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EXTENDED ABSTRACTS

13th BMR SYMPOSIUM
CANBERRA, 7-8 NOVEMBER 1984

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CONTENTS

* Speaker
** Paper to be given by F J Moss

NOTES

Structural concepts in extensional basin interpretation

M.A. Etheridge, J.C. Branson, & P.G. Stuart-Smith

Lithospheric stretching is generally considered to be one of the most important mechanisms of subsidence and basin formation, especially at passive continental margins. In the upper part of the crust, the stretching is accomplished by normal faulting. Extensions of the magnitude proposed for typical basins (50-100%) require specific and unusual fault geometry, which may play a key role throughout subsequent basin development. We suggest that the structural concepts of large-extension faulting should be routinely applied in seismic interpretation of extensional basins.

The structural history of extensional basins is most conveniently considered in three phases:-

1.) <u>Extensional Phase</u> - The main extensional structures are of two types; a set of rotational, planar, or listric normal faults, and a perpendicular set of sub-vertical transfer faults. The normal faults are straight to gently curved, have low to moderate dips, and bound tilted basement blocks and syn-rift fill (with poor seismic data the dip of the syn-rift is commonly the best guide to fault orientation and position). The faults commonly dip the same way across the whole basin, but they may change dip across transfer faults. Large displacements (>1 km) are possible, making it unlikely that such faults die out over a short distance. However, they will generally terminate against transfer faults, which are accommodation structures analogous to oceanic transform faults. At rift-fill level, displacement across a transfer fault varies along its length, giving rise to discontinuous traces and unusual geometry (e.g., hinge faults). Seismic sections oblique to normal and transfer faults may give rise to unusual geometry, whose interpretation would be difficult without application of extensional structural concepts.

2.) <u>Subsidence Phase</u> - Subsistence follows extension owing to cooling of the stretched lithosphere. During subsidence, displacement are essentially vertical, smoothly varying, and relatively small, giving rise to the closely spaced steep faults with less than 1 km displacement that are typical of so many basins. These faults will generally be down-to-basin and irrotational. They tend to be uniformly distributed throughout the basin, but reactivation of the extensional structures during subsidence may control their distribution in detail.

3.) <u>Later Reactivation</u> - At any stage in the basin history, a change in tectonic setting may superimpose structures on an extensional basin. Most importantly, the major normal and transfer faults developed during extension provide zones of weakness through much of the crust. Reactivation of these zones of weakness controls the style, orientation, and location of a wide variety of later structures. For example, early normal faults may be reactivated as reverse faults, and subsequent strike-slip movement on transfer faults may produce a range of wrench-style structures in the overlying sequence.

NOTES

Dynamical models of lithosphere extension, with reference to sedimentary basin formation

G.A. Houseman

Research School of Earth Sciences, Australian National University

The lithosphere extension model proposed by McKenzie (1978) has recently received increasing attention in tha analysis of basin tectonic and subsidence histories. It specifies a uniform horizontal extension, followed by thermal subsidence as the lithosphere returns to its original thermal equilibrium. This model or some variant of it has been applied by different authors to the Aegean Sea, the North Sea, the Bass Basin, and several other examples. The modelling to date is essentially kinematic, in that extension factors have been estimated without reference to the forces driving the tectonic activity. The work described here examines the stress state in the extending lithosphere in order to further develop the extensional model, and, possibly, to obtain useful constraints on the rheology of the lithosphere.

An extensional stress field in the lithosphere can result from localised elevation of the lithosphere by a hot rising thermal sheet or plume in the convecting mantle below. The lithosphere responds to an extensional deviatoric stress by normal faulting in the upper part of the crust and by ductile flow at greater depths. The model assumes that the strongest part of the lithosphere is the upper mantle, and uses the rheological laws for olivine summarised by Goetze (1978). For uplift of 1 km by a convective plume, the depth-averaged deviatoric extensional horizontal stress is around 16 MPa. The resulting strain rates depend strongly on the temperature in the upper part of the mantle.

Numerical models have been used to calculate the evolving temperature and stress fields in the extending lithosphere. The extension will be self limiting if the initial strain rate is sufficiently small, since cooling of the upper mantle associated with the thinning crust causes the ductile rheology to freeze (England, 1983). The subsidence histories for these theoretical extension models show several stages: (i) uplift (and possibly erosion), owing to plume formation; (ii) contemporaneous extension (active normal faulting), resulting in subsidence, owing to the thinned crust; (iii) thermal subsidence, owing to the cooling of the extended lithosphere; and (iv) further subsidence associated with the removal of the mantle plume.

References

England, P.C., 1983—Journal of Geophysical Research, 88, 1145-1152

Goetze, C., 1978—Philosophical Transactions of the Royal Society, London, A, 288, 99-119

McKenzie, D.P., 1978—Earth and Planetary Science Letters, 40, 25-32

NOTES

Evolution of sedimentary basins at convergent plate boundaries

H.L. Davies, C.J. Pigram, & D.A. Falvey

In contrast to the relatively simple extensional tectonics of the Australian continental margin, the sedimentary basins of the southwest Pacific have developed in a great variety of tectonic environments, commonly in response to convergent or transcurrent plate motions. We examine some of these basins and recognise a number of categories, as follows: forearc, backarc, rift, pull-apart, terrane collision, and foreland basins.

A transect across the central part of the island of New Guinea takes in the Papuan Basin and the northern New Guinea (NNG) basins. The Papuan Basin developed by rifting of the margin of the Australian craton in the Mesozoic and Paleocene, and was modified by local development of foreland basins in the Plio-Quaternary. The foreland basins developed by flexure of the lithosphere in response to loading by a south-vergent thrust belt on the northern margin of the basin. The NNG basins are Neogene forearc basins that formed in response to oblique subduction at the New Guinea Trench; they show a combination of north-vergent compressional and left-lateral wrench structures. One or more small deep basins may have formed as pull-aparts in a wrench environment.

The Bintuni and oil-producing Salawati basins of western Irian Jaya formed after collision of fragments of craton in the mid-Tertiary; Oligocene and older shallow marine sediments in the Salawati Basin were folded during the collision of Misool and Kemum cratonic fragments. The Bintuni Basin developed in the late Miocene, when the Kemum-Misool terrane collided with the Australian craton to form the Lengguru Fold Belt.

The New Ireland offshore basin is a former forearc basin that developed in a northeast-facing subduction system prior to Miocene collision with thick crust of the Ontong Java Plateau. The Central Solomons Basins developed along strike on the approxiamte line of the same volcanic arc, but is now in the backarc region of a southwest-facing arc, following arc reversal in the late Miocene. The Vanuatu interarc basins, similarly, have developed through an episode of arc reversal. In both the Central Solomons and Vanuatu Basins the sediments deposited prior to arc reversal were folded and faulted at the onset of the present tectonic regime.

The West Bougainville and Trobriand Basins are Neogene forearc basins related to to active New Britain Trench and the recently active Trobriand Trough trench, respectively. The Cape Frere Basin, south of the Trobriand Basin, is an active rift basin that developed as the Woodlark Basin spreading system propagated westward. Plio-Quaternary uplift of the Papuan peninsula and the D'Entrecasteaux Islands and consequent high-energy sedimentation in the Trobriand Basin were triggered by rift-related thermal arching.

N O T E S

Tectonic models for eastern Australian basins

H.J. Harrington

Between the earliest Permian and the opening of the Tasman Sea in the Late Cretaceous, five sets of tectonostratigraphic units formed in eastern Australia:

Unit	Age	Tectonic Unit	Duration (Ma)
5	'Mid' Cretaceous	Whitsunday	27
4	Early Cretaceous	Maryborough	35
3	Jurassic	Surat, Moreton	75
2	Late Trias	Ipswich, Tarong	18
1	Permian	Sydney, Bowen	48

The units can be correlated with events as far afield as New Zealand, New Caledonia, and the Eromanga Basin. It is curious that the basins that form units 1 to 4 all went through the same cycle, starting with volcanics and ending with coal measures, even though they were associated with different kinds of regional tectonic events.

The Sydney-Bowen Basin belt seems to be a set of transform basins formed by strike-slip associated with the development of oroclines (bends) in the New England-Yarrol Orogen. A Mid-Trias unconformity between units 1 and 2 occurs from Sydney and Brisbane to the central Eromanga Basin. Its origin has been a mystery, but it cannot be a mere coincidence that it correlates with the accretion (docking) of the Gympie Terrane. The breaks 2/3 and 3/4 correlate with other equally major tectonic events. Unit 5 was part of a felsic magmatic belt that was erupted immediately before the opening of the Tasman Sea.

A picture is emerging that is similar to those being obtained in eastern and western North America and in the European Alps by terrane analysis and COCORP studies.

N O T E S

Developments in concepts of hydrocarbon generation from terrestrial sources

T.G. Powell

The majority of Australia's hydrocarbon reserves have been generated from source rocks containing non-marine organic matter. Terrestrial organic matter consists of a mixture of hydrogen-rich and hydrogen-poor components. Hydrogen-rich components include cuticle, spores, suberin, and resin, and are capable of generating oil on maturation, whereas the structural parts of plants (wood, etc) are hydrogen-poor and produce only gas on maturation. The mix of these components depends, in part, on the type of plant that supplied the organic matter, and may be related to the evolutionary stage of the land plants. Mesozoic and Tertiary floras in Australia appear to have produced a greater abundance of hydrogen-rich cuticle, suberin, and resin components compared with their Permian counterparts. A second control is the depositional environment. Deposition of terrestrial organic matter in a mildly oxidising, aquatic environment results in fungal and bacterial degradation of wood and cellulose, and the concentration of hydrogen-rich components. Approximately 20 to 30% of hydrogen-rich components are required for terrestrial organic matter to be a source for oil. Oil generation from terrestrial organic matter occurs at vitrinite reflectance levels above 0.7% Ro, except where resin is a major component, when oil generation can occur at reflectance levels as low as 0.5% Ro. Gas generation is significant at reflectance levels above 0.55% Ro, and entrainment of liquid hydrocarbons in the gaseous phase means that condensate can be included in gas at all stages of maturation.

Most oils from terrestrial sources are paraffinic and may have a high wax content. The wax content is extremely variable and is favoured where depositional conditions result in the concentration of hydrogen-rich components in the source. Resin contributes a variable amount of naphthenic and aromatic oils and condensates. High pristane to phytane ratios (>3.5) and a high proportion of acyclic isoprenoids are typical of most terrestrial source oils, but those extremely waxy oils formed in lacustrine environments may have lower values. The importance of microbial processes in the formation of the source organic matter for non-marine oils is shown by the presence in the oils of a variety of hydrocarbons derived from bacterial precursors. The overall composition and isotopic composition of gases formed from terrestrial organic matter are extremely variable and poorly understood.

NOTES

Fission track thermal history analysis in sedimentary basins

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The most rapidly developing new application for fission track dating is in the study of the thermal evolution of sedimentary basins. Fission track analysis of detrital apatites is particularly important because of a substantial overlap between the apatite track annealing zone and the critical temperature interval for maximum generation of petroleum. Apatites associated with suitable source rocks thus contain a record of their heating in the oil generation window.

More information is needed than the fission track ages alone if the maximum information is to be extracted from the apatite track record. We have found that five different fission track parameters can be used to examine the thermal history of a sedimentary sequence:

1. The amount by which the each FT age has been reduced.
2. The shape of the apatite age profile with depth in the well.
3. The distribution of single grain ages in each sample.
4. The reduction in mean track length shown in each sample.
5. The shape of each track length distribution.

The shape of the age profile with depth is the product of both variations in thermal gradient and the burial history at a particular part of the basin. Sediments now at relatively low temperatures may contain evidence of past exposure to temperatures in the annealing zone. Where possible, the original pattern of ages and track lengths in the apatites prior to deposition needs to be ascertained. Additional complexity may be introduced by the increasingly clear evidence of variable annealing behaviour between apatites of different composition. In a typically mixed apatite population, however, this property results in a distinctive broadening in the range of single grain ages in the central part of the annealing zone.

When first produced, fission tracks have a very narrow distribution of lengths, which becomes progressively shorter and broader during annealing. The very broad pattern of track lengths at the highest temperatures in the annealing zone is particularly distinctive. New tracks are continually added to the apatite, so that each will experience a different fraction of the total thermal history and be shortened accordingly. The lengths therefore give an integrated record of annealing, so that characteristic length distributions result from different thermal histories. The annealing process is now sufficiently well understood that the track length distribution resulting from any given thermal history can be calculated.

N O T E S

An overview of the BMR Eromanga Basin project

F.J. Moss

The Bureau of Mineral Resources carried out a multidisciplinary program of geological and geophysical work in the central Eromanga Basin during 1980-1982 in cooperation with the Geological Survey of Queensland. The project was aimed at studying the regional structure and depositional history of the central Eromanga Basin and the underlying Cooper, Galilee, and Adavale Basins, to provide information on their petroleum prospectivity.

Geophysical work involved 1400 km of 6-fold CDP seismic reflection coverage on regional traverses up to 400 km long; gravity measurements along these traverses; refraction surveys along two major east-west and north-south traverses, and magnetotelluric soundings. LANDSAT imagery studies provided new information on structures; wireline logs and synthetic seismograms were used to re-examine stratigraphic correlations; palynological and lithological studies were aimed at determining depositional environments and source rock maturation; hydrogeological and geochemical studies provided information on the generation and migration of hydrocarbons.

Since the project commenced, there has been a renewal of interest in the prospectivity of the central Eromanga Basin area by petroleum exploration companies. This has been stimulated in part by the BMR work, data from which have been publicly available. The seismic data that were recorded through key wells in the area provided regional data to assist companies in designing major programs, involving thousands of kilometres of new seismic coverage. Company interest has intensified with the major petroleum discoveries at Jackson, Tintaburra, and Bodalla South.

BMR is now concentrating on studies of the tectonic evolution of the central Eromanga Basin area. The deep seismic reflection and refraction results provide key information to assist in these studies.

N O T E S

The structure of the Eromanga Basin from shallow seismic refraction

C.D.N. Collins

Seismic refraction recordings were made in the Eromanga Basin along an east-west traverse between Cheepie and Mt Howitt No. 1 well. This traverse crossed the Cheepie Shelf, Quilpie Trough, Canaway Ridge, Warrabin Trough, and the eastern margin of the Cooper Basin. It was coincident with six-fold CDP reflection profiling and a long-range deep refraction traverse. Recordings were made along a total of 262.5 km at a station spacing of 1.875 km, with shots every 37.5 km. The recording scheme was designed to give seven reversed 37.5 km spreads, and six overlapping reversed 75 km spreads.

The purpose of the detailed refraction study was to map the velocity structure of the Eromanga Basin, its sub-basins, and, in particular, the basement. No reflectors have been recorded within the basement, ie. between the base of the Devonian sediments of the Adavale Basin and its extensions, the Quilpie and Warrabin Troughs, and a mid-crustal horizon 24 km deep. Faults identified from reflections within the Devonian and younger sediments cannot be followed in the basement. Three wells penetrate to the top of the basement along this traverse. In all of them, steeply dipping, tightly folded metasediments were found, which is consistent with the observed reflection character and velocities. It is therefore unlikely that there is a significant velocity contrast across the boundaries of the basement blocks, and, indeed, the boundaries may not be defined in terms of a single fault. However, gross variations in the basement velocity might identify faulted basement blocks at depth. The velocity structure of the upper 10 km of the crust derived from this study was also used during interpretation of the deep refraction data from below the mid-crustal horizon.

Velocities within the Eromanga Basin sediments vary from 2.0 km/s at the surface to about 3.8 km/s at the base, at a depth of 1 km in the east and 2 km in the west. The velocity within the Cooper Basin is around 5.0 km/s; at the western end of the basin the sediments have a maximum thickness of 900 m and they wedge out at the western margin of the Warrabin Trough. The velocities within the Devonian sediments of the Troughs vary from about 4.3 km/s to 5.0 km/s. The base of the sediments is not well defined, but their maximum thickness is about 3.8 km in the Quilpie Trough, and about 3 km in the Warrabin Trough.

The velocity within the top part of the basement varies between 5.0 and 5.5 km/s, and increases with depth. It reaches 6.0 km/s at depths below 7 km, but under the Cheepie Shelf reaches this velocity at 4 km depth. This shallowing of higher velocity rocks under the Cheepie Shelf coincides with a shallowing of mid-crustal reflections by 1 to 2 seconds; these features may be related, and indicate that the block faulting may extend to at least mid-crustal depths. Elsewhere, lateral variations of velocity indicate that the faulting observed in the overlying sediments extends into the basement to at least 5 km depth.

NOTES

Palynology, cyclic sedimentation, and age of sediments in the Eromanga Basin

D. Burger

Recent oil and gas discoveries in Queensland and South Australia have shown the desirability of accurately dating sedimentary formations in the Eromanga Basin. Good results have been obtained by the use of palynology in this field, particularly with regard to the non-marine Jurassic-Neocomian sequence, where other means of age determination are dubious or insufficient. Independent checks on the present estimated ages of individual formations by correlation of recurrent sandstone-mudstone cycles with eustatic sea-level changes documented in the literature lead to the following conclusions (Burger, in press; see also Fig. 1).

Four Jurassic sedimentary cycles are outlined, each cycle including a basal arenaceous unit, possibly following a gap in the sequence connected with a phase of low sea level, and an upper argillaceous interval, indicating slow drainage and quiet deposition during a phase of high sea level. Cycle 1 includes the lower part of the Hutton Sandstone (in its extended sense) and is tied to a Sinemurian-Toarcian sea-level cycle. Cycle 2 includes the upper part of the formation (in its restricted sense) and the Birkhead Formation, and is dated Aalenian-Bathonian. Cycle 3 is dated Callovian, and includes the Adori Sandstone and Westbourne Formation. Oxfordian-Tithonian Cycle 4, outlined in the Surat Basin, is indistinct, and neither Cycle 3 nor Cycle 4 may be fully developed, as in many areas of the Eromanga Basin palynology indicates a significant hiatus between the Westbourne Formation and the Hooray Sandstone.

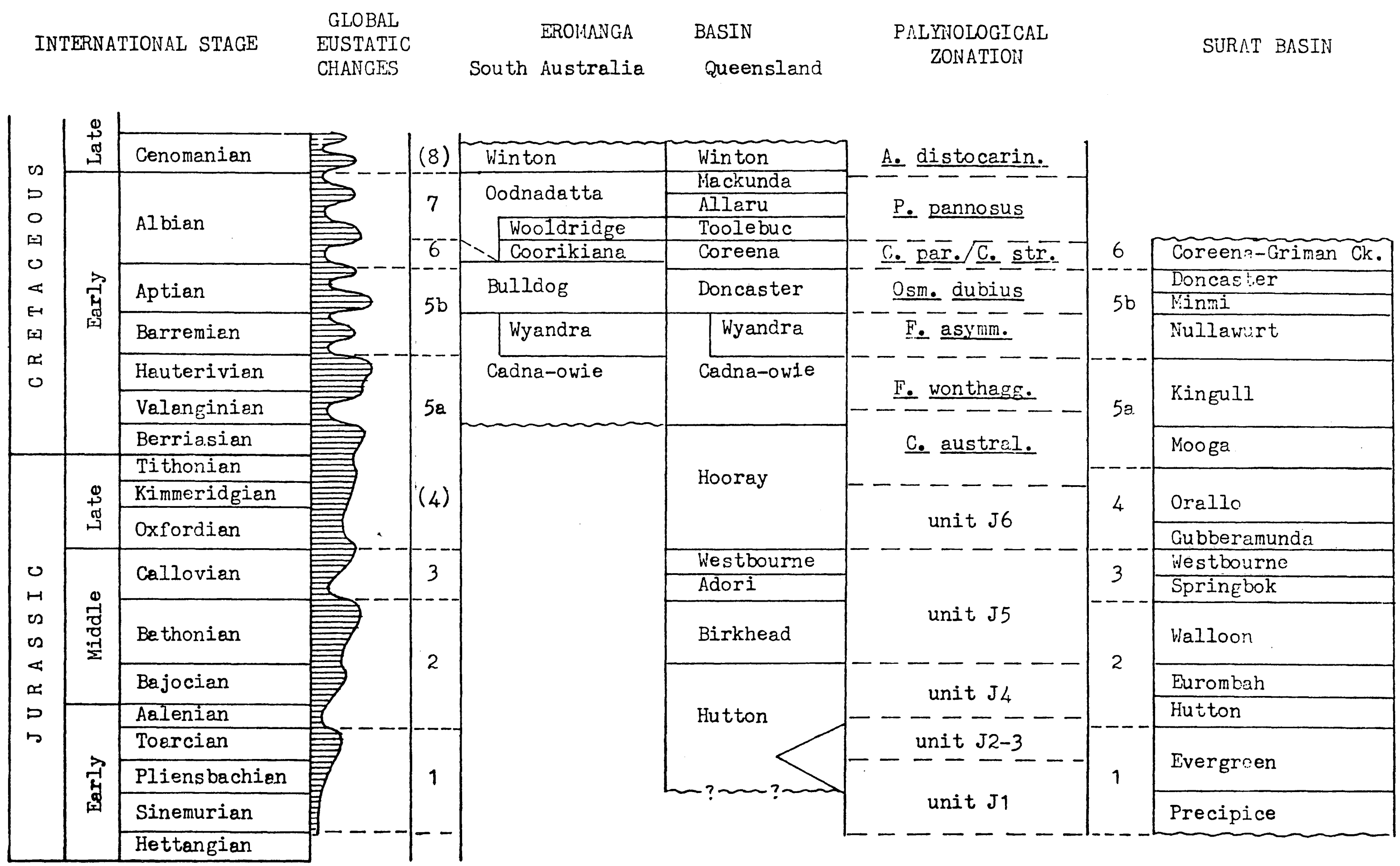
Four Cretaceous sedimentary cycles are outlined, of which basal Cycle 5 is compound. Subcycle 5A, which, in the Surat Basin, forms a distinct interval, is interpreted as constituting a larger Cycle 4-5A in the Eromanga Basin, including part of the Hooray Sandstone and the lower Cadna-owie Formation, which is palynologically dated mid-Neocomian (Hauterivian). The upper Cadna-owie Formation (Wyandra Sandstone Member) and lower Wallumbilla Formation (Doncaster Member) constitute Barremian-Aptian Subcycle 5B, which together with Albian and Cenomanian Cycles 6, 7, and 8 are well dated and need no discussion. They differ from the older cycles in that they represent alternating non-marine and marine environments in the basin as a result of successive phases of low and high eustatic sea levels.

BURGER, D., in press - Palynology, cyclic sedimentation, and palaeoenvironments in the Late Mesozoic of the Eromanga Basin. In D.I. Gravestock & others (eds) - Contributions to the geology and hydrocarbon potential of the Eromanga Basin. Geological Society of Australia, Special Publication.

NOTES

Figure 1

Stratigraphy of Eromanga and Surat Basins, palynological zones, and global sea level changes



NOTES

Maturation history of the basins in the central Eromanga region: a tool for understanding basin development

V.L. Passmore

The maturation level of rocks, derived by organic geochemical analyses, is commonly used to estimate the hydrocarbon prospectivity of different formations and their potential for generation of either oil or gas. Maturity values can be plotted against depth to produce a maturation profile (a graphic plot of the maturation history) for a single well or a region. As the maturation history of a basin provides information on that basin's burial and thermal history, it is also a tool for understanding development of that basin.

In the central Eromanga Basin region 51 wells were sampled for maturation data. Vitrinite reflectance values were used in the eastern part of the study area, and values from vitrinite reflectance and head space gas analysis, in the western part. Maturation data from the central Eromanga Basin and the underlying Cooper and Galilee Basins indicate rocks in the western part of area have been buried deeper and subjected to higher geothermal temperatures than those in the eastern part. Major burial took place during the Cretaceous, when up to 2000 m of sediment was deposited in the deeper troughs, mainly in the early Late Cretaceous. Recent studies on geothermal gradients and organic maturation levels suggest a rise in thermal gradient in the western part of the central Eromanga Basin occurred at a later date, possibly in the Tertiary. Data from the Adavale Basin suggest a different thermal and depositional history for the Devonian sediments than that for the overlying basins. In the Adavale Basin greatest burial was along the eastern side of the basin, and palaeotemperatures may have been higher in the east than in the west, especially during the early part of the basin's development.

Data from maturation profiles for the Eromanga, Cooper, and Galilee Basins suggest little deformation has occurred in these basins; however, in the Adavale Basin there is evidence of significant post-depositional movement. A major break in the maturation profiles for two wells (Gilmore No. 1 and Quilberry No. 1) implies a mid-Devonian unconformity and significant erosion of sediment, but no significant deformation or movement.

N O T E S

BMR seismic reflection investigations in the central Eromanga Basin- their contribution to understanding basin evolution

M.J. Sexton

The Bureau of Mineral Resources (BMR) has recorded 1400 km of 6-fold CDP seismic reflection data in the central part of the Jurassic-Cretaceous Eromanga Basin. Underlying the Eromanga sequence in this area are the Devonian Adavale Basin and the Late Carboniferous-Triassic Cooper and Galilee Basins.

To augment the BMR data, over 2300 km of mainly single-fold analogue seismic data was digitally reprocessed, PSSA (Petroleum Search Subsidy Act) seismic data were copied and a large quantity of recent company seismic data acquired. Interpretation of these data and preliminary attempts at producing structure-contour and isopach maps have revealed several factors that must be considered in order to understand the evolution of the sedimentary basins in the area.

Firstly, a mid-Devonian unconformity in the Adavale Basin sequence is a major event that effectively divides the sequence into a predominantly shallow marine lower part and a continental upper part. This unconformity is particularly marked in the south and east of the Adavale Basin, although it is present throughout the basin. A second orogeny in the mid-Carboniferous terminated Adavale Basin deposition and produced intensive folding and reverse faulting. Seismic data over the Cothalow Arch indicate that it is a positive 'flower' structure and that a significant component of strike-slip motion also existed. The region was reactivated during the Late Carboniferous, when the Cooper and Galilee Basins formed. In general, the thickest sediments appear to reflect the downwarps in the Adavale Basin sequence. A similar phenomenon is observed in the Eromanga Basin sediments. Subsequent folding and faulting in the Eromanga Basin tend to overlie similar structures in the Adavale Basin.

The seismic data support the view that the lower part of the Adavale Basin was initiated as a foreland basin to the west of a volcanic arc - trench system that was active during the early Devonian. A compressional episode resulted in uplift and significant erosion of the early Adavale Basin sediments. This was followed by a jumping of the volcanic arc eastward to the present Anakie Inlier with the Drummond Basin as a foreland basin and the upper part of the Adavale Basin as a pericratonic basin connected to the Drummond. In the mid-Carboniferous a similar compressional episode occurred, followed by an eastward jumping of the arc resulting in the Sydney-Bowen foreland basin and the Cooper-Galilee pericratonic basins. A third compressional episode in the Triassic was followed by an easterly migration of the arc, with the Maryborough Basin as a foreland basin and the Surat and Eromanga Basins as pericratonic basins. With each phase of compression and arc jumping the central Eromanga Basin area was further removed from the plate margin and, consequently, suffered less deformation each time.

This model relies considerably on observations outside the central Eromanga Basin. However, the 1984 BMR seismic program, which extends a previous BMR seismic line from the Cooper Basin to the Queensland coast and, consequently, crosses many of these structural elements, will provide an excellent basis for testing it.

NOTES

Tectonic evolution of the central Eromanga Basin area from seismic reflection data

S.P. Mathur

Between 1980 and 1982 the Bureau of Mineral Resources (BMR) recorded seismic reflection data to 20 s over about 1400 km of traverses in the central Eromanga Basin, to study the structure of the crust, the sedimentary history, and the tectonic evolution of the area. The reflection results and interpretation along a major east-west traverse are shown in Fig. 1. The features revealed by the seismic data are consistent with the following model of tectonic evolution of the area.

During the Late Proterozoic/Early Cambrian a back-arc basin developed at the eastern margin of the Australian continent (Fig. 2A). Asthenospheric upwelling associated with the subducting oceanic lithosphere to the east caused the extensional thinning of the continental crust under the basin, separating the continental fragment with volcanic arc environment from the main continental crust. The upwelling asthenosphere intruded the stretching crust. The intruded dykes were rotated by the stretching to produce the subhorizontal lenses seen as strong reflection segments in the lower crust of the central Eromanga Basin area. Cambrian and Ordovician clastic sediments and volcanics that accumulated in the back-arc basin were deformed and metamorphosed in Mid to Late Ordovician time to form the Thomson Orogen (Fold Belt) (Fig. 2B). Thick shallow-marine and continental sediments and volcanics were deposited during the transitional orogenic stage in the Devonian, interrupted by a hiatus in the Middle Devonian. During the Mid-Carboniferous orogeny a change in the stress regime, probably related to the termination of the subduction zone and the formation of a new one further to the east, caused compressional deformation of the entire crust, seen as intense folding and reverse faulting in the Devonian sequence and low-angle ($<30^{\circ}$) thrusting in the lower crust. Extensive erosion of the uplifted anticlinal areas truncated the widespread Devonian sequence and separated the Adavale Basin from its associated troughs (Fig. 2C). During the Late Carboniferous-Triassic period Cooper/Galilee Basin sediments accumulated in broad shallow downwarps of the stable craton. After a period of gentle folding and erosion the area was covered by a blanket of Jurassic-Cretaceous sediments of the Eromanga Basin. Minor basement uplifts, movements along pre-existing faults, and compaction of sediments produced the gentle folding and faulting in the pericratonic basins (Fig. 2D).

NOTES

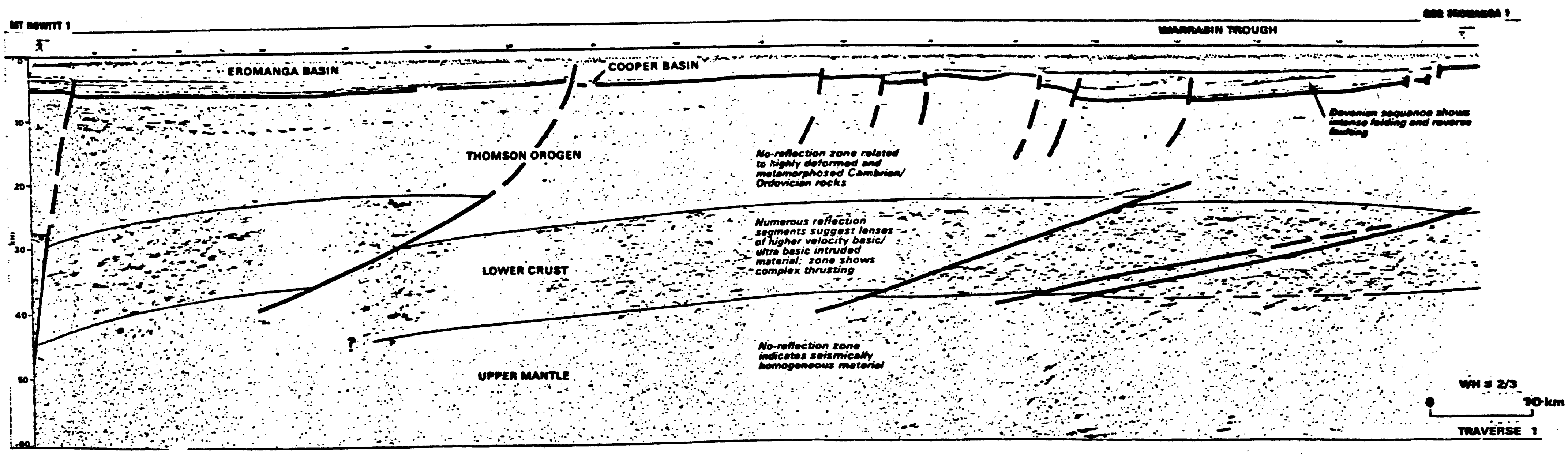

WARRABIN TROUGH
EROMANGA BASIN
COOPER BASIN
Devonian sequence shows intense folding and reverse faulting
THOMSON OROGEN
No-reflection zone related to highly deformed and metamorphosed Cambrian/Ordovician rocks
Numerous reflection segments suggest lenses of higher velocity basic/ultra basic intruded material; zone shows complex thrusting
LOWER CRUST
No-reflection zone indicates seismically homogeneous material
UPPER MANTLE
?
WH = 2/3
0 10 km
TRAVERSE 1

FIG. 1

N O T E S

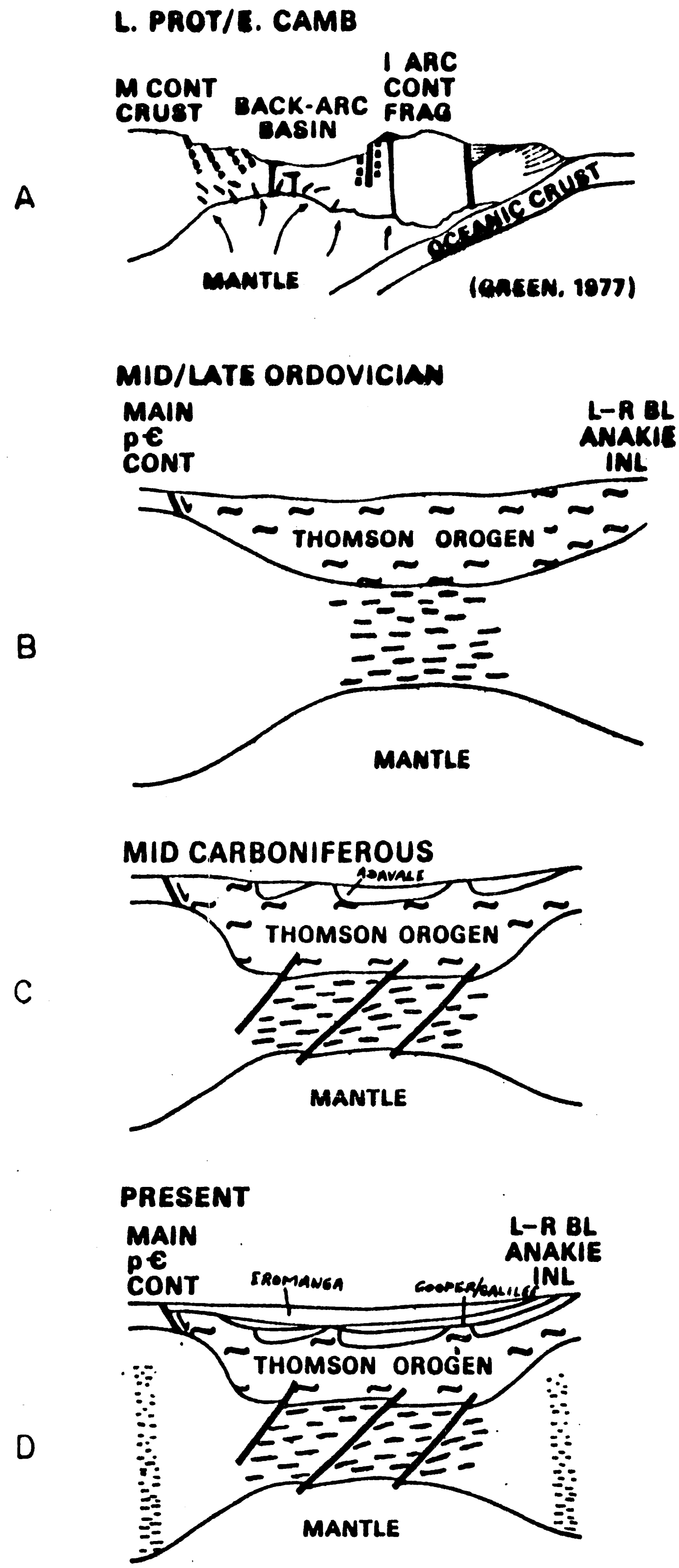

A
L. PROT/E. CAMB
M CONT CRUST
BACK-ARC BASIN
I ARC CONT FRAG
OCEANIC CRUST
MANTLE
(GREEN, 1977)
B
MID/LATE ORDOVICIAN
MAIN p€ CONT
L-R BL ANAKIE INL
THOMSON OROGEN
MANTLE
C
MID CARBONIFEROUS
ADAVALE
THOMSON OROGEN
MANTLE
D
PRESENT
MAIN p€ CONT
L-R BL ANAKIE INL
EROMANGA
COOPER/GALILEE
THOMSON OROGEN
MANTLE

FIG. 2

NOTES

Deep velocity structure of the lithosphere under the central Eromanga Basin and comments on basin evolution

D.M. Finlayson

During the Devonian the region of Queensland near Adavale was a major centre of continental to shallow-marine sedimentation, which subsequently underwent considerable tectonic deformation, resulting in fault relief of up to 7 km. Hence, the Adavale Basin and contemporaneous sediments in the Quilpie, Warrabin, Cooladdi, and Barcoo Troughs are the oldest recognised remnants of a major basin-forming event, after which the region was effectively part of the wider Australian craton as it is today. The subsequent Permo-Triassic event that produced the Cooper-Galilee Basin resulted in only minor sedimentation in the Advale region. The Jurrasic-Cretaceous event that blanketed the whole of western Queensland with the Eromanga Basin sequence was a much less severe tectonic event than that during the Devonian.

During 1980-81 the pre-Devonian lithosphere, contained in the basement to the Adavale Basin, was the target of a deep seismic refraction/wide-angle reflection study to determine the deep velocity structure to depths of about 60 km and contribute to a tectonic synthesis of the region.

From shallow refraction data the velocities within the identified sedimentary sequences vary from about 2.0 to 5.3 km/s, but these are underlain by a 2-3 km thick transition zone with a velocity of 5.4-5.8 km/s before a basement velocity of about 5.9 km/s is reached. The structural relief on these upper crustal velocity features produces marked variations on the travel times and amplitudes of deeper seismic phases. For instance, the 8-9 km sedimentary sequence suspected to be in the main depression of the Adavale Basin can now be identified with confidence, using upper mantle phases.

The transition zone above basement is identified with a gradual metamorphic facies change to highly deformed, metasedimentary rocks that do not produce reflections on the 6-fold CDP seismic profiling, but which form a basement with a velocity of 5.9-6.4 km/s. The character of the transition zone and underlying basement suggest that the Adavale Basin was formed by the rifting of a quasi-continental crust.

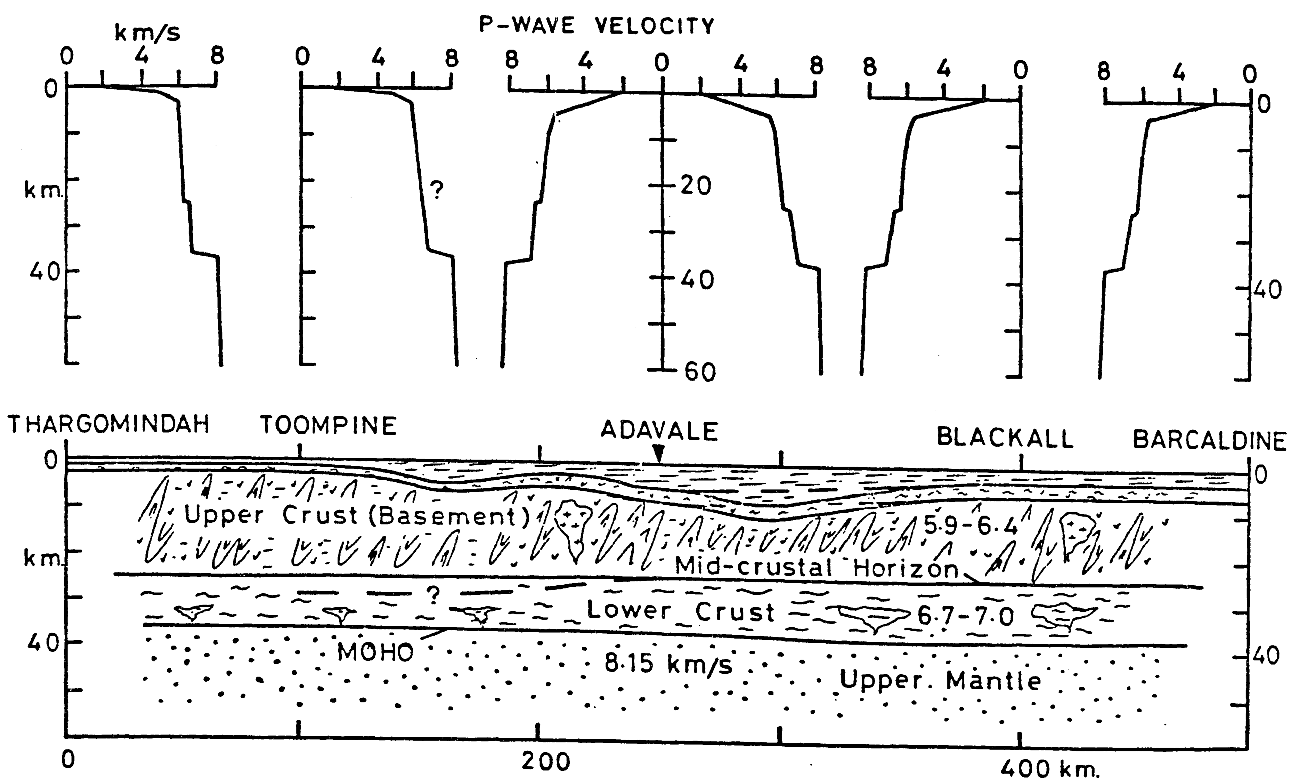
At depths of 22-25 km under the Adavale Basin there is a prominent velocity increase from about 6.3-6.4 km/s to 6.7-6.8 km/s. This mid-crustal velocity horizon coincides with the onset of a major zone of discontinuous relections seen on profiling records, and emphasises the different tectonic processes predominating in the upper and lower crust. Under the Canaway Ridge, however, this horizon occurs at a deeper level (29-34 km), indicating a different crustal velocity structure.

The crust/mantle boundary (Moho) at a depth of 36-37.5 km is marked by a velocity increase from about 6.9-7.1 km/s to 8.15 km/s and the disappearance of lower crustal reflections. The low relief on the Moho and the mid-crustal horizon under the Devonian basin suggest mobile intrusive rocks and/or metamorphic fronts caused the discontinuous reflections in the lower crust. Any lower crustal relief from the Devonian has probably been overprinted by the thermal events that resulted in the Permo-Triassic and Jurassic-Cretaceous basins.

N O T E S

The velocity structure of the lithosphere in the Adavale Basin region is, therefore, evident in the cool, comparatively rigid, upper crust with the velocities being preserved into pre-Devonian basement. In a mobile lower crust and upper mantle it is more likely that the seismic signatures of the older Devonian events at about 350 Ma are degraded by younger events at 200-250 Ma and 100 Ma.

The mid-crustal velocity horizon is a feature of other rifts such as the Early Palaeozoic Mississippi Embayment and the Palaeogene Rhine-graben. In the Rio Grande Rift the mid-crustal velocity horizon is interpreted as the location of current magmatism. It is speculated that the horizon represents the highest level of magmatic intrusion in the older rifts. In the North Sea no mid-crustal horizon is interpreted, but the Moho is evident at a comparatively shallow level (minimum of 20 km). It is possible that post-Palaeozoic evolution and crustal extension have included some form of sub-crustal erosion.



N O T E S

Bass Basin surveying and deep seismic information

J.C. Branson, G.D. Karner*, K.L. Lockwood & A.S. Scherl

BMR recorded 3209 km of seismic, gravity, and magnetic data between March and May 1982, using a contract vessel, Lady Vilma. Traverses were centred on the Bass Basin and connected with traverses across parts of the Gippsland and Otway Basins. A seismic processing contract was let in June 1982 to Geophysical Service Inc., Sydney. The contractor completed tests, batch processing, and migration of BMR 1982 data and reprocessing of 941 km of data by June 1984. Recording and processing details are given in Table 1.

The major volume of digital processing was made available to lease holders in the survey area in April 1983. and then released to the general public in October 1983. These results provide the highest quality seismic information available in the deepest parts of the Bass Basin and also give good quality seismic correlations between the adjacent basins in Bass Strait. Reprocessing of 1975 regional seismic data by the same techniques used for 1982 data has shown that the 1982 recording techniques improved data quality by use of high channel numbers, high digital sampling rates, longer seismic records, and large capacity tuned airgun arrays.

Analysis of the Bass Basin structure showed that seismic events need to be recorded down to basement. Shallow data recorded in the past to 4 or 5 seconds two-way time do not allow analysis to adequately discriminate between basin-forming structures and the effects of superimposed later tectonic movements. The origin of the Bass Basin and its structural history are important in defining the thermal and sedimentary histories, which in turn are used by the hydrocarbon industry to define subsidence curves.

A thermo-mechanical model of the Bass Basin was developed by Garry Karner in BMR during 1983. The model is based on stretching of the lithosphere by brittle and ductile failure of the crust and mantle, respectively. The results provide an analysis of competing isostatic effect of crustal subsidence, which forms a rift phase, and a following slower thermal decay, which forms a superimposed flexural phase. Structures from deep in the Bass Basin show that large extensions took place in the Early Cretaceous. The magnitude of this extension and the dimensions of the known rift basin have been applied to the model, and the results provide a series of thermal decay curves that are used in geohistory models. There are a number of thermal decay curves developed for various positions within the Bass Basin whose form depends on basement structure and relative proximity of the test sites to a depocentre or basin margin. The example discussed here is located over an elevated region of basement near the basin depocentre and this provides an estimate of thermal maturation during burial history.

The value of detailed deep seismic information is also discussed by scientists studying sedimentary facies and other scientists working on a grid of data to define broad leads in hitherto unexplored Cretaceous and Paleocene sequences.

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N O T E S

Table 1. Seismic processing

BMR Survey 40

Recorded 2 ms, 6 seconds, every 16.67 m cdp point processed.
Recorded 48 fold and 96 channels

Bass Basin	1503 km	365 km demult process
Otway Basin	453 km	- demult process
Otway Basin 24 fold	273 km	- demult process
Gippsland Basin	884 km	238 km demult process

Migration

Bass Basin	365 km	
Otway Basin	238 km	488 24 fold
Gippsland Basin	107 km	

Inversion using 4 wells

Bass Basin	228 km

Depth conversion

Otway Basin	238 km	488 24 fold

Experimental processing

Bass & Gippsland Basins

Reprocessing

1975 data 4 ms, 5 seconds, every 11.11 m cdp point processed.
Recorded 48 fold 48 channel.

Bass Basin	551 km	130 km demult processed

1970 data 4 ms, 7 seconds, every 25 m cdp point processed.
Recorded 24 fold 24 channel.

Otway Basin	238 km
Gippsland Basin	152 km

N O T E S

Extensional basin-forming structures in the Bass Basin

M.A. Etheridge, J.C. Branson, & P.G. Stuart-Smith

Major Cretaceous normal faults bounding substantially tilted blocks were recognised early in the interpretation of the 1982 BMR Bass Strait seismic survey. This recognition led to a specific structural study of the early fault configurations, using extensional faulting concepts. The structural study, which also utilised all post-1974 company data, concentrated on the gross fault pattern at Cretaceous level, without detailed horizon picking.

The Early Cretaceous basin-forming normal faults are shallow to moderately dipping, rotational, and approximately planar down to the base of the section (6 sec TWT; 10-12 km). They have displacements of up to 10 km, strike consistently 290 to 300 degrees, mostly dip towards the south-southwest. Rotation on these faults has produced tilts of up to 35 degrees in the basement surface. Mapping shows that the faults are relatively short along strike, being disrupted by a set of steeply-dipping transfer faults that trend 020 to 030 degrees across the full width of the basin. The transfer faults developed at the same time as the normal faults, and are thus restricted to the Early Cretaceous and older sequences. They do not simply displace the normal faults and tilt blocks, but accommodate variations in the positions of and displacements on the extensional structures. They are therefore analogous to oceanic transform faults. The transfer faults in Bass Basin tend to displace the normal faults in a right-lateral sense, giving rise to the basin's overall northwesterly trend.

In the southeast corner of the Bass Basin, an apparently separate set of extensional normal faults and tilt blocks developed during the Late Cretaceous. These faults trend about 320 degrees and dip towards the northeast. Because their age and orientation are different from those of faults underlying most of the basin, and because they are superimposed on an Early Cretaceous graben fill, we conclude that they were not primary basin-forming structures. This conclusion is supported by preliminary thermomechanical modelling, and we further suggest that these structures are related to the early stages of opening of the Tasman Sea.

Preliminary interpretation of BMR and company seismic data from the Gippsland and Otway Basins has identified Early Cretaceous normal and transfer faults with the same trends as those throughout the Bass Basin. It is therefore proposed that all three basins developed by north-northeast to south-southwest extension, and that their gross configuration resulted from offsets on major transfer fault systems.

N O T E S

Bass Basin stratigraphy

C.J. Pigram, J.B. Colwell, & K.L. Lockwood

The stratigraphy of the Bass Basin is known from the 19 wells* that were drilled between 1965 and 1982. The succession (Table 1.), consisting of thick Early Cretaceous to Eocene non-marine and Eocene to Pliocene marine sediments, rests unconformably on basement of presumed Palaeozoic age. Only two wells (Bass 2 and 3), drilled on basement highs, encountered basement rocks, which are generally assumed to consist of low-grade metasediments, granite, and Late Palaeozoic glacigene sediments similar to those found in northern Tasmania and southern Victoria.

The oldest sediments in the basin are referred to the Early Cretaceous Otway Group and have been intersected in 2 wells. They consist of lithic sandstone, siltstone, minor volcanics, rare conglomerate and thin coal seams. The Otway Group is overlain unconformably by up to 7 km of Late Cretaceous to Eocene non-marine sediments referred to the Eastern View Coal Measures.

The lower, pre-Maastrichtian (Tricolpites longus) part of the sequence has been intersected only in the Durroon well, where it consists of grey to dark brown, non-calcareous shale, siltstone, and fine sandstone.

The Maastrichtian and Tertiary portion of the Eastern View Coal Measures consists of silty shale with thin fine-grained sandstone and rare coal in the lower part. These sediments typically pass up into a coal-rich sequence that is in turn overlain by a sand-rich sequence.

A thin, but extensive restricted marine shale and siltstone sequence of the upper Eocene Demon's Bluff Formation overlies the Eastern View Coal Measures and is in turn conformably overlian by the marine Oligocene-Pliocene Torquay Group. The Torquay Group consists of marl, calcarenite, calcareous shale, and minor volcanics.

Intrusive and extrusive igneous rocks occur throughout the Bass Basin sequence, and probably range in age from Cretaceous to Miocene.

Understanding of the stratigraphy and geological development of the Bass Basin is limited by the small number of wells and their relatively shallow level of penetration. To gain a better understanding of the stratigraphy of the basin, a seismic stratigraphic analysis of some BMR dip lines has been carried out. Four seismic sequences have been identified (Table 1) and each sequence subdivided into seismic facies, which have been given a palaeoenvironmental interpretation.

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* Two further wells - Squid-1, Tasmanian Devil-1 - have been drilled in 1984.

NOTES

SEISMIC SEQUENCES OF THE BASS BASIN

Sequence	Lower Boundary	Configuration	INTERNAL PROPERTIES					Palaeoenvironmental interpretation	Age of Sequence
			Continuity	Amplitude	Frequency	Interval velocity range km/sec	Max. Thickness m.		
A	Concordant, onlapping at basin edges	parallel	continuous	moderate to high	moderate to high	1.6-2.9*	2400	Restricted marine basin grading up into a carbonate-rich open marine shelf	Upper Eocene to Recent (Demons Bluff Formation & Torquay Group)
B	Concordant, onlapping at basin edges	parallel	continuous	variable, but generally moderate	moderate	2.5-3.1*	1100	Non-marine basin: predominantly floodplain association including extensive coal swamps	Eocene (Eastern View Coal Measures)
C	Erosional truncation	variable	variable	moderate to low	moderate to low	3.1-5.5Ø	6900	Non-marine basin: alluvial fan, floodplain & lacustrine associations	Late Cretaceous to Eocene (Eastern View Coal Measures)
D	-	irregular	discontinuous to moderately continuous	high	low	-	-	Predominantly non-marine sediments unconformably on Palaeozoic & Precambrian basement	?Late Cretaceous and older (Otway Group and basement).

*Interval velocity derived from a velocity inversion analysis for line 4D.

ØStacking velocities

N O T E S

Cretaceous to Paleocene structural and stratigraphic leads in the Bass Basin

P.E. Williamson & A.S. Scherl

Paleocene and Cretaceous hydrocarbon exploration plays have not been extensively tested in the Bass Basin. Only about half the 21 wells have penetrated to the late Paleocene (Lygistepollenites balmei) level and only about a quarter have penetrated the top Cretaceous.

Cretaceous to Paleocene leads for hydrocarbon prospectivity within the Bass Basin have been investigated by regional seismic mapping, using an approximate 15 x 15 km grid of BMR and petroleum industry multichannel seismic data. These leads are defined at Paleocene (L. balmei), Cretaceous rift unconformity and at prerift unconformity levels.

Both structural and stratigraphic leads occur at these levels. Structural leads are predominantly fault-bounded and are the result of normal faulting in longitudinal and traverse directions associated with rifting and extension in the basin at Middle to Late Cretaceous time. Growth on some faults from prerift unconformity to rift unconformity time indicates that the Cretaceous rift phase may have built on an earlier rift phase or at least on existing structural faults. Reactivation of Cretaceous rift faults occurs into the Paleocene, producing structural leads. However, it rarely extends as high in the section as the Eocene top Eastern View Coal Measures, where significant reactivation and reversal of rift faulting has formed structures at top Latrobe in the Gippsland Basin, with associated oil fields. At the equivalent level in the Bass Basin only minor closures occur and many of these were drilled unsuccessfully in the early exploration of the basin. Stratigraphic leads fall into two classes. The predominant type is associated with truncation of Paleocene and Cretaceous strata at the basin edges. These are considered to be lower-order stratigraphic leads. The more attractive stratigraphic leads are associated with clastic accumulations down-thrown to large faults.

The high component of transverse faulting in the Bass Basin has resulted in a large number of fault-bounded structural leads (a number with areas in the order of 100 sq kms), occurring at depths between about 3 and 4 kilometres in Paleocene and Cretaceous stratigraphy. Multiple stacked exploraion targets at these levels are possible, since the strata penetrated are suggestive of suitable reservoir and source-rock facies. Maturation studies also suggest that these levels are more likely to be mature or to have access to mature source rock than are the traditional shallower Eocene Eastern View Coal Measures exploration targets.

Delineation of Paleocene and Cretaceous leads within the Bass Basin thus gives indications of substantial exploration potential in the mature strata of the Basin.

The analysis suggests that the Eastern View Coal Measures have a complex depositional history, involving sediments of alluvial fan, floodplain, lacustrine, and volcanic associations.

NOTES

A new look at the Gippsland Basin

P.G. Stuart-Smith, M.A. Etheridge, & J.C. Branson

Major extensional structures have recently been identified in the Bass Strait basins, following a deep seismic survey conducted in 1982 by the Bureau of Mineral Resources and reappraisal of company data. The Gippsland Basin, like the Bass and Otway Basins, was initiated during the Early Cretaceous by north-northeast-south-southwest extension.

Extensional structures in the Gippsland Basin consist of rotational planar normal faults that are up to 5 km in strike length and terminated by a perpendicular set of subvertical transfer faults that trend between 205° and 210°. The normal faults dip between 30° and 60° and show displacements of up to 5 km. Displacements on the transfer faults are mostly sinistral (left-lateral), giving rise to the overall easterly trend of the basin and its bounding structures (e.g., south-bounding Foster Fault System). A major transfer fault zone passing beneath the Kingfish, Halibut, Fortescue, and Tuna oil fields separates predominantly northeast-dipping normal faults to the east. Another major transfer fault possibly terminates the major transfer fault zone terminating significant extension in the southeast Bass Basin.

Identification of the Early Cretaceous extensional structures is limited to the basin margins, owing to the paucity of good quality deep seismic information in the centre of the basin. However, some transfer faults can be matched across the basin and, in places, they are coincident with magnetic trends and sea-bed canyons.

The extensional structures have been a major influence throughout the development of the basin. The normal and transfer faults have partly controlled the distribution and orientation of Late Cretaceous subsidence structures and were important controls on the development of late Eocene and younger hydrocarbon-bearing structures. These structures were, in the main, produced by wrench reactivation of transfer faults and reverse movements on older normal faults during Eocene to Recent northwest-southeast compression.

N O T E S

Otway margin - a Bass Basin and Gippsland comparison

J.C. Branson & D.A. Falvey

The Otway Basin has provided an ideal area for testing currently proposed models for the formation of passive continental margins. Despite intensive studies in the Atlantic Ocean of regions like the Bay of Biscay, West Africa, and northeast North America, and the North Sea, many processes of continental margin development are poorly understood. The distinction of different types of margin development relies on accurate data from the earliest periods of continental breakup, and most of the Atlantic margin transects have been unsuitable, owing to thick sedimentary sequences, which also include halite. The Otway Basin was surveyed by two long traverse lines during the 1982 Bass Strait Geophysical Survey, and these data augmented by reprocessed 1979 Shell 'Petrel' lines in the same area. Results of these surveys show that detailed sedimentary and structural information is readily available across the whole margin, and some deeper events have been recorded from the upper crust. These high quality data owe their origin to a low sediment supply over long periods of geological time and to high quality recording and processing techniques developed by BMR.

Studies of the deep section in the Bass and Gippsland Basins provide evidence for a regional north-northeast rift and apparent extension at the primary stage of continental separation in the Early Cretaceous. This extension direction is probably also present throughout the Otway Basin. Recognition of the dominant trend for the later, mid-Cretaceous rift in the Otway Basin relied on an analysis of widely spaced lines within the continental margin. Further high-quality geophysical survey data will be required in the future to confirm the tectonic fabric. The present-day trend of the tilted basement blocks and Early Cretaceous sediment across the deep continental margin was imposed during the thermal decay phase of continental margin formation. This follows a possible northwest trend of the earliest breakup phase of the Antarctic and Australian continents. The period from 65 Ma to 44 Ma was a time when the seafloor spreading direction changed to nearly north-south. Also, structures can be seen in BMR traverses across the Torquay Embayment at the northeast end of the Otway Basin, in lines in the Bass Basin, and along the northern margin of the Gippsland Basin. They were formed by a tectonic event that folded and faulted all pre-Pliocene sequences. The structures are consistent with southeast-northwest compression, and this stress field has been measured throughout southeastern Australia. The origin of this regional stress has been attributed to late Miocene to Recent interplate stress transmitted from the Pacific/Australia plate boundary.

Dredged rock samples are required from the deep-water sequences of the rift and postrift fill of the Otway Basin margin. Estimates of age and lithology have been extrapolated over 150 km from shelf exploration wells, and on the slope are expected to be different. The trends of structures within the sea floor and the position of suitable sample sites within continental slope are prime objectives for future scientific investigation in the Australian margin.