THERMAL HISTORY of the ERINGA TROUGH and WESTERN EROMANGA BASIN

P.R. Tingate* and
I.R. Duddy†

Chapter 8

INTRODUCTION

The major aims of this study are to examine the thermal history of the Eringa Trough and the western Eromanga Basin. In the vicinity of the Eringa Trough, the drillholes selected for Apatite Fission Track Analysis (AFTA) include Afmeco Cur 3 and 5, Mount Hammersley 1, Mount Crispe 1 and Purni 1. Previously unpublished data from McDills 1 are also presented and the implications for petroleum generation examined. Drillhole samples were supplemented with outcrop samples from the Dalhousie Anticline and Musgrave Block. As part of a more regional investigation of the western Eromanga Basin, samples were also analysed from the Poolowanna Trough (Poolowanna 1), Birdsville Track Ridge (Mulapula 1, Koonchera 1 and Poonarunna 1) and southern Cooper Basin (Tinga Tingana 1, Cherri 1 and Weena 1).

AFTA METHODS

AFTA data for 33 samples were generated by Geotrack International (Geotrack, 1995a, b, 1996). The remaining data comes from Tingate (1990) and Gleadow *et al*. (1988). Detrital apatite grains were separated from samples ranging from 0.5 to 3 kg in weight using conventional heavy liquid and magnetic techniques (Green, 1986). Apatites were analysed using the external detector method (Gleadow, 1981; Green, 1981) and fission track ages calculated using the zeta calibration technique (Fleischer and Hart, 1972; Hurford and Green, 1982, 1983). Irradiations were carried out at the X-7 facility of the Hifar Reactor, Lucas Heights, New South Wales. Apatite fission track ages were calculated from pooling single grain track counts unless the probability given by the chi-squared statistic, $P(\chi^2)$, was <5%, in which case the central age was used (Galbraith, 1981, 1992). Further details of data generation are given in Geotrack (1995a, b, 1996) and Tingate (1990).

Apatite chemical composition can affect track annealing (Tingate, 1990; Green *et al*., 1985, 1986) so apatites, except those from McDills 1, were chemically analysed. Apatites from McDills 1 are assumed to be similar to other Amadeus Basin apatites which are fluorine-rich with a mean chlorine content of 0.1 wt% (percent by weight; Tingate, 1990, 1991). Software used for modelling is based on the mathematical description of induced track annealing in monocompositional Durango apatite (Laslett *et al*., 1987; Duddy *et al*., 1988; Green, Duddy, Laslett *et al*., 1989).

Interpretation of AFTA data is based upon the annealing behaviour of spontaneous fission tracks (Gleadow *et al*., 1983; Green, Duddy, Gleadow *et al*., 1989), length data (Gleadow *et al*., 1986), and induced fission track annealing in laboratory experiments (Green *et al*., 1986; Laslett *et al*., 1987; Duddy *et al*., 1988) that have been extended to geological situations (Green, Duddy, Laslett *et al*., 1989). Laboratory studies have concentrated on track length measurements, and their relation to fission track density (hence age) has been described by Laslett *et al*. (1984) and Green (1988).

RESULTS

The AFTA data is discussed as a generalised traverse from west to east. Drillhole and sample locations are shown on Figure 8.1. Sample and analytical data are given in Table 8.1 and palaeotemperature data in Table 8.2.

Musgrave Block and Afmeco Cur 3 and 5

Sample GC582-13 is the westernmost sample and comes from granitic gneiss in the Musgrave Block (~2 km south of De Rose Hill, Fig. 1.2). It has a fission track age of 410±24 million years (Ma) and a relatively long mean track length of 14.0±0.1 µm. The sample could represent initial track retention below 120°C associated with a geological cooling event starting at ~450 Ma. No major geological event occurred at this time and it is likely that the sample underwent initial track retention during the Delamerian or Petermann Ranges Orogeny, followed by cooling from temperatures between 120 and 90°C to <50°C during the Alice Springs Orogeny (~340 Ma). The long mean track length for the sample indicates that it has not been exposed to temperatures >40°C in the last 100 Ma.

Further to the east, the three Cambrian and Mesozoic samples in Cur 3 and 5 are from shallow depths at temperatures <40°C yet they exhibit annealing consistent with higher temperatures in the past (Fig. 8.2). Modelling of Cur 5 suggests that it has cooled from palaeotemperatures in the range 60–90°C between 100 Ma and present day (Fig. 8.3). In Cur 3 cooling occurred between 300 and 90 Ma. Two events of different age have probably affected each drillhole, but a single event with cooling at ~100 Ma, is also possible. The time of cooling within Cur 3 is consistent with a widespread Triassic – Early Jurassic

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*NCPGG, Thebarton Campus, The University of Adelaide, Adelaide, SA, 5005 (email: ptingate@pet2.ncpgg.adelaide.edu.au)
†Geotrack International Pty Ltd, 37 MelvilleRd, West Brunswick, Vic., 3055 (email: Geotrack@maccontent.apana.org.au)

regional cooling event in the Amadeus Basin, between 240 and 180 Ma (Tingate, 1990).

The Cambrian Arcoeillinna Sandstone samples have both experienced an earlier, higher temperature event (Fig. 8.3). Both samples have cooled from temperatures >100°C between 360 and 320 Ma (combining their time constraints). The timing of cooling is consistent with the Alice Springs Orogeny (Shaw *et al.*, 1992) when major uplift and erosion occurred between 360 and 300 Ma.

McDills 1

McDills 1 is the most northerly drillhole analysed on the eastern margin of the Eringa Trough. It has an uncorrected thermal gradient of 29°C/km (Smyth and Saxby, 1981) which has been corrected to 32°C/km using the method of Gorter (1984). All samples, except the shallowest, have apatite fission track ages that are significantly less than the stratigraphic age of the Devonian Finke Group (Fig. 8.4). The mean track lengths of all the samples are <11 µm and decrease with increasing depth to ~9 µm, indicating that considerable annealing has occurred since deposition.

The fission track age decreases from ~350 to ~230 Ma down through the top three samples and then decreases more rapidly to ~75 and 15 Ma in the two lowest samples. The upper four samples have significant spreads in single grain age, reflecting differences in apatite chemical composition. Track length histograms indicate that most of the samples have experienced higher temperatures in the past and the samples have cooled relatively recently to present thermal conditions.

Judging from the fission track parameters, all samples have been hotter in the past and cooling started at some time between 80 and 20 Ma. The fission track data clearly indicate that the Finke Group reached maximum temperatures after deposition of Cretaceous sediments. All samples show evidence of having been heated to temperatures ~30°C higher than present prior to cooling which started between 80 and 20 Ma (Fig. 8.5). The difference between the estimated maximum palaeotemperature and present temperature is similar for each sample, suggesting that the present geothermal gradient was similar at the time of maximum temperature.

Assuming a cooling of ~30°C and using the present geothermal gradient, ~1 km of uplift and erosion is interpreted to have taken place between 80 and 20 Ma. The structure upon which McDills 1 was drilled had ~600 m of post-Cretaceous uplift and erosion (Fig. 8.6). This estimate does not appear to be sufficient to explain the amount of cooling interpreted in McDills 1 and regional uplift of ~400 m is likely.

Mount Hammersley 1

Samples from the Algebuckina Sandstone (present temperature <50°C) in Mount Hammersley 1 show evidence of cooling from palaeotemperatures ~40°C higher than present between 180 and 0 Ma. Permian samples from the same drillhole appear to have cooled from palaeotemperatures 10–20°C higher than present between 60 and 0 Ma. The deepest sample from the early Palaeozoic Pacoota Sandstone, shows evidence of recent heating

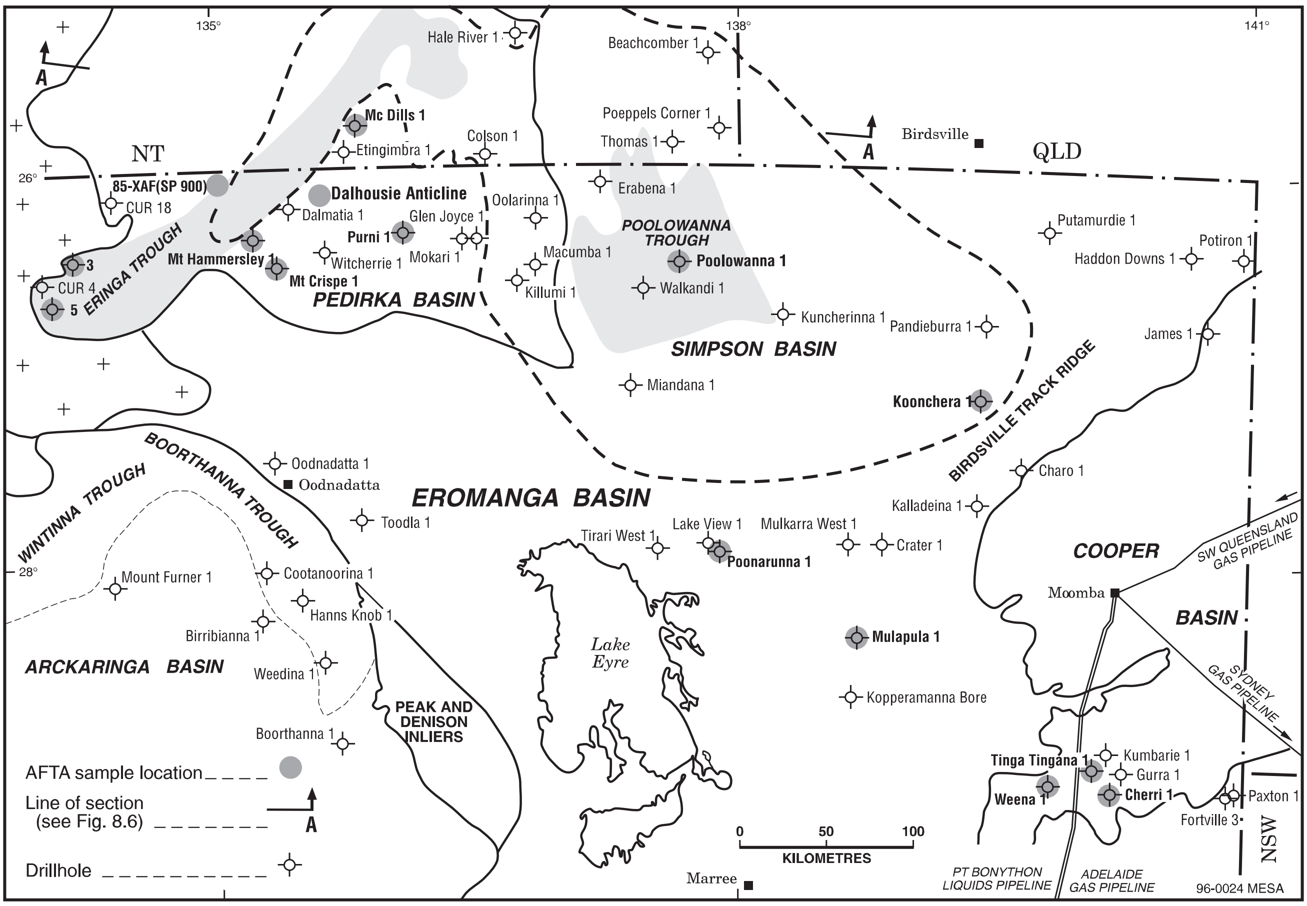

Fig. 8.1 Location of drillhole and outcrop samples selected for AFTA.

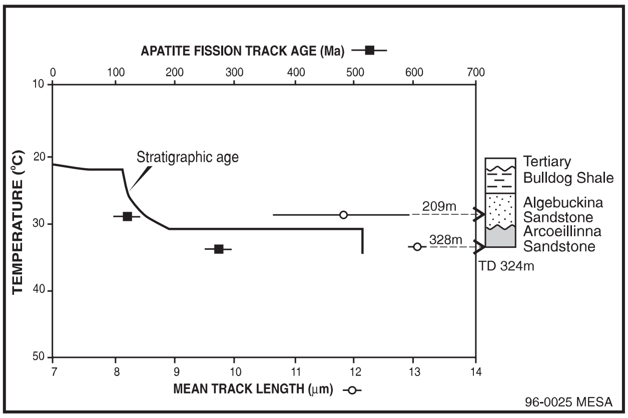

***Fig. 8.2** AFTA parameters versus present temperature and sample depths for Cur 5.*

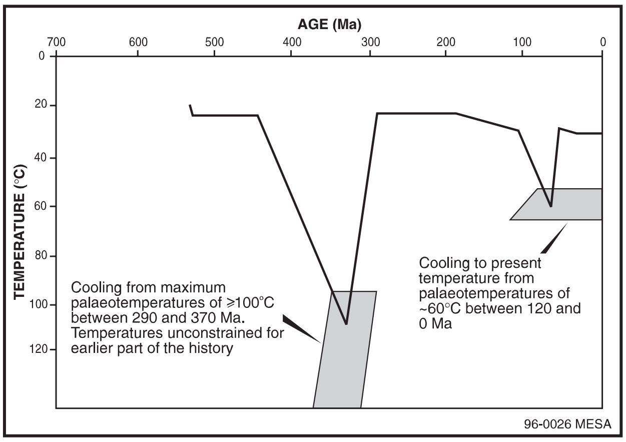

***Fig. 8.3** Schematic thermal history of the Arcoeillinna Sandstone, Cur 5, using AFTA palaeotemperature constraints.*

(<5 Ma) to its current temperature of 94°C from palaeotemperatures around 80°C. The AFTA parameters from the Pacoota Sandstone sample are consistent with total annealing prior to cooling during the Alice Springs Orogeny, but the present high level of annealing does not allow precise assessment. Apart from the deepest one, most samples indicate, or are consistent with, cooling from elevated temperatures between 60 to 0 Ma. The decrease in the amount of cooling with depth suggests that the present geothermal gradient has not remained constant through time. Two explanations are offered. The first is that the geothermal gradient has remained approximately linear through time but has recently (<5 Ma) increased in magnitude. The palaeotemperatures down the drillhole are consistent with an increase from 25–30°C/km to 40°C/km in the last 5 Ma. This variation in geothermal gradient combined with uplift and erosion of ~1 km starting between 60 and 5 Ma is consistent with the palaeotemperature variation. The second explanation is that the elevated palaeotemperatures suggested by the data higher in the drillhole are partly related to heated water movement in Mesozoic aquifers which may have been associated with non-linear temperature–depth profiles.

Mount Crispe 1

Mount Crispe 1 samples exhibit a similar thermal history to those from Mount Hammersley 1. AFTA data suggest Cambrian ‘Mount Crispe beds’ cooled from palaeotemperatures >110°C between 400 and 300 Ma, consistent with cooling during the Alice Springs Orogeny. The upper samples in the drillhole have also experienced higher temperatures associated with a younger event. The highest samples in the drillhole from

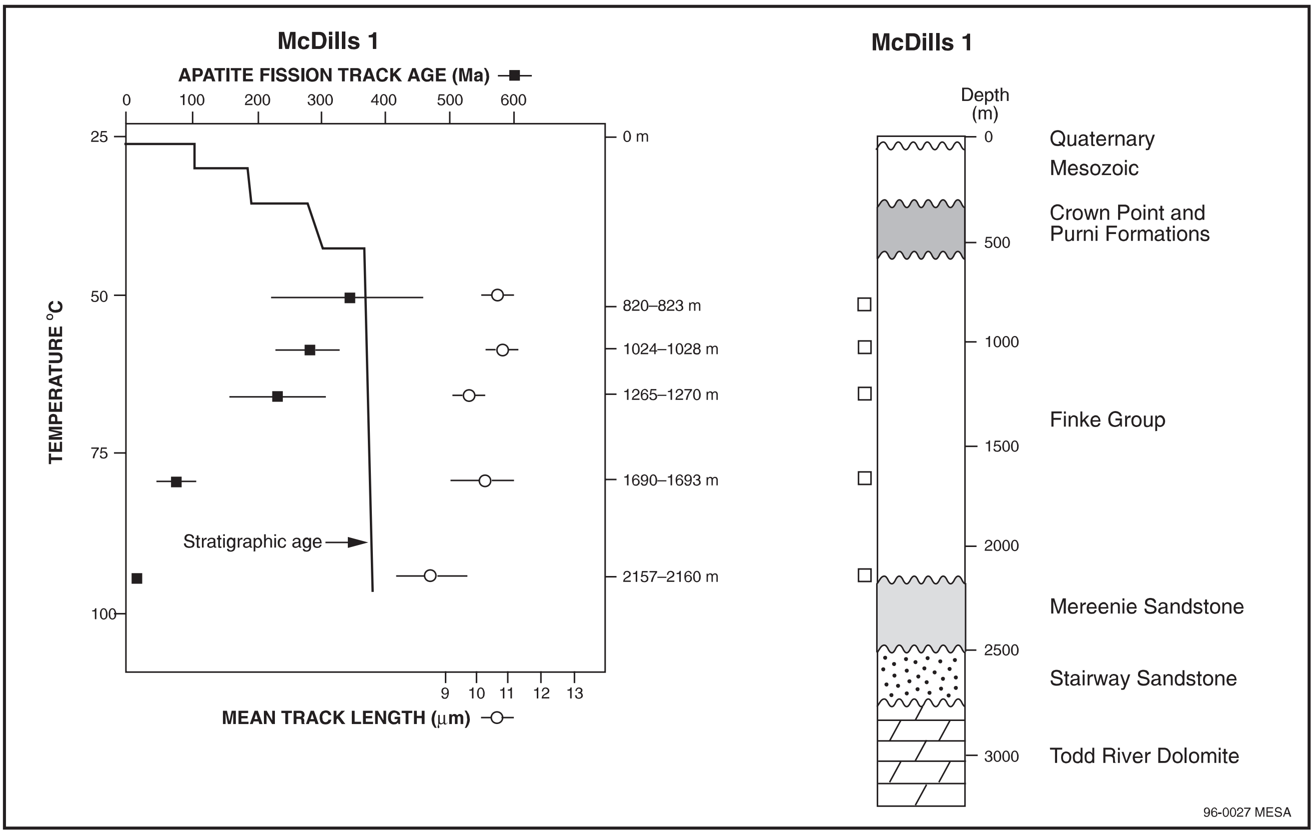

***Fig. 8.4** AFTA parameters versus present temperature and sample depths for McDills 1.*

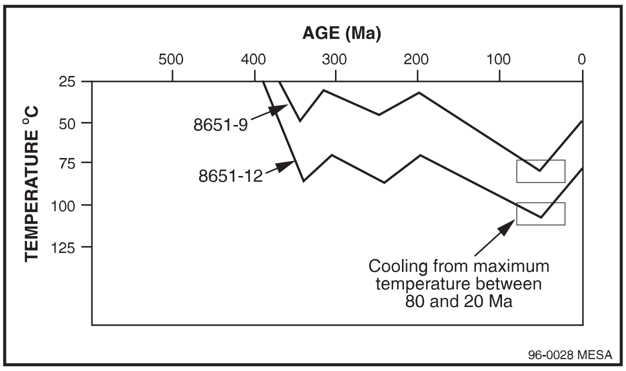

***Fig. 8.5** Schematic thermal history of the Finke Group, McDills 1, using AFTA palaeotemperature constraints.*

the Algebuckina Sandstone and 'Mount Crispe beds' probably experienced palaeotemperatures ~40°C higher than present, prior to cooling in the last 50 Ma. Considering the younger event, the difference between maximum palaeotemperature and present temperature decreases downhole. The deepest sample from the 'Mount Crispe beds' appears to have been heated to present temperatures within the last 5 Ma. A similar thermal history style to Mount Hammersley 1 is considered likely.

Dalhousie Anticline

Sample GC582-18 comes from the Coorikiana Sandstone outcropping within the Dalhousie Anticline. Stratigraphically, it lies ~250 m below the youngest Tertiary formation folded by the structure (G.W. Krieg, MESA, pers. comm. 1996). It has a fission track age (102±11 Ma) which is within error of its stratigraphic age (108–105 Ma) but its track length characteristics (Table 8.1) indicate that it has experienced higher temperatures than present (21°C). Modelling of AFTA parameters shows that the sample has experienced cooling from ~90°C between 90 and 50 Ma. Cooling from maximum palaeotemperatures does not appear to be linked with the main phase of late Tertiary structuring and instead is related to some earlier event. Possible causes include changes in aquifer conditions, regional uplift and erosion, or a combination of both.

Purni 1

Purni 1 is further east from the Eringa Trough and has a more complete Eromanga Basin succession. Samples from the Winton Formation and Algebuckina Sandstone in Purni 1 are currently close to maximum temperature. AFTA data from the Algebuckina Sandstone suggest that ~10°C cooling has occurred in the last 100 Ma.

Poolowanna 1

Poolowanna 1, in the Poolowanna Trough, has the thickest preserved Winton Formation of the drillholes analysed using AFTA. Sample GC582-11 comes from the Winton Formation in Poolowanna 1. Its fission track age and length are consistent with being at maximum temperature now (44°C). The fission track age indicates that a significant proportion of tracks formed prior to deposition of the Winton Formation. Gleadow *et al.* (1988) concluded from three deeper samples in Poolowanna 1 that the drillhole was presently at maximum temperatures and that these temperatures had been maintained for 1–10 Ma. Sample GC582-11 is consistent with this temperature history. If the present geothermal gradient is assumed to have been constant for the last 10 Ma, calculated vitrinite reflectance (R_o) in Poolowanna 1 is typically greater than measured values, indicating that it is more likely that the geothermal gradient has increased in the last 5 Ma (Geotrack, 1995b).

Mulapula 1

Three samples were analysed from Mulapula 1 on the Birdsville Track Ridge. Each sample has experienced higher palaeotemperatures than present. The three samples are consistent with palaeotemperatures ~20°C greater than present but have different ranges for the timing of cooling. All samples are consistent with cooling from maximum temperatures in the last 60 Ma. The data are also consistent with a recent increase (<5 Ma) in geothermal gradient. Vitrinite reflectance measurements also support higher palaeotemperatures than present (Geotrack, 1995b).

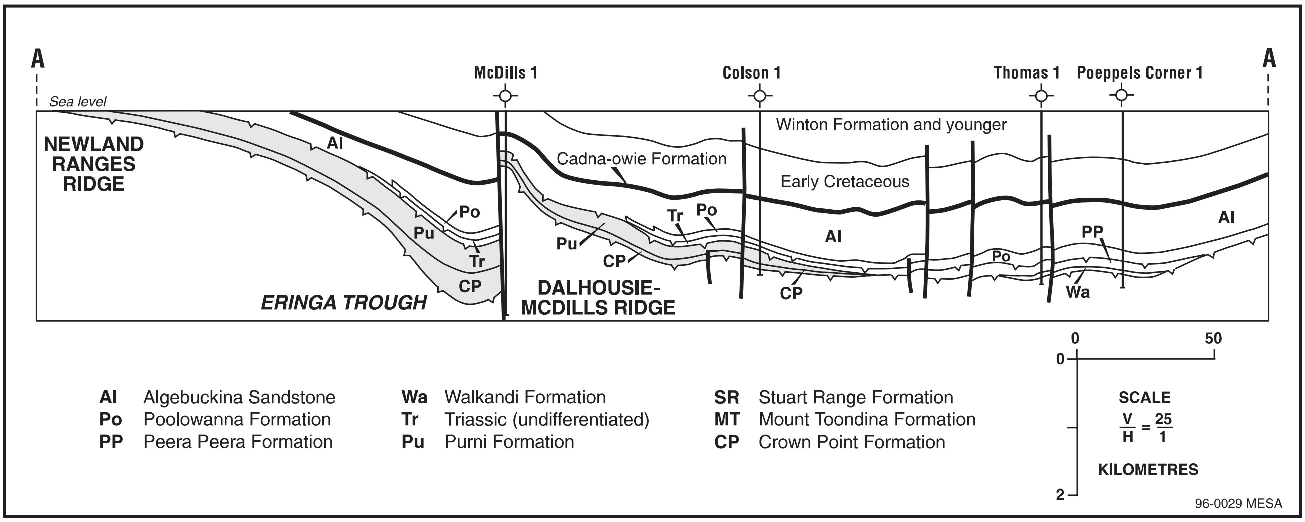

***Fig. 8.6** Schematic cross-section through the western Eromanga Basin, Northern Territory. The line of section is located on Figure 8.1.*

Koonchera 1

Five samples were taken from Koonchera 1. The uppermost sample from the Winton Formation (GC582-6) is currently at a maximum temperature of 48°C and probably experienced palaeotemperatures of ≤35°C until the last 5 Ma. Sample GC582-7 from the Namur Sandstone has experienced higher palaeotemperatures than present. It appears to have cooled from ~100°C between 40 Ma and present. The AFTA parameters from the deeper Hutton Sandstone suggest that it is currently close to maximum temperature (98°C). The sample is also consistent with having experienced temperatures of ~100°C between 40 Ma and present, cooling to lower temperatures, and then recently heating back to ~100°C. Sample GC582-9 (Poolowanna Formation) has probably only recently reached its current temperature of 110°C. The lowest sample, GC582-10, consists of data from two grains. The age and length data suggest that the grains may be from cavings from higher up the drillhole since the age and length do not display enough annealing to be consistent with the present temperature, even taking into account a recent increase in geothermal gradient.

The thermal effects observed in Koonchera 1 do not appear to be consistent with uplift and erosion in the past under a lower geothermal gradient, followed by a recent increase in geothermal gradient. It is more likely that the data represent localised heating below the Winton Formation that is unrelated to increased depth of burial. Some form of heated water flow in the Namur and Hutton Sandstones and the Poolowanna Formation, that ceased in the mid–late Tertiary (40–15 Ma), is a likely cause. Vitrinite data (Geotrack, 1995b) from Koonchera 1 support a recent rise in geothermal gradient within the drillhole.

Poonarunna 1

Three samples were analysed from Poonarunna 1. The shallowest sample (GC582-14) is currently at maximum temperature and probably has experienced heating recently. The two deeper samples are consistent with cooling from higher temperatures (100–110°C) in the last 40 Ma (Table 8.2). The lengths from each sample suggest that the current temperatures are related to recent (<5 Ma) heating. Maximum palaeotemperatures in the Namur Sandstone and Birkhead Formation appear to be related to hot water flow that ceased in the mid–late Tertiary.

Tinga Tingana 1, Weena 1 and Cherri 1

Samples were analysed from three drillholes near the southern margin of the Cooper Basin. Gleadow *et al.* (1988) analysed two Early Permian samples from Tinga Tingana 1, concluding that the present temperatures in the drillhole were a recent event (<10 Ma). Sample 8642-54 (Tirrawarra Sandstone) was reanalysed as part of this study and the results are presented in Table 8.1, along with sample 8642-55. Sample 8642-54 has an age and mean length which indicate that the present temperature has only been acting for <5 Ma. The mean length suggests that the sample was probably at ~80°C immediately prior to the recent increase in geothermal gradient. Sample 8642-54 is consistent with cooling from ~95 to 80°C between 90 and 0 Ma. It also contains single grain ages that are close to its stratigraphic age indicating that it has not been totally overprinted by any event since deposition. Sample 8642-55 would be expected to be more annealed than is observed unless the current temperature was a relatively recent (<2 Ma) phenomenon as suggested by Gleadow *et al.* (1988).

Sample GC582-17 is from the Merrimelia Formation in Weena 1. Its AFTA parameters suggest that it has experienced greater palaeotemperatures than present. It is consistent with cooling from temperatures of ~100°C in the last 100 Ma.

The AFTA data from sample GC582-1 (Cherri 1) comes from only a few grains and the AFTA parameters are imprecise. The sample has a similar style of thermal history to 8642-54 in Tinga Tingana 1. Its AFTA parameters are consistent with cooling from a palaeotemperature of 90 to 100°C between 90 Ma and present. Its current temperature is the product of a recent increase (<5 Ma) in geothermal gradient.

DISCUSSION

Eringa and Poolowanna Troughs

The AFTA results indicate that thermal events of different ages have affected the margins of the Eringa Trough. The earliest event affects the eastern Musgrave Block and Cambro-Ordovician samples from Cur 3 and 5, Mount Crispe 1 and probably Mount Hammersley 1. These samples experienced temperatures of ~90°C prior to cooling between 360 and 320 Ma, and this is correlated with uplift and erosion during the final stages of the Alice Springs Orogeny. The second event is only seen in Cur 3; it involves cooling from temperatures ~40°C higher than present day between 300 and 90 Ma. It may be related to regional uplift and erosion between 240 and 180 Ma that affected the Amadeus Basin and Musgrave Block (Tingate, 1990).

The third event is seen in all drillholes apart from Cur 3. It involves widespread cooling from elevated temperatures in the last 100 Ma. Assuming this cooling is associated with one event, using all drillhole samples, the best estimate for the start of cooling is between 60 and 20 Ma. All Permian and Mesozoic drillhole samples west of Purni 1 show evidence of cooling from palaeotemperatures ~30–40°C higher than present. The outcrop sample from Dalhousie Anticline may represent another slightly earlier event. The sample exhibits cooling from ~90°C, starting between 90 and 50 Ma. Due to the relatively high palaeotemperatures it is likely that hot water flow is involved.

Vitrinite reflectance and MPI (Methylphenanthrene index) data also support elevated palaeotemperatures in the drillholes examined using AFTA. Figure 8.7 illustrates vitrinite reflectance values from Permian and Mesozoic samples that are currently close to 500 m depth. Two zones can be seen on the map: reflectance values <0.4% to the east of 136° longitude, and reflectance values mainly between 0.4 and 0.5% west of 136°. The AFTA and reflectance data show that elevated palaeotemperatures have occurred over a large part of the Eromanga Basin margin. Likely causes for these elevated palaeotemperatures are uplift and erosion of missing Cretaceous section (~1 km) during the Late Cretaceous and

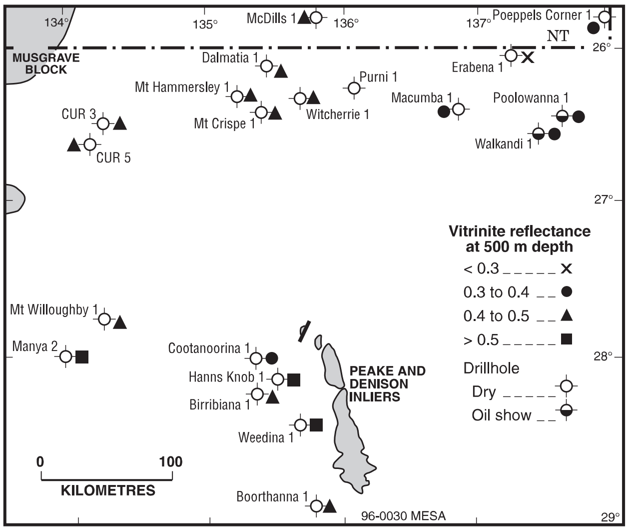

Fig. 8.7 *Vitrinite reflectance data from Permian and Mesozoic samples at 500 m depth.*

Tertiary, possibly combined with heating related to groundwater flow in Mesozoic aquifers.

The last event inferred from the AFTA data is recent heating in deeper samples from Mount Hammersley 1, Mount Crispe 1 and Poolowanna 1. The present geothermal gradients in these drillholes are 35–40°C/km which probably reflects a very recent increase (<5 Ma) in geothermal gradient as proposed for other drillholes in the Eromanga Basin (Pitt, 1986; Gleadow *et al.*, 1988).

Birdsville Track Ridge

Mulapula 1, Koonchera 1 and Poonarunna 1 show evidence of two thermal events. The first is cooling in the Jurassic units from 90 to 100°C in the last 40 Ma. Further up section in the Winton Formation, there is no evidence for higher palaeotemperatures. The cooling in the Jurassic section is therefore likely to be related to changes in heated water movement which has not affected the upper part of the Eromanga Basin sequence. The second thermal event is a recent increase (<5 Ma) in geothermal gradient.

Southern Cooper Basin

Tinga Tingana 1, Weena 1 and Cherri 1 show evidence of two thermal events. The first is cooling in the Permian units from 90 to 100°C in the last 90 Ma. This cooling in the Permian section is possibly related to uplift and erosion and/or changes in heated water movement. The second thermal event is a recent increase (<5 Ma) in geothermal gradient.

RELATION TO PETROLEUM GENERATION

Eringa and Poolowanna Troughs

The thermal history data suggest that the top of the oil window is closer to the surface than previously thought in the vicinity of the Eringa Trough, making shallow targets more prospective. Burial history models have been made using the AFTA constraints for McDills 1, Mount Hammersley 1 (Figs 8.8, 8.9), and a site in the deepest part of the Eringa Trough (85-XAF, shot point (SP) 900; Fig. 8.10). Modelling was carried out via BasinMod® using the LLNL (Lawrence

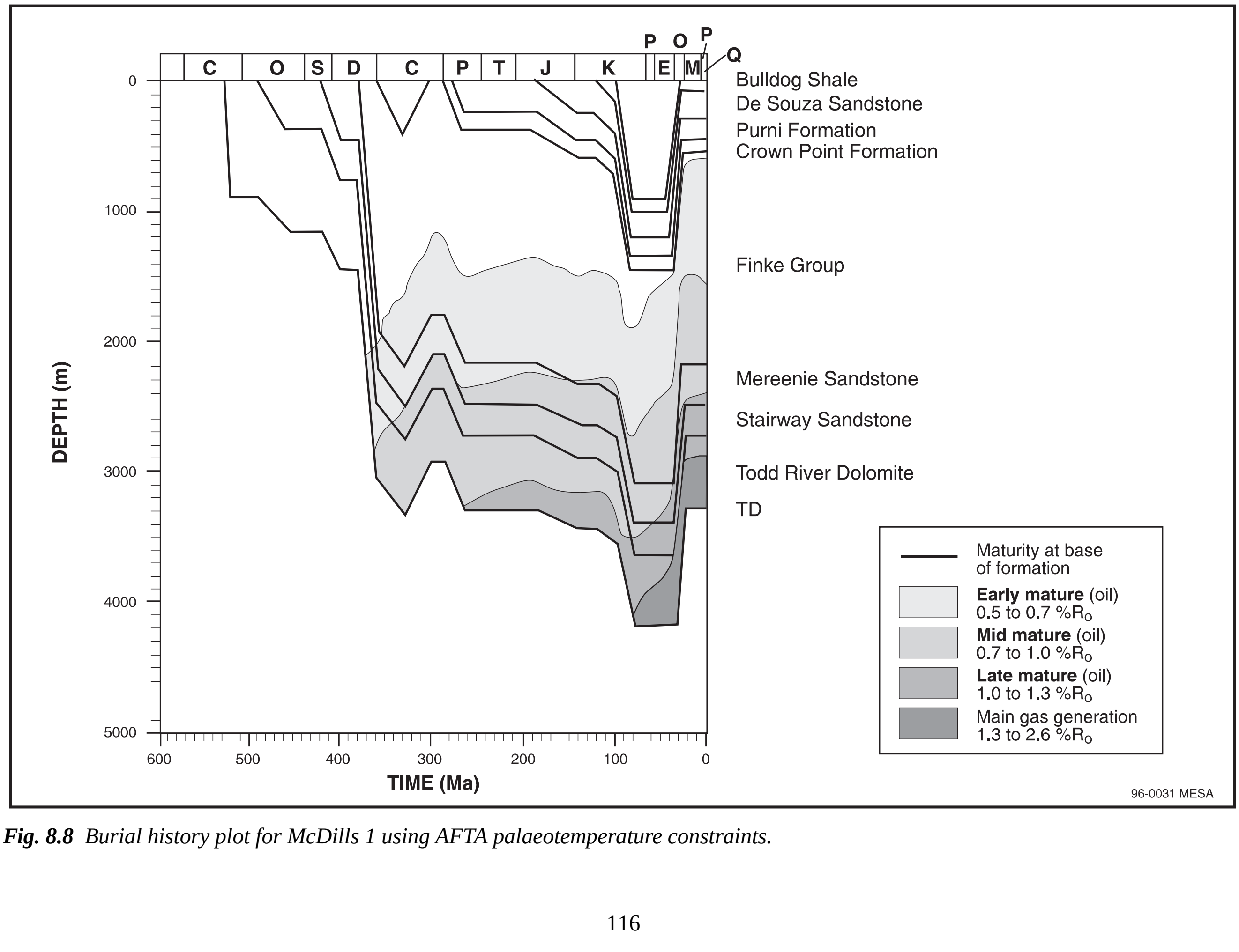

Fig. 8.8 *Burial history plot for McDills 1 using AFTA palaeotemperature constraints.*

Livermore National Laboratories) kinetics option. Figure 8.8 shows that all section in McDills 1, including mid-Palaeozoic, reached maximum temperatures prior to Tertiary uplift and any hydrocarbon generation is likely to have occurred prior to that time. Figure 8.9 shows that in Mount Hammersley 1, maximum temperatures for the Pacoota Sandstone and older strata were reached during the Alice Springs Orogeny and potential hydrocarbon generation is likely to have occurred prior to or during this event. Permian units probably entered the upper part of the oil window under Late Cretaceous burial and, if suitable source rocks were present, could have generated in the Late Cretaceous – mid-Tertiary (Figs 8.9, 8.11).

Figure 8.10 shows a burial history for site 85-XAF (SP 900). Present depths are based upon seismic picks. This history was made assuming a geothermal gradient of 30°C/km until 3 Ma, when it increased to 40°C/km. The recent increase in geothermal gradient has little effect on the present maturity levels (Fig. 8.11). Three kilometres of erosion has been modelled for the Alice Springs Orogeny and 1 km for the Tertiary event. For this model, the maturity–time paths (Fig. 8.11) show that the base of the Permian at site 85-XAF (SP 900) entered the upper part of the oil window in the Permian and passed through the main oil window during Cretaceous burial. The base of the Cadna-owie Formation entered the oil window at ~100 Ma and reached maximum maturity in the mid-Tertiary. Figures 8.10 and 8.11 show that the Permian and lower part of the Eromanga Basin sequence are likely to have experienced temperatures suitable for hydrocarbon generation in the deeper part of the Eringa Trough. Pre-Permian formations are more likely to have generated oil prior to the Alice Springs Orogeny. It should be noted that Figure 8.10 is not representative of the thermal history style in McDills 1, in which pre-Permian rocks reach maximum temperatures prior to Tertiary cooling.

Birdsville Track Ridge

The AFTA data from the three drillholes along the Birdsville Track Ridge suggest that the Jurassic sequence cooled from elevated palaeotemperatures in the last 40 Ma, close to the last major period of structural growth (post mid-Miocene). The recent increase in geothermal gradient observed in most drillholes has not increased the maturity greatly within the drillholes due to its short duration.

Southern Cooper Basin

The AFTA data from three drillholes along the southern margin of the Cooper Basin suggest that the Permian sequence cooled from elevated palaeotemperatures in the last 90 Ma and has recently undergone an increase in geothermal gradient. The Permian succession in this region probably reached maximum temperatures after deposition of the Eromanga Basin and is a potential source interval for Eromanga Basin reservoirs. Similar to the Birdsville Track Ridge, the recent increase in geothermal gradient has not increased the maturity greatly within the drillholes studied, but deeper, hotter kitchen regions should have increased maturity related to this event.

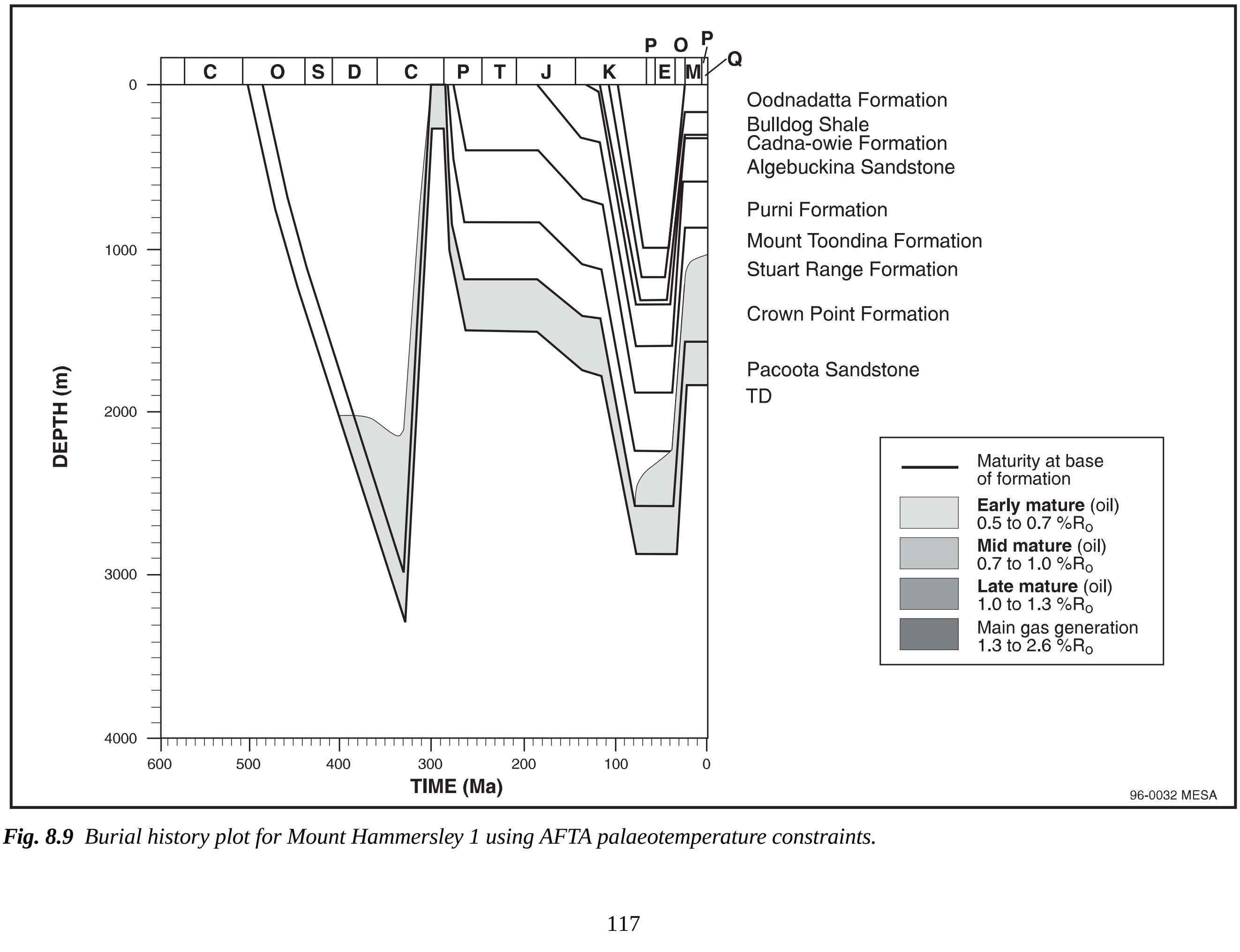

Fig. 8.9 *Burial history plot for Mount Hammersley 1 using AFTA palaeotemperature constraints.*

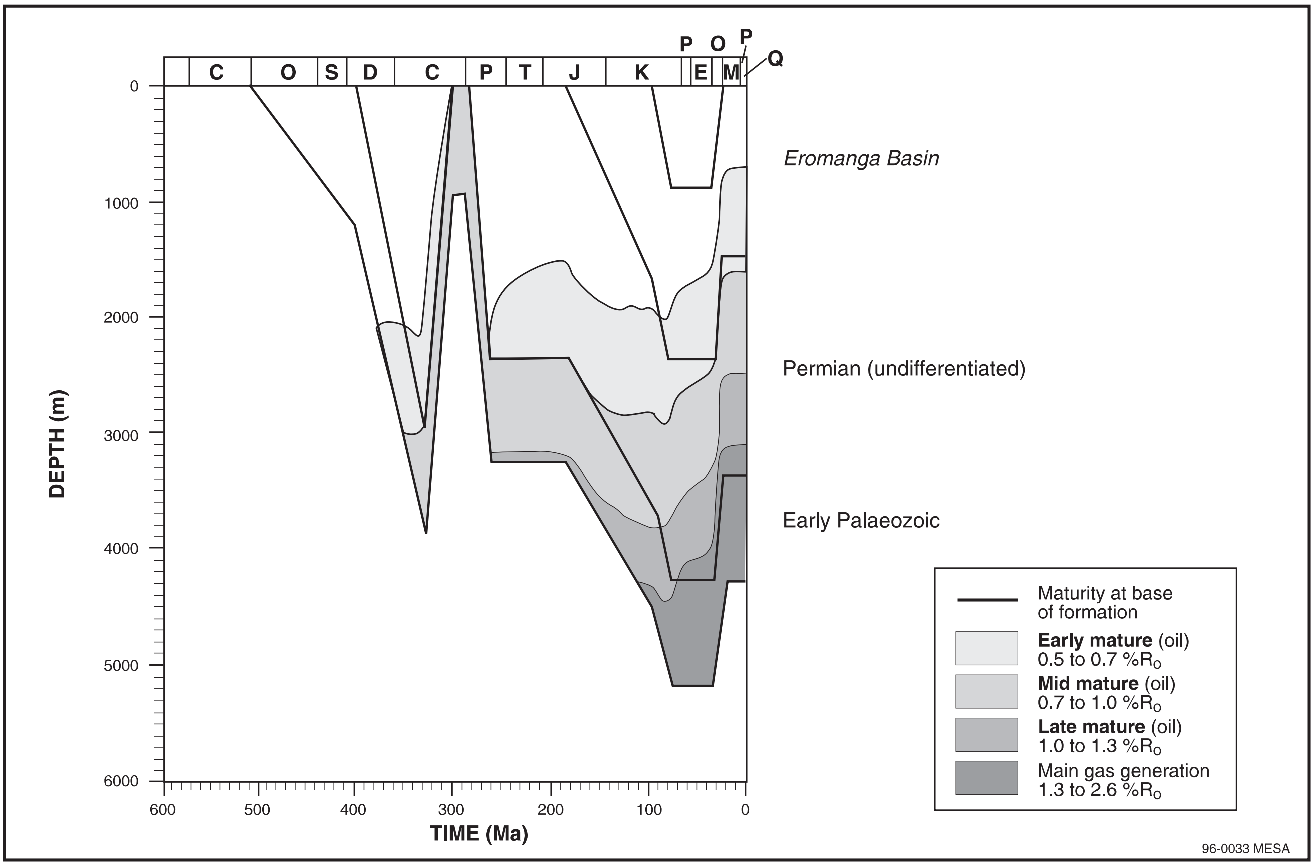

Fig. 8.10 *Burial history plot at site 85-XAF (SP 900) using AFTA palaeotemperature constraints.*

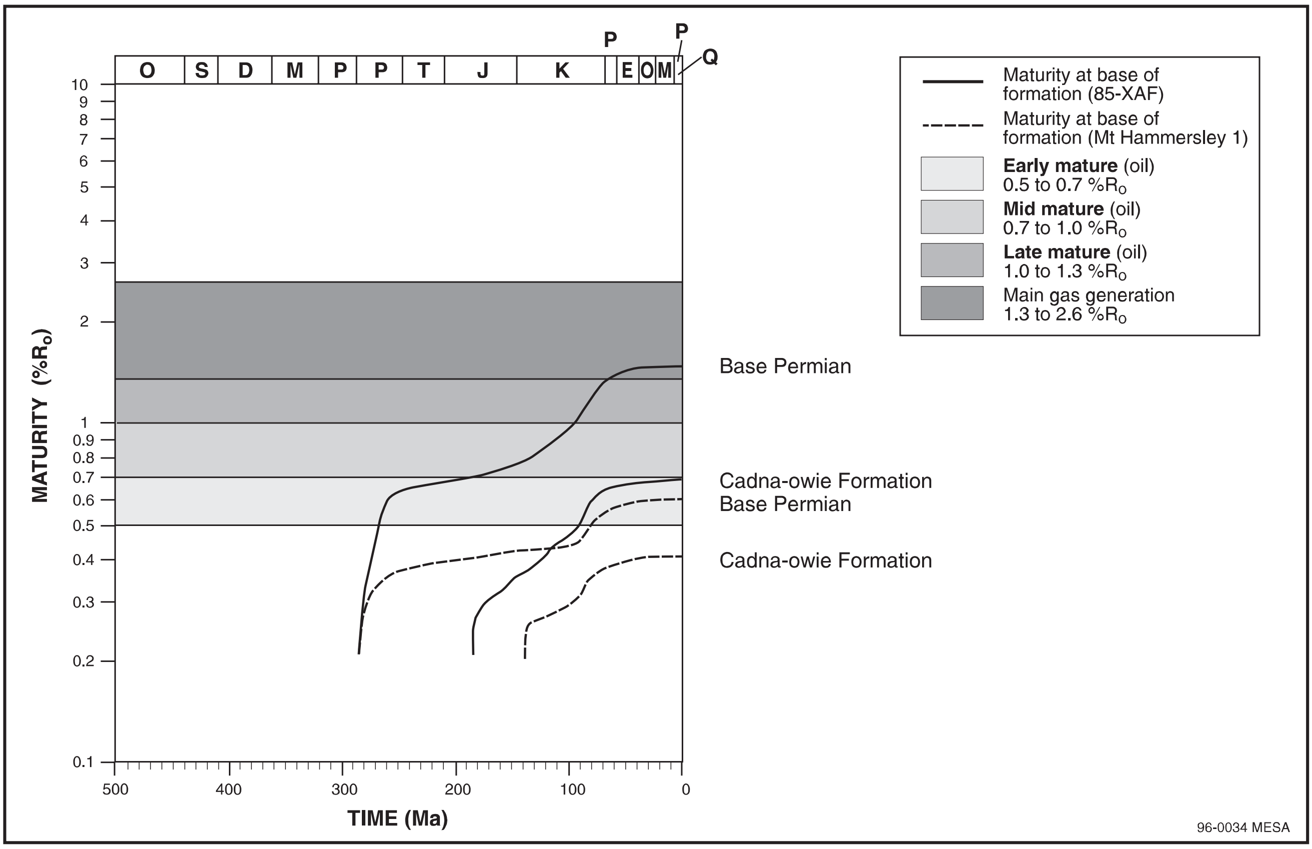

Fig. 8.11 *Maturity-time paths for the base of Permian and base of Cadna-owie Formation in Mount Hammersley 1 and site 85-XAF (SP 900).*

Table 8.1 *Sample information and AFTA analytical data.*

Sample	Type	Depth (m)	Temperature (°C)	Formation	Number of grains	ρ_d x 10^6 (ND)	ρ_s x 10^6 (Ns)	ρ_i x 10^6 (Ni)	P(χ^2) (%)	Fission track age* (Ma)	Mean track length (μm)	σ(μm) (no. of tracks)
Musgrave Block												
GC582-13	outcrop		21	Musgrave Block	20	1.302 (2129)	2.052 (1038)	1.221 (618)	20	410±24	14.0±0.1	1.0 (100)
Cur 5 (assumed GG = 35°C/km)												
GC550-1	core	208.7–209.25	29	Algebuckina Sandstone	4	1.256 (1975)	1.266 (145)	2.052 (235)	5	146±16 **129±23**	11.8±0.7	1.8 (7)
GC550-2	core	327.6–328.15	34	Arcoeillinna Sandstone	20	1.256 (1975)	1.964 (1634)	1.743 (1450)	2	264±12 **268±16**	13.0±0.1	1.0 (104)
Cur 3 (assumed GG = 35°C/km)												
GC550-3	core	376.6–376.9	36	Arcoeillinna Sandstone	19	1.256 (1975)	2.743 (1431)	2.155 (1124)	<1	297±14 **286±21**	13.2±0.1	1.3 (100)
McDills 1 (GG = 32°C/km)												
8651-9	core	820–823	51	Finke Group	6	1.190 (4163)	1.800 (320)	1.270 (226)	<1	293±26 **345±68**	10.59±0.2	1.82 (47)
8651-10	core	1024–1028	58	Finke Group	16	1.190 (4163)	1.589 (547)	1.275 (439)	<1	258±17 **278±23**	10.71±0.3	1.79 (47)
8651-11	core	1265–1270	66	Finke Group	17	1.190 (4163)	1.160 (346)	1.126 (336)	<1	215±17 **233±40**	9.65±0.3	2.45 (85)
8651-12	core	1690–1693	79	Finke Group	20	1.190 (4163)	0.805 (271)	2.453 (826)	<1	69±4 **74±14**	10.21±0.5	2.24 (19)
8651-14	core	2157–2160	94	Finke Group	19	1.190 (4163)	0.113 (21)	1.588 (296)	15	15±3	8.59±0.6	2.81 (42)
Mount Hammersley 1 (GG = 40°C/km)												
GC550-4	cuttings	350.5–381	36	Algebuckina Sandstone	5	1.198 (1856)	3.082 (256)	2.444 (203)	12	290±29	12.1±0.3	1.61 (22)
GC550-5	cuttings	554.7–582.2	44	Algebuckina Sandstone	8	1.186 (1856)	2.274 (465)	1.858 (380)	21	279±21	12.3±0.3	1.3 (25)
GC550-7	core	1309.4–1310.9	73	Crown Point Formation	20	1.174 (1856)	2.284 (1669)	2.908 (2125)	<1	179±8 **205±25**	10.5±0.2	1.59 (104)
GC550-8	cuttings	1527–1551.4	82	Crown Point Formation	20	1.162 (1856)	0.540 (334)	1.115 (690)	<1	110±8 **102±18**	9.7±0.2	2.36 (102)
GC550-9	cuttings	1834.9–1865.4	94	Pacoota Sandstone	20	1.150 (1856)	1.037 (519)	1.391 (696)	<1	166±11 **158±25**	10.2±0.3	2.36 (62)
Mount Crispe 1 (GG = 36°C/km)												
GC550-12	cuttings	219.5–234.7	29	Algebuckina Sandstone	2	1.292 (1958)	0.540 (18)	1.619 (54)	34	81±22	–	–
GC550-13	core	869–868.1	53	'Mount Crispe beds'	9	1.279 (1958)	3.402 (668)	3.662 (719)	<1	221±13 **233±33**	11.8±0.3	1.6 (28)
GC550-14	core	1026.3–1027.2	58	'Mount Crispe beds'	1	1.251 (1958)	3.011 (36)	8.280 (99)	–	86±17	–	–

Sample	Type	Depth (m)	Temperature (°C)	Formation	Number of grains	ρ_d x 10^6 (ND)	ρ_s x 10^6 (Ns)	ρ_i x 10^6 (Ni)	$P(\chi^2)$ (%)	Fission track age* (Ma)	Mean track length (μm)	σ(μm) (no. of tracks)
GC550-15	core	1333.1–1333.3	70	'Mount Crispe beds'	20	1.238 (1958)	4.020 (468)	3.513 (409)	63	264±19	11.3±0.2	1.4 (32)
GC550-16	core	1534.1–1535	77	'Mount Crispe beds'	6	1.225 (1958)	5.103 (228)	5.640 (252)	94	207±20	10.5±0.3	0.8 (6)
GC550-17	cuttings	1699.3–1717.5	83	'Mount Crispe beds'	12	1.197 (1958)	2.754 (565)	2.915 (598)	<1	212±14 **227±27**	11.6±0.2	1.5 (41)
Dalhousie Anticline												
GC582-18	outcrop		21	Coorikiana Sandstone	20	1.333 (2129)	0.235 (128)	0.601 (327)	83	102±11	13.3±0.2	1.8 (86)
Purni 1 (GG = 39°C/km)												
GC550-10	cuttings	140.2–161.5	27	Winton Formation	13	1.255 (1975)	0.515 (177)	0.832 (286)	61	146±15	14.7±0.3	1.62 (24)
GC550-11	core	1391.7–1392.6	75	Algebuckina Sandstone	3	1.306 (1958)	2.747 (242)	2.962 (261)	1	226±20 **235±38**	10.0±0.2	0.9 (23)
Poolowanna 1 (GG = 42.3°C/km)												
GC582-11	cuttings	515–570	44	Winton Formation	10	1.299 (2033)	0.313 (84)	0.392 (105)	86	198±30	14.9±0.7	2.0 (10)
Mulapula 1 (GG = 50.7°C/km)												
GC582-3	cuttings	969–997	71	Namur Sandstone	19	1.272 (2033)	1.347 (630)	2.008 (939)	<1	163±10 **158±24**	11.3±0.4	1.7 (21)
GC582-4	core	1218–1230	83	Birkhead Formation	20	1.275 (2033)	0.585 (460)	1.195 (940)	<1	120±8 **135±21**	11.5±0.2	1.54 (63)
GC582-5	core	1413–1415	92	Dullingari Group	7	1.279 (2033)	0.534 (46)	1.461 (126)	<1	90±16 **93±28**	9.2	– (1)
Koonchera 1 (GG = 44.5°C/km)												
GC582-6	cuttings	585–631	48	Winton Formation	20	1.282 (2033)	0.464 (414)	0.834 (744)	<1	137±9 **143±14**	14.4±0.2	1.36 (74)
GC582-7	cuttings	1375–1402	83	Namur Sandstone	8	1.286 (2033)	0.989 (249)	4.219 (1062)	<1	58±4 **77±21**	10.8±0.5	1.85 (12)
GC582-8	cuttings	1710–1740	98	Hutton Sandstone	16	1.289 (2033)	0.484 (194)	1.771 (710)	<1	68±6 **86±20**	10.9±0.5	1.71 (12)
GC582-9	cuttings	1987–2012	110	Poolowanna Formation	5	1.292 (2033)	0.294 (27)	1.469 (135)	17	50±11	no tracks	–
GC582-10	cuttings	2036–2048	112	Cuddapan Formation	2	1.296 (2033)	0.247 (28)	0.380 (43)	91	161±39	14.1±0.6	0.8 (2)
Poonarunna 1 (GG = 42.7°C/km)												
GC582-14	cuttings	210–250	31	Winton Formation	20	1.306 (2033)	0.279 (299)	0.527 (564)	<1	133±10 **131±15**	15.2±0.1	1.2 (100)
GC582-15	core	1403–1404	81	Namur Sandstone	7	1.309 (2033)	0.912 (205)	2.996 (673)	<1	77±7 **96±36**	11.5±0.7	2.3 (12)
GC582-16	core	1588–1590	89	Birkhead Formation	20	1.312 (2033)	0.314 (180)	2.644 (1516)	<1	30±3 **29±5**	10.2±0.4	1.8 (21)

Sample	**Type**	**Depth** (m)	**Temperature** (°C)	**Formation**	**Number of grains**	ρ_d x 10^6 (ND)	ρ_s x 10^6 (Ns)	ρ_i x 10^6 (Ni)	**P(χ^2)** (%)	**Fission track age*** (Ma)	**Mean track length** (μm)	**σ(μm) (no. of tracks)**
Tinga Tingana 1 (GG = 45°C/km)												
8642-54	core	1732	99	Tirrawarra Sandstone	20	1.396 (5971)	2.394 (1924)	3.331 (2677)	<1	176±7 **147±18**	11.2±0.2	1.6 (100)
8642-55	core	2096	118	Merrimelia Formation	21	1.396 (5971)	0.422 (528)	2.006 (2508)	<1	**119±35**	10.0±0.3	2.5 (100)
Cherri 1 (GG = 43.2°C/km)												
GC582-1	cuttings	1327–1333	78	Tirrawarra Sandstone	2	1.269 (2033)	3.589 (262)	3.507 (256)	<1	246±23 **140±77**	13.3±0.7	1.7 (7)
Weena 1 (GG = 42.5°C/km)												
GC582-17	core	1516–1518	85	Merrimelia Formation	12	1.323 (2129)	1.424 (173)	2.742 (333)	2	134±13 **132±20**	10.8±0.6	2.8 (19)

GG: geothermal gradient.

ρ_s: fossil track density in apatite.
ρ_i: induced track density counted in external (muscovite) detector.
ρ_d: standard glass CN5 samples (GC550–1 to 17) or SRM612 (8651–9 to 15) track density (measured in mica external detector).
Numbers in brackets refer to number of tracks counted in track density measurements.

***Fission track ages:** have been obtained using the external detector method (Gleadow, 1981). Ages are calculated using zeta calibrations of 356 (8651–9 to 14), 380 (GC550–1 to 3, and 10 to 17), and 393 (GC550–4 to 9) as outlined in Hurford and Green (1983). The central age (bold) is used when the probability given by the chi-squared statistic, **P(χ^2)**, is <5%. All ages quoted at ±1 sigma.

Data for samples prefixed by GC550, GC582 and 8642–54 were generated by Geotrack International, 8642–55 by I. Duddy (Gleadow *et al.*, 1988), and those with 8651 indicate P. Tingate.

Table 8.2 *AFTA palaeotemperature data.*

Well	Formation	Present temp. (°C)	Present temp. duration (Ma)	Palaeo-temp. 1 (°C)	Time 1 (Ma)	Palaeo-temp. 2 (°C)	Time 2 (Ma)	Palaeo-temp. 3 (°C)	Time 3 (Ma)
Musgrave Block									
GC582-13	Musgrave undifferentiated	21	–	≤40	100–0	–	–	90–120	360–300
Cur 5									
GC550-1	Algebuckina Sandstone	29	–	60–90	80–0	–	–	–	–
GC550-2	Arcoeillinna Sandstone	34	–	60	120–0	–	–	>100	360–290
Cur 3									
GC550-3	Arcoeillinna Sandstone	36	–	–	–	60–90	300–90	>100	410–320
McDills 1									
8651-9	Finke Group	51	–	85	80–20	–	–	–	–
8651-10	Finke Group	58	–	90	80–20	–	–	–	–
8651-11	Finke Group	66	–	95	80–20	–	–	–	–
8651-12	Finke Group	79	–	100–110	80–20	–	–	–	–
8651-14	Finke Group	94	–	>110	80–20	–	–	–	–
Mount Hammersley 1									
GC550-4	Algebuckina Sandstone	36	–	80	140–0	–	–	–	–
GC550-5	Algebuckina Sandstone	44	–	80	180–0	–	–	–	–
GC550-7	Crown Point Formation	73	–	90	60–0	–	–	–	–
GC550-8	Crown Point Formation	82	–	95	60–0	–	–	–	–
GC550-9	Pacoota Sandstone	94	<5	–	–	–	–	–	–
Mount Crispe 1									
GC550-12	Algebuckina Sandstone	29	–	70	100–0	–	–	–	–
GC550-13	‘Mount Crispe beds’	53	–	75–90	60–0	–	–	>110	400–200
GC550-14	‘Mount Crispe beds’	58	–	>60	200–0	–	–	–	–
GC550-15	‘Mount Crispe beds’	70	–	–	–	–	–	>100	420–300
GC550-16	‘Mount Crispe beds’	77	–	–	–	–	–	>100	450–200
GC550-17	‘Mount Crispe beds’	83	<5		–	–	–	>100	400–250
Dalhousie Anticline									
GC582-18	Coorikiana Sandstone	21	–	90–100	90–50	–	–	–	–
Purni 1									
GC550-10	Winton Formation	27	–	–	–	–	–	–	–
GC550-11	Algebuckina Sandstone	75	–	80–90	100–0	–	–	–	–
Poolowanna 1									
GC582-11	Winton Formation	44	–	–	–	–	–	–	–
Mulapula 1									
GC582-3	Namur Sandstone	71	–	90	90–0	–	–	–	–
GC582-4	Birkhead Formation	83	<5	95	60–0	–	–	–	–
GC582-5	Dullingari Group	92	–	100+	300–0	–	–	–	–
Koonchera 1									
GC582-6	Winton Formation	48	<5	–	–	–	–	–	–
GC582-7	Namur Sandstone	83	–	100	40–15	–	–	–	–
GC582-8	Hutton Sandstone	98	–	–	–	–	–	–	–
GC582-9	Poolowanna Formation	110	<5	–	–	–	–	–	–
GC582-10	Cuddapan Formation	112	?<5	–	–	–	–	–	–
Poonarunna 1									
GC582-14	Winton Formation	31	<5	–	–	–	–	–	–
GC582-15	Namur Sandstone	81	<5	100	40–0	–	–	–	–
GC582-16	Birkhead Formation	89	–	105	40–0	–	–	–	–
Cherri 1									
GC582-1	Tirrawarra Sandstone	78	–	90–100	90–0	–	–	–	–
Tinga Tingana 1									
8642-54	Tirrawarra Sandstone	99	<5	95	90–0	–	–	–	–
8642-55*	Early Permian	118	<2	–	–	–	–	–	–
Weena 1									
GC582-17	Merrimelia Formation	85	–	100	90–0	–	–	–	–

Temperatures are based upon an assumed heating duration of ~10 Ma with a precision of ±10°C unless stated otherwise.
Times given for each event are the timing of cooling (or heating for first event) from accompanying palaeotemperatures.
*Data generated by I. Duddy (Gleadow *et al.*, 1988).

CONCLUSIONS

Extrapolating thermal history constraints from the margins of the Eringa Trough, thermal history modelling suggests that the base of the Permian in the deepest part entered the upper part of the oil window in the Permian and passed through the main oil window in the Cretaceous. The base of the Eromanga Basin sequence probably entered the oil window at ~100 Ma and reached maximum maturity in the mid-Tertiary. The top of the oil window is closer to the surface than previously thought, making the shallow prospects delineated in South Australia and the Northern Territory more prospective.

Cooling from elevated temperatures in the last 100 Ma has affected the Jurassic sequence along both the Birdsville Track Ridge and the Permian succession on the southern margin of the Cooper Basin. The timing of maximum temperature within the Permian source rocks is suitable for charging Eromanga Basin reservoirs.

Widespread evidence for a recent increase (<5 Ma) in geothermal gradient has been found across the South Australian part of the Eromanga Basin. This recent heating has not had sufficient time to increase the thermal maturity of most of the formations sampled but has probably caused recent petroleum generation in deeper parts of the Cooper Basin.