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Preliminary insights

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APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

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by

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Abstract

Twenty-four samples provided by Geoscience Australia were analysed using screening methods to provide a preliminary insight into the gas shale potential of the Amadeus and Georgina Basins, Australia. Eleven samples from the Amadeus Basin include the Bitter Springs Formation (Late Neoproterozoic), Lower Giles Creek Dolomite (Middle Cambrian), Goyder Formation (Middle Cambrian) and Horn Valley Siltstone (Early Ordovician). Thirteen samples of core from the Georgina Basin are from the Middle Cambrian, and most of them from the “hot shale” of the Arthur Creek Formation. Results indicate that samples from both the Amadeus and Georgina basins have high potential for gas shale.

AMADEUS BASIN

The Bitter Springs Formation, Lower Giles Creek Dolomite, and Goyder Formation are poor gas shale candidates, based on the samples analysed here. Although they are characterised by high Production Indices (PI) ranging from 0.24-0.50 (wt ratio), a generally positive signal for overmature gas shales, the organic carbon contents are very low (in the range 0.07 to 0.16%), as are remaining petroleum generating potentials (S2 yield is around 0.08-0.21 µg/g sample). Their free hydrocarbons, as well as their pyrolysis products, consist mainly of gases. A wide range of Tmax values (287-490°C) simply reflects the broad and irregular shape of the S2 peaks, the samples all being overmature. The remaining gas yield potential of these samples is around 15 µg/g sample. Of the three samples from the Horn Valley Siltstone analysed here, two (G006481 and G006482) might have gas shale potential because of their high Total Organic Carbon (TOC) (3.16-3.42%), moderate production index (PI ~ 0.2) and Tmax of 445-449°C (close to the minimum of 450°C). These two samples can be classified as kerogen type II. Upon pyrolysis, they produce products signalling Paraffinic-Naphthenic-Aromatic Low Wax Oil potential, but very close to the boundary with the gas condensate field. Another sample (G006480) from the Horn Valley Siltstone, analysed to elucidate shale gas characteristics where organic richness at a similar level of maturity was only moderate, appears inherently gas-prone and to contain adsorbed gas. The remaining gas-generating potential of G006481 and G006482 are 1775 and 2486 µg/g sample, respectively, and for the leaner sample G006480 only 250 µg/g sample.

GEORGINA BASIN

In the MacIntyre 1 well, two samples (G006484 and G006485) have TOCs around 1%, and Hydrogen Indices of 80 and 100 mg/g TOC, respectively, whereas the remaining two samples (G006486 and G006487) have much higher organic carbon contents of 5.3-8.6%. The Hydrogen Index values of the latter samples are around 70 mg/g TOC. The Tmax values range from 457-475°C for four samples in this well, which is ideal shale gas potential. Pyrolysis shows samples G006484 and G006485 to be classified as gas- and condensate-prone, with total remaining gas generation potential in each case amounting to 300 µg/g sample. This latter potential yield is significantly smaller than that of samples G006486 and G006487, whose remaining gas yields are 1230 and 3181 µg/g sample. Additionally, the free hydrocarbons in samples G006486 and G006487 consist of paraffins below n-C_{20} thereby fulfilling an empirical prerequisite for gas shales. Samples from the Baldwin-1 well have a high content of organic matter (TOC = 5.47-11%), Hydrogen Index in the range 22-34 mg/g TOC and very high Tmax values (522-586°C). Their remaining petroleum potential is for 660-1300 µg gas condensate /g sample. Three samples from the BMR Mt Isa-1 drillhole were analysed, and are all characterised by very low production indices (0.03-0.05 wt ratio). Two of these samples (G006491 and G006492) have high organic carbon contents (TOC = 9.0 – 16.0%) and high petroleum-generating potential (HI ~ 600 mg/g TOC). They generate

petroleum enriched in light hydrocarbons, even at low stages of thermal evolution. Remaining primary gas potential is very high, up to 8700-20000 (µg/g sample). Based on that criteria, this source rock is worthy of serious consideration as a potential gas shale. The remaining sample (G006493) is of lower quality (TOC = 0.5%, HI ~ 300 mg/g TOC) and was not analysed in any further detail. Similar to samples from the Horn Valley Siltstone in the Amadeus Basin, samples from the NTGS Elkedra-3 drillhole also fulfil the empirical criteria to be considered as gas shale candidates. They have high organic carbon content (TOC = 9.66-12.2%), Hydrogen Index (HI) values in range of 64-73 (mg/g TOC) and high Tmax values (467-474°C). Upon pyrolysis, samples from the Arthur Creek Formation in the NTGS Elkedra-3 drillhole produce gas condensate. Their total gas potential ranges from 2500-3100 (µg/g sample).

Samples

Twenty-four samples from the Amadeus and Georgina Basins were provided for this study by Geoscience Australia (Table 1). Eleven cuttings and core samples from the Amadeus Basin were collected from seven different wells, namely Dingo 1, Murphy 1, Orange 1, Mount Winter 2A, Tempe Vale 1, Tent Hill 1 and Rodinga 6. These samples include the Bitter Springs Formation (Late Neoproterozoic), Lower Giles Creek Dolomite (Middle Cambrian), Goyder Formation (Middle Cambrian) and the Horn Valley Siltstone (Early Ordovician).

Thirteen core samples from the Georgina Basin were selected from the MacIntyre 1, Baldwin 1, BMR Mt Isa 1 and NTGS Elkedra 3 wells. They are of Middle Cambrian age (Boreham and Ambrose, 2007), most of them being from the “hot shale” of the Arthur Creek Formation.

Experimental details

ROCK EVAL ANALYSIS

Rock Eval analysis was performed on all samples using a Rock-Eval 6 instrument. TOC determination was performed on all samples using a LECO CS244 device. Internal standards were run in parallel and checked against the acceptable range.

Rock Eval Temperature Programme

Pyrolysis: 300°C (3 min.) at 25 °C/min. to 650 °C (0 min.)

The Rock-Eval and TOC results for samples from both Amadeus and Georgina Basins are summarised in Table 2. The Rock-Eval chromatograms of samples from the Amadeus Basin are shown in Figure 1, with samples from the Georgina Basin being shown in Figure 2. The relationships of Hydrogen Index to Oxygen Index (OI) and to Tmax value are shown in Figure 3 and Figure 4, respectively.

THERMOVAPORISATION

Thermovaporisation was used to analyse free hydrocarbons in selected unheated samples and performed using the Quantum MSSV-2 Thermal Analysis System©. Milligram quantities of each sample were sealed in a glass capillary and heated to 300°C in the injector unit for 5 minutes. The tube was then cracked open using a piston device coupled with the injector, and the released volatile hydrocarbons analysed by gas chromatography.

The thermovaporisation results of selected samples are reported in Table 3 and the chromatograms are shown in Figure 5.

Table 1: Geological background of investigated samples from Amadeus and Georgina Basins, and analysis details. (* = Batch 2)

Sample	Short ID	Basin	Well	Depth	Type	Formation	RE	Thermo VAP	PyGC	Lat	Long
Group A											
G006473	1	Amadeus	Dingo 1	7860'-7870'	cutting	Lower Giles Creek Dolomite	1	1	1	-24.225	133.897382
G006474	2	Amadeus	Dingo 1	7740-7750´	cutting	Lower Giles Creek Dolomite	1			-24.225	133.897382
G006475	3	Amadeus	Murphy 1	1527m	cutting	Bitter Springs Formation	1	1	1	-25.3269	132.631859
G006476	4	Amadeus	Murphy 1	1272m	cutting	Bitter Springs Formation	1			-25.3269	132.631859
G006477	5	Amadeus	Orange 1	4070'8"	core	Goyder Formation	1			-24.0413	133.776826
G006478	6	Amadeus	Orange 1	4072'	core	Goyder Formation	1	1	1	-24.0413	133.776826
Group B											
G006479	7	Amadeus	Mount Winter 2A	242.9m	core	Horn Valley Siltstone	1			-23.8626	130.798157
G006480	8	Amadeus	Tempe Vale 1	404.65m	core	Horn Valley Siltstone	1	1*	1*	-24.0119	131.309349
G006481	9	Amadeus	Tempe Vale 1	409.4m	core	Horn Valley Siltstone	1	1	1	-24.0119	131.309349
G006482	10	Amadeus	Tent Hill 1	1145.9m	core	Horn Valley Siltstone	1	1	1	-24.2277	132.042956
G006483	11	Amadeus	Rodinga 6	75.3m	core	Horn Valley Siltstone	1			-24.3794	133.703333
G006484	12	Georgina	MacIntyre 1	766.7m	core	Arthur Creek Formation	1	1	1	-22.0377	135.543226
G006485	13	Georgina	MacIntyre 1	782.6m	core	Arthur Creek Formation	1	1*	1*	-22.0377	135.543226
G006486	14	Georgina	MacIntyre 1	797.7m	core	Arthur Creek Formation	1	1*	1*	-22.0377	135.543226
G006487	15	Georgina	MacIntyre 1	803.2m	core	Arthur Creek Formation	1	1	1	-22.0377	135.543226
G006488	16	Georgina	Baldwin 1	879.2m	core	Arthur Creek Formation	1	1*	1*	-22.2619	136.039407
G006489	17	Georgina	Baldwin 1	883.8m	core	Arthur Creek Formation	1	1	1	-22.2619	136.039407
G006490	18	Georgina	Baldwin 1	887.7m	core	Arthur Creek Formation	1	1*	1*	-22.2619	136.039407
G006491	19	Georgina	BMR Mt Isa 1	101.5m	core	"Middle Cambrian Shale"	1		1	-20.02221	138.661111
G006492	20	Georgina	BMR Mt Isa 1	107.45m	core	"Middle Cambrian Shale"	1		1	-20.02221	138.661111
G006493	21	Georgina	BMR Mt Isa 1	114.35m	core	"Middle Cambrian Shale"	1			-20.02221	138.661111
G006494	22	Georgina	NTGS Elkedra 3	102.25m	core	Arthur Creek Formation	1	1	1	-21.7444	135.708
G006495	23	Georgina	NTGS Elkedra 3	110.25m	core	Arthur Creek Formation	1	1	1	-21.7444	135.708
G006496	24	Georgina	NTGS Elkedra 3	113.42m	core	Arthur Creek Formation	1	1	1	-21.7444	135.708

PYROLYSIS GAS CHROMATOGRAPHY

Pyrolysis gas chromatography was performed on selected samples using the Quantum MSSV-2 Thermal Analysis System©. Thermally extracted (300°C 10 minutes) whole rock samples were heated in a flow of helium, and products released over the temperature range 300-600°C (40K/min) were focussed using a cryogenic trap, and then analysed using a 50 m x 0.32 mm BP-1 capillary column equipped with a flame ionisation detector. The GC oven temperature was programmed from 40°C to 320°C at 8°C/minute. Boiling ranges (C_1, C_2-C_5, C_6-C_{14}, C_{15}+) and individual compounds (n-alkenes, n-alkanes, alkylaromatic hydrocarbons and alkylthiophenes) were quantified by external standardisation using n-butane. Response factors for all compounds were assumed the same, except for methane whose response factor was 1.1.

Pyrolysis gas chromatography results are summarised in Tables 4 and 5. The chromatograms are given in Figure 6. The ternary diagrams for assessing phenol enrichment (Larter, 1984), petroleum type organofacies (Horsfield et al, 1989) and sulphur content (Eglinton et al., 1990; di Primio and Horsfield, 1996) are given in Figures 7-10. The remaining gas potential of investigated samples is listed in Table 4 and Figure 11.

Table 2: TOC and Rock-Eval parameters

Samples	Short ID	Group	S1	S2	S3	Tmax	PP	PI	HI	OD	TOC
			mg/g sediment			°C	mg/g	wt ratio	mg/g TOC		%
G006473	1		0.15	0.21	0.36	490.00	0.36	0.42	159.00	273.00	0.13
G006474	2		0.05	0.08	0.36	489.00	0.13	0.38	68.00	305.00	0.12
G006475	3	A	0.04	0.08	0.29	429.00	0.12	0.33	63.00	230.00	0.13
G006476	4		0.07	0.15	0.37	324.00	0.22	0.32	96.00	236.00	0.16
G006477	5		0.02	0.02	0.32	287.00	0.04	0.50	27.00	437.00	0.07
G006478	6		0.05	0.16	0.19	450.00	0.21	0.24	132.00	157.00	0.12
G006479	7		0.16	0.60	0.24	435.00	0.76	0.21	134.00	54.00	0.45
G006480	8		0.11	0.53	0.23	442.00	0.64	0.17	98.00	43.00	0.54
G006481	9	B	3.02	12.08	0.26	444.00	15.10	0.20	353.00	8.00	3.42
G006482	10		1.80	6.98	0.24	449.00	8.78	0.21	221.00	8.00	3.16
G006483	11		0.07	0.22	0.26	430.00	0.29	0.24	62.00	73.00	0.35
G006484	12		0.73	1.24	0.28	457.00	1.97	0.37	101.00	23.00	1.23
G006485	13		0.47	0.85	0.22	475.00	1.32	0.36	84.00	22.00	1.01
G006486	14		1.23	6.40	0.50	469.00	7.63	0.16	74.00	6.00	8.65
G006487	15		1.68	3.50	0.28	473.00	5.18	0.32	66.00	5.00	5.34
G006488	16		0.33	1.30	0.27	522.00	1.63	0.20	24.00	5.00	5.47
G006489	17		0.53	2.45	0.41	586.00	2.98	0.18	22.00	4.00	11.00
G006490	18		0.51	3.74	0.29	531.00	4.25	0.12	34.00	3.00	10.90
G006491	19		2.02	56.02	1.69	431.00	58.04	0.03	620.00	19.00	9.04
G006492	20		4.53	94.95	2.85	428.00	99.48	0.05	601.00	18.00	15.80
G006493	21		0.07	1.65	0.37	433.00	1.72	0.04	330.00	74.00	0.50
G006494	22		1.92	8.38	0.38	472.00	10.30	0.19	73.00	3.00	11.50
G006495	23		1.57	7.58	0.33	467.00	9.15	0.17	78.00	3.00	9.66
G006496	24		1.47	7.86	0.41	474.00	9.33	0.16	64.00	3.00	12.20

Table 3 Thermovaporisation individual yields and boiling ranges.

	G006473	G006475	G006478	G006481	G006482	G006484	G006487	G006489	G006494	G006495	G006496	G006480	G006485	G006486	G006488	G006490
Formation	Lower Giles Creek Dolomite	Lower Giles Creek Dolomite	Goyder Formation	Horn Valley Siltstone	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation
								μg/g sample								
$C_{1*1.1}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	1.33	0.67	1.41	0.89	0.21
C_2	0.8	0.4	0.8	6.5	3.6	1.3	2.4	2.8	4.3	6.0	8.60	0.73	0.82	4.81	1.44	0.32
C_3	1.5	0.1	0.2	19.0	13.9	1.3	8.8	10.2	6.3	8.3	22.80	5.37	1.73	13.68	10.83	2.67
iC_4	0.8	0.4	1.3	10.3	5.3	0.2	2.1	13.7	1.9	1.5	18.70	2.73	2.11	20.19	9.20	3.98
nC_4	34.9	7.1	5.8	15.3	46.5	10.8	7.6	27.2	16.9	10.5	28.30	7.98	6.10	21.64	8.13	3.70
C_2-C_5 Total	55.1	10.6	7.5	80.9	94.9	16.5	29.4	92.0	48.9	38.2	151.50	27.13	17.80	148.32	75.63	17.89
C_6-C_{14} Total (-Blank)	21.6	13.2	4.0	1937.3	754.3	98.3	1632.2	454.8	1454.6	1152.7	1719.00	72.05	169.19	1314.71	388.56	47.33
C_{15}_+ Total (-Blank)	0.0	0.0	0.0	1719.9	1003.6	525.1	467.6	13.2	846.7	655.9	228.50	2.97	190.90	130.12	6.30	0.00
C_1-C_5 Total	55.2	10.7	7.5	80.9	94.9	16.5	29.4	92.0	48.9	38.2	151.50	28.46	18.47	149.73	76.52	18.10
$C_{1\text{-}30}$+ Total (-Blank)	76.8	23.8	11.6	3738.1	18.5	639.9	2129.3	560.0	2350.2	1846.8	2099.00	103.48	378.56	1594.56	421.39	65.42
GOR Total	2.6	0.8	1.9	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.08	0.38	0.05	0.1	0.22	0.38
C_6-C_{14} Resolved	10.5	2.6	1.9	1435.3	459.7	31.3	1232.4	396.1	1031.7	658.0	1427.90	46.99	128.03	1098.09	298.90	29.22
C_{15}+ Resolved	0.0	0.0	0.0	638.5	337.7	126.7	142.6	8.5	244.6	148.2	79.60	0.00	50.70	24.92	0.00	0.00
$C_{1\text{-}30}$ Resolved	65.7	13.2	9.5	2154.7	892.3	174.5	1404.5	496.6	1325.1	844.3	1659.00	75.45	197.19	1270.75	375.43	47.32
GOR Resolved	5.23	4.13	3.94	0.04	0.12	0.10	0.02	0.23	0.04	0.05	0.10	0.61	0.1	0.13	0.26	0.62
								μg/g TOC								
$C_{1*1.1}$	0	0	0	0	0	0	0	0	0	0	0	245.40	66.60	16.32	16.26	1.91
C_2	606	329	676	191	115	104	44	26	37	62	70	134.77	81.24	55.66	26.38	2.94
C_3	1152	70	207	556	441	103	164	92	55	86	187	994.88	171.23	158.13	198.00	24.49
iC_4	593	312	1064	300	168	13	39	125	17	16	153	506.22	209.00	233.39	168.16	36.54
C_2-C_5 Total	42398	8162	6259	2366	3005	1338	551	837	425	395	1242	5024.68	1762.17	1714.68	1382.71	164.12
C_6-C_{14} Total (-Blank)	16615	10130	3367	56647	23870	7990	30566	4134	12649	11933	14090	13343.09	16751.42	15198.96	6189.46	434.18
C_{15}_+ Total (-Blank)	0	0	0	50290	31759	42695	8757	120	7362	6790	1873	549.93	18900.72	1504.31	115.14	0.00
C_1-C_5 Total	42461	8197	6283	2366	3005	1338	551	837	425	395	1242	5270.08	1828.77	1731.01	1398.97	166.03
$C_{1\text{-}30}$+ Total (-Blank)	59076	18327	9650	109302	58634	52023	39874	5091	20436	19118	17205	19163.10	37480.91	18434.27	7703.58	600.20
C_6-C_{14} Resolved	8112	1987	1597	41968	14549	2544	23080	3601	8971	6811	11704	8702.02	12676.01	12694.71	5464.42	268.12
C_{15}+ Resolved	0	0	0	18670	10685	10305	2670	77	2127	1535	652	0.00	5019.45	288.14	0.00	0.00
$C_{1\text{-}30}$ Resolved	50573	10184	7880	63003	28239	14188	26301	4515	11523	8741	13598	13972.09	19524.23	14713.86	6863.40	434.15

Table 4 Pyrolysis gas chromatogram (PyGC) boiling ranges.

Sample	G006473	G006475	G006478	G006481	G006482	G006484	G006487	G006489	G006491	G006492	G006494	G006495	G006496	G006480	G006485	G006486	G006488	G006490
Formation	Lower Giles Creek Dolomite	Lower Giles Creek Dolomite	Goyder Formation	Horn Valley Siltstone	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	"Middle Cambrian Shale"	"Middle Cambrian Shale"	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation
μg/g sample																		
$C_{1*1.1}$	6.0	5.2	3.8	638.0	439.8	81.8	504.2	408.5	2063.6	5292.2	1479.2	1067.2	1457.1	75	115	1323	359	688
C_{2-5} Total	8.8	8.7	8.8	1847.9	1335.0	215.9	729.1	328.0	6615.4	14626.6	1645.2	1413.6	1713.3	175	177	1857	302	611
C_{6-14} (-Blank)	16.8	10.8	10.9	3211.3	1869.5	297.3	706.7	96.4	11428.2	23015.3	1590.8	1440.1	1553.7	170	188	1996	173	552
C_{15}+ Total (-Blank)	0.0	0.0	0.0	1880.4	565.8	91.2	135.1	0.0	7885.1	19071.0	856.7	397.9	354.1	9	32	805	19	296
C_{1-5} Total	14.7	13.9	12.7	2485.9	1774.8	297.7	1233.3	736.5	8679.1	19918.8	3124.4	2480.8	3170.4	250	292	3181	661	1299
C_{1-30}+ Total	31.5	24.7	23.5	7577.5	4210.1	686.3	2075.1	832.9	27992.3	62005.1	5571.8	4318.8	5078.2	429	512	5981	853	2147
GOR Total	0.9	1.3	1.2	0.5	0.7	0.8	1.5	7.6	0.5	0.5	1.3	1.4	1.7	1	1	1	3	2
C_{6-14} Resolved	16.8	10.8	10.9	2643.8	1494.7	204.1	508.8	93.8	8625.1	17170.4	1265.8	1100.6	1211.1	165	143	1517	132	229
C_{15}+ Resolved	0.0	0.0	0.0	480.6	150.8	11.9	25.8	0.0	1198.5	2778.5	156.6	80.6	126.0	9	16	188	19	69
C_{1-30} Resolved	31.5	24.7	23.5	5610.3	3432.2	513.7	1767.8	830.3	18502.7	39867.7	4537.8	3662.0	4507.5	423	452	4886	812	1597
GOR Resolved	0.88	1.28	1.17	0.80	1.08	1.38	2.31	7.85	0.88	1.00	2.21	2.10	2.37	1.44	1.84	1.87	4.38	4.36
μg/g TOC																		
$C_{1*1.1}$	4582.4	3984.9	3203.7	18655.1	13917.2	6653.2	9442.1	3713.7	22828.0	33495.0	12862.6	11047.4	11943.4	13852	11396	15297	6564	6315
C_{2-5} Total	6735.6	6704.3	7362.7	54030.9	42246.9	17551.1	13653.1	2982.2	73179.7	92573.3	14305.8	14633.8	14043.5	32361	17558	21474	5516	5601
C_{6-14} (-Blank)	12902.7	8335.9	9056.4	93896.4	59162.4	24172.8	13234.5	876.4	126417.9	145666.4	13832.8	14908.0	12735.2	31527	18596	23071	3165	5063
C_{15}+ Total (-Blank)	0.0	0.0	0.0	54982.9	17905.9	7416.1	2529.6	0.0	87224.2	120702.6	7449.3	4118.9	2902.9	1620	3140	9302	347	2717
C_{1-5} Total	11318.0	10689.2	10566.5	72686.0	56164.0	24204.3	23095.1	6695.9	96007.7	126068.3	27168.4	25681.1	25986.9	46213	28954	36771	12080	11916
C_{1-30}+ Total	24220.7	19025.0	19622.9	221565.3	133232.4	55793.2	38859.3	7572.3	309649.8	392437.3	48450.5	44708.1	41625.0	79360	50689	69144	15592	19696
GOR Total	0.9	1.3	1.2	0.5	0.7	0.8	1.5	7.6	0.5	0.5	1.3	1.4	1.7	1.39	1.33	1.14	3.44	1.53
C_{6-14} Resolved	12902.7	8335.9	9056.4	77303.6	47299.2	16591.2	9527.5	852.6	95409.9	108673.5	10929.0	11393.4	9927.0	30473	14189	17537	2417	2103
C_{15}+ Resolved	0.0	0.0	0.0	14053.6	4771.0	966.6	482.3	0.0	13258.3	17585.3	1361.6	834.6	1032.0	1620	1562	2176	339	632
C_{1-30} Resolved	24220.7	19025.0	19622.9	164043.3	108234.2	41762.1	33104.9	7548.5	204675.9	252327.1	39459.0	37909.2	36946.8	78305	44705	56485	14836	14652
GOR Resolved	0.88	1.28	1.17	0.80	1.08	1.38	2.31	7.85	0.88	1.00	2.21	2.10	2.37	1.44	1.84	1.87	4.38	4.36

Results

AMADEUS BASIN

Bulk source rock characteristics

Total organic carbon contents and Rock Eval results are listed in Table 2. The samples from the Amadeus Basin can be divided into two groups based on these results (Group A and B, see Table 1). Samples in Group A (G006473-G006478) are from the Bitter Springs Formation, Lower Giles Creek Dolomite and Goyder Formation. They have very low organic carbon contents, in the range 0.07 to 0.16%. Group B consists of samples from the Horn Valley Siltstone (G006479-G006483), and is more enriched in organic carbon, its total organic carbon content range being 0.45-3.42%.

The Rock-Eval chromatograms of samples in Group A are characterised by relatively high S1 peaks and more or less flattened, irregular S2 peaks, except sample G006478 from the Goyder Formation, whose S2 peak appears as a bell-shape. The S2 peaks of samples in Group A (Figure 1) vary in both size and shape, displaying multiple-lobed S2 peaks which are not symmetrical and have a shoulder or tail. These samples have high production indexes (PI, Table 2) ranging from 0.24-0.5 (wt ratio). Group A samples have low Hydrogen Indices (27-159 mg HC/g TOC) and particularly high Oxygen Indices (157-437 mg CO2/g TOC), and a wide range of Tmax values (287-490°C) attributable to the irregular shapes of the broad S2 peaks. In both the HI versus OI (Figure 3, after Espitalie et al., 1977) and HI verses Tmax (Figure 4, after Espitalie et al., 1984) diagrams, these samples (short labels as 1-6) represent low petroleum generating potential.

Samples in Group B release more or less bell-shaped S2 peaks (Figure 1) whose yields are between 0.22 and 12.08 mg/g sediment. Group B is characterised by lower production index values (0.17-0.24 wt ratio; Table 2) in comparison with that of samples in the Group A. These values do not approach the 0.7 value, which Jarvie et. al., (2007) states is needed for high shale gas prospectivity, but gas loss from the provided samples cannot be ruled out, meaning that PI values represent minima. Group B has higher Hydrogen Indices (62-353 mg HC/g TOC) and lower Oxygen Indices (8-73 mg CO2/g TOC) than those of Group A. In both the HI versus OI (Figure 3) and the HI versus Tmax diagrams (Figure 4), the Group B samples abbreviated as 7-11 (Table 2) represent higher hydrocarbon generating potential. The Tmax values of these samples fall in a narrower range, from 430-449°C. These Tmax values are not above the minimum (450°C according to Jarvie et al., 2007) for shale gas prospectivity. Two samples, G006481 and G6482, however, might have shale gas potential because of their high TOC (3.16-3.42%), moderate PI ~ 0.2 (although gases might be lost) and Tmax of 445-449°C (close to the minimum 450°C cut-off).

Free Hydrocarbons

Thermovaporisation analysis run on three samples in Group A (G006473, G006475 and G006478) reveals that the free hydrocarbons consist mainly of gases. The same is true for one sample from Group B (G006480). The thermally extracted products from two samples in Group B (G006481, G006482), however, consist of mainly higher molecular weight alkanes, including both normal and branched alkanes in the range of C_9 to C_{19} and gaseous hydrocarbons. The odd-even predominance for the Horn Valley Siltstone is typical of many Ordovician source rocks and crude oils worldwide (Reed et al., 1986).

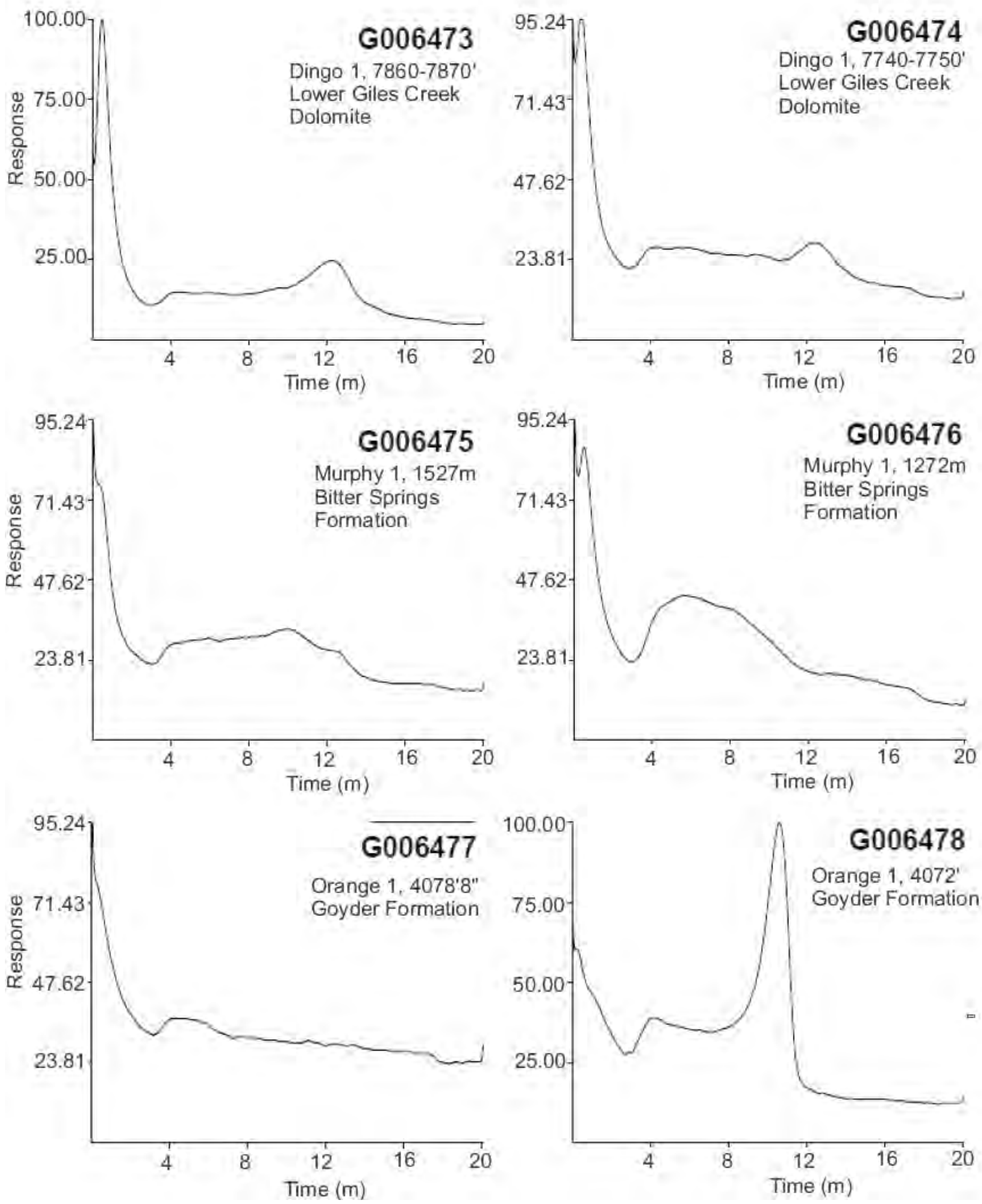


Figure 1 *Rock-Eval chromatograms of samples in Group A from the Amadeus Basin.*

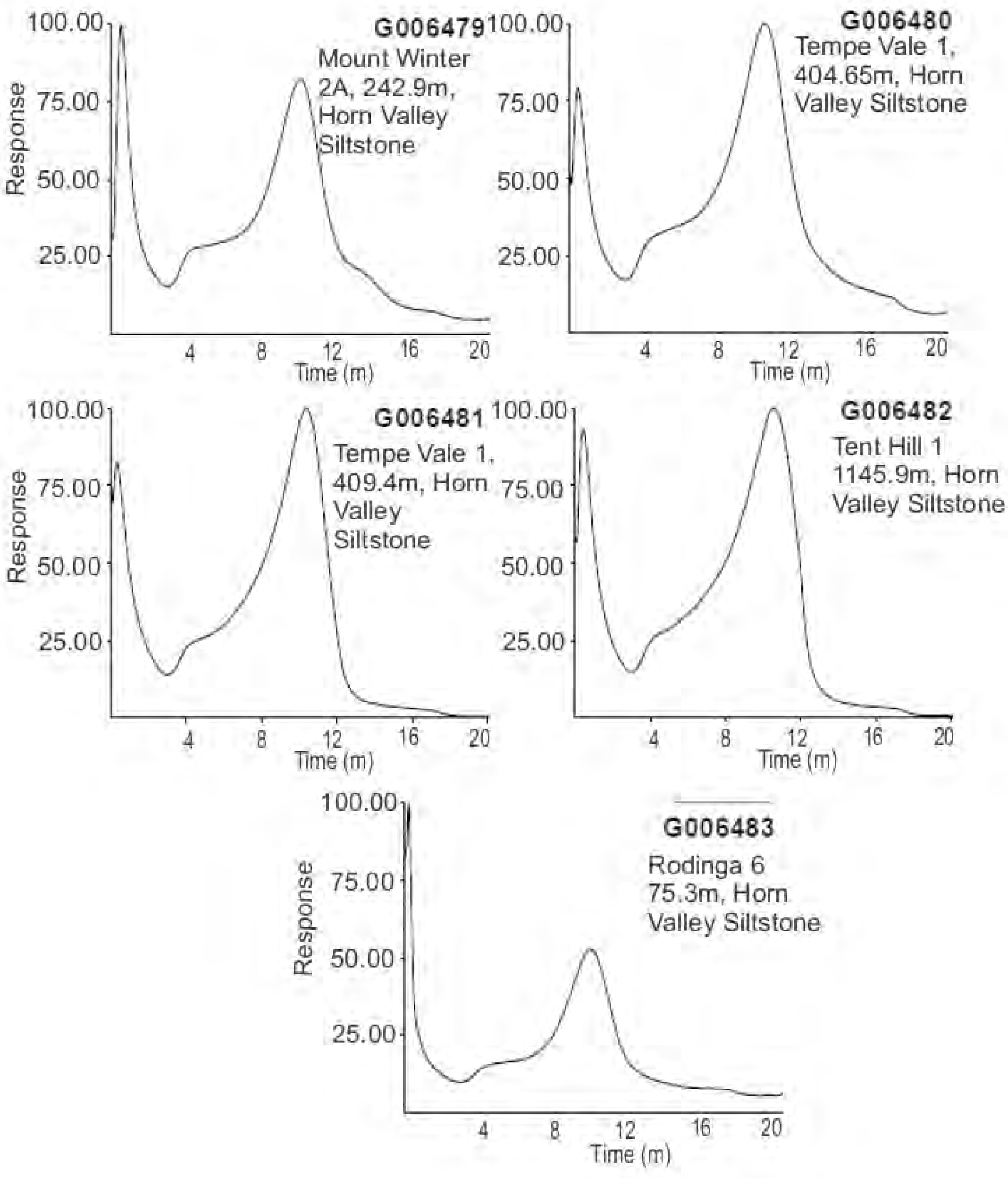


Figure 1 (continued) *Rock-Eval chromatograms of Horn Valley samples (Group B) from the Amadeus Basin.*

Table 5 Normal aliphatic yields (μg/g TOC)

sample	G006473	G006475	G006478	G006481	G006482	G006484	G006487	G006489	G006491	G006492	G006494	G006495	G006496	G006480	G006485	G006486	G006488	G006490
Formation	Lower Giles Creek Dolomite	Lower Giles Creek Dolomite	Goyder Formation	Horn Valley Siltstone	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	"Middle Cambrian Shale"	"Middle Cambrian Shale"	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation
									Normal aliphatics (μg/g TOC)									
C2:1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2:0	2552.1	2245.8	2933.3	17209.2	14633.3	6398.6	5834	1679	27135.2	35043.3	6256.7	6066.5	6173.8	8094.96	6924.79	9142.14	2714.46	2952.63
nC3:1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nC3:0	1531.1	1552.5	1890.9	14821.0	12032.4	5158.7	3952	839.5	20284.3	25506.6	3921.7	4167	3886.2	9336.52	5186.75	6106.43	1455.14	1571.55
nC4:1	1065.0	1449.8	1634.1	4399.0	3964.9	1814.4	987.3	174.6	7724.7	9834.8	1188.2	1256.2	1073.3	3465.1	1494.23	1509.09	254.42	211.68
nC4:0	554.2	460.9	705.5	5374.8	3990.4	1356.5	1019.8	134.3	5132.2	6323.5	886.2	1012.5	982.2	2287.49	1280.38	1471.39	244.45	291.31
nC5:1	220.8	252.8	398.3	2278.1	1953.2	690.5	340.1	26	3412.2	3848.6	369.4	402.9	341.4	632.77	439.52	529.81	25.46	34.74
nC5:0	49.3	110.8	177.2	3375.5	2221.8	556.2	505.2	25.6	2972.9	4001.3	451.8	463	478.1	1011.53	596.96	805.73	33.86	66.08
nC6:1	0	0	0	2496.5	1964.6	706.1	302.6	4.2	3716.9	4161	339.8	335.2	286.6	529.34	467.78	429.94	22.31	23.89
nC6:0	50.3	149.2	228.8	2983.7	1864.3	429.4	355.8	12.4	2116.9	2773.8	318.9	321.3	340.1	1066.98	389.27	603.86	32.78	30.59
nC7:1	0	0	0	1854.5	1400.2	460.2	197.4	0	2652.2	2800.2	221.4	208.6	172.6	258.77	315.94	272.83	12.98	11.13
nC7:0	0	0	0	2744.7	1588.1	332.5	266.9	0	2152.5	2716.2	272.5	260.5	250.6	753.54	327.39	495.08	19.26	22.4
nC8:1	0	0	0	1461.7	998.9	255	110.1	0	1838.2	1930.5	136.4	113.9	94.7	88.96	222.21	164.09	5.61	4.28
nC8:0	0	0	0	2344.3	1286.7	303.3	200.7	0	1623.4	1869.7	187.4	186.5	176.7	648.44	244.25	326.55	10.67	5.24
nC9:1	0	0	0	1137.3	766.4	182.8	63.9	0	1400.7	1448.7	106.8	92.2	65.5	70.53	151.22	123.26	2.62	1.77
nC9:0	0	0	0	1691.7	923.4	194.5	132.5	0	1282.1	1400.7	127.5	118.6	106.5	387.71	168.61	217.68	5.13	2.2
nC10:1	0	0	0	956.6	650.1	175.1	99.2	0	1206.7	1223.8	113.6	64.9	64.2	23.3	122.67	78.28	1.68	0.72
nC10:0	0	0	0	1373.5	705.1	174.1	100.6	0	1113.6	1213.5	109.3	88.2	76.4	293.25	135.49	176.81	4.53	3.1
nC11:1	0	0	0	735.8	413	143.8	53.2	0	889.5	995.9	66.6	42.7	36.0	38.53	96.92	51.99	2.66	1.66
nC11:0	0	0	0	1081.5	578.7	127.2	82.8	0	940.1	1029.7	80.8	79.0	65.0	202.12	110.29	133.9	6.68	0.92
nC12:1	0	0	0	728.8	319.4	94.4	30.8	0	992.4	1047.9	57.3	33.6	23.4	41.78	87.11	62.39	1.72	0
nC12:0	0	0	0	793.1	380.7	100.6	50.8	0	810.9	821.9	55.8	51.4	41.5	148.5	93.29	114.13	8.65	0
nC13:1	0	0	0	674.6	182.7	65.9	15.3	0	660.2	587.3	28.6	21.9	15.8	7.08	45.86	24.07	0.87	0
nC13:0	0	0	0	672.4	321.2	76.8	47.8	0	641.3	598.1	44.2	46.8	30.7	267.03	128.49	0	0	0
nC14:1	0	0	0	434.9	138	35	6.3	0	496.5	535.4	23.2	13	10.7	6.99	64.07	11.64	1.1	0
nC14:0	0	0	0	483.8	223.7	53.6	24.7	0	633.3	786.4	32.5	32.9	22.5	100.58	83.87	77.28	13.21	0
nC15:1	0	0	0	121.3	67.3	28.1	5.9	0	354.5	339	13.3	11.1	7.7	7.59	48.18	9.54	0	0
nC15:0	0	0	0	319.5	182.5	55.6	21	0	540.8	600.8	23.9	20.9	18.5	47.66	78.22	77.54	5.8	0
nC16:1	0	0	0	142.7	53.7	22.7	4.1	0	235.9	276	9.7	5.6	5.4	0	31.63	20.34	0	0

Table 5 (continued) Normal aliphatic yields (µg/g TOC)

sample	G006473	G006475	G006478	G006481	G006482	G006484	G006487	G006489	G006491	G006492	G006494	G006495	G006496	G006480	G006485	G006486	G006488	G006490
Formation	Lower Giles Creek Dolomite	Lower Giles Creek Dolomite	Goyder Formation	Horn Valley Siltstone	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	"Middle Cambrian Shale"	"Middle Cambrian Shale"	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation
	Normal aliphatics (µg/g TOC)																	
nC16:0	0	0	0	324.1	111.6	45.3	17.8	0	386.6	394.3	16.7	14.9	10.7	28.89	48	50.39	2.19	0
nC17:1	0	0	0	148.3	18.3	13.6	2.7	0	248.7	234.8	7	5.8	2.8	0	17.63	9.61	0	0
nC17:0	0	0	0	266	113.7	40.6	11.4	0	301	316	15	13.8	10.2	9.17	34.42	62.2	3.24	0
nC18:1	0	0	0	107.4	9.7	6	0	0	181.4	166.3	5.3	1.6	2.2	0	8.94	3.99	0	0
nC18:0	0	0	0	124.8	46.1	26.3	9.2	0	249.6	216.6	21.6	7.8	18	0	15.99	25.07	0	0
nC19:1	0	0	0	35.3	5	0	0	0	133.4	128.4	7.9	0	3.1	0	3.15	0	0	0
nC19:0	0	0	0	126.2	44.6	20.8	8.7	0	218.4	243.5	10	7.5	9.6	0	8.05	67.83	0	0
nC20:1	0	0	0	21.6	6.6	0	0	0	120.4	120.9	14	0	0	0	0	0	0	0
nC20:0	0	0	0	86.6	26.1	13.3	7.7	0	153.5	155.3	16.1	8.6	19.5	0	0	11.86	0	0
nC21:1	0	0	0	20.1	3.9	0	0	0	78.7	113.2	0	0	0	0	0	0	0	0
nC21:0	0	0	0	66.8	12.3	8.9	7.1	0	109.8	140.6	8	7	6.6	0	0	11.93	0	0
nC22:1	0	0	0	4.7	4.9	0	0	0	64.3	73.1	0	0	1.8	0	0	0	0	0
nC22:0	0	0	0	48.4	11.4	5.1	4.1	0	89.1	102.3	8	3.1	5.7	0	0	2.76	0	0
nC23:1	0	0	0	7	0	0	0	0	30.8	56.2	0	0	0	0	0	0	0	0
nC23:0	0	0	0	19.7	5.1	0	1.2	0	76.6	78.9	5.9	2.6	3	0	0	0	0	0
nC24:1	0	0	0	5.6	0	0	0	0	25	24.3	0	0	0	0	0	0	0	0
nC24:0	0	0	0	26	0	0	0	0	47.8	48.4	4.5	1.4	2.3	0	0	0	0	0
nC25:1	0	0	0	0	0	0	0	0	24.6	16.9	0	0	0	0	0	0	0	0
nC25:0	0	0	0	20.5	0	0	0	0	47.9	32.8	3.3	0	2	0	0	0	0	0
nC26:1	0	0	0	0	0	0	0	0	20.7	21	0	0	0	Sum nC6-14				
nC26:0	0	0	0	25	0	0	0	0	35.4	37.8	3.2	0	0.9	26.64	32.87	290.97	8.34	11.76
nC27:1	0	0	0	0	0	0	0	0	13.2	13.2	0	0	0	Sum nC15+				
nC27:0	0	0	0	15.3	0	0	0	0	23.9	19.4	2.4	0	0	0.5	2.97	30.54	0.61	0
nC28:1	0	0	0	0	0	0	0	0	10.2	7.2	0	0	0					
nC28:0	0	0	0	14.5	0	0	0	0	14.2	16.3	0	0	0					
nC29:1	0	0	0	6.4	0	0	0	0	6.5	0	0	0	0					
nC29:0	0	0	0	0	0	0	0	0	10.4	14.5	0	0	0					
nC30:1	0	0	0	5.1	0	0	0	0	0	0	0	0	0					
nC30:0	0	0	0	0	0	0	0	0	8.2	4.9	0	0	0					
nC31:1	0	0	0	0	0	0	0	0	0	0	0	0	0					
nC31:0	0	0	0	0	0	0	0	0	0	0	0	0	0					
nC32:1	0	0	0	0	0	0	0	0	0	0	0	0	0					
nC32:0	0	0	0	0	0	0	0	0	0	0	0	0	0					

Bulk chemical composition from pyrolysis gas chromatography

The pyrolysis gas chromatograms of samples from the Amadeus Basin are shown in Figure 6. The pyrolysis boiling ranges and individual yields are given in Table 4 and 5.

Three samples in Group A were selected for pyrolysis gas chromatography analysis. These are G006475 (Bitter Springs Formation), G006473 (Lower Giles Creek Dolomite) and G006478 (Goyder Formation). These samples generated only gaseous hydrocarbons and benzene upon pyrolysis. Their compositions fall in the gas and condensate facies of Horsfield (1989), as shown in Figure 8. The remaining gas generating potential yield of these samples is around 15 µg/g sample (Figure 11).

The three samples Group B analysed include G006480, G006481 and G006482, all from the Horn Valley Siltstone. Upon pyrolysis, these samples produce a mixture of aliphatic hydrocarbons and aromatic hydrocarbons (benzene and toluene). Doublets extend to medium-chain length (C_{15}) and decrease in relative abundance with increasing carbon number from C_6 to C_{15}, which is typical for type II kerogen (van de Meent et al., 1980; Muscio et al., 1993; Clegg et al., 1997). The pyrolysis compositions of these samples fall in type II intermediate sulfur enrichment field of Eglinton et al. (1990) and di Primio and Horsfield (1996), as illustrated in Figures 9 and 10. The kerogen structure is phenol-poor, according to the diagram of Larter (1984; Figure 7). The petroleum type is defined as paraffinic-naphthenic-aromatic low wax oil extending into gas-condensate, based on the ternary diagram of Horsfield (1989; Figure 8), although the Horn Valley Siltstone may have started out in the low wax paraffinic facies at lower maturity (Horsfield, 1989). Their present-day compositions (especially the pyrolysate composition of G006482, abbreviated as 10) are very close to the boundary with the gas condensate field. The remaining gas generating potentials of G006481 and G006482 are 2486 and 1775 µg/g sample respectively, but only 250 µg/g sample in the case of G006480.

GEORGINA BASIN

Bulk source rock characteristics

Total organic carbon content and Rock Eval results are listed in Table 2. Samples from the Georgina Basin have high organic carbon contents, mainly in the range 5.34 to 15.8%. There are three samples, however, with lower organic carbon contents. They are G006484 and G006485 (1.23 % and 1.01 % respectively) from MacIntyre 1, and sample G006493 (0.5%) from BMR Mt Isa 1.

The Rock-Eval chromatograms of the samples from the Georgina Basin (except for the three samples G006491 to G006493 from the BMR Mt Isa 1 drillhole, see Table 1), shown in Figure 2, are characterised by significant S1 peaks and multiple lobed S2 peaks, since they are not symmetrical and have a shoulder or tail. These samples have moderate to high Production Indices (PI, Table 2) ranging from 0.12-0.37 (weight ratio). These values do not approach the 0.7 value, which Jarvie et al., (2007) states is needed for high shale gas prospectivity, but gas loss from the samples cannot be ruled out. Hydrogen Indices of the aforementioned samples are low, and range from 22 to 101 mg HC/g TOC. Oxygen Indices ranging from 3 to 23 (CO_2/g TOC) are relatively low. In the HI versus OI (Figure 3, after Espitalie et al. 1977) and HI versus Tmax (Figure 4, after Espitalie et al. 1984) diagrams, these samples (short labelled as 12-18 and 22-24) are at the end of the mean evolution pathways. Their Tmax values of 457-586°C are above 450°C, the minimum for shale gas prospectivity according to Jarvie et al. (2007).

Three samples from the BMR Mt Isa 1 drillhole release relatively small S1 peaks, in comparison with their respective S2 peaks, and the latter are bell-shaped (Figure 2). These samples are characterised by very low Production Indices, which range from 0.03-0.05 (weight ratio). The

Hydrogen Index values of 330-620 (mg/g TOC) are high. According to Figures 3 and 4, two samples, G006491 and G006492, whose total organic carbon contents of 9.04-15.8%, fall between the mean evolutionary paths of kerogen type I and II. Clearly, these are very good potential source rocks for petroleum, both conventional and, at higher maturity levels, unconventional. Meanwhile, sample G006493, which has much lower TOC value (0.5%), can be classified as mixture of kerogen type II and III, representing lower petroleum generating potential. Tmax values in range of 428-433°C show these samples to be immature.

Free Hydrocarbons

The volatile products released upon thermal extraction of G006484 from the MacIntyre 1 well consist of gaseous hydrocarbons and normal-plus branched-alkanes in the range of C_{12}-C_{22}. In the case of sample G006485 from the same well, n-paraffins, up to octadecane, are present, with depletion in the gasoline range, whereas the volatile products of samples G006486 and G006487 reveal n-alkane envelopes in the low molecular weight range (< nC_{19}), an empirical prerequisite for high productivity, according to Jarvie et al. (2007).

The same holds true for three samples from the Elkedra 3 well, which release paraffins below nC_{20} upon thermovaporisation. Sample G006495 also produces a relatively large unresolved complex mixture.

In the case of samples G006488 to G006490 (Baldwin 1), thermovaporisation products are dominated by gas and condensate components, the latter being rich in aromatic hydrocarbons.

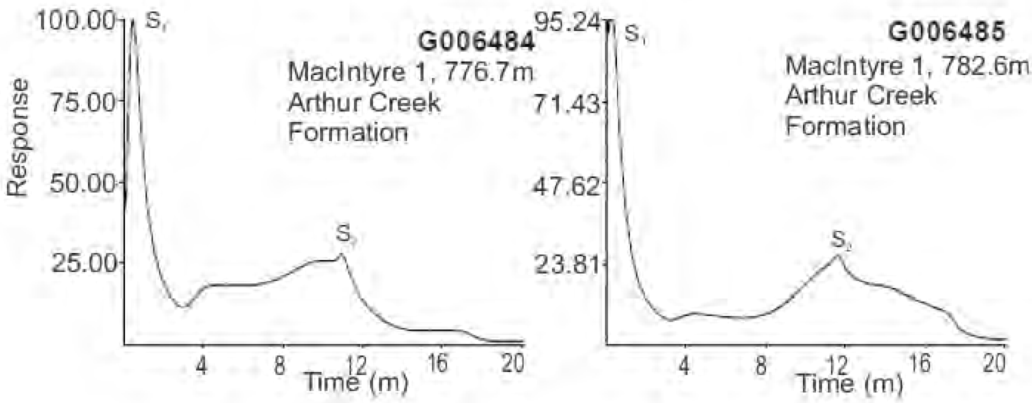


Figure 2. Pyrolysis program (FID) *Rock-Eval of samples from the Georgina Basin, with identified peaks labelled.*

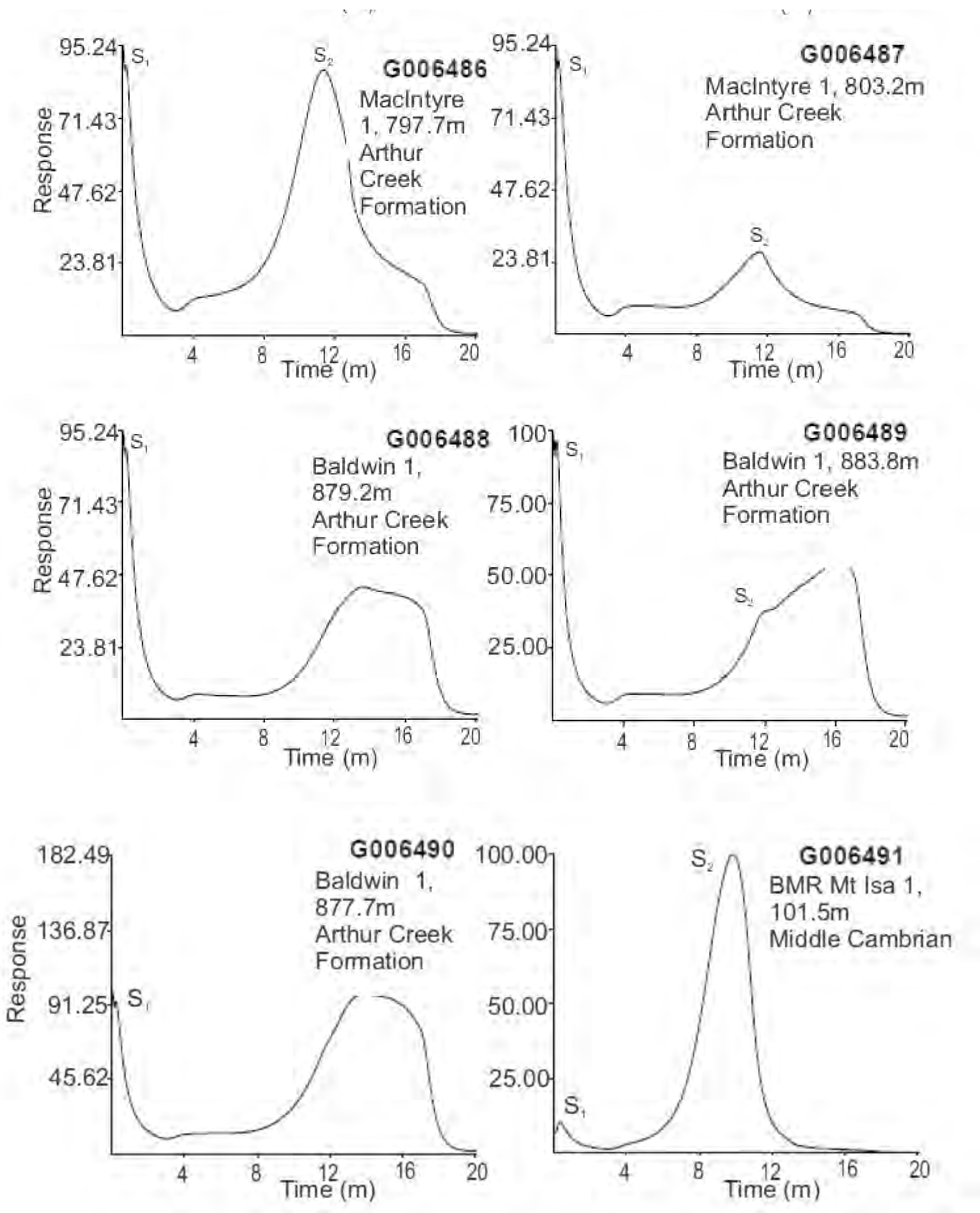


***Figure 2. (Continued) Pyrolysis program (FID)** Rock-Eval of samples from the Georgina Basin, with identified peaks labelled.*

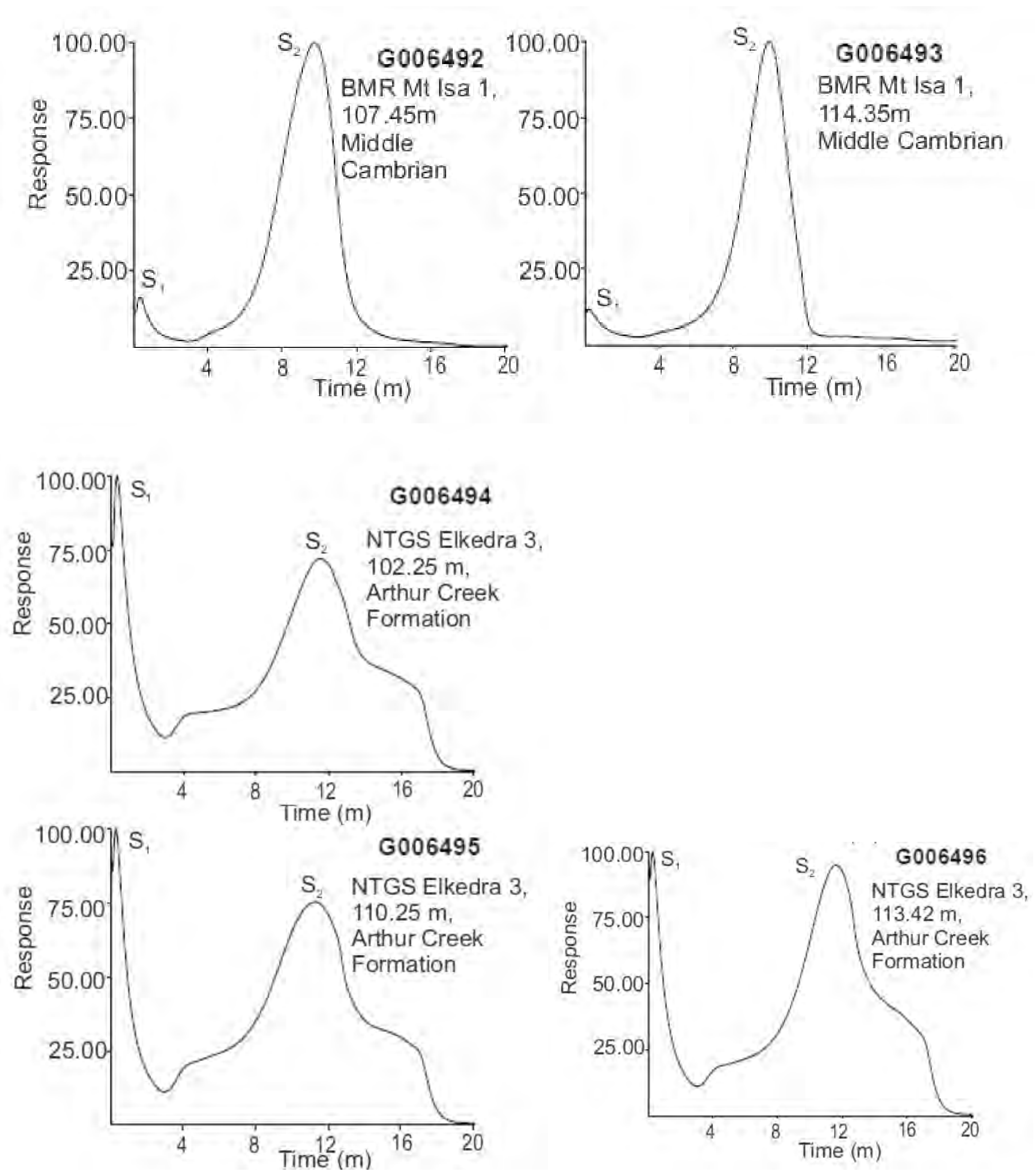


Figure 2. (Continued) Pyrolysis program (FID) *Rock-Eval of samples from the Georgina Basin, with identified peaks labelled.*

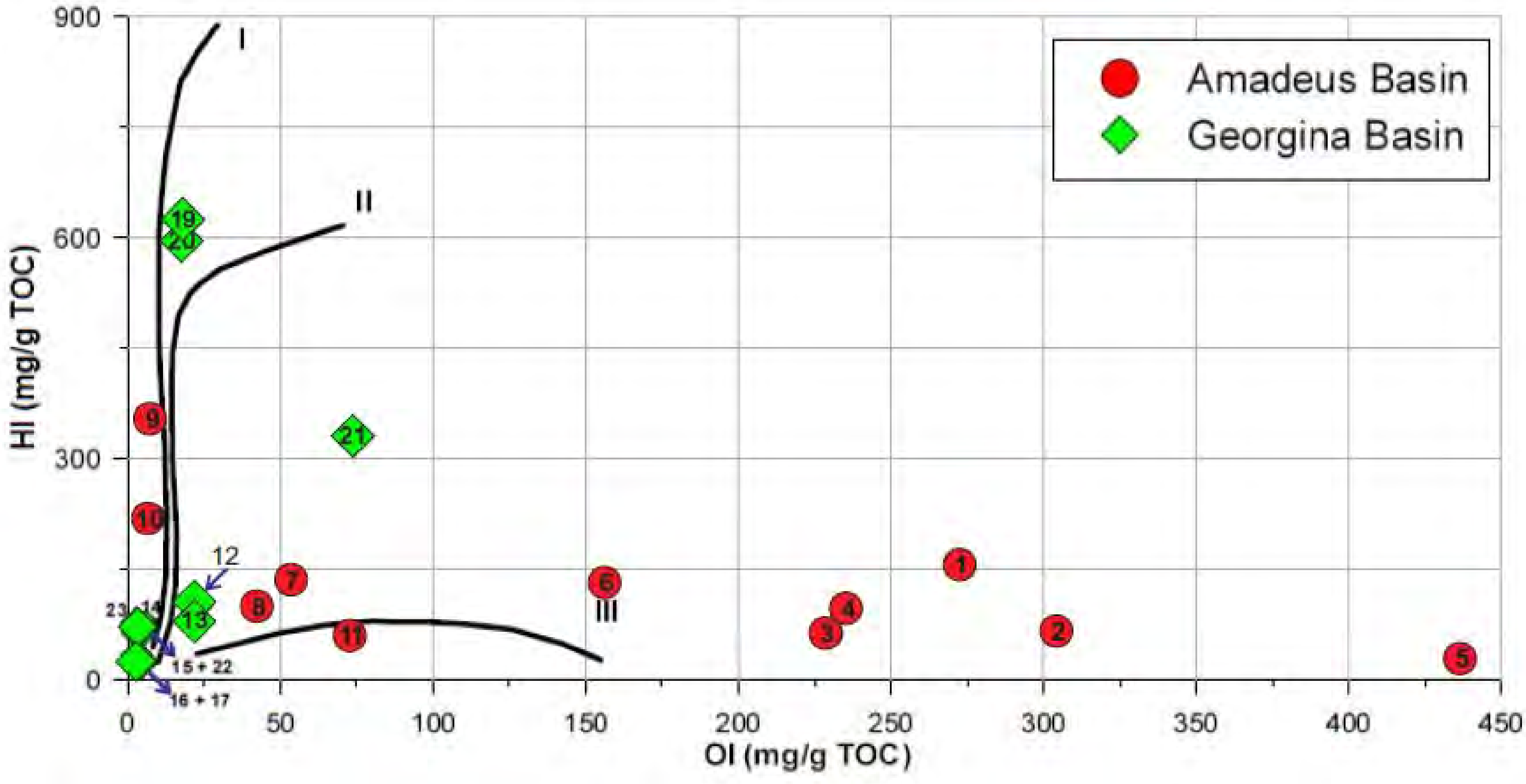


Figure 3. *Hydrogen Index against Oxygen Index (after Espitalie et.al., 1977). Numbers refer to short labels (see Table 1).*

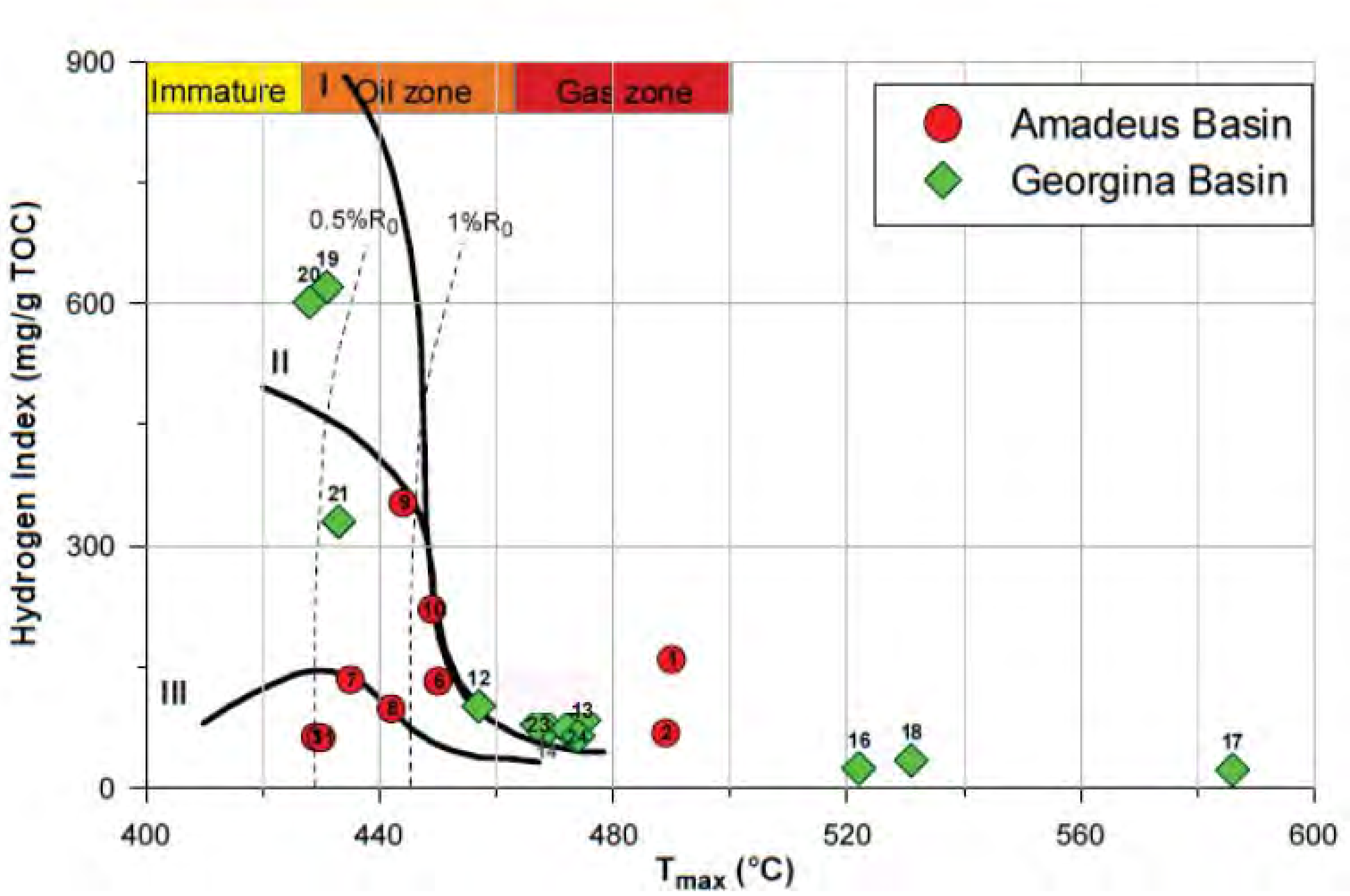


Figure 4 *Hydrogen Index against Tmax diagram (after Espitalie et. al., 1984). Numbers refer to the short labels (see Table 1).*

Bulk chemical composition from pyrolysis gas chromatography

The pyrolysis gas chromatograms of samples from the Georgina Basin are shown in Figure 6. Boiling ranges and individual compound yields are given in Tables 4 and 5.

Four samples from the MacIntyre 1 well were selected for pyrolysis gas chromatographic analysis, these being samples G006484 to G006487 from the Arthur Creek Formation. The pyrolysis gas chromatograms of these samples are characterised by the predominance of gaseous hydrocarbons. The aromatic hydrocarbons, including benzene and toluene, appear as significant peaks in the gas chromatograms. Doublets are found in lower abundance extending to C_{22}. Phenolic compounds have also been found. The composition of samples from the MacIntyre 1 well falls in the kerogen type II field of Eglinton et al. (1990) (Figure 9), and of di Primio and Horsfield (1996) (Figure 10). The kerogen structure can be relatively enriched in phenol, as revealed from the diagram of Larter (1984) (Figure 7). The petroleum type can be classified as gas condensate according to Horsfield (1989) (Figure 8). The total remaining gas-generating potential is ~300-3200 (µg/g sample; Table 4 and Figure 11).

The gas chromatograms of samples G006488 to G006490 (Baldwin 1 well) consists of a mixture of gaseous hydrocarbons and aromatic compounds (benzene and toluene). Their petroleum type is defined as gas condensate, according to the plot of Horsfield (1989) (Figure 8). The remaining gas-generating potential of these samples is in the range 660-1300 µg/g sample.

Two samples (G006491 and G006492) from the BMR Mt Isa 1 well, which have high Hydrogen Index values of 600-620 (mg/g TOC) and Tmax ~ 430°C, produce a mixture of aliphatic and aromatic hydrocarbons upon pyrolysis. Methane appears as a significant peak in the chromatograms. Phenols and sulfur compounds make only a small contribution. Doublets extend to C_{24} and decrease in relative abundance with increasing carbon number, which is typical for marine kerogen (van de Meent et al., 1980; Muscio et al., 1993; Clegg et al., 1997). The presence of 1,2,3,4-tetramethylbenzene (TeMB), eluting between the nC_{11} and nC_{12} doublets, is suggestive of photic zone euxinia during deposition (Muscio et al., 1994). The pyrolysis compositions of these two samples fall in the type II field of Eglinton et al. (1990), in the type II intermediately enriched in sulfur field of di Primio and Horsfield (1996), and the phenol-poor field of Larter (1984). Their petroleum types are defined as paraffinic-naphthenic-aromatic low wax oil (Horsfield, 1989). Their compositions are very close to the boundary with the gas condensate field (Figure 8). They have the highest remaining gas-generating potential yields (between 8679 and ~20000 µg/g sample) among the investigated samples, as illustrated in Figure 11. It is clear that while this source rock (Middle Cambrian shale) has a very high petroleum potential (HI ~ 600 mg/g TOC), this potential is manifested by the light hydrocarbon predominance throughout the liquid window. The ability to generate light hydrocarbons predominantly at low stages of thermal evolution might be an important characteristic of high quality gas shales in general.

The gas chromatograms of three samples from the NTGS Elkedra 3 are shown in Figure 6. They all generate significant amount of gaseous hydrocarbons and aromatic compounds. Doublets in the range of C_{10}-C_{20} make a lesser contribution. The presence of 1,2,3,4-tetramethylbenzene (TeMB) indicates photic zone anoxia during deposition (Muscio et al., 1994). These samples can be defined as a mixture of kerogen type II and III (Figure 9) enriched in aromatics (Figure 10). They could be moderately enriched in phenol (Figure 7). The pyrolysis composition falls in the gas condensate field of Horsfield (1989). Remaining gas-generating potential yield is around 2500-3100 µg/g sample as shown in Figure 11.

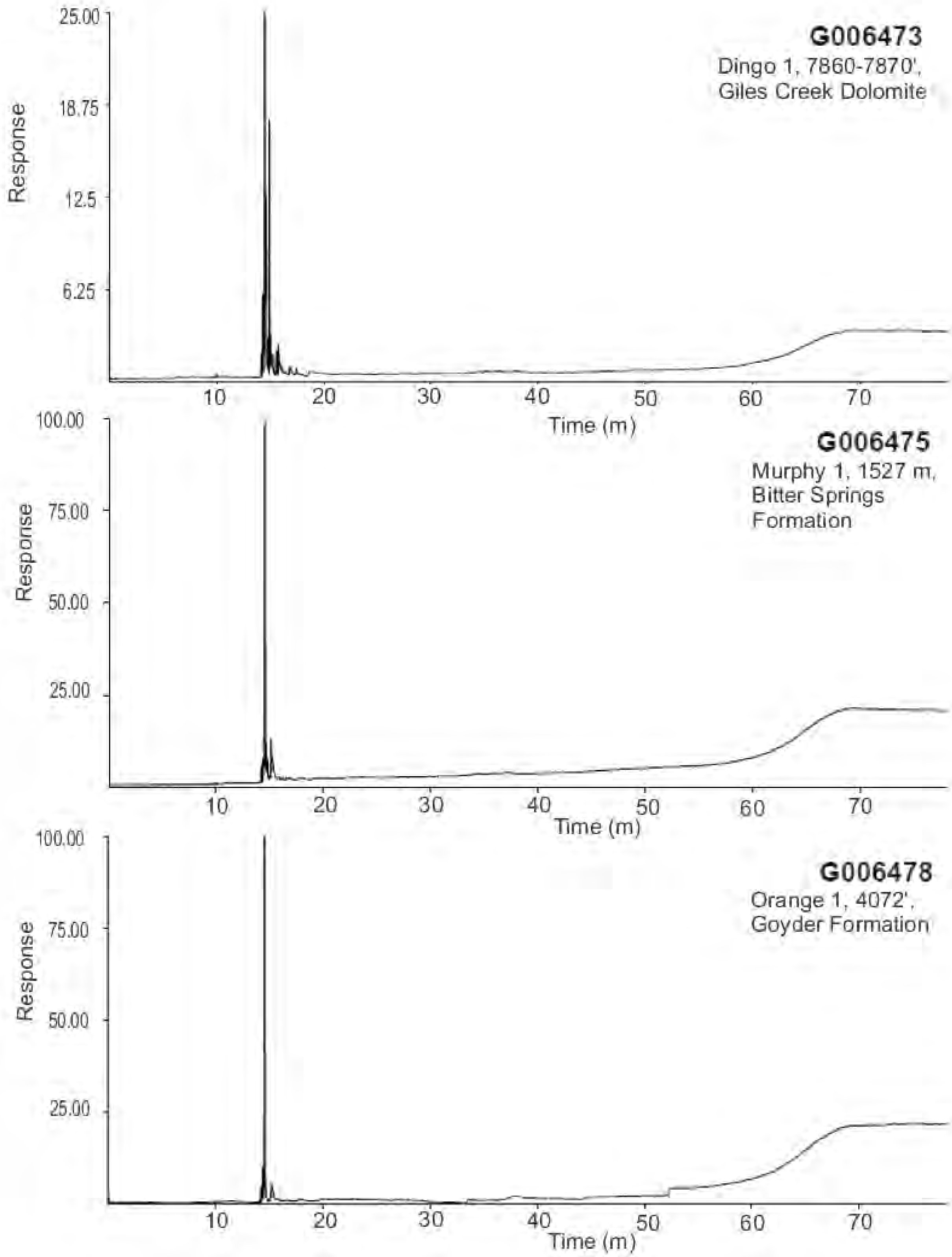


***Figure 5** Thermovaporisation chromatograms of samples G006473 (top), G006475 (middle) and G006478 (bottom).*

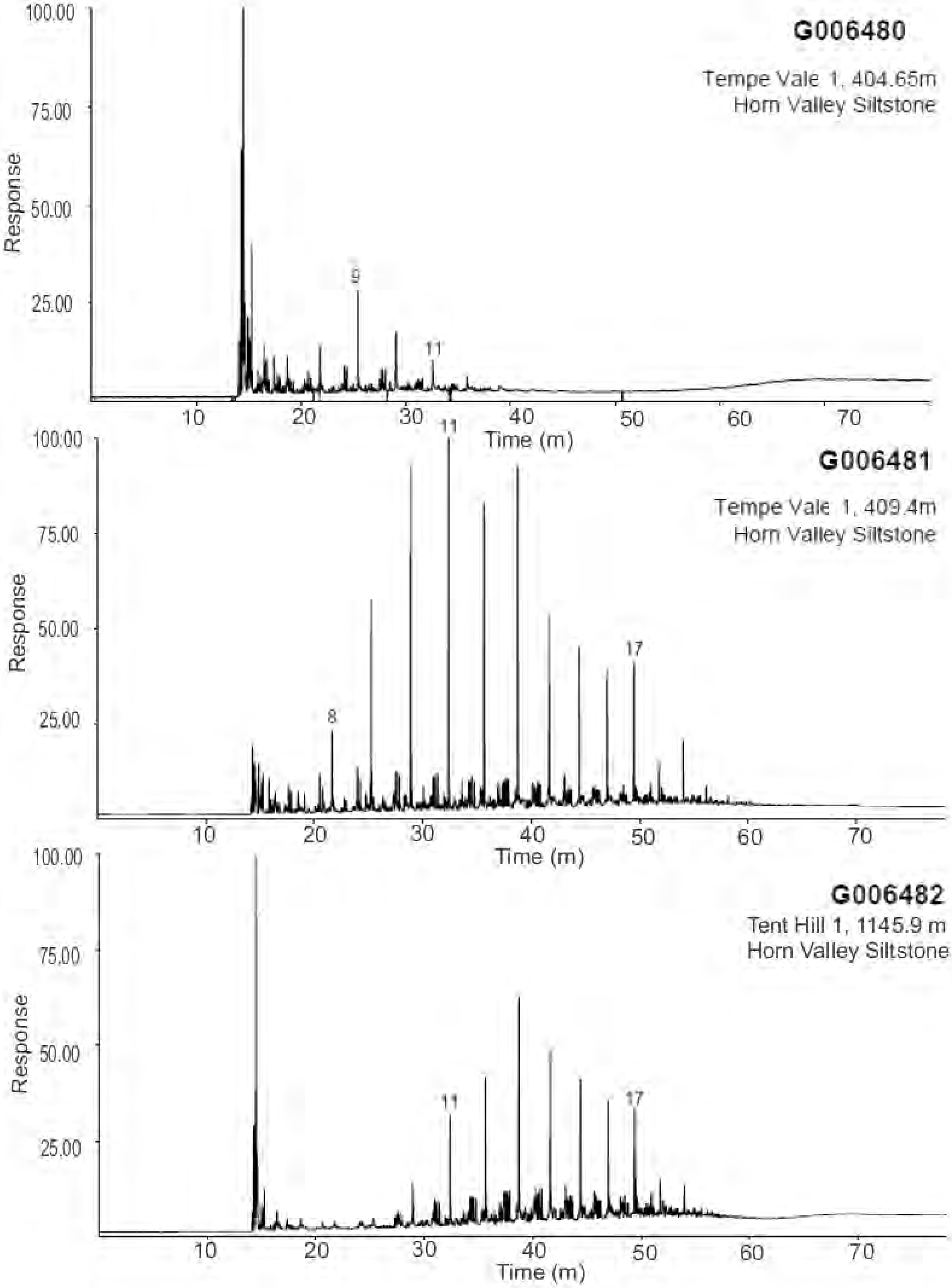


Figure 5 (continued) *Thermovaporisation chromatograms of samples G006480 (top), G006481 (middle) and G006482 (bottom). Number refers to chain length of n-alkanes.*

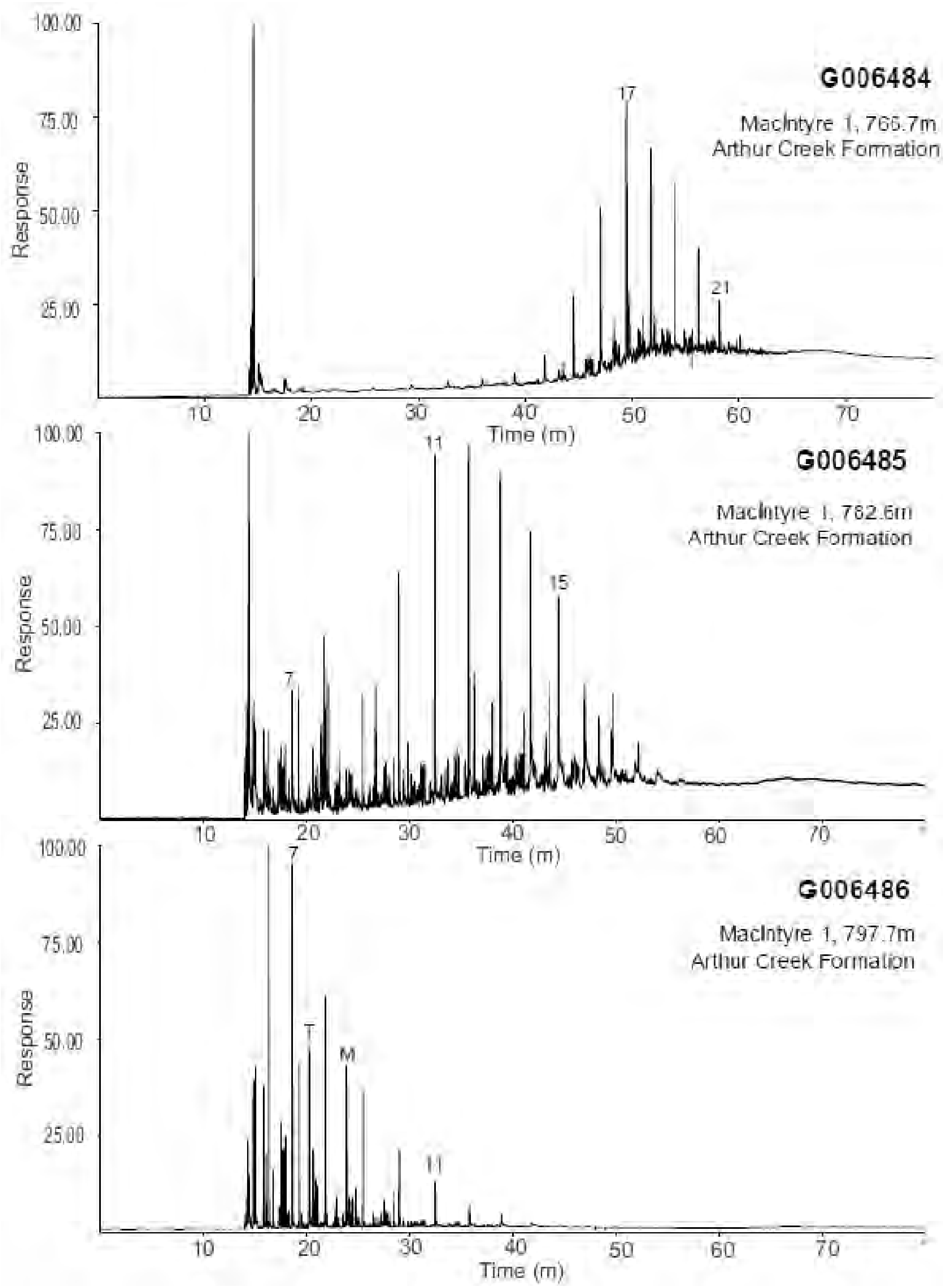


***Figure 5 (continued)** Thermovaporisation chromatograms of samples G006484 (top), G006485 (middle) and G006486 (bottom). Numbers refer to chain length of n-alkanes. T=toluene, M=meta- plus para-xylenes.*

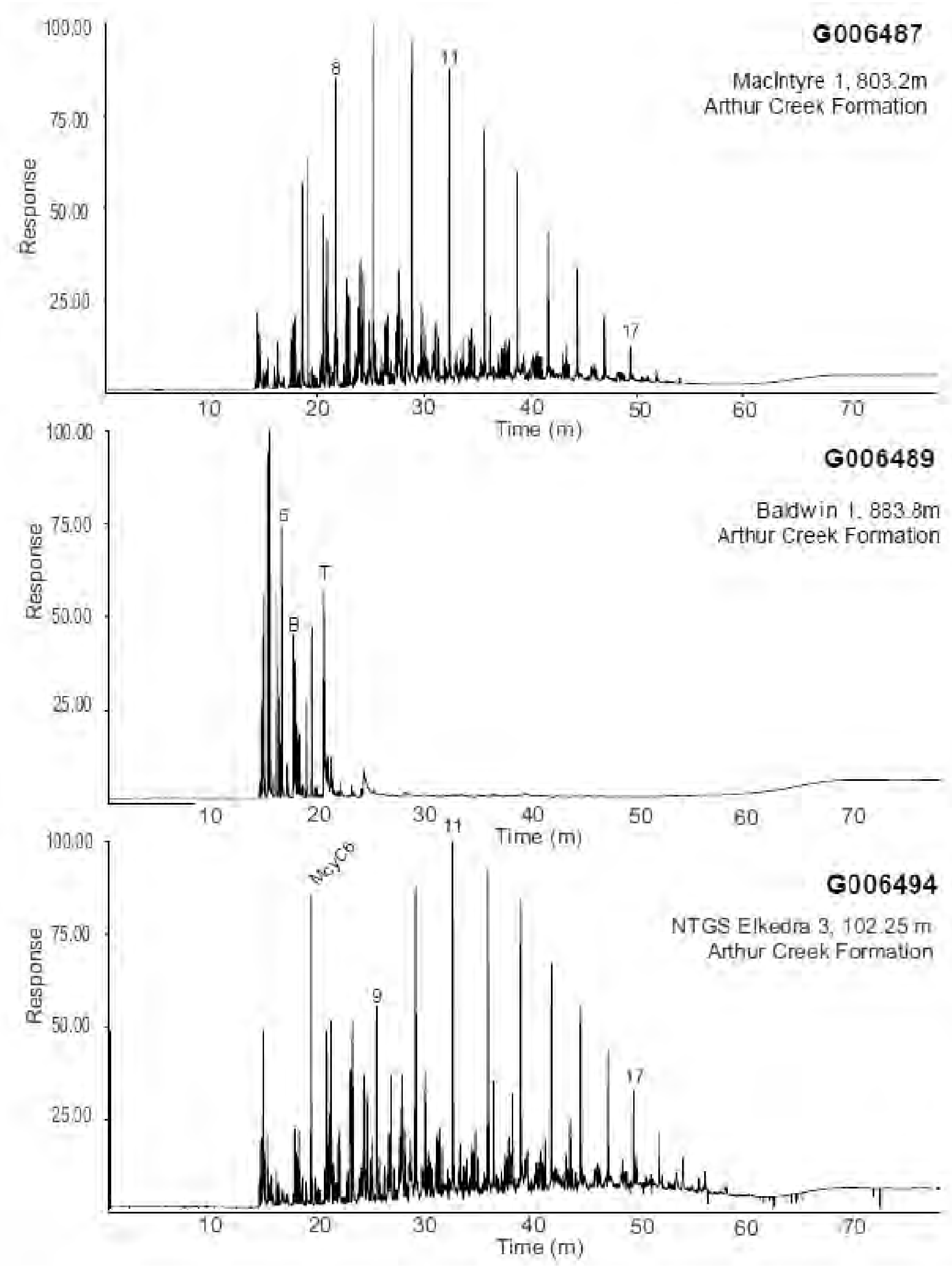


Figure 5 (continued) *Thermovaporisation chromatograms of samples G006487 (top), G006489 (middle) and G006494 (bottom). Numbers refer to chain length of n-alkanes. B=benzene, T= toluene, McyC6 = methylcyclohexane.*

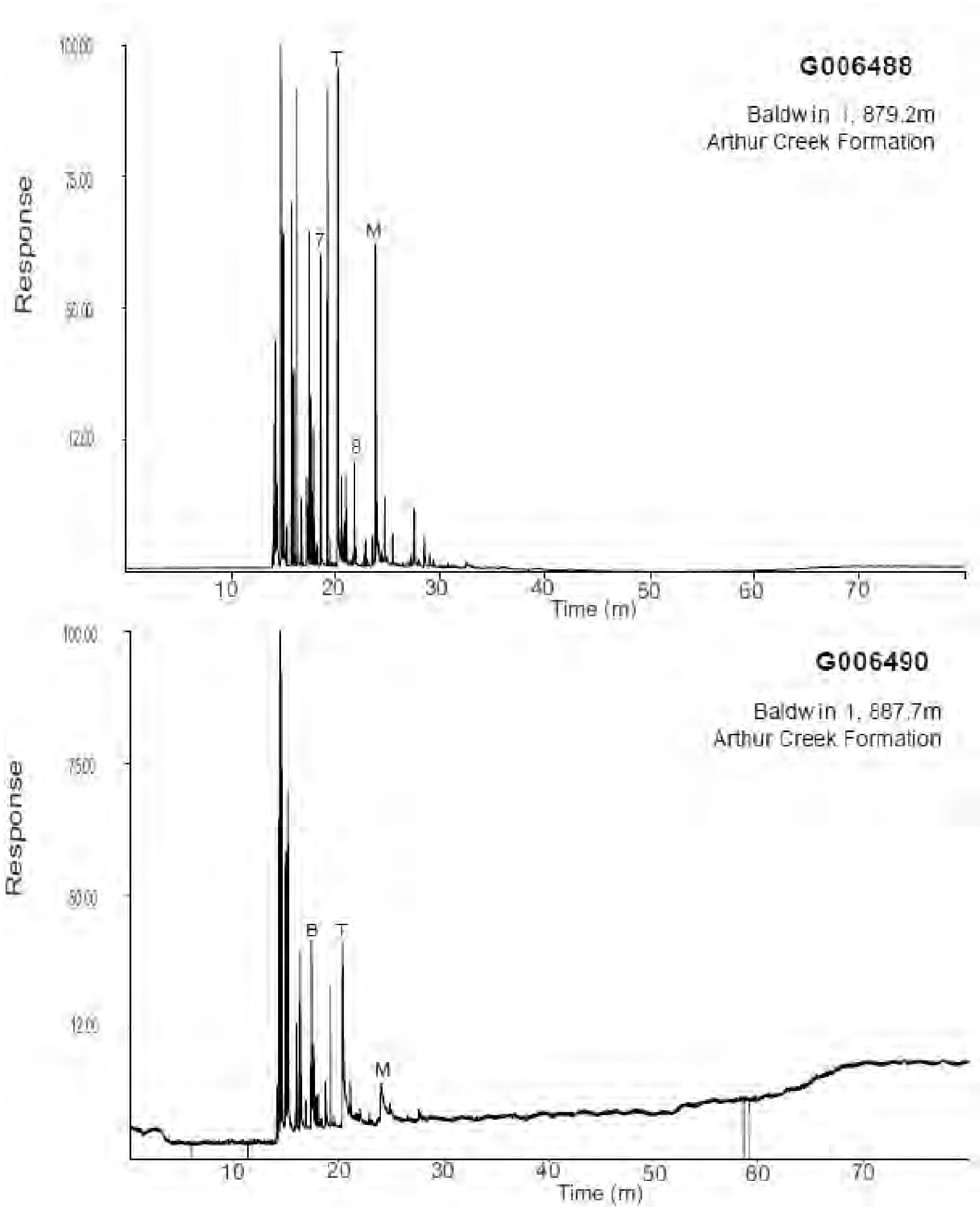


Figure 5 (continued) *Thermovaporisation chromatograms of samples G006488 (top) and G006490 (bottom). Numbers refer to chain length of n-alkanes. B=benzene, T= toluene, M=meta- plus para-xylenes.*

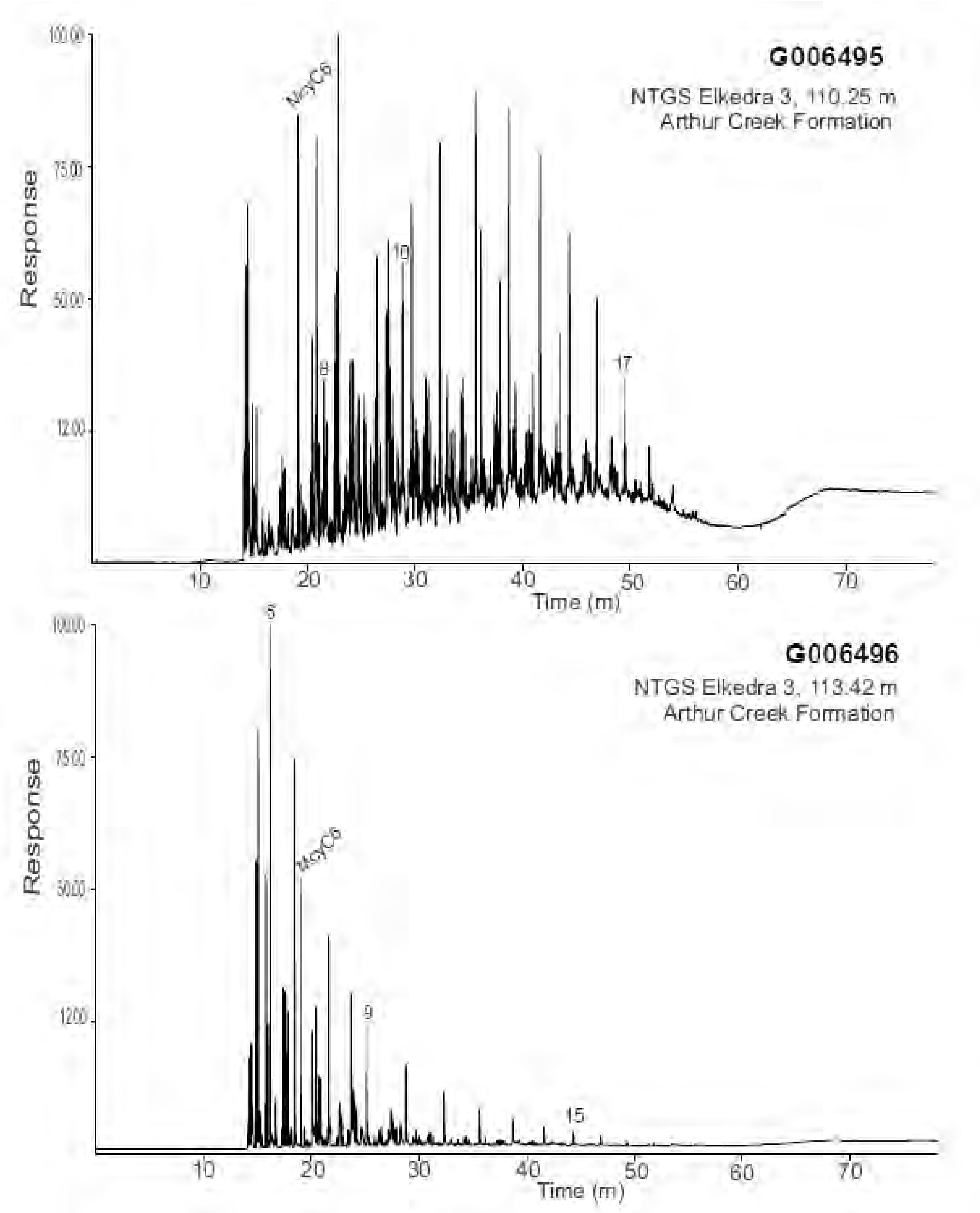


Figure 5 (continued) *Thermovaporisation chromatograms of samples G006495 (top) and G006496 (bottom). Numbers refer to chain length of n-alkanes. McyC6 = methylcyclohexane.*

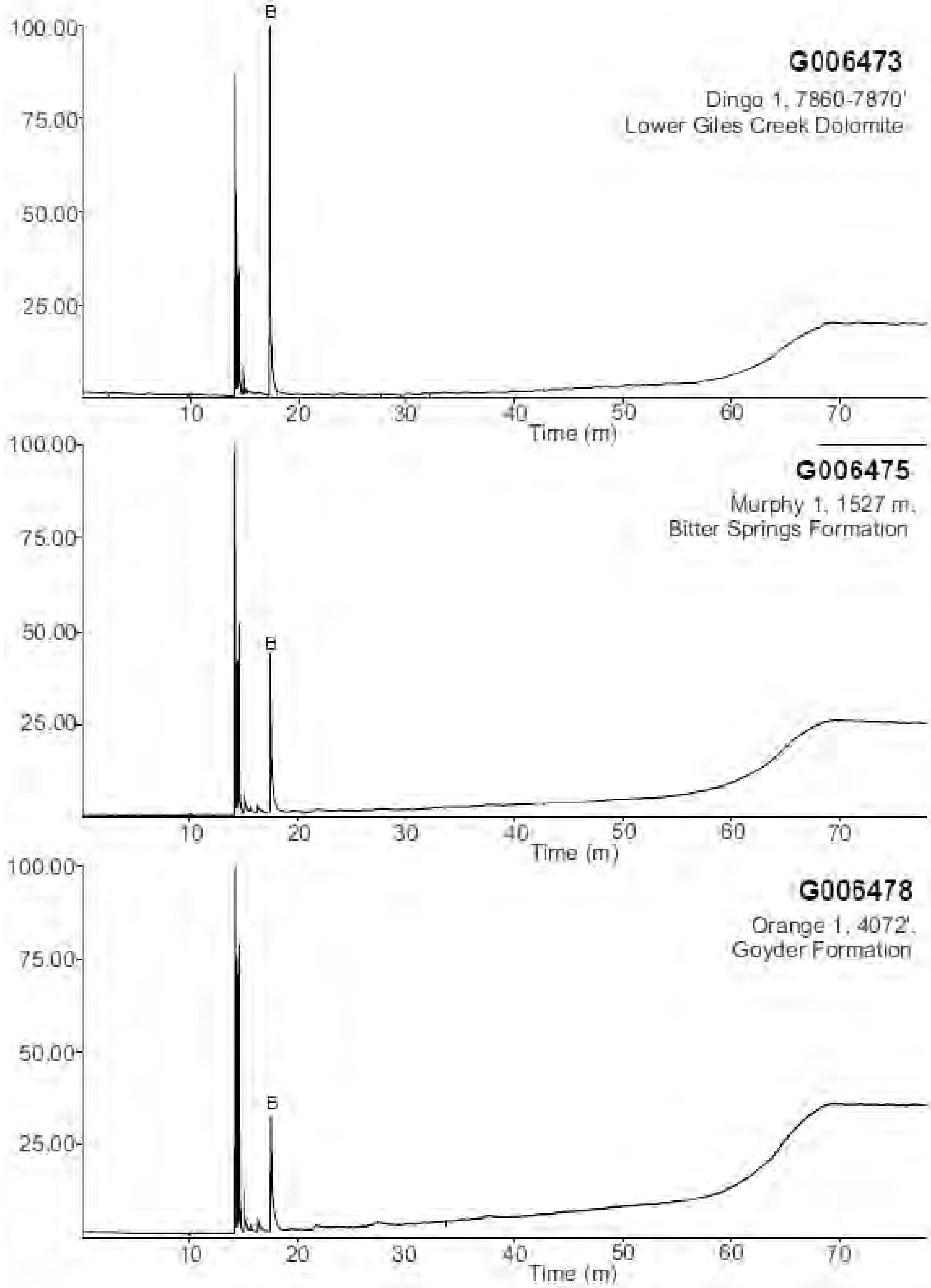


Figure 6 *Pyrolysis gas chromatograms of samples G006473 (top), G006475 (middle) and G006478 (bottom). B = benzene*

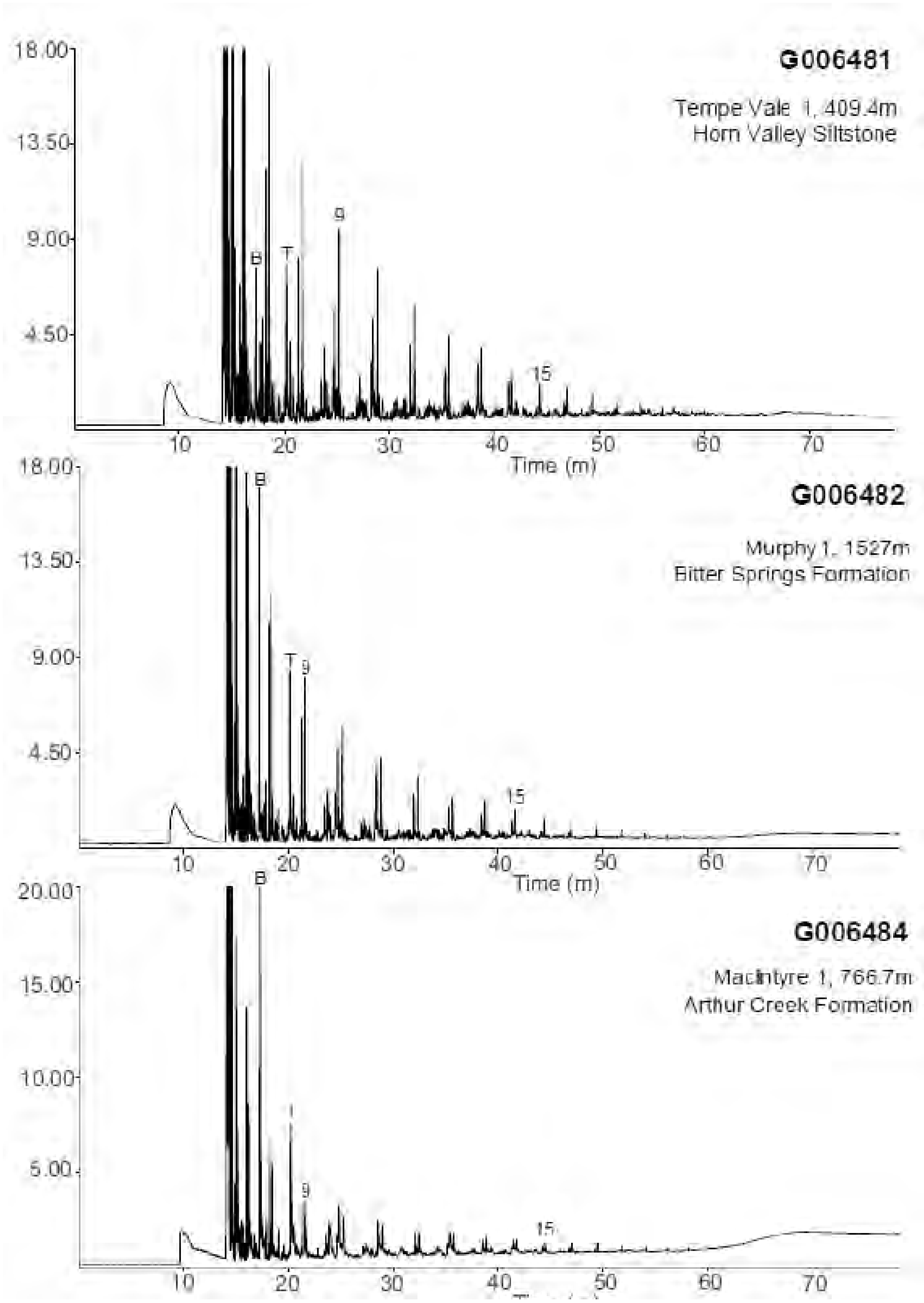


***Figure 6 (continued)** Pyrolysis gas chromatograms of samples G006481 (top), G006482 (middle) and G006484 (bottom). Numbers refer to chain length of n-alkene/-alkane doublets. B = benzene, T = toluene.*

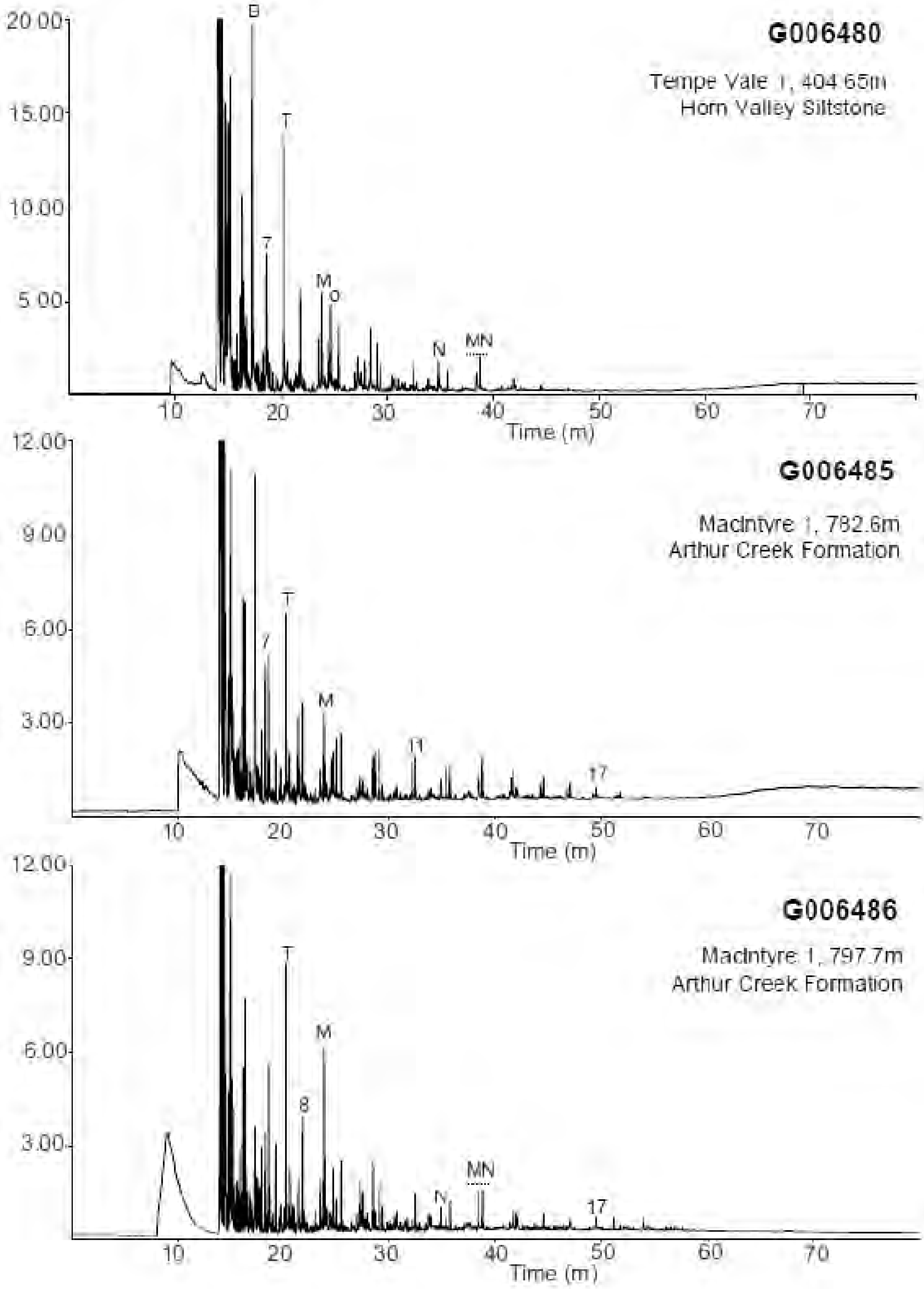


Figure 6 (continued) *Pyrolysis gas chromatograms of samples G006480 (top), G006485 (middle) and G006486 (bottom). Numbers refer to length of n-alkene/-alkane doublets. B = benzene, T = toluene, M = meta- plus para-xylenes, O = ortho-xylene, N = naphthalene, MN = methylnaphthalene.*

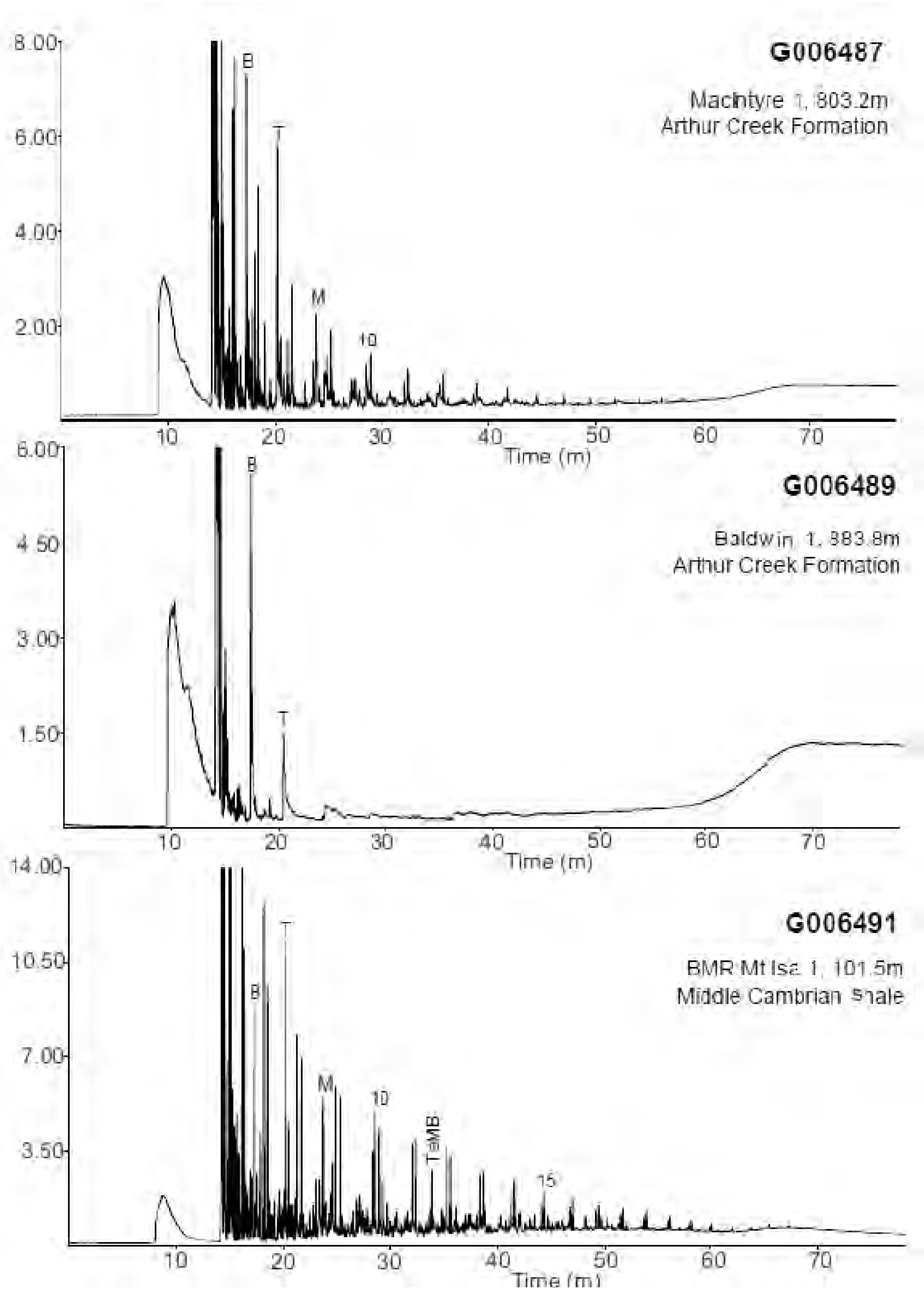
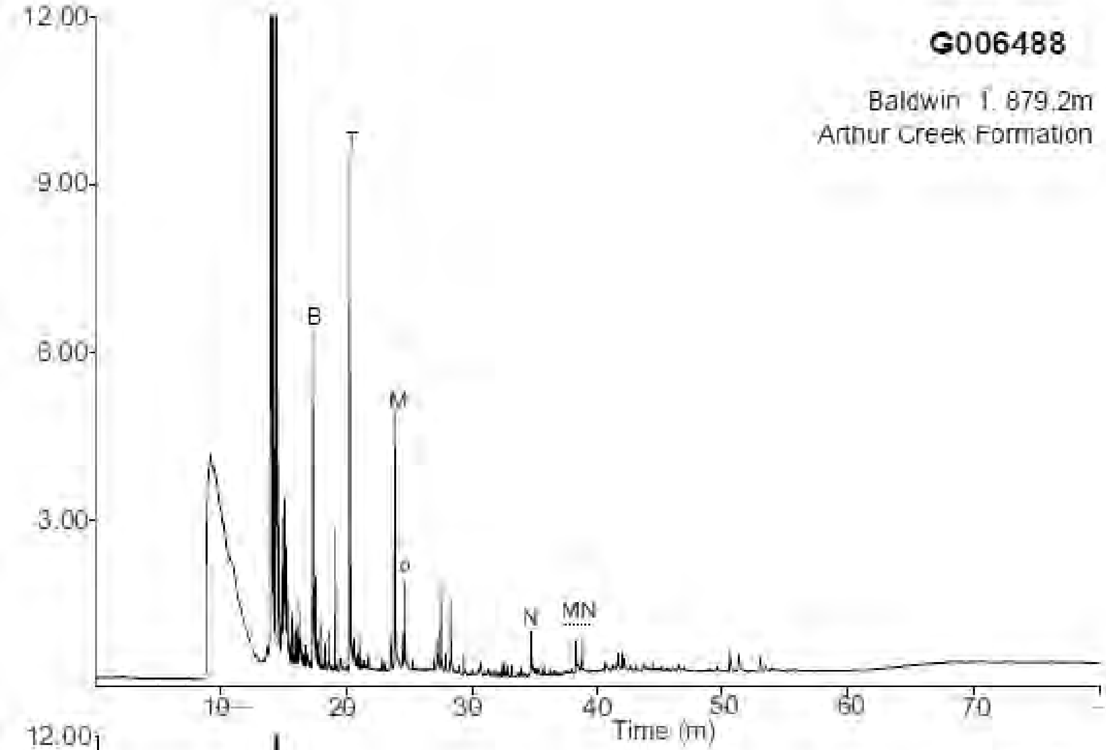


Figure 6 (continued) *Pyrolysis gas chromatograms of samples G006487 (top), G006489 (middle) and G006491 (bottom). Numbers refer to chain length of n-alkene/-anes doublets. B = benzene, T = toluene, M = meta – plus para-xylenes, TeMB = Tetramethylbenzene.*



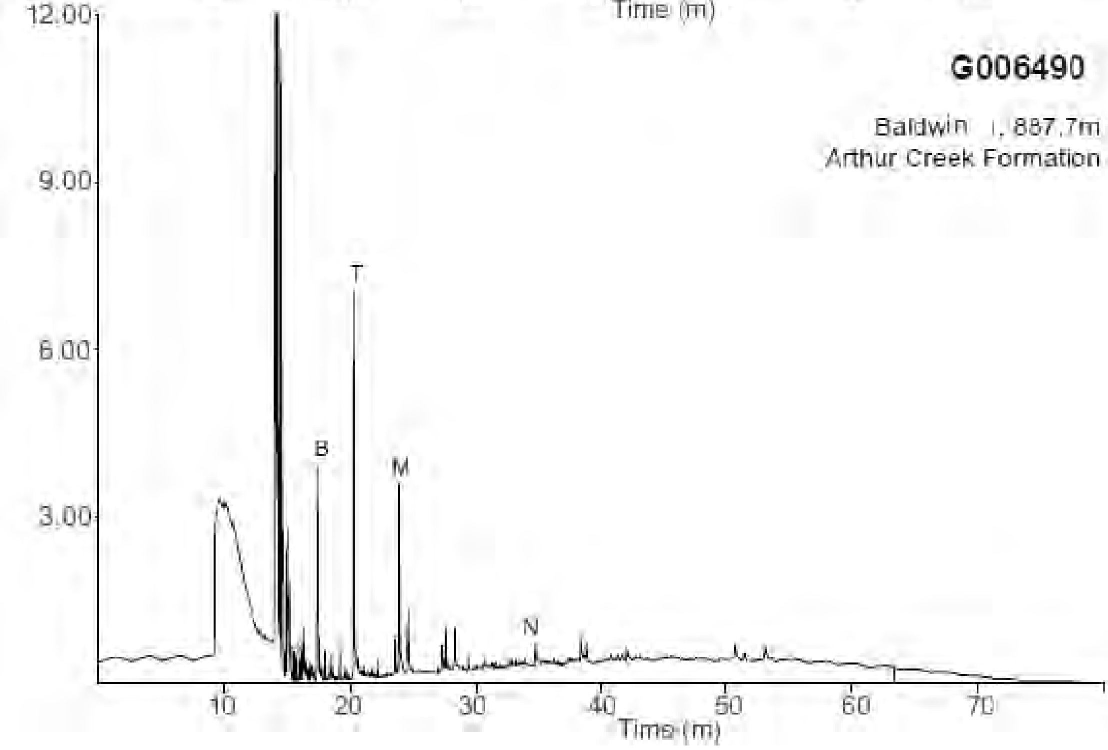


Figure 6 (continued) *Pyrolysis gas chromatograms of samples G006488 (top) and G006490 (bottom). Numbers refer to chain length of n-alkene/-alkanes doublets. B = benzene, T = toluene, M = meta- plus para-xylenes, O = ortho-xylene, N = naphthalene, MN = methylnaphthalene.*

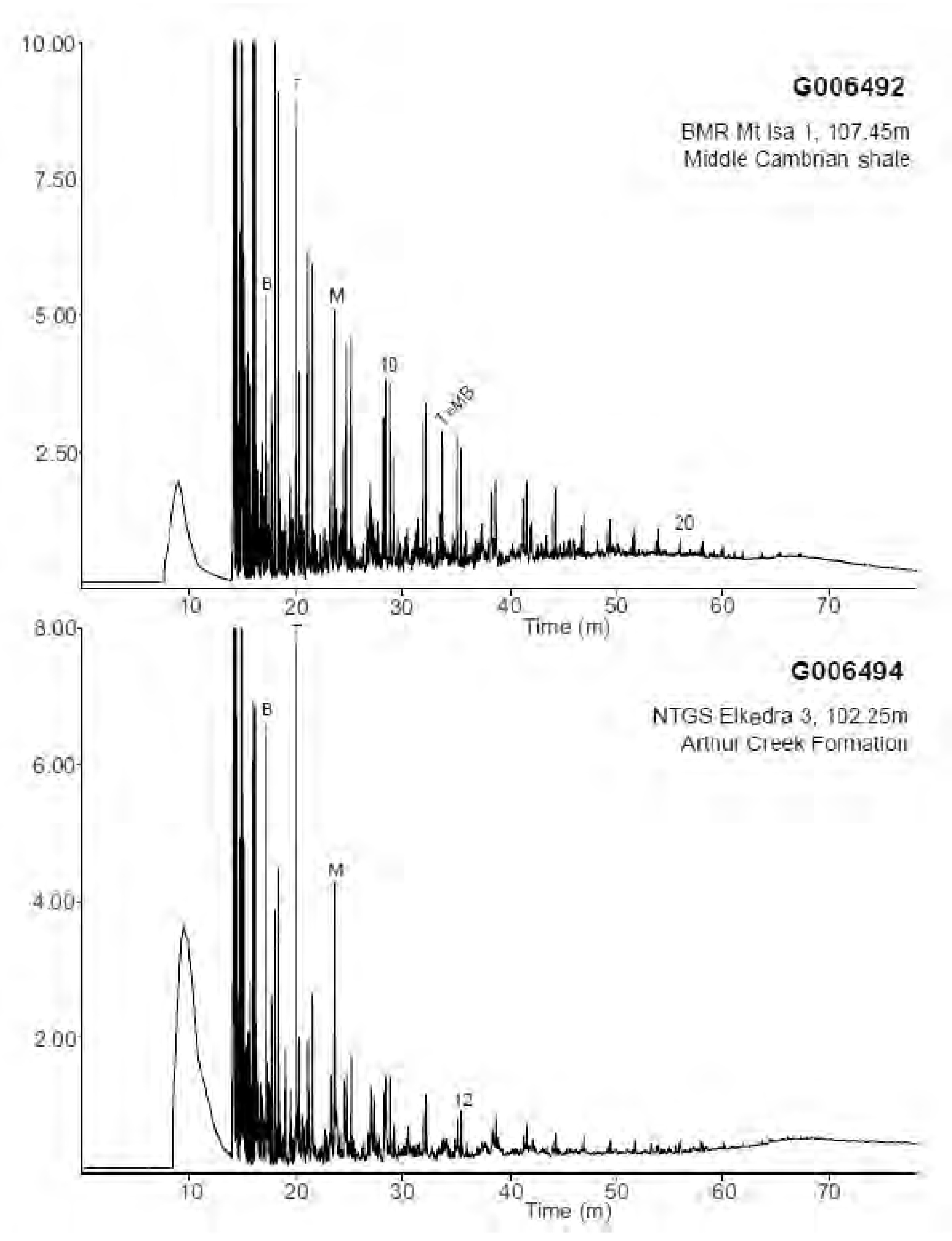


Figure 6 (continued) *Pyrolysis gas chromatograms of samples G006492 (top) and G006494 (bottom) Numbers refer to chain length of n-alkene/-alkanes doublets. B = benzene, T = toluene, M = meta- plus para-xylenes, TeMB = tetramethylbenzene.*

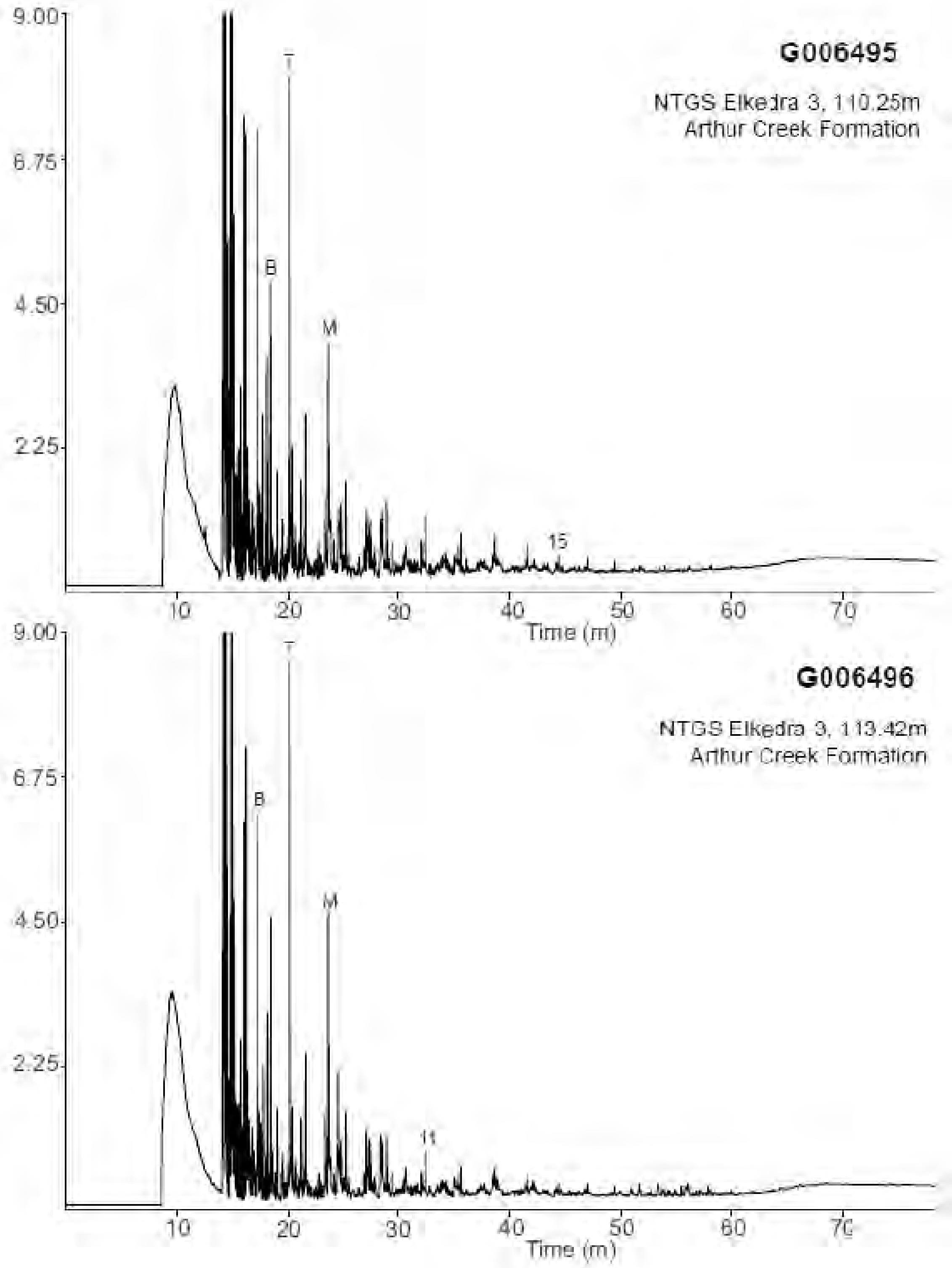


Figure 6 (continued) *Pyrolysis gas chromatograms of samples G006495 (top) and G006496 (bottom). Numbers refer to chain length of n-alkene/-alkane doublets. B = benzene, T = toluene, M = meta- plus para-xylenes.*

Table 6 Pyrolysis gas chromatograms (PyGC) individual compound yields (µg/gTOC)

Sample	G006473	G006475	G006478	G006481	G006482	G006484	G006487	G006489	G006491	G006492	G006494	G006495	G006496	G006480	G006485	G006486	G006488	G006490
Formation	Lower Giles Creek Dolomite	Lower Giles Creek Dolomite	Goyder Formation	Horn Valley Siltstone	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	"Middle Cambrian Shale"	"Middle Cambrian Shale"	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Horn Valley Siltstone	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation	Arthur Creek Formation
Aliphatics - Normals (µg/g TOC)																		
Sum nC_{6-14}	50.3	149.2	228.8	24649.5	14705.3	3910.4	2141.3	16.6	25167.4	27940.7	2322.7	2111.1	1879.6					
Sum nC_{15}+	0.0	0.0	0.0	2108.6	722.8	286.5	100.9	0.0	3861.3	4012.8	195.6	111.8	130.1					
Aliphatics - Isoprenoides (µg/g TOC)																		
iC_{18}	0.0	0.0	0.0	106.4	0.0	0.0	0.0	0.0	209.9	188.6	4.1	0.0	0.0	0.0	7.8	8.2	0.0	0.0
Prist-1-ene	0.0	0.0	0.0	33.4	14.9	0.0	0.0	0.0	157.4	173.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prist-2-ene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aromatics (µg/g TOC)																		
Bez	6715.3	4422.5	2823.6	1325.2	2388.0	1286.5	439.2	132.8	2064.5	1668.9	411.8	430.0	361.2	2190.87	1564.03	317.44	182.94	128.72
tol	0.0	0.0	0.0	1585.6	1550.2	889.1	455.1	108.7	2835.3	2895.7	567.7	575.8	594.1	1641.01	780.90	798.50	298.27	293.60
et-Benz	0.0	0.0	0.0	446.3	415.1	176.2	91.9	0.0	682.7	747.8	105.7	105.4	118.9	366.95	130.27	189.11	24.32	25.53
m+p Xyl	0.0	0.0	0.0	1161.2	784.0	446.6	301.8	31.0	1949.9	2299.4	464.5	416.7	534.7	861.74	327.62	781.07	206.32	182.44
Styr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
o-Xyl	0.0	0.0	0.0	584.3	526.4	165.9	59.0	0.0	854.8	925.3	113.5	95.2	172.4	517.63	157.84	209.64	48.33	42.13
Phenol	0.0	0.0	0.0	361.6	246.6	54.1	72.0	0.0	406.5	449.8	95.5	99.6	94.7	142.30	71.50	96.80	7.30	4.42
o-Cresol	0.0	0.0	0.0	93.3	43.4	15.7	10.4	0.0	264.8	255.7	18.9	14.7	9.8	25.46	18.24	52.79	2.93	3.82
m+p Cresol	0.0	0.0	0.0	531.6	281.3	30.3	16.0	0.0	537.3	511.5	71.3	63.6	58.6	60.74	36.05	78.05	6.94	7.31
Napht	0.0	0.0	0.0	227.0	185.0	104.4	30.2	0.0	341.4	320.8	22.4	15.6	33.7	287.20	148.51	116.70	39.57	22.43
2meNapht	0.0	0.0	0.0	186.1	120.0	23.5	10.6	0.0	351.5	468.5	34.5	22.9	46.7	196.16	62.35	171.99	26.97	30.18
1meNapht	0.0	0.0	0.0	186.8	75.9	18.0	11.7	0.0	173.2	217.1	17.0	16.5	22.3	0.00	0.00	158.40	23.62	14.64
sum dimeNapht	0.0	0.0	0.0	780.0	211.1	23.5	19.7	0.0	770.6	1144.1	41.2	32.7	55.5	174.61	112.36	260.81	29.40	24.23
tetra-meNapht	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
Sum monoaromatic HC	6715.3	4422.5	2823.6	5102.6	5663.6	2964.2	1347.1	272.4	8387.2	8537.1	1662.5	1623.0	1781.3	5578.20	2960.65	2295.77	760.17	672.42
Sum diaromatic HC	0.0	0.0	0.0	1379.8	592.0	171.2	72.1	0.0	1636.6	2150.5	115.1	87.7	158.1	657.97	323.23	707.90	119.57	91.48
Sum phenols	0.0	0.0	0.0	986.6	571.2	100.1	98.3	0.0	1208.6	1217.0	185.6	177.9	163.1	228.50	125.79	227.63	17.17	15.55
Sulfur Compounds (µg/g TOC)																		
Thioph	0.0	0.0	0.0	542.9	279.3	91.8	54.2	0.0	1018.3	1435.7	84.7	87.4	76.4	0.00	0.00	146.98	0.00	0.00
2meThioph	0.0	0.0	0.0	102.5	77.3	0.0	41.6	0.0	571.2	612.3	38.2	39.9	63.4	210.36	0.00	73.00	0.00	0.00
3meThioph	0.0	0.0	0.0	726.3	324.8	0.0	99.5	0.0	1085.2	1419.3	120.8	132.3	95.0	189.71	133.74	200.39	9.44	9.08
2,5dimeThioph	0.0	0.0	0.0	23.0	0.0	0.0	0.0	0.0	365.9	422.5	6.0	7.4	0.0	0.00	0.00	0.00	0.00	0.00
2,3dimeThioph	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	252.2	308.8	0.0	0.0	0.0	55.20	35.43	69.22	0.95	0.00
Sum alkythiophenes	0.0	0.0	0.0	851.8	402.0	0.0	141.1	0.0	2274.5	2762.9	165.0	179.6	158.4	455.27	169.17	342.62	10.39	9.08

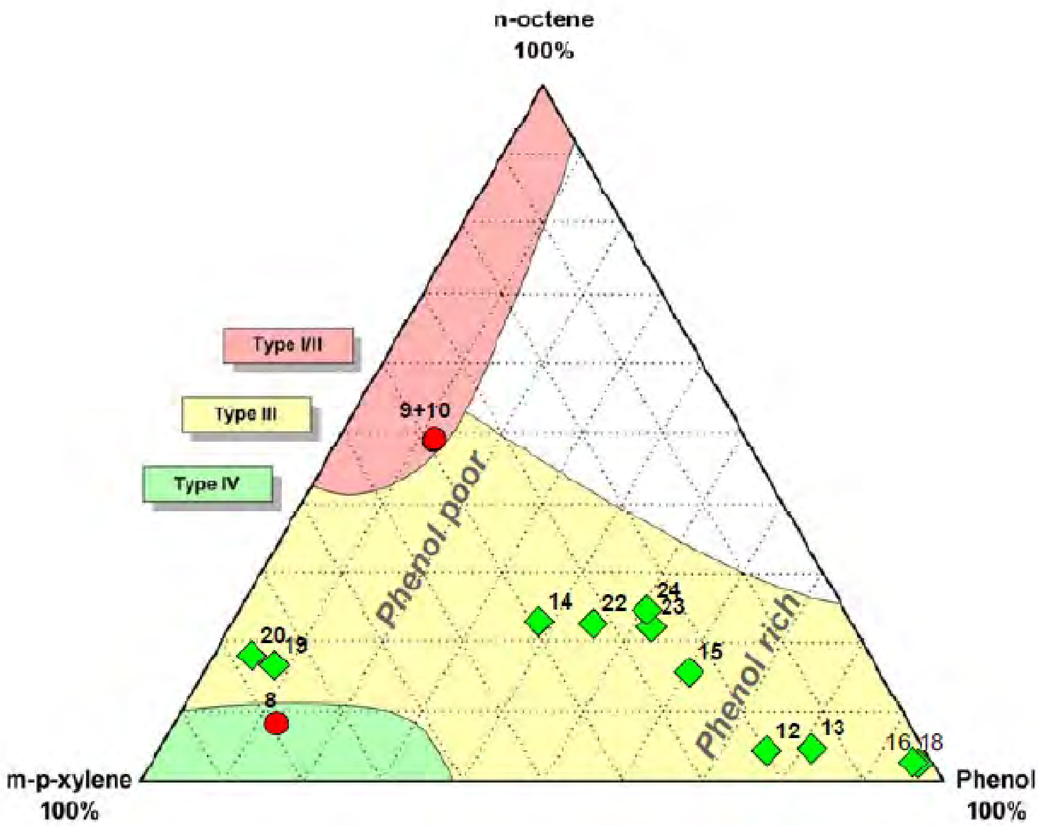


Figure 7. *Kerogen type characterisation (after Larter, 1984). Numbers refer to the short labels (see Table 1).*

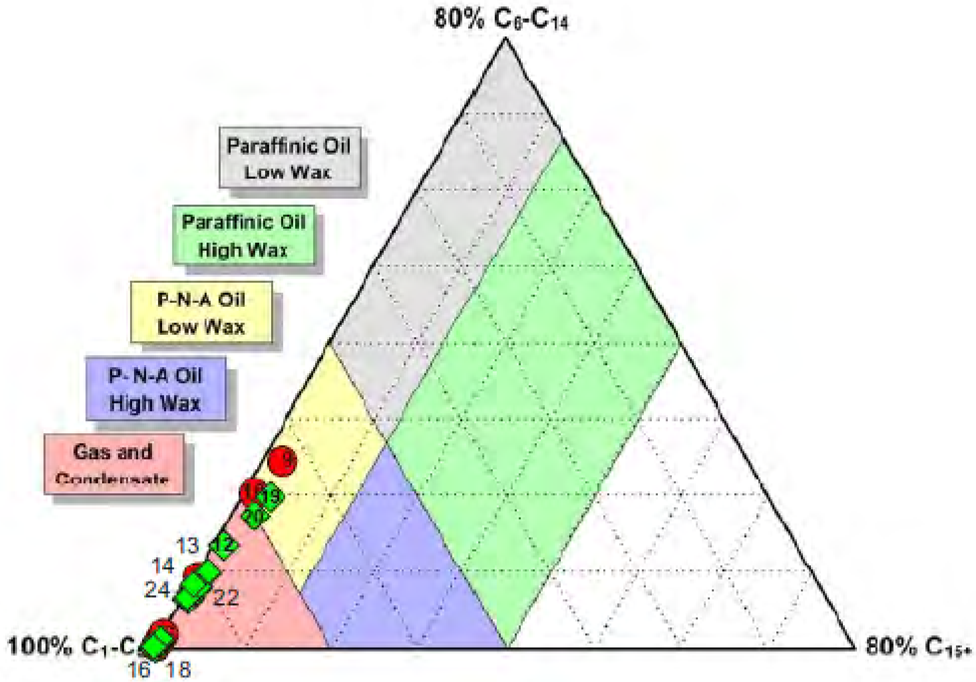


Figure 8. *Petroleum type organofacies (after Horsfield, 1989). Numbers refer to the short labels (see Table 1).*

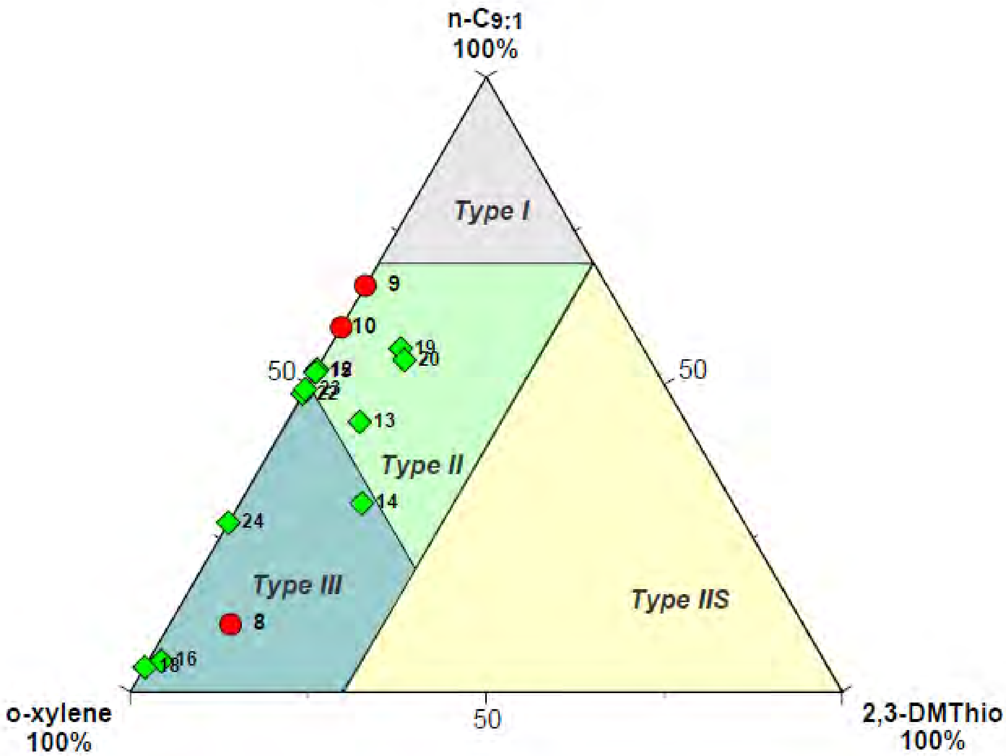


Figure 9. *Kerogen type characterisation (after Eglinton et. al., 1990). Numbers refer to the short labels (see Table 1).*

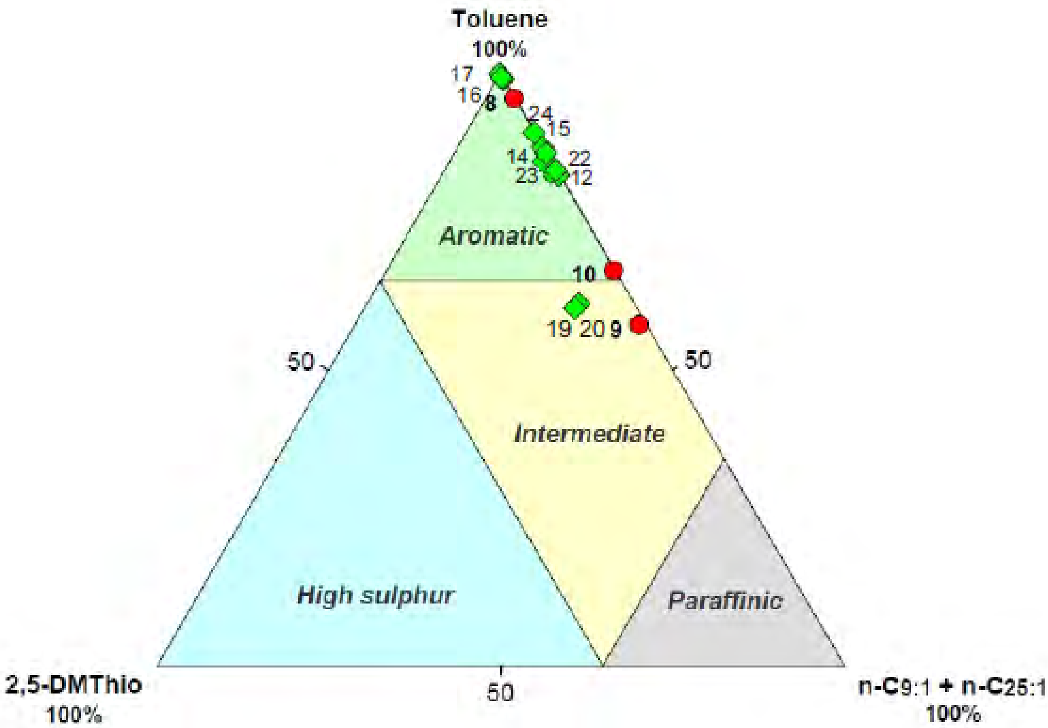


Figure 10. *Differentiation of pyrolysate composition using relative proportions of selected alkyl-, aromatic-, and sulfur compounds (after di Primio and Horsfield, 1996). Numbers refer to short labels (see Table 1).*

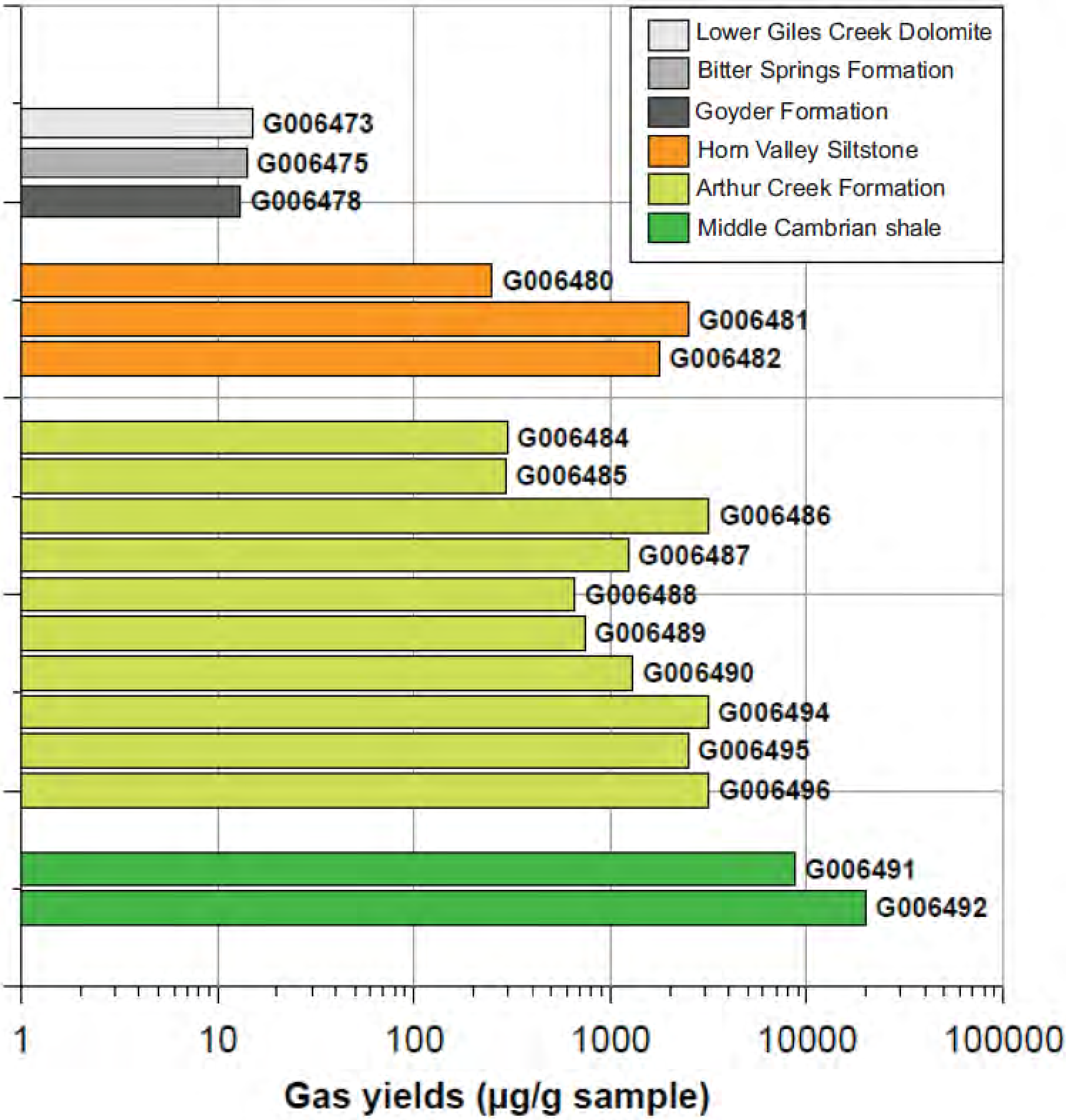


Figure 11. *Remaining gas potential of samples from the Amadeus and Georgina Basins.*

Conclusions

AMADEUS BASIN

Screening analysis shows that samples from the Bitter Springs Formation, Lower Giles Creek Dolomite and Goyder Formation all have very low organic carbon contents (in the range 0.07 to 0.16%) and low petroleum generating potential. These samples are characterised by high Production Indices ranging from 0.24-0.5 (weight ratio) and a wide range of Tmax values (287-490°C). Thermovaporisation of three selected samples shows that their free hydrocarbons are mainly gases. These samples generate only gaseous hydrocarbons and benzene on pyrolysis. Their compositions fall in the gas and condensate facies of Horsfield (1989). The remaining gas yield potential of these samples is around 15 µg/g sample.

Samples belonging to the Horn Valley Siltstone have a relative higher organic richness (TOC = 0.35-3.42%) and petroleum potential (HI = 62-353 mg/g TOC), in comparison with samples from the Bitter Springs Formation, Lower Giles Creek Dolomite, and Goyder Formation. Tmax ranges from 430-449°C.

Among these samples, there are two (G006481 and G006482) which might have gas shale potential, because of their high TOC (3.16-3.42%), moderate production index (PI ~ 0.2) and Tmax of 445-449°C (close to the minimum of 450°C). These two samples can be classified as kerogen type II. Upon pyrolysis, these samples produce paraffinic-naphthenic-aromatic low wax oil. Their compositions are very close to the boundary with the gas condensate field. Another sample (G006480) from the Horn Valley Siltstone, analysed to elucidate shale gas characteristics where organic richness at a similar level of maturity was only moderate, appears inherently gas-prone and to contain adsorbed gas. The remaining gas-generating potential of G006481 and G006482 ranges from 1775-2486 µg/g sample, and for the leaner sample G006480 only 250 µg/g sample.

GEORGINA BASIN

MacIntyre 1 well

Samples G006484 and G006485 have TOC values around 1%, and Hydrogen Indices of 80-100 mg/g TOC, respectively. In contrast, the two other samples (G006486 and G006487) have much higher organic carbon contents of 5.3-8.6%. The Hydrogen Index of these two latter samples is around 70 (mg/g TOC). The four samples in this well have ideal conditions for shale gas with Tmax values ranging from 457 to 475°C.

In the case of sample G006485, n-paraffins up to octadecane are present, with depletion in the gasoline range, whereas sample G006484 contains gases and alkanes in range of C_{12}-C_{22}. Pyrolysis shows the samples are classified as gas- and condensate-prone, with total remaining gas-generating potential in each case amounting to 300 µg/g sample, which is significantly smaller than that of samples G006486 and G006487, whose remaining gas yields are 1230-3181 µg/g sample. Additionally, the free hydrocarbons in samples G006486 and G006487 consist of paraffins below n-$C_{20,}$ thereby fulfilling an empirical prerequisite for gas shales.

Baldwin 1 well

Samples in this well have a high content of organic matter (TOC = 5.47-11%), Hydrogen Index in the range 22-34 mg/g TOC, and very high Tmax values (522-586°C). The free hydrocarbon fingerprint of sample G006489 is characterised by gaseous hydrocarbons and aromatic compounds. The gas chromatograms of samples G006488 to G006490 consist of mixtures of gaseous hydrocarbons and aromatic compounds, most notably benzene and toluene. Their petroleum type is defined as gas condensate according to the plot of Horsfield (1989). The remaining gas-generating potential of these samples is in the range 660-1300 µg/g sample.

BMR Mt Isa 1 drillhole

Three samples from the BMR Mt Isa 1 drillhole are characterised by very low production indexes (0.03-0.05 weight ratio), but high organic carbon content (TOC = 0.5-15.8%) and high petroleum generating potential (HI ~ 330-620 mg/g TOC). These samples can be classified as a mixture of kerogen type II and III, with Tmax values in range of 428-433°C.

Samples G006491 and G006492 (Middle Cambrian shale) have a very high petroleum potential (HI ~ 600 mg/g TOC) and high organic carbon content (TOC = 9.04-15.8%). They generate petroleum enriched in light hydrocarbons, even at low stages of thermal evolution. Remaining primary gas potential is very high, up to 8700-20000 µg/g. Based on that criteria, this source rock is worthy of serious consideration as a potential gas shale.

NTGS Elkedra 3 drillhole

Similar to samples from the Horn Valley Siltstone of the Amadeus Basin, samples from the NTGS Elkedra 3 drillhole also fulfil the empirical criteria to be considered as gas shale candidate. They have high organic carbon content (TOC = 9.66-12.2%), Hydrogen Index values in the range of 64-73 (mg/g TOC) and high Tmax values (467-474°C). This is supported by their volatile products, including paraffins below nC_{20} upon thermal vaporisation. Sample G006495, however, produces relatively large unresolved complex mixtures, which might cause its relatively lower gas flow rates, according to Jarvie et al. (2007). Upon pyrolysis, the samples from the Arthur Creek Formation in the NTGS Elkedra 3 drillhole produce gas condensate. Their total gas potential ranges from 2500-3100 µg/g sample.

References

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