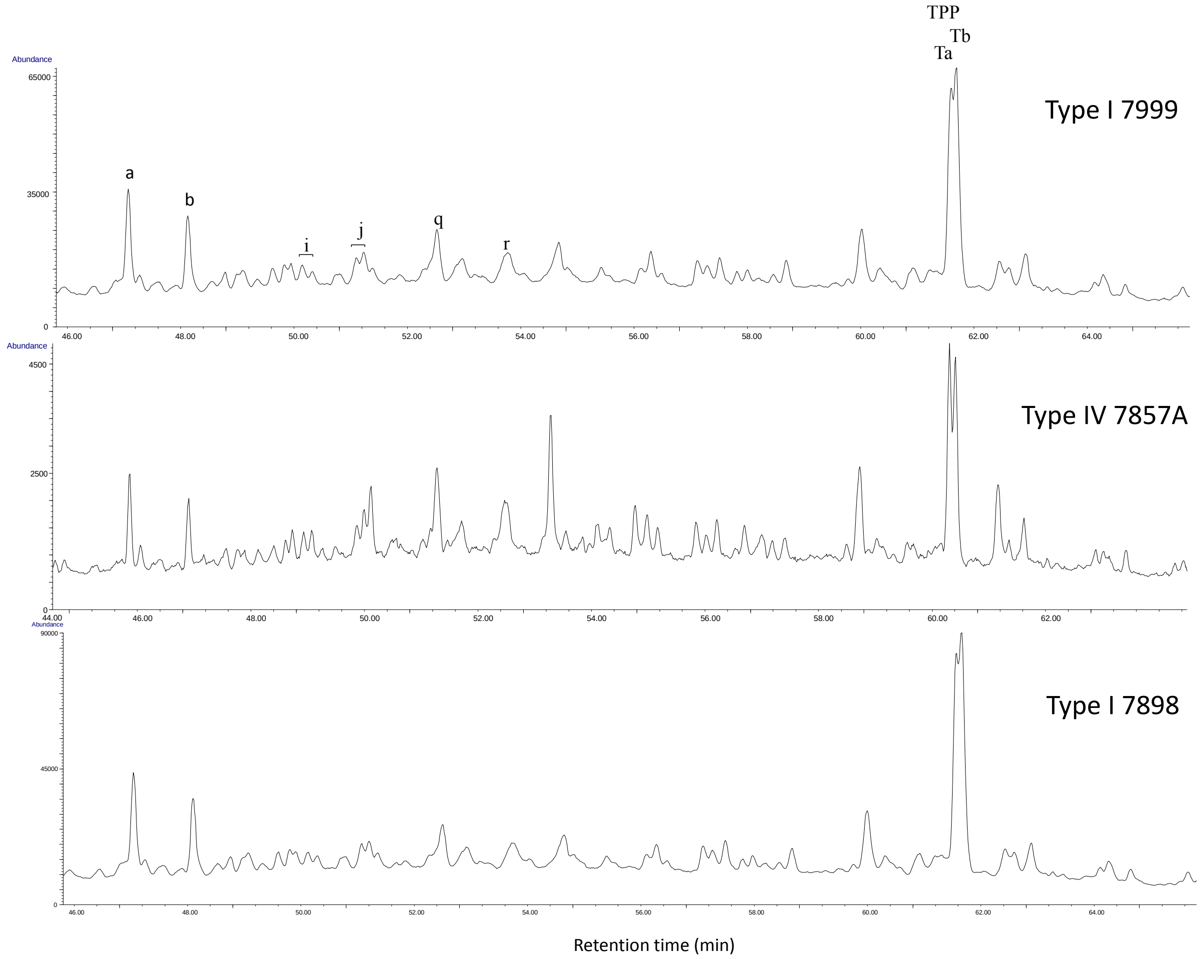


**Figure 75: Partial *m/z* 259 mass chromatograms of representative Type I waxy bitumens (7898 and 7999) and Type IV waxy bitumen (7857A) in Group 1 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

## *Group 2*

Group 2 consists of Type III low waxy bitumen samples with a similarity value of only 0.6 (Figure 76). It is further divided into three sub groups (Groups 2A, 2B and 2C). All the waxy bitumen samples in this group contain no botryococcane.

The abundances of tricyclic terpanes in the Group 2A and 2B samples are generally similar to the Group 1 samples with $C_{23}$ tricyclic terpane/ $C_{30}$ $\alpha\beta$ hopane ratios ranging from 0.07 to 0.17 but much lower than those in the Group 2C samples ($C_{23}$ tricyclic terpane/$C_{30}$ $\alpha\beta$ hopane=0.26-0.76, Figure 77). $C_{24}$ tetracyclic terpane, a biomarker for carbonate or evaporite source rock settings (Connan et al., 1986; Connan & Dessort, 1987; Mann et al., 1987; Clark & Philp, 1989) although in rare instances also believed to originate from terrigenous organic matter (Philp & Gilbert, 1986), is present in relatively low abundance in the Group 2 samples with $C_{24}$ tetracyclic/$C_{26}$ tricyclic terpane ratios ranging from 0.08 to 1.03. $C_{26}$/$C_{25}$ tricyclic terpanes ratios range from 1.6 to 2.3 which is indicative of lacustrine source rocks (Peters et al., 2005). Extended tricyclic terpanes ($C_{28}$-$C_{33}$) are present in much higher abundances in the Group 2C samples compared to the Group 2A and 2B samples.

$C_{30}$ $\alpha\beta$ hopane is the dominant compound in the *m/z* 191 chromatogram (Figure 77) with $C_{29}/C_{30}$ $\alpha\beta$ hopane ranging from 0.46 to 0.82, indicating that the potential source rocks are not carbonates. The abundances of rearranged hopanes (Ts and $C_{29}$Ts) and diahopane ($C_{30}$*) are higher in the Group 2A samples ($C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane = 0.35-0.39; $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane = 0.32-0.34) comparing to the Group 2B and 2C samples ($C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane=0.16-0.23; $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane = 0.06-0.11), indicating that the potential source rocks for the Group 2A samples were possibly deposited in a more oxic/clay-rich depositional environment than was the case for the Group 2B and 2C samples (Moldowan et al., 1991; Peters et al., 2005).

2$\alpha$-Methylhopanes and 3$\beta$-methylhopanes are present in the Group 2 samples (Figure 78) probably indicating inputs of oxygen-producing cyanobacteria (Summons & Jahnke, 1990) and aerobic methanotrophic bacteria (Burhan et al., 2002; Farrimond et al., 2004). The abundances of 2$\alpha$-methylhopanes in the Group 2A samples are much higher than in the Group 2B and 2C samples.

Oleanane, a biomarker for angiosperm higher plants that radiated during the Middle Jurassic to Late Cretaceous or younger (Moldowan et al., 1994; Bell et al., 2005; Zheng & Wang, 2010), is present in low abundance (Figure 77) with oleanane/$C_{30}$ $\alpha\beta$ hopane ranging from 0.08 to 0.22.

Bicadinanes are common biomarkers in source rocks containing resins of the Dipterocarpaceae family (van Aarssen et al., 1990) or non-tropical angiosperm families (van Aarssen et al., 1994; Murray et al., 1994). Bicadinanes are present in low abundances in the Group 2 samples based on MRM data.

$C_{29}$ $\alpha\beta\beta$ steranes are equivalent to or higher than $C_{27}$ $\alpha\beta\beta$ steranes in the Group 2 samples ($C_{29}/C_{27}$ $\alpha\beta\beta$ steranes = 0.8-1.2) indicating that they were likely derived from source rocks with mixed algal and terrestrial higher plant inputs. 24-*n*-Propycholestanes that are diagnostic compounds for marine organic matter input (Moldowan et al., 1990) are not present in low abundances in the Group 2 samples. 4-Methylsteranes, biomarkers for lacustrine algal inputs when in high abundances (Peters et al., 2005), are present in trace amounts in the Group 2A and 2B samples and in high abundances in the Group 2C samples. Very low sterane/hopane ratios (0.05-0.08) indicate terrigenous or microbially reworked organic matter inputs.

$C_{27}$ diasteranes are present in relatively high abundances compared to the regular steranes with $C_{27}$ dia/(dia+reg) sterane ratios ranging from 0.46 to 0.64 in the Group 2B and 2C samples and from 0.59 to 0.72 in the Group 2A samples. This is consistent with high abundances of rearranged hopanes in the Group 2A samples.

A doublet of late-eluting peaks identified as the tetracyclic polyprenoids Ta and Tb in the *m/z* 259 mass chromatogram, biomarkers for a freshwater lacustrine algal input (Holba et al., 2000, 2003), are present in high abundances (Figure 80).

In summary, the Group 2A samples were likely derived from marine shale deposited in a sub-oxic depositional environment with mixed marine algal, lacustrine organic matter and bacteria with minor contributions from terrestrial angiosperm higher plants (Table 20). The Group 2B and 2C samples were possibly derived from lacustrine source rocks deposited in a less sub-oxic depositional environment compared to the Group 2A samples, with significant lacustrine organic matter input and minor contributions from terrestrial angiosperm higher plants and bacteria (Table 20).

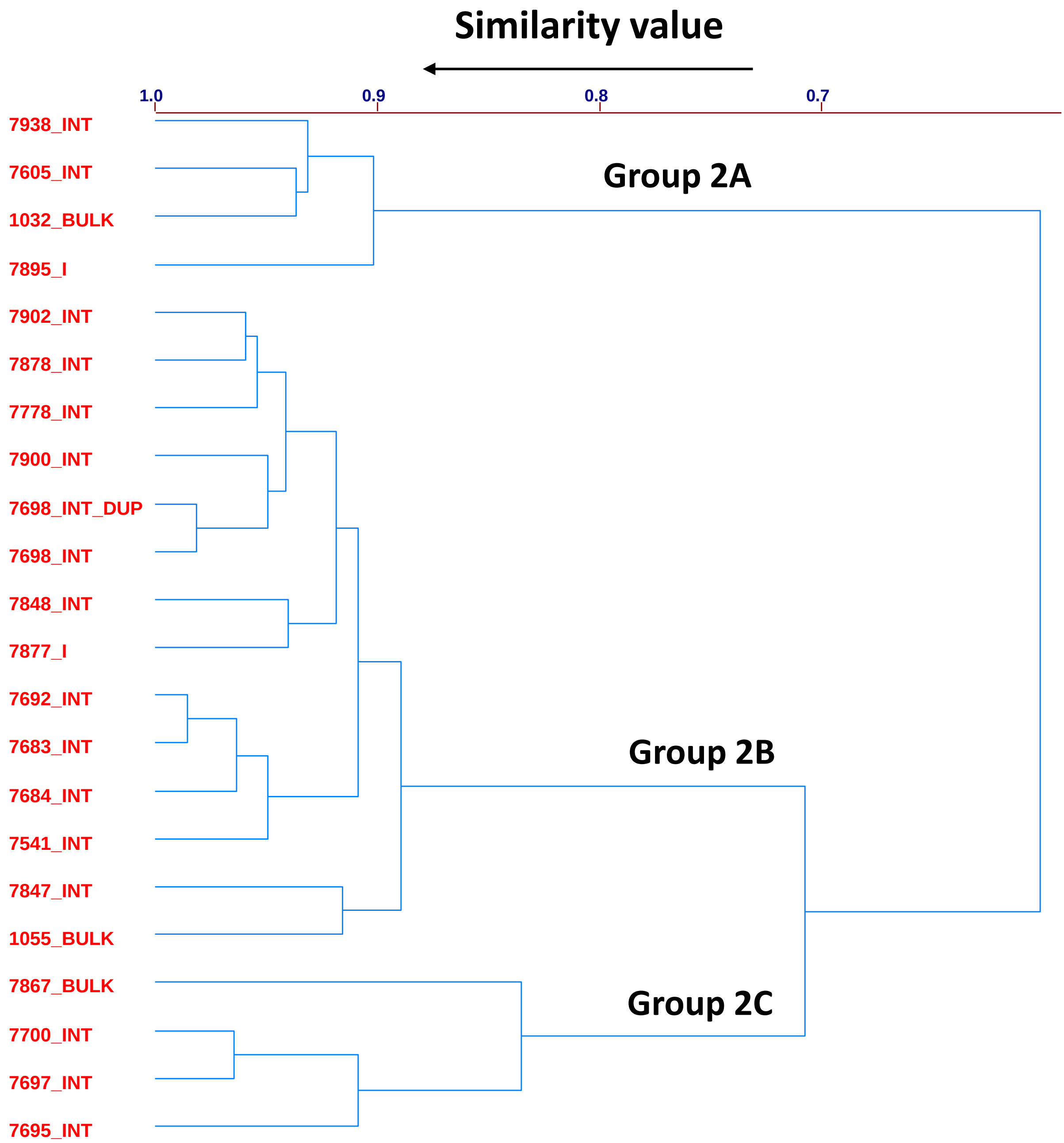


**Figure 76: Partial dendrogram of the hierarchical cluster analysis of Group 2 in Figure 70.**

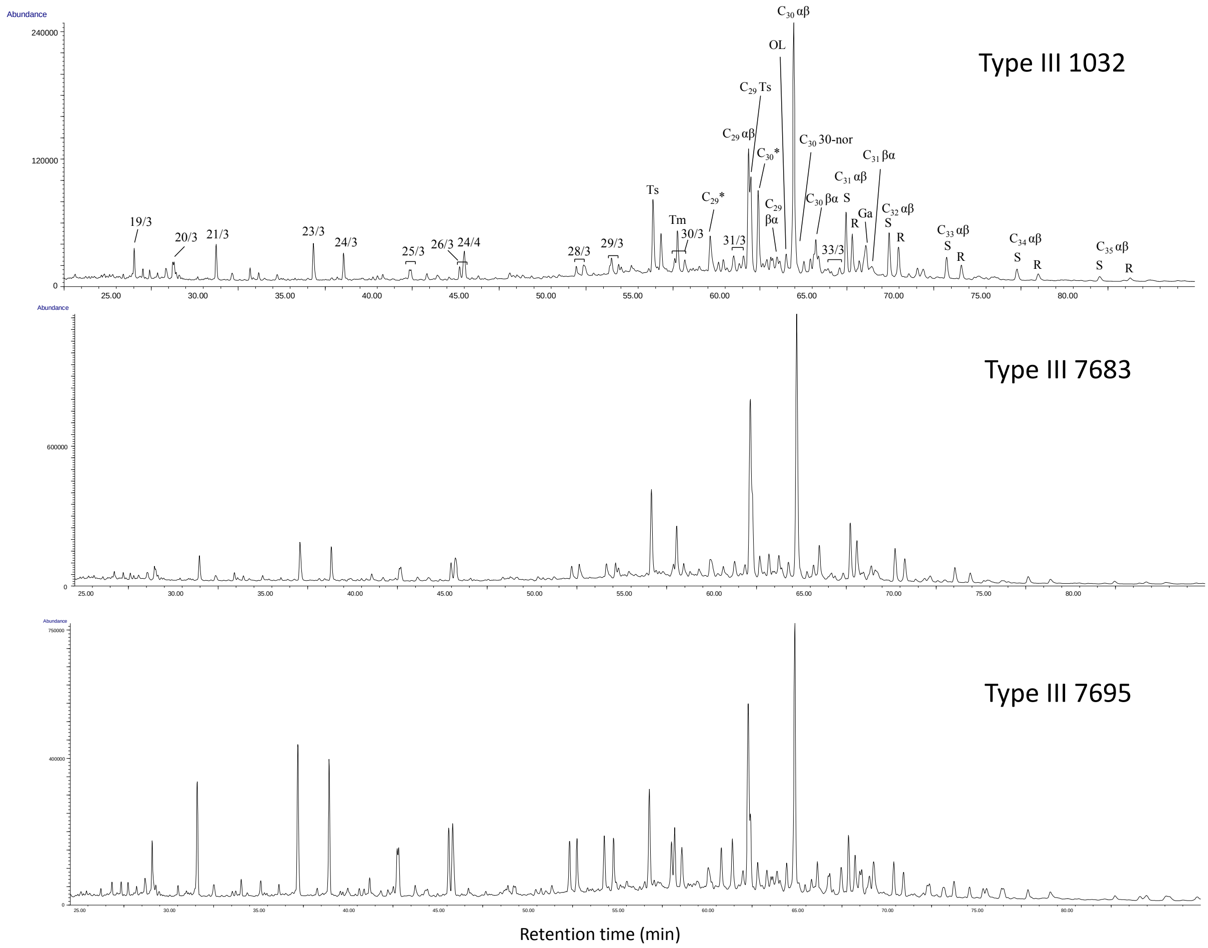


**Figure 77: Partial *m/z* 191 mass chromatograms of representative Type IV waxy bitumen (7593) and unclassified high wax bitumen (7978) and Type III waxy bitumen (7503) in Group 2 showing the distribution of tricyclic terpanes and hopanes. For peak identifications refer to table 18.**

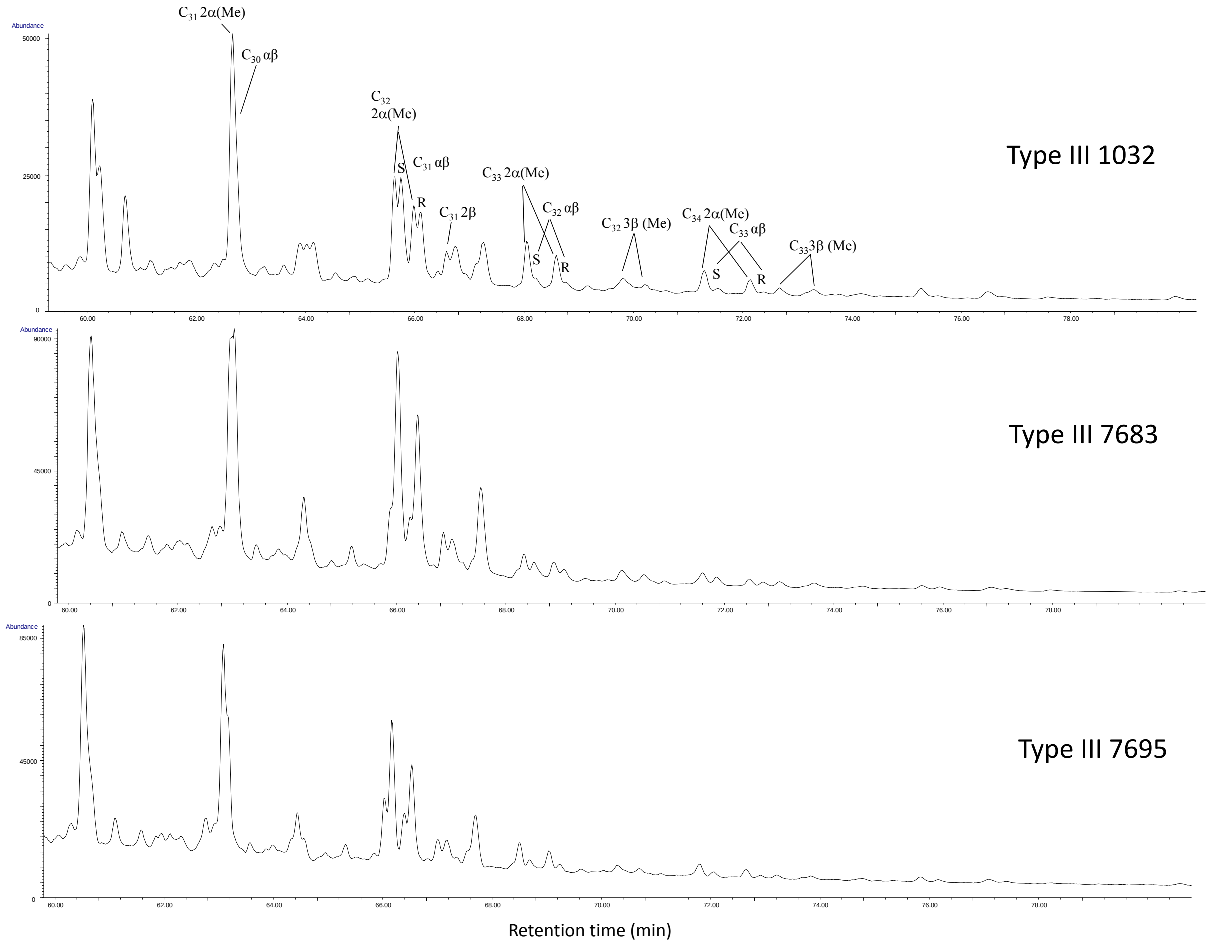


**Figure 78: Partial *m/z* 217 mass chromatograms of representative Type III waxy bitumen samples (1032, 7683 and 7695) in Group 2 showing the distribution of methylhopanes. For peak identifications refer to table 19.**

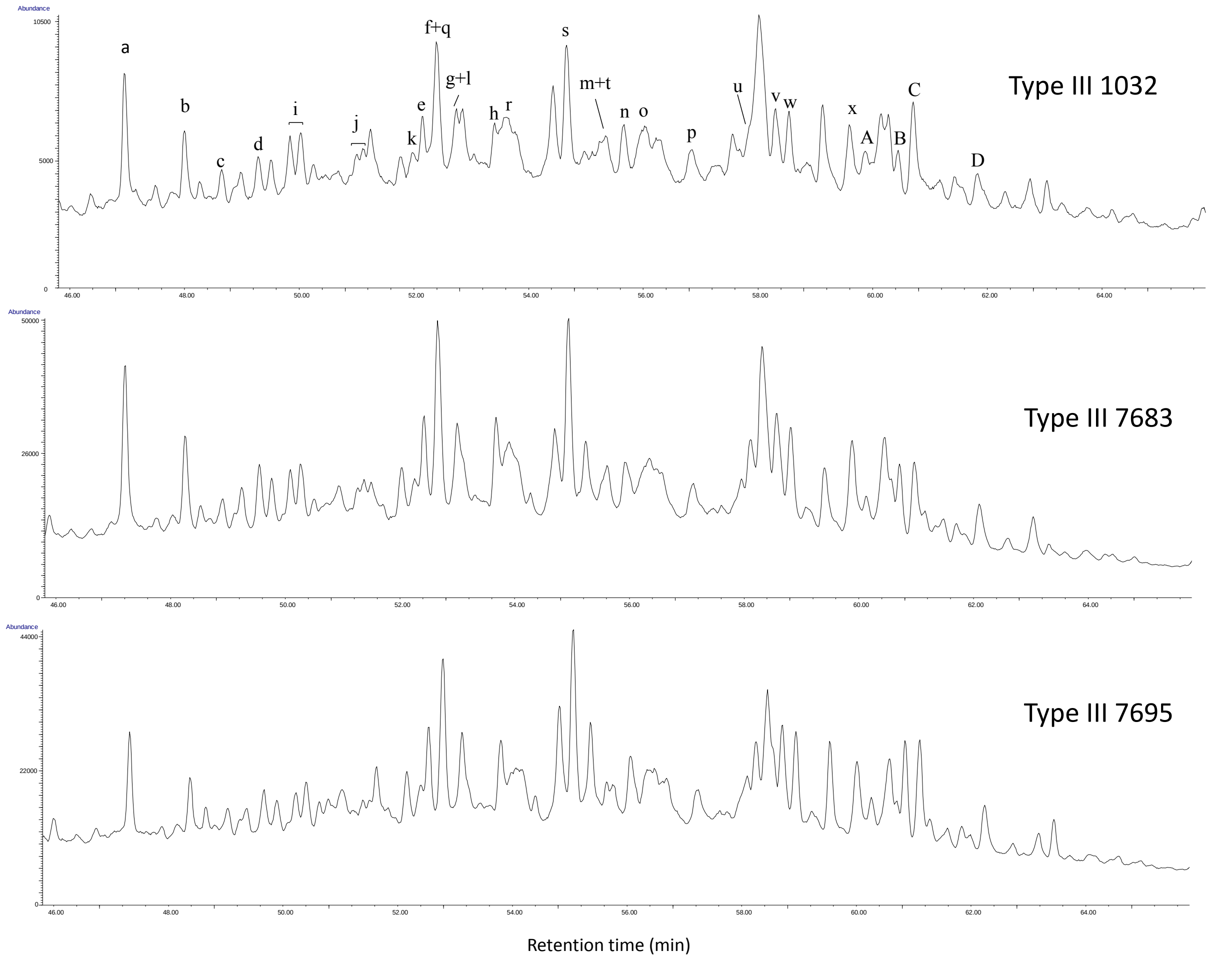


**Figure 79: Partial *m/z* 217 mass chromatograms of representative Type III waxy bitumen samples (1032, 7683 and 7695) in Group 2 showing the distribution of steranes and diasteranes. For peak identifications refer to table 18.**

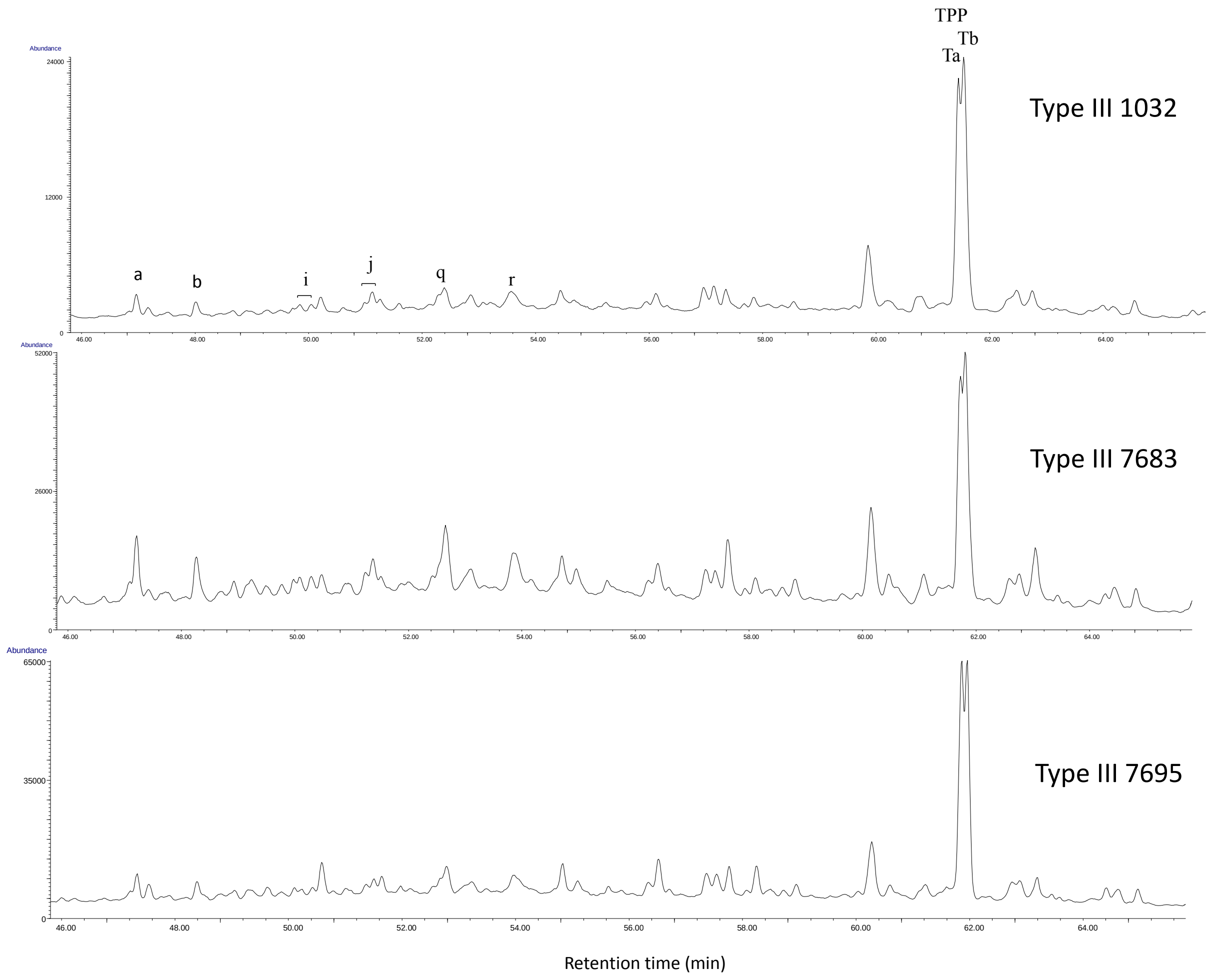


**Figure 80: Partial *m/z* 259 mass chromatograms of representative Type III waxy bitumen samples (1032, 7683 and 7695) in Group 2 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

### *Group 3*

Group 3 consists of Type IV waxy bitumen samples only (Figure 81). They are very closely related with a similarity value of 0.8. All the Group 3 samples contain no botryococcane.

Tricyclic terpanes are in relatively high abundances compared to hopanes in this group with the $C_{23}$ tricyclic terpane/$C_{30}$ $\alpha\beta$ hopane ratio ranging from 0.31 to 0.67. The $C_{24}$ Tetracyclic terpane, a biomarker for carbonate or evaporite source rock settings (Connan et al., 1986; Connan & Dessort, 1987; Mann et al., 1987; Clark& Philp, 1989) and in rare instances believed to originate from terrigenous organic matter (Philp & Gilbert, 1986), is in low abundances in all the samples ($C_{24}$ tetracyclic/$C_{26}$ triclcyclic terpane ranging from 0.13 to 0.49). $C_{26}$/$C_{25}$ tricyclic terpanes ratios range from 1.1 to 2.5, indicating lacustrine organic matter inputs (Peters et al., 2005). Extended tricyclic terpanes ($C_{28}$-$C_{31}$) are present in all Group 3 samples (Figure 82).

$C_{30}$ $\alpha\beta$ hopane is the dominant compound in the *m/z* 191 chromatogram (Figure 82) with $C_{29}$/$C_{30}$ $\alpha\beta$ hopane ranging from 0.54 to 0.67, indicating that the potential source rocks of the Group 3 samples are not calcareous. Rearranged hopanes ($C_{29}$Ts) and diahopane ($C_{30}$*) are present in relatively high abundances ($C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane = 0.15-0.28; $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane = 0.21-0.27) which is similar to Group 1 and 2A samples, indicating that the Group 3 samples were possibly derived from source rocks deposited in a sub-oxic/clay-rich depositional environment (Moldowan et al., 1991; Peters et al., 2005).

$C_{31}$-$C_{34}$ 2$\alpha$-methylhopanes and $C_{31}$-$C_{33}$ 3$\beta$ methylhopanes are not present in the Group 3 samples (Figure 83), which probably indicates no inputs of oxygen-producing cyanobacteria (Summons & Jahnke, 1990) and aerobic methanotrophic bacteria (Burhan et al., 2002; Farrimond et al., 2004).

Oleanane, a biomarker for angiosperm higher plants that radiated during the Middle Jurassic to Late Cretaceous or younger (Moldowan et al., 1994; Bell et al., 2005; Zheng & Wang, 2010), is detected in trace amounts in the Group 3 samples (Figure 82; oleanane/$C_{30}$ $\alpha\beta$ hopane = 0.02-0.04).

Bicadinanes, common biomarkers for resins of Dipterocarp hard wood trees (van Aarssen et al., 1990) or non-tropical angiosperm families (van Aarssen et al., 1994; Murray et al., 1994), are not present in the Group 3 samples.

$C_{29}$ $\alpha\beta\beta$ steranes are in slightly lower relative abundances compared to $C_{27}$ $\alpha\beta\beta$ steranes in the Group 3 samples ($C_{29}$/$C_{27}$ $\alpha\beta\beta$ steranes = 0.8-0.97) indicating that the Group 3 samples were likely derived from source rocks with greater marine organic matter inputs. 24-*n*-propycholestanes that is diagnostic of a marine organic matter input (Moldowan et al., 1990) and 4-methylsteranes that indicates lacustrine organic matter inputs when in high abundances (Peters et al., 2005) are absent in Group 3 samples. High sterane/hopane ratios (2.26-2.57) indicate marine organic matter inputs with a major contribution from planktonic and/or benthic algae.

$C_{27}$ diasteranes are present in high relative abundances with $C_{27}$ dia/(dia+reg) sterane ratios ranging from 0.71 to 0.79. This is consistent with high relative abundances of rearranged hopanes and diahopane.

A doublet of late-eluting peaks identified as the tetracyclic polyprenoids Ta and Tb in the *m/z* 259 mass chromatogram (Figure 85), biomarkers for freshwater (lacustrine) algal input (Holba et al., 2000, 2003), are present in very low abundances in all Group 3 samples.

In summary, the Type IV waxy bitumen samples in Group 3 were likely derived from clay-rich source rocks deposited in a sub-oxic depositional environment with mixed marine and lacustrine organic matter inputs (Table 20).

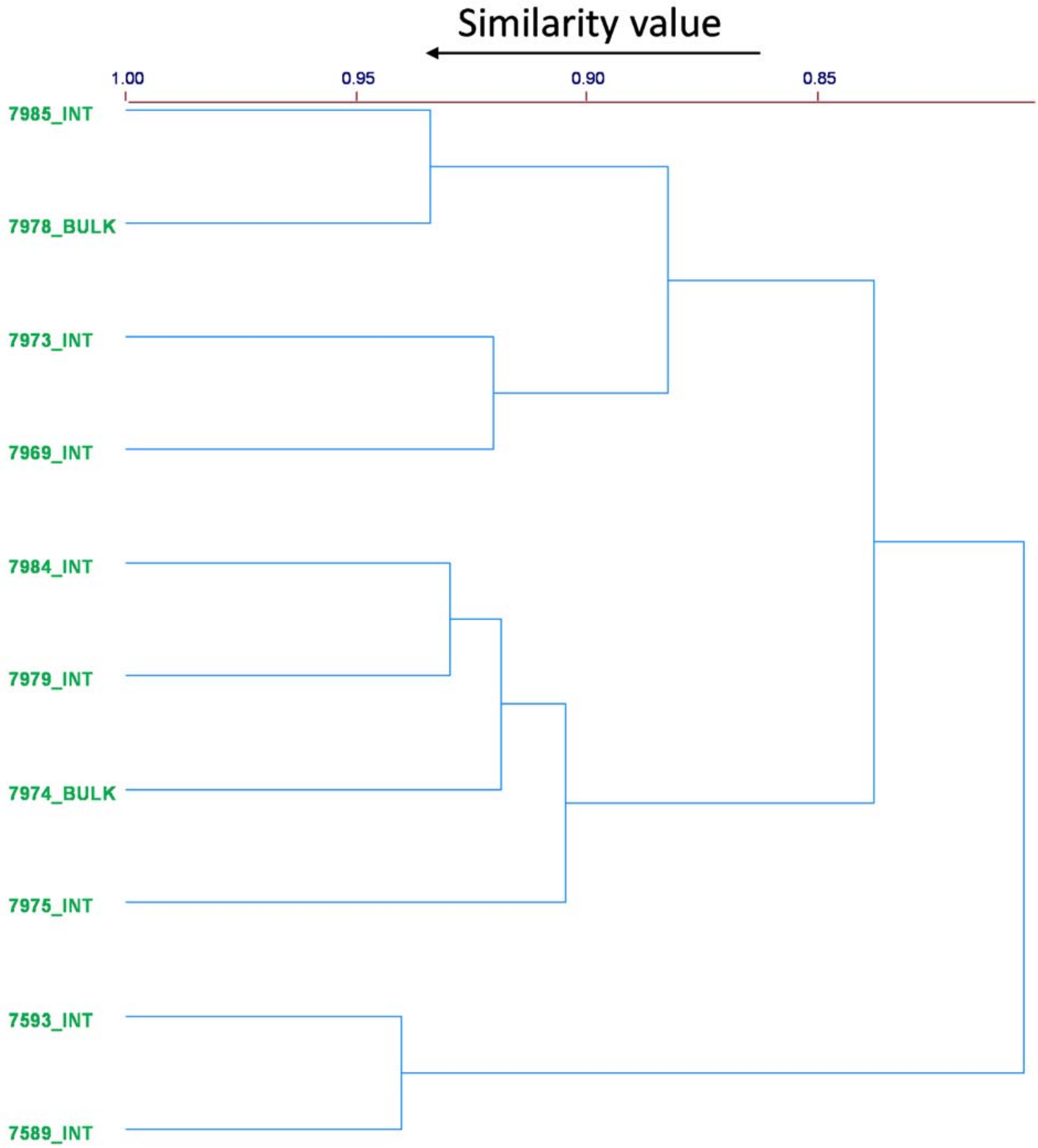


**Figure 81: Partial dendrogram of the hierarchical cluster analysis of Group 3 in Figure 70.**

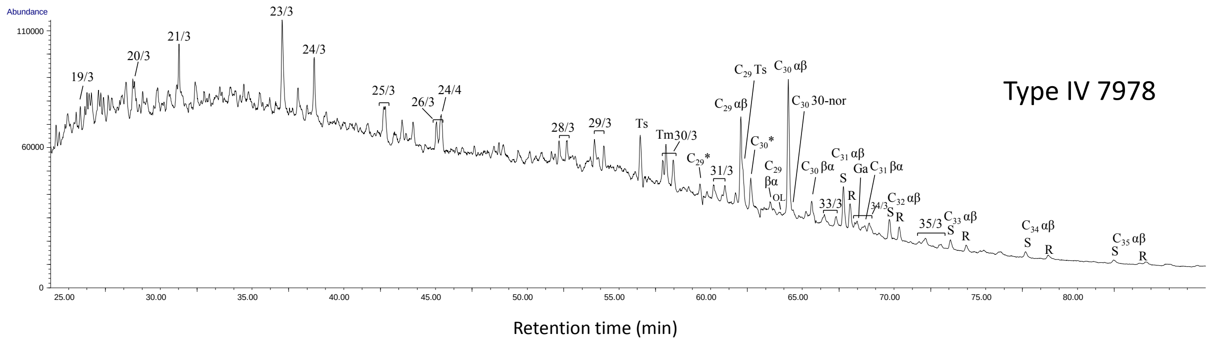


**Figure 82: Partial *m/z* 191 mass chromatograms of representative Type IV waxy bitumen (7978) in Group 3 showing the distribution of tricyclic terpanes and hopanes. For peak identifications refer to table 18.**

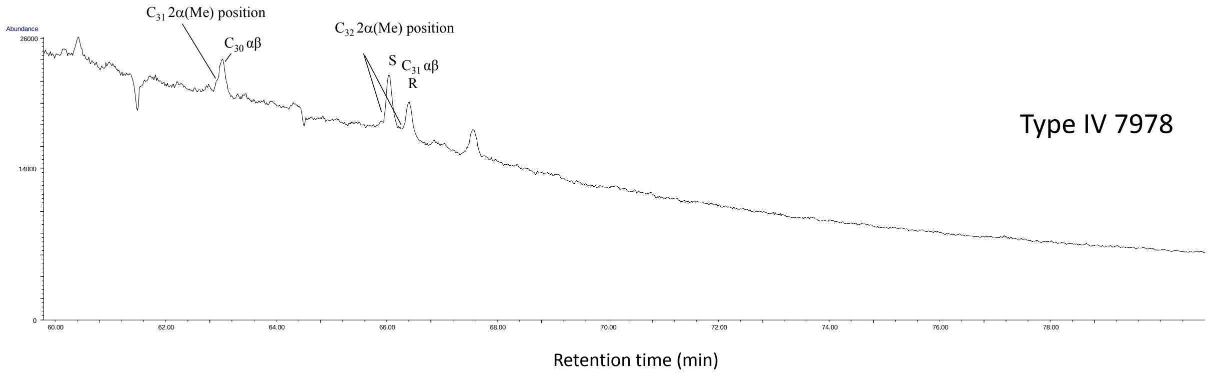


**Figure 83: Partial *m/z* 205 mass chromatograms of representative Type IV waxy bitumen (7978) in Group 3 showing the distribution of methylhopanes. For peak identifications refer to table 18.**

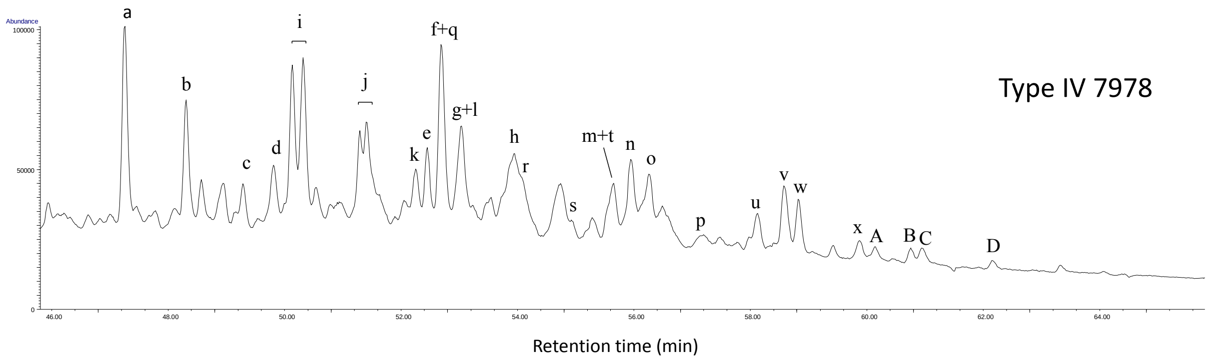


**Figure 84: Partial *m/z* 217 mass chromatograms of representative Type IV waxy bitumen (7978) in Group 3 showing the distribution of steranes and diasteranes. For peak identifications refer to table 19.**

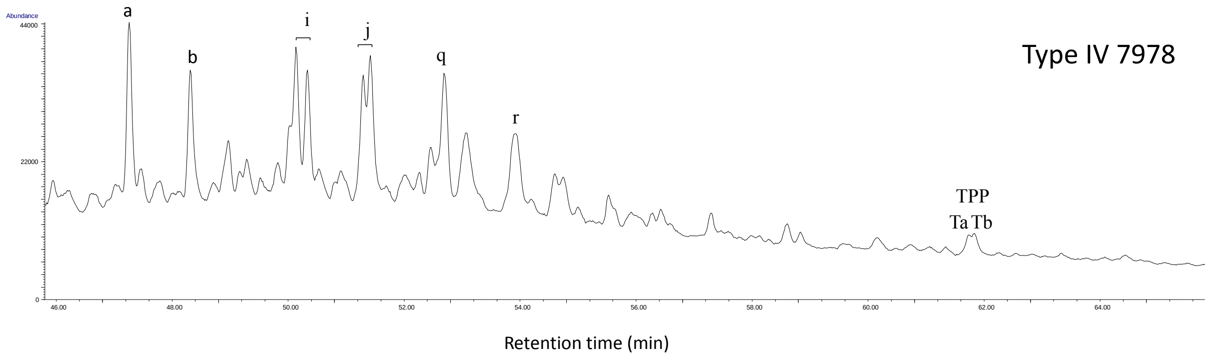


**Figure 85: Partial *m/z* 259 mass chromatograms of representative Type IV waxy bitumen (7978) in Group 3 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

### *Group 4*

Group 4 consists of four sub-groups, Group 4A, 4B, 4C and 4D (Figure 86). Group 4A consists of twenty asphaltites and two Type IV waxy bitumen samples with a similarity value of 0.87. The Group 4B consists of one Type IV waxy bitumen and one unclassified high wax bitumen sample with a similarity value of 0.95. The Group 4C consists of seven Number 1&2 Rocks soft bitumen samples with a similarity value of 0.94. The Group 4D consists of two degraded asphaltite and seven Type II waxy bitumen samples with a similarity value of 0.85. The Group 4 samples contain no botryococcane except the Type II waxy bitumen samples in Group 4D which contain low abundance of botryococcane.

The abundances of tricyclic terpanes are very low relative to hopanes in the asphaltite and Type IV waxy bitumen samples of Group 4A and the degraded asphaltite samples in Group 4D, with $C_{23}$ tricyclic terpane/$C_{30}$ $\alpha\beta$ hopane ratios ranging from 0.04 to 0.08. They are also low by comparison with the values of this parameter in other sub-groups (0.13-0.5). The $C_{24}$ tetracyclic terpane, a biomarker for carbonate or evaporite source rock settings (Connan et al., 1986; Connan & Dessort, 1987; Mann et al., 1987; Clark & Philp, 1989) and in rare instances for terrigenous organic matter (Philp & Gilbert, 1986), is in high abundances in all the Group 4 samples ($C_{24}$ tetracyclic/$C_{26}$ triclcyclic terpane = 0.92 to 3.53). $C_{26}$/$C_{25}$ tricyclic terpane ratios range from 1 to 3.5, indicating lacustrine organic matter inputs (Peters et al., 2005). Extended tricyclic terpanes ($C_{28}$-$C_{31}$) are present in low abundances in all the Group 4 samples (Figure 87).

$C_{30}$ $\alpha\beta$ hopane is the dominant compound in the *m/z* 191 chromatograms (Figure 87) of the Group 4A ($C_{29}$/$C_{30}$ $\alpha\beta$ hopane = 0.6-0.69) and 4C ($C_{29}$/$C_{30}$ $\alpha\beta$ hopane = 0.73-0.82) samples. Moreover, the $C_{29}$/$C_{30}$ $\alpha\beta$ hopane values of the Group 4B (1.1) and most of the Group 4D samples (1.05 to 1.16) are higher than 1. $C_{35}$/$C_{34}$ homohopane ratios range from 0.8 to 0.95 in the Group 4A samples, from 0.9 to 1 in the Group 4D samples, and from 1 to 1.07 in the Group 4B and 4C samples. Most oils derived from marine carbonate source rocks have high $C_{35}$/$C_{34}$ homohopane ratios (>0.8) and high $C_{29}$/$C_{30}$ $\alpha\beta$ hopane ratios (>0.6). This implicates marine carbonates or evaporites deposited under reducing conditions as the likely source of these samples (Connan et al., 1986; Mello et al., 1988; Peters et al., 2005).

Relatively lower abundances of rearranged hopanes ($C_{29}$Ts) and diahopane ($C_{30}$*) in the Group 4 samples indicate that they were possibly derived from clay-rich source rocks deposited in a sub-oxic

depositional environment (Moldowan et al., 1991; Peters et al., 2005). $C_{29}Ts/C_{29}$ $\alpha\beta$ hopane ranges from 0.08 to 0.22 and $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane ranges from 0.03 to 0.1.

$C_{31}$-$C_{34}$ 2$\alpha$-methylhopanes and $C_{31}$-$C_{33}$ 3$\beta$ methylhopanes are present in high abundances in the Group 4B, 4C and 4D samples but in low relative abundances in the Group 4A samples (Figure 88), which probably indicates that the source rocks of the Group 4B, 4C and 4D samples had greater inputs of oxygen-producing cyanobacteria (Summons & Jahnke, 1990) and aerobic methanotrophic bacteria (Burhan et al., 2002; Farrimond et al., 2004) than did those of the Group 4A samples.

Oleanane, a biomarker for angiosperm higher plants that radiated during the Middle Jurassic to Late Cretaceous or younger (Moldowan et al., 1994; Bell et al., 2005; Zheng & Wang, 2010), is either not detected or in trace amounts in most of the Group 4 samples (oleanane/$C_{30}$ $\alpha\beta$ hopane = 0-0.18), except those in Group 4B (Figure 86) with oleanane/$C_{30}$ $\alpha\beta$ hopane = 0.18.

Bicadinanes, common biomarkers for resins of Dipterocarp tropical hard woods (van Aarssen et al., 1990) or non-tropical angiosperm families (van Aarssen et al., 1994; Murray et al., 1994), are not present in the Group 4 samples except the Group 4D sample wich have low abundances of bicadinanes.

$C_{29}$ $\alpha\beta\beta$ steranes are equivalent to $C_{27}$ $\alpha\beta\beta$ steranes in the Group 4A samples ($C_{29}/C_{27}$ $\alpha\beta\beta$ steranes = 0.77-1.04), whereas in the Group 4B, 4C and 4D samples $C_{29}$ $\alpha\beta\beta$ steranes are relatively higher than $C_{27}$ $\alpha\beta\beta$ steranes ($C_{29}/C_{27}$ $\alpha\beta\beta$ steranes = 1.02-2.63) indicating mixed marine algal and terrestrial higher plant inputs for the Group 4A samples, but high terrestrial plant inputs for the Group 4B, 4C and 4D samples. Low relative abundances of 24-*n*-propycholestane, a diagnostic marker for marine algal organic matter (Moldowan et al., 1990), were identified in the Group 4A, 4C and 4D samples based on MRM data. 4-Methylsteranes, biomarkers for lacustrine organic matter when abundant (Peters et al., 2005), are present in low abundances in the Group 4A and 4C samples, but in high relative abundances in the Type II waxy bitumen samples in Group 4D. No MRM analyses were performed on the Group 4B samples and hence the presence or absence of diagnostic compounds such as 24-*n*-propycholestane and 4-methylsteranes is not known. Low sterane/hopane ratios (0.19-0.75) are indicative of terrigenous and/or microbially reworked organic matter.

$C_{27}$ diasteranes are present in relatively lower abundances compared to the Group 1, 2A and 3 samples with $C_{27}$ dia/(dia+reg) sterane ratios ranging from 0.33 to 0.49. This is consistent with lower abundances of rearranged hopanes and diahopane.

A doublet of late-eluting peaks identified as the tetracyclic polyprenoids Ta and Tb in the *m/z* 259 mass chromatogram (Figure 90), biomarkers for freshwater (lacustrine) algal input (Holba et al., 2000, 2003), are present in low abundances in the Group 4 samples.

In summary, the Group 4A samples were likely derived from marine source rocks deposited in a sub-oxic depositional environment with significant marine algal inputs and only minor contributions from terrestrial higher plants (Table 21). The Group 4B samples were likely derived from carbonate source rocks deposited in an anoxic depositional environment with significant terrestrial higher plant inputs and some contributions from bacteria (Table 21). The Group 4C samples were probably derived from marine calcareous source rocks deposited in an anoxic depositional environment, with significant terrestrial higher plant inputs and minor contributions from bacteria (Table 21). The 4D samples were possibly derived from marine carbonate source rocks deposited in an anoxic depositional environment with predominant terrestrial higher plant inputs and some lesser contributions from lacustrine organic matter and bacteria (Table 21).

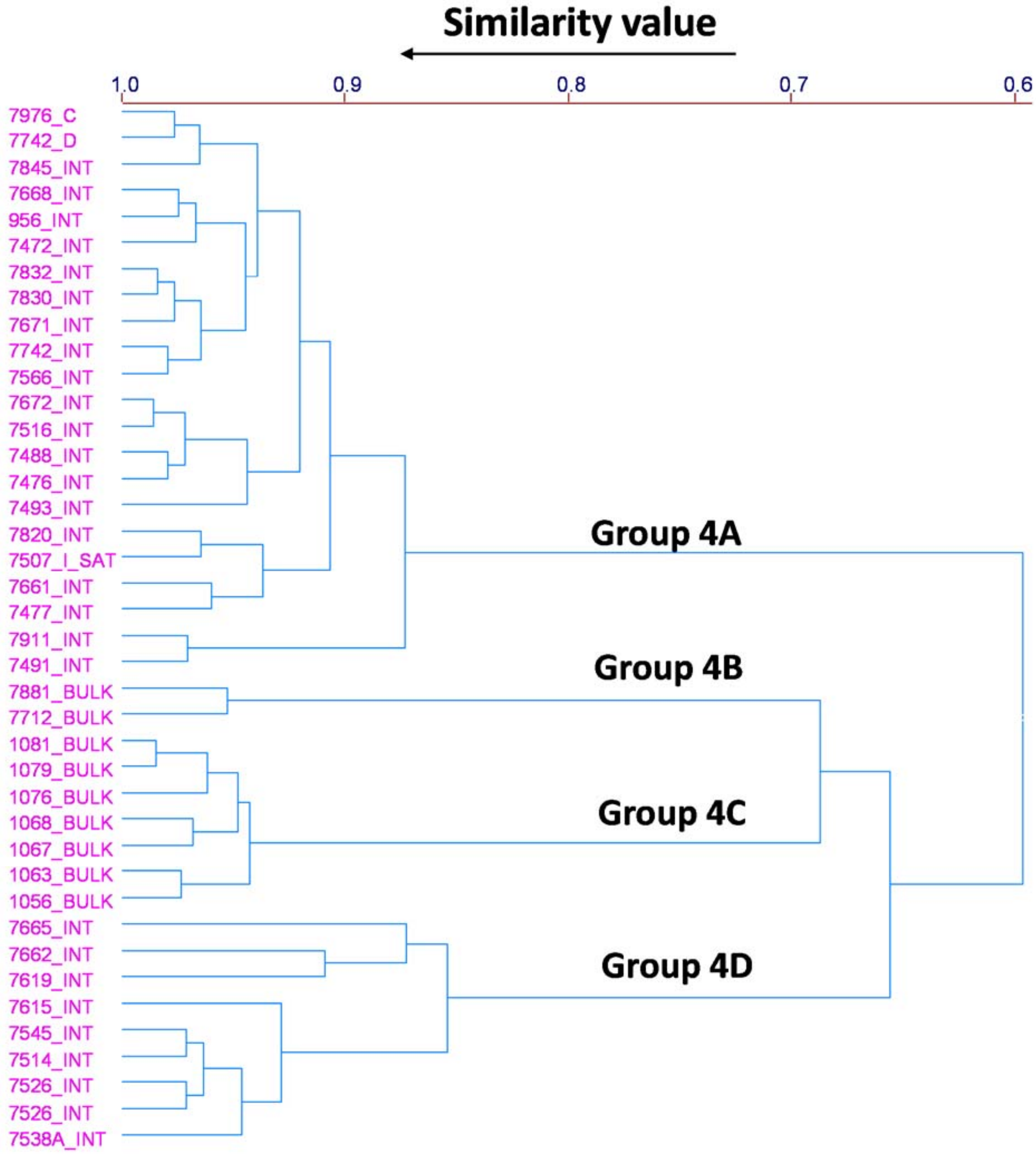


**Figure 86: Partial dendrogram of the hierarchical cluster analysis of Group 4 in Figure 70.**

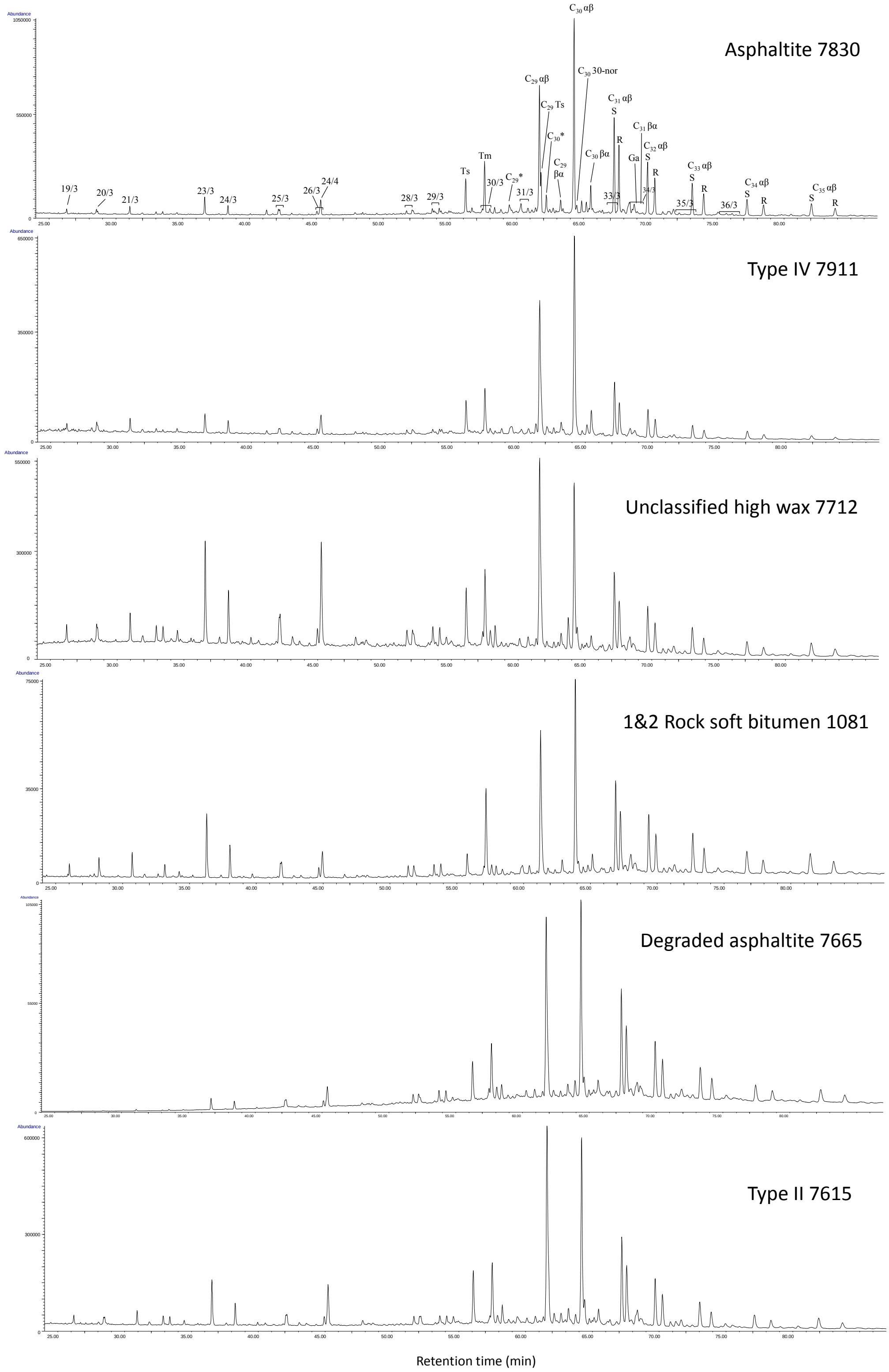


**Figure 87: Partial *m/z* 191 mass chromatograms of representative asphaltite (7830), Type IV waxy bitumen (7911), unclassified high wax (7712), Number 1&2 Rocks soft bitumen (1081), degraded asphaltite (7665) and Type II waxy bitumen (7615) in Group 4 showing the distribution of tricyclic terpanes and hopanes. For peak identifications refer to table 18.**

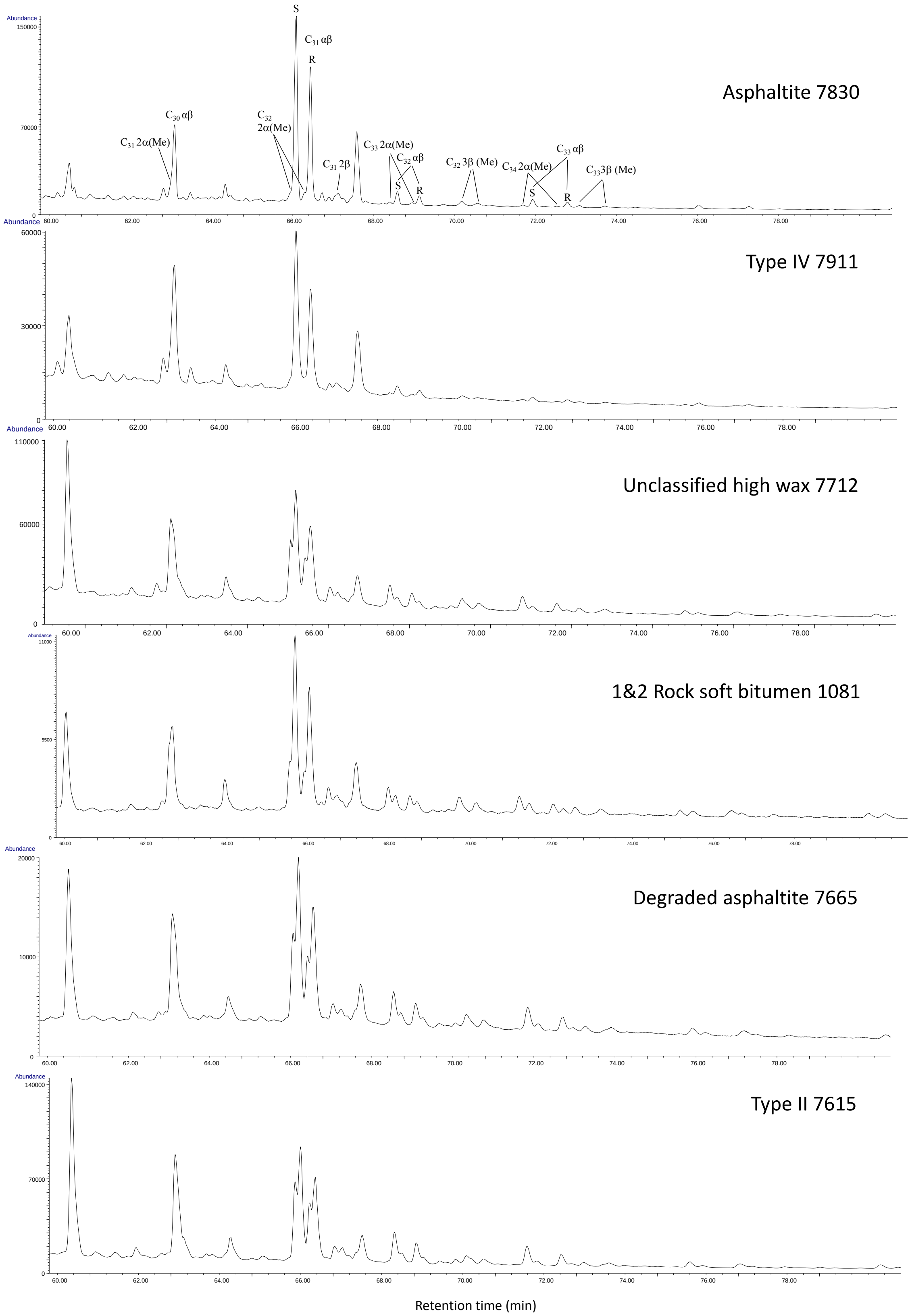


**Figure 88: Partial *m/z* 205 mass chromatograms of representative asphaltite (7830), Type IV waxy bitumen (7911), unclassified high wax (7712), Number 1&2 Rocks soft bitumen (1081), degraded asphaltite (7665) and Type II waxy bitumen (7615) in Group 4 showing the distribution of methylhopanes. For peak identifications refer to table 18.**

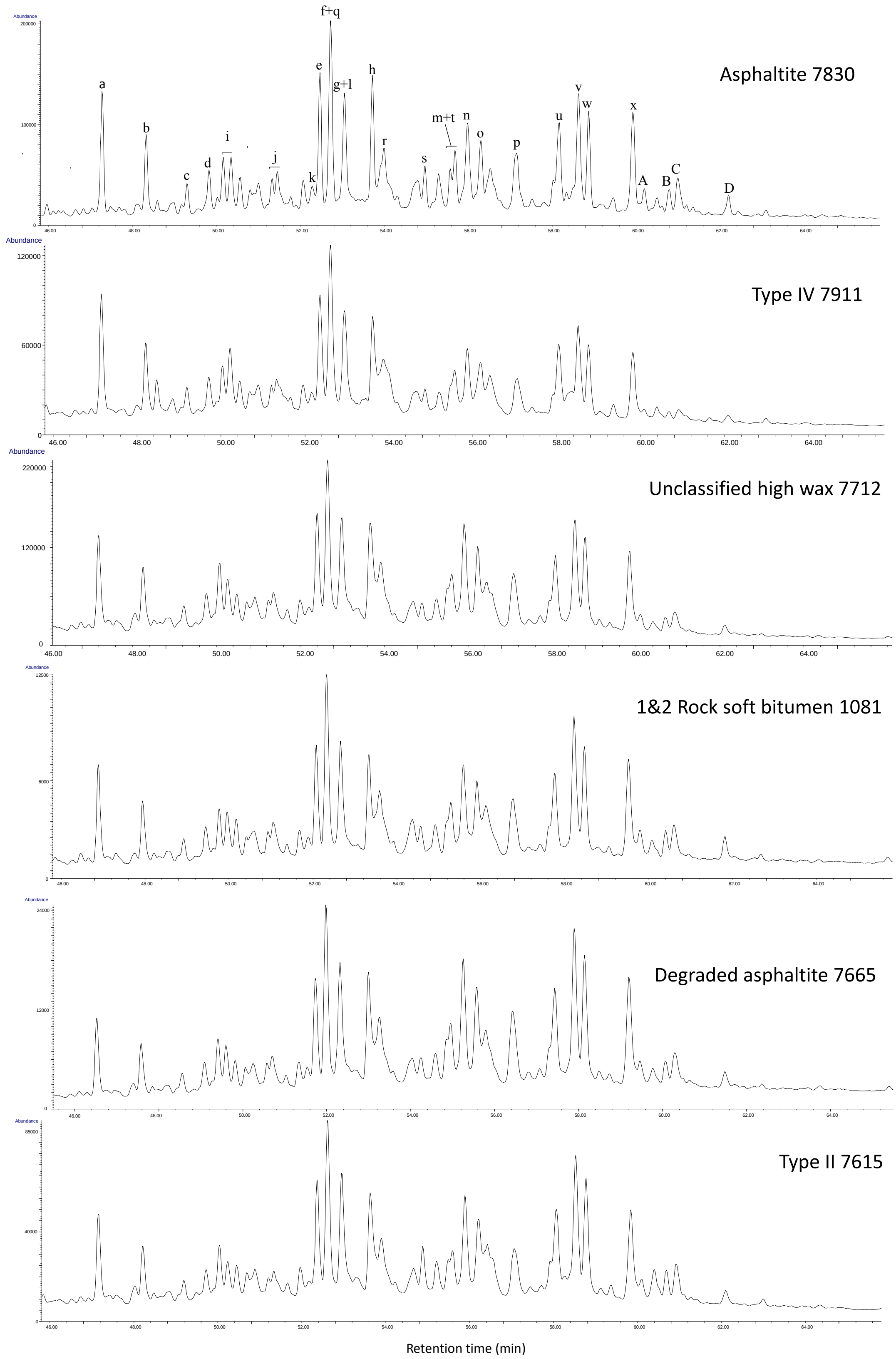


**Figure 89: Partial *m/z* 217 mass chromatograms of representative asphaltite (7830), Type IV waxy bitumen (7911), unclassified high wax (7712), Number 1&2 Rocks soft bitumen (1081), degraded asphaltite (7665) and Type II waxy bitumen (7615) in Group 4 showing the distribution of steranes and diasteranes. For peak identifications refer to table 19.**

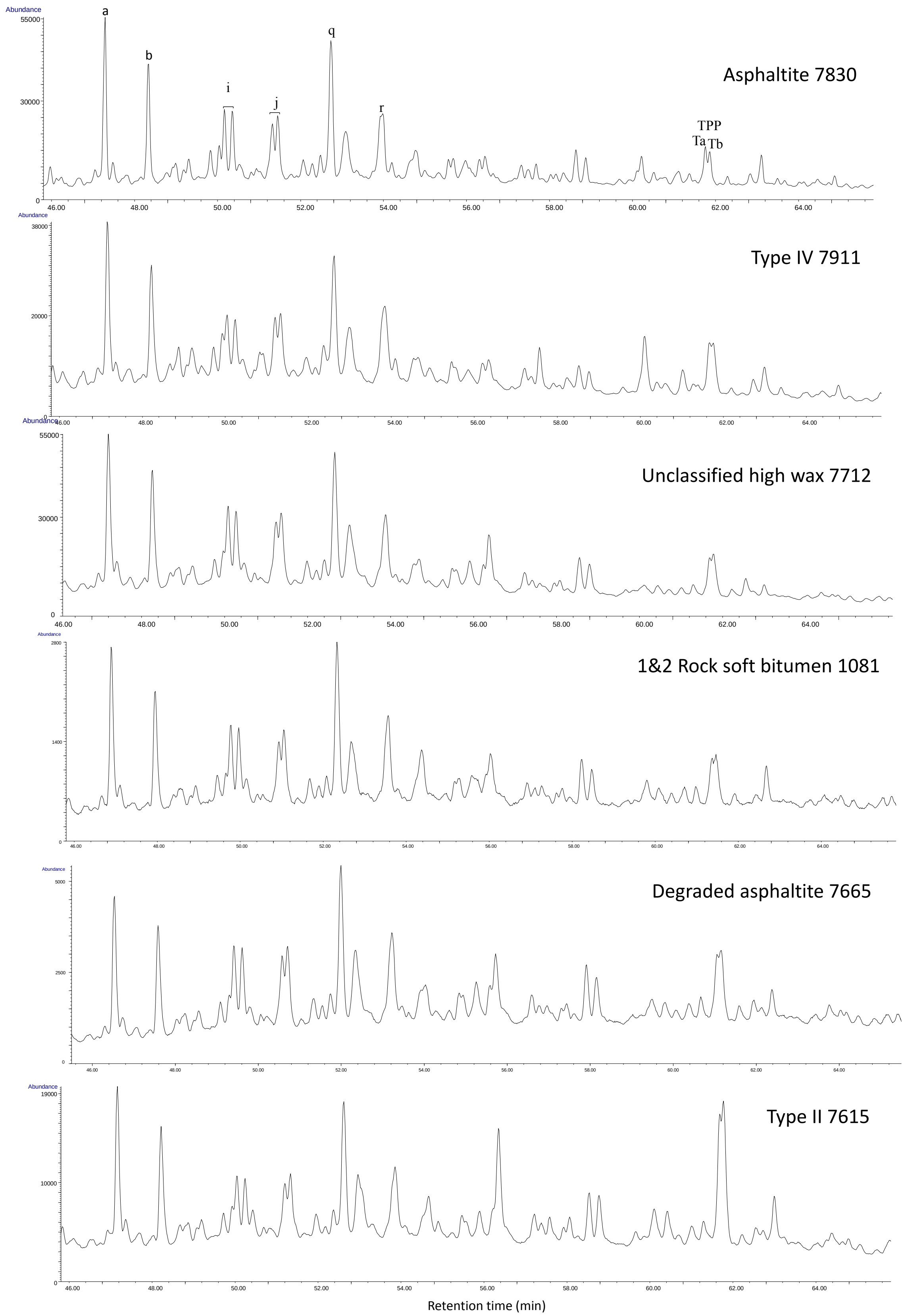


**Figure 90: Partial *m/z* 259 mass chromatograms of representative asphaltite (7830), Type IV waxy bitumen (7911), unclassified high wax (7712), Number 1&2 Rocks soft bitumen (1081), degraded asphaltite (7665) and Type II waxy bitumen (7615) in Group 4 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

### *Group 5*

Group 5 consists of eight Sandy River soft bitumen samples and one Type IV waxy bitumen (Figure 91). They are very closely related with a similarity value of 0.86. The Group 5 samples contain no botryococcane.

Tricyclic terpanes are present in much lower relative abundances compared to hopanes (Figure 92) with $C_{23}$ tricyclic terpane/ $C_{30}$ $\alpha\beta$ hopane ratios ranging from 0.18 to 0.4. The $C_{24}$ tetracyclic terpane, a biomarker for carbonate or evaporite depositional environments, is in low abundance (Figure 92) ($C_{24}$ tetracyclic/$C_{26}$ tricyclic terpane = 0.5-0.72) except in the Type IV waxy bitumens ($C_{24}$ tetracyclic/$C_{26}$ tricyclic terpane = 1.92). Extended tricyclic terpanes ($C_{28}$-$C_{36}$) are not present in the Group 5 samples.

$C_{29}$ $\alpha\beta$ hopane is the dominant compound in the *m/z* 191 chromatogram (Figure 92) with $C_{29}/C_{30}$ $\alpha\beta$ hopane ratios ranging from 0.57 to 0.73. The $C_{35}$ homohopanes are less abundant than $C_{34}$ homohopanes with $C_{35}/C_{34}$ homohopane ratios ranging from 0.7 to 0.84. This indicates that the source rocks for Sandy River soft bitumen are not calcareous (Connan et al., 1986; Mello et al., 1988; Peters et al., 2005).

Rearranged hopanes ($C_{29}$Ts) and diahopane ($C_{30}$*) are present in relatively low abundances compared to those in the Group 1, 2A and 3 samples, indicating that the Group 5 samples were possibly derived from a source rock deposited in a less oxic/clay-rich environment. The $C_{29}Ts/C_{29}$ $\alpha\beta$ hopane ratio ranges from 0.15 to 0.22 and $C_{30}^*/C_{30}$ $\alpha\beta$ hopane from 0.02 to 0.05.

High abundances of $C_{31}$-$C_{34}$ 2$\alpha$-methylhopanes and relatively high abudances of $C_{31}$-$C_{33}$ 3$\beta$ methylhopanes are present in the Group 5 samples (Figure 93) probably indicating inputs of oxygen-producing cyanobacteria (Summons & Jahnke, 1990) and aerobic methanotrophic bacteria (Burhan et al., 2002; Farrimond et al., 2004).

Oleanane, a biomarker for angiosperm higher plants that radiated during the Middle Jurassic to Late Cretaceous or younger (Moldowan et al., 1994; Bell et al., 2005; Zheng & Wang, 2010), is present in high relative abundances in this group (oleanane/$C_{30}$ $\alpha\beta$ hopane = 0.79-0.9). The Group 5 samples also contain other oleanoid land-plant markers such as A-ring contracted oleanoids (de-A-oleanane (dO), de-A-lupane (dL) and de-A-ursane (dU)), bisnoroleanane and bisnorlupane (Figure 92) that evolved during the Late Cretaceous. Taraxastane is also present in the Group 5 samples and is a marker for organic matter from mangroves. This indicates that angiosperms (flowering land plants) had a significant contribution to the source rocks that generated the Sandy River soft bitumen.

Bicadinanes are present in high abundances in the Group 5 samples. They are likewise common biomarkers in Southeast Asian oils derived from Cenozoic fluvio-deltaic source rocks where they indicate inputs from the resins of Dipterocarp tropical hardwoods (van Aarssen et al., 1990). Their precursors also occur in non-tropical angiosperms (van Aarssen et al., 1994; Murray et al., 1994) which possibly accounts for their detection in low relative abundance in rock extracts of Jurassic age in the Eromanga Basin (Armanios et al., 1995), in oils attributed to Jurassic sources in the Perth Basin (Summons et al., 1995) and also in oils from Jurassic sources in the Gippsland Basin (George et al., 1998; Volk et al., 2010).

$C_{29}$ $\alpha\beta\beta$ steranes are more abundant than $C_{27}$ $\alpha\beta\beta$ steranes ($C_{29}/C_{27}$ $\alpha\beta\beta$ steranes = 1.8-3.59) indicating that the Group 5 samples were likely derived from source rocks with predominant higher plant inputs. 24-*n*-Propycholestane, a diagnostic marker for marine algal organic matter input

(Moldowan et al., 1990), is present in relatively low abundances in this group (Figure 94). The 4-methylsteranes, biomarkers for lacustrine dinoflagellates when in high abundances (Peters et al., 2005), are present in low abundances. Low sterane/hopane ratios (0.04-0.11) indicate terrigenous and/or microbially reworked organic matter inputs.

$C_{27}$ diasteranes are present in lower abundances than found in the samples of Groups 1, 2 and 3 with $C_{27}$ dia/(dia+reg) sterane ratios ranging from 0.27 to 0.44. This is consistent with lower abundances of rearranged hopanes and diahopane.

A doublet of late-eluting peaks identified as the tetracyclic polyprenoids Ta and Tb in the *m/z* 259 mass chromatogram, biomarkers for freshwater (lacustrine) algal input (Holba et al., 2000, 2003), are present in moderate abundances in all the Sandy River soft bitumens other than the Type IV waxy bitumen in this group (Figure 95).

In summary, the Sandy River soft bitumen samples in Group 5 were likely derived from source rocks deposited in a less sub-oxic depositional environment compared to Group 1,2A and 3 samples, with predominant terrestrial angiosperm higher plant inputs and some contributions from bacteria (Table 21).

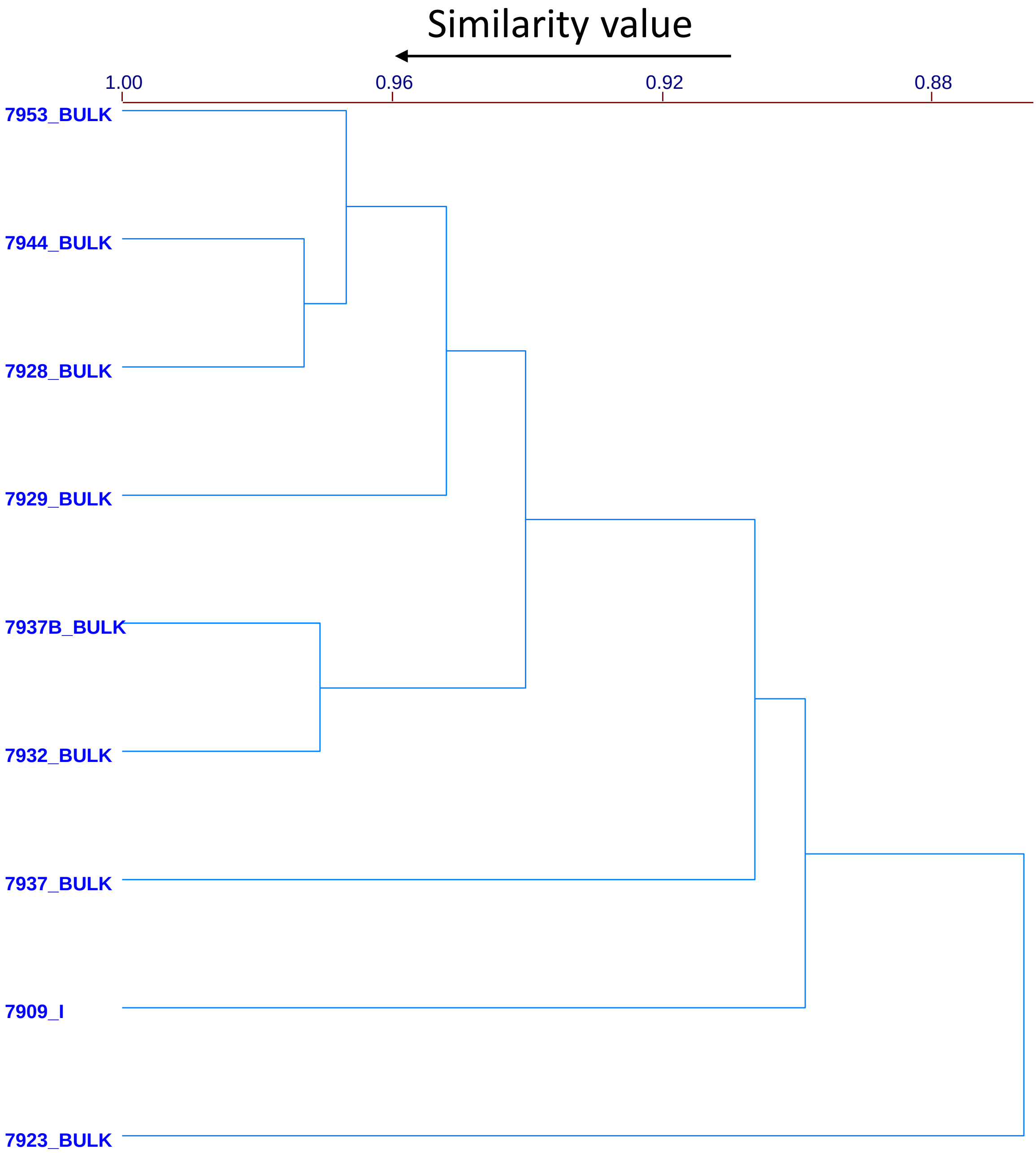


**Figure 91: Partial dendrogram of the hierarchical cluster analysis of Group 5 in Figure 70.**

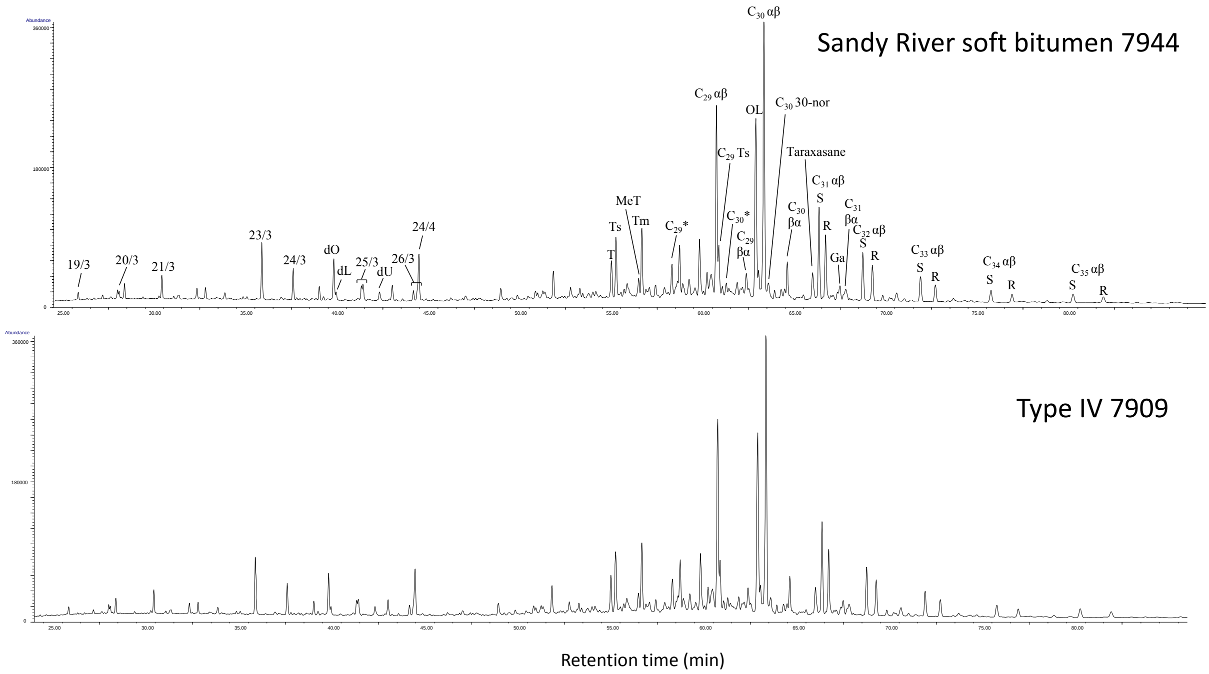


**Figure 92: Partial *m/z* 191 mass chromatograms of representative Sandy River soft bitumen (7944) and Type IV waxy bitumen (7909) in Group 5 showing the distribution of tricyclic terpanes and hopanes. For peak identifications refer to table 18.**

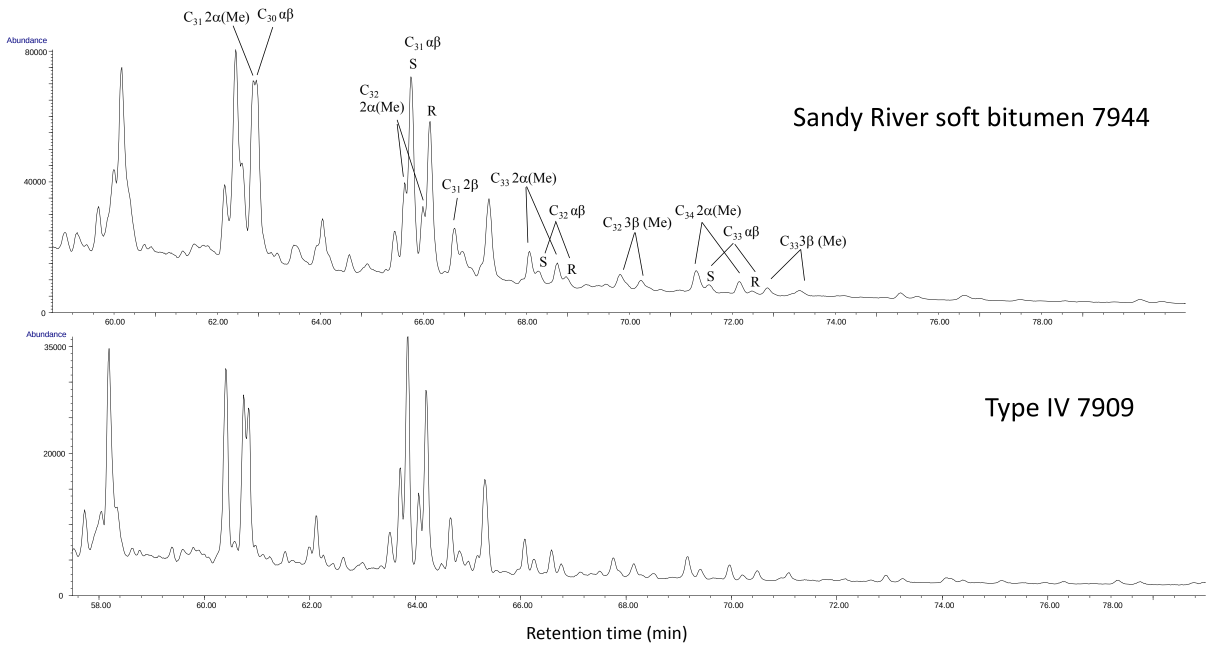


**Figure 93: Partial *m/z* 205 mass chromatograms of representative Sandy River soft bitumen (7944) and Type IV waxy bitumen (7909) in Group 5 showing the distribution of methylhopanes. For peak identifications refer to table 18.**

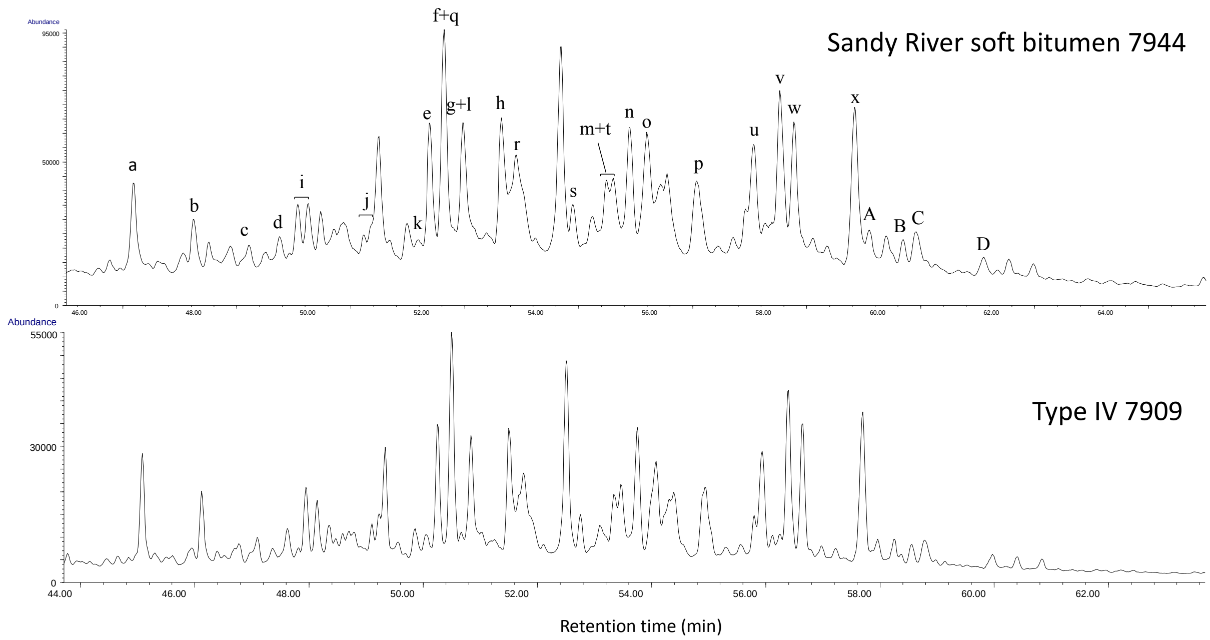


**Figure 94: Partial *m/z* 217 mass chromatograms of representative Sandy River soft bitumen (7944) and Type IV waxy bitumen (7909) in Group 5 showing the distribution of steranes and diasteranes. For peak identifications refer to table 19.**

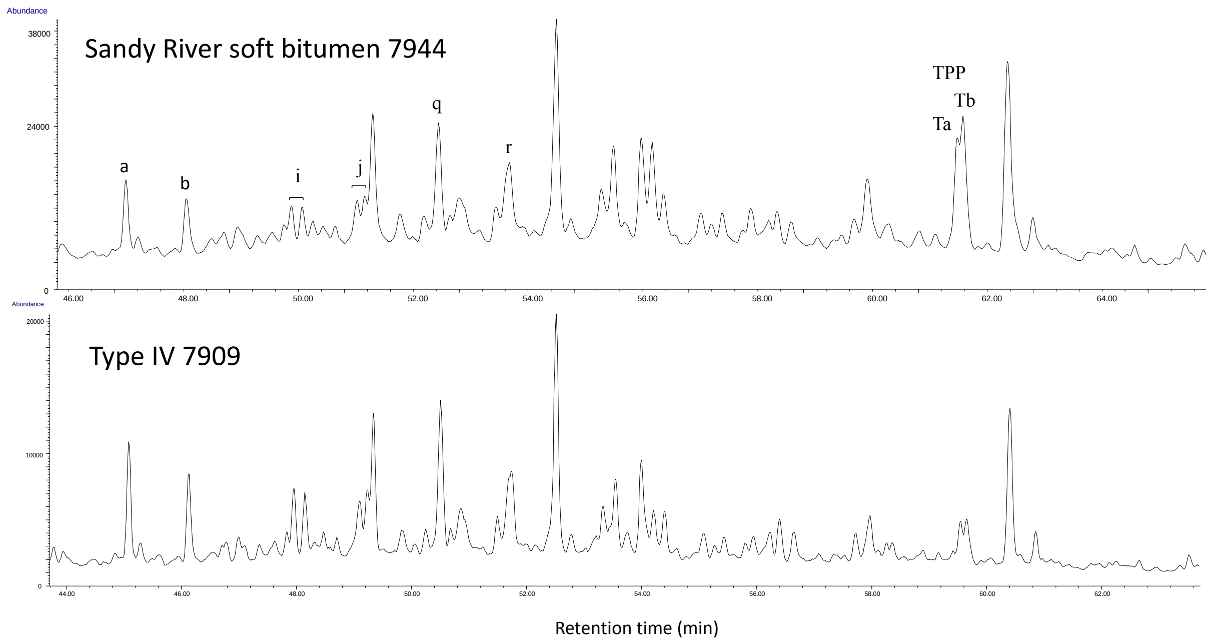


**Figure 95: Partial *m/z* 259 mass chromatograms of representative Sandy River soft bitumen (7944) and Type IV waxy bitumen (7909) in Group 5 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

### *Group 6*

Group 6 consists of two sub-groups (Groups 6A and 6B) with a similarity value of 0.65 (Figure 96). Group 6A includes three Type I waxy bitumen samples and Group 6B includes three Type III waxy bitumen samples. The Type I waxy bitumens contain high abundances of botryococcane, whereas the Type III waxy bitumens contain no botryococcane.

Tricyclic terpanes in the Group 6 samples are in low abundances relative to hopanes (Figure 97) with $C_{23}$ tricyclic terpane/$C_{30}$ $\alpha\beta$ hopane ratio ranging from 0.02 to 0.13. The $C_{24}$ tetracyclic terpane, a biomarker for carbonate or evaporite source rock settings (Connan et al., 1986; Connan & Dessort, 1987; Mann et al., 1987; Clark & Philp, 1989) and in rare instances for terrigenous organic matter (Philp & Gilbert, 1986), is present in low relative abundance in the Group 6A samples ($C_{24}$ tetracyclic/$C_{26}$ triclcyclic terpane = 0.5 to 0.67) except for one Type I sample (1.63). It is consistently more abundant in the Group 6B samples where $C_{24}$ tetracyclic/$C_{26}$ tricyclic terpane values range from 1.03 to 2.49. Extended tricyclic terpanes are not present in the Group 6 samples.

$C_{30}$ $\alpha\beta$ hopane is the dominant compound in the *m/z* 191 chromatograms (Figure 97) with $C_{29}/C_{30}$ $\alpha\beta$ hopane ranging from 0.5 to 0.61, indicating that the potential source rocks for the Group 6 samples are not calcareous. Rearranged hopanes ($C_{29}$Ts) and diahopane ($C_{30}$*) are present in high abundances in the Group 6A samples ($C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane = 0.31-0.37 and $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane = 0.19-0.31) but in low abundances in the Group 6B samples ($C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane = 0.12-0.15 and $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane = 0.06-0.07), indicating that the Group 6A samples were possibly derived from source rocks deposited in a less oxic/clay-rich environment (Moldowan et al., 1991; Peters et al., 2005) than was the case for the Group 1, 2A, 3 and 6B samples.

Relatively high abundances of $C_{31}$-$C_{34}$ $2\alpha$-methylhopanes and $C_{31}$-$C_{33}$ $3\beta$ methylhopanes in the samples of Group 6 (Figure 98) probably indicate inputs of oxygen-producing cyanobacteria (Summons & Jahnke, 1990) and aerobic methanotrophic bacteria to the source rock (Burhan et al., 2002; Farrimond et al., 2004).

Oleanane, a biomarker for angiosperm higher plants that radiated during the Middle Jurassic to Late Cretaceous or younger (Moldowan et al., 1994; Bell et al., 2005; Zheng & Wang, 2010), is present in low relative abundance in the Group 6A samples (oleanane/$C_{30}$ $\alpha\beta$ hopane = 0.08 to 0.18) but in high relative abundance in the Group 6B samples (oleanane/$C_{30}$ $\alpha\beta$ hopane = 0.75 to 0.86). A-ring contracted oleanoids such as de-A-oleanane (dO), de-A-lupane (dL) and de-A-ursane (dU) (Figure 97) which are biomarkers for angiosperm plants that evolved during the Upper Cretaceous, are also present in relatively low abundances in the Group 6A samples but in relatively high abundances in the Group 6B samples. Taraxastane, a marker for organic matter from mangroves, is present in relatively higher abundances in the Group 6B samples than in the Group 6A samples. This indicates that angiosperms (flowering land plants) made a significant contribution to the source rocks that generated the Group 6B samples.

Bicadinanes are present in all Group 6 samples, with higher relative abundances observed in the Group 6B samples. Bicadinanes are common biomarkers in Southeast Asian oils with Cenozoic fluvio-deltaic source rocks where they indicate inputs from resins of Dipterocarp tropical hardwood trees (van Aarssen et al., 1990). An alternative source of these biomarkers is non-tropical angiosperms (van Aarssen et al., 1994; Murray et al., 1994)

$C_{29}$ $\alpha\beta\beta$ steranes are more abundant than $C_{27}$ $\alpha\beta\beta$ steranes ($C_{29}/C_{27}$ $\alpha\beta\beta$ steranes = 1.8-3.59) indicating that the Group 6 samples were likely derived from source rocks with predominant higher plant inputs. 24-*n*-Propycholestane, a diagnostic marker for marine algal organic matter (Moldowan

et al., 1990), is absent from the Group 6 samples, while 4-methylsteranes, biomarkers for lacustrine dinoflagellates when abundant (Peters et al., 2005), are present in high abundances in the Group 6A samples but in very low relative abundances in the Group 6B samples. Low sterane/hopane ratios (0.03-0.11) indicate terrigenous and/or microbially reworked organic matter.

$C_{27}$ diasteranes are less abundant in the Group 6 samples than in the Group 1, 2A and 3 samples, with $C_{27}$ dia/(dia+reg) sterane ratios ranging from 0.27 to 0.44. This is consistent with low relative abundances of rearranged hopanes and diahopane in the Group 6B samples.

A doublet of late-eluting peaks identified as the tetracyclic polyprenoids Ta and Tb in the m/z 259 mass chromatogram, biomarkers for freshwater (lacustrine) algal input (Holba et al., 2000, 2003), are present in high relative abundances in the Group 6A samples but in low relative abundances in the Group 6B samples (Figure 100).

In summary, the Group 6A samples were likely derived from lacustrine shale deposited in a sub-oxic depositional environment with mixed algal, terrestrial higher plant and bacterial inputs (Table 22). The Group 6B samples were possibly derived from source rocks deposited in a less sub-oxic depositional environment compared to the Group 6A samples, with significant terrestrial angiosperm higher plant and bacteria inputs (Table 22).

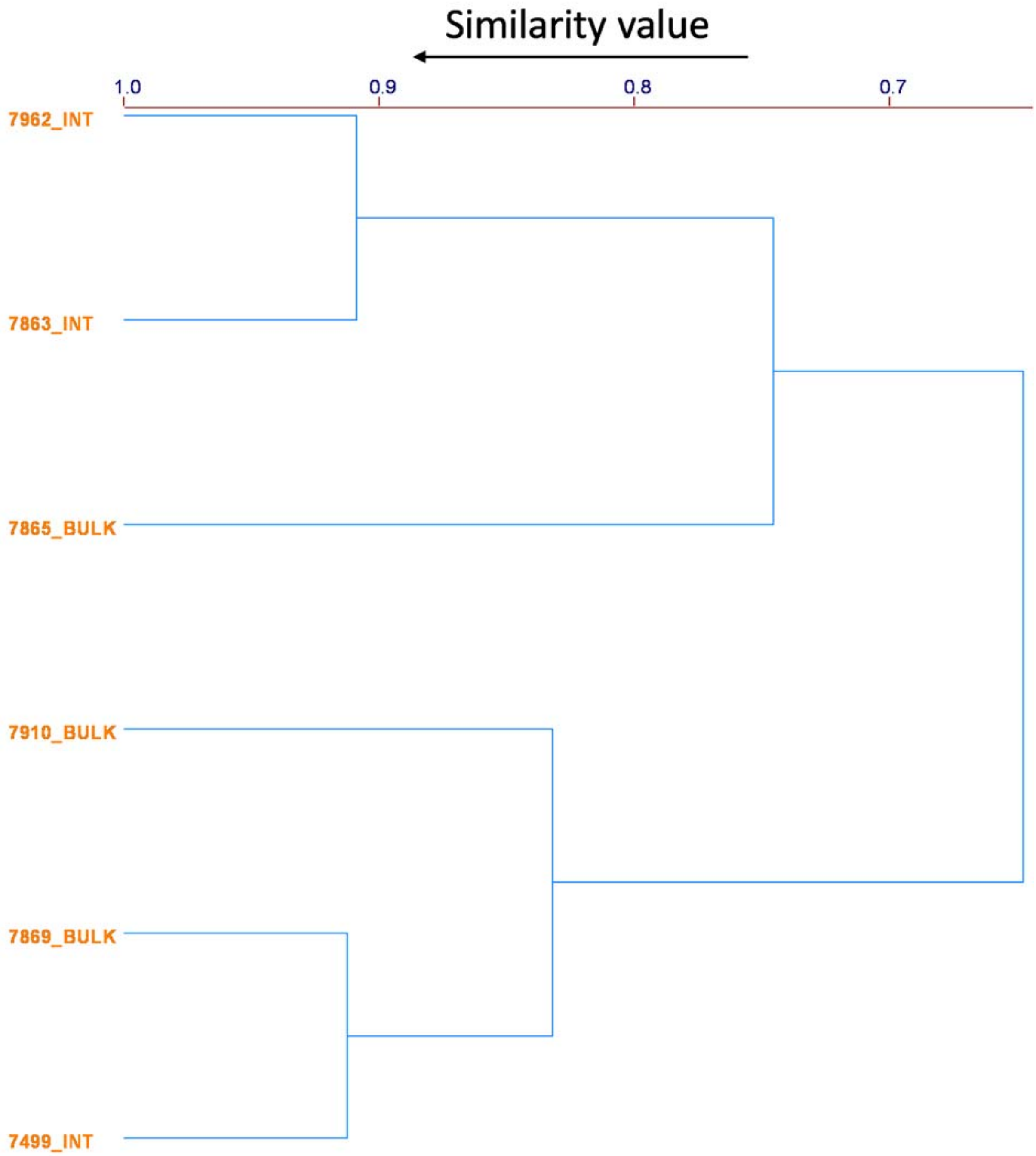


**Figure 96: Partial dendrogram of the hierarchical cluster analysis of Group 6 in Figure 70.**

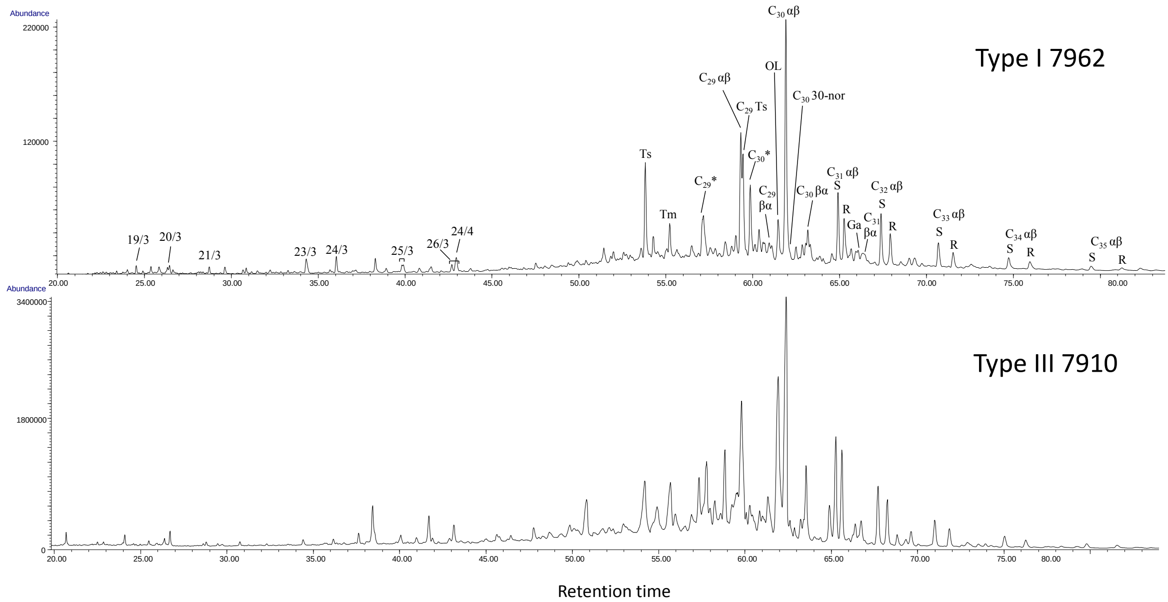


**Figure 97: Partial *m/z* 191 mass chromatograms of representative Type I (7962) and Type III waxy bitumen (7910) in Group 6 showing the distribution of tricyclic terpanes and hopanes. For peak identifications refer to table 18.**

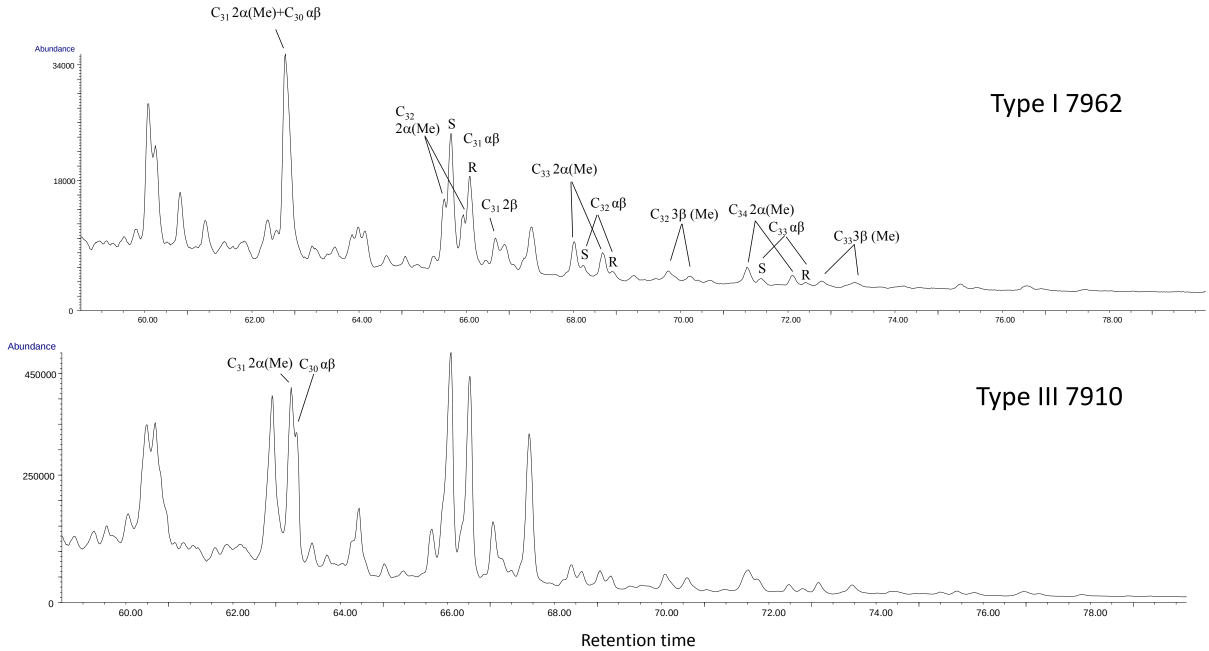


**Figure 98: Partial *m/z* 205 mass chromatograms of representative Type I (7962) and Type III waxy bitumen (7910) in Group 6 showing the distribution of methylhopanes. For peak identifications refer to table 18.**

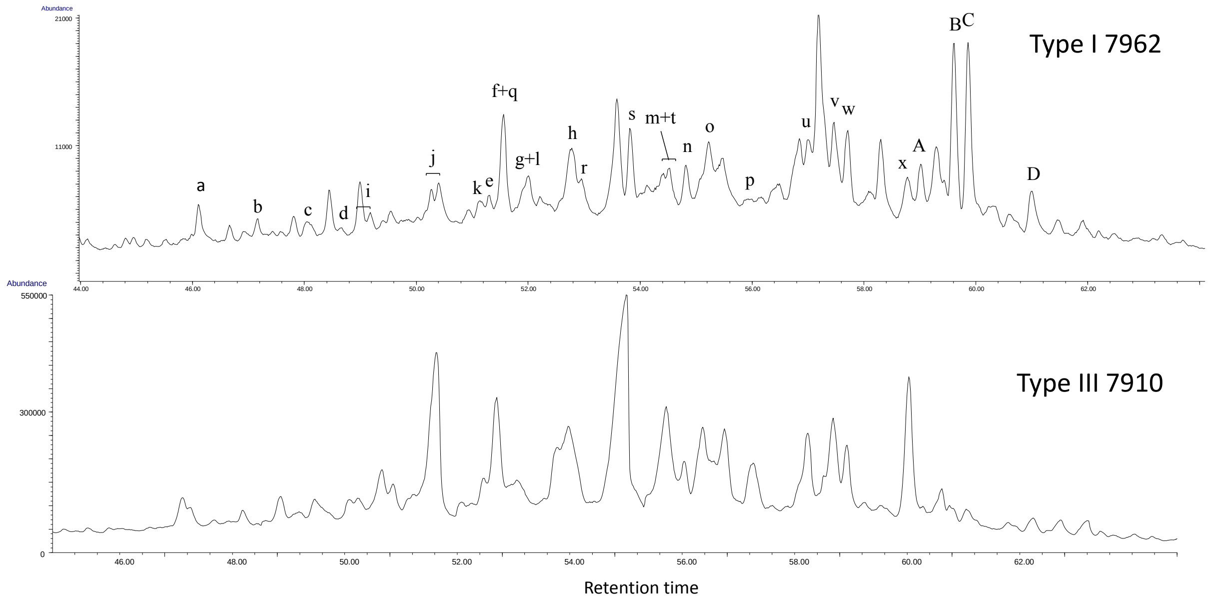


**Figure 99: Partial *m/z* 217 mass chromatograms of representative Type I (7962) and Type III waxy bitumen (7910) in Group 6 showing the distribution of steranes and diasteranes. For peak identifications refer to table 19.**

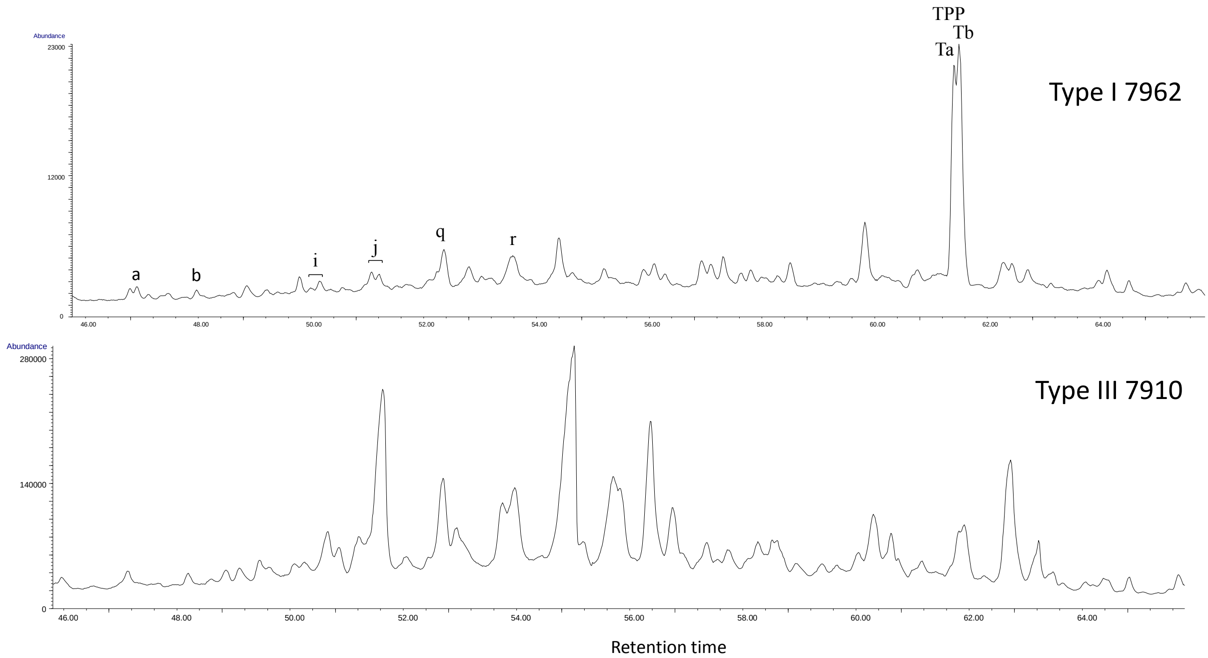


**Figure 100: Partial *m/z* 259 mass chromatograms of representative Type I (7962) and Type III waxy bitumen (7910) in Group 6 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

### *Group 7*

Group 7 consists of six degraded asphaltites with a similarity value of 0.9 (Figure 101). The samples in this group contain no botryococcane.

Tricyclic terpanes are present in extremely low abundances relative to hopanes (Figure 102) with $C_{23}$ tricyclic terpane/ $C_{30}$ $\alpha\beta$ hopane ratios ranging from 0 to 0.01. The $C_{24}$ tetracyclic terpane, a biomarker for carbonate or evaporite depositional environment, is much more abundant than the $C_{26}$ tricyclic terpane (Figure 102), with $C_{24}$ tetracyclic/$C_{26}$ tricyclic ratios ranging from 4.34 to 7.93. Overall, the relative abundance of $C_{24}$ tetracyclic terpane in the Group 7 samples is the highest among all the groups. $C_{26}/C_{25}$ tricyclic terpane ratios range from 1.27 to 1.87, indicating lacustrine source rocks (Peters et al., 2005). Extended tricyclic terpanes ($C_{28}$-$C_{36}$) are not present in these samples.

$C_{29}$ $\alpha\beta$ hopane is equivalent to $C_{30}$ $\alpha\beta$ hopane in relative abundance (Figure 102) with $C_{29}/C_{30}$ $\alpha\beta$ hopane ratios ranging from 0.99 to 1.03. The $C_{35}$ homohopanes slightly exceed the $C_{34}$ homohopanes in this group with $C_{35}/C_{34}$ homohopane values ranging from 1 to 1.08. High values of $C_{29}/C_{30}$ $\alpha\beta$ hopane (>1) and $C_{35}$/ $C_{34}$ homohopane (>1) indicate a derivation from marine carbonate and evaporite lithofacies deposited under highly reducing conditions (Peters et al., 2005).

Rearranged hopanes ($C_{29}$Ts) and diahopane ($C_{30}$*) are present in much lower relative abundances than in the Group 1, 2A and 3 samples, indicating that the Group 7 samples were possibly derived from source rock(s) with a lower clay content and less oxic depositional l environment. $C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane ranges from 0.04 to 0.09 and $C_{30}$*/$C_{30}$ $\alpha\beta$ hopane ranges from 0.01 to 0.02.

High relative abundances of $C_{31}$-$C_{34}$ 2$\alpha$-methylhopanes and relatively high abudances of $C_{31}$-$C_{33}$ 3$\beta$–methylhopanes present in the Group 7 samples (Figure 103) probably indicate inputs of oxygen-producing cyanobacteria (Summons & Jahnke, 1990) and aerobic methanotrophic bacteria (Burhan et al., 2002; Farrimond et al., 2004) to their source rocks.

Oleanane, a biomarker for angiosperm higher plants (Moldowan et al., 1994; Bell et al., 2005; Zheng & Wang, 2010), is in present in the Group 7 samples but only in trace abundances (oleanane/$C_{30}$ $\alpha\beta$ hopane from 0.01 to 0.02).

Bicadinanes, biomarkers derived from Dipterocarp tropical hardwood trees (van Aarssen et al., 1990), are not present in the Group 7 samples.

$C_{29}$ $\alpha\beta\beta$ steranes are more abundant than $C_{27}$ $\alpha\beta\beta$ steranes ($C_{29}/C_{27}$ $\alpha\beta\beta$ steranes = 2.54 to 2.97) indicating that the Group 7 samples were likely derived from source rocks with predominant higher plant inputs. 24-*n*-Propycholestane, a diagnostic marker for marine algae (Moldowan et al., 1990), is present in low abundances in this group (Figure 104). Likewise, 4-methylsteranes, biomarkers for lacustrine dinoflagellate algae when abundant, are also present in low abundances in the Group 7 samples. Low sterane/hopane ratios (0.05 to 0.07) indicate terrigenous or microbially reworked organic matter inputs to the source rock.

$C_{27}$ diasteranes are present in lower relative abundances than in the Group 1, 2A and 3 samples with $C_{27}$ dia/(dia+reg) sterane ratios ranging from 0.16 to 0.18. This is consistent with lower relative abundances of rearranged hopanes and diahopane.

A doublet of late-eluting peaks identified as the tetracyclic polyprenoids Ta and Tb in the m/z 259 mass chromatogram, biomarkers for freshwater (lacustrine) algal input (Holba et al., 2000, 2003), are present in relatively high abundances in all the Group 7 samples (Figure 105).

In summary, degraded asphaltite samples in the Group 7 were likely derived from a marine carbonate source rock deposited in an anoxic depositional environment with mixed algal, higher plant and bacterial inputs (Table 22).

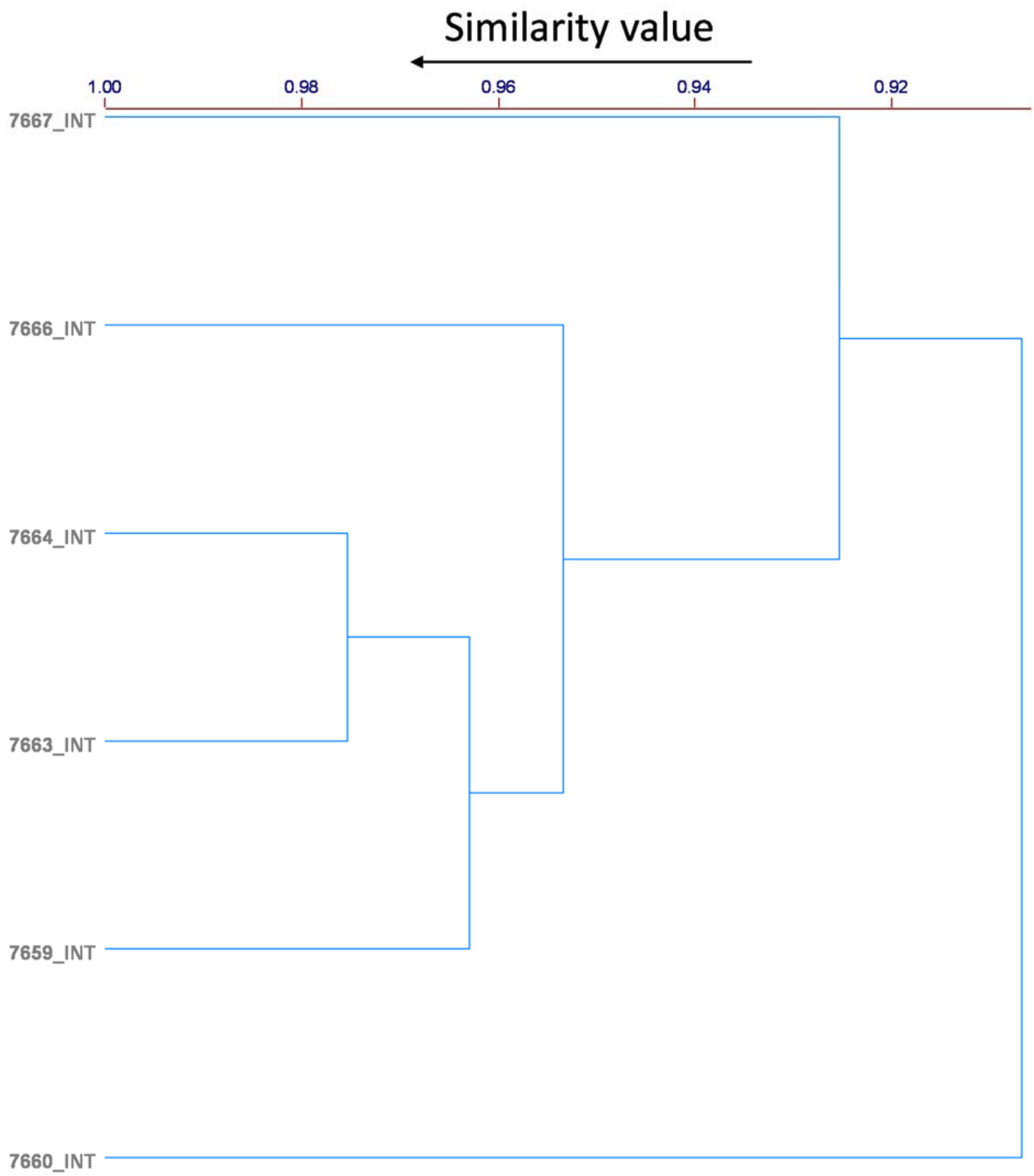


**Figure 101: Partial dendrogram of the hierarchical cluster analysis of Group 7 in Figure 70.**

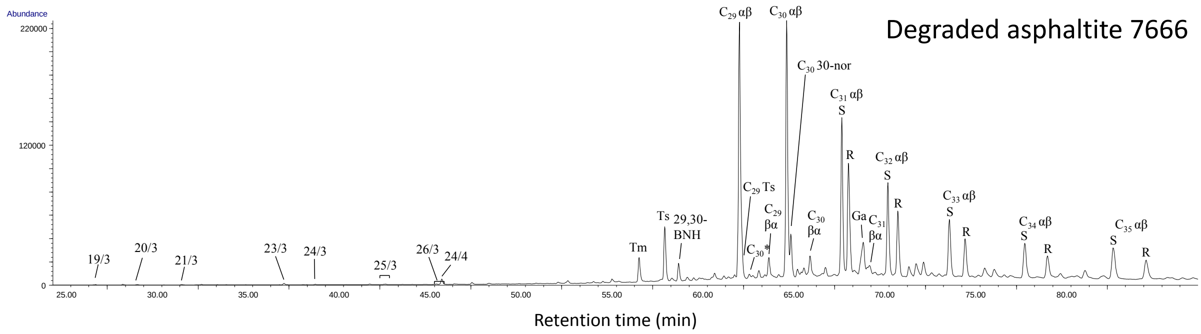


**Figure 102: Partial *m/z* 191 mass chromatograms of representative degraded asphaltite (7666) in Group 7 showing the distribution of tricyclic terpanes and hopanes. For peak identifications refer to table 18.**

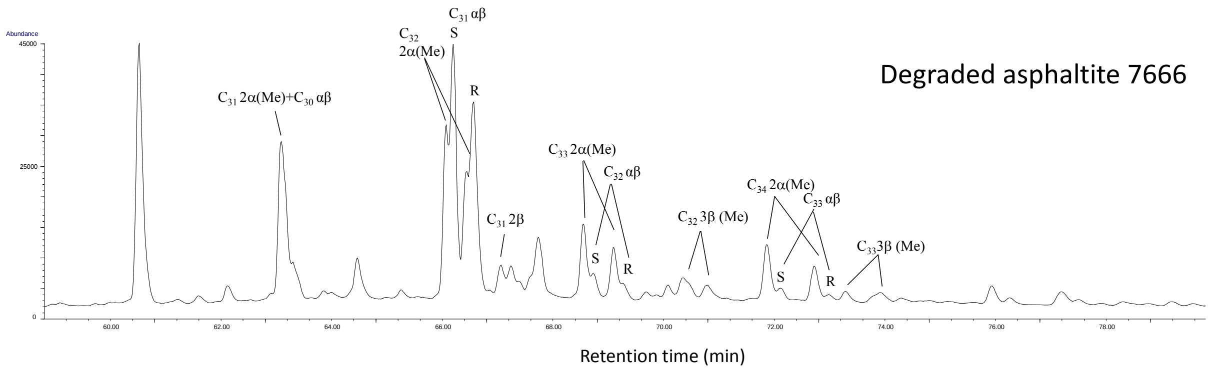


**Figure 103: Partial *m/z* 205 mass chromatograms of representative degraded asphaltite (7666) in Group 7 showing the distribution of methylhopanes. For peak identifications refer to table 18.**

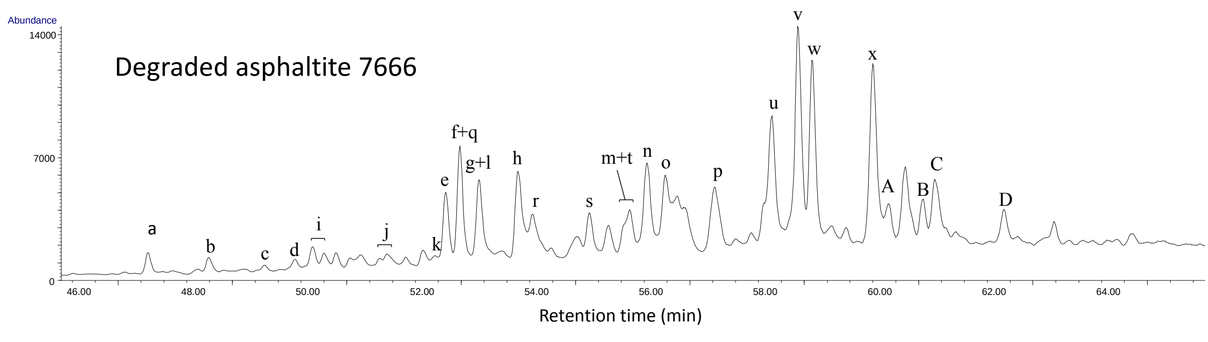


**Figure 104: Partial *m/z* 217 mass chromatograms of representative degraded asphaltite (7666) in Group 7 showing the distribution of steranes and diasteranes. For peak identifications refer to table 19.**

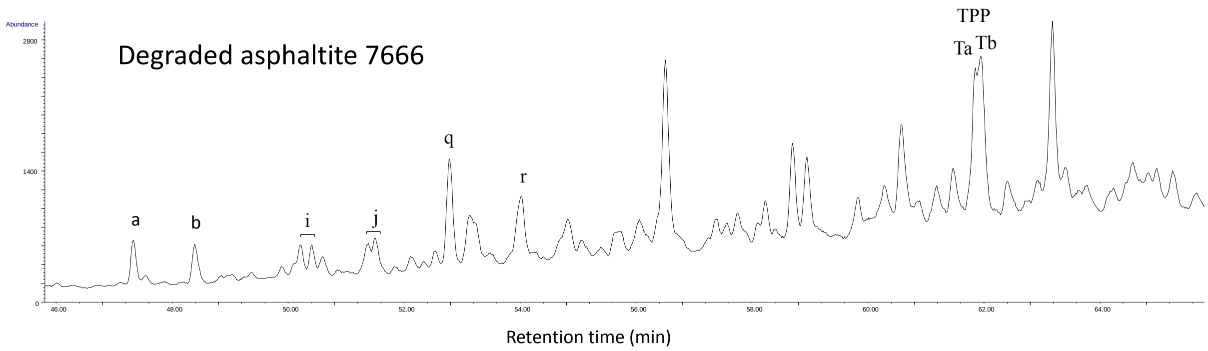


**Figure 105: Partial *m/z* 259 mass chromatograms of representative degraded asphaltite (7666) in Group 7 showing the distribution of diasteranes and tetracyclic polyprenoids. For peak identifications refer to table 19.**

**Table 20: Summary of potential source rocks of the Group 1, 2 3 bitumens and their biomarker indicators.**

| GROUPS | POTENTIAL SOURCE ROCKS | INDICATORS |
|---|---|---|
| Group 1 | Lacustrine shale deposited in a sub-oxic depositional environment with significant lacustrine algal and bacteria inputs and minor contribution from terrestrial angiospern higher plants | High abudances of 4-methylsteranes |
| | | Absence of 24-*n*-propycholestanes |
| | | High abudances of rearranged hopanes, diahopane and diasteranes |
| | | High abundances of botryococcane |
| | | High abundances of tetracyclic polyprenoids |
| | | High $C_{26}/C_{25}$ tricyclic terpanes |
| | | Low abundance of oleanane |
| | | Relatively higher abundances of $C_{27}$ steranes |
| | | Presence of bicadinanes in low to moderate abundances |
| | | High abundances of 2a-methylhopanes |
| Group 2A | Marine shale deposited in a sub-oxic depositional environment with mixed marine algal, lacustrine organic matter and bacteria inputs with minor contribution from terrestrial angiosperm higher plants | Presence of 24-*n*-propycholestanes |
| | | Trace abundances of 4-methylsteranes |
| | | High abudances of rearranged hopanes, diahopane and diasteranes |
| | | High abundances of tetracyclic polyprenoids |
| | | High $C_{26}/C_{25}$ tricyclic terpanes |
| | | Low abundance of oleanane |
| | | Equivalent abundances of $C_{27}$ to $C_{29}$ steranes |
| | | Presence of bicadinanes in low abundances |
| | | High abundances of 2a-methylhopanes |
| | | Absence of botryococcane |
| Group 2B and 2C | Lacustrine source rock deposted in a less sub-oxic depositional environment compared to the Group 1 and 2A samples, with significant lacustrine organic matter input and minor contributions from | Presence of 4-methylsteranes |
| | | Absence of 24-*n*-propycholestanes |
| | | Relatively low abundances of rearranged hopanes and diahopane |
| | | Moderate abundances of diasteranes |
| | | High abundances of tetracyclic polyprenoids |

| Groups | Potential source rocks | Indicators |
|---|---|---|
| | terrestrial angiosperm higher plants and bacteria | High $C_{26}/C_{25}$ tricyclic terpanes |
| | | Low abundance of oleanane |
| | | Equivalent or higher abundances of $C_{29}$ to $C_{27}$ steranes |
| | | Presence of bicadinanes in low abundances |
| | | Moderate abundances of 2a-methylhopanes |
| | | Absence of botryococcane |
| Group 3 | Clay-rich source rocks depostied in a sub-oxic depostioinal environment with mixed marine and lacustrine organic matter inputs | Absence of 24-*n*-propycholestanes and 4-methylsteranes |
| | | High abudances of rearranged hopanes, diahopane and diasteranes |
| | | High $C_{26}/C_{25}$ tricyclic terpanes |
| | | High sterane/hopane ratio (>1) |
| | | Presence of oleanane in trace abundances |
| | | Equivalent abundances of $C_{29}$ to $C_{27}$ steranes |
| | | Absence of 2a-methylhopanes |
| | | Low abundances of tetracyclic polyprenoids |
| | | Absence of botryococcane |

**Table 21: Summary of potential source rocks of the Group 4 and 5 bitumens and their biomarker indicators.**

| Groups | Potential source rocks | Indicators |
|---|---|---|
| Group 4A | Marine source rocks deposited in a less sub-oxic depostional environment compared to the Group 1, 2A and 3 samples, with significant marine organic matter input with minor contributions from terrestrial higher plants | Presence of 24-*n*-propycholestanes and 4-methylsteranes |
| | | Low abudances of rearranged hopanes, diahopane and diasteranes |
| | | Low $C_{26}/C_{25}$ tricyclic terpanes |
| | | Trace abundance or absence of oleanane |
| | | Equivalent abundances of $C_{29}$ to $C_{27}$ steranes |
| | | Very low abundances of 2a-methylhopanes |
| | | Low abundances of tetracyclic polyprenoids |
| | | Absence of botryococcane |
| Group 4B | Carbonate deposited in an anoxic depositional environment with significant terretrial higher plant inputs and some contributions from bacteria. | Low abundances of rearranged hopanes, diahopane and diasteranes |
| | | High $C_{29}/C_{30}$ ab hopane (1.1) |
| | | High $C_{35}/C_{34}$ homohopanes (1.07) |
| | | Low $C_{26}/C_{25}$ tricyclic terpanes |
| | | Trace or low abundance of oleanane |
| | | High abudances of $C_{29}$ steranes |
| | | High abudance of $C_{24}$ tetracyclic terpane |
| | | Absence of botryococcane |
| | | High abundances of 2a-methylhopanes |
| Group 4C | Marine calcareous source rocks deposited in an anoxic depositional environment with significant terretrial higher plant | Presence of 24-*n*-propycholestanes |
| | | Presence of 4-methylsteranes |
| | | Low abudances of rearranged hopanes, diahopane and diasteranes |

| Groups | Potential source rocks | Indicators |
|---|---|---|
| | inputs and minor contributions from bacteria. | Relatively high $C_{29}/C_{30}$ ab hopane (0.73-0.82) |
| | | High $C_{35}/C_{34}$ homohopanes (1-1.04) |
| | | Low $C_{26}/C_{25}$ tricyclic terpanes |
| | | Trace or low abundance of oleanane |
| | | High abudances of $C_{29}$ steranes |
| | | High abudance of $C_{24}$ tetracyclic terpane |
| | | Absence of botryococcane |
| | | Moderate abundances of 2a-methylhopanes |
| Group 4D | Marine carbonate deposited in an anoxic depositional environment with significant terretrial higher plant and bacteria inputs and minor contributions from lacustrine organic matter. | Presence of 24-*n*-propycholestanes |
| | | High abundances of 4-methylsteranes |
| | | Low abudances of rearranged hopanes, diahopane and diasteranes |
| | | High $C_{29}/C_{30}$ ab hopane (0.9-1.15) |
| | | High $C_{35}/C_{34}$ homohopanes (0.9-1.0) |
| | | Low $C_{26}/C_{25}$ tricyclic terpanes |
| | | Low abundance of oleanane |
| | | High abudances of $C_{29}$ steranes |
| | | High abudance of $C_{24}$ tetracyclic terpane |
| | | Low abundances of bicadinanes |
| | | Low abundance of botryococcane |
| | | High abundances of 2a-methylhopanes |
| Group 5 | Source rocks deposited in a less sub-oxic depostional environment compared to the Group 1, 2A and 3 samples, with significant terrestrial angiosperm higher plant inputs and some contributions from bacteria | Presence of 24-*n*-propycholestanes in very low abundances |
| | | Presence of 4-methylsteranes in low abundances |
| | | Low abudances of rearranged hopanes, diahopane and diasteranes |
| | | High abundance of oleanane, bisnoroleanane and bisnorlupane |
| | | Relatively high abundances of A-ring contracted oleanoids |
| | | Presence of taraxastane |
| | | High abundances of bicadinane |
| | | High abudances of $C_{29}$ steranes |
| | | High abundances of 2a-methylhopanes |
| | | Absence of botryococcane |

**Table 22: Summary of potential source rocks of the Group 6 and 7 bitumens and their biomarker indicators.**

| Groups | Potential source rocks | Indicators |
|---|---|---|
| Group 6A | Lacustrine shale deposited in a sub-oxic depostional envrionment with mixed lacustrine algal, terrestiral angiosperm higher plant and bacteria inputs | High abundances of 4-methylsteranes |
| | | Absence of 24-*n*-propycholestanes |
| | | High abudances of rearranged hopanes and diahopane |
| | | Low abundances of diasteranes |

| GROUPS | POTENTIAL SOURCE ROCKS | INDICATORS |
|---|---|---|
| | | High abundance of botryococcane |
| | | High abundance of oleanane |
| | | Low abundances of bicadinanes |
| | | High abudances of $C_{29}$ steranes |
| | | High abundances of tetracyclic polyprenoids |
| | | High abundances of 2a-methylhopanes |
| Group 6B | Source rocks depostied in a less sub-oxic depositional environment compared to the Group 6A samples, with significant terrestrial angiosperm higher plant and bacteria inputs | Presence of 4-methylsteranes in very low abundances |
| | | Absence of 24-*n*-propycholestanes |
| | | Low abudances of rearranged hopanes and diahopane |
| | | High abundance of oleanane |
| | | High abudance of $C_{24}$ tetracyclic terpane |
| | | High abundances of bicadinanes |
| | | High abudances of $C_{29}$ steranes |
| | | Low abundances of tetracyclic polyprenoids |
| | | High abundances of 2a-methylhopanes |
| | | Absence of botryococcane |
| Group 7 | Marine carbonate deposited in an anoxic depositional envirnment with mixed terrestrial higher plant and lacustrine organic mater and bacteria inputs | Presence of 24-*n*-propycholestanes in low abundances |
| | | Presence of 4-methylsteranes in low abundances |
| | | Low abudances of rearranged hopanes and diahopane |
| | | High $C_{29}/C_{30}$ ab hopane (0.99-1.03) |
| | | High $C_{35}/C_{34}$ homohopanes (1-1.08) |
| | | High $C_{26}/C_{25}$ tricyclic terpanes |
| | | Trace abundance of oleanane |
| | | High abudance of $C_{24}$ tetracyclic terpane |
| | | High abudances of $C_{29}$ steranes |
| | | Moderate abundances of tetracyclic polyprenoids |
| | | High abundances of 2a-methylhopanes |
| | | Absence of botryococcane |

## Comparison with fluid inclusion oils

To geochemically fingerprint their hydrocarbons, the minute quantities of oil extracted from the fluid inclusions in two exploration wells from the Bight Basin were analysed using the *Molecular Composition of oil Inclusions (MCI)* protocol. Fluid inclusion (FI) oil from Gnarlyknots-1A (4,390 to 4,425 mMD; Tiger Supersequence) shows a mixed organic matter input from both algae and terrestrial plants and was generated from source rock(s) deposited in a sub-oxic depositional environment. The Gnarlyknots-1A FI oil suggests either a mixture of oil charges generated from different source rocks – the Blue Whale and Tiger source units having potential marine algal inputs and the White Pointer a potential terrestrial plant input – or from the same source rock at different maturity stages, perhaps an unrecognised paralic facies of the White Pointer containing both algal and terrestrial organic matter.

FI oil from Greenly-1 (4,806-4,818 mMD; White Pointer Supersequence) indicates significant organic matter input from terrestrial plants with a minor contribution from bacteria, and generation from a source rock deposited in an oxic, clay-rich fluvio/deltaic environment. Previous suggestions that these oil indications correlate to a Bronze Whaler source sequence are not supported by the MCI data, which lacks algal input and potentially indicates a White Pointer source sequence instead.

The comparison of the Gnarlyknots-1A and Greenly-1 oils with naturally stranded asphaltites and waxy bitumens along the South Australian coast, was assessed here by hierarchical cluster analysis (HCA) of 29 source variables derived from the molecular distribution of hopanes and steranes (Figure 106). The Greenly-1 FI oil plots in Group 6 and is closely related to the Type III waxy bitumen samples of Group 6B with a similarity value of 0.77 (Figure 107). The Gnarlyknots-1A FI oil plots in Group 4 and is closely related to the Group 4B samples with a similarity value of 0.71 (Figure 108).

Based on this multivariate statistical analysis, some of the collected waxy bitumen samples and the FI oils appear to have similar source facies. However, these source facies could be from anywhere, which does not exclude a local source since these waxy bitumen samples do not contain botryococcane.

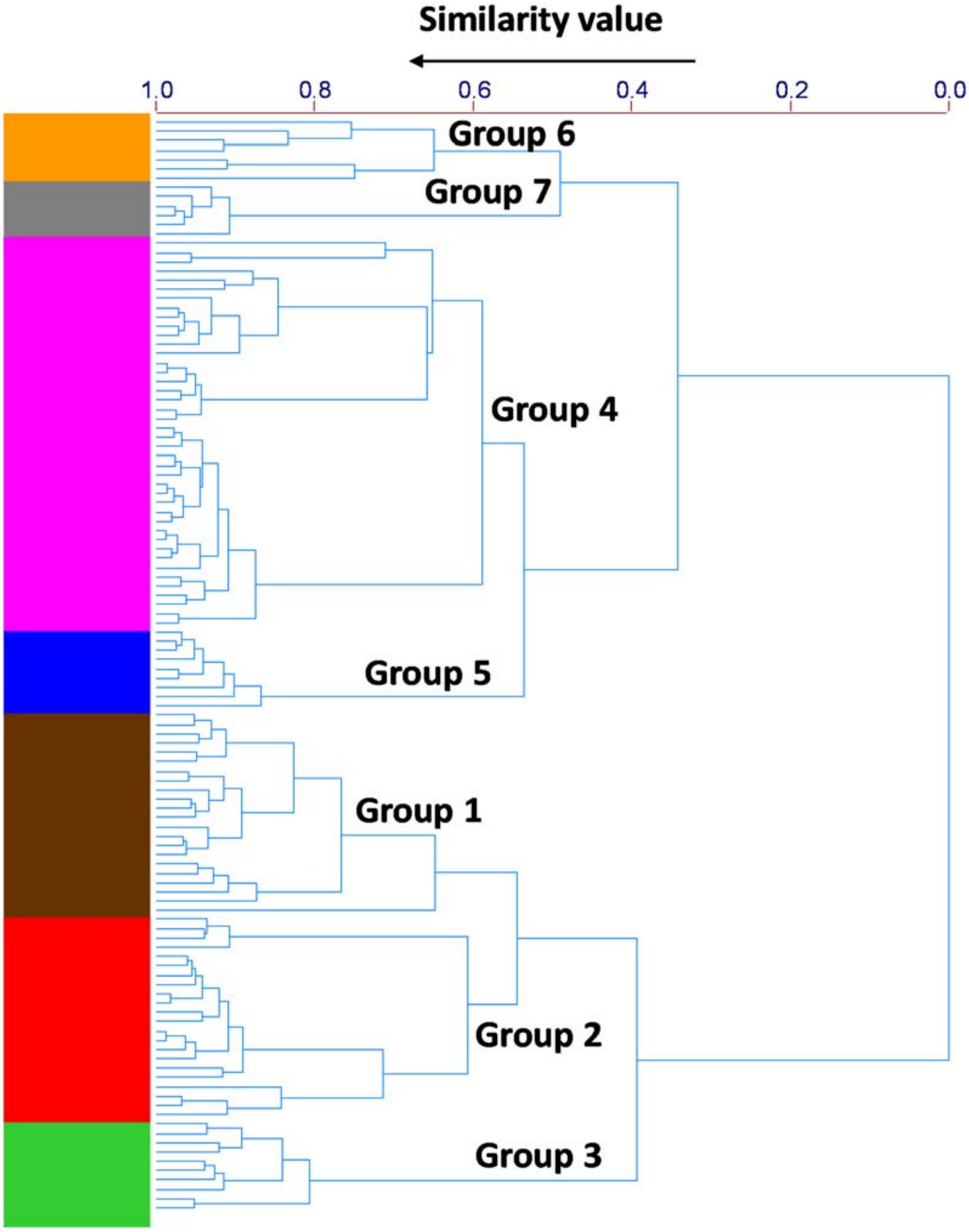


**Figure 106: Dendrogram of the hierarchical cluster analysis (HCA) of 29 source variables showing the relationship between asphaltite, waxy bitumen samples and FI oils. The groups are the same as those in Figure 70.**

The source variables used for calculation of Euclidean distance (autoscale preprocessing, incremental linkage) are: **1**. $C_{19}/C_{23}$ tricyclic terpanes, **2**. $C_{22}/C_{21}$ tricyclic terpanes, **3**. $C_{22}/C_{24}$ tricyclic terpanes, **4**. $C_{24}/C_{23}$ tricyclic terpanes, **5**. $C_{26}/C_{25}$ tricyclic terpanes, **6**. $C_{24}$ tetracyclic/$C_{23}$ tricyclic terpanes, **7**. $C_{24}$ tetracyclic/$C_{26}$ tricyclic terpanes, **8**. $C_{23}$ tricyclic terpanes/ $C_{30}$ $\alpha\beta$ hopane, **9**. $C_{24}$ tetracyclic terpane/ $C_{30}$ $\alpha\beta$ hopane, **10**. $C_{24}$ bisnorhopane/ $C_{30}$ $\alpha\beta$ hopane, **11**. $C_{29}$ $\alpha\beta$ hopane/$C_{30}$ $\alpha\beta$ hopane, **12**. $C_{30}$* hopane/$C_{30}$ $\alpha\beta$ hopane, **13**. Oleanane/$C_{30}$ $\alpha\beta$ hopane, **14**. $C_{30}$-nor hopane/$C_{30}$ $\alpha\beta$ hopane, **15**. Ga/$C_{30}$ $\alpha\beta$ hopane, **16**. Ga/$C_{31}$ $\alpha\beta$ hopane R, **17**. $C_{35}$ $\alpha\beta$ hopane S/$C_{34}$ $\alpha\beta$ hopane S, **18**. $C_{35}$ homohopane Index, **19**. $C_{29}$Ts/$C_{29}$ $\alpha\beta$ hopane, **20**. $C_{27}$ $\alpha\alpha\alpha$ steranes 20 *R* (%), **21**. $C_{28}$ $\alpha\alpha\alpha$ steranes 20 *R* (%), **22**. $C_{29}$ $\alpha\alpha\alpha$ steranes 20 *R* (%), **23**. $C_{27}$ diasteranes/ (diasteranes+steranes), **24.** $C_{27}$ diasteranes/ steranes, **25.** $C_{27}$ $\alpha\beta\beta$ steranes 20 *S*+*R* (%), **26**. $C_{28}$ $\alpha\beta\beta$ steranes 20 *S*+*R* (%), **27**. $C_{29}$ $\alpha\beta\beta$ steranes 20 *S*+*R* (%), **28.**$C_{29}/C_{27}$ $\alpha\beta\beta$ steranes, **29**. Tricyclic/Pentacyclic terpanes.

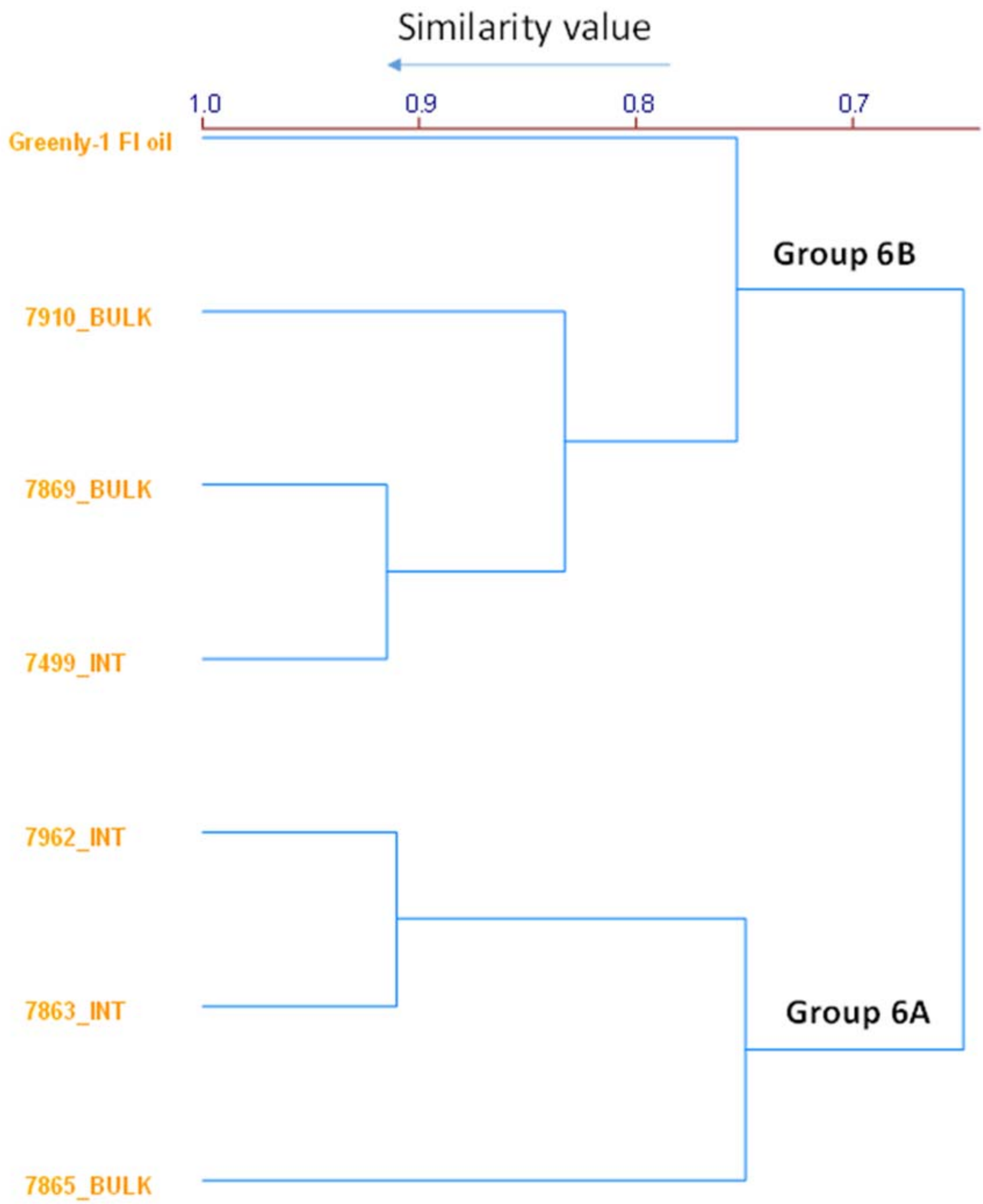


**Figure 107: Partial dendrogram of the hierarchical cluster analysis of Group 6 in Figure 106 showing the relationship of Greenly-1 FI oil and the Group 6 samples.**

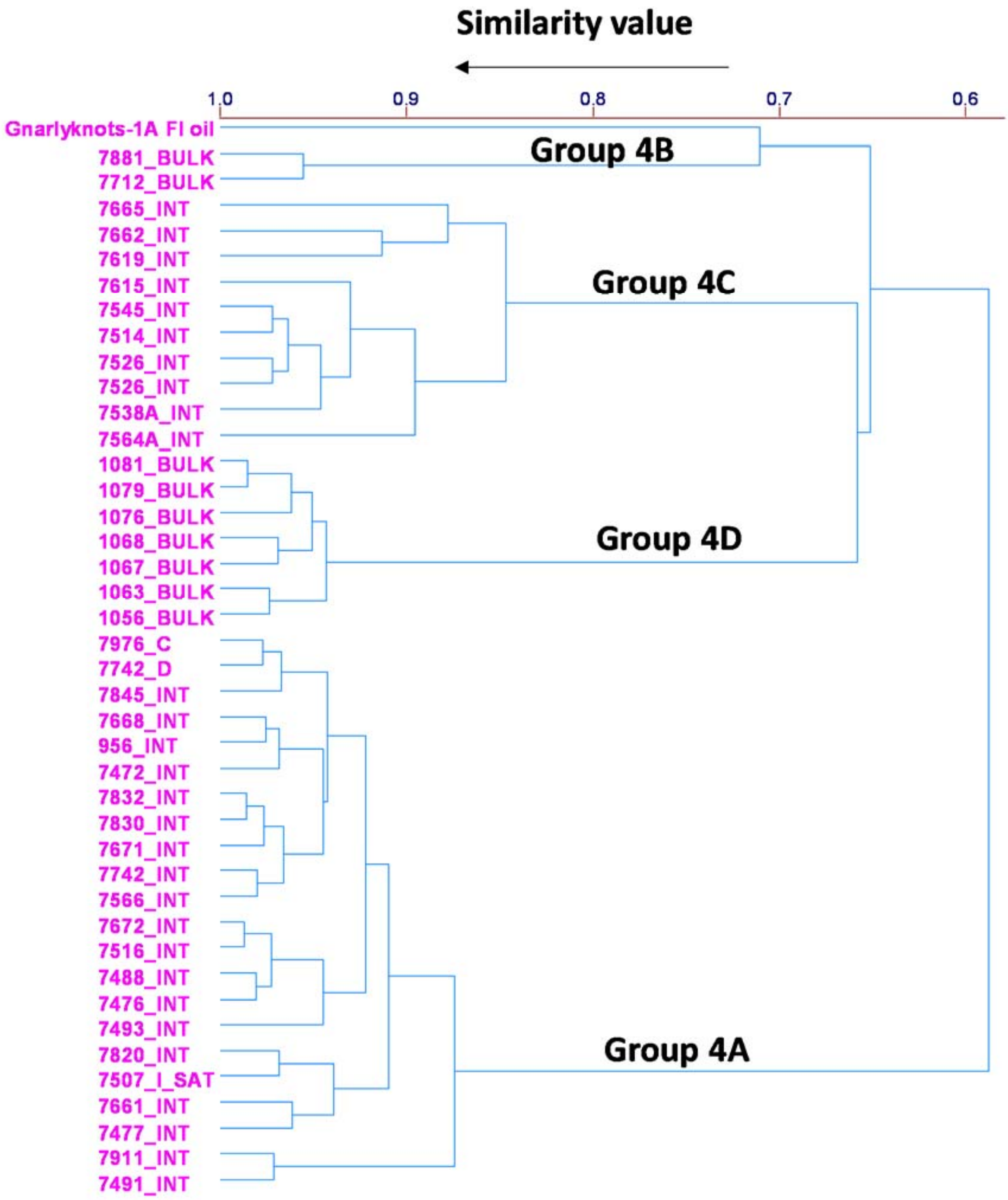


**Figure 108: Partial dendrogram of the hierarchical cluster analysis of Group 1 in Figure 106 showing the relationship of Gnarlyknots-1A FI oil and the Group 4 samples.**

## Biomarker Families Sub-division

The analytical rationale and methods section describes the bulk geochemical screening procedure developed to provide a straightforward classification scheme for the large number of coastal bitumen samples collected. Following their initial allocation to major families (asphaltite and Type I-IV waxy bitumens) utilising their whole-oil GC-MS chromatograms, key representative samples are further classified into sub- families based on their source-specific biomarker geochemistry, using the indicators shown inTable 23.

**Table 23: Summary of key source-related biomarker indicators (after Peters et al., 2005)**

| Source information | | Biomarker | Specificity & age |
|---|---|---|---|
| Organic matter inputs | Terrigenous | Oleananes<br>Lupanes, bisnorlupanes | Angiosperm higher plants<br>Late Cretaceous or younger |
| | | Bicadinanes<br>Methylbicadinanes | Tropical angiosperms of family *Dipterocarpaceae*<br>Late Cretaceous or younger |
| | | Taraxastane | Mangroves |
| | | Ethylcholestane ($C_{29}$) | Dominant sterane in higher plants |
| | | Steranes/hopanes <1 | Higher plants < bacteria |
| | | Pristane/phytane >3 | |
| | Lacustrine | Tetracyclic polyprenoids | Freshwater algae |
| | | Botryococcane | Freshwater/brackish green algae of family *Botryococcus* |
| | | $C_{30}$ 4-methylsterane | Freshwater dinoflagellates |
| | | $C_{26}/C_{25}$ tricyclic terpane ≥1 | Freshwater |
| | | Pristane/phytane = 1–3 | |
| | Marine | $C_{30}$ 24-*n*-propylcholestane | Chrysophyte algae |
| | | Dinosterane | Marine dinoflagellates |
| | | Cholestane ($C_{27}$) | Dominant sterane in marine algae |
| | | Steranes/hopanes ≥1 | Algae > bacteria |
| | | Pristane/phytane <2 | |
| Source rock lithofacies | Carbonate/evaporite | $C_{29}/C_{30}$ hopane >1 | Bacteria |
| | | 2-methylhopanes | Cyanobacteria |
| | | 29,30-bisnorhopane | Bacteria |
| | Shale | Diasterane/sterane high | Clay-rich |
| Depositional environment | Hypersaline | Gammacerane | Ciliates feeding on bacteria |
| | | Pregnane, homopregnane | Precursor biota unknown |
| | Anoxic | 28,30-bisnorhopane | Anaerobic bacteria |
| | | $C_{35}/C_{34}$ homohopane ≥1 | |
| | | Pristane/phytane <1 | |
| | Sub-oxic | Pristane/phytane = 1–3 | |
| | Oxic | Pristane/phytane >3 | |

## Asphaltite and Number 1 & 2 Rocks soft bitumen

Whole-oil analyses of the asphaltites and soft bitumens found at Number 1 & 2 Rocks revealed that they typically preserve gasoline and kerosine-range hydrocarbons (from $C_8$–$C_{10}$), along with unaltered norpristane (Np), pristane (Pr) and phytane (Ph) and Pr/Ph ratios of 1.1-1.3 and 0.8-0.9, respectively. These bitumens do not contain significant high-molecular-weight waxy *n*-alkanes, yielding extremely low response peaks for homologues >$C_{31}$.

Preliminary assessment of the biomarker compounds identified by TIC GC-MS, SIM GC-MS and MRM GC-MS-MS in the least altered specimens (summarised in Table 24) suggest they are derived from a marine calcareous shale deposited under sub-oxic conditions. There are differences in specific biomarkers related to thermal maturity. However, there is a distinct correlation when comparing many diagnostic peak patterns (Figure 109 and Figure 110), suggesting that they share a common source facies.

These bitumen samples are potentially derived from the Bight Basin.

**Table 24: Summary of source characteristics and key features of asphaltites and Number 1 & 2 Rocks soft bitumen.**

| Oil Family | Source Characteristics | Key Features |
|---|---|---|
| Asphaltite | Marine calcareous shale deposited under sub-oxic conditions<br><br>Potentially derived from the Bight Basin | Pr/Ph = 1.1-1.3 |
| | | Botryococcane absent |
| | | $C_{27}/C_{29}$ sterane >1 |
| | | 24-*n*-propylcholestane |
| | | Dinosterane |
| | | $C_{30}$ 4-Me sterane < $C_{29}$ sterane |
| | | $C_{27}$ dia/(dia+reg) sterane = 0.43 |
| | | $C_{26}/C_{25}$ tricyclic terpane = 0.88 |
| | | $C_{29}/C_{30}$ αβ hopane = 0.66 |
| | | $C_{35}/C_{34}$ homohopane = 0.87 |
| | | $C_{35}$ homohopane index = 0.08 |
| | | Gammacerane |
| | | Oleanane absent |
| | | Bicadinanes absent |
| | | TPP (very low) |
| Number 1 & 2 Rocks soft bitumen | Marine calcareous shale deposited under anoxic conditions<br><br>Potentially derived from the Bight Basin | Pr/Ph < 1 |
| | | Botryococcane absent |
| | | $C_{27}/C_{29}$ sterane ≈ 1 |
| | | 24-*n*-propylcholestane |
| | | Dinosterane (low) |
| | | $C_{30}$ 4-Me sterane < $C_{29}$ sterane |
| | | $C_{27}$ dia/(dia+reg) sterane = 0.42 |
| | | $C_{26}/C_{25}$ tricyclic terpane = 0.64 |
| | | $C_{29}/C_{30}$ αβ hopane = 0.78 |

| | |
|---|---|
| | $C_{35}/C_{34}$ homohopane = 1.02 |
| | $C_{35}$ homohopane index = 0.11 |
| | Gammacerane |
| | Oleanane absent |
| | Bicadinanes absent |
| | TPP (low) |

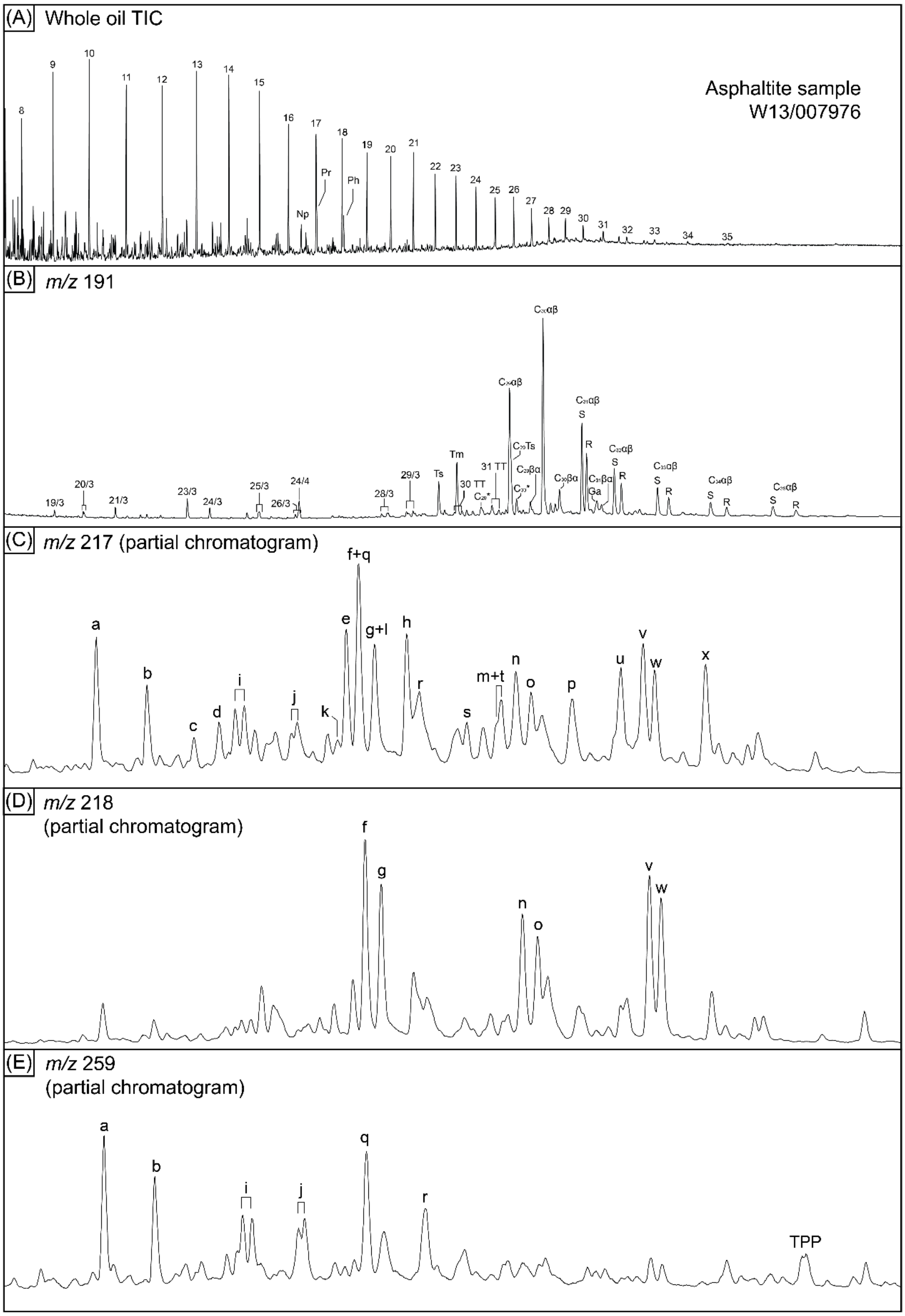


**Figure 109: Representative chromatograms for asphaltite samples. (A) Whole-oil GC-MS TIC showing alkane distribution. (B) m/z 191 chromatogram showing distribution of terpanes. (C) m/z 217 chromatogram showing distribution of steranes and diasteranes. (D) m/z 218 chromatogram showing distribution of C27-C29 αββ steranes. (E) m/z 259 chromatogram showing distribution of C27-C29 βα diasteranes and TPP. For peak identifications refer to tables 18 and 19.**

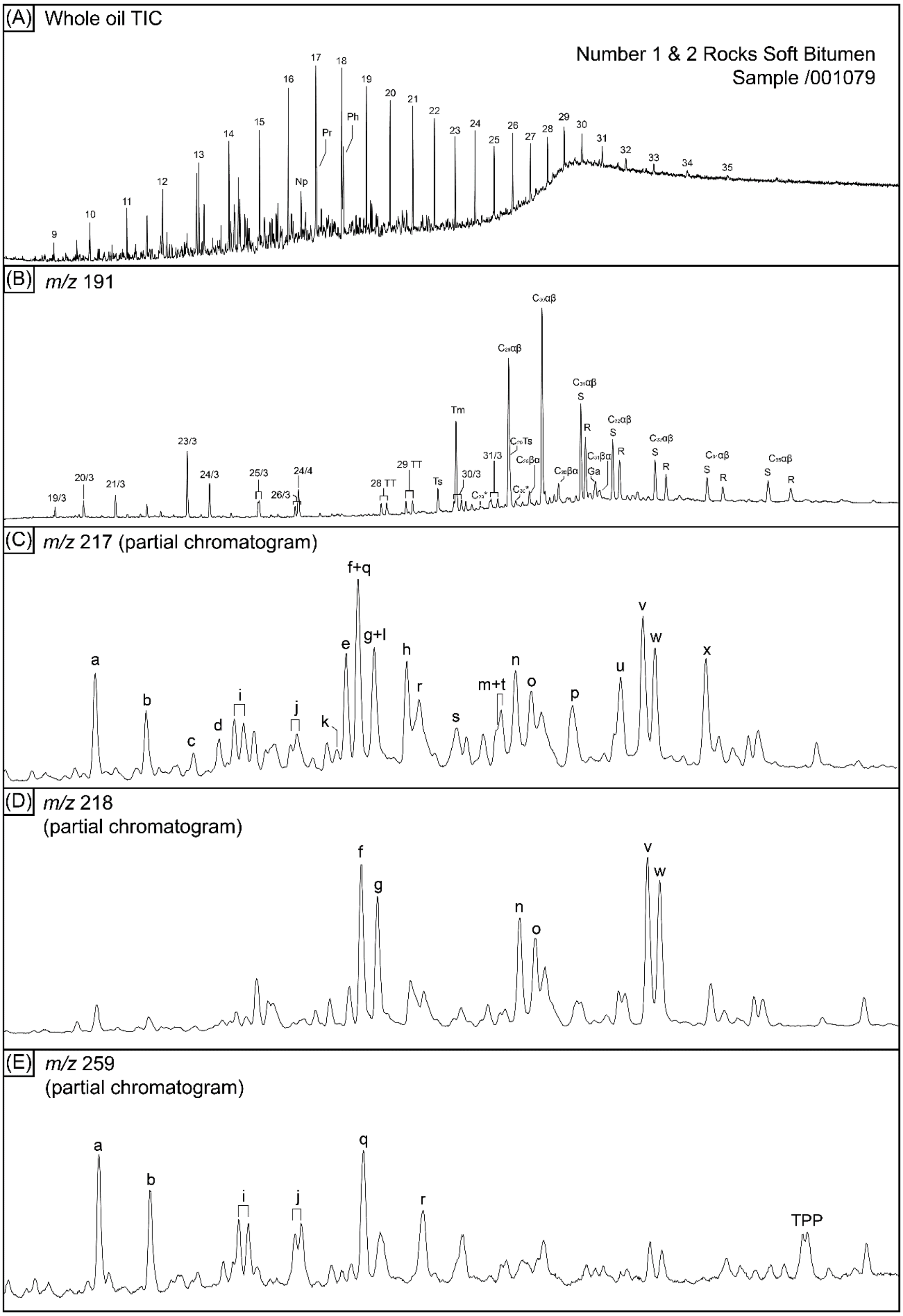


**Figure 110: Representative chromatograms for Number 1 & 2 Rocks soft bitumen samples. (A) Whole-oil GC-MS TIC showing alkane distribution. (B) m/z 191 chromatogram showing distribution of terpanes. (C) m/z 217 chromatogram showing distribution of steranes and diasteranes. (D) m/z 218 chromatogram showing distribution of C27-C29 αββ steranes. (E) m/z 259 chromatogram showing distribution of C27-C29 βα diasteranes and TPP. For peak identifications refer to tables 18 and 19.**

### Type I Waxy Bitumens (High Botryococcane)

Type I waxy bitumens (Figure 111) are the most clearly identifiable variety of waxy bitumen due to their high abundance of the $C_{34}$ irregular isoprenoid botryococcane. These bitumens show a decline in waxy *n*-alkanes in towards $C_{39}$. Whilst pristane and phytane are present, these compounds have already undergone significant depletion and could not be used for interpretation of source conditions, or for the purposes of oil-oil and oil-source correlation.

Preliminary assessment of the biomarker compounds identified by TIC GC-MS, SIM GC-MS and MRM GC-MS-MS of the least altered specimens (summarised in Table 25) suggest that these bitumens are derived from a lacustrine (deep freshwater) shale with algal and lesser higher-plant (dipterocarp angiosperm) inputs.

The presence of botryococcane, bicadinanes and tetracyclic polyprenoids supports the interpretation of these bitumen samples being derived from an Indonesian source rock of Cenozoic age (cf. ten Haven & Schiefelbein, 1995).

**Table 25: Summary of source characteristics and key features of Type I waxy bitumens.**

| Oil Family | Source Characteristics | Key Features |
|---|---|---|
| Type I waxy bitumen | Lacustrine (deep freshwater) shale with algal and lesser higher plant (dipterocarp angiosperm) inputs<br><br>Presence of botryococcane, tetracyclic polyprenoids and bicadinanes supports Indonesian Cenozoic origin | Pr & Ph absent (biodegradation) |
| | | Botryococcane (high) |
| | | $C_{27}/C_{29}$ sterane >1 |
| | | 24-*n*-propylcholestane absent/trace |
| | | $C_{30}$ 4-Me sterane > $C_{29}$ sterane |
| | | $C_{27}$ dia/(dia+reg) sterane = 0.68 |
| | | $C_{26}/C_{25}$ tricyclic terpane = 1.77 |
| | | $C_{29}/C_{30}$ αβ hopane = 0.56 |
| | | $C_{35}/C_{34}$ homohopane = 0.47 |
| | | $C_{35}$ homohopane index = 0.05 |
| | | Gammacerane absent |
| | | Oleanane (low) |
| | | Bicadinanes |
| | | TPP (high) |

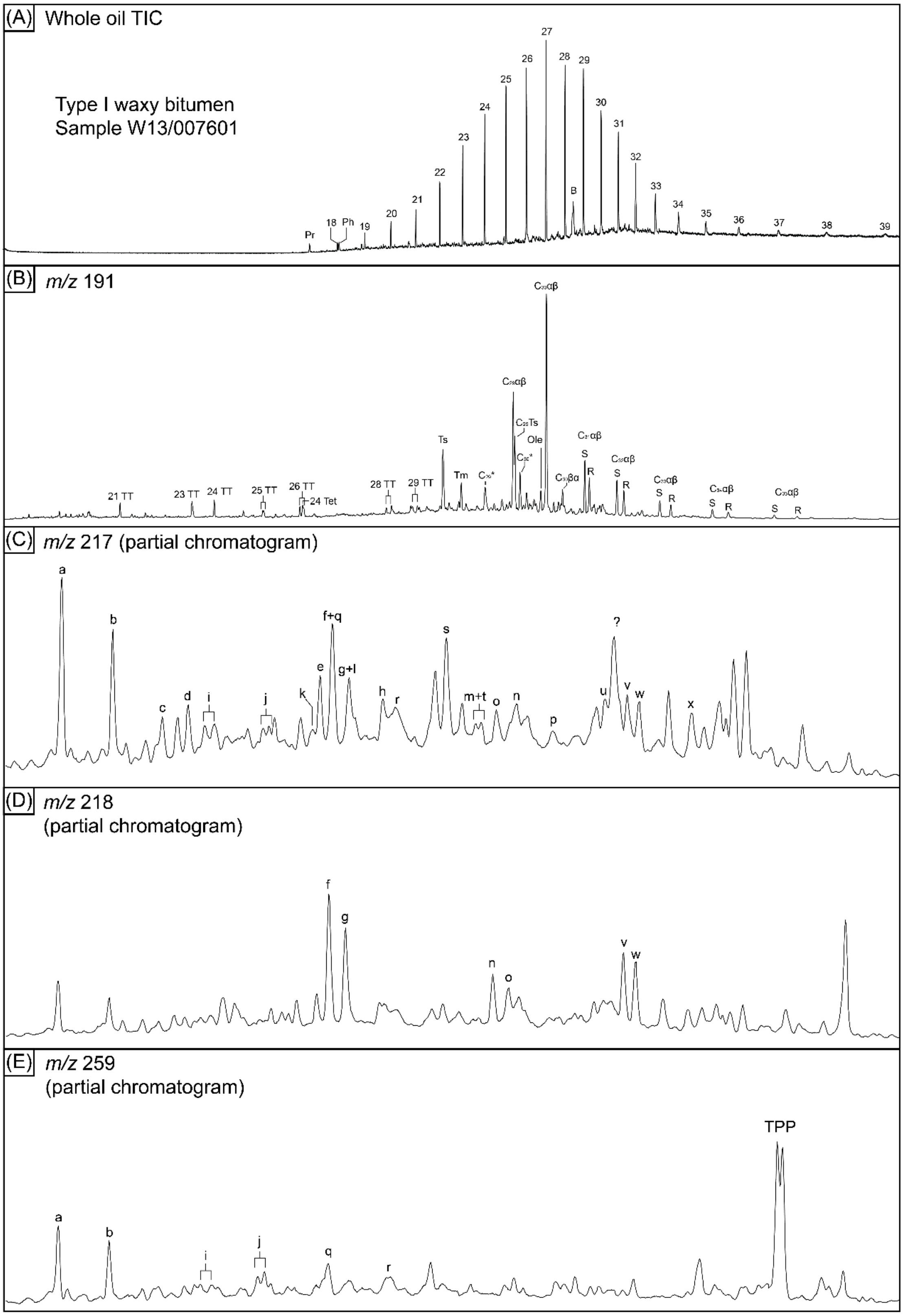


**Figure 111: Representative chromatograms for Type I waxy bitumens. (A) Whole-oil GC-MS TIC showing alkane distribution. (B) m/z 191 chromatogram showing distribution of terpanes. (C) m/z 217 chromatogram showing distribution of steranes and diasteranes. (D) m/z 218 chromatogram showing distribution of C27-C29 αββ steranes. (E) m/z 259 chromatogram showing distribution of C27-C29 βα diasteranes and TPP. For peak identifications refer to tables 18 and 19.**

## Type II Waxy Bitumens (Low Botryococcane)

Type II waxy bitumens (Figure 112) are recognisable by their low botryococcane contents and high abundance of waxy *n*-alkanes in comparison to the Type I bitumens. Whilst pristane and phytane are present, they have undergone significant biodegradation and hence could not be used for interpretation of source conditions or for correlation.

Preliminary assessment of the biomarker compounds identified by TIC GC-MS, SIM GC-MS and MRM GC-MS-MS for the least altered specimens (summarised in Table 26) suggest them to be derived from a marine carbonate with lesser input from a lacustrine shale with mixed algal and higher-plant inputs.

The presence of botryococcane, bicadinanes and tetracyclic polyprenoids supports the interpretation that these bitumens are derived from an Indonesian source rock of Cenozoic age (see above).

**Table 26: Summary of source characteristics and key features of Type II waxy bitumens.**

| Oil Family | Source Characteristics | Key Features |
|---|---|---|
| Type II waxy bitumen | Marine carbonate > lacustrine shale with mixed algal and higher plant inputs<br><br>Presence of botryococcane, tetracyclic polyprenoids and bicadinanes supports Indonesian Cenozoic origin | Pr/Ph altered/absent (biodegradation) |
| | | Botryococcane (low) |
| | | $C_{27}/C_{29}$ sterane ≥1 |
| | | 24-*n*-propylcholestane |
| | | Dinosterane |
| | | $C_{30}$ 4-Me sterane < $C_{29}$ sterane |
| | | $C_{27}$ dia/(dia+reg) sterane = 0.35 |
| | | $C_{26}/C_{25}$ tricyclic terpane = 1.06 |
| | | $C_{29}/C_{30}$ αβ hopane = 1.09 |
| | | $C_{35}/C_{34}$ homohopane = 0.92 |
| | | $C_{35}$ homohopane index = 0.07 |
| | | Gammacerane |
| | | Bicadinanes |
| | | Oleanane (low) |
| | | TPP (high) |

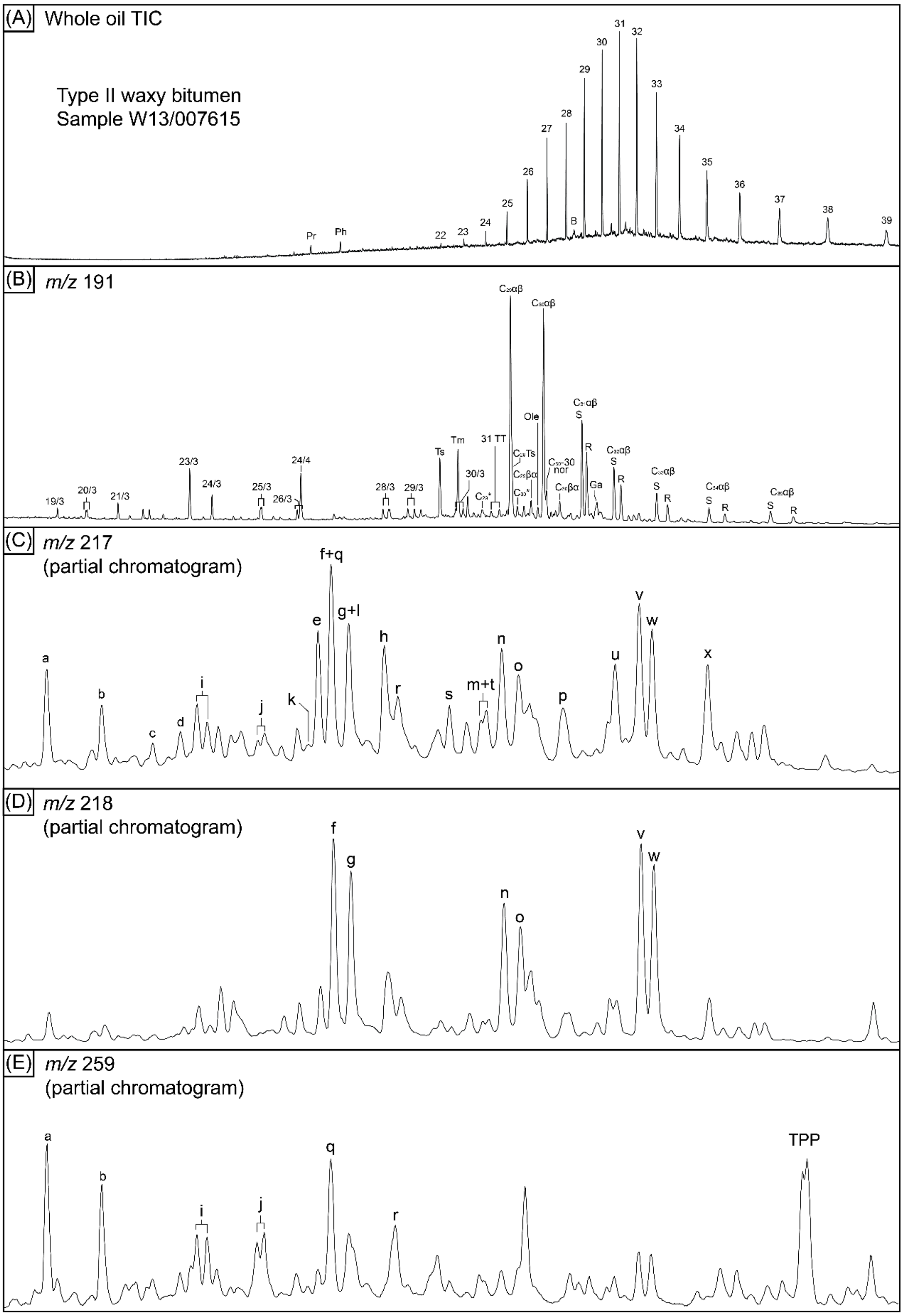


**Figure 112: Representative chromatograms for Type II waxy bitumen. (A) Whole-oil GC-MS TIC showing alkane distribution. (B) m/z 191 chromatogram showing distribution of terpanes. (C) m/z 217 chromatogram showing distribution of steranes and diasteranes. (D) m/z 218 chromatogram showing distribution of C27-C29 αββ steranes. (E) m/z 259 chromatogram showing distribution of C27-C29 βα diasteranes and TPP. For peak identifications refer to tables 18 and 19.**

## Type III Waxy Bitumens (No Botryococcane, Low Wax)

Type III waxy bitumens are characterised by their lack of botryococcane and low abundances of high-molecular-weight *n*-alkanes ($C_{35}$–$C_{39}$).

Biomarker analysis (discussed below) demonstrates that five potential oil families exist within the whole-oil category of Type III waxy bitumen. Although pristane and phytane are intact in certain samples, it was degraded in others and could not be used in any interpretation of source conditions or for correlation purposes.

### *Type IIIA waxy bitumens*

Representative chromatograms for Type IIIA waxy bitumen are shown in Figure 113. Preliminary assessment of the biomarker compounds identified by TIC GC-MS, SIM GC-MS and MRM GC-MS-MS for the least altered specimens (summarised in Table 27) suggest they are derived from a lacustrine shale deposited under sub-oxic conditions.

The presence of bicadinanes, oleanane and tetracyclic polyprenoids supports the interpretation that these bitumens are derived from an Indonesian source rock of Cenozoic age (see above).

**Table 27: Summary of source characteristics and key features of Type IIIA waxy bitumens.**

| Oil Family | Source Characteristics | Key Features |
|---|---|---|
| Type IIIA waxy bitumen | Lacustrine shale deposited under sub-oxic conditions<br><br>Presence of bicadinanes, tetracyclic polyprenoids and oleanane supports Indonesian Cenozoic origin | Pr/Ph = 1.5-1.7 |
| | | Botryococcane absent |
| | | $C_{27}/C_{29}$ sterane ≈ 1 |
| | | 24-*n*-propylcholestane absent/trace |
| | | $C_{30}$ 4-Me sterane > $C_{29}$ sterane |
| | | $C_{27}$ dia/(dia+reg) sterane = 0.59 |
| | | $C_{26}/C_{25}$ tricyclic terpane = 1.9 |
| | | $C_{29}/C_{30}$ αβ hopane = 0.73 |
| | | $C_{35}/C_{34}$ homohopane = 0.40 |
| | | $C_{35}$ homohopane index = 0.03 |
| | | Gammacerane (low) |
| | | Bicadinanes |
| | | Oleanane (low) |
| | | TPP (high) |

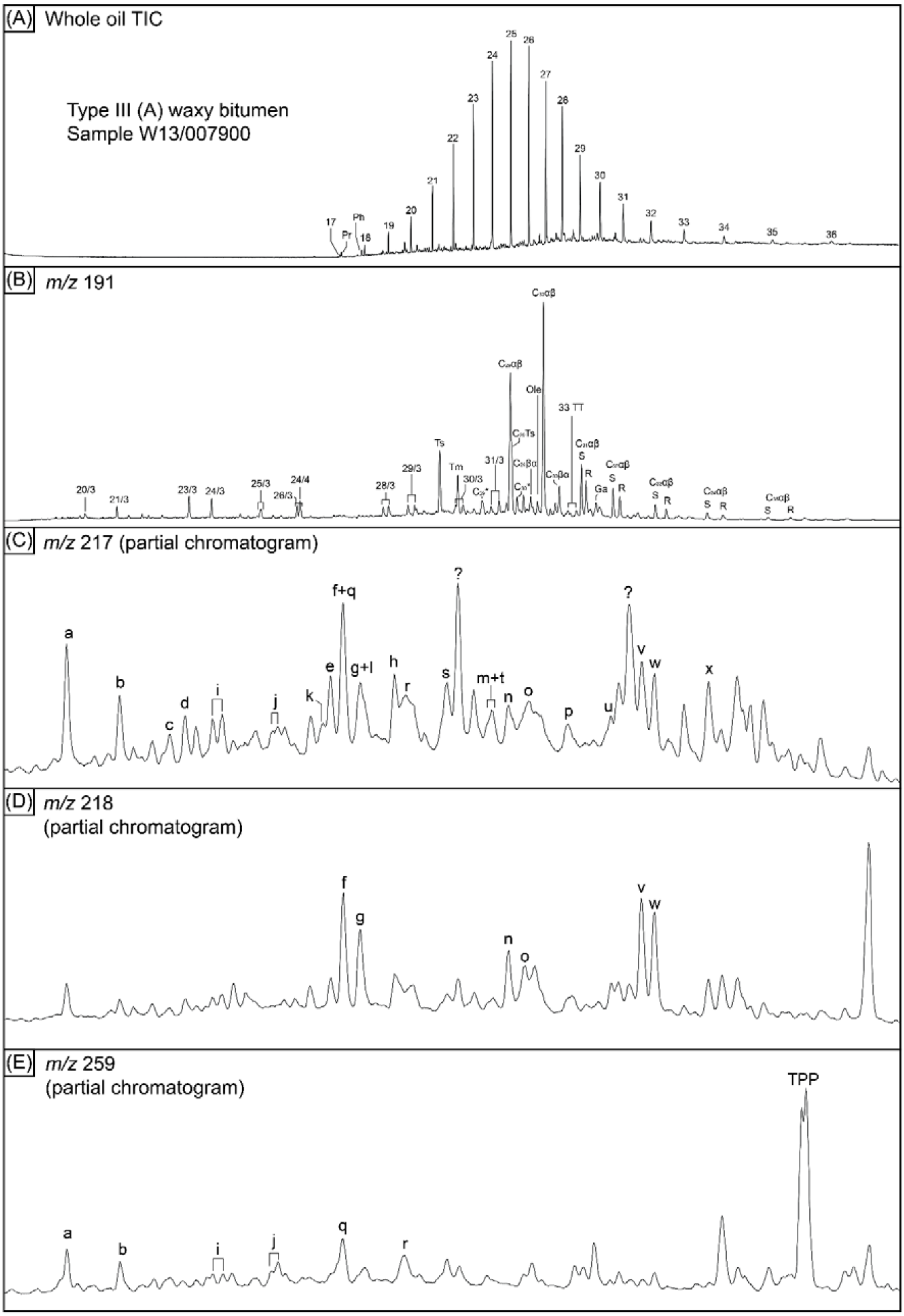


**Figure 113: Representative chromatograms for Type IIIA waxy bitumen. (A) Whole-oil GC-MS TIC showing alkane distribution. (B) m/z 191 chromatogram showing distribution of terpanes. (C) m/z 217 chromatogram showing distribution of steranes and diasteranes. (D) m/z 218 chromatogram showing distribution of C27-C29 αββ steranes. (E) m/z 259 chromatogram showing distribution of C27-C29 βα diasteranes and TPP. For peak identifications refer to tables 18 and 19.**

### *Type IIIB waxy bitumens*

Representative chromatograms for Type IIIB waxy bitumen are shown in Figure 114. Preliminary assessment of the biomarker compounds identified by TIC GC-MS, SIM GC-MS and MRM GC-MS-MS for the least altered specimens (summarised in Table 28) suggest them to be derived from a lacustrine shale deposited under sub-oxic conditions, with a lower input from freshwater dinoflagellate algae than was the case for Type IIIA.

The presence of botryococcane, bicadinanes and oleanane supports the interpretation these bitumens are derived from an Indonesian source rock of Cenozoic age (see above).

**Table 28: Summary of source characteristics and key features of Type IIIB waxy bitumens.**

| Oil Family | Source Characteristics | Key Features |
|---|---|---|
| Type IIIB waxy bitumen | As for Type IIIA, except for lower input from freshwater dinoflagellate algae | Pr/Ph = 1.8 |
| | | Botryococcane present (low) |
| | | $C_{27}/C_{29}$ sterane ≈ 1 |
| | | 24-*n*-propylcholestane |
| | | $C_{30}$ 4-Me sterane < $C_{29}$ sterane |
| | | $C_{27}$ dia/(dia+reg) sterane = 0.56 |
| | | $C_{26}/C_{25}$ tricyclic terpane = 1.52 |
| | | $C_{29}/C_{30}$ αβ hopane = 0.5 |
| | | $C_{35}/C_{34}$ homohopane = 0.46 |
| | | $C_{35}$ homohopane index = 0.04 |
| | | Gammacerane |
| | | Oleanane (low) |
| | | Bicadinanes (high) |
| | | TPP (high) |