and/or web site. Some may be handled by a document management system, such as 'TRIM', that can use the Oracle 8i database management system as its backend. Alternatively, Oracle's WebDB 3.0 may be used to place many documents on the intranet and web. Either way, vast amounts of unstructured written material will find their way into the backend database management system in the near future. It is also likely that processed images and project GIS datasets will eventually migrate into the corporate database system, rather than, as at present, be kept in computer files on 'corporate' UNIX disk systems. Almost all datasets that projects currently publish on CD-ROM will probably end up in the corporate database system for online delivery.[3] The demands on the backend will be heavy indeed. The infrastructure to handle the metadata for ad-hoc information is already at hand as the AGSO Catalog.[4]

The formally structured national geoscience databases that have been an integral part of AGSO's information store for more than 20 years are being made available on the web in user-specified chunks. In one mode, the user is able to construct a map of the area in which they are interested by selecting required GIS layers. They should then be able to obtain all the spatially related attribute data that AGSO has in the backend databases (as in figure 1). All laboratory data should be made available, and in the case of geological field data there are thoughts of capturing videos of critical outcrops, in which geologists explain the relationships.

Another mode of use is where other web sites transparently access AGSO data via portals, as if it were their own. AGSO is a participant in the Australian Spatial Data Initiative which has already demonstrated distributed web mapping, with data drawn online from dispersed agencies. The web enables many different data types to be integrated from many sources, but the components are best kept in well-controlled backend databases.

Restructuring for online delivery

One of the main lessons to be learned as we enter the dotcom era is that we must organise properly for online delivery of geoscience data. The task should not be left to individuals scattered among disparate projects. Individual projects can, and sometimes do, set up web interfaces for online delivery of certain types of data, and some of these interfaces are effective. However, such practices 'reinvent the wheel', and time and money are wasted on systems that cannot be readily integrated with other online systems. The web site can easily become an expensive mishmash of disparate systems. We have already experienced instances of this in AGSO.

Information management and delivery is too important a core function in today's geological surveys to relegate to dispersed groups within the organisation. In the current climate it is axiomatic for a dotcom organisation that online information delivery be managed by a well-integrated, multidisciplinary team with good communication skills. Furthermore, this team should act as an ongoing service group, rather than a project. The team must include a strong backend group, specifically those with database administration and development skills. In time, when the systems and procedures for online delivery become established, responsibility can be more devolved. As procedures become routine, the team size can be reduced and many members redeployed into other areas.

There is little doubt in my mind that geological surveys should consider setting up formal information divisions (if they have not already done so) to properly handle the difficult new paradigm of online geoscience information delivery.

Conclusions

- Successful online delivery of geoscience information requires good backend databases.
- Web sites that rely exclusively on hierarchical directory systems do not scale well.
- Object-relational databases, such as Oracle 8i, are built to handle all sorts of information.
- Database administration has recently become a much more complex and critical job.
- Online delivery requires a focused approach to data acquisition and database design.
- Both structured and unstructured types of information must be catered for on the web.
- Geological surveys may need to restructure to better support online information delivery.

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Customised regolith maps incorporate hydrologic modelled attributes for geochemical exploration

JR Wilford & D Butrovski

Regolith-landform maps provide an important geomorphic and landscape evolution framework for developing more effective geochemical exploration strategies, and in the interpretation of geochemical datasets in highly weathered terrains. Recently, customised and more focused regolith-landform maps have been compiled to provide direct information for the exploration industry. These new maps show specific information for geochemical exploration including, for example, recommended sampling strategies, estimated thickness of transported cover, and modelled hydromorphic attributes to assist in metal dispersion studies.

Regolith is particularly well developed in Australia with more than 80 per cent of the continent's surface characterised by highly weathered bedrock and/or transported materials. The formation of an extensive blanket of transported regolith and weathered bedrock in Australia is largely due to:

- long exposure of most of the land surface to sub-aerial weathering;
- preservation due to the overall low relief and recent arid climate with associated low rates of geomorphic processes; and
- tectonic stability of the Australian landmass.

Mapping the regolith, understanding past and present geomorphic/geochemical processes and developing models of landscape evolution are key factors that underpin geochemical exploration in deeply weathered landscapes.[1]

Mapping regolith in Australia is largely based on a lands system approach. A lands system is defined by Christian and Stewart as an area of land throughout which recurring patterns of topography, soils and vegetation can be recognised.[2] The key to the land system approach is the recognition of the interrelationships between landforms, soils and vegetation. Soil scientists have long recognised these relationships and have used the term 'catena' to describe a repeating sequence of soils that are spatially associated with changes in topography. These relationships form the basis for regolith-landform mapping. Regolith-landform maps use landforms as the principal surrogate for mapping regolith materials and this is justified by the close spatial and genetic associations between regolith and topography. Landform attributes are derived from aerial photography and, where available at appropriate detail, digital elevation models. In areas of poor landform expression, other mapping surrogates such as gamma-ray spectrometry and enhanced Landsat TM imagery become the principal datasets from which regolith boundaries are derived.[3]

The first 1:250 000 regolith-landform map over the Ebagoola map sheet was compiled by AGSO in 1992.[4] The map was compiled from existing geological mapping, aerial photographs and gamma-ray spectrometric imagery. The use of gamma-ray imagery for mapping regolith including soils[5] and in understanding landscape processes was relatively new at the time, but the imagery is now used widely in regolith map compilation and more recently in soil/landscape modelling.[6]

The Ebagoola map and other similar maps[7,8] are generic products with equal application for mineral exploration and land-use assessment. Since the mid-90s a new generation of specialised and tailored regolith and thematic maps for the exploration industry have been developed—through the activities of the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME). Examples from Leonora (WA), Tanami (NT), and Selwyn (Qld) are used to illustrate these new thematic maps (see locations in figure 1).

Geochemical sampling strategy maps

Geochemical sampling strategy maps are hybrid regolith-landform maps (figure 2) that have been specifically designed to aid interpretation of geochemical datasets and for developing geochemical sampling strategies. Geochemical sampling strategy maps build on the standard regolith maps that show in-situ and transported materials. They do this by incorporating additional information from detailed regolith-geochemical orientation studies.[9] These studies are usually undertaken at local district scales (e.g. a 5 x 5 km area or mine sites). They provide detailed descriptions on the composition and distribution of the regolith, and information on the physical and chemical dispersion processes that have occurred or are currently active within the regolith.

Knowledge gained from these studies, in particular metal dispersion processes and recommended sample

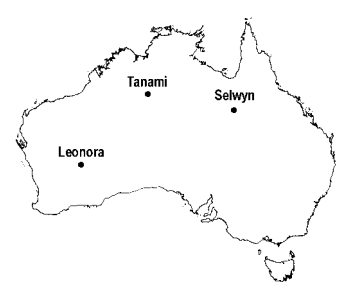

Figure 1. Location diagram of the study areas—Leonora, Tanami and Selwyn

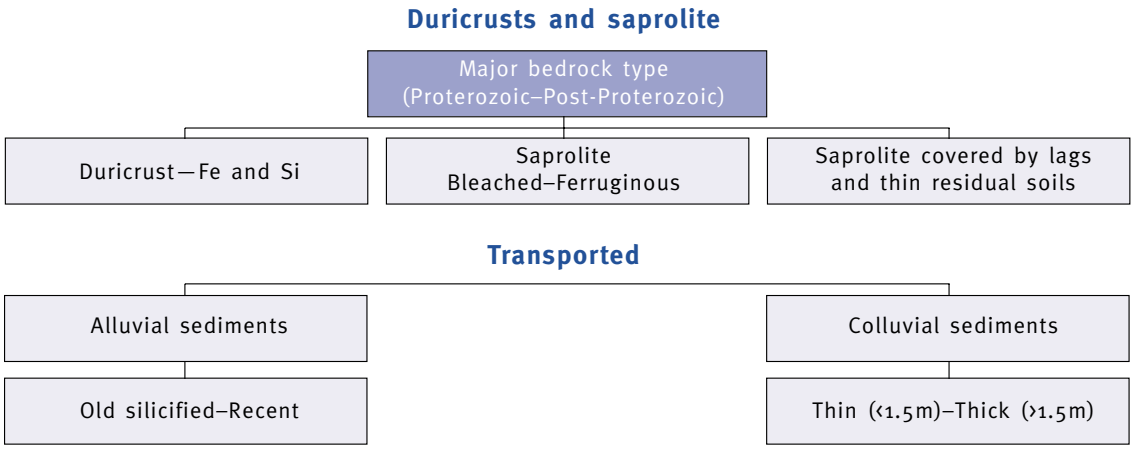

Figure 2 (above). Major geochemical sampling groups that are used in a geochemical sampling strategy compiled over the Selwyn area 140 kilometres south-east of Mount Isa.[9] Bedrock age is used first to separate the landscape into prospective and non-prospective terrains. Then major in-situ and transported regolith materials are identified and grouped into geochemical exploration domains. These major geochemical groups are specific to the Selwyn region; other areas are likely to show different associations reflecting their specific geologic and landscape histories.

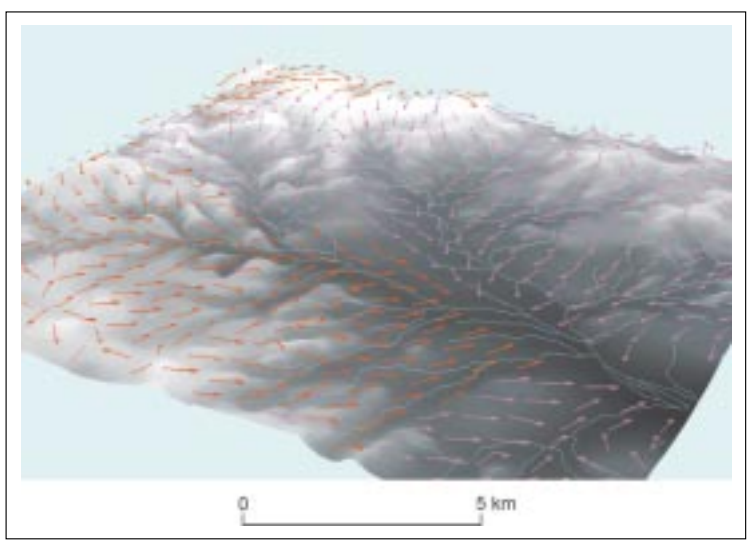

Figure 3 (left). Surface flow vectors draped over a digital elevation model. The length of the arrows generated by the algorithm can be proportionally scaled to the flow accumulation or slope of the DEM. Surface flow direction including areas of flow convergence and divergence is readily interpreted from the model.

types, are then incorporated and extrapolated to the wider area via geochemical sampling strategy maps. Units on a geochemical sampling strategy map are grouped by their regolith-geochemical characteristics and sampling approach—for example, lag (lithic, ferruginous, calcareous), soil or drilling. Although the units on a geochemical sampling map are largely based on the physical and chemical characteristics of the regolith, genetic landscape models are involved in the classification processes. The geochemical sampling strategy map is therefore an interpretive product that has more focus than the standard descriptive-based regolith-landform map. Primary descriptive regolith and landform attributes are also provided in the GIS from which the maps are generated, allowing the user to modify or develop new geochemical strategy classification schemes where necessary. The maps are further enhanced by incorporating hydrological attributes (see figure 3) derived from digital elevation models (DEMs).

Integrating hydrologic attributes

From a mineral exploration perspective, hydro-geomorphological processes are critical in understanding landscape geochemistry—particularly in element dispersion studies. Chemical weathering through hydrolysis, oxidation and reduction reactions, and movement of sediment and solute materials (both vertically and laterally in the landscape) are mainly controlled by surface and near-surface hydrologic pathways.

Water will move downslope in two ways: as overland flow and as through-flow. Overland flow or runoff consists of surface flow that occurs when rainfall exceeds the infiltration rate of the upper part of the regolith. Sheetflow is a common form of overland flow. Concentrated or channelled overland flow typically results in stream flow. Through-flow in contrast is the movement of water through the regolith. Water

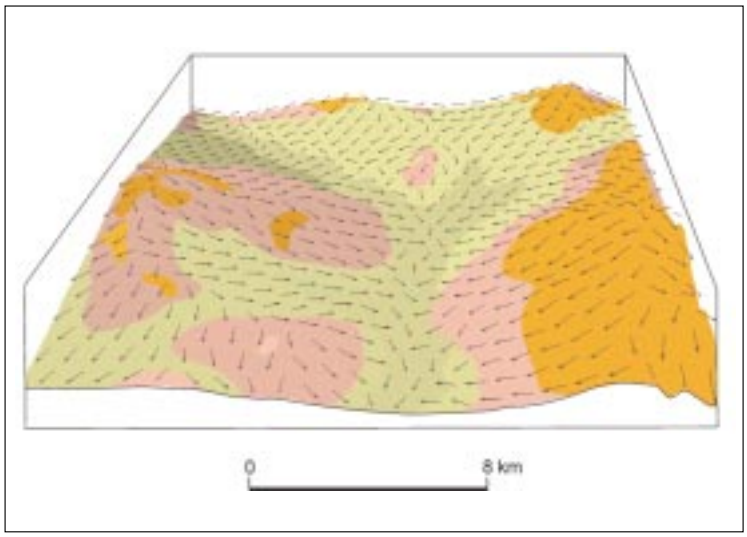

Figure 4 (left). Flow vectors superimposed on a regolith map over part of the Tanami region in the Northern Territory. Regolith units are classified according to thickness of sediments (orange-brown ‹1 m, green 1–10 m). The Tanami area has poorly defined drainage patterns and very low relief. Most sediment is being shed into lower parts of the landscape in the form of colluvial sheet flood fans, rather than in discrete channels. The surface flow vectors predict the likely movement of colluvial sediments in the landscape. As a consequence, flow vectors are important to understanding geomorphic dispersion processes—particularly in relation to soil or lag geochemical surveying.

movement as through-flow has an important control on the intensity and depth of weathering and the movement of solute materials in the regolith.

Although regolith map units imply past palaeo and present hydro-geomorphic processes (e.g. colluvial sheet flood fans, alluvial sediments), the direction of transport and provenance of sediments are generally not well shown. This is particularly true in areas with gentle slopes and poorly defined surface drainage, which typify large parts of central Australia (figure 4).

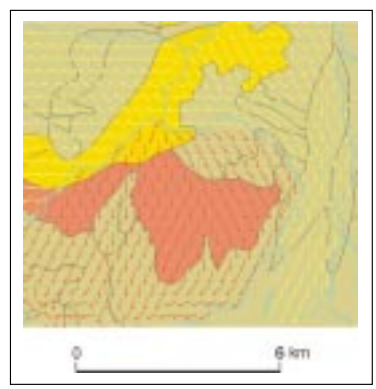

Figure 5 (above). Flow vectors superimposed on a DEM over part of the Leonora map sheet in the Eastern Goldfields of Western Australia. Sediments derived from granite and greenstone lithologies have been coloured red and yellow, respectively. Catchment boundaries are shown in blue.

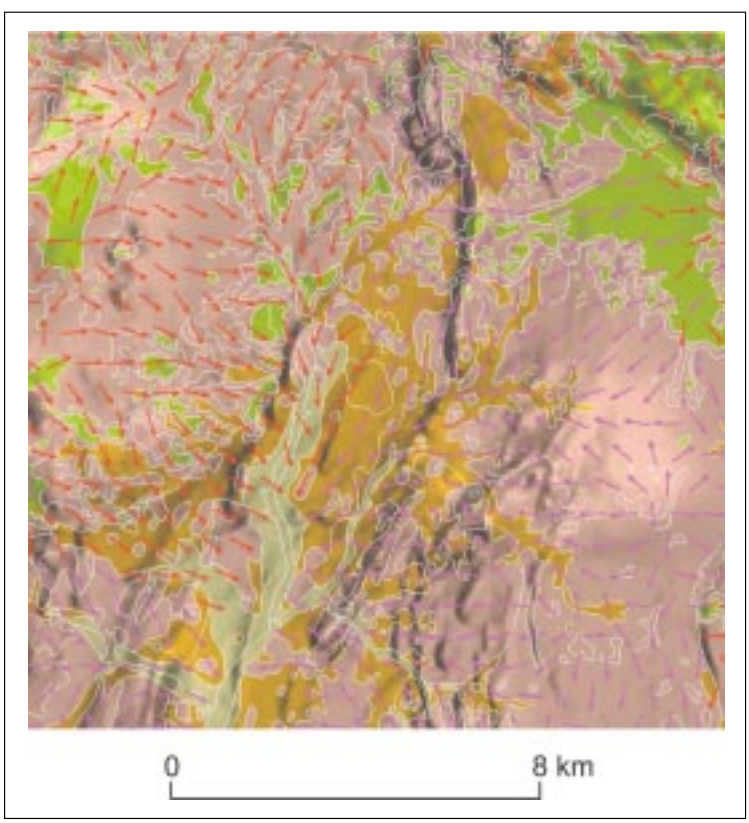

Figure 6 (left). An airborne magnetic image with a first vertical gradient (courtesy of Mount Isa Mines) has been embedded into the map to add a bedrock/structure dimension to the interpretative process. Flow vectors overlayed on a geochemical sampling strategy map over part of the Selwyn region 140 kilometres south-east of Mount Isa. This combination allows geochemical datasets to be interpreted in terms of the regolith materials, areas of active erosion, potential mechanical and chemical dispersion patterns, and provenance of sediments.

DEM-derived surfaces can complement regolith maps by providing information about hydrological and geomorphological processes in the landscape.[10] Holyland discusses the use of DEM for generating slope vectors maps for soil sampling and hydromorphic dispersion studies, and in generating drainage divides and stream intersections points for stream sediment surveys.[11] Building on Holyland's work, an algorithm has been developed that uses DEMs to generate overland (surface) flow vectors and then integrates the vectors with regolith and geological maps using stream catchment boundaries.

The first part of the algorithm generates surface flow vectors in the form of arrows that indicate the likely movement of sediments and solutes in the landscape.

Overlaying the flow vectors on regolith and geochemical maps allows surface flow directions, including areas of flow convergence and divergence, to be analysed with respect to regolith/lithological materials.

After the arrows have been generated, the second part of the algorithm uses drainage catchments to analyse these flow characteristics in association with regolith or geological units. Catchment boundaries are generated automatically from the DEM or imported as a polygon layer. The algorithm is capable of automated delineation of catchment boundaries at various scales. Catchment scaling is controlled by factors such as the minimum allowed catchment size (area), flow accumulation threshold at which drainage networks derived from the DEM begin to form, and the minimum stream order at which catchments may form. To prevent discontinuity in creation of drainage networks, and to ensure correct catchment delineation, all sinks that may be present in the DEM are filled before applying the algorithm.

Regolith types or lithologies likely to contribute to the greatest supply of sediment within each catchment are automatically identified. The arrows are then coloured to indicate sediments derived from different sources (figures 5 & 6). This is done by firstly identifying the active eroding parts of the catchment using a slope derived from the DEM. High slopes correspond to zones of active erosion. Intersecting the zones of high slope with the underlying geological or regolith map units is used to determine the predominant lithology or regolith material that is likely to be contributing the most sediment within each catchment.

Combining the datasets in this manner allows potential mechanical and chemical dispersion patterns to be linked directly to regolith and lithological materials. These DEM-derived surfaces are then overlayed on the geochemical sampling strategy map allowing geochemical datasets to be interpreted in a regolith, hydromorphic and geomorphic context. Further integration and customisation are achieved by combining these themes with other datasets such as airborne magnetics (figure 6). This integration is achieved using colour–space transformations where the intensity, hue and saturation components of colour are used to combine different datasets.

Limitations in interpretations

There are some important assumptions and limitations to consider when interpreting surface flow maps. Surface water flow maps generated by this technique are based exclusively on information presented in a DEM. They do not take into account variation in infiltration rates caused by factors such as soil depth, texture and vegetation cover. Flow patterns are likely to relate to present-day geomorphic processes or the last geomorphic event. If the present-day topography differs markedly from the palaeo-topography, the hydrological regime predicted by this technique is unlikely to correlate with the distribution of older regolith materials. In such cases, the surface flow maps will show the likely re-distribution of these older materials in the landscape by present-day processes. Also the flow grids are based on surface flow only; movement of deeper groundwater may have little correlation with the topography-derived water flow model, particularly in low-relief landforms.

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