zinc. Uranium, thorium, and cerium are significant in places, particularly in the more alkaline granitic rocks in the southwestern extension of the Schwaner Range.

The wide range of ages and rocks associated with the gold strongly suggests that the small-scale geological mapping has provided only the broad picture and that much more research must be done to determine more precisely the origins of the widespread gold in Kalimantan. In structural terms, for example, there are indications that gold may occur in both detachment horizons and normal faults. (Published with the permission of the Director, GRDC.)

Some results of the collaborative surveys in both Irian Jaya and Kalimantan are available in published form or as open-file reports at GRDC, Jalan Diponegoro, 57, Bandung, Indonesia; these may be discussed with Dr Rob Sukamoto and Mr Sam Supriatna at GRDC, and Mr David Trail and Dr Peter Pieters (BMR) in Bandung at Jalan Cikasak, 49, phone (022) 72103. Information on the project can be obtained in Australia from Mr John Casey at BMR (Special Projects & Geoscience Services Branch).

Biomarker research and its application in petroleum exploration

Hydrocarbon biomarkers are being increasingly used to determine the geological history of a petroleum deposit and have application in the determination of thermal history, oil and oil-source correlation and in recognition of altered oils. BMR is actively engaged in identification of new hydrocarbon biomarkers and their application in petroleum exploration.

What are biomarkers?

Sedimentary rocks record a wide variety of ancient environments and are hosts for the fossilised remains of the living creatures which populated those habitats. The bulk of biomass is, however, composed of microorganisms, comprising bacteria, algae and fungi. Most of these are without skeletal tissue and have little chance of preservation in a recognisable form, except in very favourable circumstances. Microbes may, however, leave a record of their presence through the modified but identifiable residues of the lipids which formed their cell membranes. Many higher plants also leave chemical residues which once constituted their cuticular waxes, resins, and essential oils. These molecules, which are mostly preserved in the form of hydrocarbons, are known as hydrocarbon biomarkers.

Chemical fossils occur in all organic-rich rocks and petroleum. They do not represent the remains of an individual organism in the same way as a shell or a bone but rather a 'brew' comprising the residue of an entire community. Such a mixture will include the relics from the original primary producers or photosynthesisers, as well as the subsequent waves of grazing or heterotrophic organisms beginning with meiofauna, protozoans, fungi, and bacteria which use oxygen, followed by anaerobes such as sulphate-reducing bacteria and finally by methanogens. If sunlight persists to depths where the waters become anaerobic then the photosynthetic bacteria may be important community members.

The usefulness of biomarkers lies in the recognition of systematic chemical structure features which can be related to specific molecules in the precursor organism. Primitive as they are, microbes have continued to evolve from their earliest appearance about 3500 million years ago, giving rise to distinctive and recognisable chemical components analogous to the morphological features that allow us to distinguish shells from insects or fish, etc.

New techniques for biomarker detection

The complexity of the mixtures of naturally occurring hydrocarbons, and the low concentration of structural and functional specificity of the molecules of interest present formidable challenges to the analyst. Gas chromatography and mass spectrometry (GC/MS) continue to be the mainstay analytical methods in organic geochemistry. Newly available aluminium coated capillary columns extend the upper temperature limits and consequently the molecular size of analysable compounds. Tandem mass spectrometers for MS/MS and GC/MS/MS are being increasingly employed to refine the specificity of the measurements and this results in significantly lower detection limits and higher accuracy in quantitative measurement. A further major advance and to be generally available in the near future is the carbon isotope GC/MS which will facilitate determination of the δ13C measurement for individual hydrocarbons in an oil or sediment extract, adding a complete new dimension to biomarker profiles. UV/VIS spectrophotometers continue to be the most sensitive detectors for high performance liquid chromatography (HPLC), restricting analyses to those compounds which absorb in these wavelengths but providing many new applications in the study of aromatic hydrocarbons and porphyrins.

Biomarkers as thermal indicators

Some of the most significant recent advances in biomarker chemistry are in the use of the ratios of key molecules to determine the thermal history of a sediment. Research into the formation and subsequent isomerisation of aromatic compound classes such as methylnaphthalenes, methylnaphthene- nes, and alkylphenyls has identified changes which are affected more by time than by temperature and vice versa. This then opens the possibility of quantifying both upper temperature limits and heating rates, data which in turn can be applied in basin modelling studies. A new source rock maturity indicator for marine sediments based on an HPLC analysis of porphyrins has recently been identified, allowing unequivocal recognition of the generation status of a particular source interval.

Biomarkers as palaeoenvironmental and biostratigraphic indicators

Continuing improvements in understanding the chemical structures of new classes of biomarkers leads to new indicators for palaeoenvironmental reconstruction and oil-source correlation. A recent example arising from research by the BMR group is the tracing of the origins of a homologous series of trimethylnaphthalenes (Fig. 8) found in certain oils and source rocks to their source organism, Chlorobium sp., by a combination of their chemical structures and carbon isotope signatures. Chlorobium sp., or green sulphur bacteria, require both low light and anaerobic, sulphide-rich waters for growth, thus indicating a quiet, stratified marine water body for the depositional environment of the source rock. In another BMR study, the distributions of C30 4-methyl sterane isomers, which are known to be produced by dinoflagellate algae, showed dramatic differences between marine oils/source rocks and those occurring in sediments deposited in deep eutrophic lakes (Figs. 9).

The C30 4-methyl steranes described above appear to be largely confined to sediments of Mesozoic and Tertiary age. Continuing BMR research has shown that a previously unknown class of steroids with methyl substitution at positions 2- or 3- of ring-A predominates in sediments of Proterozoic and Palaeozoic age (Fig. 10). Research associated with BMR projects on potential Proterozoic source rocks has led to the recognition of distinctive patterns of bacterial triterpanes and branched alkanes. Carboniferous and younger rocks with input of terrestrial higher plants contain distinctive diterpenoid hydrocarbons. These are just a few examples of biomarkers which show restricted distribution in time and space, and have the potential to confine the possible age of oils and indicate where the age of reservoir and source rock may be significantly different.

Biomarkers for oil-oil and oil-source correlations

The advent of GC/MS/MS has meant that we can visualise distribution patterns for specific classes of biomarkers unaffected by interference from other components in the oil and can detect
compounds which up to now were screened by co-eluting components. The value of determining carbon isotope signatures of individual hydrocarbons has also been demonstrated for delineating their source organisms. Sophisticated methods exist to separately identify changes in hydrocarbon composition of oils arising from thermal effects and from biodegradation. A combination of all these advances is leading to widespread and confident use of biomarkers to relate oils to each other and to their original source rocks. Together with improved recognition of the factors affecting conversion of kerogen to petroleum and its primary and secondary migration, organic geochemistry and particularly biomarker studies are going to be increasingly useful tools for the explorationist.

BMR organic geochemistry research

The principal thrust of the BMR organic geochemistry research is a thorough characterisation of the petroleum source rocks of Australia. Projects in their concluding stages have concentrated on Proterozoic and early Palaeozoic basins, the Toolebuc Formation (Cretaceous), and a general study of coals and non-marine sediments to identify criteria for source rock quality and the timing of oil generation. The Canning Basin and a selection of potentially important Palaeozoic and Mesozoic sediments will be the focus of new studies together with continuing work on the chemical characterisation of new biomarkers and the biology of their source organisms. The longer-term aim of these individual projects is the marriage of biomarker and other source rock data to the sedimentological and palaeoenvironmental setting of the host rocks, leading to predictive models of source rock distribution and characteristics in Australia. Explorationists are invited to collaborate in organic geochemical studies related to particular regional problems or specific exploration objectives in Australia.

For further information contact Dr Roger Simmons or Dr Trevor Powell, at BMR (Division of Continental Geology).

Petroleum potential of the Clarence–Moreton Basin upgraded

The Clarence–Moreton Basin in southeastern Queensland and northeastern NSW contains Mesozoic sediments in part equivalent to oil-producing sequences in the Surat and Eromanga Basins to the west. BMR, together with the Geological Surveys of NSW and Queensland, has been studying the basin for the past four years. This has included a source-rock investigation with CSIRO and the University of Melbourne School of Earth Sciences. Mature, high-quality oil-prone source rocks have been identified, enhancing the basin's petroleum potential.

Until this study, little was known of the basin's source-rock potential in comparison with the Mesozoic oil-producing basins in eastern Australia. Four hundred samples of carbonaceous mudrocks and coals were examined by Rock Eval pyrolysis. Some of these were further subjected to (1) extraction and analysis of hydrocarbons, (2) organic petrographic analysis, (3) vitrinite reflectance measurement, and (4) elemental analysis and pyrolysis gas chromatography of kerogen isolates. Sampling concentrated on the Walloon Coal Measures and underlying units because younger formations crop out extensively and are not considered to have hydrocarbon potential.

Source rock abundance

Figure 11 shows the revised stratigraphic column and histograms of the abundance of potential source rocks. The first set of histograms shows that the Walloon Coal Measures contain the largest proportion of fine-grained facies; the second set shows that the Walloon shales and coals are the richest in total-organic-carbon (TOC), followed by the Koukandowie Formation. Other units contain some mudrocks but are low in TOC. The histograms are only a broad guide to source-rock abundance because mudrock facies are very variable in these non-marine units and sampling was biased towards organic-rich lithologies. They indicate, however, that carbonaceous shales and coals are abundant not only in the Walloon Coal Measures but also in the Koukandowie Formation.

Source-rock quality

Rock Eval pyrolysis data show that the coals and carbonaceous shales are at least as rich in oil-prone terrestrial organic matter as their contemporaneous equivalents in the oil-producing Eromanga Basin, and in some cases richer. The Walloon coals are renowned for their high hydrogen content, and in petroleum source-rock terms are classified as Type II/III organic matter (Fig. 12). These hydrogen-rich coals are not confined to the Walloon Coal Measures but occur throughout the Clarence–Moreton sequence. The organic matter in the carbonaceous shales ranges from superior to inferior in source rock quality to that in the coals; it ranges from Type III to Type II, the better quality organic matter occurring as cannel coal.

Source rock maturity and burial history

Vitrinite reflectance and Tmax data (from Rock Eval) indicate a progressive eastward increase in source-rock maturity. The isoreflectance map for the Walloon Coal Measures (Fig. 13, overleaf) shows that they are immature in the western part of the basin but reach oil maturation levels in the south-central part. They are overmature along the eastern basin margin. The underlying Raceview Formation is in the oil generation zone where the Walloons are immature, and overmature where the Walloons are in the oil zone. Fission track ages of apatites from surface samples analysed by the Fission Track Research Group show that burial history and source-rock quality in the Walloon Coal Measures have been controlled by tectonic events rather than simple burial.

Fig. 11. Revised stratigraphy of the Clarence–Moreton Basin, and petroleum source rock abundance. The histograms show the percentage of shale + coal in each unit versus the number of subsurface sections, and total-organic-carbon versus the number of samples.

Fig. 12. Oxygen index versus hydrogen index from Rock Eval analysis of coals and shales from the Walloon Coal Measures. The kerogens are mostly Type II and III, i.e. oil-prone.