woodside

# Noblige-1
# Well Completion Report
## Interpretive Data

WA-404-P
Exmouth Plateau
January 2011

# WELL COMPLETION REPORT

# NOBLIGE-1

# Interpretive Data
# (WA-404-P, Exmouth Plateau)

**Lee Taylor,** Operations Geology

Date: February 2011

Status: Published

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# 1. INTRODUCTION

## 1.1 Overview

The Noblige-1 exploration well was drilled by the Jack Bates semi-submersible drilling rig in Exploration Permit WA-404-P (Figure 1) within the Exmouth Plateau of the Northern Carnarvon Basin.

Water depth at the Noblige-1 location is 1312 metres at lowest astronomical tide (LAT). The rotary table elevation was 29.0 metres up to 11 January 2010, but after this date was adjusted to 30.5 metres. Depth measurements in this report are with reference to a rotary table elevation of 30.5 mRT and are indicated by mRT.

Noblige-1 was drilled to test the hydrocarbon potential of numerous, stacked, Triassic, sandstone reservoirs within a four-way dip closed structure covering an area of about 15 $km^2$ at top Triassic level. The primary reservoir objectives were the Triassic aged Mungaroo Formation sandstones, deposited in an upper/lower delta plain environment.

Noblige-1 was spudded on 5 January 2010, reaching the total depth of 4581 mRT in sandstones, siltstones and claystones of Carnian age on 27 January 2010. Wireline logs were run across the reservoir section, but no production testing was carried out. Six individual hydrocarbon columns were encountered; at 3281 mRT, 3808 mRT, 3884 mRT, 3929 mRT, 3984 mRT and 4080 mRT. Approximately 101.6 metres of net pay has been interpreted over these six gas sands.

The well was suspended and the rig released from contract on 18 February 2010. Table 1 gives a summary of key information for the well.

## 1.2 Exploration History

Permit WA-404-P, awarded on 17 July 2007, is operated by Woodside Energy Ltd on behalf of the WA-404-P Joint Venture. Noblige-1 was the second exploration well to be drilled within the permit.

Participating interests in the WA-404-P Exploration Permit t the time of drilling Noblige-1 were:

| | |
|---|---|
| Woodside Energy Ltd. (Operator) | 50% |
| Hess Exploration (Carnarvon) Pty Ltd | 50% |

On 5 November 2010, Woodside Energy Ltd purchased the Hess interest in the block. Woodside Energy Ltd is now the operator and has 100% working interest in WA-404-P.

**Table 1**

# WELL INDEX SHEET

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *WELL:* | **NOBLIGE-1** | *WD:* | **1312 m LAT** | *Rig on Contract:* | **1 January 2010** | *LAT:* | **19° 23' 55.061"S** |
| *PERMIT:* | **WA-404-P** | *RT:* | **30.5 m (LAT)** | *Date on Location:* | **2 January 2010** | *LONG:* | **114° 19' 58.698"E** |
| *BASIN:* | **EXMOUTH PLATEAU** | *TD:* | **4581.0 mRT** | *Spud Date:* | **5 January 2010** | | **GDA 94** |
| *OPERATOR:* | **WOODSIDE** | *Well Status:* | **Suspended** | *Date at TD:* | **27 January 2010** | *Easting:* | **219 891.38 mE** |
| *RIG:* | **JACK BATES** | | **Gas Discovery** | *Rig Released:* | **18 February 2010** | *Northing:* | **7 852 897.87 mN** |
| | | *Seismic Ref.:* | **Colombard 3D, Inline 5661** | | | | **MGA Zone 50, CM 117°E** |
| | | | **XLine 2597** | | | | |

| Formation | Age | Marker | Depth mRT | Depth mtvdss (LAT) | Lithology |
|---|---|---|---|---|---|
| | | | | | NB Sample collection commenced @ 2424 mRT |
| **QUATERNARY - TERTIARY (inferred)** | | | | | |
| Delambre Formation (inf) | *Recent-Pliocene (inf.)* | **WB** | 1342.5 | 1312.0 | |
| **TERTIARY (inferred)** | | | | | |
| Bare-Mandu Fms (inf) | *Paleocene to Miocene (inf)* | **T40.0_SB** | 1512.0 | 1481.5 | |
| Upper Walcott Formation (inf) | *Paleocene to Miocene (inf)* | **T30.0_SB** | 1587.5 | 1557.0 | |
| L. Walcott/Dockrell Fms (inf) | *Paleocene to Miocene (inf)* | **T27.1_TS** | 1732.5 | 1702.0 | |
| **CRETACEOUS (inferred in part)** | | | | | |
| Miria Mrl/Withnell Fm (inf) | *Maastrichtian-Campanian (inf.)* | **T10.0_SB** | 2035.9 | 2005.4 | |
| Toolonga/Haycock Fms | *Campanian (inf)-Turonian* | **K60.0_SB** | 2330.0 | 2299.0 | Calcilutite, claystone and calareous claystone |
| Haycock/Windalia Rad. | *Turonian-(inf)Aptian* | **K50.0_SB** | 2451.0 | 2420.5 | Calcilutite, claystone and calareous claystone |
| Muderong Shale | *Aptian-Valanginian (inf)* | **K40.0_SB** | 2597.6 | 2567.1 | Claystone, calcareous claystone with minor calcilutite. |
| Forestier Claystone | *Valanginian -Berriasian* | **K20.0_SB** | 2703.0 | 2672.0 | Claystone, silty claystone |
| **JURASSIC** | | | | | |
| Murat Sltst/Nth Rankin Beds | *Pleinsbachian-Hettangian* | **J40.0_SB** | 2800.5 | 2770.0 | Calcilutite, claystone, siltstone |
| **TRIASSIC** | | | | | |
| Brigadier Formation | *Rhaetian* | **J10.0_SB** | 2846.9 | 2816.4 | Calcilutite |
| Mungaroo Formation | *Norian* | **TR30.1_TS** | 2889.3 | 2858.8 | Silty claystone, sandstone, claystone, siltstone and coal |
| **Total Depth** | | **TD** | 4581.0 | 4549.8 | |

**HOLE SUMMARY**

| Size | Depth (mRT) | Casing | Shoe (mRT) | LOT | MW (sg) | Mud (sg) | Cement Plugs (mRT) |
|---|---|---|---|---|---|---|---|
| 914mm | 1407.2 | 914mm | 1407.2 | | | | |
| 444mm | 2425.5 | 340mm | 2421.7 | 1.255sg @ 2429mRT | 1.03 | Seawater + PHG sweeps | 2096-2196 |
| 311mm | 2750.0 | 244mm | 2750.0 | 1.22sg @ 2750 mRT | 1.1-1.12 | PER-FLEX | 4250-4581 |
| 216mm | 4581.0 | 177mm | 4246 | 1.32sg @ 2755 mRT | 1.12-1.14 | PER-FLEX | |

**SAMPLE RECORD**

| Type | No. | Interval (mRT) | Remarks |
|---|---|---|---|
| Ditch Cuttings | | 2424-4581 | 2 to 10 metre intervals |
| MSCT | | 2896.3-4545 | 29 attempted, 28 recovered |
| SWC | | 2776.6-4554 | 74 attempted, 12 empty, 5 lost |
| MGIL (Isotubes) | | 2445-4581 | 236 samples |
| MGII (Isojars) | | 2424-4581 | 194 samples |

**MWD**

| Run No. | Interval (mRT) | Remarks |
|---|---|---|
| 1 | 1341-2424 | HEL-BAP-TVM-HAGR-MFR |
| 2 | 2425.5-2750 | HEL-BAP-TVM-HAGR-MFR-AZD-TNP |
| 3 | 2750-2791 | HEL-BAP-TVM-HAGR-MFR-AZD-TNP |
| 4 | 2791-3257 | HEL-BAP-TVM-HAGR-MFR-AZD-TNP |
| 5 | 3257-4581 | HEL-BAP-TVM-HAGR-MFR-AZD-TNP |

**WIRELINE LOGS**

| Suite & Run | Log | Interval (mRT) | MRT °C |
|---|---|---|---|
| 1/1 | GR-CN-ZDL-STAR-ORIT-XMAC-DLL-MLL | 2700-4571 | 103.5 |
| 1/2 | GR-RCI-DSL | 2950-4378 | 110 |
| 1/3 | GR-GEOCHAIN (VSP) | 1735-4540 | 106.7 |
| 1/4 | GR-RCI-sample | 2950-4378.3 | 110 |
| 1/5 | MREX-ZDL-CN-DSL | 2735.9-4558.1 | 102.2 |
| 1/6 | GR-RCOR | 2896.3-3889 | 95.6 |
| 1/7 | GR-RCOR | 3889-4545 | 105.6 |
| 1/8 | SWC | 2776.6-4454 | 110.6 |

**MDT**

| Sample No. | Depth (mRT) | Interpreted Fluid |
|---|---|---|
| 1 | 4374.2 | water |
| 2-4 | 3932.5 | gas |
| 5-7 | 3286.8 | gas |
| 8, 9 | 3812.5 | gas |
| 10, 11 | 4,097.5 | gas |

**PRODUCTION TESTING**

| TEST | DEPTH (mRT) | RECOVERY | | | | | |
|---|---|---|---|---|---|---|---|
| | | CONDENSATE (stbd) | GAS (MMscf/d) | WATER (bwpd) | CHOKE | °API | CGR (bbl/MMscf) |
| n/a | | | | | | | |

Date: February 2011 Author: L. Taylor **Rev.: 0**

# 2. REGIONAL GEOLOGY

The WA-404-P permit is located on the Exmouth Plateau immediately to the west of the Kangaroo Syncline (Figure 2). The Exmouth Plateau is a proven hydrocarbon province containing multiple, large, dry gas accumulations. An Exmouth Plateau tectonic elements map and generalised stratigraphic column are shown in Figures 2 and 3. Note that the seismic marker nomenclature is currently being revised (Figure 4) and Figure 3 shows the old nomenclature. Where a new name is used in this text, the original one from Figure 3 is also given in parentheses.

The Northern Carnarvon Basin is a composite basin comprising a Late Palaeozoic cratonic sag overlain by an Early Mesozoic rift basin and Late Mesozoic/Tertiary passive margin.

Onshore outcrops and offshore seismic interpretation suggest that a significant thickness (in excess of 8500m) of Permo-Triassic sediment (Figure 3) is present beyond the shelfal areas of the basin. The Permian section is thought to have been deposited in a series of half-grabens associated with a Late Permian rift phase.

Following Permian rifting, a regional marine transgression in the Early Triassic resulted in the deposition of the marine claystones of the Locker Shale. This transgression was conformably overlain by the thick, regionally extensive, fluvio-deltaic Mungaroo Formation. The Mungaroo Formation forms a primary reservoir target on the Exmouth Plateau and recent nearby discoveries in this reservoir include Martell, Pluto, Chandon, Clio, Urania, Wheatstone and Maenad.

In the latest Triassic to earliest Jurassic initial rifting resulted in a major flood and the deposition of marginal marine clastics and platform carbonates of the Brigadier Formation and North Rankin Beds.

Continued extension during the Early to Middle Jurassic focused rifting in the Dampier, Barrow and Exmouth Sub-basins, resulting in the deposition of thick Jurassic successions in these areas. Middle Jurassic clastics were deposited in a shallow marine to fluvial environment as part of the Legendre delta which prograded from the northeast to southwest. During the Late Jurassic coarse clastics were deposited adjacent to the rift margins and thick source prone claystones within the grabens.

Oxfordian to Valanginian “break-up” associated with the separation of the Australian and Indian plates south of the Exmouth Plateau initiated isostatic uplift, which sourced the north/northwest progradation of the Barrow Group delta system. This system eventually spread out from the area west of the Alpha Arch to cover a large portion of the Barrow and Exmouth Sub-basins. Local deposition of Tithonian sediments sourced from adjacent highs accompanied the initial Tithonian uplift.

Synrift sedimentation ceased in the early Valanginian with final separation of the Indian Plate from Western Australia, resulting in a major marine transgression and resultant deposition of the Muderong Shale. Low energy shelf and slope depositional environments followed through the Aptian to Cenomanian, with the deposition of the Windalia Radiolarite and Gearle Formation/Haycock Marl, as the passive margin developed. The Toolonga Calcilutite was deposited during the remainder of the Cretaceous.

Tertiary deposition was characterised mainly by carbonates and calcareous claystones deposited in cycles of shelf edge progradation and transgression caused by relative and eustatic sea level fluctuations. A carbonate shelf edge built out across the subsiding Barrow

and Dampier Sub-basins, but is represented by a condensed carbonate section across the Exmouth Plateau.

# 3. SEISMIC INTERPRETATION

## 3.1 Seismic Data

Seismic interpretation over the WA-404-P permit was originally carried out using mixed vintage 2D seismic data. Recent mapping has been carried out on the recently acquired block-wide Colombard 3D MSS. This survey, covering 3166 $km^2$, was completed on 10 August 2008, and was acquired using the CGG-Veritas MSV Symphony. This survey formed the primary part of the permit work programme for Year 1. The Noblige pre-drill interpretation was based on a data set comprising PreSTM and PreSDM migrated stacks, angle stacks and gathers.

## 3.2 Well to Seismic Calibration

The closest offset well, Martell-1 is approximately 2km from Noblige-1 and has been tied to the Colombard 3D seismic data. This is a high confidence well-to-seismic tie utilising a VSP log. The Noblige-1 well was successfully tied to both the PreSTM data and the PreSDM data. A good tie to the PreSDM data is achieved, particularly around the gas bearing reservoir section, after a 2ms shift is applied.

## 3.3 Seismic Time Interpretation

In general the correlation of the WB, T40.0 (TM1), T30.3 (TO), K60.0 (KS/C), K50.0 (KC), K40.0 (KA), K20.0 (KV), J40.0 (JO) and TR30.1 (TRR) events was very good due to excellent seismic character. The interpreted horizons are listed in Table 2. The correlation of the intra-Mungaroo events TR27.2 (MCM52) and TR27.0 (MCS50) is from Martell-1 and are good. The deeper intra-Mungaroo events not penetrated by Martell [TR26.1 (MCT42), TR22.1 (MCT12), TR22.0 (MCS10), TR21.1 (MCT5), TR21.0 (MCS2), TR20.0 (TRC1)] were correlated from Jupiter-1 and Mercury-1 which are approximately 85 km and 40 km to the south west, respectively. These ties are considered fair to good despite the separation by extensive faulting and non-continuous seismic character.

The TR30.1 (TRR) seismic horizon is a strong peak at the top of the Triassic Mungaroo Formation. The strong soft is generated at the base of an *A. reducta* age carbonate sequence that is penetrated in all of the Outer Exmouth Plateau wells. This event has been mapped as the top of porosity. It is the top of an extensive fluvio-deltaic to marginal marine sequence of interbedded sands and shales. Reservoir has been intersected in key offset wells namely; Martell-1, Jupiter-1, Mercury-1, Belicoso-1 and Chandon-1 wells. There is little evidence of erosion of the Mungaroo Formation within the permit, and therefore, it is interpreted that the Upper Mungaroo Formation would be fully preserved.

The J40.0 (JO) horizon is a strong trough that shows little or no evidence of erosional truncation. This is in stark contrast to the J40.0 (JO) event further to the east, such as over the Geryon Field, where the strongly erosive nature of the J40.0 (JO) unconformity is clearly visible on the seismic data. Within permit WA-404-P, the J40.0 (JO)-TR30.1 (TRR) interval was interpreted to comprise shales and carbonates.

Table 2: Interpreted Horizons

| Marker | Polarity | Level | Age | Comment |
|---|---|---|---|---|
| WB | Trough | Seabed | Present Day | Excellent Pick |
| T40.0 (TM1) | Trough | Top Bare | Miocene | Good Pick |
| T30.0 (TO) | Trough | Top Walcott / Wilcox | Oligocene | Good Pick |
| K60.0 (KS/C) | Trough | Top Toolonga | Campanian | Good Pick |
| K50.0 (KC) | Peak | Near Top Haycock | Campanian | Good Pick |
| K40.0 (KA) | Peak | Top Muderong / Base Windalia | L. Aptian | Good to Excellent Pick |
| K20.0 (KV) | Peak | Top Forestier Claystone | L. Valanginian | Fair to Good Pick |
| J40.0 (JO) | Trough | Top MuratFormation | Oxfordian | Good Pick |
| TR30.1 (TRR) | Peak | Base Brigadier / Top Mungaroo Formation | U. Norian / L. Rhaetian | Good Pick |
| TR27.2 (MCM52) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR27.0 (MCS50) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR26.1 (MCT42) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR22.1 (MCT12) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR22.0 (MCS10) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR21.1 (MCT5) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR21.0 (MCS2) | Peak | Intra-Mungaroo Formation | Norian | Fair to Good Pick |
| TR20.0 (TRC1) | Trough | Intra-Mungaroo Formation | Norian | Fair to Good Pick |

The intra-Valanginian seismic event K20.0 (KV) is picked as an easily mappable trough, which strictly speaking is a near-K20.0 (KV) event.

The K40.0 (KA) and K50.0 (KC) seismic events are strong peaks that can be easily correlated across the WA-404-P area. K40.0 (KA) is the Top of the Muderong Shale, and K50.0 (KC) is the near top Haycock Marl.

In addition to the above events, the top Bare Formation [T40.0 (TM1)], top Dockrell/Lambert Formations [T20.0 (TP1)], top Miria/Withnell Formations [T10.0 (T)] and top Toolonga Calcilutite [K60.0 (KS/C)] were interpreted over the Noblige-1 well location to provide additional picks for the well prognosis. These events were tied to the Martell-1 Titania-1, Belicoso-1, Atlas-1, Jupiter-1 and Mercury-1 wells and picked on a coarse grid.

### 3.4 Structural Interpretation

At the Triassic level (Figure 5) the WA-404-P area is dissected by a series of north-northeast oriented fault blocks. The fault blocks are draped by a carbonate and shale dominated interval of Late Triassic to Middle Jurassic age which thickens into the grabens. This growth

demonstrates Late Triassic fault movement. The faults moved intermittently throughout the Lower Cretaceous. The hanging wall fill of each of the fault blocks is unknown, but may contain sandstones of Upper Jurassic and/or Lower Cretaceous age.

Following burial in the Late Cretaceous, no structural influence on sedimentation is observed until the Early Tertiary, when rapid deposition of the Paleocene Dockrell Formation into the Kangaroo Syncline to the east created massive instability and a series of large, easterly dipping, listric faults developed. These faults have up to several hundred metres of throw and sole out into the Haycock Marl. The Dockrell Formation is extensively cut by polygonal faults, indicating rapid dewatering of the interval. Some of these dewatering faults extend through the Upper Cretaceous and “hard-link” to the underlying Jurassic faults.

Noblige-1 tested a 4-way dip closure interpreted as a late inversion anticline resulting from north-south compression during the late Jurassic. There is a larger 3-way dip closure which closes against the Martell bounding fault to the west. The Noblige 4-way dip closure is cut by several minor east-west trending faults and the area of the structure tightens with depth.

### 3.5 Predicted and Actual Stratigraphy

Figure 5 is a depth map at the TR30.1 (TRR) level across the Noblige structure. Table 3 gives the prognosed and actual stratigraphy for the Noblige-1 well. All markers except for TR22.1 (Tr-MCT12) & TR20.7 (TRC2) were intersected within the error margins of the pre-drill prediction. The top errors appeared to get larger towards the base of the well and this was due to the lack of deep penetrations in offset wells and an ultimate under estimation of velocities in the deep Mungaroo.

Table 3: Noblige-1 Predicted vs Actual Stratigraphy

| Formation | Marker | Prognosed Depth (mTVDss MSL) | Actual Depth (mTVDss MSL) | Difference (metres) |
|---|---|---|---|---|
| Seabed | WB | 1316.2 +/- 20 | 1313.2 | 3.0 |
| Top Bare Formation | T40.0 (TM1) | 1476.2 +/- 20 | 1482.7 | -6.5 |
| Top Walcott / Wilcox Formations | T30.0 (TO) | 1544.2 +/- 25 | 1558.2 | -14.0 |
| Lower Walcott Fm | T27.1 (TE) | 1685.2 +/- 25 | 1703.2 | -18.0 |
| Top Miria / Withnell Formations | T10.0 (T) | 2017.2 +/- 25 | 2006.6 | 10.6 |
| Top Toolonga Calcilutite | K60.0 (KS/C) | 2305.2 +/- 30 | 2300.7 | 4.5 |
| Top Haycock | K50.0 (KC) | 2435.2 +/- 30 | 2421.7 | 13.5 |
| Top Muderong Fm | K40.0 (KA) | 2582.2 +/- 30 | 2568.3 | 13.9 |
| Top Forestier Claystone | K20.0 (KV) | 2688.2 +/- 30 | 2673.7 | 14.5 |
| Top Murat Fm | J40.0 (JO) | 2784.2 +/- 35 | 2771.2 | 13.0 |
| Top Mungaroo Fm | TR30.1 (TRR) | 2879.2 +/- 35 | 2860 | 19.2 |
| Intra-Mungaroo Fm | TR27.2_MFS (MCM52) | 3123.2 +/- 30 | 3119.9 | -3.3 |
| Intra-Mungaroo Fm | TR26.7_TS | 3240.2 +/- 30 | 3249.6 | 9.4 |
| Intra-Mungaroo Fm | TR26.1_TS (MCT42) | 3407.2 +/- 40 | 3422.8 | -15.6 |
| Intra-Mungaroo Fm | TR22.7_TS | 3742.2 +/- 40 | 3777.4 | -35.2 |

| | | | | |
|---|---|---|---|---|
| Intra-Mungaroo Fm | TR22.1_TS (MCT12) | 3808.2 +/- 40 | 3855.1 | -46.9 |
| Intra-Mungaroo Fm | MCT11 | 3865.2 +/- 45 | 3899.7 | -34.5 |
| Intra-Mungaroo Fm | TR21.1_TS (MCT5) | 3925.2 +/- 45 | 3967.2 | -42.0 |
| Intra-Mungaroo Fm | TR21.0_SB (MCS2) | 4000.2 +/- 45 | 4043.7 | -43.5 |
| Intra-Mungaroo Fm | TR20.7_TS (TRC2) | 4267.2 +/- 45 | 4327.7 | -60.5 |
| **Total Depth** | **TD** | **4671.2 +/- 50** | **4551.7** | |

*Difference: + deep, - shallow
np:  not picked

# 4. WELL STRATIGRAPHY

Figure 3 and Tables 1 and 3 summarise the stratigraphy seen in Noblige-1. A more detailed lithological and biostratigraphic breakdown is given on the Composite Well Log (Enclosure 1).

The following stratigraphic description is a summary of the lithologies seen in the well, based on their broad lithostratigraphic subdivisions. All depths are given with reference to the Rotary Table (mRT), which is 30.5 metres above sea level (LAT). True vertical depths of the intervals are given on the Well Index Sheet (Table 1).

Sample collection began at 2424 mRT in Noblige-1, with biostratigraphic studies from 2430 mRT (Appendix 1 –Micropalaeontology).

**QUATERNARY to TERTIARY (inferred) Seabed (1342.5 mRT) to 2035.9 mRT (693.4 metres)**

**Recent to Paleocene (inferred)**

*Delambre to Dockrell Formations* *1342.5 to 2035.9 mRT (693.4 metres)*

No samples were collected from this interval. The section is inferred to be Recent to Paleocene in age from correlation with offset wells and has been subdivided into formations (see composite log) based on seismic correlation from nearby wells and log character. The T marker at the base of the section is picked at the base of a characteristic peak on the gamma ray log.

**CRETACEOUS (inferred in part) 2035.9 to 2703 mRT (667.1 metres)**

**Maastrichtian to Campanian (inferred)**

*Miria Marl and Withnell Formation* *2035.9 to 2330 mRT (294.1 metres)*

No samples were collected in this interval. The section is inferred to belong to the Mira Marl and Withnell Formations from correlation with offset wells. The K60.0 (KS/C) marker at the base of the section is picked at the top of the barrel-shaped gamma ray log which is characteristic of the underlying Toolonga Calcilutite.

**Campanian to Aptian (inferred in part)**

*Toolonga Calcilutite, Haycock Marl and Windalia Radiolarite* *2330 to 2597.6 mRT (267.6 metres)*

Sample collection began at 2424 mRT. Above this the section is interpreted to belong to the Toolonga Calcilutite and the Haycock Marl from correlation to offset wells and log character. Below this the Haycock Marl and Windalia Radiolarite consist of calcilutite interbedded with calcareous claystone and claystone. The calcilutites are light greenish grey and contain traces of glauconite and foraminifera. The claystones and calcareous claystones are dark greenish grey and contain traces of pyrite. They contain minor ferruginous material below 2550 mRT.

The base of the section, the K40.0 (KA) marker, corresponds to an abrupt increase in the gamma ray log.

Micropalaeontological data between 2430 and 2475 mRT supports an upper bathyal or deeper environment of deposition (Appendix 1), while the occurrence of abundant Spumellarian radiolaria between 2495 and 2515 mRT is consistent with deposition in a distal marine setting.

**Aptian to Valanginian (inferred)**

*Muderong Shale* *2597.6 to 2703 mRT (105.4 metres)*

The Muderong shale consists of a massive dark to very dark grey claystone with minor interbedded white to pale grey calcilutite between 2650 and 2675 mRT. The claystones become silty with depth. Traces of carbonaceous material, lithic grains and glauconite are present.

The base of the unit, the K20.0 (KV) marker, corresponds to a decrease on the gamma ray log and increase in resistivity.

No biostratigraphic studies were carried out over this interval

**CRETACEOUS to JURASSIC (inferred in part) 2703 to 2846.9 mRT (143.9 metres)**

**Valanginian (inferred) to Berriasian**

*Forestier Claystone* *2703 to 2800.5 mRT (97.5 metres)*

The sequence below the Muderong Shale has been assigned to the Forestier Claystone. It consists of medium to olive grey claystones interbedded with dark grey, silty claystones, which are sideritic in part. The claystones contain traces of carbonaceous material, pyrite and glauconite. The base of the unit, J40.0 (JO) marker, corresponds to sharp decrease on the gamma ray and sonic logs and an increase in resistivity values.

Palynological studies indicate a Berriasian age for the basal part of the formation and a nearshore to offshore marine environment of deposition for the sediments.

**Pleinsbachian to Hettangian**

*Murat Siltstone and North Rankin Beds* *2800.5 to 2846.9 (46.4 metres)*

The sequence of interbedded calcareous claystones, argillaceous calcilutites and calcilutites below the Eliassen Formation have been assigned to the Murat Siltstone and North Rankin Beds. The sediments are light to medium grey and greenish grey and contain traces of glauconite and pyrite. The base of the sequence is the J10.0 (top TR) marker and marks a sharp transition to underlying calcilutites, with a sharp decrease on the gamma ray and sonic logs and a small increase on the resistivity logs.

Micropalaeontological analysis indicates the sediments are Pleinsbachian to Hettangian in age and were deposited in an inner to middle neritic environment. Palynological analysis indicates the same age and a possible brackish marine environment of deposition

**TRIASSIC** **2846.9 to 4581 mRT [TD] (1734.1 metres)**

**Rhaetian**

*Brigadier Formation* *2846.9 to 2889.3 mRT (42.4 metres)*

In Noblige-1 the Brigadier Formation consists of light grey, argillaceous calcilutites, which grade to white calcilutites and are interbedded with minor, medium to dark grey, calcareous claystones. All sediments have traces of pyrite and glauconite. The base of this unit, the TR30.1 (TRR) marker represents the transition from marine to marginal marine depositional environment downhole.

Micropalaeontological analysis of the sediments indicates an inner to middle neritic environment of deposition.

**Norian to Carnian**

*Mungaroo Formation* *2889.3 to 4581 mRT [TD] (1691.7 metres)*

Noblige-1 penetrated 1691.7 metres of Mungaroo Formation. The formation can be divided into series of sandstone rich intervals separated by intervals of fine-grained sediments and coals. The formation is also divided by a series of regional markers, shown on the composite log.

Sandstone rich intervals typically consist of blocky and fining upward sandstones interbedded with silty claystones, claystones and siltstones. The sandstones are generally very fine to fine-grained, fine to coarse in places and contain up to 5% silica and calcite cement. They are argillaceous in part and moderately to well sorted with traces of pyrite and lithic grains. The interbedded claystones are generally thin, silty and contain carbonaceous material and mica. Siltstones are brownish black and carbonaceous. The petrophysical properties of the sandstone rich intervals is discussed in more detail in the Petrophysical Report (Appendix 3) and in Section 5.3 below.

The intervals of fine-grained sediments typically comprise interbedded silty claystones, claystones, siltstones and minor, thin, fine-grained sandstones and coals. The claystones and silty claystones are generally brownish grey to brownish black and olive grey and contain carbonaceous material and very fine mica, while the siltstones are brownish black and carbonaceous in part and grade to silty claystone. Coal beds are less than 5 metres thick, brownish black to black and silty in part.

Palynological analysis indicates a marginal marine depositional environment for the Mungaroo Formation sediments down to about 2935 mRT and a non-marine, to in places possibly marginal marine, depositional environment below that.

# 5. PROSPECT EVALUATION

## 5.1 Trap

Noblige-1 tested multiple levels within a 4-way dip Triassic structure formed as part of a late North-South trending inversion event. The structure is approximately 15km$^2$ in area and contains six hydrocarbon bearing intervals defined by bright seismic amplitudes. The Noblige structure is intersected by several small east west faults with approximately 10 metres of throw. The structure sits within a larger 3-way dip structure (~90km$^2$) closing against the large Martell Fault to the west.

## 5.2 Seal

Ultimate top seal for the Mungaroo Formation is provided by calcilutites of the Brigadier Formation, overlain by the Murat/Athol Formations and the Forestier Claystone. The same interval provides a good top seal at Martell-1 (113m gas column) and Chandon-1 (195m gas column). The six interpreted gas columns intersected in Noblige-1 are sealed by intra-formational claystones and siltstones of the Mungaroo Formation.

The Noblige structure does not require lateral fault seal, and it appears that each gas column spills when the 4-way dip structure intersects the fault separating Noblige from the Martell Horst. This observation is consistent with both seismic amplitudes and pressure data.

No leakage indicators (gas chimney) are interpreted in the immediate area.

## 5.3 Reservoir

The primary reservoir objective for the Noblige-1 well was Triassic aged Mungaroo Formation sandstones. These sandstones were deposited by dominantly fluvial processes in an upper/lower delta plain environment. Channel sands have been intersected at Martell-1 and in all other Mungaroo tests in the vicinity. In addition, numerous channel belts, which trend dominantly east west, can be observed on the Colombard 3D data. These channel belts vary from 1-5 km in width and are similar to channel belts observed intersecting the Chandon-1 well on the Chandon 3D. High amplitude events within the Noblige structure indicate the presence of high net-to-gross intervals which are gas saturated.

Petrophysical analysis indicates 592.8 metres of net reservoir over the total Mungaroo Formation, with an average sandstone porosity of 18.6%. Six individual gas-bearing intervals were encountered, at 3281 mRT, 3808 mRT, 3884 mRT, 3929 mRT, 3996 mRT and 4080 mRT. Approximately 121m of this gas bearing section is considered to be net, with the sands having an average log derived porosity of 15.6% and permeabilities of 194mD. These estimates are based on petrophysical log data and pressure sampling (MDT) observations. An average gas saturation of 53% is calculated from the log data. Based on the above, the sands penetrated by Noblige-1 are expected to form a good quality reservoir for gas production. A detailed petrophysical analysis of the hydrocarbon bearing intervals is found in the Appendix 3.

A petrological study is being undertaken on SWC and MSCT samples but the results were

unavailable at the time of compiling this report.

Image log data is currently being processed and the raw data is found in the digital data folder attached to this well completion report. The final report will be forwarded when the study is complete.

## 5.4 Charge

Charge was a low risk for the Noblige prospect due to the close proximity to the Martell gas discovery. The charge migration is interpreted to be a combined vertical and lateral charge from mature intra-Mungaroo Triassic source rocks.

A Mungaroo Formation source, from lower delta plain coals and carbonaceous shales, is demonstrated by high Total Organic Carbon and moderate Hydrogen Indices measurements from rock samples taken in Noblige-1. Charge modelling in the Noblige area also demonstrated the Mid Triassic, Carnian section is within the gas expulsion window. A maturity above 0.9 % Vr is reached during the Tertiary; however, the low burial rates through the Cretaceous and Tertiary suggest low expulsion rates. Low expulsion rates require efficient migration and trapping in order to accumulate and preserve a significant accumulation. The presence of hydrocarbons in the Noblige structure implies charge into the area.

# 6. PETROPHYSICAL EVALUATION AND CORE ANALYSIS

## 6.1 Petrophysics

Petrophysical analyses were carried out over the Triassic-aged Mungaroo Formation sands in the Noblige-1 well. Wireline logs were successfully run over the entire open hole section, including NMR, sidewall rotary and percussion cores, formation pressure tests and fluid samples.

Across the Mungaroo Formation, 593 metres of net sand was interpreted, with a Net to Gross for the total interval of 35 %, an average porosity of 18.6 % for the sandstones and an average permeability of 247 mD. There is considerable variation in properties over this 1693m interval and details of the individual zones can be found in the Petrophysics Report, Appendix 3.

Six distinct gas columns have been interpreted, with 101.6m of pay interpreted over these six intervals. Porosity values range from 13.8% to 24% in these sandstones.

## 6.2 Coring

No conventional cores were cut in Noblige-1.

# 7. HYDROCARBONS

## 7.1 Occurrence

Chromatographic breakdowns of the ditch gas, total gas and trip gas were recorded from 2424 to 4581 mRT in Noblige-1 (Noblige-1 Well Completion Report Basic Data). Excluding trip and connection gas, maximum recorded ditch gas during drilling was 26% at a depth of 3944 mRT, ranging from C1 to C5. Hydrocarbon fluorescence was described from ditch cuttings and sidewall samples over several intervals in Noblige-1 and is summarized in the table below.

Table 4: Hydrocarbon Fluorescence Summary

| Depth (mRT) | Summary of Fluorescence Description |
|---|---|
| *Ditch Cuttings* | |
| 3995-4065 | Trace dull yellow pin-point fluorescence associated with rock fluorescence only, nil to very slow, blue white diffuse cut, very slow bleeding dull cut, moderate thick, occasionally patchy, blue white residual ring |
| 4070-4080 | Minor to common dull to moderately bright yellow pin-point - even direct fluorescence, nil to slow dull to moderately bright blue white diffuse cut, very slow streaming cut, thin moderate bright blue white residual ring. |
| 4080-4110 | Minor dull to green yellow pin-point to even direct fluorescence, nil to slow dull to moderate bright blue white diffuse cut, very slow blooming cut, thin and thick patchy dull green yellow residual ring, decrease with depth to trace dull to green yellow pin-point direct fluorescence, no cut. |
| 4140-4165 | Nil to trace yellow gold pin-point direct fluorescence, slow diffuse white cut. |
| *Sidewall Cores (SWC)* | |
| 4077 | 100% dull to moderately bright green yellow even natural fluorescence, trace very slow diffuse to bleeding dull blue cut, moderately thick blue residual ring. |
| 4171 | 100% dull yellow gold natural fluorescence, very slow, diffuse blue milky cut, thin to patchy blue white residual ring. |
| *Sidewall Cores (MSCT)* | |
| 3956.01, 3995.53, 4006.03, 4093.03, 4251.01, 4342.51 | 100% Dull even yellow green / white fluorescence, fast to moderately fast moderately bright white/blue cut; no crush cut, moderately thin moderately bright white residual ring under UV light. |
| 3889.03, 3932.98, 3945.5, 4373.01, 4545.02, 4454, 4335, 4185.5, 4103.99, 4097.99, 4074.01 | 60-100% Moderate yellow green / bright yellow patchy-even fluorescence, very slow diffuse white/blue cut; no crush cut, very thin dull white residual ring under UV light. |

## 7.2 Geochemical Analysis and Maturation Studies

A series of figures relating to geochemical analyses can be found in Appendix 4, the Fluid Inclusion Studies Report can be found in Appendix 5 and the Vitrinite Reflectance results can be found in Appendix 6.

**Source rock screening**

Forty two cuttings and side-wall core (SWC) samples were analysed for total organic carbon (TOC) and by Rock-eval Pyrolysis. Cretaceous to Triassic aged sediments have a maximum TOC of 28.3% and average of 2.9%. All samples underwent basic solvent (hot-water)

extraction to remove glycols. The majority of samples exhibit fair to rich gas prone source rock potential with TOC's < 3% and hydrogen indices (HI's) around 200mg/g TOC. Where TOC's are greater than 3%, the samples have a wide spread of HI indicating some liquids potential.

Sixteen SWC and cuttings samples were selected for vitrinite reflectance (Ro) analysis. A maximum maturity of 0.76% Ro was recorded at the base of the well (Cuttings sample 4575-4581m). Most samples have large well-defined vitrinite populations. The top of the section sampled lies at or very close to the top of the oil window. The vitrinite reflectance gradient is relatively low so the deepest sample is mid-mature for oil generation indicating that the zone of oil generation is relatively thick in this well. Liptinite is absent to common and is dominated by sporinite although cutinite is also a distinctive component. Vitrinite is more abundant than inertinite in the coals, but within the dispersed organic matter inertinite tends to be more abundant than vitrinite.

**Fluids analysis**

The analyses carried out included:

- Rig-site mud gas anlaysis
- Mud gas carbon isotope analysis (Isotubes)
- Analysis of gas and condensate from wireline samples
- Source-rock extract analysis

Two hundred and thirty six (236) mud gas samples in Isotubes were collected while drilling Noblige-1. These samples were sent to Geotechnical Services for mud gas compositional and carbon isotope analysis. One hundred and seventy six (176) Isotubes were selected for analysis. The results showed that the Noblige gases have similar ethane and propane carbon isotope ratios, which is characteristic of Mungaroo Formation coal sourced gases. Mud gas isotope analysis in combination with rig-site mud gas data indicates lower maturity thermogenic gas shows in the Cretaceous section from 2600 to 2800mRT. A diffusion or mixing trend is evident in the methane isotope profile from 3000 to 3300mRT. There is a remarkably uniform methane isotope signature (~ -36 per mil) through ~1.2km of vertical Triassic section below ~3300mRT, despite the presence of intra-formational seals. There is some evidence of isolated, higher maturity gas in a sand below the TR22.0 (Tr-MSC10) marker and at the base of the well.

One hundred and ninety four (194) headspace gas samples were also collected in Isojars. These samples were also sent to Geotechnical Services for analysis. Ninety eight (98) samples were selected for compositional analysis, however no further isotope analyses were carried out.

Eleven wireline fluid samples were obtained from four depths with the RCI tool. Sample 1 was taken primarily to identify fluid type. It was found to be 92% water-based mud (WBM) filtrate. The water was flashed to standard conditions and a small volume of gas was evolved (2.5scf/bbl). The remaining samples were all taken from gas zones. The gas samples and compositional analysis by Corelab were generally of a high quality. The bulk fluid composition of the Noblige-1 samples is as follows: methane content is 84 mole%, carbon dioxide content ranges from 0.4 – 3 mole% (increasing with depth), nitrogen content ranges from 5.1 to 6.4 mole%, and ideal condensate gas ratios (CGR) range from 13 – 24 barrels of condensate per million standard cubic feet of gas (bbl/MMscf). Contamination by water based mud was not an issue. However, the samples appear to have a small amount of contamination, which is believed to be a hydraulic fluid associated with the RCI tool called sebacate, which has a similar gas chromatographic retention time to *n*-C28. Gas

subsamples were taken for geochemical analysis from samples 4, 6, 8 and 10. Gas samples were sent to Isotech Laboratories in the USA (via Geotechnical Services, Perth) for gas compositional and isotope analysis. The results showed that the Noblige gases have similar ethane and propane carbon isotope ratios, which is characteristic of Mungaroo Formation coal sourced gases. The methane isotopes were also consistent with Mungaroo Formation gas.

Condensate was collected after blowing down one sample from each of the four depths. These were sent to Geotechnical Services for geochemical analysis, and subsequently sent to Kernow Analytical Technology in the UK for wax testing. Geochemical analysis of the condensate confirmed the presence and identification of the sebacate contaminant. The wax testing produced some anomalous results, for example unusual and highly variable wax appearance temperatures. It is possible the wax testing of the condensate has been affected by the presence of the sebacate contaminant.

Extracts of Mungaroo Formation. coaly shales in Noblige are mixtures of indigenous (natural) hydrocarbons and Saraline OBM contamination. The latter is restricted to the boiling range below about *n*-$C_{19}$. Noblige-1 was drilled with Perflex WBM, however there is minor contamination with SBM (Saraline) which remained resident in the Jack Bates mud pits from a previous well. Despite the contamination, the indigenous hydrocarbons represent a non-waxy, typical condensate pattern. A summary of the extract data is as follows:

- High Pr/Ph (>3) indicates terrigenous organic matter input under oxic conditions for all but the shallowest sample
- The Pr/Ph ratio = 2.74 for the shallower sample could be indicative of a more marine setting (given the location of the sample in the stratigraphic section) or could be affected by the mud contamination
- Pr/n-C17 > 0.6 indicates terrigenous organic matter
- Pr/n-C17 and Ph/n-C18 should decrease with thermal maturity as more *n*-alkanes are generated from kerogen by cracking, here, the mud contamination effects the parameters
- The odd over even preference for the sample at 3805m cf. the sample at 4575m and CPI (carbon preference index: odd over even) > 1 indicates low thermal maturity, a CPI ~ 1 for the sample at 4575m indicates rock extract is thermally mature, this is in agreement with the Vitrinite Reflectance data for these samples

## Maturity data from Spore Colour

Apart from vitrinite reflectance measurements, maturity data were generated in the form of Spore Colour Index for the well. The uppermost sample studied at 2789.2 mRT is marginally mature for oil generation, with samples becoming early mature for oil from a depth of 3270 mRT and mature from a depth of 4305 mRT. Samples are immature for gas/condensate production to a depth of 3720 mRT and from there to 4581 mRT are early marginal mature for gas/condensate production. Further details on the spore colour studies can be found in Appendix 2.

# 8. FORMATION TESTING

## 8.1 Formation Pressure Testing and Fluid Sampling

Two runs were carried out with the Baker Atlas Modular Dynamic Tester (RCI). Forty three valid pressure points were obtained from 124 attempts over the interval 2950 to 4538.6 mRT. Eleven fluid samples were obtained as listed below. A full list of pressures and samples can be found in Appendix 19 of the Noblige-1 Well Completion Report (Basic Data) and the results of gas analyses and condensate characterization can be found in Appendix 18 of the same report. A PVT report by Core Laboratories is also included in the basic data report.

Table 5 : RCI Fluid Samples

| Sample No. | Depth (mRT) | Chamber Size | Interpreted Fluid |
|---|---|---|---|
| 1 | 4374.2 | 1 x 560cc | filtrate |
| 2, 3, 4 | 3932.48 | 3 x 560cc | gas |
| 5, 6, 7 | 3286.81 | 3 x 560cc | gas |
| 8, 9 | 3812.5 | 2 x 560cc | gas |
| 10, 11 | 4097.5 | 2 x 560cc | gas |

## 8.2 Production Testing

No production testing was performed on the Noblige-1 well.

# 9. CONTRIBUTIONS TO GEOLOGICAL KNOWLEDGE

Noblige-1 was drilled as an exploration well in southern WA-404-P. The well was drilled vertically to evaluate multiple levels within the Triassic Mungaroo Formation in a 4-way dip closure with an areal closure of approximately 15 $km^2$ at Top Mungaroo Formation (TRR) level. Pre-drill, several bright amplitudes were observed on seismic data.

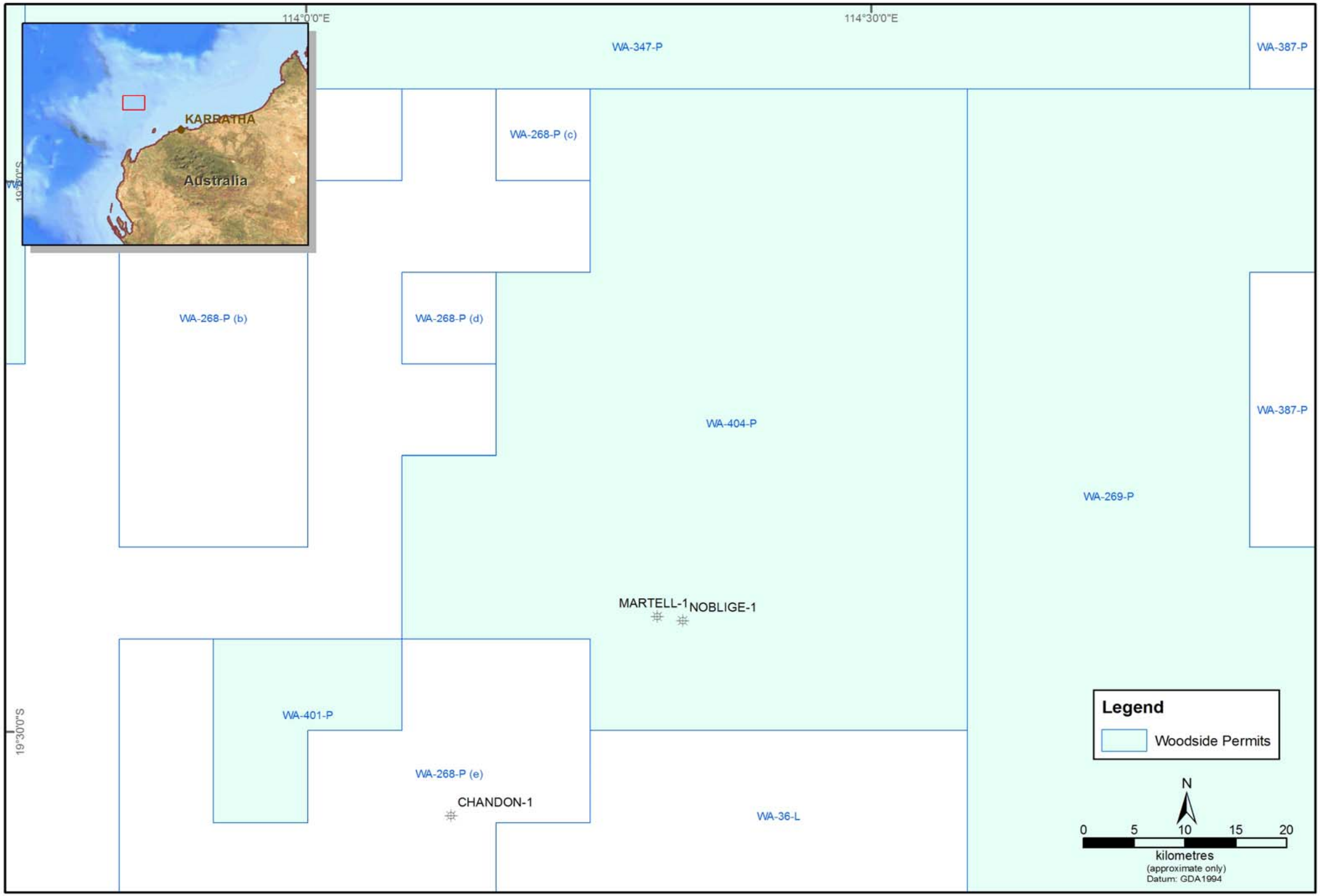
Noblige-1 encountered six individual hydrocarbon-bearing intervals at 3281 mRT, 3808 mRT, 3884 mRT, 3929 mRT, 3984 mRT and 4080 mRT. The interpretation of hydrocarbon columns is based on gas shows while drilling, good quality petrophysical log data, wireline pressures and gas samples. Formation pressures recorded in gas sands at Noblige-1 lie on different gradients indicating 6 separate gas columns. No water gradients were obtained below the main gas interval, however “gas on rock” depth indicates a normally pressured aquifer gradient.

Well results indicate:

- Multiple hydrocarbon columns with separate GWC closely coinciding with the 4-way dip closures and bright seismic amplitudes.
- The Mungaroo Formation contains claystones/siltstones which act as effective top seals. These seals are commonly less than 5m thick.
- There is no evidence that Mungaroo / Mungaroo cross fault seal is effective. Hydrocarbon columns are restricted to the 4-way dip closures.
- The fluvial sandstones of the Triassic Mungaroo Formation have excellent reservoir quality; with porosity ranging from 11 to 24%, a net-to-gross ranging from 32 to 68% and excellent inferred permeability over the gas zone.
- The gas-bearing intervals include both amalgamated channel sands (>30 m thick) and individual channel sands (<10 m thick).
- Amalgamated gas filled channel sands can be observed on seismic.
- A total of ten gas samples (three from 3932.48 mRT, three from 3286.81 mRT, two from 3812.5 mRT and two from 4097.5 mRT) were recovered to surface from a single wireline RCI run. The composition of the gas samples are summarised below:
    - **3286.81mRT**: CO2 content is 0.4 - 0.5 mole%, N2 content is 5.7 - 5.8 mole%, and ideal CGR is 22 - 24 bbl/MMscf
    - **3812.5mRT**: CO2 content is 2.2 - 2.3 mole%, N2 content is 5.1 mole%, and ideal CGR is 18 - 19 bbl/MMscf
    - **3932.48mRT**: CO2 content is 3.1 mole%, N2 content is 5.3 mole%, and ideal CGR is 13 - 16 bbl/MMscf
    - **4097.5mRT**: CO2 content is 3.2 - 3.3 mole%, N2 content is 6.3 - 6.4 mole%, and ideal CGR is 19-20 bbl/MMscf

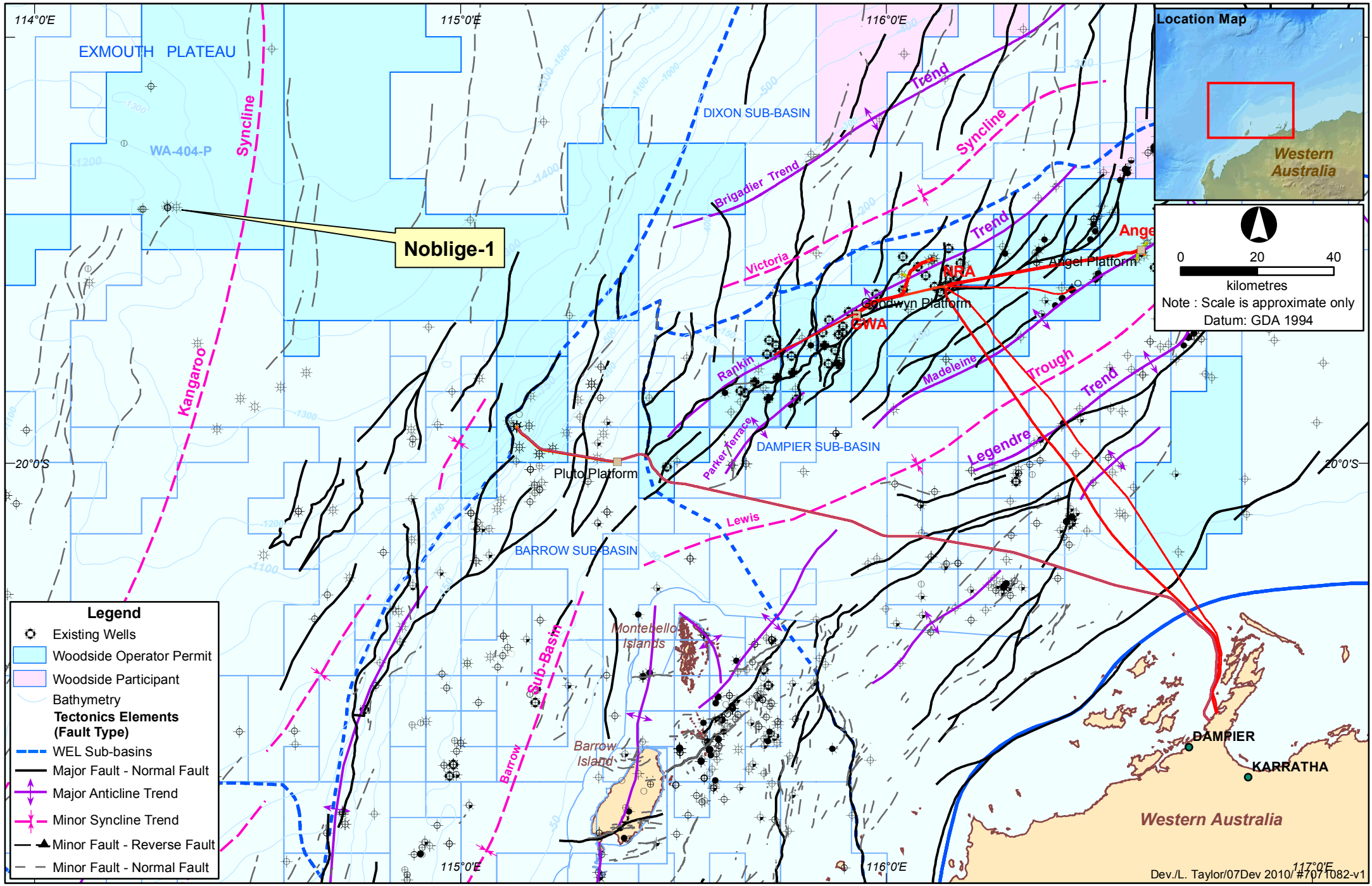
# 10. BIBLIOGRAPHY

1. Well Proposal, Noblige-A, WA-404-P, Exmouth Plateau WEL, November 2009;
2. Noblige-1 Well Completion Report, Basic Data; WEL, February 2011




woodside

**Figure 1 : Noblige-1 Location Map, WA-404-P**




**NOBLIGE-1 – TECTONIC ELEMENTS AND LOCATION MAP : WA-404-P**

woodside

Figure 2

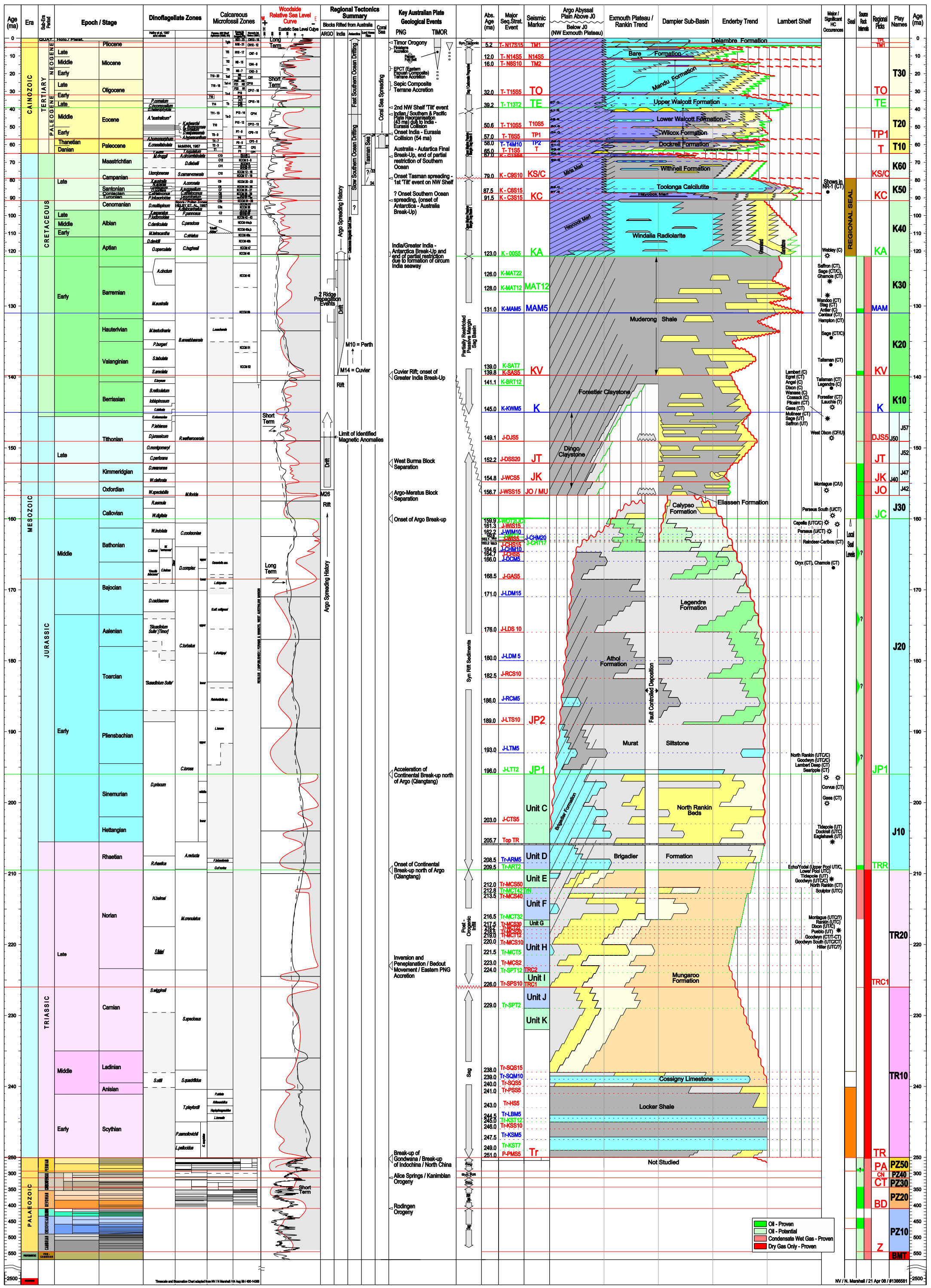



**FIGURE 3 : EXMOUTH PLATEAU-DAMPIER SUB-BASINS CHRONOSTRATIGRAPHIC SCHEME**

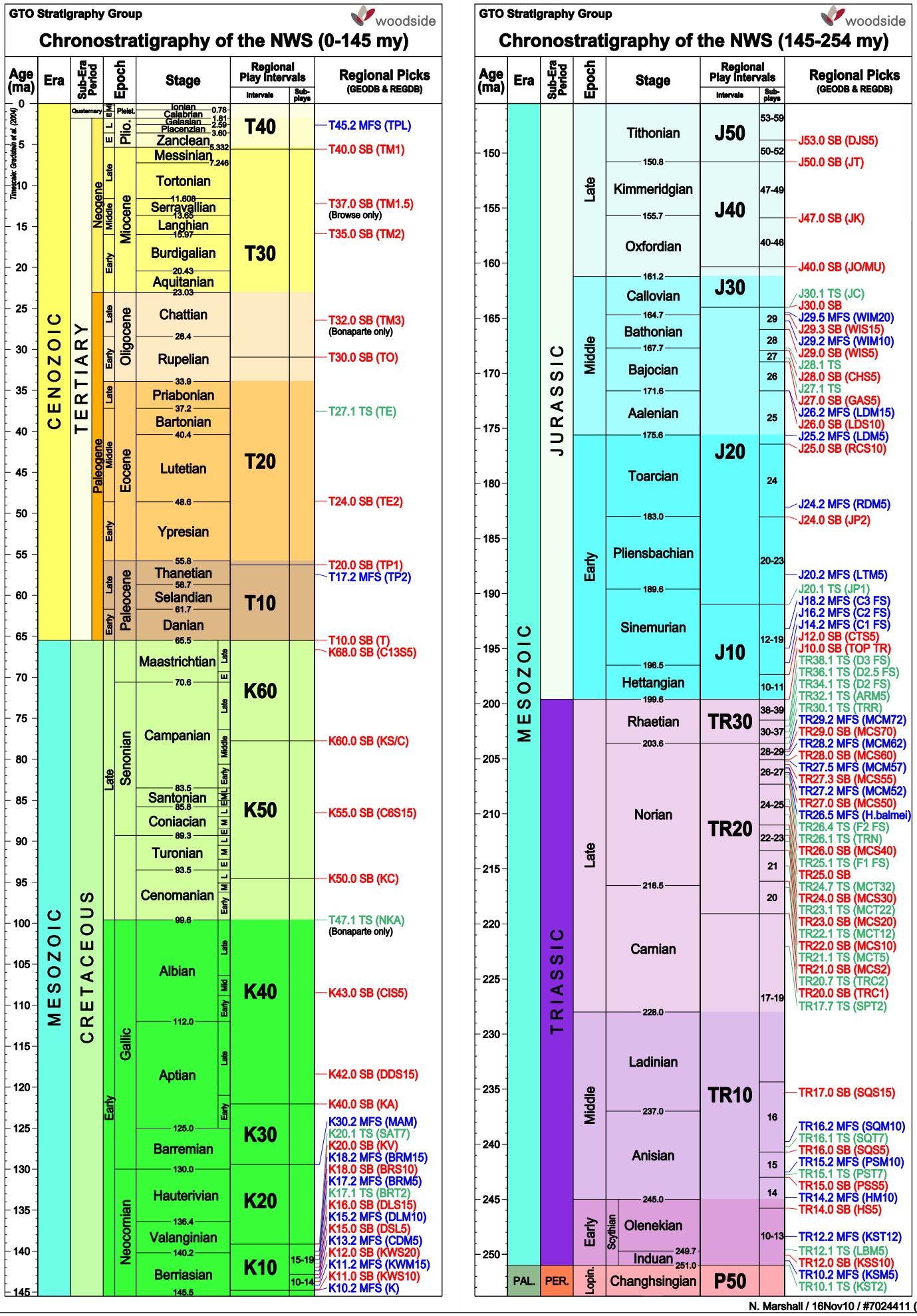



**FIGURE 4 : CHRONOSTRATIGRAPHY OF THE NORTH WEST SHELF (REVISED NOMENCLATURE)**

woodside

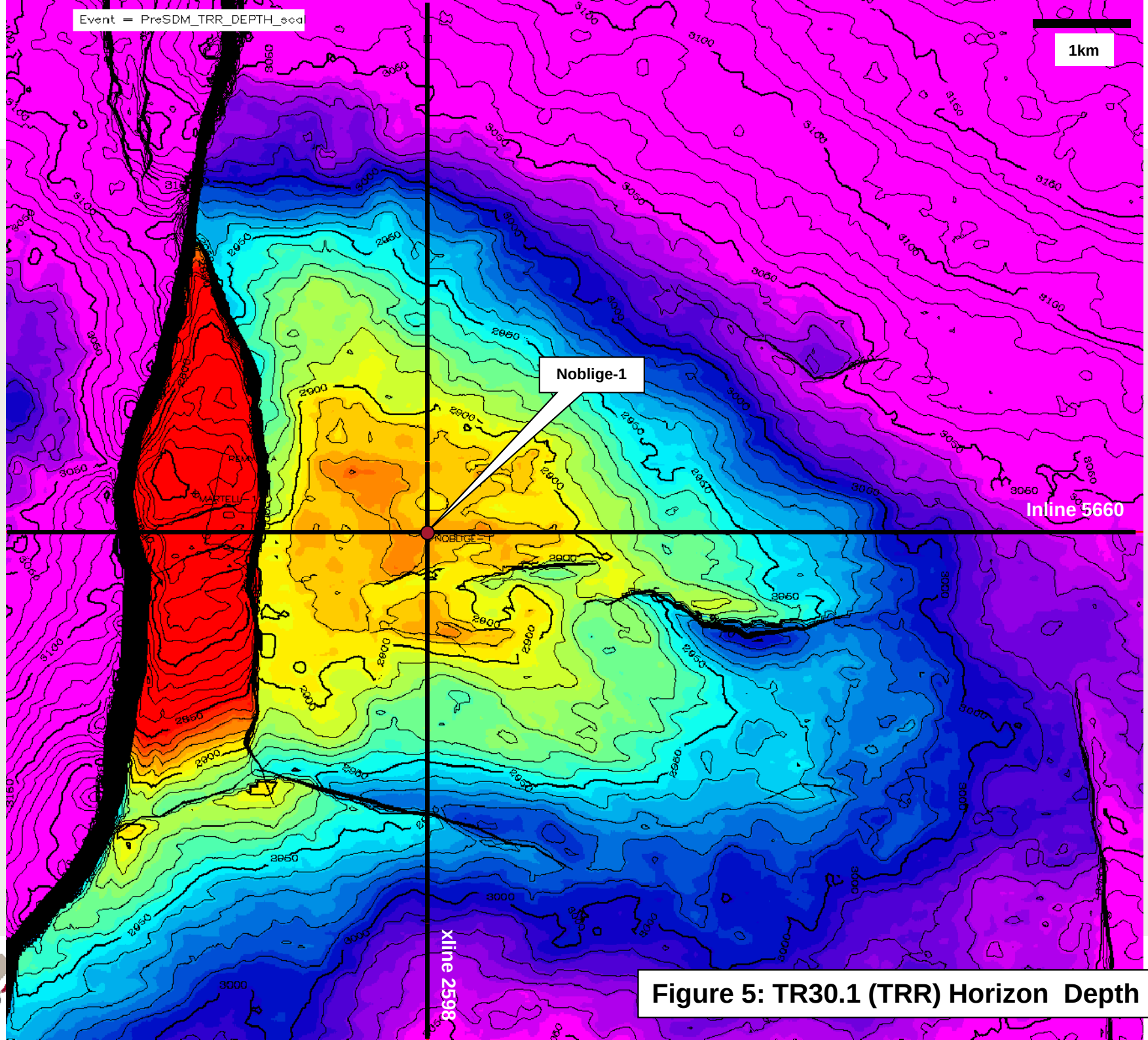



**Figure 5: TR30.1 (TRR) Horizon Depth Map**

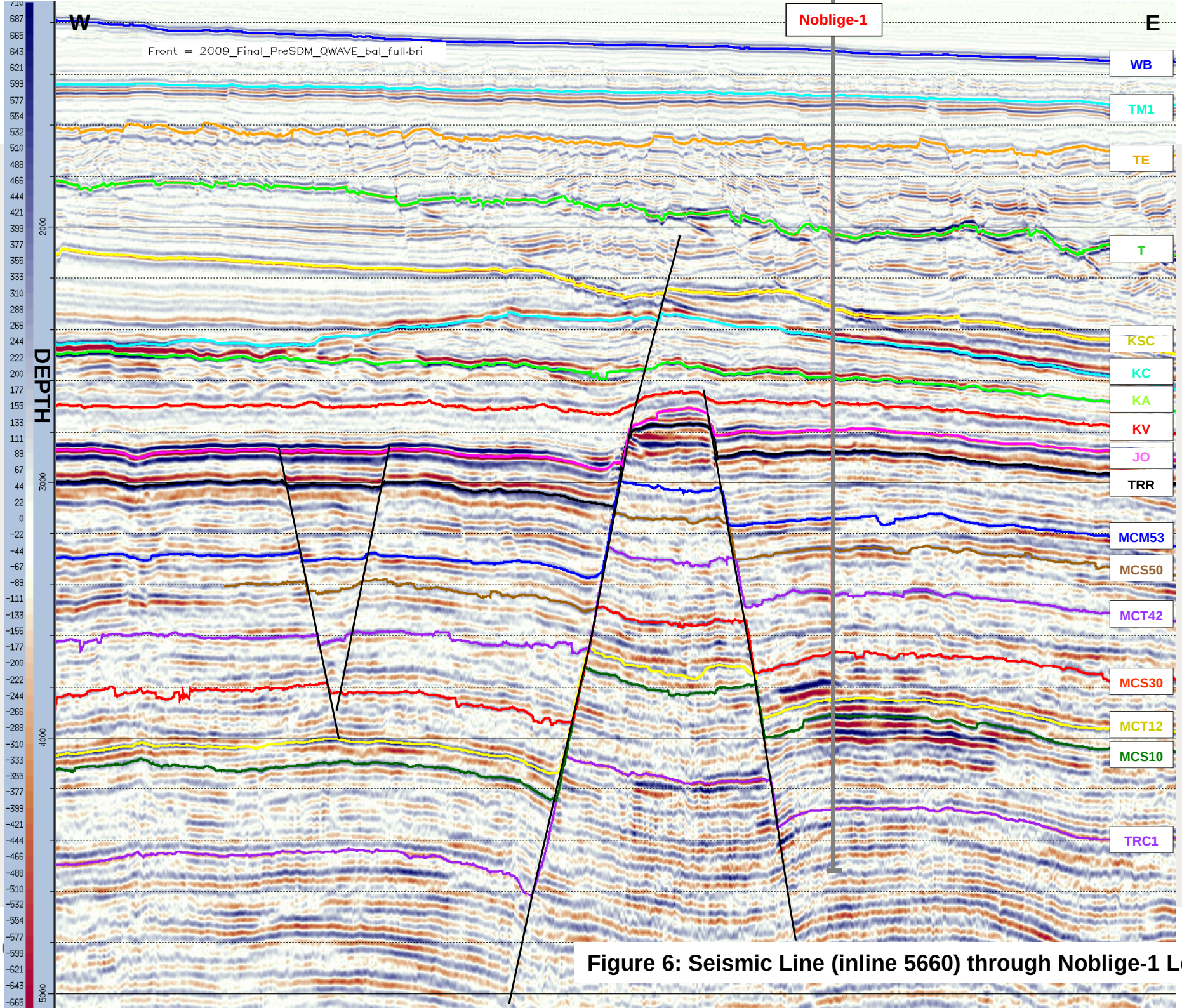



**Figure 6: Seismic Line (inline 5660) through Noblige-1 Location**

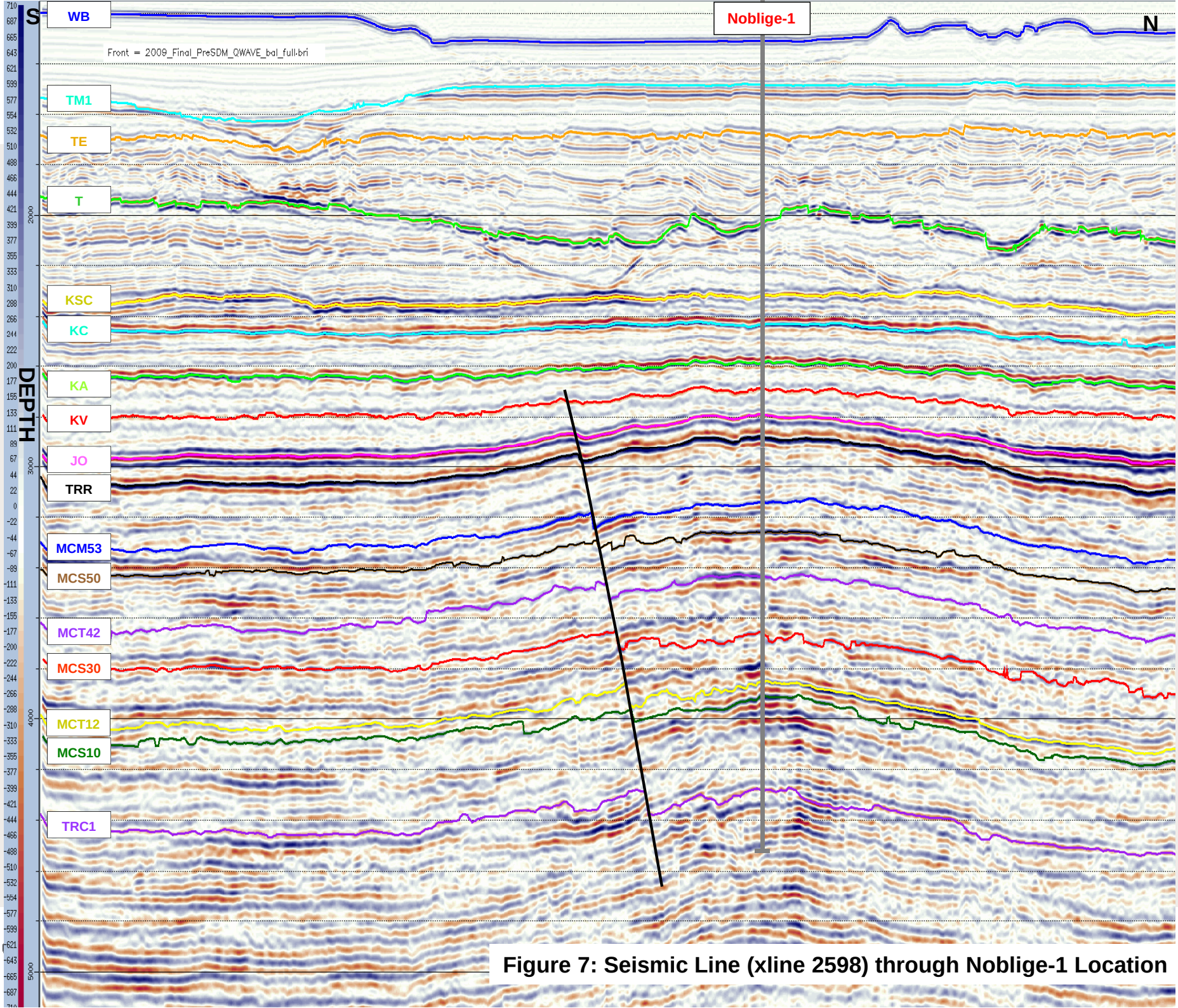



**Figure 7: Seismic Line (xline 2598) through Noblige-1 Location**

Enclosure 1

# Composite Well Log

## Noblige-1

1:1000

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Well Name:** | Noblige-1 | **Rig Name and Number:** | Jack Ward Drilling Barge | **Date on Location:** | 2 January 2010 | **Rig:** | Jack Ward |
| **Operator:** | Woodside Energy Ltd | **Drilling Contractor:** | Jack Ward Drilling | **Date Spud:** | 2 January 2010 | **Drilling Contractor:** | Jack Ward Drilling |
| **Location:** | Victoria | **Drilling Type:** | Vertical | **Date Reached TD:** | 4 January 2010 | **Drilling Fluid:** | Seawater/Gel |
| | | | | **Date Rig Released:** | 4 January 2010 | **Casing Program:** | 30in@150m |
| | | | | **Date Well Completed:** | 4 January 2010 | **Total Depth:** | 1000.0 mRT |
| | | | | | | **Suspended/Abandoned:** | Suspended |
| **Latitude:** | 38° 37' 24.000"S | **Total Depth:** | 4551.487 | **Well Status:** | Suspended | **Outside Sponsorship:** | |
| **Longitude:** | 142° 58' 48.000"E | | | | | | |
| **Datum:** | GDA94 | | | | | | |
| **Water Depth:** | 70.000 m | | | | | | |
| **Rig Elevation:** | 21.000 m (Above MSL) | **Cement Plugs:** | 2030-2000 mRT | | | **Drilling/Fitting Drilling Material:** | Drilling Fluid |
| | | | 2000-1900 mRT | | | | Gravel |
| **Distance Line:** | Calculated 30 metres MAT, 30 cm SAT | | | | | | |

**Author:** J. Tubb

### WIRELINE LOGGING DATA

| Run No. | Log | Date | Time Arrival | Time Commence | Time Finish | Logged Interval (m) | Log Type | Tool Type | Tool Serial No. | Tool Length (m) | Max Temp (°C) | Max Deviation (°) | Log Quality | Logging Company | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gamma Ray | 12-1-10 | 0800 | 0800 | 0900 | 0-150 | Open Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 2 | Gamma Ray | 12-1-10 | 0900 | 0900 | 1000 | 0-150 | Open Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 3 | Dual Induction | 12-1-10 | 1000 | 1000 | 1100 | 150-1000 | Open Hole | DIT | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 4 | Compensated Sonic | 12-1-10 | 1100 | 1100 | 1200 | 150-1000 | Open Hole | BHC | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 5 | Gamma Ray | 12-1-10 | 1200 | 1200 | 1300 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 6 | Compensated Neutron | 12-1-10 | 1300 | 1300 | 1400 | 150-1000 | Open Hole | CNT | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 7 | Gamma Ray | 12-1-10 | 1400 | 1400 | 1500 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 8 | Vertical Seismic Profile | 12-1-10 | 1500 | 1500 | 1600 | 150-1000 | Open Hole | VSP | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 9 | Gamma Ray | 12-1-10 | 1600 | 1600 | 1700 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 10 | Sidewall Core | 12-1-10 | 1700 | 1700 | 1800 | 150-1000 | Open Hole | SWC | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 11 | Gamma Ray | 12-1-10 | 1800 | 1800 | 1900 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |

### MWD

| Run No. | Log | Date | Time Arrival | Time Commence | Time Finish | Logged Interval (m) | Log Type | Tool Type | Tool Serial No. | Tool Length (m) | Max Temp (°C) | Max Deviation (°) | Log Quality | Logging Company | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gamma Ray | 12-1-10 | 1900 | 1900 | 2000 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 2 | Formation Pressure | 12-1-10 | 2000 | 2000 | 2100 | 150-1000 | Open Hole | FMT | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 3 | Gamma Ray | 12-1-10 | 2100 | 2100 | 2200 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 4 | Vertical Seismic Profile | 12-1-10 | 2200 | 2200 | 2300 | 150-1000 | Open Hole | VSP | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 5 | Gamma Ray | 12-1-10 | 2300 | 2300 | 2400 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 6 | Sidewall Core | 12-1-10 | 2400 | 2400 | 2500 | 150-1000 | Open Hole | SWC | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 7 | Gamma Ray | 12-1-10 | 2500 | 2500 | 2600 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 8 | Formation Pressure | 12-1-10 | 2600 | 2600 | 2700 | 150-1000 | Open Hole | FMT | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 9 | Gamma Ray | 12-1-10 | 2700 | 2700 | 2800 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 10 | Sidewall Core | 12-1-10 | 2800 | 2800 | 2900 | 150-1000 | Open Hole | SWC | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |
| 11 | Gamma Ray | 12-1-10 | 2900 | 2900 | 3000 | 0-150 | Cased Hole | GR | | 0.00 | 0.00 | 0.00 | Good | Schlumberger | |

### CASING AND HOLE RECORD

| Casing Type | Casing Size (in) | Casing Depth (m) | Hole Size (in) | Hole Depth (m) |
|---|---|---|---|---|
| Conductor | 30 | 150.0 | 36 | 150.0 |
| Surface | 13 3/8 | 1000.0 | 17 1/2 | 1000.0 |

| Casing Type | Casing Size (in) | Casing Depth (m) |
|---|---|---|
| Cement Plug | | 2030.0 |
| Cement Plug | | 2000.0 |
| Cement Plug | | 1900.0 |

### SAMPLE RECORD

| Type | Interval (m) | Quantity | Comments |
|---|---|---|---|
| Cuttings | 0-1000 | 1000 | 10 m samples collected |
| Sidewall Core | 1000-2900 | 190 | 190 Sidewall Core samples collected |
| Fluid | 1000-2900 | 1 | Fluid sample collected at 1000 m |

### FORMATION TOPS

| Formation | Depth (m) | Depth (mRT) |
|---|---|---|
| Top Gippsland Limestone | 0.000 | 0.000 |
| Top Lakes Entrance Formation | 1000.000 | 1000.000 |
| Top Mitchell River Group | 1000.000 | 1000.000 |
| Top Emperor Subgroup | 1000.000 | 1000.000 |
| Top Golden Beach Subgroup | 1000.000 | 1000.000 |
| Top Latrobe Group | 1000.000 | 1000.000 |
| Top Gurnard Formation | 1000.000 | 1000.000 |
| Top Longford Subgroup | 1000.000 | 1000.000 |
| Top Halibut Subgroup | 1000.000 | 1000.000 |
| Top Cod Subgroup | 1000.000 | 1000.000 |
| Top Flounder Formation | 1000.000 | 1000.000 |

### WIRELINE FLUID SAMPLES

| Sample No. | Run No. | Depth (m) | Comments |
|---|---|---|---|
| 1 | 2 | 1000.000 | |
| 2 | 2 | 1000.000 | |
| 3 | 2 | 1000.000 | |
| 4 | 2 | 1000.000 | |
| 5 | 2 | 1000.000 | |
| 6 | 2 | 1000.000 | |
| 7 | 2 | 1000.000 | |
| 8 | 2 | 1000.000 | |
| 9 | 2 | 1000.000 | |
| 10 | 2 | 1000.000 | |
| 11 | 2 | 1000.000 | |

### PRODUCTION TESTS

| Interval (m) | Test Type | Duration (hrs) | Choke Size (mm) | Oil (bbl/day) | Condensate (bbl/day) | Gas (MMscf/day) | Water (bbl/day) | CO2 (%) | H2S (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

### KEY

**Rock Types**

Limestone, Calcarenite, Calcilutite, Calcirudite, Coquina, Calcareous claystone, Marl, Claystone, Siltstone, Claystone, Siltstone, Sandstone, Coal, Coal seam, Conglomerate, Igneous, Basalt, Volcanics, Intrusive, Metamorphic, Unknown

**Cements/Matrix**

Calcite, Dolomite, Siderite, Anhydrite, Gypsum, Halite, Glauconite, Pyrite, Hematite, Carbonaceous, Argillaceous, Siliceous, Unknown

**Accessories**

Coal, Carbonaceous material, Glauconite, Pyrite, Mica, Bioturbation, Carbonaceous laminae, Fossils, Lithic fragments, Quartz, Feldspar, Glauconite, Volcanic glass, Unknown

**Fossils**

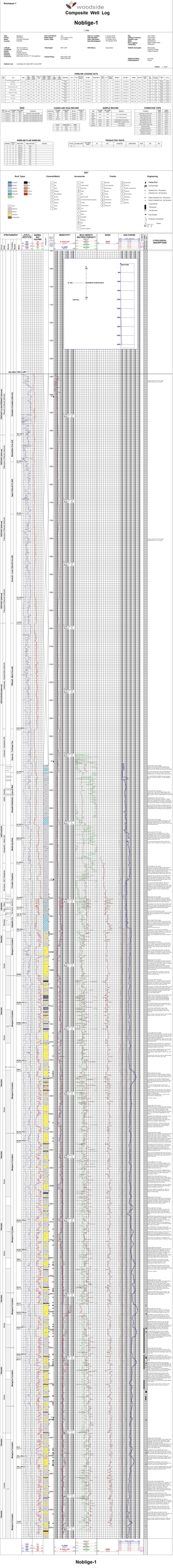
Foraminifera, Coralline algae, Molluscs, Echinoderms, Bryozoans, Brachiopods, Corals, Sponges, Gastropods, Bivalves, Cephalopods, Crinoids, Echinoids, Ostracods, Belemnites, Serpulids, Unknown

**Engineering**

Casing Shoe, Casing Weight, Casing Hanger, Sidewall Core - Recovered, Sidewall Core - No Recovery, Rotary Sidewall Core - Recovered, Rotary Sidewall Core - No Recovery, Conductivity, Recovered, Not Recovered, No Recovery, Fluid Sample, Production Test Interval, Survey

**Survey**

Inclination, Azimuth, Magnetic Declination, Total Field, Dip, Gravity, Drift, Error




## Noblige-1

4551 mRT

# Micropalaeontology Report

# MICROPALAEONTOLOGICAL ANALYSIS OF NOBLIGE-1, WA-404-P, EXMOUTH PLATEAU

FOR

Woodside Energy Ltd

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August, 2010

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# C O N T E N T S

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II. INTRODUCTION

III. BIOSTRATIGRAPHIC ANALYSIS

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(B) Planktonic Foraminiferal Subdivision
(C) Calcareous Nannofossil Subdivision
(D) Integrated Biostratigraphic Subdivision

IV. ENVIRONMENT OF DEPOSITION

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APPENDIX NO. 1
Summary of micropalaeontological sample analysis, Noblige-1.

APPENDIX NO. 2
Micropalaeontological distribution chart, Noblige-1.

# I. SUMMARY

A summary of the biostratigraphic breakdown of the respective microfossil groups and environment subdivision is given below:-

### Benthonic Foraminiferal Subdivision

| Depth Range (m) | Zone | Age |
|---|---|---|
| 2430/40 – 2510/15 | indeterminate | indeterminate |
| 2800/05 – 2840/45 | Lingulina tenera | Pliensbachian - Hettangian |
| 2850/55 – 2870/75 | unassigned | Rhaetian |

### Planktonic Foraminiferal Subdivision

| Depth Range (m) | Zone | Age |
|---|---|---|
| 2430/40 | KPF10 or older | Santonian – Late Coniacian or older |
| 2440/50 | KPF13 | Late Turonian |
| 2460/65 | KPF14 – KPF16 | Middle Turonian – Late Cenomanian |
| 2470/75 | KPF17 or older | Late Cenomanian or older |
| 2495/2500 - 2870/75 | indeterminate | indeterminate |

### Calcareous Nannofossil Subdivision

| Depth Range (m) | Zone | Age |
|---|---|---|
| 2430/40 | KCN18 – KCN19 | Late – Middle Coniacian |
| 2440/50 | KCN18 – KCN19 or older | Late – Middle Coniacian or older |
| 2460/65 | KCN21 – KCN22 | Middle – Early Turonian |
| 2470/75 | KCN24a or older | Late Cenomanian or older |
| 2495/2500 | KCN25c | Late Albian |
| 2510/15 | KCN25c or older | Late Albian or older |
| 2800/05 | indeterminate | indeterminate |
| 2810/15 | NJ5 – NJ3 | Early Toarcian – Late Sinemurian |
| 2825/30 | NJ3 | Early Toarcian – Late Sinemurian |
| 2831.0 | indeterminate | indeterminate |
| 2840/45 | NJ3 – NJ2a | Late Sinemurian – Late Hettangian |
| 2845.0 | NJ1 | Early Hettangian |
| 2850/55 – 2870/75 | NT2b | Rhaetian – Late Norian |
| 2893.0 | indeterminate | indeterminate |

## Integrated Biostratigraphic Subdivision

| Depth Range (m) | **Zone** | **Age** |
|---|---|---|
| 2430/40 | KCCM27 – KCCM28 | Late – Middle Coniacian |
| 2440/50 | KCCM28 | Late Turonian |
| 2460/65 | KCCM29 – KCCM30 | Middle – Early Turonian |
| 2470/75 | KCCM34 or older | Late – Middle Cenomanian or older |
| 2495/2500 | KCCM39 – KCCM42 | Late Albian |
| 2510/15 | KCCM39 – KCCM42 or older | Late Albian or older |
| 2800/05 | Lingulina tenera | Pliensbachian - Hettangian |
| 2810/15 | Lingulina tenera, NJ5 – NJ3 | Pliensbachian - Late Sinemurian |
| 2825/30 | Lingulina tenera, NJ3 | Late Sinemurian |
| 2831.0 | indeterminate | indeterminate |
| 2840/45 | Lingulina tenera, NJ3 – NJ2a | Late Sinemurian – Late Hettangian |
| 2845.0 | NJ1 | Early Hettangian |
| 2850/55 – 2870/75 | NT2b | Rhaetian – Late Norian |
| 2893.0 | indeterminate | indeterminate |

## Environment Subdivision

| **Depth Range (m)** | **Environment** |
|---|---|
| 2430/40 to 2470/75 inclusive | Upper bathyal or deeper |
| 2495/2500 & 2510/15 | Distal marine |
| 2800/05, 2810/15 & 2825/30 | Inner – middle neritic |
| 2831.0 | Undifferentiated marine |
| 2840/45 | Inner neritic |
| 2845.0 | Undifferentiated marine |
| 2850/55 | Inner – middle neritic |
| 2865.0 | Undifferentiated marine |
| 2870/75 | Inner – middle neritic |
| 2893.0 | indeterminate |

## II. INTRODUCTION

A total of 12 ditch cuttings and 4 sidewall core samples between 2430/40m and 2893.0m were analysed for nannofossils. Foraminiferal analysis was undertaken on the DC samples only.

A summary of results for each sample is shown in Appendix No. 1.Fossil assemblages identified in the well section are shown in Appendix No. 2.

# III. BIOSTRATIGRAPHIC ANALYSIS

Cretaceous

The KPF, KCN and KCCM zonation is in the process of being published. The first stage (Maastrichtian - Campanian) is finalised (Howe, Campbell & Rexilius, 2003 and Campbell, Howe & Rexilius, 2004). The first stage commenced in July 2000. It is planned to eventually publish the entire KCCM zonation (Berriasian to Maastrichtian).

Jurassic

Middle to Early Jurassic nannofossil assemblages have been correlated to the NJ zonal scheme of Bown & Cooper (1998). Other studies consulted include Bown (1992), Bown et al. (1998), Bralower et al. (1992) and Mutterlose (1992).

The Middle and Early Jurassic benthonic foraminiferal assemblages have been correlated to the NWS Middle – Early Jurassic benthonic foraminiferal zonal scheme of Apthorpe & Heath (1981) and Apthorpe (2003b). Other studies consulted include Bartenstein (1974) and Quilty (1980).

Late Triassic

Late Triassic nannofossil assemblages have been correlated to the NT zonal scheme of Bown (1998). Other studies consulted include Bralower et al. (1992).

There is no formal NWS Triassic benthonic foraminiferal zonal scheme. Rhaetian – Norian taxa have been recorded in a number of NWS wells during the past few years. It is proposed to develop a zonation and correlate it to the NT nannofossil zonal scheme. The following studies of Triassic foraminiferal faunas from the NWS have been consulted: Apthorpe (2003a, b), Apthorpe & Heath (1981) and Quilty (1980).

A. Benthonic Foraminiferal Subdivision

**2430/40m – 2510/15m : Indeterminate**

The DC samples in the interval lack age-diagnostic benthonic foraminiferal taxa.

**2800/05m – 2840/45m : *Lingulina tenera* Zone [Pliensbachian – Hettangian]**

The presence of *Lingulina tenera* and the absence of Triassic taxa in the samples suggests a position within the Early Jurassic *Lingulina tenera* Zone. The base of the *L. tenera* Zone is tentatively placed in the Sinemurian by Apthorpe (2003) though it is remarked that facies could preclude the zone being identified into the base of the Jurassic. Nannofossil dating from this and adjacent wells at Larsen-1 and Hine-1 (Rexilius & Powell, Report in Prep.) suggest that this zone can be extended down to the base of the Jurassic.

**2850/55m – 2870/75m : Unassigned [Rhaetian]**

The presence of *Variostoma cochlea* in the basal sample of the interval at 2870/75m constrains the sample to the Rhaetian. The sample overlying at 2850/55m contains the highest occurrence of Triassic taxa with *?Auloconus "laevis"* and *Oberhauserella* spp. identified in that sample. These taxa are considered to range no higher than the Rhaetian. They have not been recorded higher in the section than the Rhaetian indicator *Variostoma cochlea* in the nearby well sections at Larsen-1 and Hine-1 (Rexilius & Powell, Reports in preparation).

B. Planktonic Foraminiferal Subdivision

**2430/40m : Zone KPF10 or older [Santonian – Late Coniacian or older]**

Zonal designation is based on the occurrence of abundant *Globotruncana linneiana* and the lack of *Globotruncana arca*.

**2440/50m : Zone KPF13 [Late Turonian]**

The downhole first appearance of *Dicarinella imbricata* [KPF13 LAD event] and lack of *Praeglobotruncana stephani* [KPF14 LAD event] is consistent with a correlation nto Zone KPF13.

**2460/65m : Zones KPF14 – KPF16 [Middle Turonian – Late Cenomanian]**

Zonal assignment is based on the downhole first appearance of *Praeglobotruncana stephani* [KPF14 LAD event] and the lack of *Rotalipora* taxa.

**2470/75m : Zone KPF17 or older [Late Cenomanian or older]**

Tthe downhole first appearance of *Rotalipora* cushmani [KPF17 LAD event] indicates assignment to Zone KPF17 or older.

**2495/2500m – 2870/75m : Indeterminate**

The samples in the interval lack in-situ age-diagnostic planktonic foraminiferal taxa.

C. Calcareous Nannofossil Subdivision

**2430/40m : Zones KCN18 – KCN19 [Late – Middle Coniacian]**

Zonal assignment is based on the occurrence of frequent *Micula concava* [KCN19 FAD event] and the lack of *Lucianorhabdus cayeuxii* [KCN FAD event].

**2440/50m : Zones KCN18 – KCN19 or older [Late – Middle Coniacian or older]**

The nannofossil assemblage looks similar to that in the overlying DC sample however the occurrence of frequent *Eprolithus florilus* suggests possibly an older zonal assignment than KCN18 – KCN19 although numbers of *Micula concava* [KCN19 FAD event] are still frequent.

**2460/65m : Zones KCN21 – KCN22 [Middle – Early Turonian]**

Zonal assignment is based on the association of *Eprolithus octopetalus* and *Quadrum gartneri* [KCN22 FAD event] and rare *Eiffellithus eximius* [KCN21 FAD event] and the lack of *Marthasterites furcatus* [KCN20 FAD event].

**2470/75m : Zone KCN24a or older [Late Cenomanian or older]**

The downhole first appearance of *Prediscosphaera columnata* is consistent with a KCN24a or older zonal assignment.

**2495/2500m : Zone KCN25c [Late Albian]**

The association of *Eiffellithus monechiae* [LAD within Zone KCN25c] and *Eiffellithus turriseiffeli* [KCN25c FAD event] indicates a correlation to Zone KCN25c.

**2510/15m : Zone KCN25c or older [Late Albian or older]**

*Eiffellithus turriseiffeli* [KCN25c FAD event] numbers are reduced compared to the overlying DC sample but it is not possible to establish if the species is in-situ.

**2800/05m : Indeterminate**

The low to moderate yielding and low to very low diversity nannofossil assemblage lacks in-situ age-diagnostic taxa.

**2810/15m : Zones NJ5 – NJ3 [Early Toarcian – Late Sinemurian]**

The downhole first appearance of *Parhabdolithus liasicus* [LAD within Zone NJ5] and the occurrence of *Crepidolithus crassus* [FAD event for Zone NJ3] indicates that the nannofossil assemblage can be correlated to Zones NJ5 to NJ3 inclusive.

**2825/30m : Zone NJ3 [Late Sinemurian]**

Zonal designation is based on the association of *Crepidolithus crassus* [FAD event for Zone NJ3] and *Crepidolithus timorensis* [LAD within Zone NJ3].

**2831.0m : Indeterminate**

The impoverished nannofossil assemblage in the SWC at 2831.0m lacks age-diagnostic taxa.

**2840/45m : Zones NJ3 – NJ2a [Late Sinemurian – Late Hettangian]**

The association of *Crepidolithus crassus* [FAD event for Zone NJ3] – if in-situ and *Parhabdolithus liasicus* [FAD event for Zone NJ2a] indicates that the nannofossil assemblage is assignable to Zones NJ3 and NJ2a.

**2845.0m : Zone NJ1 [Late Hettangian]**

The SWC sample at 2845.0m contains a high yielding nannofossil assemblage with only *Schizosphaerella punctulata* present. This is consistent with assignment to Zone NJ1.

**2850/55m – 2870/75m : Zone NT2b (Rhaetian – Late Norian)**

Assignment to Zone NT2b is based on the association of high numbers of *Prinsiosphaera triassica* and *Eoconusphaera ziambachensis.*

**2893.0m : Indeterminate**

The SWC sample is barren of nannofossils.

D. Integrated Biostratigraphic Subdivision

See Integrated Biostratigraphic Subdivision (Chapter 1: Summary) and Appendix No. 1.

# IV. ENVIRONMENT OF DEPOSITION

Bathymetric estimates for the Late to Mid Cretaceous section are based on Nyong & Olsson (1984) and Olsson & Nyong (1984), and on experience of benthonic foraminiferal assemblages from previously drilled wells on the Northwest Shelf. Bathymetric estimates for the pre Aptian section is based primarily on experience of benthonic foraminiferal assemblages from previously drilled wells on the Northwest Shelf.

**2430/40m to 2470/75m inclusive : Upper bathyal or deeper**

The calcareous claystone facies in the interval are interpreted to have been deposted in an upper bathyal or deeper setting based on containing benthonic foraminiferal assemblages that include *Nuttalides* spp., *Osangularia* spp., *Osangularia utaturensis* and *Valvulineria erugata*.

**2495/2500m & 2510/15m : Distal marine**

The dark grey claystone facies contain very impoverished in-situ benthonic foraminiferal faunas with bathymetrically diagnostic taxa lacking. The occurrence of abundant Spumellarian radiolaria is consistent with deposition in a distal marine setting.

**2800/05m, 2810/15m & 2825/30m : Inner – middle neritic**

The siltstones and minor calcilutites in the DC samples in the interval are interpreted to have been deposited in an inner to middle neritic environment based on the moderately diverse Nodosarid faunas. Agglutinated taxa are also present in moderate abundance and diversity throughout this interval, although it is suspected that many of these taxa have caved from overlying Early Cretaceous strata. Glauconite is common to abundant in the interval. Ostracods become more frequent in the lower samples of the interval.

**2831.0m : Undifferentiated marine**

The SWC sample was only examined for nannofossils. The occurrence of nannofossils is consistent with deposition in a marine environment.

**2840/45m : Inner neritic**

The foraminiferal fauna at 2840/45m is similar in composition to those of the immediately overlying interval with DC sample control, although the abundance and diversity is reduced. Deposition is interpreted to have occurred in an inner neritic depositional setting.

**2845.0m : Undifferentiated marine**

The SWC sample was only examined for nannofossils. The occurrence of nannofossils is consistent with deposition in a marine environment.

**2850/55m : Inner - middle neritic**

The sample contains benthonic foraminiferal faunas of moderate diversity and abundance. Taxa recorded include frequent *Lenticulina*, rare *Lingulina borealis*, rare *Lingulina tenera* and rare *?Auloconus "laevis"*. Smooth ostracods are common. Deposition is interpreted to have occurred in an inner to middle neritic setting.

**2865.0m : Undifferentiated marine**

The SWC sample was only examined for nannofossils. The occurrence of nannofossils is consistent with deposition in a marine environment.

**2870/75m : Inner - middle neritic**

The sample contains benthonic foraminiferal faunas of moderate diversity and abundance. Taxa recorded in the interval include frequent *Lenticulina*, rare *Lingulina borealis*, rare *Lingulina tenera*, single *Glomospirella* spp. and frequent *?Auloconus "laevis"*. Smooth ostracods are abundant. Deposition is interpreted to have occurred in an inner to middle neritic setting.

**2893.0m : Indeterminate**

The SWC sample is barren of nannofossils. Foraminiferal analysis was not undertaken.

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# Appendix No. 1 : Micropalaeontological distribution chart, Noblige-1. Page 1 of 2.

| DEPTH (m) | SAMPLE TYPE | LITHOLOGY [based on processed foram residue] | FORAM YIELD | FORAM PRESERV. | FORAM DIVERSITY | NANNO YIELD | NANNO PRESERV. | NANNO DIVERSITY | FORAM ZONE | NANNO ZONE | FORAM / NANNO ZONE | AGE | ENVIRONMENT | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2430 - 2440 | DC | light green calcareous claystone & abundant casing cement. | high | moderate | low - moderate | high | moderate | high | KPF10 or older | KCN18 - KCN19 | KCCM27 - KCCM28 | Late - Middle Coniacian | upper bathyal or deeper | LAD *L. septenarius* |
| 2440 - 2450 | DC | light green calcareous claystone & common casing cement. | high | moderate | moderate - low | high | moderate | moderate - high | KPF13 | KCN18 - KCN19 or older | KCCM28 | Late Turonian | upper bathyal or deeper | LAD *D. imbricata* |
| 2460 - 2465 | DC | light green calcareous claystone & minor pale reddish brown calcareous claystone. | moderate (in-situ) | moderate | low - moderate (in-situ) | moderate - high | moderate | low - moderate | KPF14 - KPF16 | KCN21 - KCN22 | KCCM29 - KCCM30 | Middle - Early Turonian | upper bathyal or deeper | LAD *P. stephani* |
| 2470 - 2475 | DC | light green calcareous claystone, minor pale reddish brown calcareous claystone & | low (in-situ) | moderate | low - moderate (in-situ) | high | moderate | low - moderate | KPF17 or older | KCN24a or older | KCCM34 or older | Late - Middle Cenomanian or older | upper bathyal or deeper | LAD *R. cushmani;* LAD *P. columnata* |
| 2495 - 2500 | DC | dark grey claystone, common Spumellarian radiolaria. | very low (in-situ) | moderate - poor | very low (in-situ) | high | moderate - good | moderate - high | indet. | KCN25c | KCCM39 - KCCM42 | Late Albian | distal marine | LAD *E. monechiae* |
| 2510 - 2515 | DC | dark grey claystone, abundant Spumellarian radiolaria. | very low (in-situ) | moderate - poor | very low (in-situ) | high | moderate - good | moderate - high | indet. | KCN25c or older | KCCM39 - KCCM42 or older | Late Albian or older | distal marine | |
| 2800 - 2805 | DC | medium & dark grey siltstone with minor medium grey calcilutite, common casing cement, rare medium brown ?limestone (?siderite). | moderate | moderate | moderate | low - moderate | moderate | low - very low | *L. tenera* | indet. | *L. tenera* | Pliensbachian - Hettangian | inner - middle neritic | LAD *L. tenera* ; LAD *S. punctulata* |
| 2810 - 2815 | DC | medium & dark grey siltstone with minor medium grey calcilutite, common casing cement, rare medium brown ?limestone (?siderite). | low - moderate | moderate | low - moderate | very low [in-situ] | moderate | very low - low [in-situ] | *L. tenera* | NJ5 - NJ3 | *L. tenera,* NJ5 - NJ3 | Pliensbachian - Late Sinemurian | inner - middle neritic | LAD *P. liasicus* |

NJ zones after Bown and Cooper (1998); NT zones after Bown (1998); LAD = last appearance datum; FAD = first appearance datum.

# Appendix No. 1 : Micropalaeontological distribution chart, Noblige-1. Page 2 of 2.

| DEPTH (m) | SAMPLE TYPE | LITHOLOGY [based on processed foram residue] | FORAM YIELD | FORAM PRESERV. | FORAM DIVERSITY | NANNO YIELD | NANNO PRESERV. | NANNO DIVERSITY | FORAM ZONE | NANNO ZONE | FORAM / NANNO ZONE | AGE | ENVIRONMENT | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2825 - 2830 | DC | dark grey siltstone with casing cement and common light green calcilutite (caved) and dark grey limestone / calcilutite, rare medium brown ? limestone (?siderite). Common fine grained sand. | moderate - high | moderate - good | moderate | low - very low [in-situ] | moderate | low - very low [in-situ] | *L. tenera* | NJ3 | *L. tenera*, NJ3 | Late Sinemurian | inner - middle neritic | |
| 2831.0 | SWC 70 | no data | not studied | | | very low | poor | very low | not studied | indet. | indet. | indet. | undiff. marine | |
| 2840 - 2845 | DC | light grey ?fine grained sandy calcisiltite & medium grey calcilutite with medium & dark grey siltstone & claystone, frequent casing cement. | moderate - low | moderate - poor | moderate - low | low - very low [in-situ] | moderate | very low [in-situ] | *L. tenera* | NJ3 - NJ2a | *L. tenera*, NJ3 - NJ2a | Late Sinemurian - Late Hettangian | inner neritic | FAD *C. crassus* ; FAD *P. liasicus* |
| 2845.0 | SWC 69 | no data | not studied | | | high | moderate | very low | not studied | NJ1 | NJ1 | Early Hettangian | undiff. marine | FAD *S. punctulata* [only species observed] |
| 2850 - 2855 | DC | light grey ?fine sandy calcisiltite with medium - dark grey limestone & medium grey calcilutite. | moderate | moderate | moderate | low - very low [in-situ] | moderate - good | very low [in-situ] | indet. (Rhaetian) | NT2b | NT2b | Rhaetian - Late Norian | inner - middle neritic | LAD *O. triassica* ; LAD *E. zlambachensis* . |
| 2865.0 | SWC 68 | no data | not studied | | | high | moderate - good | very low | not studied | NT2b | NT2b | Rhaetian - Late Norian | undiff. marine | |
| 2870 - 2875 | DC | light grey calcilutite with medium - dark grey calcilutite & minor dark grey siltstone. Abundant casing cement. | moderate - high | moderate | moderate | high | moderate - good | very low | indet. (Rhaetian) | NT2b | NT2b | Rhaetian - Late Norian | inner - middle neritic | FAD *O. triassica* ; FAD *E. zlambachensis* . |
| 2893.0 | SWC 67 | no data | not studied | | | barren | | | not studied | indet. | | indet. | indet. | |

NJ zones after Bown and Cooper (1998); NT zones after Bown (1998); LAD = last appearance datum; FAD = first appearance datum.

# Appendix No. 2 : Micropalaeontological distribution chart, Noblige-1. Page 1 of 3.

| TAXA / DEPTH (m) | 2430 - 2440 DC | 2440 - 2450 DC | 2460 - 2465 DC | 2470 - 2475 DC | 2495 - 2500 DC | 2510 - 2515 DC | 2800 - 2805 DC | 2810 - 2815 DC | 2825 - 2830 DC | 2831.0 SWC 70 | 2840 - 2845 DC | 2845.0 SWC 69 | 2850 - 2855 DC | 2865.0 SWC 68 | 2870 - 2875 DC | 2893.0 SWC 67 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BENTHONIC FORAMINIFERA** | | | | | | | | | | NS | | NS | | NS | | NS |
| Indeterminate Miliolids | s | s | | | | | | | | | | | | | | |
| Nuttalides spp. | s | | | | | | | | | | | | | | | |
| Eponides diversus | s | | | s | | | | | | | | | | | | |
| Fissurina spp. | s | | | | | | | | | | | | | | | |
| Indeterminate Nodosarids | s | | | | | | r | r | r | | r | | r | | r | |
| Osangularia spp. | | r | r | s | sCv | | | | | | | | | | | |
| Anomalinoides eriksdalensis | | s | | | | | | | | | | | | | | |
| Dentalina spp. | | s | r | s | | | | | | | | | | | | |
| Pleurostomella spp. | | s | | | | | | | | | | | | | | |
| Ellipsoidella binaria | | s | | | | | | | | | | | | | | |
| Lagena spp. | | s | | | | | | | | | | | | | | |
| Lenticulina spp. | | | r | | | s | f | r | f | | r | | f | | f | |
| Indeterminate Agglutinates | | | s | | | | f | f | f | | f | | r | | r | |
| Praebulimina spp. | | | r | s | | | | | | | | | | | | |
| Marssonella oxycona | | | r | | | | | | | | | | | | | |
| Glomospirella gaultiana | | | s | | | | sCv | | | | | | | | | |
| Valvulineria erugata | | | s | s | | | | | | | | | | | | |
| Pyrulina cylindroides | | | s | r | | | | | | | | | | | | |
| Bathysiphon spp. (very fi) | | | s | | | | | sCv | | | | | | | | |
| Gaudryina spp. | | | | s | | | | | | | | | | | | |
| Verneuilina howchini | | | | s | | | s | | | | s | | | | | |
| Gavelinella intermedia | | | | s | | | | | | | | | | | | |
| Valvulineria lenticula | | | | s | | | | | | | | | | | | |
| Osangularia utaturensis | | | | s | | | | | | | | | | | | |
| Ammodiscus cretacea | | | | | s | | | | | | | | | | | |
| Gavelinella spp. | | | | | sCv | | | | | | | | | | | |
| Gyroidinoides globosa | | | | | | sCv | | | | | | | | | | |
| Gyroidinoides gracillima | | | | | | s | | | | | | | | | | |
| Hyperammina spp. (very fi) | | | | | | s | | | | | | | | | | |
| Trochammina spp. (fi) | | | | | | | f | f | r | | f | | r | | s | |
| Ammobaculites spp. (fi) | | | | | | | r | r | r | | s | | r | | | |
| Ammobaculites spp. (very fine) | | | | | | | r | s | | | | | | | | |
| Astacolus spp. | | | | | | | r | s | s | | | | | | | |
| Globulina prisca | | | | | | | rCv | sCv | rCv | | | | | | | |
| Haplophragmoides spp. (very fine) | | | | | | | r | r | s | | s | | | | | |
| Lenticulina muensteri | | | | | | | r | | r | | r | | f | | f | |
| Lingulina tenera carinata | | | | | | | r | | f | | r | | r | | r | |
| Trochammina spp. (very fi) | | | | | | | r | | s | | | | | | | |
| Dentalina communis | | | | | | | s | | | | | | | | | |
| Dentalina gracilis | | | | | | | s | r | s | | | | s | | r | |
| Eoguttulina spp. | | | | | | | s | | | | | | | | | |
| Haplophragmoides spp. (fi) | | | | | | | s | | | | r | | | | | |
| Lenticulina subalata | | | | | | | s | r | s | | r | | r | | r | |
| Opthalmidium orbiculare | | | | | | | s | | | | | | | | | |
| Reophax spp. (fi) | | | | | | | sCv | | | | | | | | | |
| Glomospirella gaultiana | | | | | | | sCv | | | | | | | | | |
| Lingulina borealis | | | | | | | s | | | | s | | r | | r | |
| Lingulina spp. | | | | | | | s | | r | | s | | r | | s | |
| Glomospira charoides | | | | | | | | rCv | s Cv | | | | sCv | | sCv | |
| Ammobaculites humei (m - co) | | | | | | | | sCv | | | | | | | | |
| Bathysiphon spp. (smooth) | | | | | | | | sCv | | | | | | | | |
| Lagena hauteriviana | | | | | | | | sCv | | | | | | | | |
| Lingulina testudinaria | | | | | | | | s | s | | s | | | | | |
| Marginulinopsis speciosa | | | | | | | | s | | | | | | | s | |
| Marginulinopsis spp. | | | | | | | | s | s | | | | s | | | |
| Nodosaria spp. (5 - 6 ribbed) | | | | | | | | s | s | | | | | | | |
| Ammodiscus tenuissimus | | | | | | | | sCv | | | | | | | | |

s = single, r = rare, f = frequent, c = common, a = abundant, B = barren, NS = not studied, fi = fine grained agglutinated, m - co = medium - coarse grained agglutinated.

# Appendix No. 2 : Micropalaeontological distribution chart, Noblige-1. Page 2 of 3.

| TAXA / DEPTH (m) | 2430 - 2440 DC | 2440 - 2450 DC | 2460 - 2465 DC | 2470 - 2475 DC | 2495 - 2500 DC | 2510 - 2515 DC | 2800 - 2805 DC | 2810 - 2815 DC | 2825 - 2830 DC | 2831.0 SWC 70 | 2840 - 2845 DC | 2845.0 SWC 69 | 2850 - 2855 DC | 2865.0 SWC 68 | 2870 - 2875 DC | 2893.0 SWC 67 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nodosaria spp. (8-10 ribbed) | | | | | | | | | f | | r | | f | | r | |
| Nodosaria spp. (15 - 20 ribbed) | | | | | | | | | r | | | | s | | s | |
| Citharina spp. (large, striate) | | | | | | | | | r | | | | r | | r | |
| Dentalina distincta | | | | | | | | | s | | | | | | | |
| Pseudonodosaria spp. | | | | | | | | | s | | | | | | | |
| "Gaudryina" cuvierensis | | | | | | | | | sCv | | | | | | | |
| Glomospira spp. | | | | | | | | | | | sCv | | | | | |
| Lagena spp. (smooth) | | | | | | | | | | | s | | | | | |
| ?Auloconus "laevis" | | | | | | | | | | | | | r | | f | |
| Ammodiscus spp. (very fi) | | | | | | | | | | | | | s | | | |
| Lenticulina aff. varians | | | | | | | | | | | | | s | | | |
| Indeterminate Rotalids | | | | | | | | | | | | | s | | f | |
| Vaginulina spp. | | | | | | | | | | | | | s | | | |
| Oberhauserella spp. | | | | | | | | | | | | | s | | s | |
| Lingulina tenera tenera | | | | | | | | | | | | | s | | s | |
| Involutina spp. | | | | | | | | | | | | | | | f | |
| Variostoma cochlea | | | | | | | | | | | | | | | r | |
| Variostoma spp. | | | | | | | | | | | | | | | r | |
| Glomospirella spp. | | | | | | | | | | | | | | | s | |
| Lenticulina cf. L. bicostata | | | | | | | | | | | | | | | s | |
| | | | | | | | | | | | | | | | | |
| **PLANKTONIC FORAMINIFERA** | | | | | | | | | | | | | | | | |
| Globotruncana linneiana | a | a | | fCv | rCv | sCv | | | | | | | | | | |
| Marginotruncana coronata | c | f | rCv | | | sCv | | | | | | | | | | |
| Whiteinella spp. | f | f | f | | | | | | | | | | | | | |
| Rosita fornicata | f | | | | | | | | | | | | | | | |
| Heterohelix globulosa | c | c | c | rCv | rCv | sCv | | | | | | | | | | |
| Globigerinelloides ultramicra | r | | | | | | | | | | | | | | | |
| Whiteinella paradubia | s | f | | | | | | | | | | | | | | |
| Hedbergella simplicissima | | r | s | s | | | | | | | | | | | | |
| Dicarinella imbricata | | s | | | | sCv | | | | | | | | | | |
| Marginotruncana marginata | | s | | | | | | | | | | | | | | |
| Praeglobotruncana stephani | | | f | f | | rCv | | | | | | | | | | |
| Helvetoglobotruncana helvetica | | | | sCv | | | | | | | | | | | | |
| Rotalipora cushmani | | | | s | | | | | | | | | | | | |
| Hedbergella spp. | | | | s | s | s | | | | | | | | | | |
| Globotruncana spp. | | | | | sCv | sCv | | | | | | | | | | |
| Caved Cretaceous taxa | | | | | | | sCv | | cCv | | rCv | | rCv | | fCv | |
| | | | | | | | | | | | | | | | | |
| **CALCAREOUS NANNOFOSSILS** | | | | | | | | | | | | | | | | B |
| Micula concava | f | f | rCv | | | | | | | | | | | | | |
| Eiffellithus eximius | f | f | s | | | | | | | | | | | | | |
| Lithastrinus septenarius | s | r | | | | | | | | | | | | | | |
| Marthasterites furcatus | f | f | rCv | sCv | | | | | | | | | | | | |
| Micula staurophora | r | r | scv | | | | | | | | | | | | | |
| Watznaueria barnesae | a | a | c | a | a | a | c | fCv | fCv | | fCv | | rCv | | fCv | |
| Arkhangelskiella confusa | r | r | | sCv | | | | | | | | | | | | |
| Eiffellithus turriseiffeli | s | s | | r | | r | | | | | | | | | | |
| Quadrum gartneri | s | | s | rCv | | | | | | | | | | | | |
| Tetrapodorhabdus decorus | s | | | | | | | | | | | | | | | |
| Prediscosphaera cretacea | r | s | | | | | | | | | | | | | | |
| Lithraphidites carniolensis | f | f | f | r | r | r | | | | | | | | | | |
| Manivitella pemmatoidea | s | s | | | r | s | | | | | | | | | | |
| Cribrosphaerella ehrenbergii | s | r | | | | | | | | | | | | | | |
| Retecapsa crenulatus | s | | | | | | | | | | | | | | | |
| Arkhangelskiella specillata | s | | | | | | | | | | | | | | | |
| Tranolithus phacelosus | s | | | | | | | | | | | | | | | |
| Zeugrhabdotus bicrescenticus | r | s | | | | | | | | | | | | | | |

s = single, r = rare, f = frequent, c = common, a = abundant, B = barren, NS = not studied, fi = fine grained agglutinated, m - co = medium - coarse grained agglutinated.

# Appendix No. 2 : Micropalaeontological distribution chart, Noblige-1. Page 3 of 3.

| TAXA / DEPTH (m) | 2430 - 2440 DC | 2440 - 2450 DC | 2460 - 2465 DC | 2470 - 2475 DC | 2495 - 2500 DC | 2510 - 2515 DC | 2800 - 2805 DC | 2810 - 2815 DC | 2825 - 2830 DC | 2831.0 SWC 70 | 2840 - 2845 DC | 2845.0 SWC 69 | 2850 - 2855 DC | 2865.0 SWC 68 | 2870 - 2875 DC | 2893.0 SWC 67 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reinhardtites anthophorus | s | s | | | | | | | | | | | | | | |
| Zeugrhabdotus diplogrammus | s | | s | f | f | f | | | | | | | | | | |
| Zeugrhabdotus embergeri | s | r | r | r | f | f | | | | | | | | | | |
| Aspidolithus parcus constrictus | sCv | | | | | | | | | | | | | | | |
| Reinhardtites levis | sCv | | | | | | | | | | | | | | | |
| Aspidolithus parcus parcus | sCv | | | | | | | | | | | | | | | |
| Prediscosphaera grandis | sCv | | | | | | | | | | | | | | | |
| Gartnerago obliquum | | s | | s | | | | | | | | | | | | |
| Eprolithus florilus | | f | c | c | f | c | | | | | | | | | | |
| Retecapsa spp. | | s | | | | | | | | | | | | | | |
| Chiastozygus litterarius | | s | | | | | | | | | | | | | | |
| Lucianorhabdus maleformis | | sCv | | | | | | | | | | | | | | |
| Ceratolithoides aculeus | | sCv | | | | | | | | | | | | | | |
| Eprolithus octopetalus | | | r | | | | | | | | | | | | | |
| Indeterminate coccoliths | | | s | r | s | r | s | | s | | | | | | | |
| Prediscosphaera columnata | | | | s | r | r | | | | | | | | | | |
| Watznaueria britannica | | | | | r | r | r | sCv | sCv | | sCv | | | | | |
| Helenea chiastius | | | | | r | r | | | | | | | | | | |
| Radiolithus planus | | | | | r | r | | | | | | | | | | |
| Seribiscutum primitivum | | | | | s | | | | | | | | | | | |
| Cyclagelopsphaera margereli | | | | | s | s | s | sCv | | | | | | | | |
| Grantarhabdus coronadventis | | | | | s | r | | | | | | | | | | |
| Eiffellithus monechiae | | | | | s | | | | | | | | | | | |
| Rhagodiscus angustus | | | | | s | | | | | | | | | | | |
| Tegmentum stradneri | | | | | | s | | | | | | | | | | |
| Watznaueria manivitiae | | | | | | s | r | | | | | | | | | |
| Rhagodiscus asper | | | | | | s | | | | | | | | | | |
| Schizosphaerella punctulata | | | | | | | s | r | f | r | f | a | rCv | | rCv | |
| Cruciellipsis cuvillieri | | | | | | | sCv | | | | sCv | | | | | |
| Staurolithites crux | | | | | | | | sCv | | | | | | | | |
| Parhabdolithus liasicus | | | | | | | | s | s | | s | | | | | |
| Crepidolithus crassus | | | | | | | | s | r | | r | | rCv | | | |
| Podolithus grassei | | | | | | | | s | | | | | | | | |
| Crepidolithus timorenis | | | | | | | | | s | | | | | | | |
| Cyclagelopsphaera deflandrei | | | | | | | | | sCv | | | | | | | |
| Prinsiosphaera triassica | | | | | | | | | | | | | f | a | a | |
| Eoconusphaera ziambachensis | | | | | | | | | | | | | r | a | c | |
| | | | | | | | | | | | | | | | | |
| **OTHER SKELETAL MATERIAL** | | | | | | | | | | | | | | | | |
| Ostracods [smooth] | | | s | | | | r | r | c | | f | | c | | a | |
| Spumellarian radiolaria | | | s | f | a | a | | | | | | | | | | |
| Nassellarian radiolaria | | | | s | | | | | | | | | | | | |
| Inoceramus bivalve fragments | | | | | | s | | rCv | rCv | | | | | | rCv | |
| ?Bryozoan debris | | | | | | | r | | r | | r | | r | | c | |
| Bivalved shell debris | | | | | | | s | | | | | | | | | |
| Ostracods [ornamented] | | | | | | | | r | s | | | | | | | |
| Gastropods | | | | | | | | | s | | s | | | | r | |
| Echinoid debris | | | | | | | | | | | | | r | | r | |
| Ostracod [reticulate sp. L] | | | | | | | | | | | | | s | | | |
| | | | | | | | | | | | | | | | | |
| **OTHER MATERIAL** | | | | | | | | | | | | | | | | |
| Glauconite | | | | | | | c | c | a | | c | | c | | c | |
| Yellow discs | | | | | | | | | | | | | | | c | |

s = single, r = rare, f = frequent, c = common, a = abundant, B = barren, NS = not studied, fi = fine grained agglutinated, m - co = medium - coarse grained agglutinated.

# Palynology Report

# PALYNOLOGY OF

# NOBLIGE-1

## CARNARVON BASIN, WESTERN AUSTRALIA

**BY**

**JOHN FILATOFF**
**&**
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**Prepared for**

**WOODSIDE ENERGY LTD**

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# PALYNOLOGY OF

# NOBLIGE-1

# CARNARVON BASIN, WESTERN AUSTRALIA

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APPENDIX 1 : Species distribution chart

# 1 SUMMARY

2789.2 m (swc) – 2810/15 m (cutts) : *D. lobispinosum* Zone, lower subzone : Berriasian : nearshore-offshore marine : marginal mature for oil, immature for gas/condensate

2831.0 m (swc) – 2870/75 m (cutts) : *C. torosa* Zone : Pliensbachian-Hettangian : ?brackish marine : marginal mature for oil, immature for gas/condensate

2893.0 m (swc) – 2925/30 m (cutts) : *A. reducta* Zone (Lower), *W. listeri* A *a*ssemblage (Tr8Ciii) : Rhaetian : marginal marine : marginal mature for oil, immature for gas/condensate

2961.2 m (swc) – 3065/70 m (cutts) : *M. crenulatus* Zone (Middle), *E. macistriatus* assemblage (Tr*8*Diii-Tr7Ai) : Norian : non-marine to marginal marine : marginal mature for oil, immature for gas/condensate

3110/15 m (cutts) – 3203.8 m (swc) : *M. crenulatus* Zone (Middle), *C.stonei* assemblage (Tr7Aiia) : Norian : non-marine : m arginal mature for oil, immature for gas/condensate

3270.0 m (swc) : *M. crenulatus* Zone (Middle), *H. balmei* assemblage (Tr7Aiib) : Norian : mar ginal marine : early mature for oil, marginally mature for gas/condensate

3278.2 m (swc) – 3625/30 m (cutts) : *M. crenulatus* Zone (Middle), Acme *C. stonei* assemblage (Tr7Aiic) : Norian : non-marine to possibly partly marginal marine (3355/60 – 3390/95 m) : ear ly mature for oil, marginally mature for gas/condensate

3655.2 m (swc) – 3800.7 m (swc) : *M. crenulatus* Zone (Mid dle), *B. communis* assemblage (Tr7Aiii) : Norian : non-marine : ear ly mature for oil, marginally mature for gas/condensate

3830/35 m (cutts) – 3960/65 m (cutts) : *M. crenulatus* Zone (Lower), *A. banksii* assemblage (Tr6Ai) : Norian : non-marine : early mature for oil, m arginally mature for gas/condensate

3985/90 m (cutts) – 4110/15 m (cutts) : *M. crenulatus* Zone (Lower), ?*A. astigmosus* assemblage (Tr6Aii) : Norian : non-marine : early mature for oil, marginally mature for gas/condensate

4138.0 m (swc) – 4287.5 m (swc) : *M. crenulatus* Zone (Lower), ?*E. vigens* assemblage (Tr6Aiii) : Norian : non-marine to marginal marine : early mature for oil, marginally mature for gas/condensate

4305/10 m (cutts) – 4575/81 m (cutts) : *S. speciosus* Zone (Upper = Tr6B), Carnian : non-marine to marginal marine : mature for oil, early mature for gas/condensate

## INTRODUCTION

A total of 71 samples (36 sidewall cores, 35 cuttings) were initially studied from **Noblige-1** for Woodside Energy Ltd. Six infill cuttings samples were added to clarify the basal section, making a total of 77 samples. John Filatoff studied all samples and wrote the report. Roger Morgan supplied the preliminary results, supervised the project and edited the final report.

The outline zonation (Figure 1) used is that of Helby, Morgan and Partridge (1987) updated as Helby, Morgan and Partridge (2004). Triassic (Tr) subzones (Figures 2, 3) are those of Helby as refined by Backhouse et al. (2002) and Morgan and Hooker (2005). Summary palynological details for each sample are presented on Table 1.

All informal species names are shown in quotation marks and listed in Section 4 with informal authorship. Names are given in full when first mentioned in the text, but only the genus initial and full species name is given when subsequently mentioned.

Raw palynological data are included in Appendix 1. The data are based on a 250+ specimen count from which an indication of marine microplankton to terrestrial palynomorph proportions can be derived. Caving appears to be minor. The microplankton percentages are listed in Table 1, which also summarizes other palynological details. Environmental assessments are derived from the palynomorph counts using content and diversity of saline taxa (dinoflagellates and spiny acritarchs), other microplankton (mostly freshwater algae), and terrestrial spores and pollen. The criteria for these assessments are defined in Table 1. In running text, frequency of taxa is discussed in the following intervals: Very rare = <1%, Rare = 1-3%, Frequent = 4-10%, Common = 11-29%, Abundant = 30-49%, Super-abundant = 50-100%.

Maturity data were generated in the form of Spore Colour Index, and are plotted on Figure 4 (Maturity Profile : Noblige-1). The oil and gas windows follow the general consensus of geochemical literature. The oil window corresponds to spore colours of light-mid brown (Staplin Spore Colour Index of 2.7) to dark brown (3.6) equal to vitrinite reflectance values of 0.6% to 1.3%. Geochemists argue variations on kerogen type, basin type and basin history. The maturity data is thus open to reinterpretation using the basic colour observations as reworked. However, the range of interpretation philosophies is not great, and probably would not move the oil window by more than 200 m.

VCEMP
Virtual Centre of Economic Micropaleontology & Palynology

# UPDATED JURASSIC – EARLY CRETACEOUS DINOCYST ZONATION NWS AUSTRALIA

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Geoscience Australia has tried to make the information in this product as accurate as possible. However, it does not guarantee that the information is totally accurate or complete. THEREFORE, YOU SHOULD NOT RELY SOLELY ON THIS INFORMATION WHEN MAKING A COMMERCIAL DECISION.

| Australian Timescale Young & Laurie 1996 | | | | Helby, Morgan & Partridge 1987 | | AAP Memoir 24 2001 | | Morgan, Hooker & Ingram, 2002 | | UPDATED AGREED SCHEME | Key species occurrences | Regional North West Shelf Events Markers |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ma | PERIOD | STAGE | | Microplankton Zones | Zone Codes | Dinocyst Zones | Sub-zones | Dinocyst Zones | Sub-zones | Dinocyst Zones | ⊤ Youngest occurrence<br>⊥ Oldest occurrence | |
| 95 | LATE CRET. | CENOMANIAN | | *Diconodinum multispinum* | 1aii | *D. multispinum* | 1aii | *D. multispinum* | | ***Diconodinum multispinum*** | ⊥ *Diconodinum multispinum*<br>⊤ *Diconodinum cristatum* suite | KC |
| | EARLY CRETACEOUS | 97.5 | | *Xenascus asperatus* | 1aiii | *X. asperatus* | 1aiiia<br>1aiiib | *X. asperatus* | | ***Xenascus asperatus*** | ⊤ *Odontochitina singhii* | |
| 100 | | ALBIAN | LATE | | | *D. armata* | 1aiiic | *P. ludbrookiae* | upper | ***Dioxya armata*** | ⊤ *Dioxya armata*<br>⊥ *Craspedodinium indistinctum* | |
| | | 100.5 | MID | *Pseudoceratium ludbrookiae* | 1b | | 1bi | | lower | | ⊥ *Xenascus asperatus*<br>⊥ *Dioxya armata* | |
| | | 103 | | | | *E. ludbrookiae* | 1bii<br>1biii | | | ***Endoceratium ludbrookiae*** | ⊤ *Cannosphaeropsis australis*<br>⊥ *Endoceratium ludbrookiae* | |
| 105 | | | EARLY | *Canninginopsis denticulata* | 1c-2bi | *C. denticulata* | 1c | *C. denticulata* | | ***Canninginopsis denticulata*** | ⊤ *Muderongia tetracantha* | |
| | | | | *Muderongia tetracantha* | 2bii | *M. tetracantha* | 2biia<br>2biib | *M. tetracantha* | upper<br>lower | ***Muderongia tetracantha*** | ⊤ *Dingodinium cerviculum* | |
| | | 108 | | | | | | | | | ⊤ *Diconodinium davidii* | |
| 110 | | APTIAN | LATE | *Diconodinium davidii* | 2biii | *D. davidii* | 2biiia<br>2biiib<br>2biiic | *D. davidii* | upper<br>middle<br>lower | ***Diconodinium davidii*** | ⊤ *Diconodinium davidii* ACME<br>⊤ ⊥ *Ovoidinium striatum* ACME<br>⊥ *Pseudoceratium turnerii* | |
| | | 111 | EARLY | *Odontochitina operculata* | 2c | *O. operculata* | 2ci<br>2ciia<br>2ciib | *O. operculata* | upper-lower<br>upper bii<br>upper bi<br>upper aii | ***Odontochitina operculata*** | ⊤ *Muderongia australis*<br>⊤ *Nummus monoculatus* influx<br>⊤ *Batioladinium longicornutum*<br>⊥ Consistent *Odontochitina* spp.<br>⊥ *Muderongia mcwhaei* & *B. longicornutum* | KA |
| 115 | | 115 | | *Ascodinium cinctum* | 2di | *A. cinctum* | 2di | | upper ai | | ⊤ ⊥ *Ascodinium cinctum* ACME | |
| 120 | | BARREMIAN | | *Muderongia australis* | 2dii | *M. australis* | 2dii | *M. australis* | middle b<br>middle aii<br>middle ai | ***Muderongia australis*** | ⊤ *Phoberocysta neocomica* (less spiny)<br>⊤ *Scriniodinium attadalense*<br>⊤ *Canningia reticulata* | |
| | | 123 | | | 2diii | | 2diii | | lower | | ⊤ *Phoberocysta neocomica* (very spiny) | |
| 125 | | HAUTERIVIAN | | *Muderongia testudinaria* | 2div | *M. testudinaria* | 2div | *M. testudinaria* | upper<br>lower | ***Muderongia testudinaria*** | ⊤ *Muderongia testudinaria*<br>⊤ *Gardodinium lowii*<br>⊤ *Phoberocysta burgeri*<br>⊥ *Dingodinium cerviculum* | |
| | | | | *Phoberocysta burgeri* | 3a | *P. burgeri* | 3a | *P. burgeri* | | ***Phoberocysta burgeri*** | ⊥ *Phoberocysta burgeri* | |
| 130 | | 130 | | *Senoniasphaera tabulata* | 3b | *S. tabulata* | 3b | *S. tabulata* | uppermost<br>upper<br>lower | ***Senoniasphaera tabulata*** | ⊥ *Muderongia* spp.<br>⊥ *Phoberocysta neocomica*<br>⊥ *Senoniasphaera tabulata* | |
| | | VALANGINIAN | | *Systematophora areolata* | 3c | *S. areolata* | 3c | *S. areolata* | | ***Systematophora areolata*** | | |
| | | | | *Egmontodinium torynum* | 4ai-4aii | *E. torynum* | 4ai-4aii | *E. torynum* | | ***Egmontodinium torynum*** | ⊤ *Egmontodinium torynum* | KV |
| 135 | | 135 | | *Batioladinium reticulatum* | 4aiii<br>4aiv | *B. reticulatum* | 4aiii<br>4aiv | *B. reticulatum* | upper<br>middle<br>lower | ***Batioladinium reticulatum*** | ⊤ *Batioladinium reticulatum*<br>⊤ *Batioladinium "apicoramosa"* Helby †<br>⊤ *Dissimulidinium lobispinosum*<br>⊥ *Batioladinium reticulatum* | |
| | | BERRIASIAN | | *Dissimulidinium lobispinosum* | 4bi | *D. lobispinosum* | 4bi | *D. lobispinosum* | upper<br>lower | ***Dissimulidinium lobispinosum*** | ⊤ *Omatidinium amphiacanthum*<br>⊥ *Dissimulidinium lobispinosum* | K |
| | | | | *Cassiculosphaeridia delicata* | 4bii | *C. delicata* | 4bii | *C. delicata* | upper<br>lower | ***Cassiculosphaeridia delicata*** | ⊤ *Cassiculosphaeridia delicata* ACME<br>⊤ *Kalyptea wiesmannian* | |

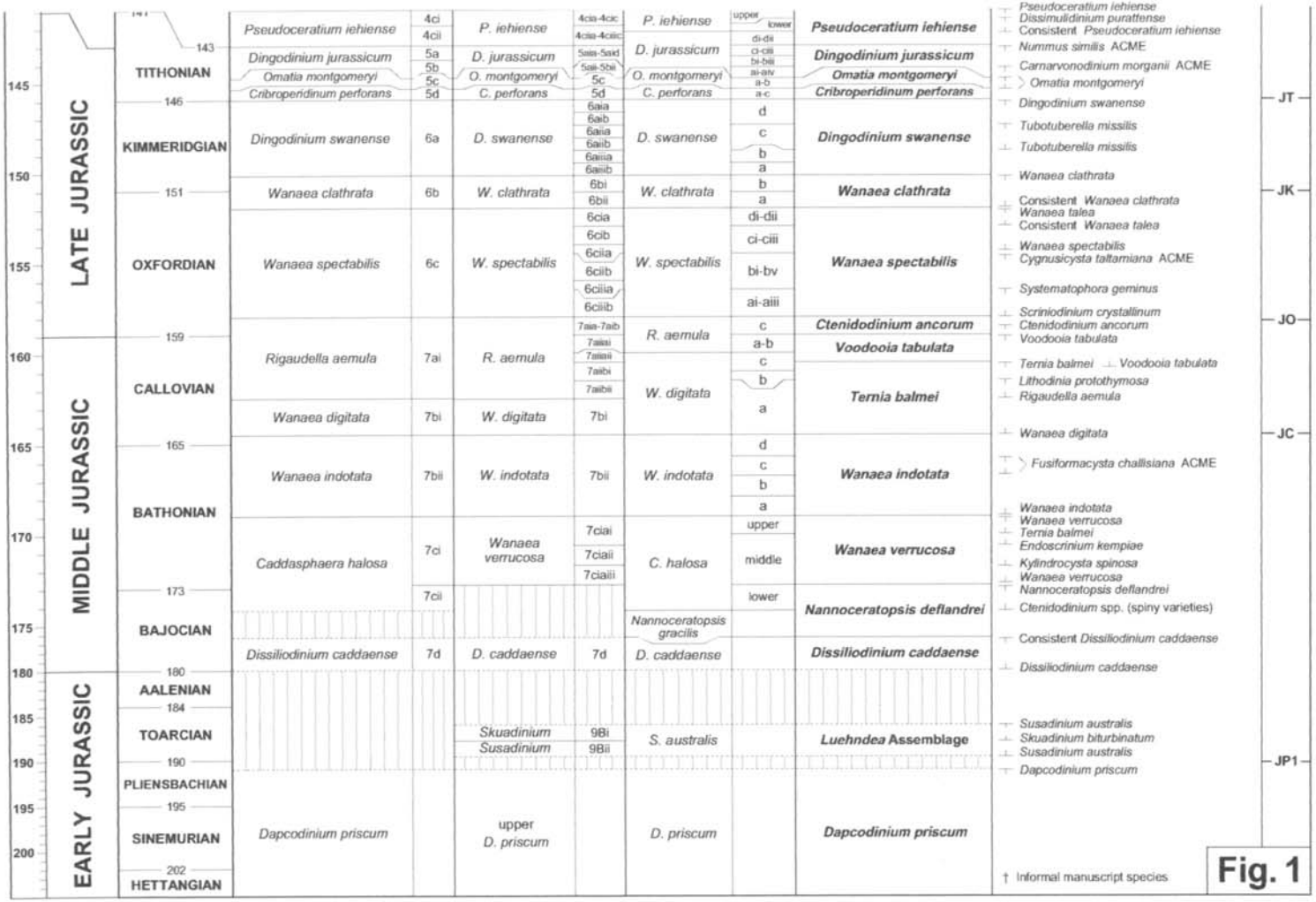



Fig. 1

Participating Companies: Santos Santos Ltd. WOODSIDE Woodside Energy Ltd.

**Bibliographic reference:** Helby, R., Morgan, R. and Partridge, A.D., 2004. Updated Jurassic – Early Cretaceous dinocyst zonation NWS Australia. Geoscience Australia publication ISBN 1 92871 01 2.

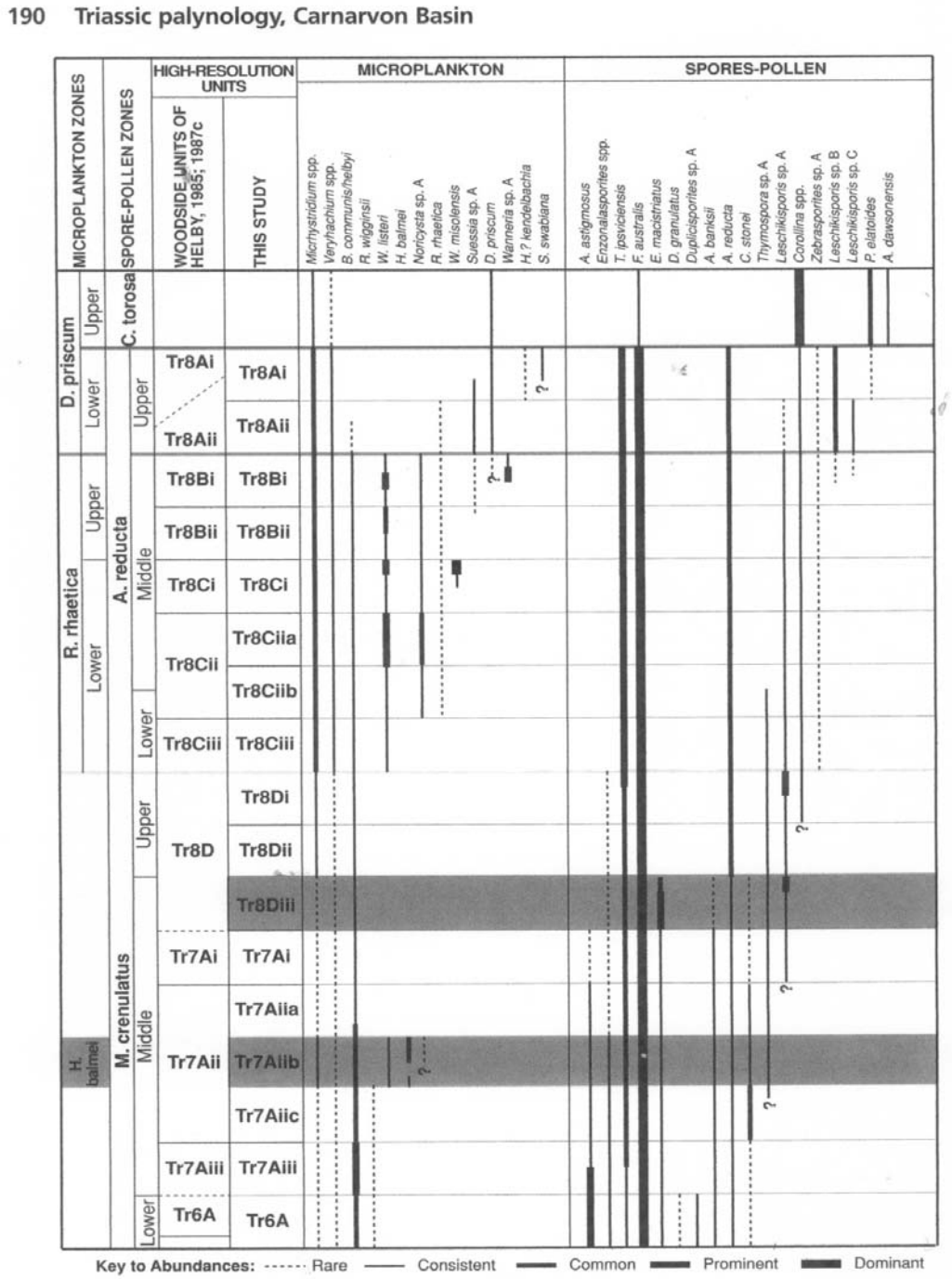


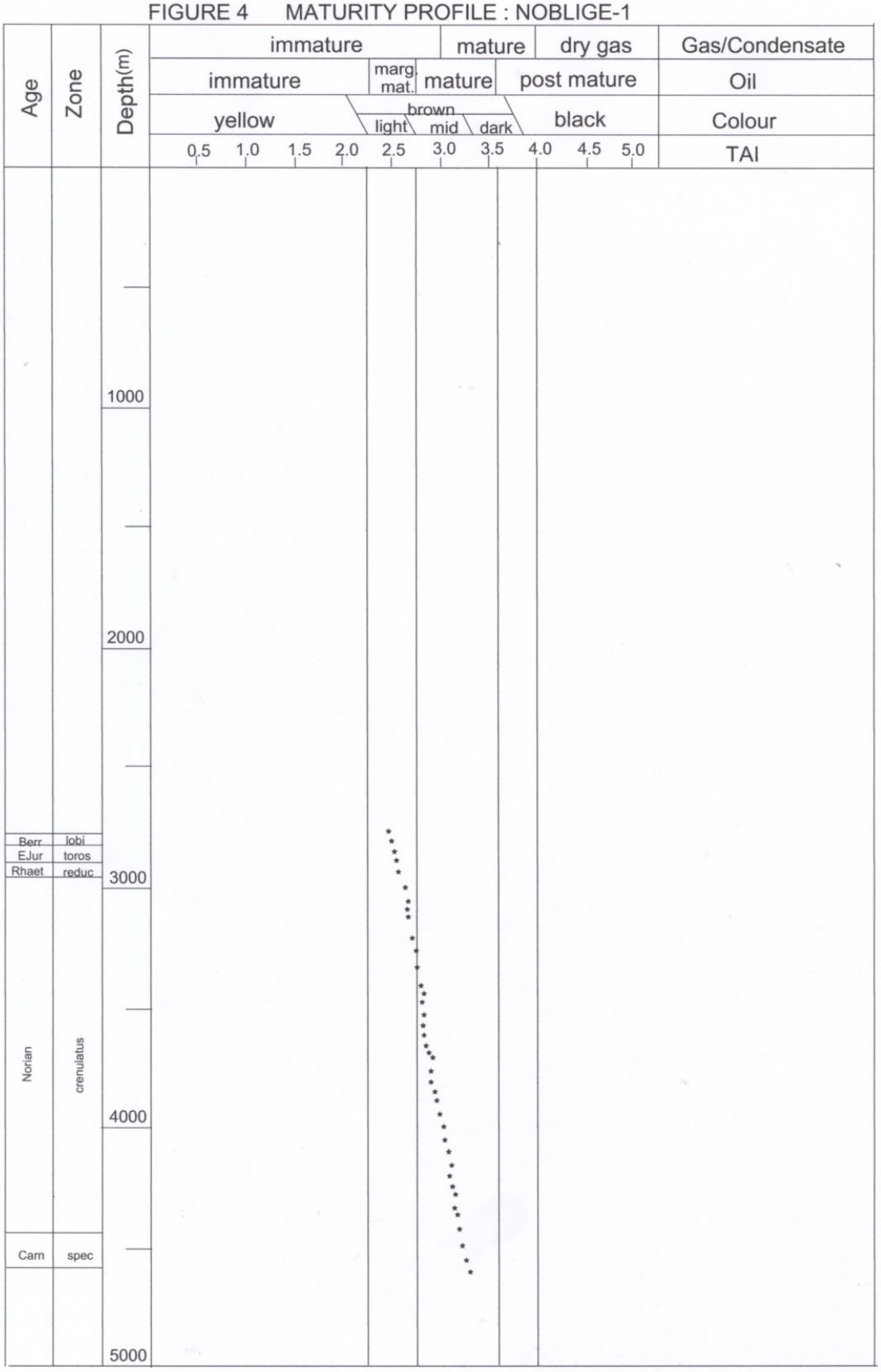

**Figure 2** **Ranges of key species against palynological zones, major bioevents and Tr units from Backhouse et al. 2002)**

**FIGURE 3 : LATE TRIASSIC EVENT PALYNOSTRATIGRAPHY (after Backhouse et. al. 2002 and *Morgan, Hooker and Ingram 2002)**

| AGE | TR UNIT | S-P ZONE | ASSEMBLAGES (NEW NAMES) | DINO ZONE | S-P EVENTS (reliable) | DINOCYST EVENTS (reliable) |
|---|---|---|---|---|---|---|
| RHAETIAN | Tr8Ai | *A. reducta* Upper | *Suessia* sp. A | *D. priscum* lower | **EVENT 1** LAD *A. reducta* * (= top frequent *F. australis*) | top *Suessia* sp.A * |
| | Tr8Aii | | *S. swabiana* | | | top *S. swabiana* |
| | Tr8Bi | *A. reducta* Middle | top *W. listeri* | *R. rhaetica* upper | | **EVENT 2** LAD *W. listeri* * base *S.* sp.A, *S. swabiana* * |
| | Tr8Bii | | *W. listeri* Acme | | | top *W. listeri* Acme 2 |
| | Tr8Ci | | *W. misolensis* | *R. rhaetica* lower | | **EVENT B** LAD *W. misolensis* FAD *W. misolensis* |
| | Tr8Ciia | | *W. listeri* C | | | base *W. listeri* acme 1 |
| | Tr8Ciib | | *W. listeri* B | | | base *R. rhaetica* |
| | Tr8Ciii | *A. reducta* Lower | *W. listeri* A | | | **EVENT 3** base consistent *W. listeri* * |
| | Tr8Di | *M. crenulatus* Upper | *D. harrisii* | | top common *Dictyophyllidites* * **EVENT C** base *C. meyeriana* | |
| | Tr8Dii | | | | | |
| | Tr8Diii | *M. crenulatus* Middle | *E. macistriatus* | | **EVENT 4** top *E. macistriatus* * Top *E. macistriatus* acme * base *E. macistriatus* acme * | spike *H. balmei* (coarse) * (upper spike, rarely seen) |
| | Tr7Ai | | | | **EVENT E** base consist *Leschikisporis* sp A | |
| | Tr7Aiia | | *C. stonei* | | **EVENT F** top *C. stonei* * Top frequent *C. stonei* * base persistent *E. macistriatus* * | |
| NORIAN | Tr7Aiib | | *H. balmei* | *H. balmei* | | **EVENT 5** top *H. balmei* (fine) * **EVENT 5** base *H. balmei* (fine) |
| | Tr7Aiic | top *M. crenulatus* lower (Hooker) | Acme *C. stonei* | | top persistent *S. speciosus* * Top common *C. stonei* * reappearance/influx *E. macistriatus* * | (MAIN SPIKE) |
| | Tr7Aiii | | *B. communis* | | Top abundant *B. communis* base abundant *B. communis* | |
| | Tr6A | top *M. crenulatus* lower (Backhouse) | *A. banksii* | | Acme *A. astigmosus*, *C. mesozoica* | |
| | | | *A. astigmosus* | | | |
| | | | *E. vigens* | | | |

**(* denotes additional events and those previously used by Morgan, Hooker & Ingram (2002))**

FIGURE 4 MATURITY PROFILE : NOBLIGE-1



# 3 PALYNOSTRATIGRAPHY

## 3.1 2789.2 m (swc) – 2810/15 m (cutts) : *D. lobispinosum* Zone

Rich, well-preserved assemblages were derived from the two sidewall core samples of the interval, whereas yield from the deepest sample (cuttings) is relatively low. The deeper assemblage differs also in containing largely land-plant palynomorphs in contrast to the shallower assemblages where marine microplankton predominate. Both Triassic and Permian reworking is well represented in the deepest sample but very minor in the shallower samples. *Corollina torosa* also in more frequent in the deeper sample.

Assignment of the sidewall core assemblages to the lower part of the *D. lobispinosum* Zone is based on youngest *Dissimulodinium lobispinosum* and *Omatidinium amphiacanthum* without older markers. Other stratigraphically significant species include *Batioladinium "apicoramosa", Belodinium neriedis, Egmontodinium torynum, Leptodinium "anchoriferum", Oligosphaeridium diluculum, Peridictyocysta mirabilis* and *Scriniodinium "parasaccatus"*. Leiospheres are superabundant in the shallowest sample; *Sentusidinium* spp. is superabundant in the deeper sidewall core assemblage where leiospheres are common and *L. "anchoriferum"* frequent. The more prominent spore-pollen in the sidewall core assemblages are *Microcachryidites antarcticus, Baculatisporites* spp., *Osmundacidites* spp. and *Cyathidites minor*.

Assignment of the cuttings sample (2810/15 m) is more problematic. Occurrences of *Gonyaulacysta* sp. A, *Leptodinium "anchoriferum"* and *Meiourogonyaulax* sp. A in the subordinate dinocyst component are, nevertheless, consistent with an earliest Cretaceous-latest Jurassic age. Nothing older to indicate the *C. delicata* Zone was seen, but neither was *D. lobispinosum*. Frequent *Contignisporites cooksoniae/glebulentus,* together with rare *Cicatricosisporites ludbrookiae*, in the dominant spore-pollen component suggests assignment to the lower, Berriasian, part of the *Cicatricosisporites australiensis* Spore-Pollen Zone. Other notable features of the terrestrial component include frequent *Baculatisporites/Osmundacidites*, *C. minor* and saccate pollen (bisaccates and *M. antarcticus*). Rare are *Callialasporites dampieri, Corollina torosa, Coronatispora perforata, Gleicheniidites senonicus, Neoraistrickia truncata, N.* spp., *Reticuloidosporites arcus* and *Retitriletes* spp. An increase to frequent of the *C. torosa* content might suggest the Early Jurassic *C. torosa* Zone (seen beneath), but might also be reworked with the abundant Triassic taxa.

It is likely the deepest sample represents a nearshore depositional environment, equating to *D. lobispinosum* dinocyst zone but clearly there is doubt. The shallower samples represent progressive deepening to shelfal and offshore marine environments.

Light brown spore c olours indicate marginal maturity for oil but immaturity for gas condensate.

### 3.2 2831.0 m (swc) – 2870/75 m (cutts) : *C. torosa* Zone

Although palynofossil preservation is fairly good in the two sidewall cores and single cuttings sample of this interval, yield is low, markedly so in the uppermost sample. The sidewall core samples lack dinocysts and although Cretaceous dinocysts dominate the assemblage from the underlying cuttings sample they are interpreted to be caved contaminants.

Zonal assignment is based on superabundant *C. torosa* is in the deeper sidewall core (2845.0 m) and common *C. torosa* in the non-dinocyst component of the cuttings sample (2870/75 m). *Corollina torosa* is very rare in the uppermost sample, which otherwise contains a lean Late Triassic assemblage that is interpreted to be reworked. Significant Late Triassic reworking is also evident in the deepest sample (2870/75 m).

Rare spinose acritarchs and *Botryococcus* in the richer samples suggest a brackish marine depositional environment for the interval. However, dinocysts are very rare in this zone worldwide and the environment may be more marine than it appears from the palynology.

Light brown spore colours indicate marginal maturity for oil but immaturity for gas condensate.

### 3.3 2893.0 m (swc) – 2925/30 m (cutts) : *A. reducta* Zone (Lower), *W. listeri* A assemblage (Tr8Ciii)

The one sidewall core and two cuttings samples from this interval have very low to moderate palynomorph yields and good to excellent preservation. The cuttings samples contain minor Cretaceous caving and all assemblages otherwise are dominated by land-

plant palynoflora (spore-pollen) with rare microplankton that include extremely rare dinocysts, spinose acritarchs and freshwater algal elements.
Assignment is based on superabundant *Falcisporites australis* and persistent though very rare occurrences of *Wanneria listeri* in the absence of younger or older markers. *Dictyophyllidites harrisii* is common, *Osmundacidites* spp. is frequent and *Baculatisporites* spp. *C. torosa, Cycadopites follicularis, Neoraistrickia taylori, Punctatosporites walkomii, Thymospora ipsciciensis*, and *Uvaesporites verrucosus* are rare. *Ashmoripollis reducta* is persistent.

A marginal marine environment is indicated by the very low content of marine microplankton in an otherwise land-plant dominated palynoflora.

Light brown spore colours indicate marginal maturity for oil but immaturity for gas/condensate.

### 3.4 2961.2 m (swc) – 3065/70 m (cutts) : *M. crenulatus* Zone (Middle), *E. macistriatus* assemblage (Tr*8*Diii-Tr7Ai)

Palynofossil yields from the two sidewall cores and two cuttings samples of this interval range from low to very high and derived assemblages exhibit excellent preservation. In addition to spore-pollen some assemblages include extremely rare dinocysts (possibly caved), frequent spinose acritarchs and assorted other non-marine aquatic elements.

Assignment is based on first down-hole occurrence of *Ephedripites macistriatus* in the absence of older markers. The marked acme of *E. macistriatus* at 3039.0 m is usually seen close to its toprange and suggests that the occurrence at 2961.2 m may be reworked. The palynoflora is dominated by *F. australis* and includes frequent to abundant *D. harrisii*, rare to frequent *Osmundacidites* spp. and *T. ipsviciensis* and rare *C. follicularis* and *N. taylorii*. *Leschikisporis mutabilis* is common in the top sample (2961.2 m) and *E. macistriatus* is frequent in sample 3039.0 m.

Very rare spinose acritarchs at 3025/30 m, and frequent spinose acritarchs and very rare dinocysts (*W. listeri, Dapcodinium* spp.) in the basal sample (3065/70 m), if not caved, indicate some marine influences through this section that otherwise is dominated by terrestrial floral elements.

Light brown spore colours indicate marginal maturity for oil but immaturity for gas condensate.

### 3.5 3110/15 m (cutts) – 3203.8 m (swc) : *M. crenulatus* Zone (Middle), *C.stonei* assemblage (Tr7Aiia)

The single cuttings sample and three sidewall core samples from this interval gave low- to high-yield palynofossil assemblages of good to excellent preservation. The assemblages are dominantly of land-plant origin but include subordinate, non-marine aquatic elements.

Assignment is based on first down-hole occurrence of *Cycadopites stonei*. The assemblage compositions are otherwise generally similar to those immediately above, other than including no marine microplankton. Sample 3164.0 m, however, is irregular in having rare *F. australis* but superabundant *D. harrisii*. Within this sample *C. stonei* is frequent, and *Aratrisporites coryliseminus, E. macistriatus, L. mutabilis, and T. ipsviciensis* are rare.

A land-plant dominated palynoflora in the absence of marine microplankton suggests a non-marine depositional environment.

Light brown spore colours indicate marginal maturity for oil and immaturity for gas/condensate.

### 3.6 3270.0 m (swc) : *M. crenulatus* Zone (Middle), *H. balmei* assemblage (Tr7Aiib)

The single sidewall core sample representing this zone gave a low to moderate palynofossil yield of good to excellent preservation. Although dominated by land-plant taxa the assemblage also includes rare dinocysts, spinose acritarchs, non-marine algal elements and a scolecodont.

Assignment is based on occurrence of marine microplankon, namely – *Hebecysta* sp. A, *Dapcodinium? "lacrimata"*, *W. listerii, Micrhystridium* spp. The specific marker species (*Hebecysta balmei*) was not observed in this sample but was noted in underlying cuttings samples where it is likely caved from this level. *Falcisporites australis* is super-abundant *D. harrisii* common and *T. ipsviciensis* frequent. Rare are *Aratrisporites*

*banksii, Baculatisporites* spp., *Botryococcus, Calamospora tener, Cycadopites* spp., *Osmundacidites* spp. and *Uvaesporites verrucosus.*

A marginal marine environment is indicated by the rare saline microplankton and solecodont.

Light to mid brown spore colours indicate early maturity for oil and early marginal maturity for gas/condensate.

### 3.7 3278.2 m (swc) – 3625/30 m (cutts) : *M. crenulatus* Zone (Middle), Acme *C. stonei* assemblage (Tr7Aiic)

Five sidewall cores and 11 cuttings samples are included within this zone. Palynofossil recoveries are generally moderate except for the uppermost sample (3278.2 m), which is rather lean. Preservation is generally good. Spore-pollen is dominant and freshwater algal elements are minor. The few marine microplankton were observed only in cuttings samples and are likely caved but consistent marine taxa in the interval 3355/60 m to 3390/95 m suggest they also might be in place and indicate a thicker *H. balmei* subzone than elsewhere. Caved Cretaceous taxa are rare as are reworked Permian species.

Assignment is based on persistence and relative abundance of *C. stonei* through this interval (mostly frequent). The coarsely sculptured variety of this species dominates most of the upper samples, the medium-sculptured variety predominates in the mid part of the interval and the finely sculptured form is most obvious in the deepest samples. *Dictyophyllidites harrisii* is also relatively more abundant in this interval than in overlying zones and even dominant over *F. australis* in some 35% of samples. *Minutosaccus crenulatus* and *Samaropollenites speciosus* are notably more persistent through this interval than in younger Triassic zones. *Aulisporites astigmosus* and *Enzonalasporites vigens*, likewise are better represented here (intermittently frequent) and, amongst the aquatic fraction, *Bartenia communis* and *Pilasporites crateraformis* are more persistent (intermittently rare). Low numbers of *Apiculatisporis "nobligense"*, a larger trilete spore that resembles *Apiculatisporis carnarvonensis*, are confined to the lower part of the interval.

As there are no definitively indigenous marine indicators the interval is likely non marine.

Light to mid brown spore colours indicate early maturity for oil and early marginal maturity for gas/condensate.

### 3.8 3655.2 m (swc) – 3800.7 m (swc) : *M. crenulatus* Zone (Middle), *B. communis* assemblage (Tr7Aiii)

Palynomorph recoveries from two sidewall cores of this interval are quite lean; yields from the remaining three sidewall cores and two cuttings samples are low to moderate. Preservation is good throughout.

Assignment is indicated by top of persistent, mostly frequent to common *B. communis*. However, this element is clearly facies controlled and the subzone boundaries are likely to be approximate. A slight influx of *B. communis* at 3500/05 m suggests the subzone top could be that high. *Cycadopites stonei* is rare to frequent in most samples with the finely sculptured variety being dominant throughout the interval. The psilate variety, though very rare occurs consistently in the lower part of the interval. *Dictyophyllidites harrisii* tends to be dominant and *F. australis* subdominant in the assemblages. *Aratrisporites* cf. *banksii* is notably frequent in the top sample (3655.2 m) but rapidly declines in abundance and disappears down section. Several robust spore species bearing reticulate and convolute sculpture are obvious in this interval even though their occurrences are quite rare within the assemblages. *Ephedripites. macistriatus* is absent in the upper samples but reappears in the lower part of the interval.

Non-marine (lacustrine) environments are indicated by the lack of saline markers and frequent freshwater algae (*B. communis*).

Light to mid brown spore colours indicate early maturity for oil and early marginal maturity for gas/condensate.

### 3.9 3830/35 m (cutts) – 3960/65 m (cutts) : *M. crenulatus* Zone (Lower), *A. banksii* assemblage (Tr6Ai)

Mostly moderate yields were obtained from the two sidewall cores and four cuttings samples assigned to this interval. Preservation is good. The assemblages are strongly

dominated by spore-pollen and include a moderate diversity of non-marine algal elements. Caved Cretaceous taxa and Permian reworked miospores are quite rare.

Assignment is based on a top to increased and persistent *Aratrisporites banksii*, coincident with a base to frequent *B. communis*. However, these definitions carry some facies control and are likely to be approximate. *Dictyophyllidites harrisii* and *F. australis* dominate the assemblages in sub-equal proportions. The finely sculptured variety of *C. stonei* is the prominent form in the two uppermost samples but the coarse- and medium-sculptured varieties resume prominence in the deeper part of the interval. Robust spores with reticulate and convolute sculpture, though still low in number, are even more conspicuous in this interval than above and include the distinctive form *Reticulatisporites* cf. sp. 808. Moreover, *Rugulatisporites permixtus*, which somewhat resembles *L. mutabilis* in the post *H. balmei* Assemblage section, is persistent in the current interval. A small spore with distinctive baculate sculpture (*Brevitriletes "bacularobustus"*) has a limited stratigraphic range confined to the lower part of the current interval and uppermost part of the underlying interval.

Non-marine, largely lacustrine environments are indicated by a lack of saline indicators but relatively strong representation of freshwater algae such as a *Bartenia communis, Botryococcus, Lecaniella "leighcreekensis"* and *Circulisporites parvus/"princei"*.

Light to mid brown spore colours indicate early maturity for oil and early marginal maturity for gas/condensate.

### 3.10 3985/90 m (cutts) – 4110/15 m (cutts) : *M. crenulatus* Zone (Lower), ?*A. astigmosus* assemblage (Tr6Aii)

A single sidewall cores and four cuttings samples are assigned to this interval. Palynofossil recoveries are generally moderate and preservation good.

Differentiation of this assemblage zone and the selection of its stratigraphic limits are tentative in the present section due to their clear facies control. Nevertheless, selection of its top is here taken on an ill-defined increase in *A. astigmosus*. Coincidently, *B. communis* reduces in prominence, whereas *E. macistriatus* assumes a greater prominence and persistence. The coarsely sculptured variety of *C. stonei* occurs only in the uppermost sample. The robust spores with coarse reticulate/convolute sculpture are

poorly represented, if at all, although the more finely sculptured, *R. permixtus*, persists through the interval. *Falcisporites australis* dominates most samples; *D. harrisii* occurrences vary from frequent to superabundant.

Non-marine floodplain and swamp margin environments are indicated by absence of saline markers and dominant bisaccate pollen and trilete spores.

Light to mid brown spore colours indicate early maturity for oil and early marginal maturity for gas/condensate.

### 3.11 4138.0 m (swc) – 4287.5 m (swc) : *M. crenulatus* Zone (Lower), ?*E. vigens* assemblage (Tr6Aiii)

Five sidewall cores and four cuttings samples represent this interval. Two of the sidewall cores are barren of palynofossils. Yields from the remaining samples vary from low to moderate and palynomorph preservation varies from poor to good. The assemblages are free of caved Cretaceous contaminants and only one sample contains reworked Permian taxa.

The *E. vigens* Assemblage is poorly defined in this section and the boundaries are likely to be approximate. The top is here based on a marked reduction in freshwater algae, notably *Bartenia communis* and *Botryococcus.* Amongst spore-pollen there is a marked reduction in *D. harrisii* (common-abundant) such that it is invariably subordinate to *F. australis*. The result is a very bland assemblage. There are notable lesser reductions for *C. stonei, E. macistriatus, M. crenulatus, R. permixtus, Uvaesporites argenteaeformis* and *Uvaesporites verrucosus*. The reductions of the last two species, however, are offset by their reappearance, persistence and relative prominence (intermittently rare) in the lower part of the interval. Corresponding downhole increases below the top boundary are evident for *Baculatisporites/Osmundacidites, C. follicularis, Kraeuselisporites* spp., *P. walkomi, N. taylorii* and *T. ipsviciensis*. *Aulisporites astigmosus* is well represented, especially in the lower part where it is frequent. *Cycadopites stonei* is persistent though low in number; the various varieties are fairly evenly distributed, but may be largely caved at these levels. *Ephedripites macistriatus* is slightly more prominent (intermittently rare).

Rare dinocysts include *Wanneria* spp. seen at 4265/70 m (cutts), and occurring into the zone beneath.

The relatively low-yield (bland) assemblages of the interval likely correspond to a drier, possibly low-stand episode in which floodplain and fluvial environments prevailed. This is supported by a palynoflora superabundant in bisaccate pollen, subordinate embryophytic spores, sparse freshwater algae and only very rare marine components.

Light to mid brown spore colours indicate early maturity for oil and early marginal maturity for gas/condensate.

### 3.12 4305/10 m (cutts) – 4575/81 m (cutts) : *S. speciosus* Zone (Upper = Tr6B)

Five sidewall cores and eleven cuttings samples represent this interval. Palynofossil yield varies from extremely low to moderate and preservation from poor to good. There is minor Cretaceous caved contamination (mostly in the basal sample) but no obvious reworking.

Assignment is based on a subtle down-hole increase in *S. speciosus* s.l coincident with youngest *Podocarpidites ?miniwaxy* and a downhole. Youngest *Alisporites* cf. *opii* occurs at 4355/60 m and persists below in low numbers. *E. vigens* is frequent at 4549.5 m and *S.* cf. *speciosus* is frequent at 4560/65 m, further suggesting the *S. speciosus* Zone in these horizons. *Dictyophyllidites harrisii* (common-abundant) and *P.? "miniwaxy"* also increase at this level and a rare but distinctive species, *Duplicisporites?* sp. 784, makes a first down-hole appearance. *Alisporites* cf. *opii* persists in low numbers through the interval. *Falcisporites australis* is abundant and dominant. *Aulisporites astigmosus* is frequent in the upper part of the interval and rare in the lower part. *Uvaesporites argenteaeformis* and *U. verrucosus* (intermittently rare) continue their relative prominence through this interval. The psilate and finely sculptured varieties of *C. stonei* are relatively poorly represented in this interval; coarse- and medium-sculptured varieties are persistent if low in number and probably largely caved. *Ephedripites macistriatus* is persistent becoming better represented (rare) towards the base. Rare and intermittent dinocysts (*Wanneria* spp.) occur at 4305/10 – 4355/60 m.

Non-marine floodplain and swamp environments are indicated by the dominance of saccate pollen and embryophytic spores, rare freshwater algae and no marine indicators.

However, samples at 4305/10 m, 4330/35 m and 4355/60 m contain very rare dinocysts (*Wanneria* spp.) and are marginal marine (if these saline markers are in place).

Mid brown spore colours indicate this section is mature for oil and early mature for gas/condensate.

# 4 UNPUBLISHED NAMES

**Cretaceous Dinocysts**

| | |
|---|---|
| *Apteodinium* sp. A | Stover & Helby (1987, p.253) |
| *Batioladinium "apicoramosa"* | Helby longstanding |
| *Belodinium "glabrum"* | Morgan longstanding |
| *Gonyaulacysta* sp. A | Morgan longstanding |
| *Leptodinium "anchoriferum"* | Morgan (= *Spiniferites* sp. Bint & Marshall 1994, p.549) |
| *Meiourogonyaulax* sp. A | Morgan longstanding |
| *Scriniodinium "parasaccus"* | Ott longstanding |

**Triassic Dinocysts**

| | |
|---|---|
| *Dapcodinium? "lacrimata* | Filatoff herein (= *Noricysta* sp. D Backhouse & Balme 2002) |
| *Hebecysta* sp. A | Backhouse & Balme (2002) |

**Triassic Spores and Pollen**

| | |
|---|---|
| *Alisporites* cf. *opii* | Filatoff herein (= *Falcisporites "giant"* Morgan) |
| *Apiculatisporis "nobligense"* | Filatoff herein (cf. *A. carnarvonensis*) |
| *Aratisporites "minimus"* | Helby longstanding |
| *Brevitriletes "bacularobustus"* | Filatoff herein |
| cf. *Florinites? balmei* | Filatoff *in* Belicoso-1 |
| cf. *Podocarpidites* spp. | Filatoff *in* Belicoso-1 |
| *Convolutispora* sp. A | Filatoff herein |
| *Convolutispora* sp. B | Filatoff herein |
| *Convolutispora* sp. 664 | Helby (1977) |
| *Cycadopites "apiobtusus"* | Filatoff *in* Belicoso-1 |

| | |
|---|---|
| *Densoisporites* sp. A | Backhouse & Balme (2002), = *Kyrtomisporites* sp. 743 (*K.* ?*corrugatus*) |
| *Dictyotriletes* sp. (fine) | Filatoff herein |
| *Duplicisporites?* sp. 784 | Helby (1977) |
| *Microreticulatispora* cf. sp. 676 | cf. Helby (1977) |
| *Neoraistrickia "irregularis"* | Filatoff |
| *Patinasporites* sp. 674 | Helby (1977) |
| *Podocarpidites? "miniwaxy"* | = *Falcisporites "miniwaxy"* Morgan longstanding |
| *Reticulatisporites* sp. A | Backhouse & Balme (2002), = ? *Dictyotriletes* sp. 830 Helby (1977) |
| *Reticulatisporites* cf. sp. 803 | cf. Helby (1977) |
| *Reticulatisporites* cf. sp. 808 | cf. Helby (1977), = *Dubrajisporites* Tiwari & Tripathi (1987) |
| *Rugulatisporites* cf. *asperatus* | Filatoff herein |
| *Samaropollenites* cf. *speciosus* | Morgan longstanding |
| *Voltziaceaesporites "eskensis"* | Filatoff *in* Belicoso-1, (= *V. heteromorpha*; de Jersey 1972, pl. 4 fig. 6. ?*Ovalipollis?* sp. Foster et al. 1994, fig. 2.15). |

**<u>Triassic Algae</u>**

| | |
|---|---|
| *Circulisporites "princei"* | = *Circulisporites* sp. 685 Helby (1976); = ? *Brodispora striata* Clarke 1965 |
| *Granodiscus ? "belicosus"* | Filatoff *in* Belicoso-1 |
| *Lecaniella "leighcreekensis"* | Filatoff *in* Belicoso-1 (= *Lecaniella* sp. Playford & Dettmann 1965; *Lecaniella* sp. A Backhouse & Balme 2002) |

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**TABLE 1: SUMMARY PALYNOLOGICAL DATA, NOBLIGE-1**
RT=m

| DEPTH [mbRT] | SAMPLE TYPE | ORGANIC YIELD *1 | MICROFOSSIL YIELD | PRESERVATION *2 | PERCENTAGE | | | | DIVERSITY *3 | | ZONE/AGE | SUBZONE | ENVIRONMENT *4 | KEY DATUMS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | MICROPLANKTON | | | SPORE-POLLEN | MICROPLANKTON | SPORE-POLLEN | | | | |
| | | | | | DINOFLAG. | SPINY AC. | OTHER | | | | | | | |
| 2789.2 | SWC | 0.040 | mod-high | excellent | 35 | <1 | 53 | 12 | high | high | D. LOBISPINOSUM | LOWER | SHELFAL MARINE | ACME C. TABULATA, O. AMPHI., D. LOBIS |
| 2797.0 | SWC | 0.040 | mod-high | excellent | 79 | 0 | 13 | 8 | high | mod | D. LOBISPINOSUM | LOWER | OFFSHORE MARINE | ACME C. TABULATA, O. AMPHI., D. LOBIS |
| 2810 / 15 | CUTTS | 0.003 | low | good | 17 | 0 | 3 | 80 | high | v. high | ?D. LOBISPINOSUM | | NEARSHORE MARINE | ACME C. COOKSONIAE, C. LUDBROOKIAE |
| 2831.0 | SWC | 0.036 | v. low | good | 0 | 0 | [5] | [95] | ext. low | low | ?C. TOROSA | | ? NON-MARINE | RARE C. TOROSA, TRIASSIC REWORKING |
| 2845.0 | SWC | 0.010 | low | good | 0 | 2 | 3 | 95 | ext. low | mod | C. TOROSA | | BRACKISH MARINE | S.ABT C. TOROSA, D. HARRISII, MICHRYSTRID. |
| 2870 / 75 | CUTTS | 0.003 | low | good | 0 | 1 | 1 | 98 | mod | mod | C. TOROSA | | BRACKISH MARINE | FREQ. C. TOROSA, D. HARRISII, BOTRYOCOCC. |
| 2893.0 | SWC | 0.028 | low-mod | good | <1 | 2 | 5 | 93 | low | v. high | A. REDUCTA (LOWER) | W. LISTERI A (Tr8Ciii) | MARGINAL MARINE | TOP S.ABT. F. AUSTRALIS, W. LISTERI, A. REDUC. |
| 2910 / 15 | CUTTS | 0.003 | low-v. low | good | <1 | <1 | 3 | 97 | low | v. high | A. REDUCTA (LOWER) | W. LISTERI A (Tr8Ciii) | MARGINAL MARINE | |
| 2925 / 30 | CUTTS | 0.003 | mod | excellent | <1 | <1 | 1 | 99 | low | v. high | A. REDUCTA (LOWER) | W. LISTERI A (Tr8Ciii) | MARGINAL MARINE | BASE CONSIST W. LISTERI |
| 2961.2 | SWC | 0.007 | v. high | excellent | 0 | 0 | 1 | 99 | low | v. high | M. CRENULATUS (MIDDLE) | E. MACISTRIATUS (Tr8Diii-Tr7Ai) | NON-MARINE | TOP E. MACISTRIATUS |
| 3025 / 30 | CUTTS | 0.003 | mod | excellent | 0 | 1 | 2 | 97 | v. low | v. high | M. CRENULATUS (MIDDLE) | E. MACISTRIATUS (Tr8Diii-Tr7Ai) | ? BRACKISH MARINE | |
| 3039.0 | SWC | 0.025 | low-mod | excellent | 0 | 0 | 2 | 98 | low | mod | M. CRENULATUS (MIDDLE) | E. MACISTRIATUS (Tr8Diii-Tr7Ai) | NON-MARINE | |
| 3065 / 70 | CUTTS | 0.003 | low | good-excellent | <1 | 5 | 2 | 93 | v. low | high | M. CRENULATUS (MIDDLE) | E. MACISTRIATUS (Tr8Diii-Tr7Ai) | ? MARGINAL MARINE | + W. LISTERI (?CAVED) |
| 3110 / 15 | CUTTS | 0.003 | mod | good-excellent | 0 | 0 | 2 | 98 | v. low | v. high | M. CRENULATUS (MIDDLE) | C. STONEI (Tr7Aiia) | NON-MARINE | TOP C. STONEI |
| 3144.6 | SWC | 0.012 | high | good-excellent | 0 | 0 | 3 | 97 | v. low | v. high | M. CRENULATUS (MIDDLE) | C. STONEI (Tr7Aiia) | NON-MARINE | |
| 3164.0 | SWC | 0.040 | low | good-excellent | 0 | 0 | 1 | 99 | low | mod | M. CRENULATUS (MIDDLE) | C. STONEI (Tr7Aiia) | NON-MARINE | |
| 3203.8 | SWC | 0.024 | low | good-excellent | 0 | 0 | 3 | 97 | mod | v. high | M. CRENULATUS (MIDDLE) | C. STONEI (Tr7Aiia) | NON-MARINE | |
| 3270.0 | SWC | 0.014 | low-mod | good-excellent | <1 | <1 | 2 | 98 | v. low | v. high | M. CRENULATUS (MIDDLE) | H. BALMEI (Tr7Aiib) | MARGINAL MARINE | W. LISTERI, HEBECYSTA SP. A, SCOLECODONT |
| 3278.2 | SWC | 0.009 | low-v. low | good | 0 | 0 | 3 | 97 | low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3300 / 05 | CUTTS | 0.003 | low-mod | good | 0 | 0 | 5 | 95 | low | v. high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3315 / 20 | CUTTS | 0.010 | mod | good-excellent | <1 | 0 | 6 | 94 | v. low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | ? NON-MARINE | ACME C. STONEI, A. ASTIGMOSUS + H. BALMEI (?CAVED) |
| 3334.7 | SWC | 0.026 | low-mod | good-excellent | 0 | 0 | 1 | 99 | v. low | mod | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3355 / 60 | CUTTS | 0.003 | low-mod | good | <1 | 0 | 4 | 96 | low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | ? NON-MARINE | + W. LISTERI (?CAVED) |
| 3375 / 80 | CUTTS | 0.003 | low-mod | good | <1 | 0 | 7 | 93 | low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | ? NON-MARINE | + W. LISTERI (?CAVED) |
| 3390 / 95 | CUTTS | 0.003 | mod-high | good-excellent | <1 | 0 | 3 | 97 | v. low | v. high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | ? NON-MARINE | BASE W. LISTERI + H. BALMEI (?CAVED) |
| 3455 / 60 | CUTTS | 0.003 | mod | good | 0 | 0 | 5 | 95 | v. low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | BASE CONSIST/FREQ C. STONEI (COARSE) |
| 3483.0 | SWC | 0.061 | mod | good | 0 | 0 | 1 | 99 | low | mod | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3500 / 05 | CUTTS | 0.003 | mod | good | 0 | 0 | 4 | 96 | low | v. high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | SLIGHT INCREASE B. COMMUNIS |
| 3529.0 | SWC | 0.024 | mod | good | 0 | 0 | 3 | 97 | low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3550 / 55 | CUTTS | 0.003 | mod | good | 0 | 0 | 5 | 95 | v. low | v. high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3570 / 75 | CUTTS | 0.003 | mod | good | 0 | 0 | 4 | 96 | v. low | v. high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3590 / 95 | CUTTS | 0.003 | mod | good | 0 | 0 | 4 | 96 | v. low | v. high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3614.2 | SWC | 0.074 | high | good-excellent | 0 | 0 | 2 | 98 | v. low | mod | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3625 / 30 | CUTTS | 0.003 | mod | good | 0 | 0 | 2 | 98 | v. low | high | M. CRENULATUS (LOWER) | ACME C. STONEI (Tr7Aiic) | NON-MARINE | |
| 3655.2 | SWC | 0.058 | low | good | 0 | 0 | 18 | 82 | v. low | mod | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | NON-MARINE | TOP ACME B. COMMUNIS |
| 3675 / 80 | CUTTS | 0.003 | mod | good | 0 | 0 | 5 | 95 | v. low | v. high | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | NON-MARINE | |
| 3709.0 | SWC | 0.052 | low-mod | good | 0 | 0 | <1 | 100 | v. low | low | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | NON-MARINE | |
| 3727.0 | SWC | 0.033 | v. low | good | 0 | 0 | 7 | 92 | v. low | mod | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | NON-MARINE | |
| 3754.5 | SWC | 0.035 | mod | good | 0 | 0 | 14 | 86 | v. low | v. high | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | NON-MARINE | |
| 3785 / 90 | CUTTS | 0.003 | mod | good | <1 | 0 | 8 | 92 | v. low | v. high | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | ? NON-MARINE | + W. LISTERI (?CAVED) |
| 3800.7 | SWC | 0.033 | ext. low | good | 0 | 0 | 32 | 68 | v. low | mod | M. CRENULATUS (LOWER) | B. COMMUNIS (Tr7Aiii) | NON-MARINE | |
| 3830 / 35 | CUTTS | 0.003 | mod | good | 0 | 0 | 5 | 95 | v. low | v. high | M. CRENULATUS (LOWER) | A. BANKSII (Tr6Ai) | NON-MARINE | TOP PERSISTENT A. BANKSII |
| 3855 / 60 | CUTTS | 0.003 | mod | good | 0 | 0 | 5 | 95 | v. low | v. high | M. CRENULATUS (LOWER) | A. BANKSII (Tr6Ai) | NON-MARINE | |
| 3882.0 | SWC | 0.054 | mod-high | good | 0 | 0 | 5 | 95 | v. low | high | M. CRENULATUS (LOWER) | A. BANKSII (Tr6Ai) | NON-MARINE | |
| 3902.4 | SWC | 0.035 | mod | good | 0 | 0 | 12 | 88 | low | high | M. CRENULATUS (LOWER) | A. BANKSII (Tr6Ai) | NON-MARINE | |
| 3925 / 30 | CUTTS | 0.003 | mod | good | 0 | 0 | 7 | 93 | v. low | v. high | M. CRENULATUS (LOWER) | A. BANKSII (Tr6Ai) | NON-MARINE | |
| 3960 / 65 | CUTTS | 0.003 | mod | good | 0 | 0 | 6 | 94 | v. low | v. high | M. CRENULATUS (LOWER) | A. BANKSII (Tr6Ai) | NON-MARINE | |
| 3985 / 90 | CUTTS | 0.003 | mod-high | good-excellent | 0 | 0 | 4 | 96 | v. low | v. high | M. CRENULATUS (LOWER) | ? A. ASTIGMOSUS (Tr6Aii) | NON-MARINE | TOP INC. A. ASTIGMOSUS, BASE RARE C. STONEI (COARSE) |
| 4036.4 | SWC | 0.058 | mod | good | 0 | 0 | 2 | 98 | ext. low | high | M. CRENULATUS (LOWER) | ? A. ASTIGMOSUS (Tr6Aii) | NON-MARINE | |
| 4050 / 55 | CUTTS | 0.003 | mod | good | 0 | 0 | 3 | 97 | v. low | high | M. CRENULATUS (LOWER) | ? A. ASTIGMOSUS (Tr6Aii) | NON-MARINE | |
| 4070 / 75 | CUTTS | 0.003 | mod | good | 0 | 0 | 4 | 96 | v. low | v. high | M. CRENULATUS (LOWER) | ? A. ASTIGMOSUS (Tr6Aii) | NON-MARINE | BASE INC. A. ASTIGMOSUS |
| 4110 / 15 | CUTTS | 0.003 | mod | good | 0 | 0 | 8 | 92 | v. low | v. high | M. CRENULATUS (LOWER) | ? A. ASTIGMOSUS (Tr6Aii) | NON-MARINE | BASE FREQ. B. COMMUNIS |
| 4138.0 | SWC | 0.063 | low-mod | poor-good | 0 | 0 | 2 | 98 | v. low | high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | NON-MARINE | TOP DECREASE D. HARRISII, B. COMMUNIS |
| 4171.0 | SWC | 0.032 | mod | poor-good | 0 | 0 | 0 | 100 | nil | high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | NON-MARINE | |
| 4195 / 4200 | CUTTS | 0.003 | mod | good | 0 | 0 | 1 | 99 | low | v. high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | NON-MARINE | |
| 4225/30 | CUTTS | 0.003 | mod | good | 0 | 0 | 1 | 44 | low | v. high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | NON-MARINE | |
| 4235.1 | SWC | 0.081 | nil | - | - | - | - | - | | | | | ? NON-MARINE | BARREN |
| 4245/50 | CUTTS | 0.003 | mod | good | 0 | 0 | <1 | 100 | v. low | v. high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | NON-MARINE | |
| 4262.1 | SWC | 0.074 | nil | - | - | - | - | - | | | | | ? NON-MARINE | BARREN |
| 4265/70 | CUTTS | 0.003 | mod | fair-good | <1 | <1 | 2 | 98 | low | v. high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | MARGINAL MARINE | TOP MARINE INFLUX (WANNERIA SPP.) |
| 4287.5 | SWC | 0.019 | low | poor-good | 0 | 0 | 2 | 98 | v. low | high | M. CRENULATUS (LOWER) | ? E. VIGENS (Tr6Aiii) | NON-MARINE | |
| 4305/10 | CUTTS | 0.003 | low-mod | good | <1 | 0 | 3 | 97 | low | v. high | S. SPECIOSUS (UPPER) | Tr6B | MARGINAL MARINE | TOP PERSISTENT P.? "MINIWAXY"; TOP CAMEROSPORITES SPP. |
| 4323.0 | SWC | 0.017 | nil | - | - | - | - | - | | | S. SPECIOSUS (UPPER) | | ? NON-MARINE | BARREN |
| 4330/35 | CUTTS | 0.003 | mod | good | <1 | 0 | 1 | 99 | v. low | high | S. SPECIOSUS (UPPER) | Tr6B | MARGINAL MARINE | |
| 4350.5 | SWC | 0.045 | nil | - | - | - | - | - | | | S. SPECIOSUS (UPPER) | | ? NON-MARINE | BARREN |
| 4355/60 | CUTTS | 0.003 | mod | good | <1 | 0 | 3 | 97 | low | v. high | S. SPECIOSUS (UPPER) | Tr6B | MARGINAL MARINE | TOP PERSISTENT A. CF. OPII, BASE DINOCYSTS |
| 4375 / 80 | CUTTS | 0.003 | low | good | 0 | 0 | 2 | 98 | low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |
| 4410 / 15 | CUTTS | 0.003 | mod | good | 0 | 0 | 4 | 96 | low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |
| 4435 / 40 | CUTTS | 0.003 | mod | good | 0 | 0 | 3 | 97 | v. low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |
| 4466.2 | SWC | 0.058 | low | poor | 0 | 0 | <1 | 100 | ext. low | high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |
| 4485 / 90 | CUTTS | 0.003 | mod | good | 0 | 0 | 2 | 98 | v. low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | TOP INC. S. SPECIOSUS |
| 4500 / 05 | CUTTS | 0.003 | mod | good | 0 | 0 | 2 | 98 | v. low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |
| 4520 / 25 | CUTTS | 0.003 | mod | good | 0 | 0 | 2 | 98 | low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |
| 4534.4 | SWC | 0.032 | ext. low | poor | 0 | 0 | 2 | 98 | ext. low | ext. low | INDETERMINATE | | NON-MARINE | NEAR BARREN |
| 4549.6 | SWC | 0.014 | low | poor-good | 0 | 0 | 3 | 97 | v. low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | FREQ. E. VIGENS |
| 4460 / 65 | CUTTS | 0.003 | low-mod | good | 0 | 0 | 3 | 97 | v. low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | FREQ. S. CF. SPECIOSUS |
| 4575 / 81 | CUTTS | 0.003 | low-mod | good | 0 | 0 | 2 | 98 | v. low | v. high | S. SPECIOSUS (UPPER) | Tr6B | NON-MARINE | |

| *1 ORGANIC YLD=VOL(cc)/WGHT(g) |
|---|
| <0.01 : EXTREMELY LOW |
| 0.01 - 0.10 : LOW |
| 0.1 - 0.5 : MODERATE |
| >0.5 : HIGH |

| *2 NOTE:PRESERVATION |
|---|
| (FRAGMENTATION INDEX) |
| 1 = SUPERB |
| 2 = EXCELLENT |
| 3 = GOOD |
| 4 = FAIR |
| 5 = POOR |

| *3 DIVERSITY | |
|---|---|
| V HIGH | 30+ SPECIES |
| HIGH | 20-29 SPECIES |
| MOD | 10-19 SPECIES |
| LOW | 5-9 SPECIES |
| EX LOW | 1-4 SPECIES |

| *4 ENVIRONMENTS | DINOFLAGELLATE CONTENT % | DINOFLAGELLATE DIVERSITY | FRESHWATER ALGAE CONTENT% |
|---|---|---|---|
| OFFSHORE MARINE | 67 to 100 | VERY HIGH | LOW |
| SHELFAL MARINE | 34 to 66 | HIGH | " |
| NEARSHORE MARINE | 11 to 33 | MODERATE | " |
| VERY NEARSHORE MARINE | 5 to 10 | MODERATE-LOW | " |
| MARGINAL MARINE | <1 to 4 | LOW-VERY LOW | " |
| BRACKISH | 0, SPINY ACRITARCHS ONLY | EXTREMELY LOW | " |
| NON-MARINE (UNDIFF) | 0, NO SPINY ACRITARCHS | NIL | LOW <3 |
| NON-MARINE (LACUSTRINE) | 0, NO SPINY ACRITARCHS | NIL | MODERATE 3-10+ |

| WELL: Noblige-1 | | | | |
|---|---|---|---|---|
| | | | | |
| LOG DEPTH | SAMPLE | RECOVERY | LITHOLOGY | PALYNOLOGY |
| [mRT] | TYPE | [mm] | | [P] |
| 2789.20 | swc 73 | 25 | SLTST, glc; med lt gy, mod calc | [P] |
| 2797.00 | swc 72 | 25 | SLTST, glc; med lt gy, mod calc | [P] |
| 2810/15 | cutts | | CL, arg; lt-med gy & 30% CL; wh-lt gy & 20% CLYST, calc; med gy & 10% CLYST; med dk gy | [P] |
| 2831.00 | swc 70 | 8 | SLTST, calc; med lt gy, med gy, tr carb lam | [P] |
| 2845.00 | swc 69 | 23 | CLYST, calc; med gy, med dk gy | [P] |
| 2870/75 | cutts | | CLYST, calc; med gy & 40% CL, arg; lt-med gy | [P] |
| 2893.00 | swc 67 | 18 | CLYST, Slty; med dk gy, dk gy | [P] |
| 2910/15 | cutts | | CLYST, slty; bn gy-dk yl bn & 35% CL, arg; lt-med gy & 10% CLYST, calc; med gy & 5% SST | [P] |
| 2925/30 | cutts | | CLYST, slty; bn gy-dk yl bn & 25% CL, arg; lt-med gy & 10% SST, arg & 5% SST | [P] |
| 2961.20 | swc 60 | 25 | CLYST; med dk gy, med grnsh gy | [P] |
| 3025/30 | cutts | | SST with 15% CLYST, slty; dk gy-ol blk & 1% COAL; blk | [P] |
| 3039.00 | swc 58 | 18 | CLYST; med dk gy, dk gy, common carb lam | [P] |
| 3065/70 | cutts | | CLYST, slty; dk gy-ol blk & 30% SST & 10% CLYST; dk gy | [P] |
| 3110/15 | cutts | | CLYST, slty; med dk gy-bn gy & 20% CLYST; bn blk & 5% SST, arg | [P] |
| 3144.60 | swc 56 | 12 | CLYST; med gy-dk gy, dk grnsh gy, carb lam | [P] |
| 3164.00 | swc 55 | 30 | CLYST; gysh blk, blk, carb lam | [P] |
| 3203.80 | swc 53 | 16 | CLYST; med gy, med dk gy , carb lam | [P] |
| 3270.00 | swc 52 | 14 | CLYST; med gy, med dk gy | [P] |
| 3278.20 | swc 51 | 12 | CLYST; med dk gy, dk grnsh gy, carb lam | [P] |
| 3300/05 | cutts | | SST with 35% CLYST, slty; lt bn gy & 25% CLYST; lt - med gy | [P] |
| 3315/20 | cutts | | CLYST, slty; lt bn gy & 25% CLYST; lt - med gy & 10% SST | [P] |
| 3334.70 | swc 48 | 16 | CLYST; med lt gy, med gy, common carb lam | [P] |
| 3355/60 | cutts | | CLYST, slty; lt bn gy & 20% SST, arg | [P] |
| 3375/80 | cutts | | CLYST, slty; lt bn gy & 20% SST, arg | [P] |
| 3390/95 | cutts | | CLYST, slty; lt bn gy & 25% SST, arg | [P] |
| 3455/60 | cutts | | SST, arg & CLYST, slty; lt bn gy | [P] |
| 3483.00 | swc 44 | 26 | CLYST; dk gy, ol blk, grnsh blk, carb lam | [P] |
| 3500/05 | cutts | | CLYST, slty; lt ol gy-lt yl bn & 25% SST, arg & 15% CLYST; dk gy | [P] |
| 3529.00 | swc 43 | 22 | CLYST; brnsh gy, olv gy, carb lam | [P] |
| 3550/55 | cutts | | CLYST; lt ol gy-lt yl bn & 35% CLYST; dk gy & 20% SST, arg | [P] |
| 3570/75 | cutts | | CLYST; lt bn gy-bn blk & 20% SST, arg & 5% SLTST, carb; brn blk | [P] |
| 3590/95 | cutts | | CLYST; lt bn gy-bn blk & 20% SST, arg | [P] |
| 3614.20 | swc 41 | 25 | CLYST; dk gy, ol blk, carb lam | [P] |
| 3625/30 | cutts | | CLYST; lt bn gy-bn blk & 30% SST, arg & 5% CLYST, slty; bn gy-bn blk & 1% COAL; blk | [P] |
| 3655.20 | swc 40 | 8 | CLYST; dk gy, ol blk, carb lam | [P] |
| 3675/80 | cutts | | CLYST; lt bn gy-bn blk & 30% SST, arg & 30% CLYST, slty; bn gy-bn blk | [P] |
| 3709.00 | swc 38 | 25 | CLYST; dk gy, ol blk, carb lam | [P] |
| 3727.00 | swc 37 | 8 | SLTST; lt gy, tl brnsh gy, tr carb | [P] |
| 3754.50 | swc 36 | 18 | CLYST; dk gy, ol blk, carb lam | [P] |
| 3785/90 | cutts | | CLYST; lt bn gy-bn blk & 30% SST, arg & 29% CLYST, slty; bn gy-bn blk & 1% COAL; blk | [P] |
| 3800.70 | swc 33 | 15 | CLYST; lt ol gy, carb lam | [P] |
| 3830/35 | cutts | | CLYST; lt bn gy-bn blk & 30% SST, arg & 30% CLYST, slty; bn gy-bn blk | [P] |
| 3855/60 | cutts | | CLYST, slty; bn gy-bn blk& 30% SST, arg & 25% CLYST; lt bn gy-bn blk | [P] |
| 3882.00 | swc 30 | 25 | CLYST; blk | [P] |
| 3902.40 | swc 29 | 21 | CLYST; gy blk- blk, tr carb | [P] |
| 3925/30 | cutts | | CLYST; lt bn gy-bn blk & 20% SST, arg & 20% SST & 15% CLYST, slty; bn gy-bn blk | [P] |
| 3960/65 | cutts | | CLYST; lt bn gy-bn blk & 30% SST, arg & 14% CLYST, slty; bn gy-bn blk & 1% COAL; blk | [P] |
| 3985/90 | cutts | | CLYST; lt bn gy-bn blk & 10% SST, arg & 10% CLYST, slty; bn gy-bn blk | [P] |
| 4036.40 | swc 23 | 13 | CLYST, slty; dk gy, rare carb | [P] |
| 4050/55 | cutts | | CLYST; lt bn gy-bn blk & 30% SST, arg & 10% CLYST, slty; lt bn gy-bn gy | [P] |
| 4070/75 | cutts | | CLYST; lt bn gy-bn blk & 20% SST, arg & 9% CLYST, slty; lt bn gy-bn gy & 1% COAL; blk | [P] |
| 4110/15 | cutts | | SST, arg with 35% CLYST; lt bn gy-bn blk & 20% CLYST, slty; lt bn gy-bn gy, med dk gy & 2% COAL; blk | [P] |
| 4138.00 | swc 20 | 18 | SLTST, arg; dk gy-lt gy, tr carb lam | [P] |
| 4171.00 | swc 19 | 18 | CLYST, Slty; dk gy-ol blk & 20% SST; wh | [P] |
| 4195/4200 | cutts | | SST, arg with 35% CLYST, slty; lt bn gy-bn gy, med dk gy & 20% CLYST; lt bn gy-bn blk | [P] |
| 4225/30 | cutts | | SST, arg with 35% CLYST, slty; lt bn gy-bn gy, med dk gy & 20% CLYST; lt bn gy-bn blk | [P] |
| 4235.10 | swc 17 | 15 | CLYST; med dk gy, tr carb | [P] |
| 4245/50 | cutts | | SST, arg with 40% CLYST, slty; lt bn gy-bn gy, med dk gy & 20% CLYST; lt bn gy-bn blk | [P] |
| 4262.10 | swc 16 | 15 | CLYST; dk gy, tr carb | [P] |
| 4265/70 | cutts | | SST, arg with 45% CLYST, slty; lt bn gy-bn gy, med dk gy & 20% CLYST; lt bn gy-bn blk | [P] |
| 4287.50 | swc 15 | 20 | SLTST, arg; ol blk, tr carb | [P] |
| 4305/10 | cutts | | SST, arg with 40% CLYST, slty; lt bn gy-bn gy, med dk gy & 15% CLYST; lt bn gy-bn blk | [P] |
| 4323.00 | swc 13 | 21 | CLYST; med dk gy, tr carb | [P] |
| 4330/35 | cutts | | SST, arg with 29% CLYST; lt bn gy-bn blk & 15% CLYST, slty; lt bn gy-bn gy, dk gy & 1% Coal | [P] |
| 4350.80 | swc 11 | 22 | CLYST; gy blk-ol blk | [P] |
| 4355/60 | cutts | | SST, arg with 40% CLYST; lt bn gy-bn blk & 10% CLYST, slty; lt bn gy-bn gy, dk gy | [P] |
| 4375/80 | cutts | | CLYST; lt bn gy- gy blk & 40% SST, arg with 1% COAL; blk | [P] |
| 4410/15 | cutts | | SST, arg with 30% CLYST, slty; lt bn gy-bn gy, med dk gy & 20% CLYST; lt bn gy-bn blk & 15% SST | [P] |
| 4435/40 | cutts | | CLYST, slty; lt bn gy- bn gy & 30% SST, arg with 20% CLYST; lt bn gy- gy blk & 10% SST | [P] |
| 4466.20 | swc 6 | 16 | SLTST; dk gy | [P] |
| 4485/90 | cutts | | CLYST, slty; lt bn gy- bn gy & 35% SST, arg with 15% CLYST; lt bn gy- gy blk & 15% SST | [P] |
| 4500/05 | cutts | | SST, arg with 30% SLTST; med gy, bn gy & 30% CLYST, slty; lt bn gy-bn gy, med dk gy & 10% CLYST; lt | [P] |
| 4520/25 | cutts | | SST, arg with 25% CLYST; lt bn gy-gy blk & 20% SLTST; med gy, bn gy & 10% CLYST, slty; lt bn gy-bn g | [P] |
| 4534.40 | swc 4 | 16 | SLTST, arg; v lt-med lt gy, tr carb | [P] |
| 4549.60 | swc 2 | 25 | SLTST, arg; dk gy-med lt gy | [P] |
| 4560/65 | cutts | | CLYST; lt bn gy-bn blk with 25% SLTST; bn gy, bn blk & 35% SST, arg & 5% COAL; blk | [P] |
| 4575/80 | cutts | | CLYST; lt bn gy-bn blk with 25% SLTST; bn gy, bn blk & 25% SST, arg & 1% COAL; blk | [P] |
| | | | | |
| | | | | 77 samples |

**Well Name : NOBLIGE-1**
**Operator : WOODSIDE ENERGY LIMITED**
**Interval : 2760m - 4601m** | **Palynological Data Chart : INTERPRETIVE DATA**
**Scale : 1:5000** | **% Abundance histogram : Highest occurrence**
**John Filatoff**

# NOBLIGE-1

**Morgan Palaeo Associates**
**Maitland, South Australia**

**Enclosure 1**

**Sampling**
- Cutting
- Core
- Sidewall core

**Text Keys**
- % within discipline (x0/xx=100%)
- n-StLT occurrences

Depth | Samples | Chronostratigraphy (Period/Epoch, Age) | DINOCYST ZONES (HMP 1997, 2004) (Zone, Sub Zone) | MOSPORE ZONES (HMP 1997, 2004) (Zone, Sub Zone)

**Dinoflagellate Cysts** | **Acritarchs** | **Algae** | **MP** | **Spores And Pollen**

Samples | **Total Count** | **% Category** (AL, ALBO, MP, FT, AC, DC, SP)

# Petrophysics Report

Appendix 3

# Petrophysical Interpretation of Noblige-1

Joe Crosby, Petrophysicist
April 2010

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# 1. SUMMARY

Petrophysical analyses were carried out across nine Triassic levels in the Mungaroo Formation in Noblige-1, with TD being called 170m short of original target.

Across the Mungaroo Formation, up to 593 metres of net was interpreted, with a Net to Gross of 35 %, average porosity of 18.6 % and average permeability of 247 mD. There is considerable variation in properties over this 1693m interval – more detail of individual zones can be found in the report

Hydrocarbon presence was interpreted in at least six distinct gas columns.

Wireline logs were successfully run over the entire open hole section, including NMR, sidewall rotary and percussion cores, formation pressure tests and fluid samples.

# 2. INTRODUCTION

This report documents the results of a Petrophysical interpretation of the LWD and Wireline logs acquired during the drilling of Noblige-1.

Noblige-1 was drilled as an exploration well in the WA-404-P block, to appraise Triassic intervals in the Mungaroo Formation. Strategic objectives included determining if amplitude responses in Triassic objectives represent hydrocarbons and determining any relationship of hydrocarbons to those encountered in other wells within the block. Technical objectives included obtaining rock property data from all hydrocarbon bearing intervals for future exploration and appraisal activities; calibrating the seismic model; target amplitude anomalies as an analogue to remaining prospects; testing the possibility of deeper Triassic charge and evaluating pressure gradient in the deep Triassic.

Several targets were identified from seismic data within the Mungaroo Formation, which was predicted at 2907mMDRT. TD was planned for 4699m.

Noblige was spudded by the Jack Bates on 5 January 2010 with water depth 1312m below LAT. The 914mm casing was jetted to 1407.2m and the 444mm hole was then drilled to 2425.5m, with 340mm casing set at 2421.7m. The 311mm hole was drilled to 2750m with a 244mm liner set at the same depth, followed by a 216mm hole drilled to TD at 4581m, with a 177mm liner set at 4246m. All sections were drilled with azimuthal density, neutron, resistivity and gamma ray (MFR-HAGR-AZD-TNP-DS-BAP). Reservoir intervals were drilled with Water Based Mud, and rig was released 18 February 2010.

The Wireline program consisted of Grandslam-STAR (GR, Resistivity, Density, Neutron, Image Log); RCI (formation pressures and samples); Geo-Chain (Vertical Seismic); MREX-DSL (NMR and Sonic); RCOR and PSWC (Rotary and Percussive Side Wall Cores).

Note that all depths in this report, unless specified otherwise, are measured depths referenced to the rotary table (RT) which was 30.5m above Lowest Astronomical Tide (LAT).

# 3. DATA ACQUISITION & LOG QUALITY

Weatherford were the LWD and Baker Hughes were the wireline contractors aboard the Jack Bates:

| | |
|---|---|
| Noblige-1 | 17 $^1/_2$" hole to section TD (2426mRT) |
| LWD | GR-Res |
| Wireline | None |
| Noblige-1 | 12 $^1/_4$ " hole to TD (2750mRT) |
| LWD | GR-Res-Dens-Neut |
| Wireline | None |
| Noblige-1 | 8 $^1/_2$ " hole to TD (~4581mRT – called early) |
| LWD | GR-Res-Dens-Neut |
| Wireline | GSLAM-STAR<br>RCI<br>Geo-Chain<br>RCI<br>MREX-DSL-ZDL<br>RCOR<br>RCOR<br>PSWC |

Table 1: Noblige-1 LWD and Wireline Log Summary

## 3.1. FEWD Data

### 3.1.1. 17.5"(445mm) Hole section

GR LWD logs were obtained.

### 3.1.2. 12.25" (315mm) Hole Section

GR, Res, Density and Neutron LWD logs were obtained.

### 3.1.3. 8.5" (216mm) Hole Section

Real time GR, Res, Density and Neutron LWD logs were obtained. A faulty HEL-BAP-IDS was experienced 41m into drilling the 216mm section - was replaced, incurring 1hr downtime. No difficulties were experienced with LWD tools. Data density for real-time data was generally poor due to poor signal to noise ratio while mud pumping, resulting in some stands being wiped over key intervals before connection. .

### 3.1.4. Hole conditions/ Drilling Fluids

The well was drilled with water based mud, and the hole was in good condition (small washouts <1inch). Casing Shoe was observed at ~2728m from calliper, and end of hole section at 2750.9 from density neutron log response.

### 3.1.5. Summary of LWD Log Data

LWD real-time data was generally poor, with significant sections having insufficient data for meaningful analysis. This occurred particularly over intervals of interest in the reservoir, and required additional wipe passes to achieve sparse data coverage. Eventually decision was made to drill on to deeper targets and wiping ceased.

## 3.2. Wireline Data

Wireline operations were generally conducted successfully, with sufficient good quality data being recovered in spite of Density RCI and RCOR tool failures. Maximum temperature observed from LWD tools was 45°C.

A 250 bbl logging pill containing Driscal-D (to prevent high temperature fluid loss) and TEA (tri-ethyl-amine: to prevent polymer degradation) was spotted on bottom of hole. This covered 1100m of open hole, above which Drilling mud remained.

### 3.2.1. Petrophysical Logs

While running in hole, at 4000mMDRT, the Density tool (ZDL) failed to report data correctly. Resetting the tool did not fix the problem, and the first run (GSLAM-STAR) was conducted without density. Density was eventually run with Spectral GR & NMR in Suite 1 Run 5.

### 3.2.2. Sidewall Core

Both RCOR and PSWC were recovered in Noblige-1. RCOR was run in two runs, with a tool hydraulic failure at 5$^{th}$ station on the first. Several core plugs exhibited extremely slow drilling. Overall recovery was 4 cores from first run and 24 cores from second run. At time of writing, cores are at CoreLabs being processed for RCA.

PSWC comprised one run of 74 shots, with 57 recovered, 12 empty, 5 lost and no misfires, resulting in 77% recovery.

### 3.2.3. Formation Tests (Pressure & Fluid Samples)

RCI was run in two runs in Noblige-1, with an electronic module failure occurring ending the first run prematurely, with no opportunity to sample or conduct mini-DST. First run results were 46 of 47 planned pre-tests performed: 31 valid, 1 repeat, 5 tight, 2 seal failure, 5 supercharged, 2 incomplete.

Geochain was run before second RCI run, as there was discussion of potentially deepening the well.

The second RCI run resulted in 54 pre-tests being performed: 12 valid, 10 tight, 9 seal failures, 5 supercharged, 3 incomplete, 13 repeat tests and 3 sample points. Measurements repeated at the same depths from the first RCI run consistently showed pressures a few psi higher. Many tests were targeting thinly bedded interval of ambiguous fluid phase.

All eleven samples taken were successfully recovered on surface. One 560cc sample taken at 4374.2 was determined to be water. Two sample stations attempted at 4209 were tight and aborted without pumping. Ten 560cc gas samples were collected at the following depths: 3932.5mMDRT(3 samples), 3286.8mMDRT(3), 3812.5mMDRT(2) and 4097.5mMDRT(2).

A straddle packer test for fluid phase analysis was attempted at 4116mRT, however packers failed to inflate.

## 3.3. Conventional Core

No conventional core was obtained in Noblige-1.

## 3.4. Production Testing

No production tests were conducted on Noblige-1.

## 3.5. Current Well Status

The well was suspended for further testing, with rig being released on 18 February, 2010.

# 4. PETROPHYSICAL EVALUATION

## 4.1. Data Preparation

Wireline data was considered excellent quality as delivered, and minimal editing was required. LWD logs were depth shifted and spliced on to the bottom of wireline logs were additional coverage was available.

### 4.1.1. Log/Environmental Corrections

No additional log or environmental corrections, other than those applied by Baker Hughes prior to delivery, were required.

### 4.1.2. Depth matching/splicing

LWD data was depth matched to the Wireline S1R1: GSLAM-STAR Gamma Ray.

## 4.2. Evaluation methodology

Preliminary Petrophysics quick look consisted of a workflow consistent with nearby offset field practice, comprising density porosity, Archie Saturation, Density/Neutron Vshale and Net cutoff. Upon receipt of image and NMR processing, a revised workflow to include NMR calculated permeability and Net cutoff was also conducted.

Routine Core Analysis of the rotary sidewall cores was being undertaken at the time of writing this report, and the results will be incorporated into NMR processing and workflow during a later study.

### 4.2.1. Temperature

Highest recorded temperature during wireline operations was during the final run (SWC). Max Temperature of 110.6°C was recorded at 4512.8 mTVDSS, 70:55hrs after last circulation.

### 4.2.2. Shale volume

Vshale was calculated from wireline density and neutron logs, using the below equations:
DPHI = (2.65 – DENSITY) / (2.65 – 0.98)
VSHAL = LIMIT((NEUTRON + 0.03 – DPHI) / (0.3 – 0.1) , 0, 1).
It is noted that current shale volume appears inconsistent with side wall cores in some of the sandier sequences, and it is recommended that Vshale calculation be reviewed when cuttings analysis is available.

### 4.2.3. Coal

A Geolog module was run for Coal identification, with some further manual refinement made to account for shoulder / lobe effects. Cutoffs used to create a Coal flag were:
COAL = IFC ( NEUTRON > 0.37 & DENSITY < 2.18, 1, 0 )

### 4.2.4. Porosity

PHIT was calculated using the density porosity equation as part of the SATCP WBM module in Geolog, corrected for Z/A and invasion effects.

PHIE was later calculated from MREX data and is used specifically for Permeability calculation and Net determination. PHIE is calculated as below:
PHIE = MPHS(HI) – MCBW
Where: MPHS(HI) is the MR Total Porosity, Hydrocarbon Indexed where available
MCBW is the MR Clay Bound Porosity Fluids

### 4.2.5. Saturation

SWT is calculated using Archie equation as part of SATCP WBM module in Geolog. Of note are Rw inputs of 0.093 and 0.185Ωm above and below 3850mMDRT respectively. The upper resistivity value corresponds to a salinity of approximately 32kppm, which is representative of perched water observed in similar zones in analogue wells. The lower resistivity value corresponds to salinity of approximately 15kppm, which is consistent with the regional understanding of Woodside's Joint Venture partner. Both values are matched by calculated Rwa values in cleaner water sands.

SWE is calculated from MREX data and is used for the calculation of permeability and Net cuttoff. SWE is calculated as below:
SWE = IFC(PHIE>2pu, (MBVI – MCBW) / PHIE, 1)
Where
PHIE is effective porosity, described above
MBVI is MR Irreducible Fluids (ie Capillary and Clay Bound Water)
MCBW is MR Clay Bound Porosity Fluids (ie Clay Bound Water only)

### 4.2.6. Permeability

Permeability was calculated using a number of methods, including offsets from various units in different nearby fields. While one of these offsets appears to be a reasonable approximation for the upper half of Noblige-1 (ie above 3850m), it was decided that permeability calculated from MREX data produced the best approximation for Mobility data throughout the well. As previously noted, RCA data from RCOR plugs is not yet available, and it is therefore likely that permeability will be reviewed in a later report.
PERM_NMR is calculated as below:
PERM_NMR = (70 * PHIE ^ 2 * (1-SWE)/SWE)^2 *Perm Coates FFI*

### 4.2.7. Net definition

Preliminary Net cut-off during Quicklook Analysis comprised a 35% Vshale cutoff as per offset field workflow. Upon availability of Image and NMR logs, it became apparent that this was not representative in many cases. Subsequent analysis based on preliminary MREX (ie not RCA calibrated) provided a more appropriate Net cutoff detailed below:
NET = IFC ( MPHS(HI) – MBCI > 3pu, 1, 0)
The 3pu cutoff was used to tune the net interval to be representative of the image logs.

Further cuttoffs: PHIT > 5pu and k_NMR > 0.1 mD have also been applied to remove tight streaks and to represent a reasonable assumption for rock that will contribute to pressure support in a gas environment. The above values were determined to be best after a +/-1 pu and +/- 1 decade sensitivity check.

### 4.2.8. Pay definition

Preliminary Pay cutoff was set to SWT < 80%. This is considered a reasonable estimate, however we are still awaiting further information regarding residual saturation levels.

## 4.3. Results

### 4.3.1. Tops and Intervals

Following is the field reported provisional formation tops picked in Real Time. These are used in this report, but are subject to revision from ongoing work. Intervals within the Mungaroo Formation referred to in this report are named with reference to the marker at the top of the interval.

Table 2: Noblige-1 Wellsite Tops

| Formation | Marker | Preliminary Top (m) | | |
|---|---|---|---|---|
| | | MDRT | TVDRT | TVDSS |
| Sea Floor | (WB) | 1342.5 | 1342.5 | -1312.0 |
| Bare | TM1 | 1512.0 | 1512.0 | -1481.5 |
| Upper Walcott | TO | 1587.5 | 1587.5 | -1557.0 |
| Lower Walcott | TE | 1732.5 | 1732.5 | -1702.0 |
| Miria/Withnell | T | 2036.5 | 2036.5 | -2006.0 |
| Toolonga | KSC | 2330.0 | 2330.0 | -2299.5 |
| Haycock | KC | 2449.5 | 2449.5 | -2419.0 |
| Windalia | - | 2576.0 | 2576.0 | -2545.5 |
| Muderong | KA | 2597.5 | 2597.5 | -2567.0 |
| Barrow Group | KV | 2703.0 | 2703.0 | -2672.5 |
| Oxfordian | JT | 2790.0 | 2790 | -2759.5 |
| Brigadier | JO | 2800.0 | 2800.5 | -2770.0 |
| Mungaroo | TRR | 2888.0 | 2888.0 | -2857.5 |
| Intra-Mungaroo | MCM53 | 3173.0 | 3172.9 | -3142.5 |
| Intra-Mungaroo | MCS50 | 3281.0 | 3280.9 | -3250.5 |
| Intra-Mungaroo | MCT42 | 3450.0 | 3449.8 | -3419.5 |
| Intra-Mungaroo | MCS30 | 3673.0 | 3672.8 | -3642.5 |
| Intra-Mungaroo | MCS20 | 3727.0 | 3726.8 | -3696.5 |
| Intra-Mungaroo | P6 | 3805.0 | 3804.8 | -3774.5 |
| Intra-Mungaroo | MCT12 | 3879.0 | 3878.8 | -3848.5 |
| Intra-Mungaroo | MCS10 | 3929.0 | 3928.7 | -3898.5 |
| Intra-Mungaroo | P9 | 3996.5 | 3996.2 | -3966.0 |
| Intra-Mungaroo | P10 | 4073.0 | 4072.7 | -4042.5 |
| Intra-Mungaroo | Near TRC1 | 4357.0 | 4357.0 | -4326.5 |

### 4.3.2. Pressure Interpretation/Contacts

Six distinct gas intervals were identified in Noblige-1; a shallow gas zone observed at 3250mTVDss with a calculated FWL at 3281mTVDss, followed by four columns from 3778mTVDss down to a calculated FWL at 3994mTVDss. A gas zone was also interpreted at 4051mTVDss. A summary of fluid contacts is presented below in
Table 3 and visually in Figure 1.

Table 3: Noblige-1 Summary of Contacts

| Interval Top | Gas up-to mTVDss LAT | FWL mTVDss LAT | Gas Column Height (m) |
|---|---|---|---|
| MCS50 | 3250 | 3281 | 31 |
| P6 | 3778 | 3832 | 54 |
| MCT12 | 3855 | 3884 | 29 |
| MCS10 | 3900 | 3966 | 66 |
| P9 | 3966 | 3994 | 28 |
| P10 | 4051 | 4068 | 17 |

### 4.3.3. Sums and averages:

Refer: Table 3: Noblige-1 Sums and Averages

### 4.3.4. Discussion

The upper gas interval from 3281 to 3310.1 mMDRT (MCS50) is supported by conventional log interpretation, RCI pressure gradient and gas samples. Conventional log interpretation calculated 17.5m of Net interval, and extrapolation to water gradient calculates a 31m gas column, above approximately 400m interval of water. Properties for this zone are summarised below:

| Zone | MCS50 |
|---|---|
| Gross Column (m) | 29.1 |
| Net Sands (m) | 17.5 |
| Net to Gross (%) | 60 |
| Average Porosity in Net Sands (%) | 22.3 |
| Average Permeability in Net Sands (mD) | 118 |
| Average Water Saturation in Net Sands (%) | 50 |
| Calculated Gas Column Height (m) | 31 |

The lower gas interval from 3800 – 4150mMDRT appears to be separated into five gas accumulations (P6, MCT12, MCS10, P9 and P10). Fluid interpretation over this interval is supported by conventional log interpretation, pressure gradients and fluid samples at 3812.5, 3932.5 and 4097.5mMDRT. Gas columns for these gas intervals are extrapolated to the water gradient above this zone, as there are no unambiguous water zones below this interval, and the formation appears over pressured below ~4200mMD. In particular the P10 gas column (verified by sample) is likely to juxtapose over pressured water, and so gas column height will be less certain. Properties for these zones are summarised below:

| Zone | P6 | MCT12 | MCS10 | P9 | P10 |
|---|---|---|---|---|---|
| Gross Column (m) | 53 | 29 | 55 | 40.1 | 68 |
| Net Sands (m) | 17.4 | 9.6 | 35.5 | 23.6 | 17.4 |
| Net to Gross (%) | 33 | 33 | 65 | 59 | 26 |
| Average Porosity in Net Sands (%) | 14 | 14.5 | 20.3 | 15.3 | 12.1 |
| Average Permeability in Net Sands (mD) | 71 | 28 | 740 | 226 | 24 |
| Average Water Saturation in Net Sands (%) | 49 | 66 | 17 | 46 | 71 |
| Calculated Gas Column Height (m) | 54 | 29 | 66 | 28 | 17 |

Interpretation for the remainder of the well is somewhat ambiguous. Formation pressure tests were few – many were tight – and the sample at 4374mMDRT was determined to contain approximately 30% water based mud, and the quantity of gas in this sample is determined to be within expectations for gas dissolved in mud. Sampling was attempted in the Peak 13 interval; however the RCI tool failed during preliminary pretests. It is therefore inconclusive whether there is any pay in this interval: NMR suggests gas presence, but doesn't distinguish between residual HC and mobile saturations.

## 4.4. Uncertainties

The wireline data used for this interpretation is of good quality. However there are several assumptions being made concerning the appropriateness of nearby fields as analogies. Combined with the not yet available RCA results from RCOR, it must be concluded that there is still uncertainty in the results being put forward.

## 4.5. Further Workflow and Data Processing

It is currently envisioned that further work will take place on this well as the remaining data being processed becomes available. As a summary of perceived workflow from this point forwards:

- When RCA data becomes available, NMR will be reprocessed with calibration points.
- Porosity and permeability will require updating to honor RCA data
- Net cut-offs and Net interpretation will likely be revised upon receipt of final NMR data.
- Other wells in this block will likely be revised upon availability of Noblige-1 RCA data.
- In the event of further data acquisition in this block, particularly any side-track conventional core data that was planned for this well, but will likely occur in a future well, existing interpretation should again be revisited.

## Well Results

NOBLIGE-1 sums and averages
Date: 13-Apr-2010 10:33:22
Evaluation method: CONVENTIONAL

Net defined by: NET FLAG LOG USED (0 or 1)
Pay defined by: Net criteria plus Sw<= 0.80su

| | |
|---|---|
| Depth: | DEPTH |
| Net flag: | NET |
| Porosity: | POR |
| Water saturation: | SW |
| Permeability: | PERM |

| | Depth | | | \|----------NET----------\| | | | | | | | | \|----------PAY----------\| | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INTERVAL | Top | Base | Gross | Net | N2G | Por | Sw | Perm | Por*h | Por*Sh*h | k*h | Pay | N2G | Por | Sw | Perm | Por*h | Por*Sh*h | k*h | Fluid |
| | metres | metres | metres | metres | FRAC | v/v | v/v | mD | m | m | mD.m | metres | FRAC | v/v | v/v | mD | m | m | mD.m | |
| MUNGAROO-TRR | 2888.1 | 3173.1 | 285 | 157.4 | 0.55 | 0.237 | 0.852 | 194.2 | 37.34 | 5.51 | 30569 | 30.8 | 0.11 | 0.279 | 0.609 | 78.6 | 8.58 | 3.36 | 2421 | Water |
| MCM53 | 3173.1 | 3281 | 107.9 | 77.3 | 0.72 | 0.211 | 0.908 | 231 | 16.28 | 1.5 | 17845 | 7.6 | 0.07 | 0.248 | 0.575 | 14 | 1.89 | 0.8 | 107 | Water |
| MCS50 | 3281 | 3310.1 | 29.1 | 17.5 | 0.6 | 0.223 | 0.499 | 118.3 | 3.91 | 1.96 | 2073 | 15.2 | 0.52 | 0.24 | 0.469 | 134.4 | 3.65 | 1.94 | 2048 | GAS |
| MCS50_BASE | 3310.1 | 3450 | 139.9 | 58.5 | 0.42 | 0.173 | 0.953 | 45.2 | 10.14 | 0.48 | 2643 | 2.6 | 0.02 | 0.236 | 0.595 | 3.3 | 0.61 | 0.25 | 9 | Water |
| MCT42 | 3450 | 3673.1 | 223.1 | 68.4 | 0.31 | 0.158 | 0.893 | 27.1 | 10.79 | 1.15 | 1855 | 12.3 | 0.06 | 0.18 | 0.675 | 10.8 | 2.22 | 0.72 | 133 | Water |
| MCS30 | 3673.1 | 3727.1 | 53.9 | 18 | 0.33 | 0.149 | 0.901 | 1319.7 | 2.69 | 0.27 | 23732 | 2.9 | 0.05 | 0.17 | 0.672 | 20.9 | 0.49 | 0.16 | 60 | Water |
| MCS20 | 3727.1 | 3808 | 80.9 | 50.6 | 0.63 | 0.153 | 0.908 | 679.5 | 7.75 | 0.71 | 34382 | 6.1 | 0.08 | 0.178 | 0.67 | 23 | 1.09 | 0.36 | 140 | Water |
| P6 | 3808 | 3861.1 | 53 | 17.4 | 0.33 | 0.14 | 0.492 | 71.1 | 2.43 | 1.24 | 1235 | 16 | 0.3 | 0.144 | 0.467 | 77 | 2.3 | 1.22 | 1232 | GAS |
| P6_END | 3861.1 | 3884.1 | 23 | 5.9 | 0.26 | 0.104 | 0.741 | 1.2 | 0.62 | 0.16 | 7 | 4.3 | 0.19 | 0.112 | 0.689 | 1.5 | 0.48 | 0.15 | 6 | GAS |
| MCT12 | 3884.1 | 3913 | 29 | 9.6 | 0.33 | 0.145 | 0.663 | 27.5 | 1.39 | 0.47 | 264 | 7.2 | 0.25 | 0.158 | 0.606 | 32.4 | 1.13 | 0.45 | 232 | GAS |
| MCT12_END | 3913 | 3929 | 16 | 0.5 | 0.03 | 0.085 | 1 | 0.1 | 0.04 | 0 | 0 | 0 | 0 | - | - | - | 0 | 0 | 0 | GAS |
| MCS10 | 3929 | 3984 | 55 | 35.5 | 0.65 | 0.203 | 0.169 | 740.2 | 7.2 | 5.98 | 26283 | 33.2 | 0.6 | 0.211 | 0.145 | 790.9 | 7 | 5.98 | 26278 | GAS |
| P9 | 3984 | 4024.1 | 40.1 | 23.6 | 0.59 | 0.153 | 0.457 | 226.3 | 3.62 | 1.97 | 5345 | 20.6 | 0.51 | 0.159 | 0.41 | 258.1 | 3.26 | 1.93 | 5310 | GAS |
| P9_END | 4024.1 | 4080.1 | 55.9 | 3.5 | 0.06 | 0.1 | 0.988 | 0.4 | 0.35 | 0 | 1 | 0 | 0 | - | - | - | 0 | 0 | 0 | GAS |
| P10 | 4080.1 | 4148 | 68 | 17.4 | 0.26 | 0.121 | 0.714 | 24.2 | 2.1 | 0.6 | 421 | 9.4 | 0.14 | 0.138 | 0.595 | 40.8 | 1.3 | 0.53 | 386 | GAS |
| P10_END | 4148 | 4328 | 180 | 16.5 | 0.09 | 0.11 | 0.978 | 1.8 | 1.81 | 0.04 | 30 | 0.3 | 0 | 0.174 | 0.503 | 1.9 | 0.05 | 0.03 | 1 | |
| NEAR TRC1 | 4328 | 4379.1 | 51.1 | 10.7 | 0.21 | 0.104 | 0.762 | 2.6 | 1.11 | 0.26 | 27 | 5.5 | 0.11 | 0.114 | 0.623 | 4.1 | 0.62 | 0.23 | 23 | GAS |
| NEAR_TRC1_END | 4379.1 | 4535.1 | 156.1 | 0.9 | 0.01 | 0.12 | 0.784 | 0.2 | 0.11 | 0.02 | 0 | 0.3 | 0 | 0.156 | 0.598 | 0.1 | 0.05 | 0.02 | 0 | |
| PEAK13 | 4535.1 | 4549.1 | 14 | 3.7 | 0.26 | 0.115 | 0.86 | 7.6 | 0.42 | 0.06 | 28 | 1.1 | 0.08 | 0.106 | 0.687 | 0.4 | 0.11 | 0.04 | 0 | GAS |
| PEAK13_END | 4549.1 | 4581.3 | 32.2 | 0 | 0 | - | - | - | 0 | 0 | 0 | 0 | 0 | - | - | - | 0 | 0 | 0 | |
| TOTAL | 2888.1 | 4581.3 | 1693.2 | 592.8 | 0.35 | 0.186 | 0.797 | 247.5 | 110.1 | 22.38 | 146739 | 175.4 | 0.1 | 0.199 | 0.479 | 218.8 | 34.85 | 18.16 | 38386 | |

Table 4: Noblige-1 Sums and Averages from Quicklook Petrophysics
NB: All depths are mMDRT.

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Summary of Fluid Contacts

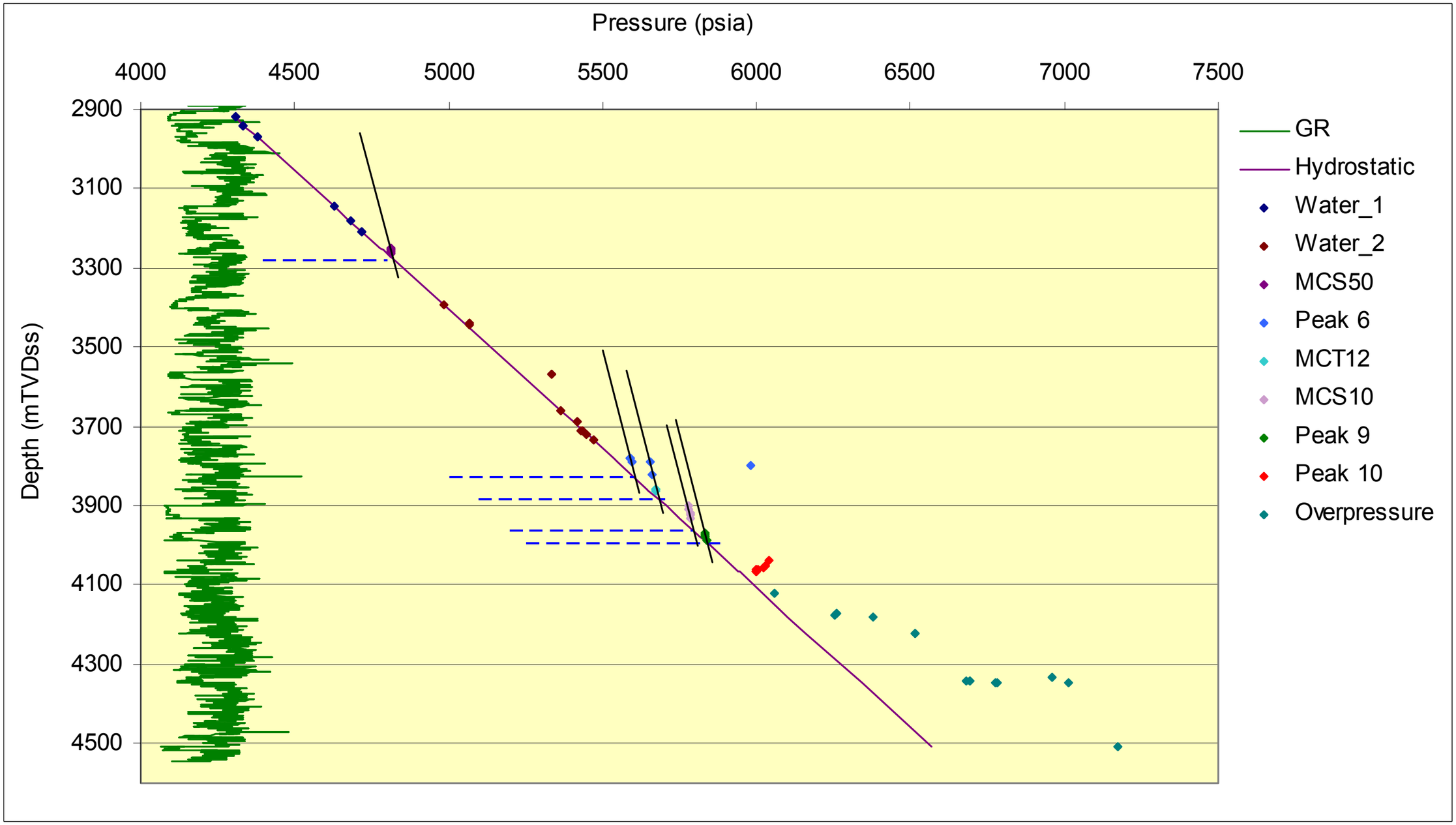


Figure 1: Noblige-1 Fluid Contacts

Well Results by Interval (2775-3360 mMD)

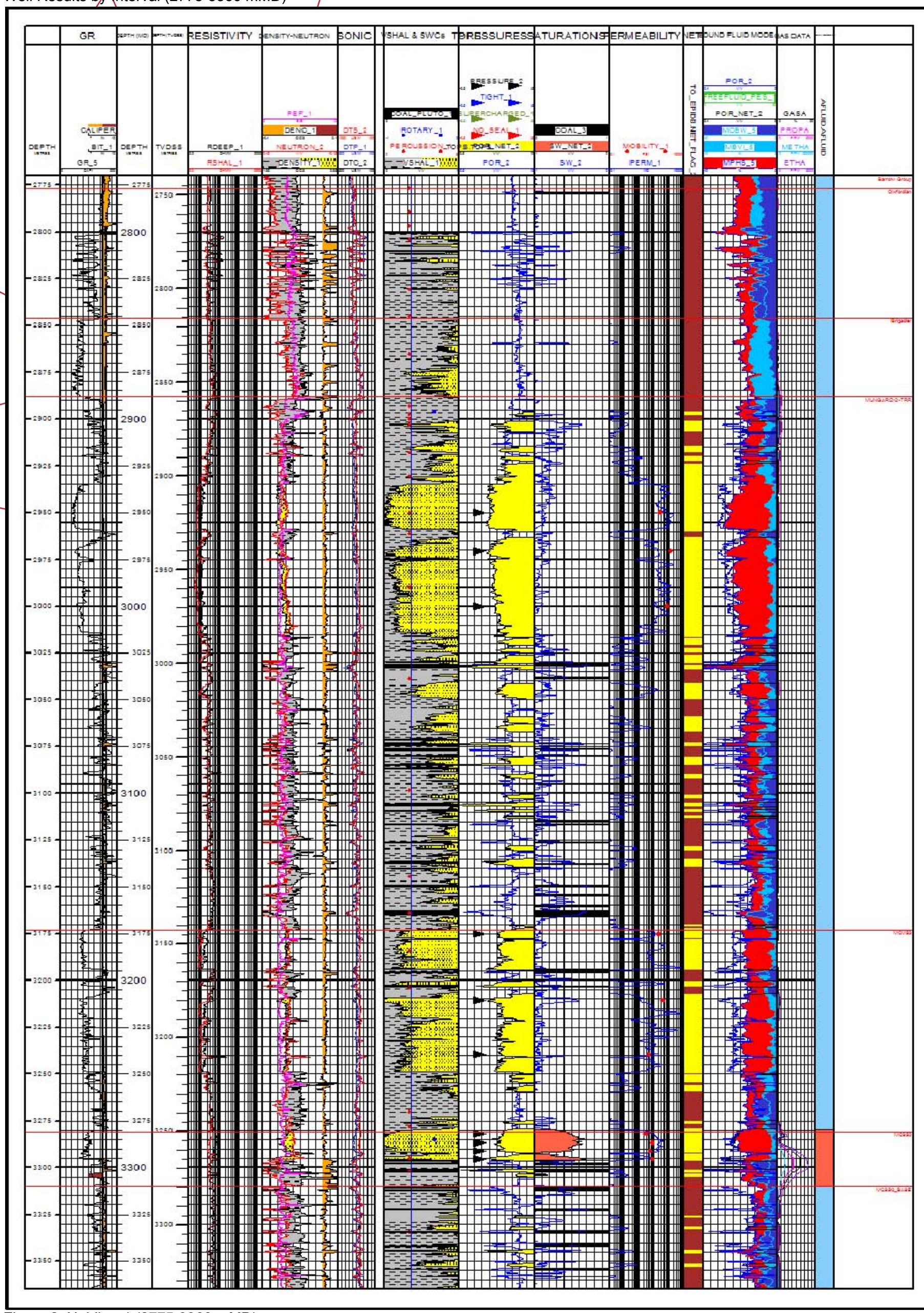


Figure 2: Noblige-1 (2775-3360 mMD)

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Well Results by Interval (3360-3975 mMD)

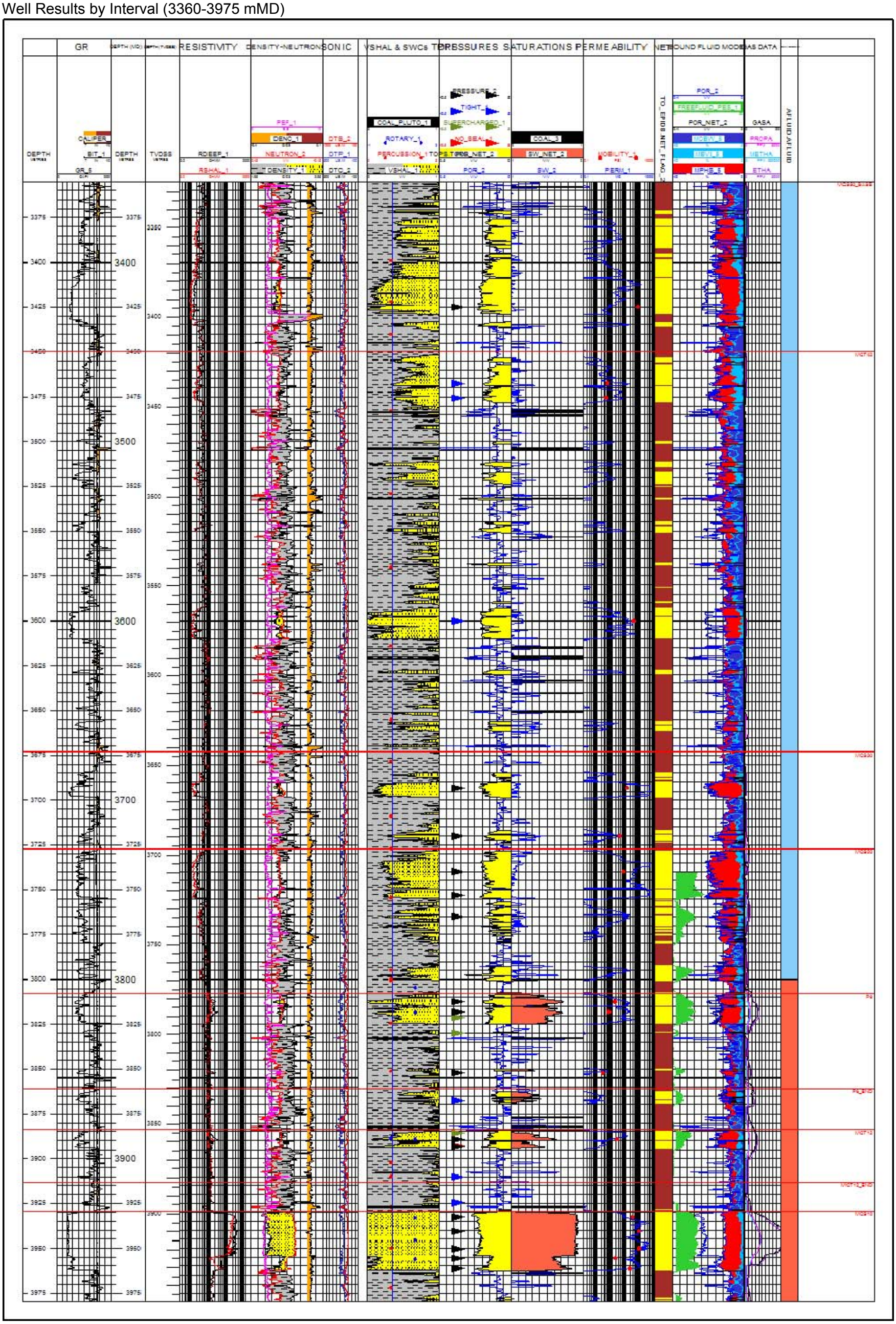



Figure 3: Noblige-1 (3360-3975 mMD)

Well Results by Interval (3975-4650 mMD)

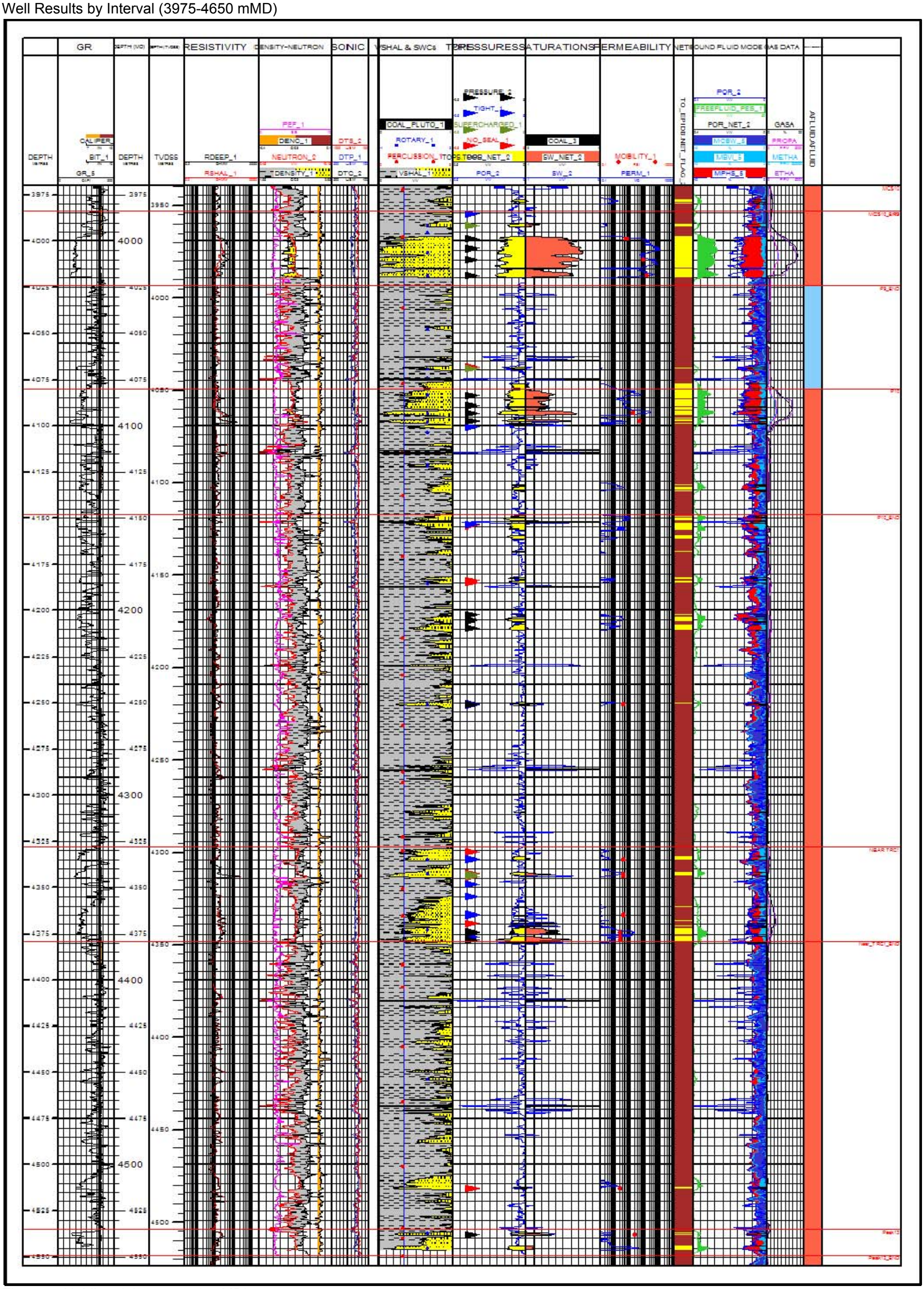



Figure 4: Noblige-1 (3975-4650 mMD)

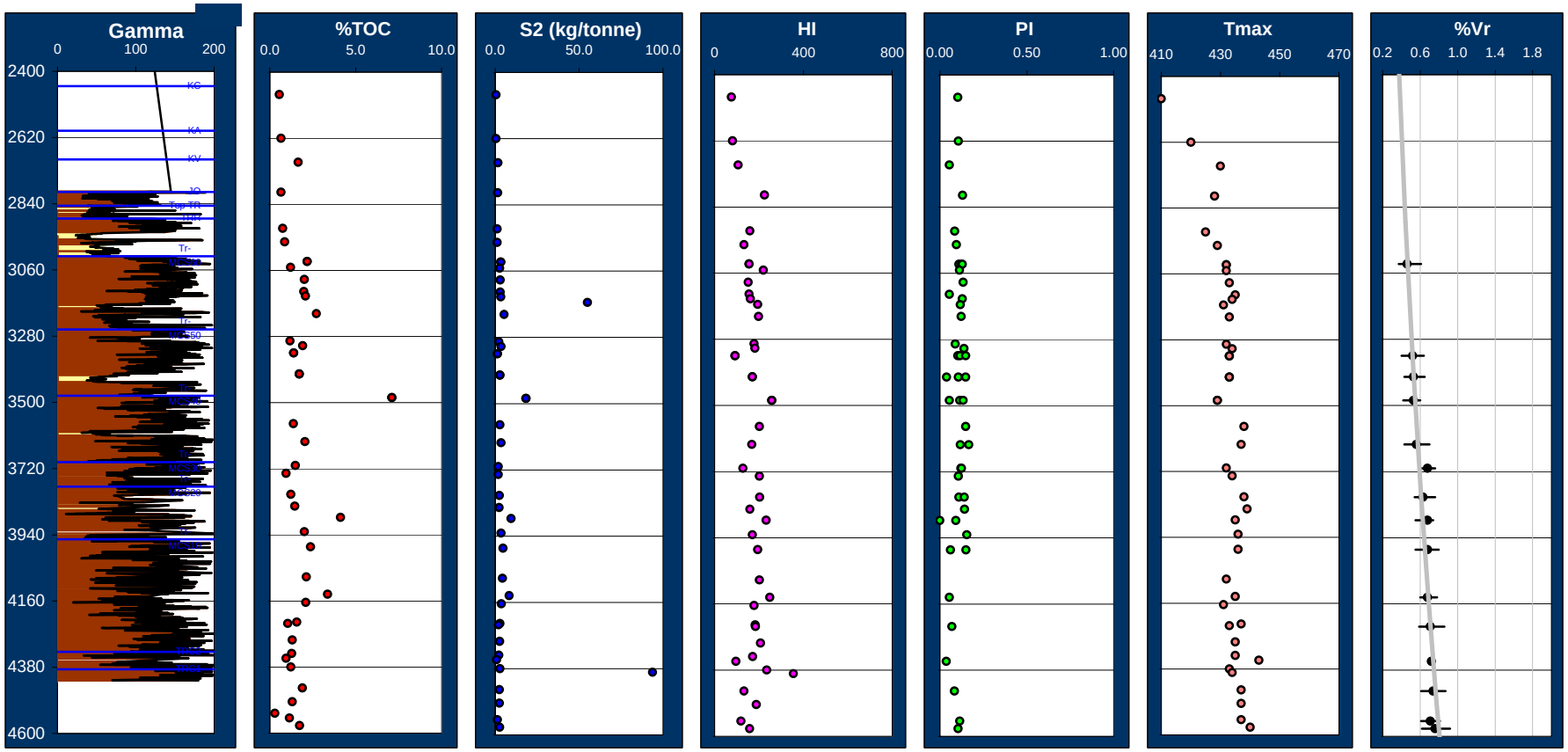
# Geochemistry and Source Rock Interpretation

# Source Rock Geochemistry Summary Sheet

## Source Rock Log: Noblige-1

woodside

**Lab:** Geotech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5.0
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50.0
100.0
HI
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400
800
PI
0.00
0.50
1.00
Tmax
410
430
450
470
%Vr
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0.6
1.0
1.4
1.8
2400
2620
2840
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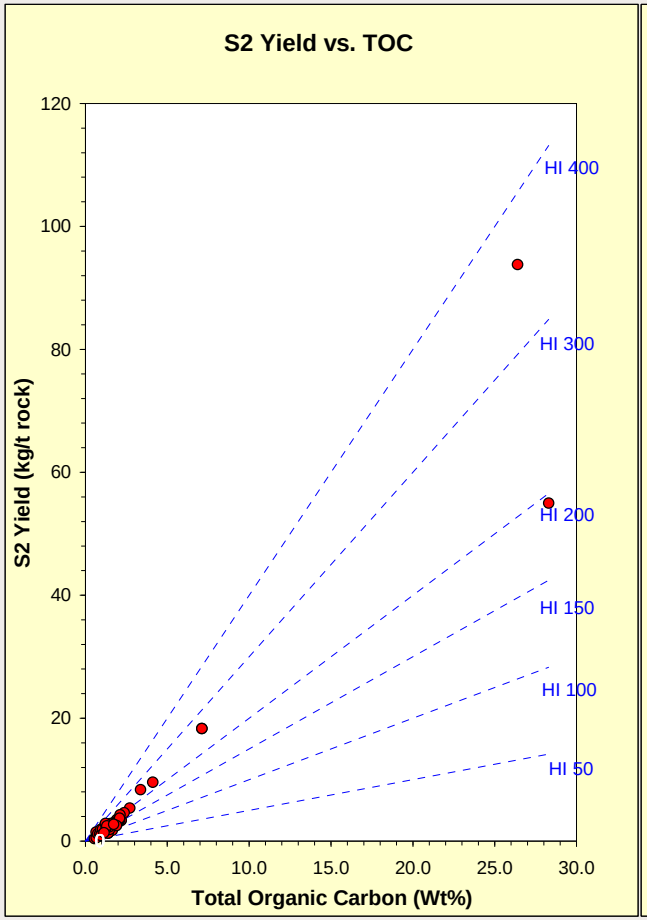
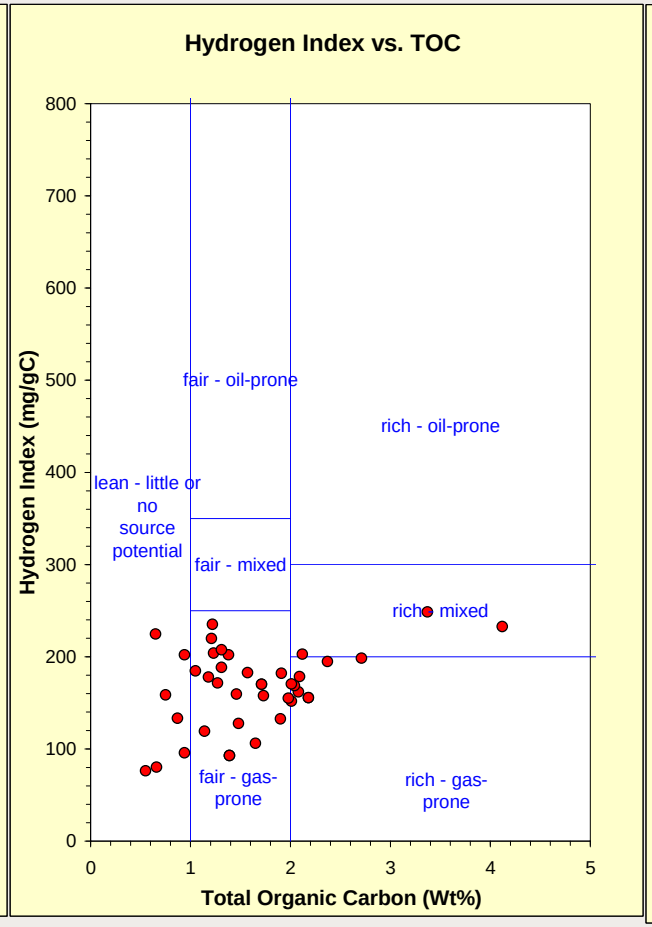
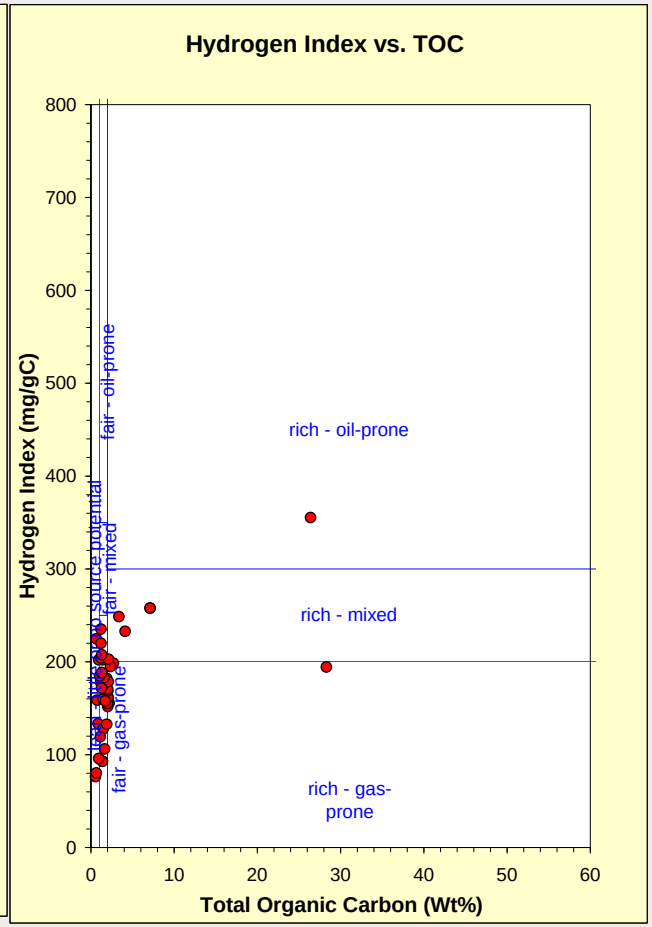
Tr-
Tr-

# Source Rock Geochemistry Plots (1)



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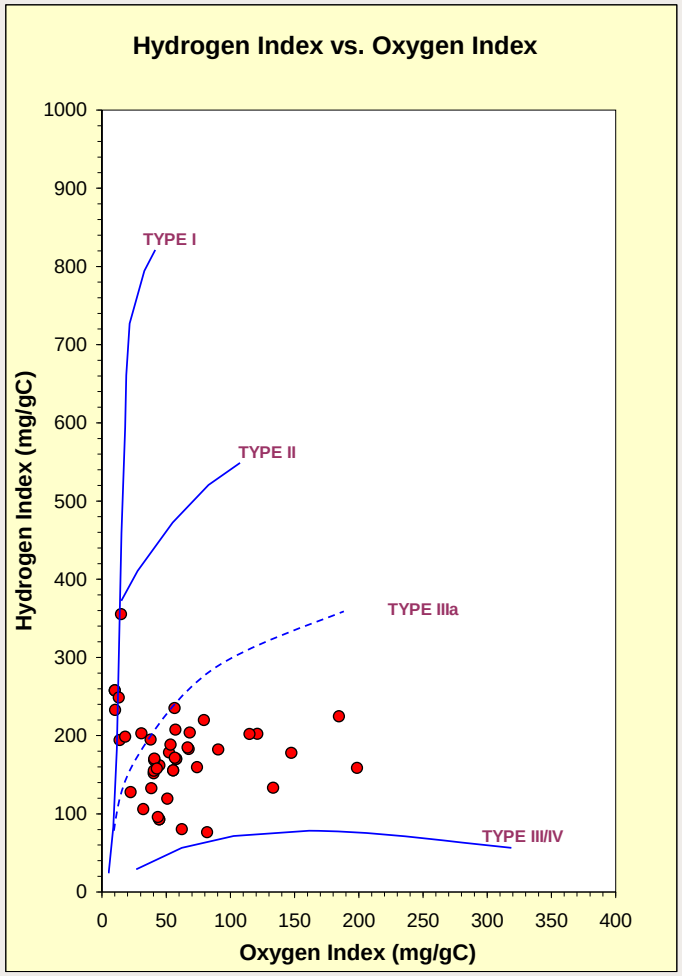
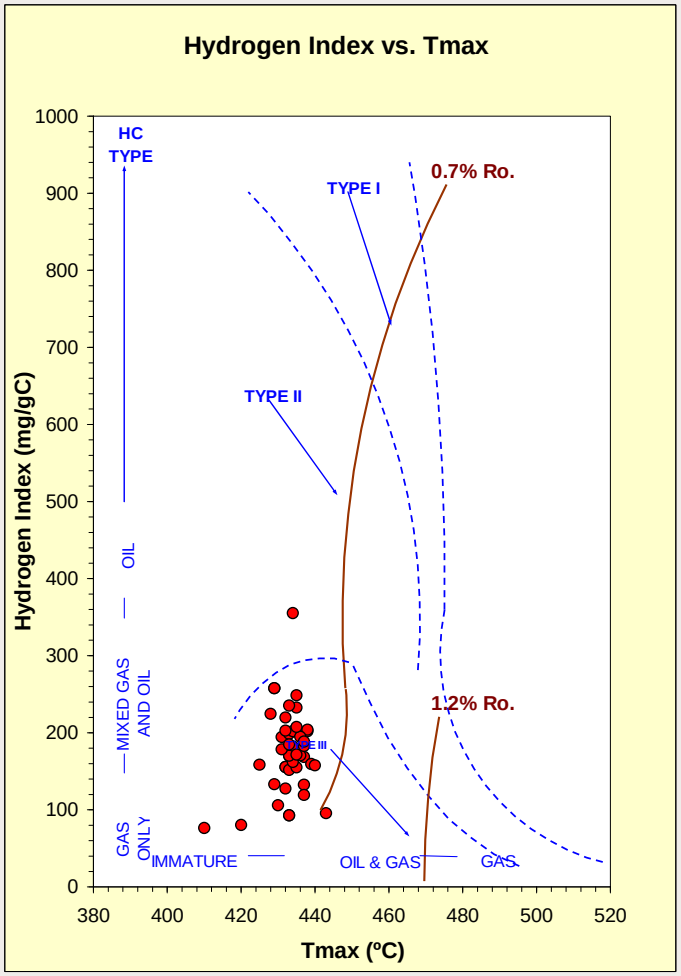
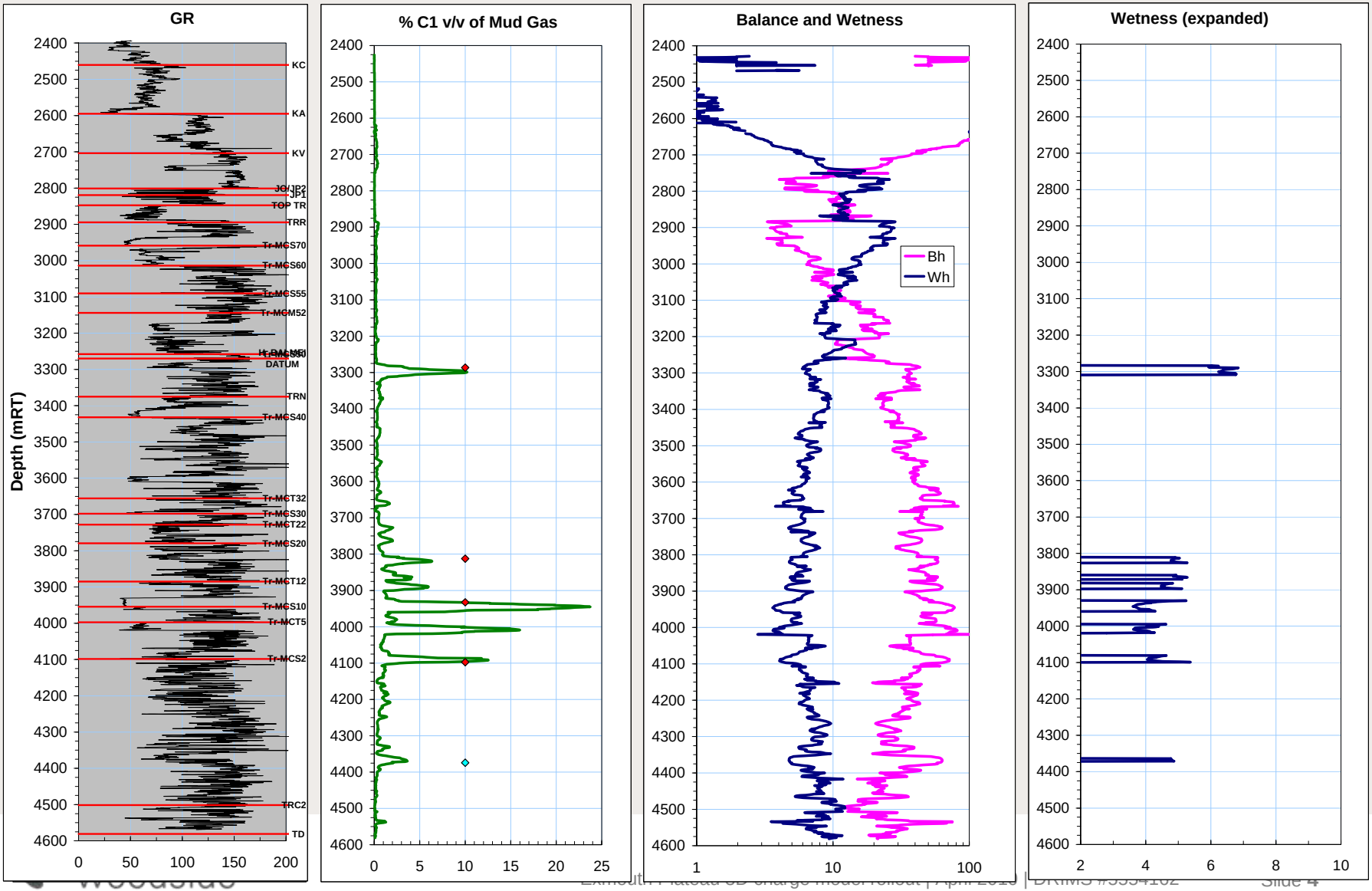
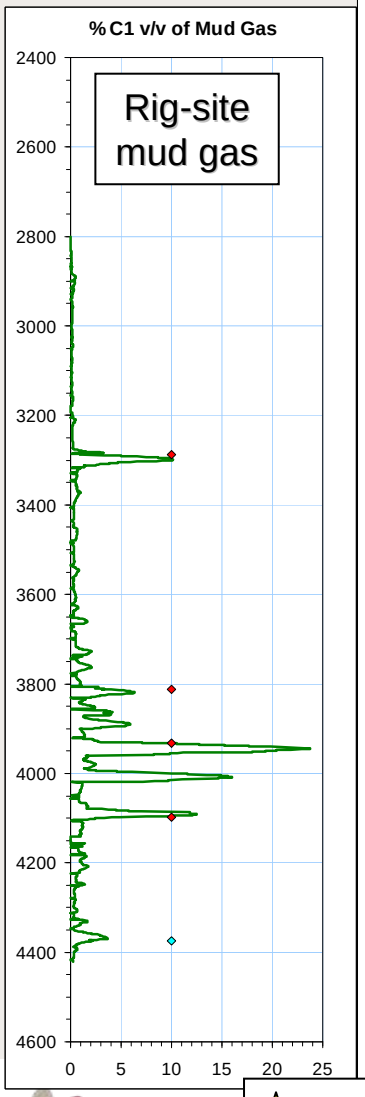


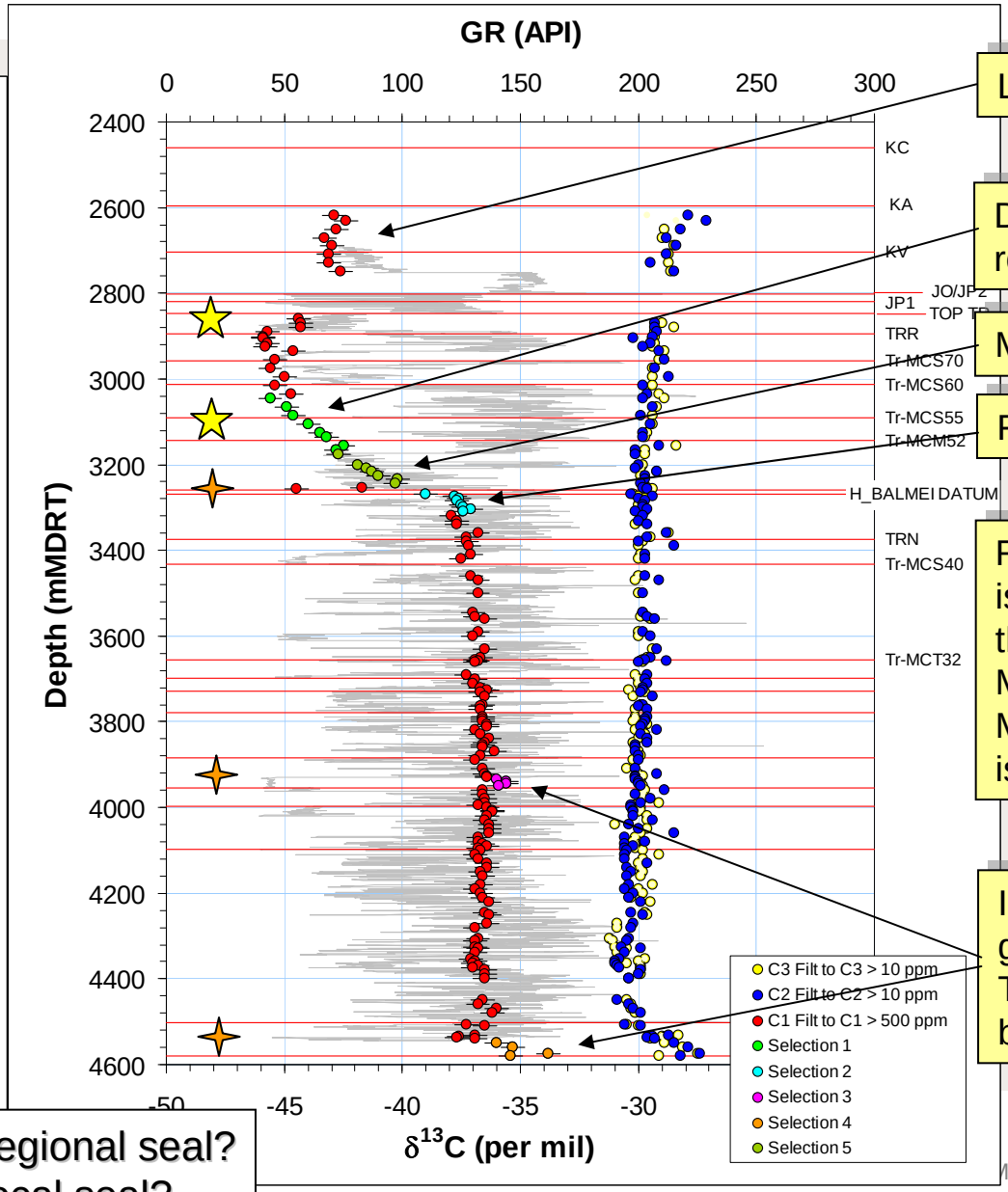



# Noblige-1 rig-site mud gas interpretation



# Noblige-1 Isotubes interpretation




Low maturity gas shows

Diffusion through tight rock (seal)

Mixing profile

First significant gas

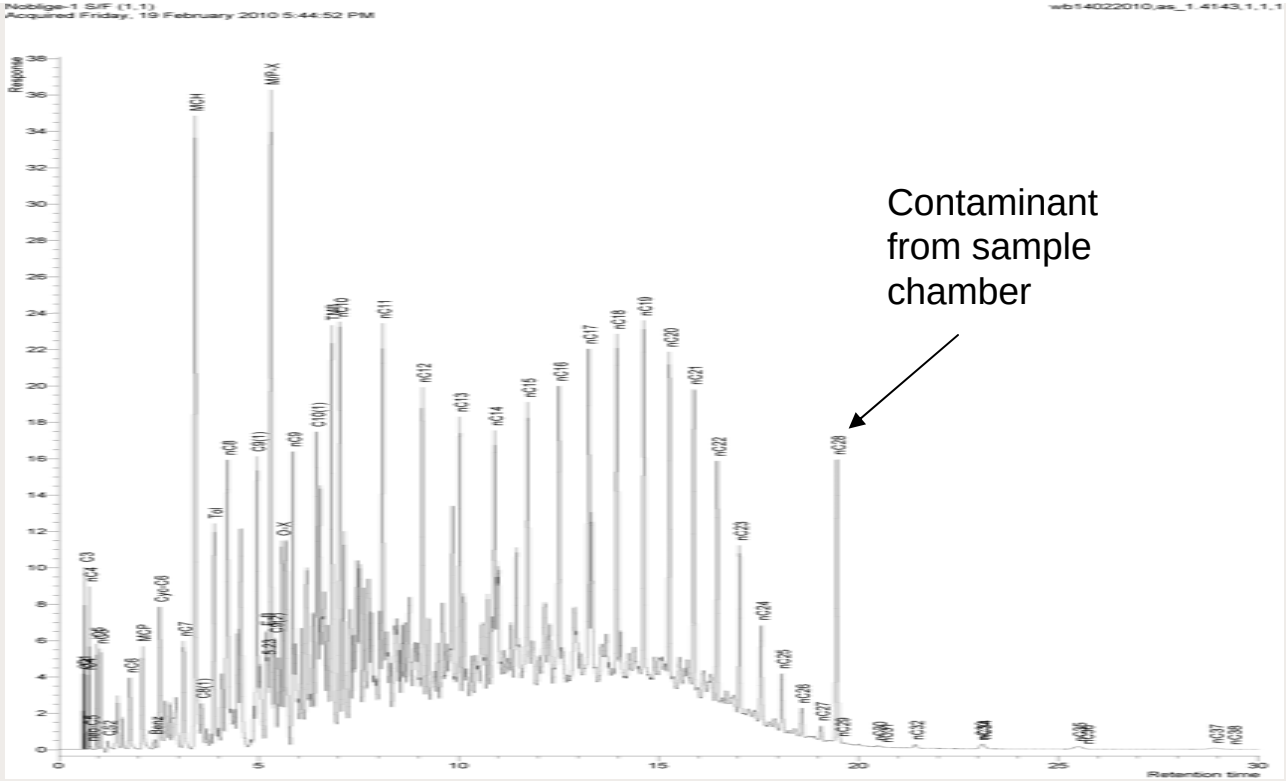
Remarkably continuous isotope profile through the majority of the Mungaroo. Typical Mungaroo coal gas isotope signature

Isolated, higher maturity gas in the sand below Tr-MCS10 and at the base of the well

Regional seal?

Local seal?

# Noblige-1 Bulk Fluid Composition




**Methane:** ~84 mole%

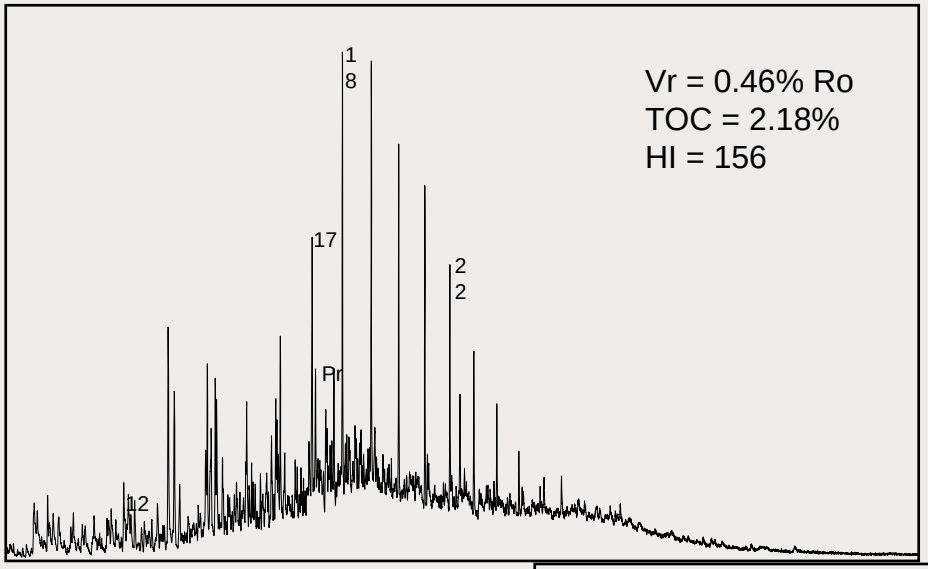
**$CO_2$:** 0.4 – 3 mole% (increases with depth)

**N2:** 5.1 – 6.4 mole%

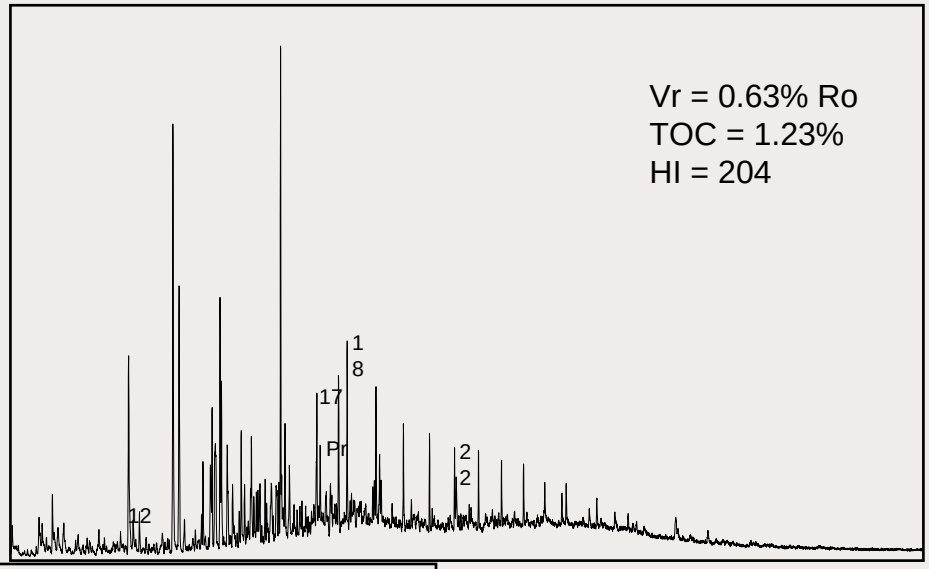
**Ideal CGR:** 13 – 24 bbl/MMscf (decreases with depth)

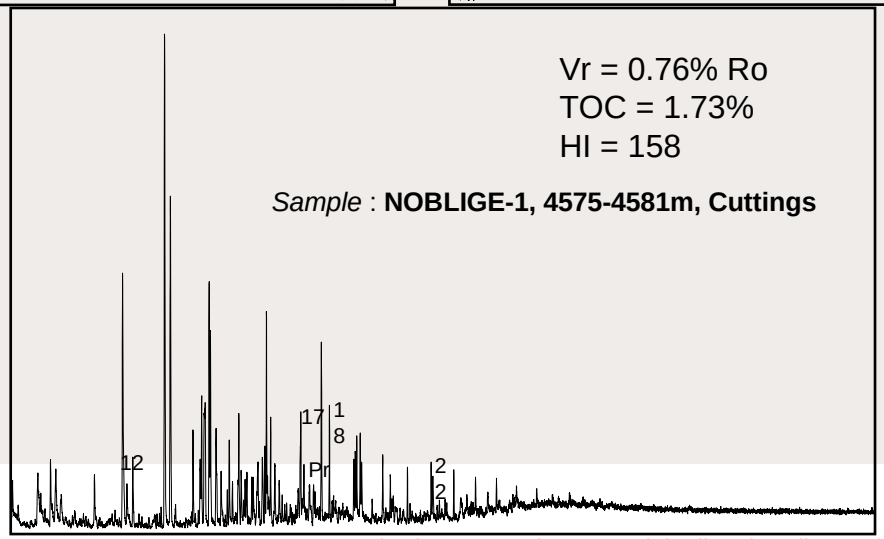
# Whole Extract GC-MS

*Sample* : **NOBLIGE-1, 3030-3035m, Cuttings**



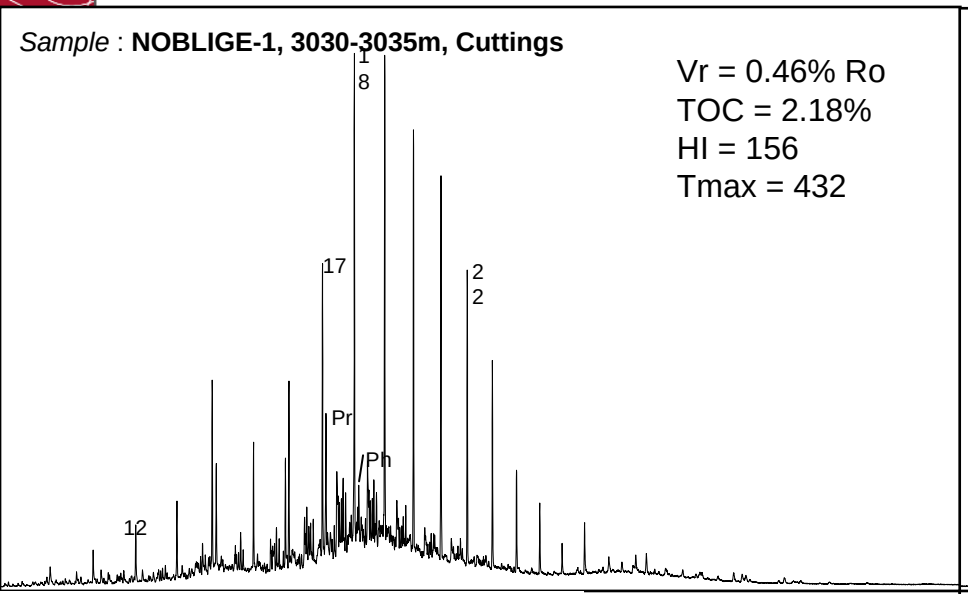

*Sample* : **NOBLIGE-1, 3805-3810m, Cuttings**

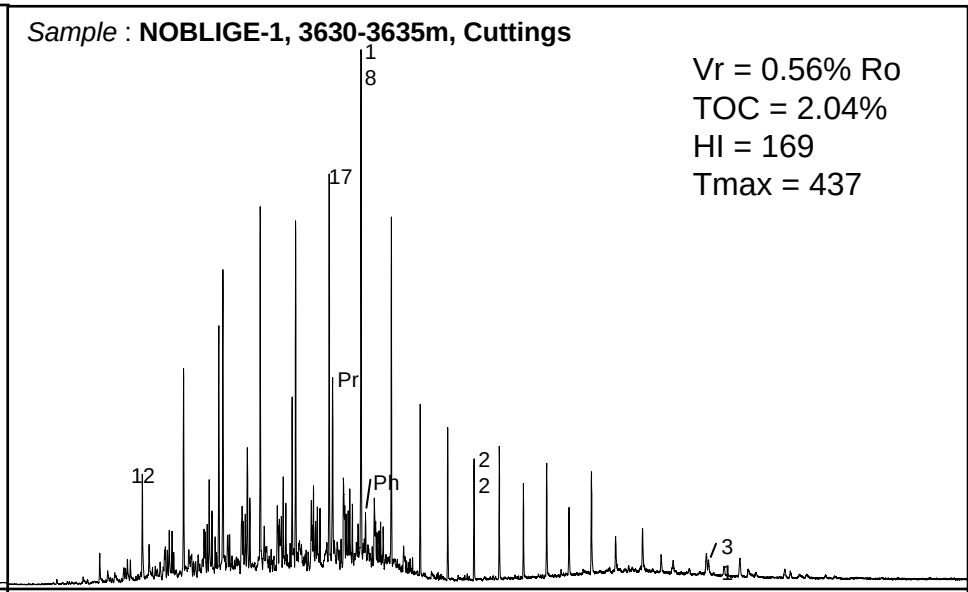


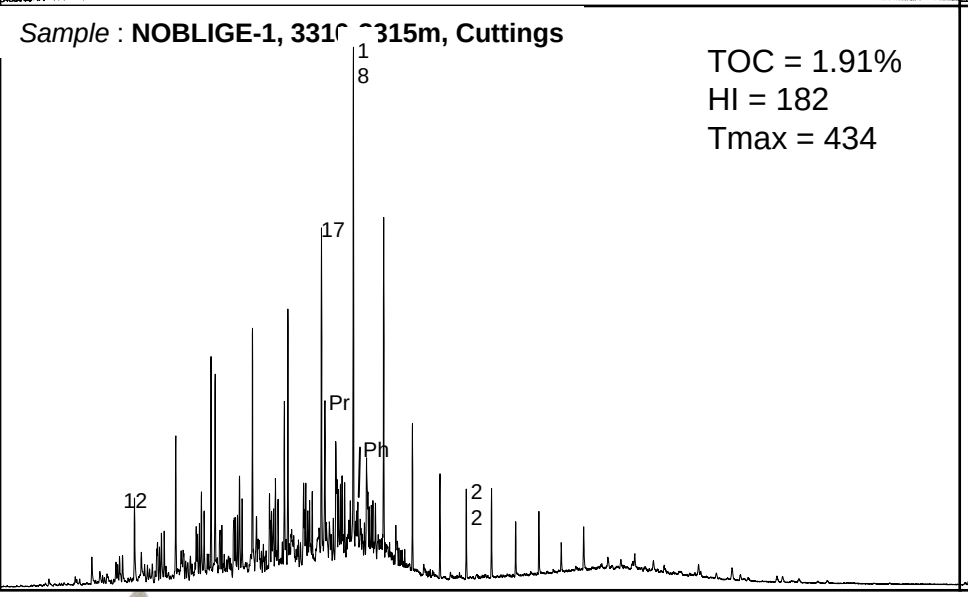



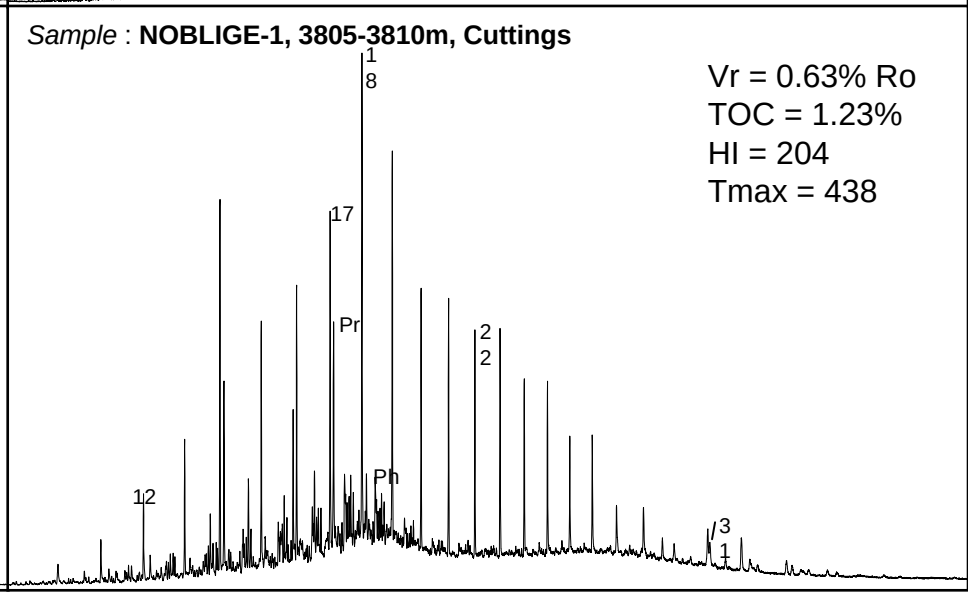

*Sample* : **NOBLIGE-1, 4575-4581m, Cuttings**

# Scan GC-MS Saturates



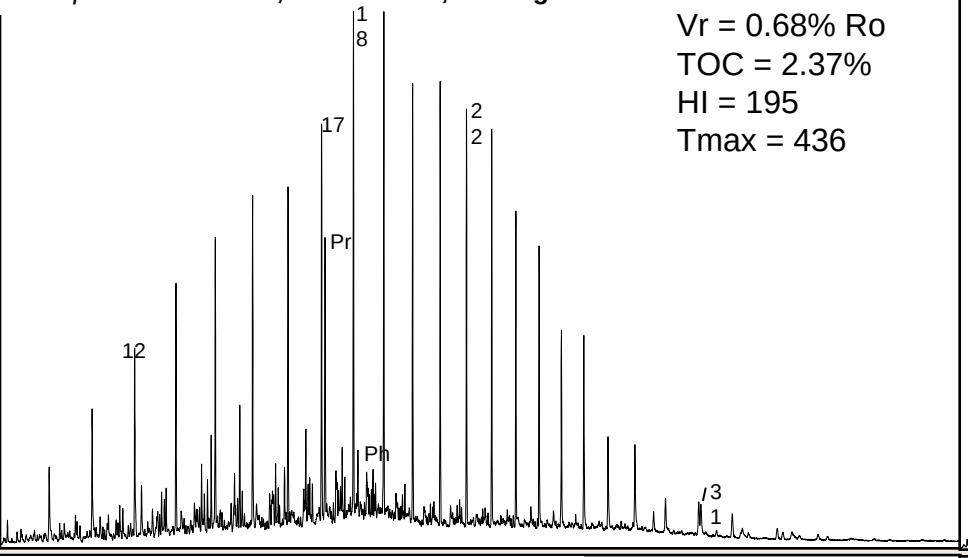



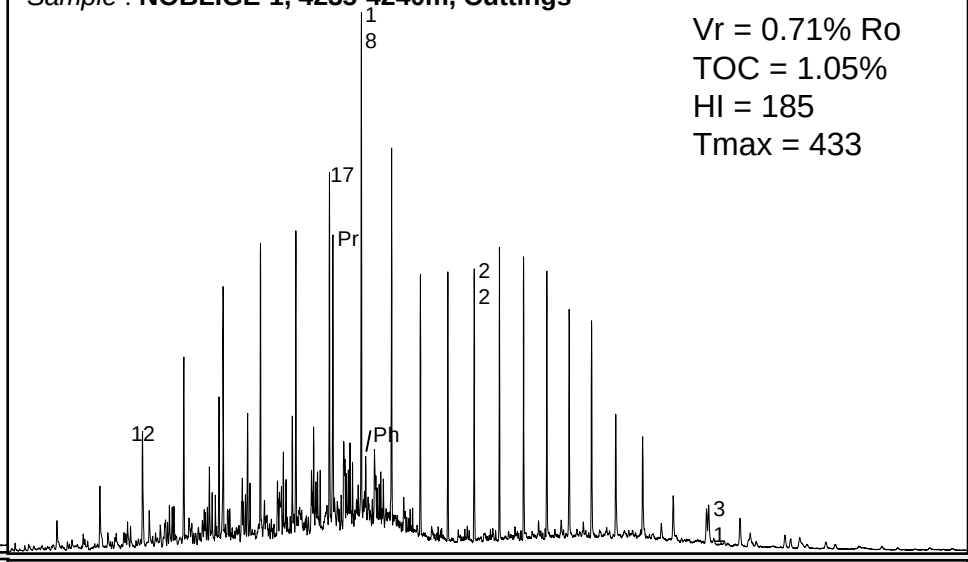
# Scan GC-MS saturates

*Sample* : **NOBLIGE-1, 3980-3985m, Cuttings**



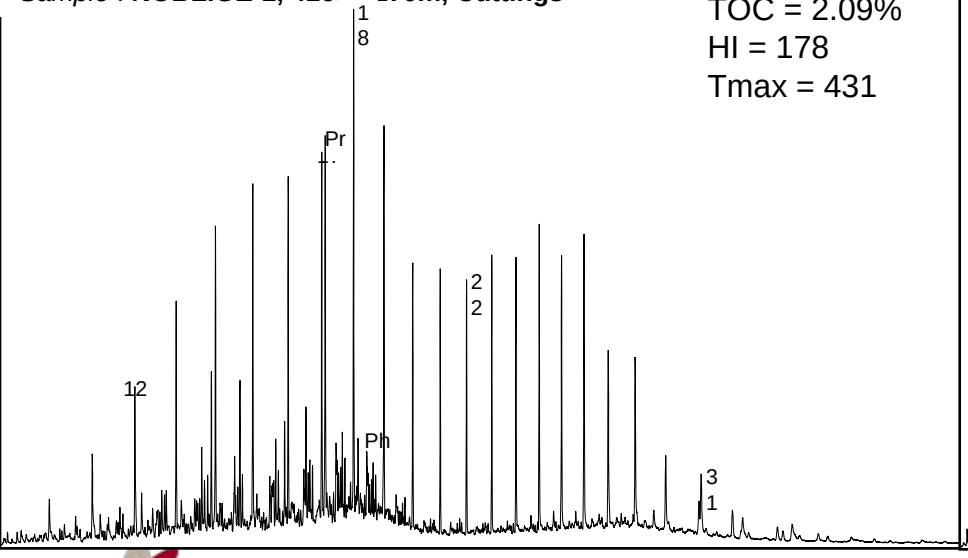

Vr = 0.68% Ro
TOC = 2.37%
HI = 195
Tmax = 436

*Sample* : **NOBLIGE-1, 4235-4240m, Cuttings**



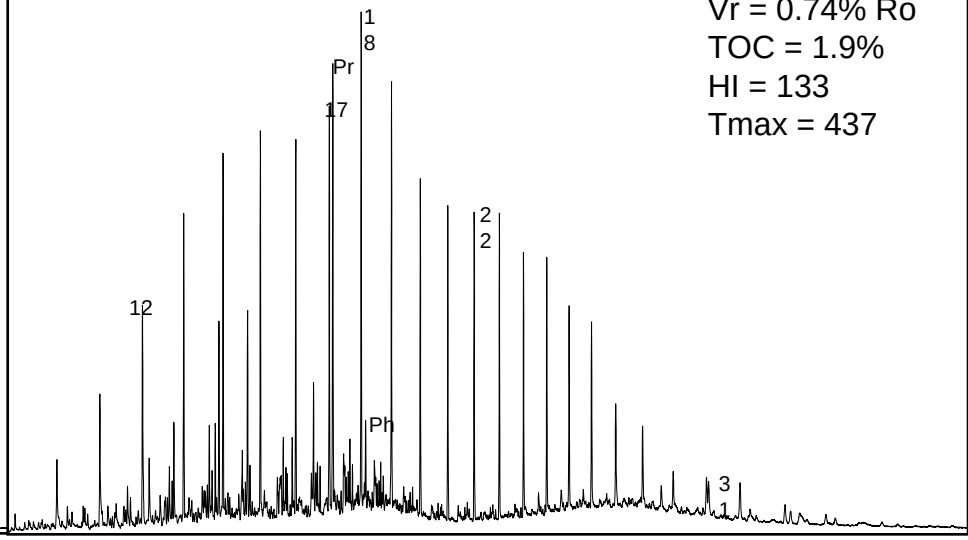

Vr = 0.71% Ro
TOC = 1.05%
HI = 185
Tmax = 433

*Sample* : **NOBLIGE-1, 4165-4170m, Cuttings**




TOC = 2.09%
HI = 178
Tmax = 431

*Sample* : **NOBLIGE-1, 4450-4455m, Cuttings**




Vr = 0.74% Ro
TOC = 1.9%
HI = 133
Tmax = 437

# A Stratigraphic Reconstruction of Bulk Volatile Chemistry from Fluid Inclusions

Appendix 5

UWI# 999999999999
FIS# FI100099a

*Fluid Inclusion Technologies, Inc.*

*Innovations in Petroleum Risk Management*

# A Stratigraphic Reconstruction of Bulk Volatile Chemistry from Fluid Inclusions in:

## *Noblige 1*

Prepared October 21, 2010 for

## *Woodside*

*Fluid Inclusion Technologies, Inc.*
*2217 North Yellowood Avenue*
*Broken Arrow, OK 74012 U.S.A.*

*Phone (918) 461-8984*
*Fax (918) 461-2085*
*FIT@fittulsa.com*

*Data Reduction:* FITsolve-5 http://www.fittulsa.com

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# A Stratigraphic Reconstruction of Bulk Volatile Chemistry from Fluid Inclusions in:

# *Noblige 1*

Prepared October 21, 2010
by
*Fluid Inclusion Technologies, Inc.*

Innovations in Petroleum Risk Management

## Executive Summary for well: Noblige 1

**Petroleum Indications, Type and Quality:** FIS data record hydrocarbon anomalies in four main intervals, as follows.

2990-3025: Dry gas to weak wet gas indications. A thin section from 3025 m consists of sandstone with no visible liquid petroleum inclusions.

3260-3265 m: Dry gas indications. A thin section from 3265 m consists of sandstone with subordinate shale and carbonate. No visible liquid petroleum inclusions are present. Minor gas-prone and immature to marginally mature oil-prone kerogen is noted in shale.

4070-4285 m: Methane-depleted wet gas spectra suggestive of weak source rock response. Samples from 4160 m and 4285 m consist of sandstone and silty shale with rare, white-fluorescent, moderate gravity oil inclusions. Shale contains common gas-prone and mature oil-prone kerogen. Some petroleum may be locally generated.

4395-4581 m: Strong wet gas spectra with some decoupled methane response in the upper section suggestive of source rock contribution, and some possible turbodrilling (bit metamorphism) effects in the deeper section. Thin sections from 4440 m, 4485 m and 4575 m consist of silty shale and sandstone with no visible liquid petroleum inclusions. Shale contains gas-prone and mature oil-prone kerogen in significant amounts. The deepest sample exhibits bit-metamorphism textures. This process creates and encapsulates species which can interfere with FIS interpretations.

Additional thin sections were prepared from 2850 m, 3445 m, 3680 m, 3855 m, 4020 m and 4365 m. Rare, yellow-fluorescent, moderate gravity oil inclusions are identified at 2850 m and 3855 m. Other samples contain no visible liquid petroleum inclusions. See the petrography table for more information.

**Proximal Pay Indications:** Anomalous concentrations of acetic acid (with or without benzene) are identified at 2845 m, 2950 m, 2990-3025 m, 3060 m, 3245-3265 m and 4440-4581 m. In general, samples containing acetic acid anomalies suggest the nearby presence of reservoired liquid petroleum (oil or condensate). Part, but not all, of the deepest anomaly may be influenced by bit metamorphism.

**Potential Seals:** Possible seals are identified at 2990 m, 3250 m, 3800 m, 4070 m, 4400 m and 4510 m.

**Evidence for Bacterial or Thermal Alteration:** Sulfur species of probable thermal origin are identified at 3020 m, 3215 m, 3495-3520 m, 4455 m and 4485 m. In this case, thermochemical sulfate reduction at temperatures in excess of 140°C is suggested. SO2 +/- S2 is identified at 3020 m. These specific sulfur species are generally associated with water-bearing, porous reservoir rock.

**Other:** Nothing of note.

## Summary of Results for well: Noblige 1

This report contains Fluid Inclusion Stratigraphy and Fluid Inclusion Petrography results for Noblige 1 and was prepared for Woodside by *Fluid Inclusion Technologies, 2217 N. Yellowood Ave., Broken Arrow, OK 74133; ph: (918) 461-8984; fax: (918) 461-2085; www.fittulsa.com.*

Table I: Logistical Information

| | | | |
|---|---|---|---|
| Client: | **Woodside** | Analyzed Depth: | **2430 - 4581 Meters** |
| Well: | **Noblige 1** | Sample Spacing: | **See Individual Spectra** |
| | | Sample Total: | **425** |

Table II: Fluid Inclusion Petrography from Noblige 1

| **Well Name: Noblige-1** | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Depth** | **Rock Type** | **Petroleum Fluid Inclusion Populations** | | | | | | | | | | | | **Kerogen (possible source rk)** | | | | | **Bitu-men** | |
| | | **Population 1** | | | | **Population 2** | | | | **Population 3** | | | | | | | | | | |
| ***Units:* (Meters)** | ***Dominant / Subordinate*** | ***Fluorescence Color*** | ***API Gravity (estimated)*** | ***Host Mineral & occurrence*** | ***Abundance*** | ***Fluorescence Color*** | ***API Gravity (estimated)*** | ***Host Mineral & occurrence*** | ***Abundance*** | ***Fluorescence Color*** | ***API Gravity (estimated)*** | ***Host Mineral & occurrence*** | ***Abundance*** | ***Host Rock*** | ***Type*** | ***OP Fluor Color*** | ***GP Abundance*** | ***OP Abundance*** | ***Type*** | ***Abundance*** |
| 2850 | cb | yl | | cm | r | | | | | | | | | | | | | | | |
| 3025 | ss | | | | | | | | | | | | | | | | | | | |
| 3265 | ss, sh, cb | | | | | | | | | | | | | sh | go | yl | sv | r | | |
| 3445 | sh, shlyss | | | | | | | | | | | | | sh | go | yl | c | sv | | |
| 3680 | siltysh, ss | | | | | | | | | | | | | sh | go | or | c | c | | |
| 3855 | siltysh, ss | yl | m | df | r | | | | | | | | | sh | go | or | c | c | | |
| 4020 | siltysh, ss | | | | | | | | | | | | | sh | go | or | c | c | | |
| 4160 | ss, siltysh | wt | m | dq | r | | | | | | | | | sh | go | or | c | c | ds | r |
| 4285 | siltysh, ss | wt | m | dq | r | | | | | | | | | sh | go | or | c | c | | |
| 4365 | siltysh, ss | | | | | | | | | | | | | sh | go | or | c | c | ds | r |
| 4440 | siltysh, ss | | | | | | | | | | | | | sh | go | or | c | c | ds | r |
| 4485 | sh, ss | | | | | | | | | | | | | sh | go | or | sv | sv | ds | r |
| 4575 | sh, ss | | | | | | | | | | | | | sh | go | or | sv | sv | ds | r |

| | | | | |
|---|---|---|---|---|
| ss: sandstone | mt: metamorphic rock | m: moderate | r: rare | ds: dead petroleum stain |
| si: siltstone | no: none | um: upper-moderate | sv: several | po: pore-occluding bitmn |
| sh: shale | br: brown | h: high | c: common | pb: pyrobitumen |
| cb: carbonate | or: orange | dq: frac in detrital quartz | a: abundant | |
| sa: salt | yl: yellow | dr: quartz dust rim | xa: very abundant | Notes: |
| an: anhydrite | wt: white | qc: quartz cement | go: oil and gas prone | |
| ch: chert | bl: blue | df: frac detrital feldspar | op: oil prone | |
| co: coal | l: low | cm: matrix carbonate | gp: gas prone | |
| ig: igneous rock | ul: upper-low | cc: carbonate cement | ls: live petroleum stain | |

Table III: FIS Terminology: Abbreviations and Acronyms

| HC Type & Quality | | Anomalous HC Zones | | Fluid Contacts | |
|---|---|---|---|---|---|
| **NHC** | non-hydrocarbon | **MP** | migration pathway | **OWC** | oil-water contact |
| **DG** | dry gas | **PC** | present day ptrlm column | **GWC** | gas-water contact |
| **WG** | wet gas | **PPC** | paleo-ptrlm column | **GOC** | gas-oil contact |
| **GC** | gas condensate | **RI** | recycled ptrlm inclusions | **POWC** | paleo-oil-water contact |
| **VO** | volatile oil | **SR** | source rock | **PGWC** | paleo-gas-water contact |
| **O** | oil | **GP** | gas prone kerogen | **PGOC** | paleo-gas-oil contact |
| **BD** | biodegraded | **OP** | oil prone kerogen | | |
| **TA** | thermally altered | **OGP** | oil and gas prone kerogen | | |
| | | **CNT** | contamination | | |

| Water-Soluble Anomalies | | Miscellaneous | |
|---|---|---|---|
| **WS** | undifferentiated water-soluble anomaly | **SL** | seal |
| **WSSR** | source rock related water-soluble anomaly | **MS** | microseep |
| **WSTA** | water-soluble anomaly sourced from thermal alteration | | |
| **PTPL** | proximity to oil or gas-condensate | | |
| **PTPG** | proximity to gas | | |

| Petrographic Observations | | | | | |
|---|---|---|---|---|---|
| **A** | abundant | **IG** | igneous rock | **SA** | salt |
| **AN** | anhydite | **L** | low | **SH** | shale |
| **BL** | blue | **LG** | large | **SI** | siltstone |
| **BR** | brown | **M** | moderate | **SM** | small |
| **C** | common | **MD** | medium | **SS** | sandstone |
| **CB** | carbonate | **MT** | metamorphic rock | **ST** | petroleum stain |
| **CC** | carbonate cement | **NO** | none | **SV** | several |
| **CH** | chert | **OR** | orange | **UL** | upper-low |
| **CM** | matrix carbonate | **PB** | pyrobitumen | **UM** | upper-moderate |
| **CO** | coal | **PF** | pore filling bitumen | **V** | variable |
| **DF** | detrital feldspar | **PR** | pore rimming bitumen | **W** | weak |
| **DQ** | detrital quartz | **QC** | quartz cement | **WT** | white |
| **DR** | quartz dust rim | **R** | rare | **XA** | extremely abundant |
| **H** | high | **S** | strong | **YL** | yellow |

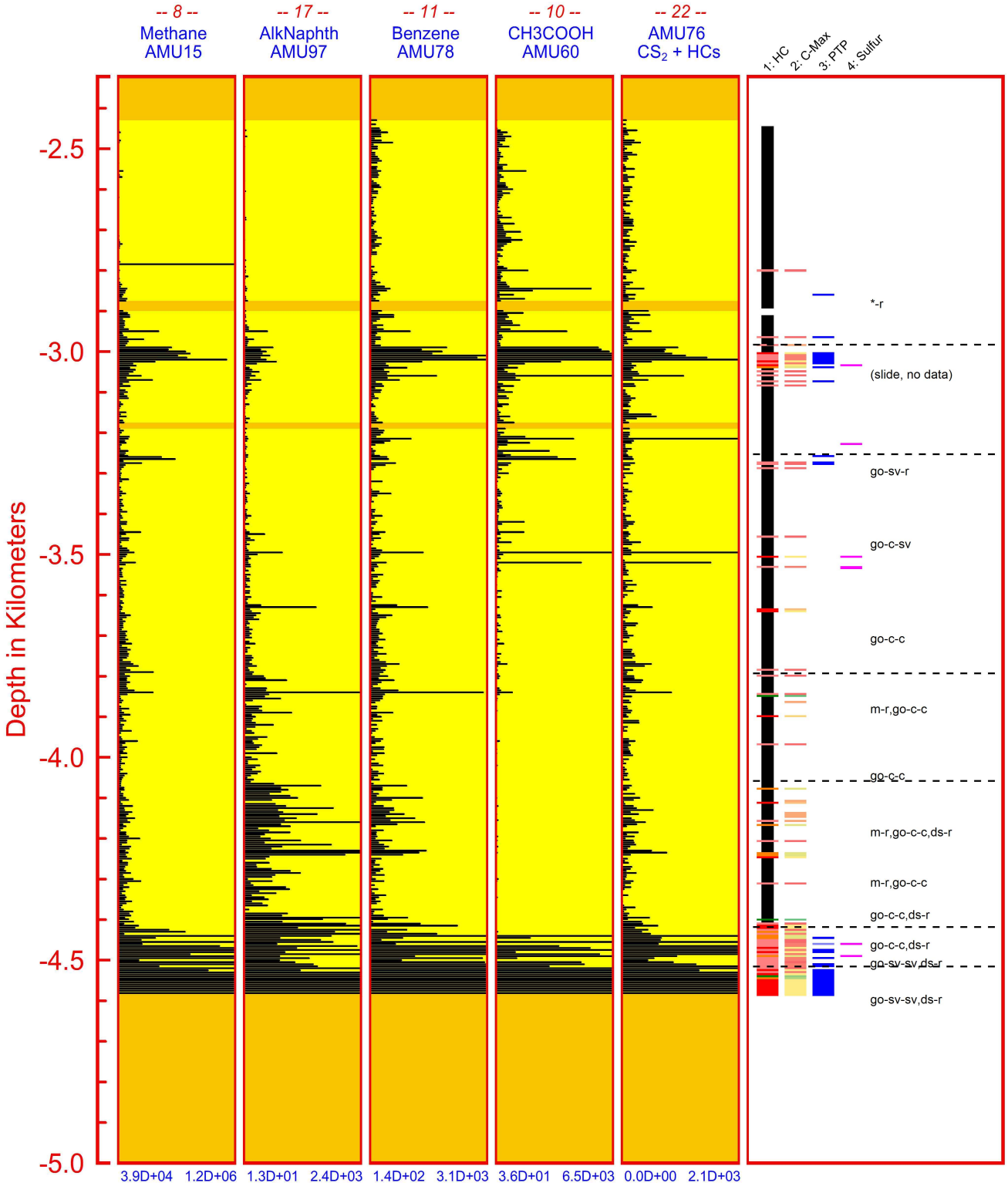
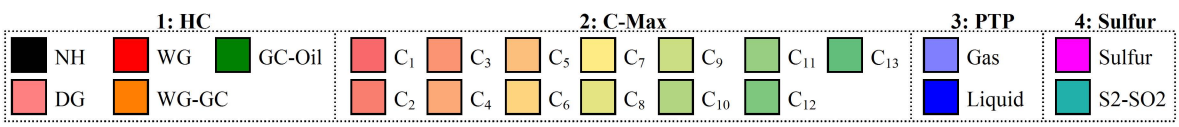
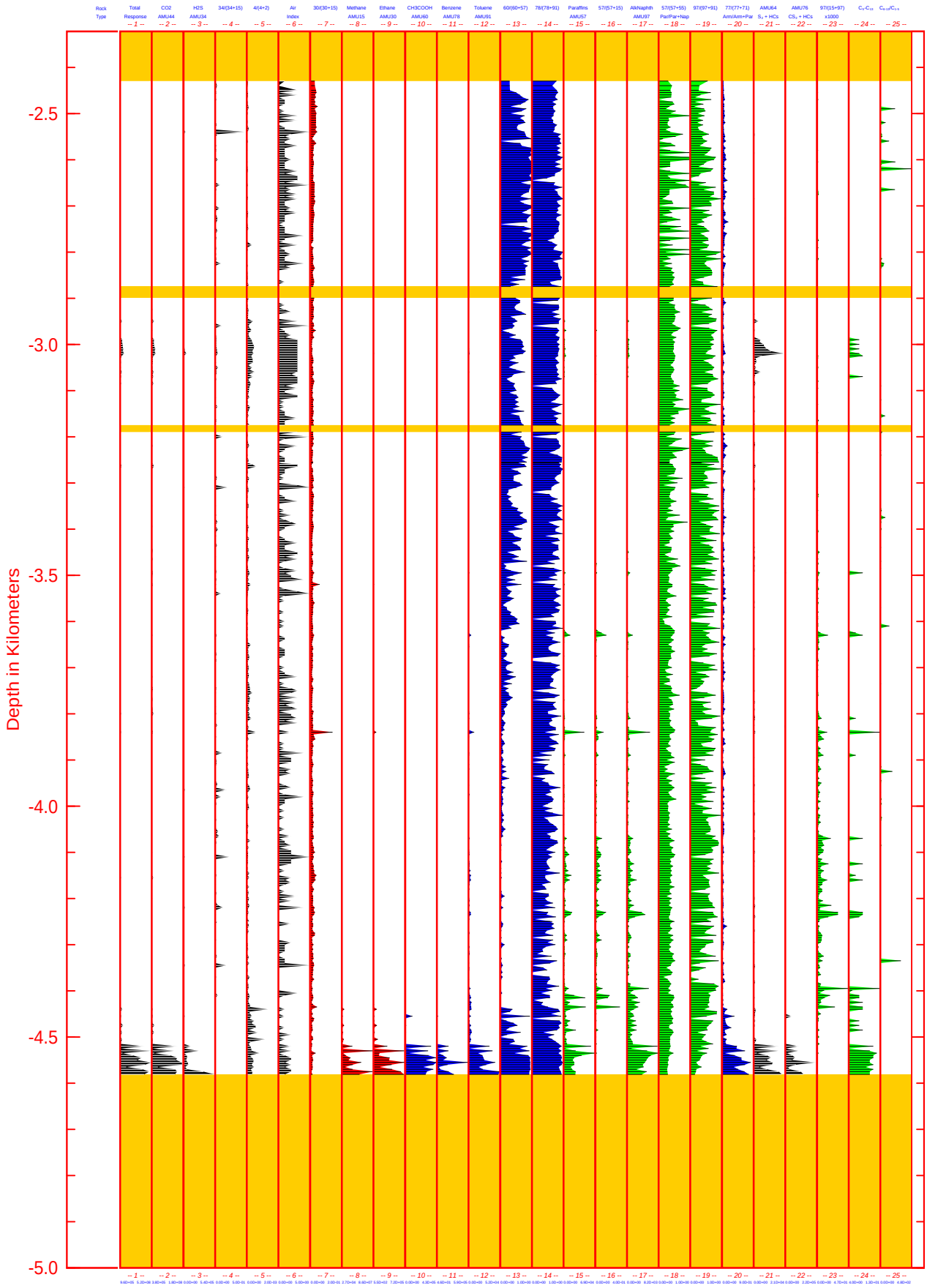



Figure 1: FIS Summary Tracks (see Sect. A for further explanation)

*FIS# FI100099a* – **Noblige 1** – *www.fittulsa.com*



# *Noblige 1 : All FIS Data*

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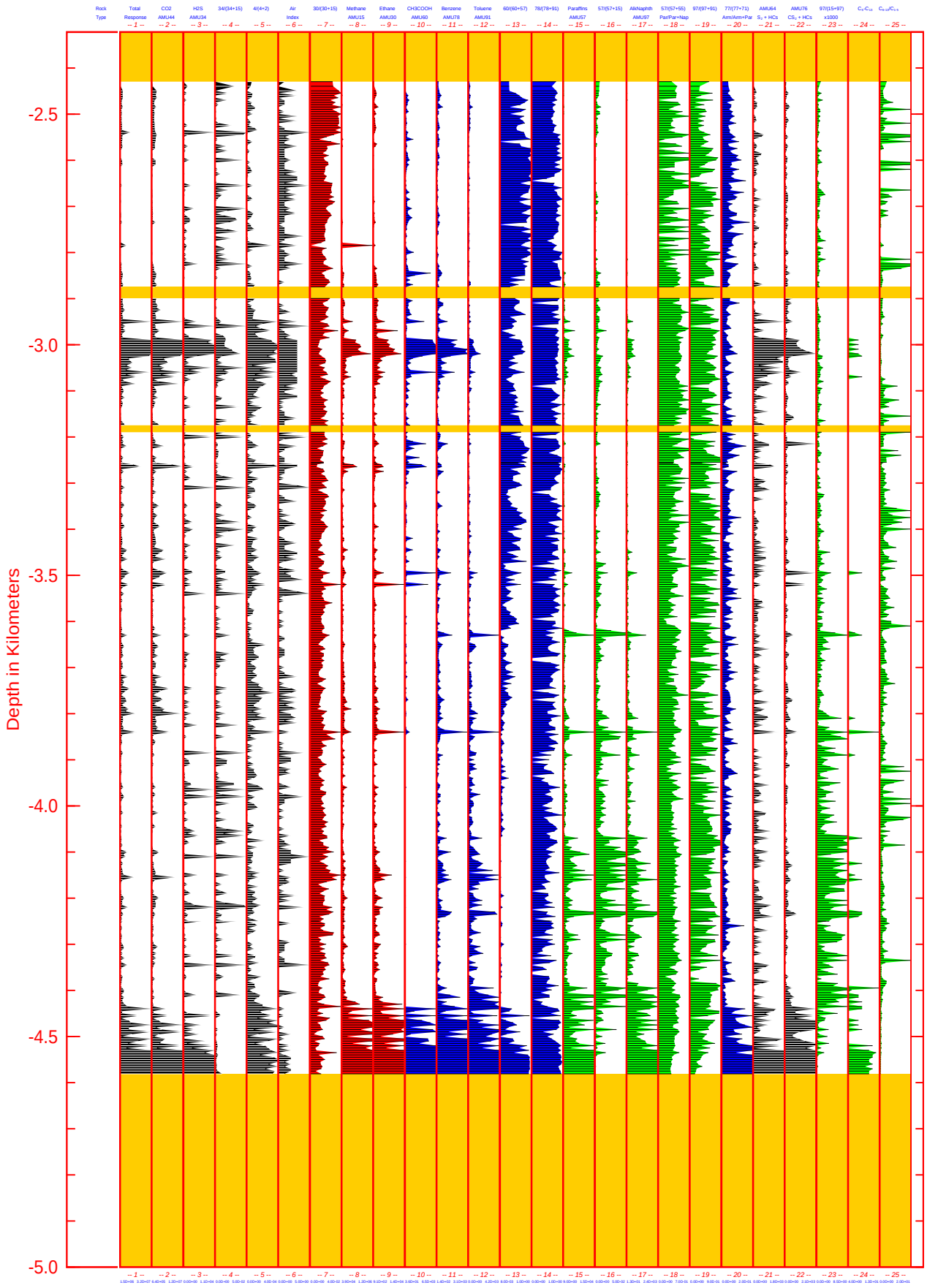
*UWI#* 999999999999
*FIS#* *FI*100099*a*

# *Noblige 1 : 90% of all FIS Data*

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*FIS*#*FI*100099*a*

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# 1 Overview of FIT, Inc. and Fluid Inclusion Stratigraphy

**Fluid Inclusion Technologies (FIT), Inc.**, is a laboratory-based petroleum service organization established in 1997 and offering a variety of analytical services including some previously proprietary technologies. **Fluid Inclusion Stratigraphy (FIS)**, the most widely applicable of these technologies is a rapid analytical technique that involves the automated analysis of volatile compounds trapped within micron-sized cavities in rock material taken from well cuttings, core or outcrop samples. These "fluid inclusions" are representative samples of subsurface fluids, and are not subject to fractionation during sampling or evaporative loss during sample storage for any length of time. The procedure has major impact in the areas of **both Petroleum Production and Exploration Applications** providing information unattainable via more traditional methods and, has been instrumental in the discovery of significant petroleum reserves, influenced exploration and acreage acquisition decisions and provided innovative options for resource estimation, petroleum production and enhanced oil recovery operations. **Fluid Inclusion Stratigraphic Analysis**, often in combination with other patented techniques, emerging geochemical methodologies and standard microscopic methods, all available through Fluid Inclusion Technologies, Inc., provides a unique and unequaled industry product boasting an impressive list of proven applications including determination of **Product Type**, **Hydrocarbon Migration**, **Seals and Seal Integrity**, **Fluid Contacts**, **Proximity to Reservoired Petroleum**, **Pay Zone/By Passed Pay Delimitation**, **Reservoir-Scale Compartmentallization** and **Fluid Pressure Compartments**. Further information regarding the application of **FIS Analysis** and the other technical services we provide to problems in petroleum exploration and production is available elsewhere in this report and on our website:"www.fittulsa.com".

## 1.1 General Logistics of Initiating an FIS Analysis

*To Initiate an FIS Analysis:* contact FIT[1] directly to discuss goals of the study, sample requirements, turnaround time, pricing, and other related aspects. New clients are particularly encouraged to consult with our staff during the early stages of project development to optimize sample selection, preparation and shipment. Rock materials for FIS Analysis are shipped directly to C&M Storage[2], our sample handling facility, for sample preparation including any necessary crushing/sieving, subsampling and washing. The turnaround time for a typical FIS Analysis is preliminary data in 1-2 weeks time following receipt of samples by C&M and final report 1-2 weeks following preliminary analysis. These times are approximate and depend on the amount of sample preparation required, job size and analytical backlog. At the time of issue of this report, the cost for obtaining an FIS Analysis was $5,500 U.S. for a full-well analysis (up to 575 samples) and $3,000 U.S. for a short-well analysis (up to 180 samples). The cost includes the automated mass spectrometric analysis, preparation of and fluid inclusion petrography on selected thin-sections sampled throughout the well, and interpretation in the form of annotated depth plots (see Figure 1).

*When sampling for FIS Analysis:* the technique is equally applicable to cuttings, core and outcrop samples, but all samples will ultimately be reduced to cuttings-sized rock material. Wells drilled with any mud system can be analyzed (including oil-based systems),

[1] Fluid Inclusion Technologies, 2217 N. Yellowood Ave., Broken Arrow, 74012, USA., phone (918) 461-8984
[2] Attn: FIS Analysis, C&M Storage, 3311 Hwy, 77 South, Schulenburg, TX 78956, USA

as can samples of any age (i.e., fresh cuttings or those warehoused for many years). Our suggested sampling interval for general well studies is 30 ft (10 m). Pay-delineation studies, reservoir-scale studies or other applications involving rapidly changing fluid chemistries should be sampled at the tightest possible spacing, depending on sample availability (e.g., 1-3 ft). A maximum of 575 samples can be analyzed for a given well. Approximately 1 gm of clean rock material is needed for each sample. In most cases, some amount of additional washing is required - even for "washed samples", thus, it is best to send enough to ensure ample material after a final wash. It is further recommended that "clean lith cuts" be provided to minimize costs associated with additional sample preparation as all sample washing and preparation costs will be charged back to the client. The quoted price for an FIS Analysis is exclusive of sample preparation, handling and shipping; estimates for these project-specific services are available upon request.

## 1.2 Organization of this Report

Analytical results of the FIS analysis of Noblige 1 are presented graphically in Sections 2.1 and 2.2 as a series of profiles each illustrating the variation of a particular atomic mass ($m/z$) or ratio of two masses with measured depth. A general discussion of the interpretation of FIS data including the significance of particular features and trends (or their absence) is provided in Appendix A. The remaining information provided in subsequent sections includes: 1) reference spectra, collected on internal standards and used to monitor inter- and intra-analytical consistency of the quadrupole analyses which are presented and discussed in Appendix B; and 2) mass spectra from all samples which are listed individually by depth in Appendix C.

## 1.3 Output Formats

Analytical results of the present study are available in electronic format as described below. The first five items are included on the 3.5" floppy diskette provided with each color hard-copy of the final report. The remaining file, FI100099a-1.pdf, is available upon request for a nominal fee.

1. FI100099a-1.las – LAS-format, 26-column file containing recorded depth and Tracks 1-25 from the *FIT Analysis* of Noblige 1

2. FI100099a-1.txt – TXT-format, 26-column file containing recorded depth and Tracks 1-25 from the *FIT Analysis* of Noblige 1

3. FI100099a-2.las.Z – LAS-format (compressed), 181-column file containing recorded depth and background corrected, normalized, standardized individual mass spectra ($m/z$ 2-180) from the *FIT Analysis* of Noblige 1

4. FI100099a-s.pdf – PDF format, electronic file of the summary tracks and annotations from the *FIT Analysis* of Noblige 1

5. FI100099a-c.pdf – PDF format, electronic file of the poster containing *90% of all FIS Data* from the *FIT Analysis* of Noblige 1

6. FI100099a-1.pdf – PDF format, electronic file of the final report (entire document) of the *FIT Analysis* of Noblige 1

# 2 Analytical Results

## 2.1 FIS Depth Profiles Showing all Data

Millivolt responses for selected ionic species or species ratios resulting from FIS mass spectrometric analysis are displayed in Figures 2-6 (trackplots one through twenty-five). The identity of the individual ions involved in construction of the trackplots are listed in Table IV below. The tracks are organized into groups of related compounds; tracks 1-6 representing inorganic gases, tracks 7-9 representing dry organic gases, tracks 8-14 representing water soluble organic species or ratios of "more soluble" to "less soluble" species, and tracks 15-20 and 21-25 representing petroleum components of higher molecular weight and two sulfur compounds. The general interpretation of *FIS* data shown in the trackplots is discussed in Appendix A.

Table IV: Identification of Organic and Inorganic Species Represented in Track Plots

| Mass # | Description |
|---|---|
| 2 | hydrogen ($H_2^+$) |
| 4 | helium ($^4He^+$) |
| 15 | $C_1$ fragment ($CH_3^+$); largely methane |
| 30 | $C_2$ fragment ($C_2H_6^+$); largely ethane |
| 34 | hydrogen sulfide ($H_2S^+$) |
| 44 | dominantly carbon dioxide ($CO_2^+$); possible $C_3$ fragment overlap |
| 55 | contribution from $C_4$ and greater naphthenes |
| 57 | contribution from $C_4$ and greater paraffins |
| 60 | dominantly acetic acid ($CH_3COOH^+$); |
| | possible dominance by carbonyl sulfide ($COS^+$) in some cases |
| 64 | $S_2$ or $SO_2$ plus hydrocarbons |
| 71 | contribution from $C_5$ and greater paraffins |
| 76 | $CS_2$ plus hydrocarbons |
| 77 | contribution from aromatic species |
| 78 | benzene ($C_6H_6^+$) with possible contribution by carbon disulfide ($CS_2^+$) |
| 91 | toluene ($C_7H_7^+$) |
| 97 | $C_7$ alkylated naphthene fragment |

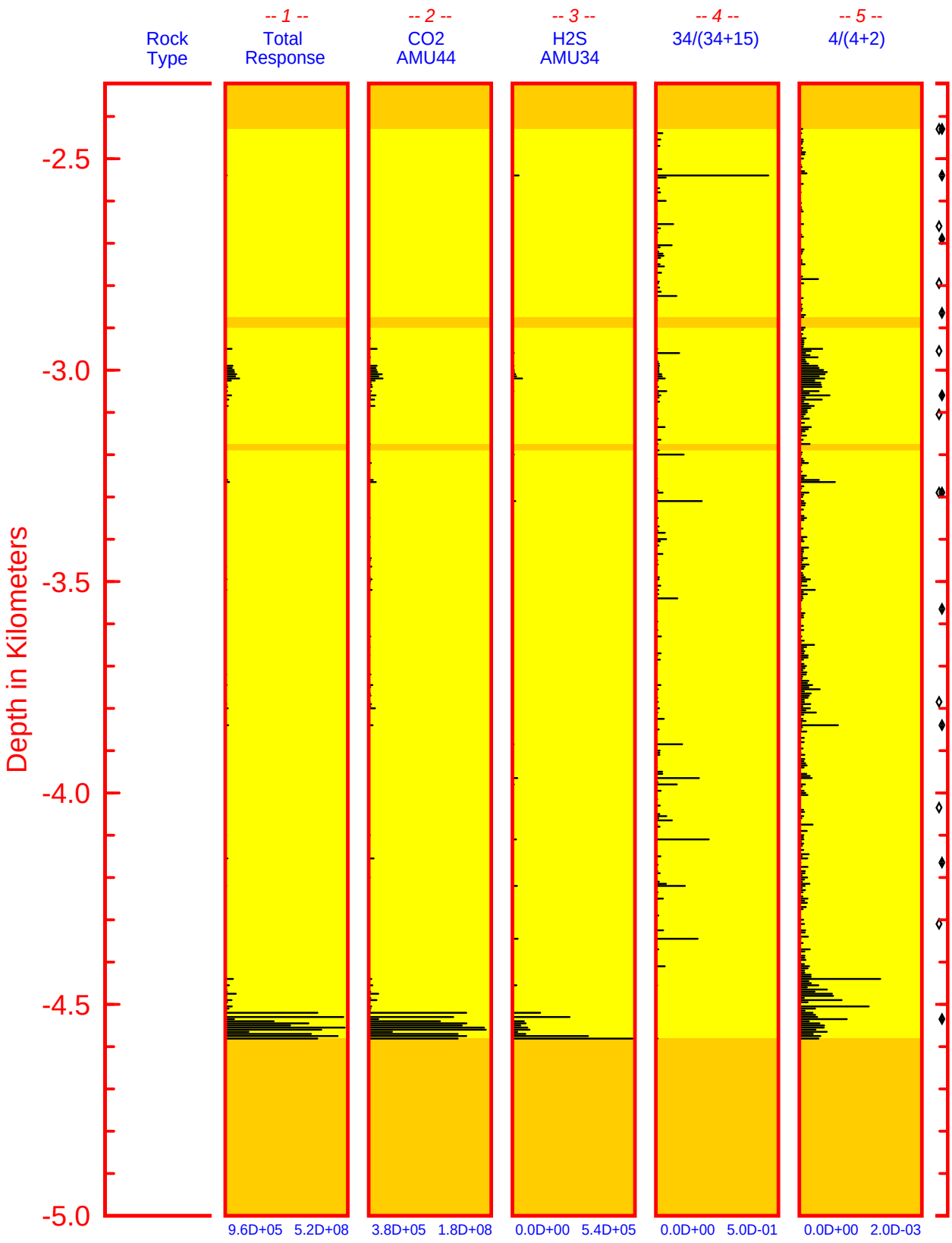



Figure 2: All FIS Data: Tracks 1 – 5 (see Sect. A.3 for explanation)

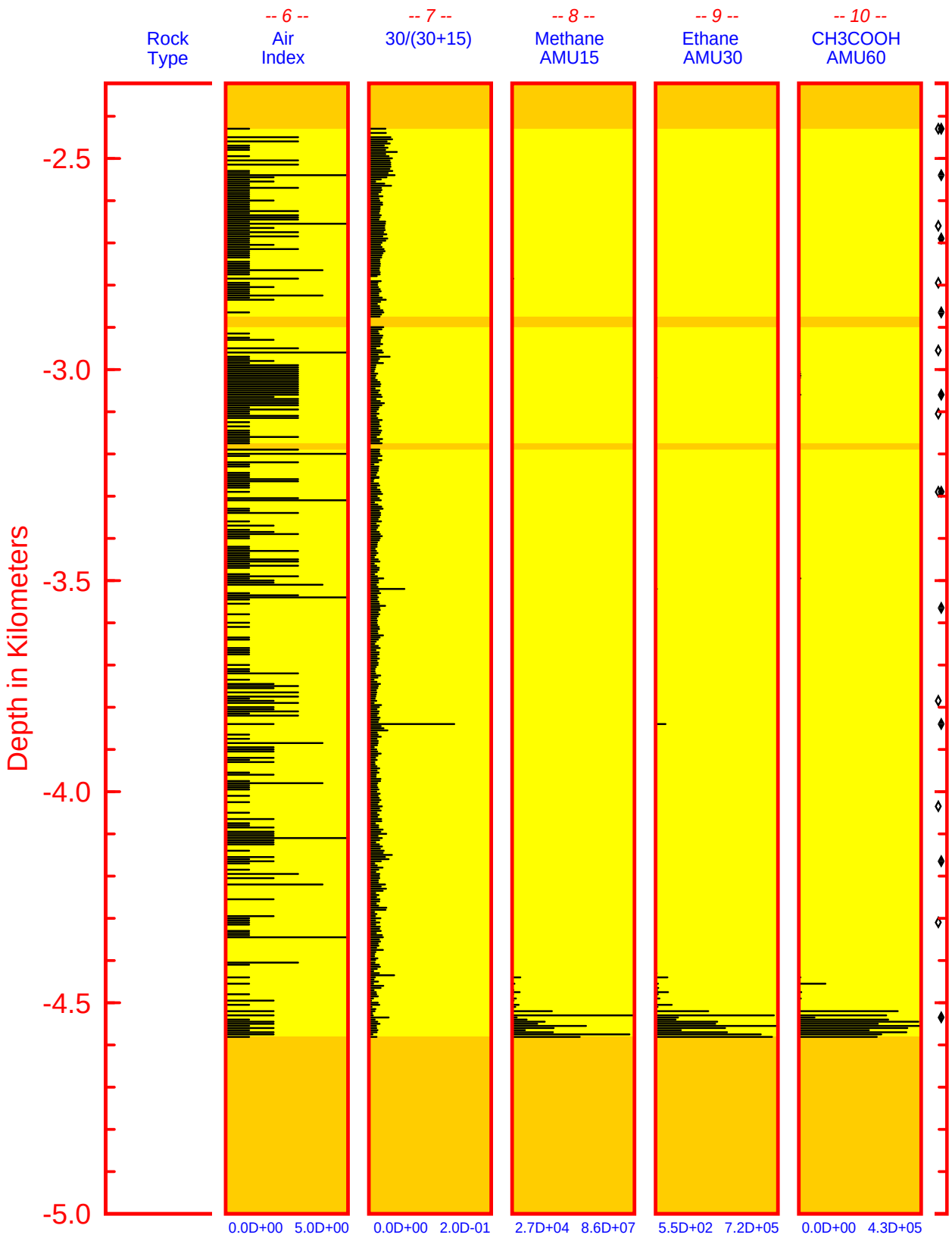



Figure 3: All FIS Data: Tracks 6 – 10 (see Sect. A.3 for explanation)

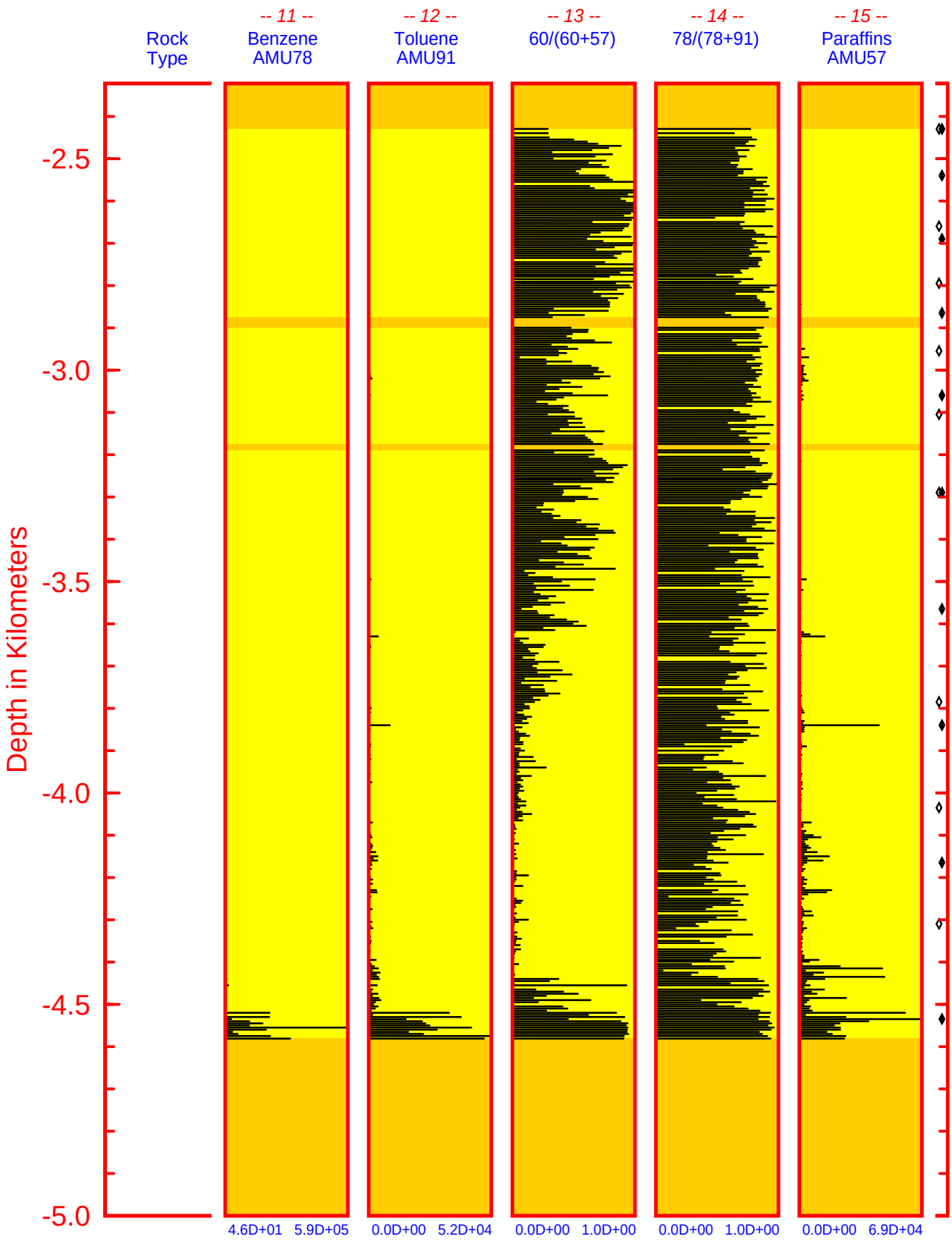



Figure 4: All FIS Data: Tracks 11 – 15 (see Sect. A.3 for explanation)

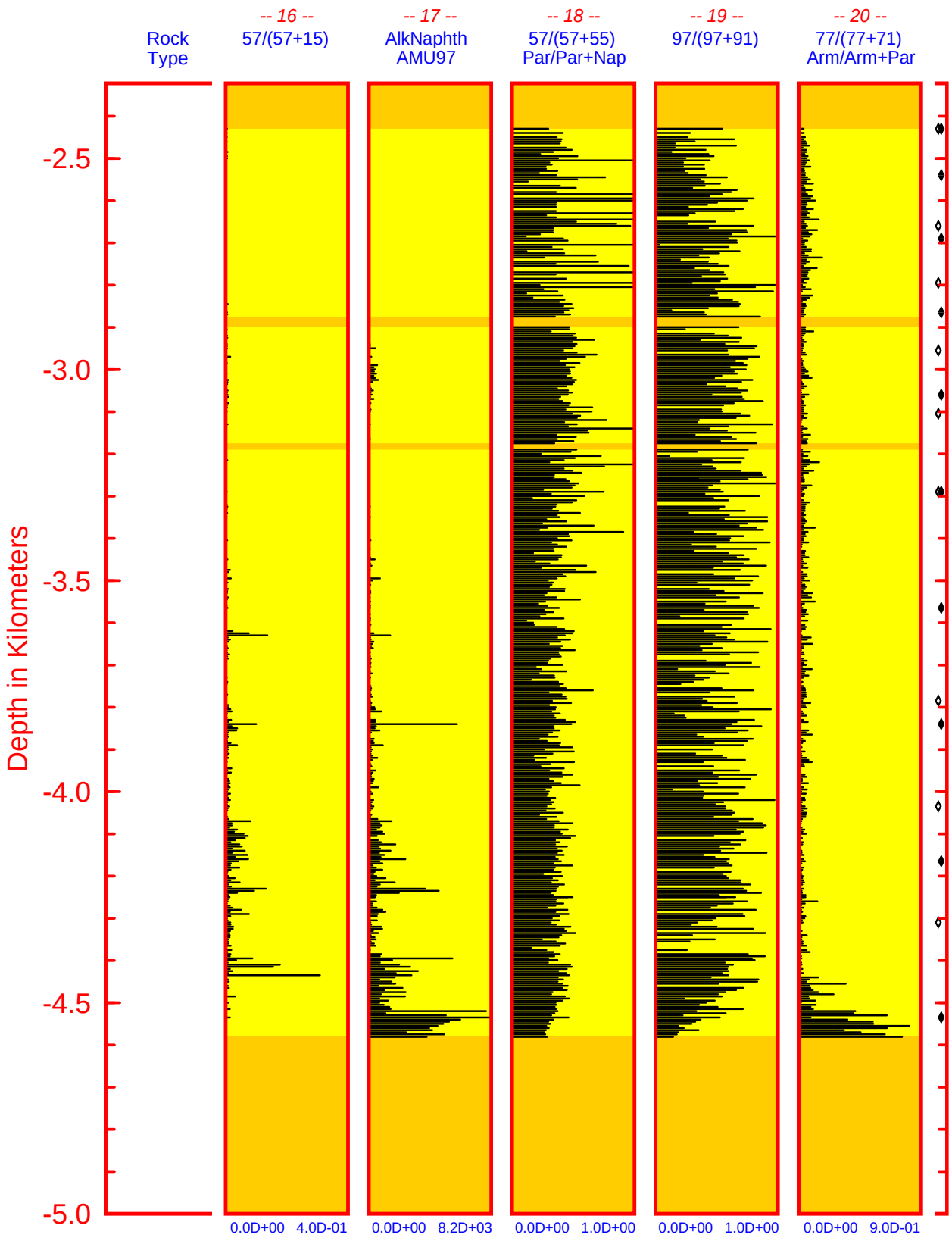



Figure 5: All FIS Data: Tracks 16 – 20 (see Sect. A.3 for explanation)

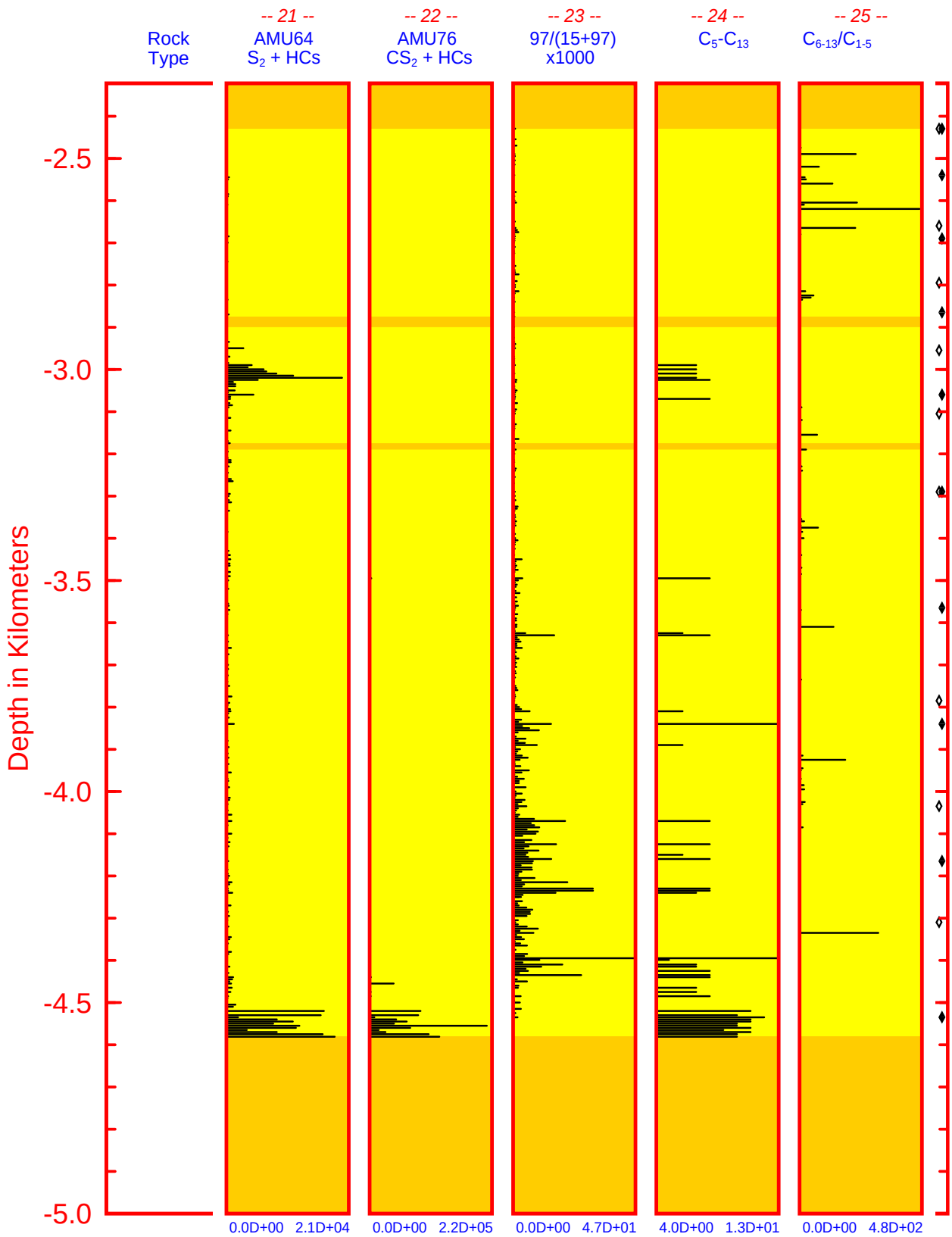



Figure 6: All FIS Data: Tracks 21 – 25 (see Sect. A.3 for explanation)

## 2.2 FIS Depth Profiles Showing 90% of all Data

Figures 7-11 show the same data as that given in Figures 2-6 of Section 2.1 *except* the upper and lower 5% of the data have been removed in each track and the scale along the abscissa adjusted accordingly in order to accentuate small deviations from background and reduce attenuation effects associated with scale-dominating responses. The identity of the individual ions involved in construction of the trackplots are listed in Table IV. The tracks are organized into groups of related compounds; tracks 1-6 representing inorganic gases, tracks 7-9 representing dry organic gases, tracks 8-14 representing water soluble organic species or ratios of "more soluble" to "less soluble" species, and tracks 15-20 and 21-25 representing petroleum components of higher molecular weight and two sulfur compounds. The general interpretation of *FIS* data shown in the trackplots is discussed in Appendix A.

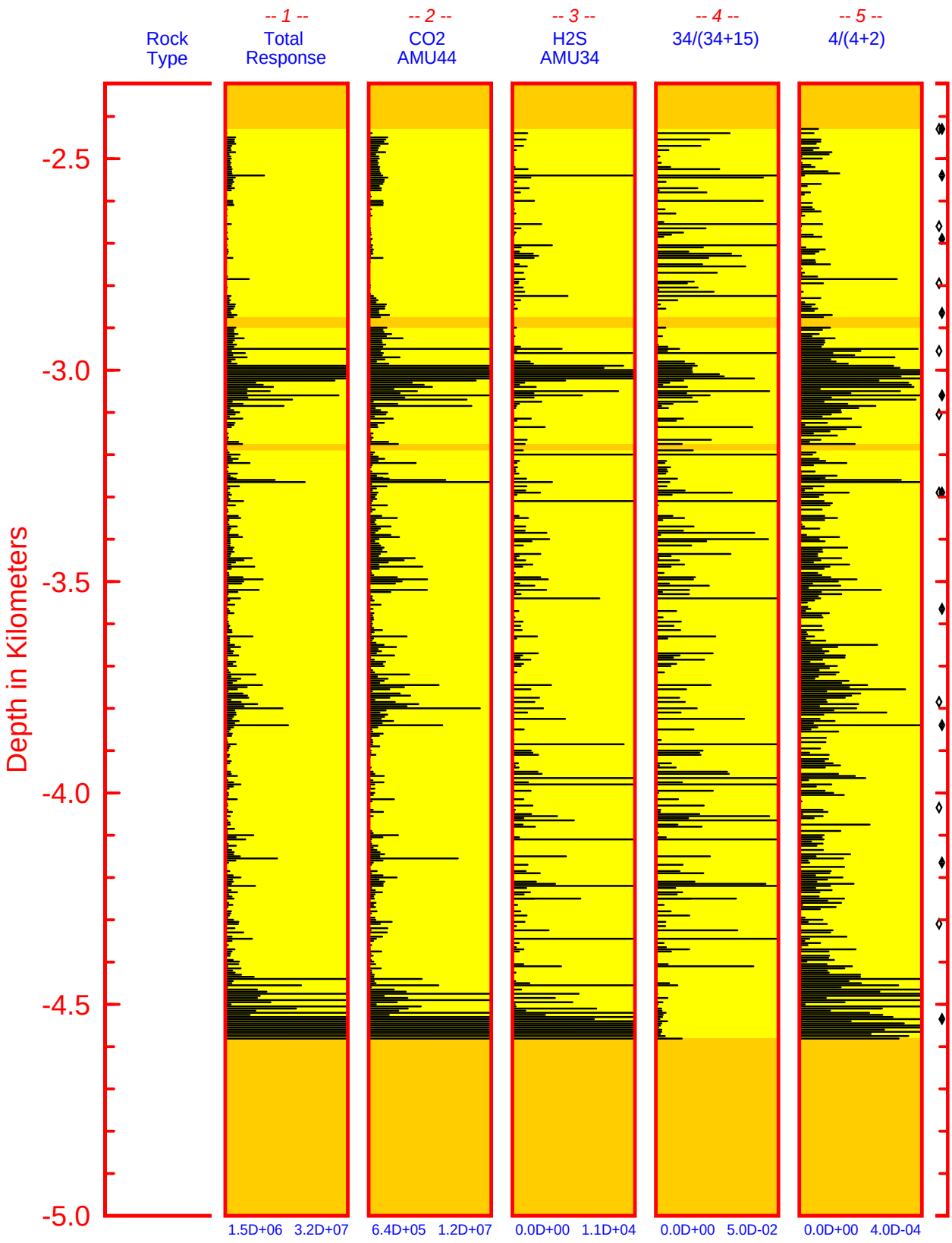



Figure 7: 90% of all FIS Data: Tracks 1 – 5 (see Sect. A.3 for explanation)

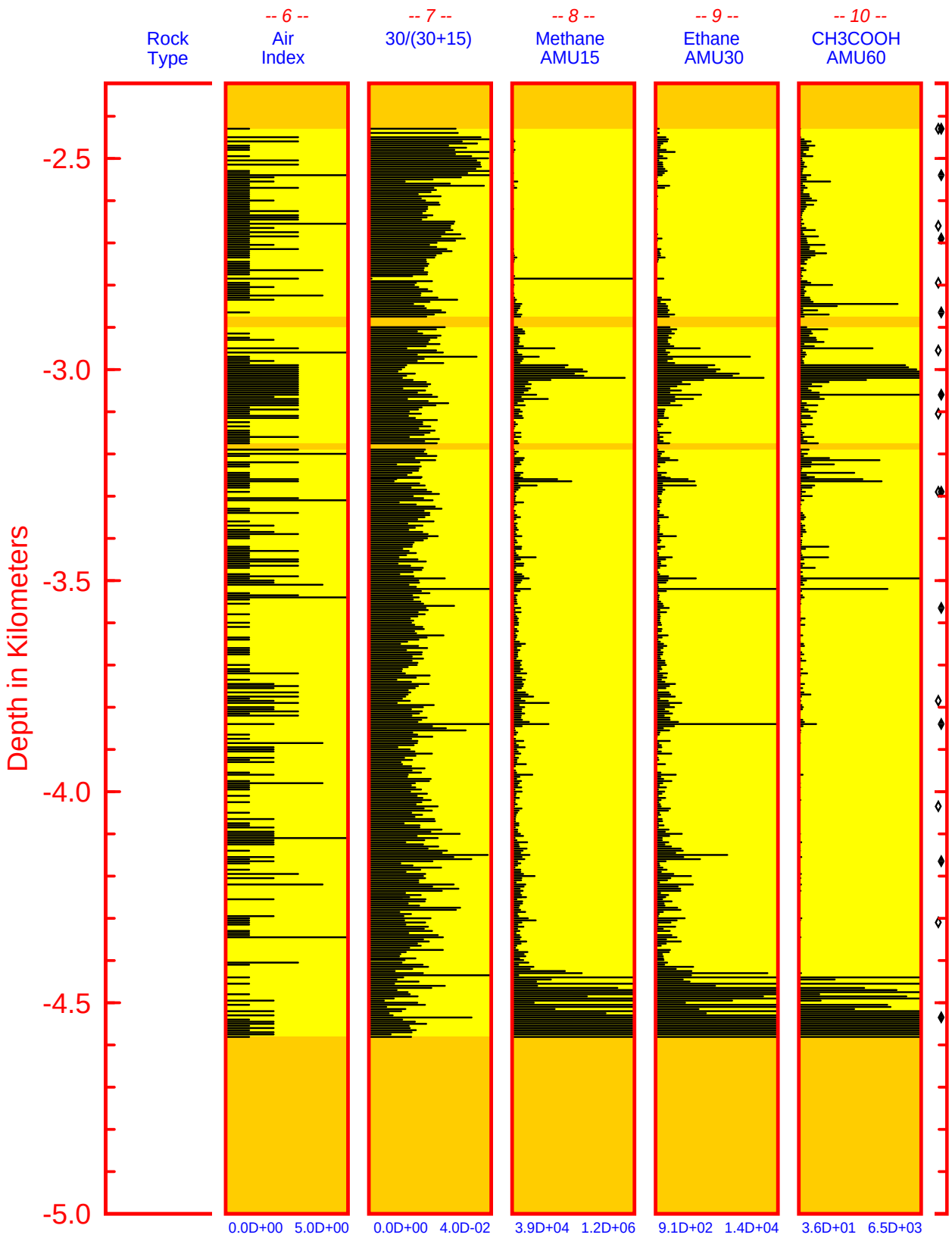



Figure 8: 90% of all FIS Data: Tracks 6 – 10 (see Sect. A.3 for explanation)

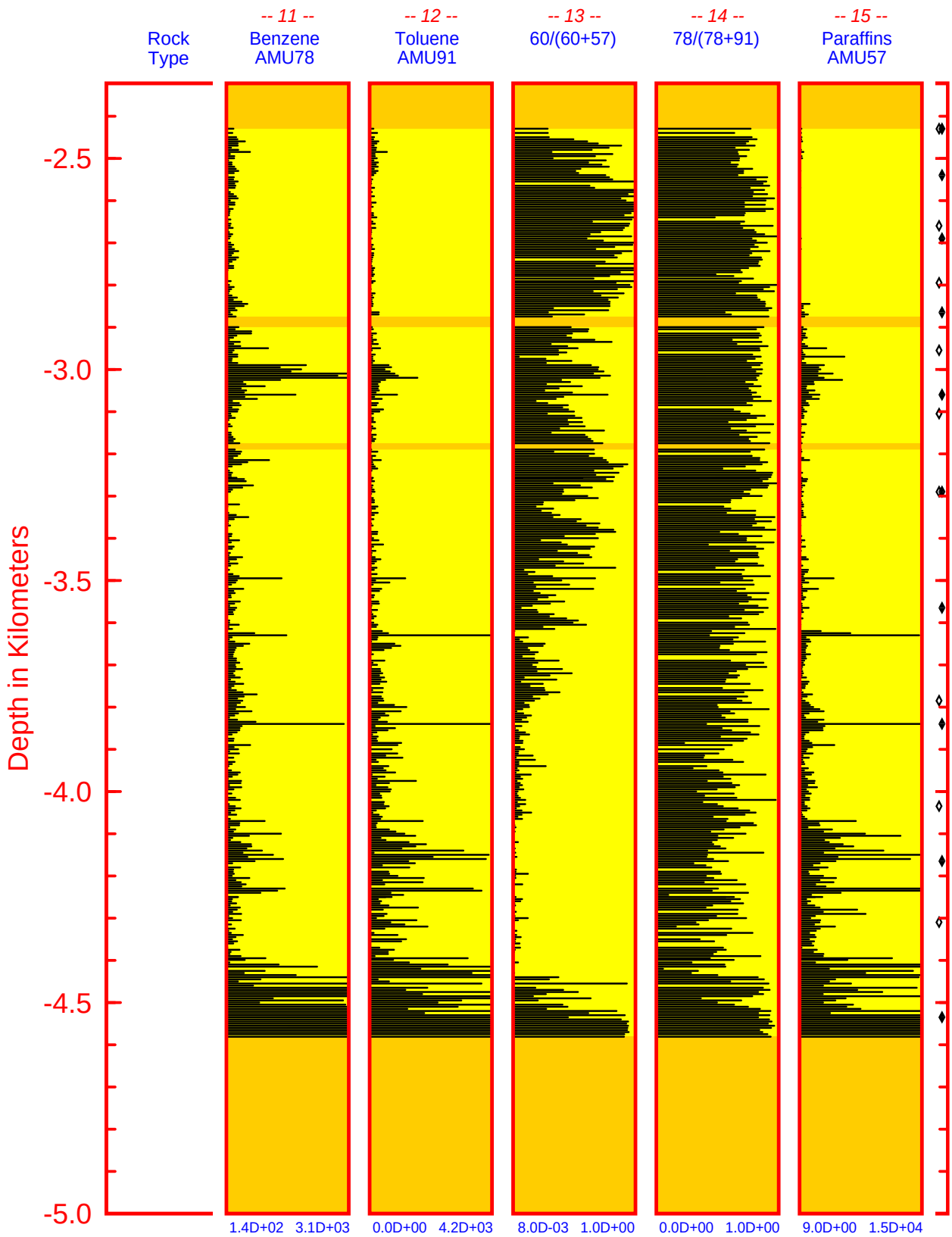



Figure 9: 90% of all FIS Data: Tracks 11 – 15 (see Sect. A.3 for explanation)

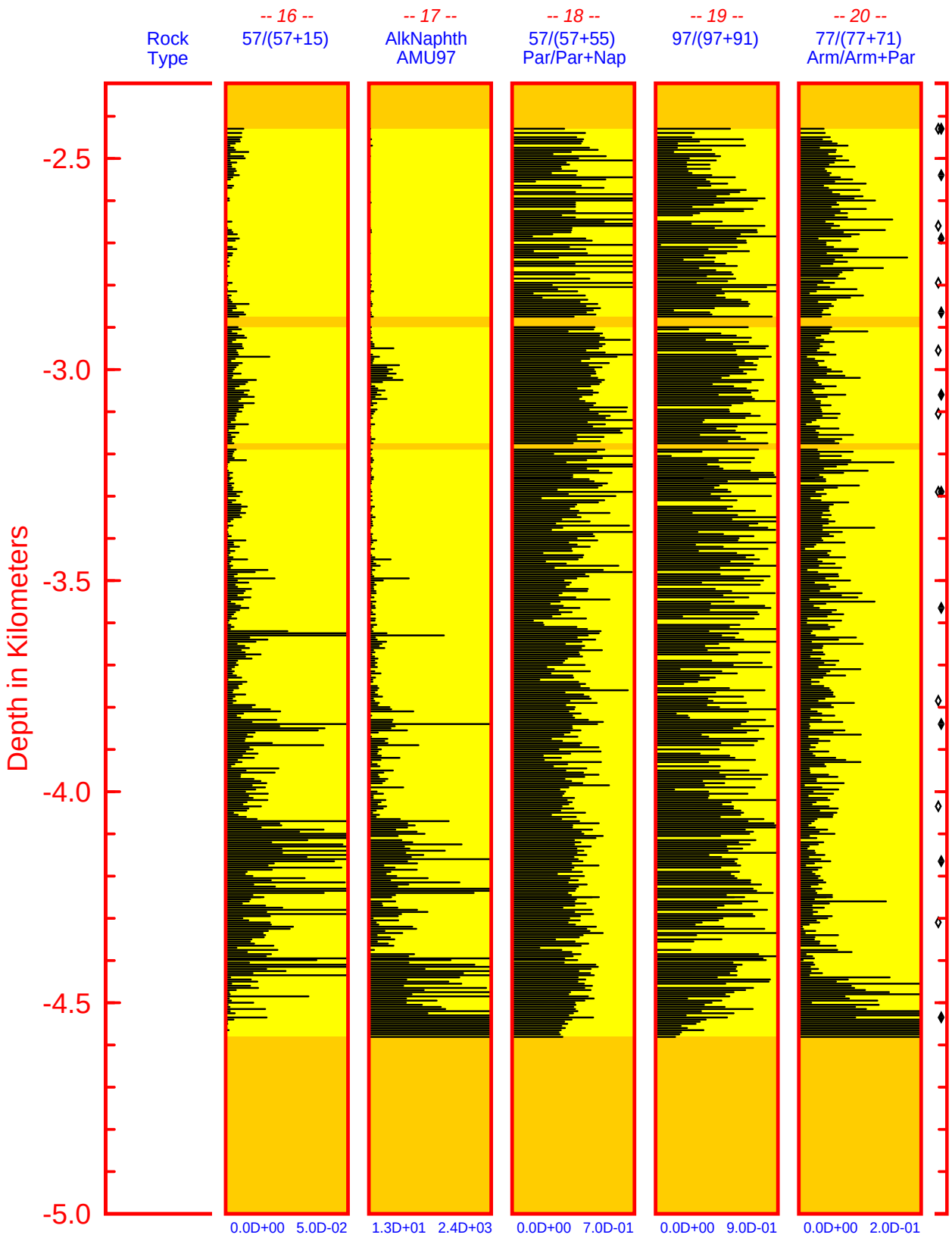



Figure 10: 90% of all FIS Data: Tracks 16 – 20 (see Sect. A.3 for explanation)

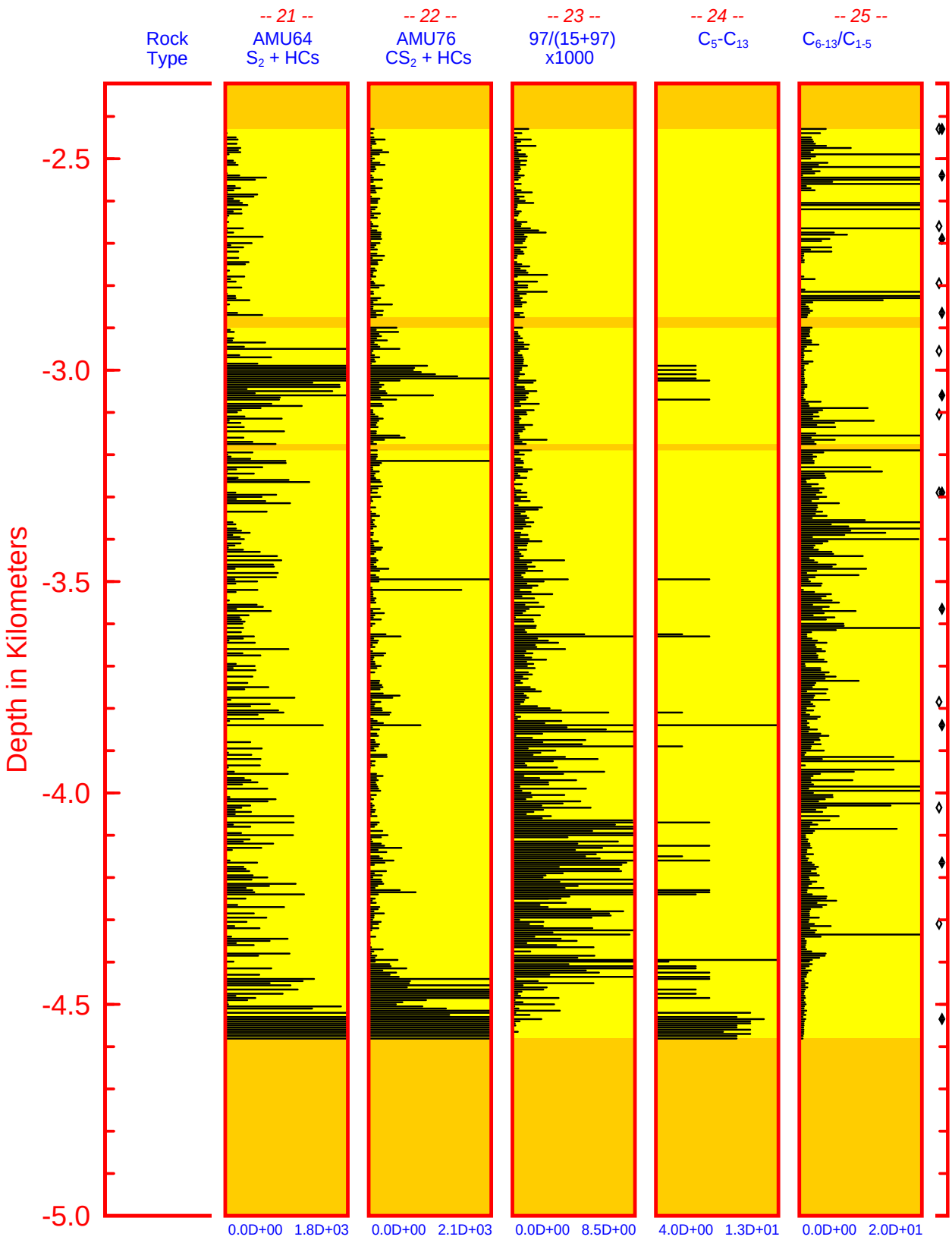



Figure 11: 90% of all FIS Data: Tracks 21 – 25 (see Sect. A.3 for explanation)

## 3 Photomicroscopy

Thin sections were prepared from Noblige 1 samples at depths warranting further examination following preliminary assessment of the *FIS* analytical results. The sections were then examined under a petrographic microscope using a variety of fluid inclusion techniques (e.g., UV-fluorescence, microthermometry, etc.) in order to verify the presence of petroleum-bearing inclusions in the rock samples and to explore textural relationships that may yield additional information on the timing of hydrocarbon migration or generation. Petrographic examination is also necessary to verify that petroleum-bearing fluid inclusions present in the samples and responsible for the observed mass spectra are not relict features (i.e., that they were not already present in the mineral grains prior to deposition). The following figures contain photomicrographs representative of samples from Noblige 1 at the depths indicated.

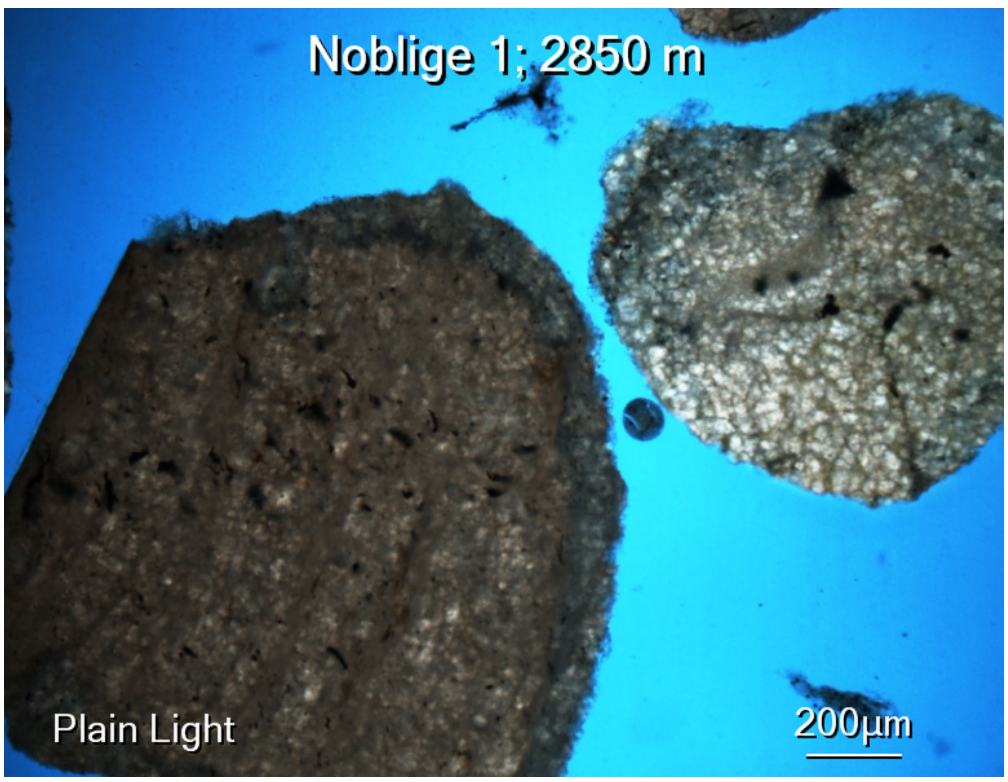



Figure 12: Photomicroscopy from Noblige 1

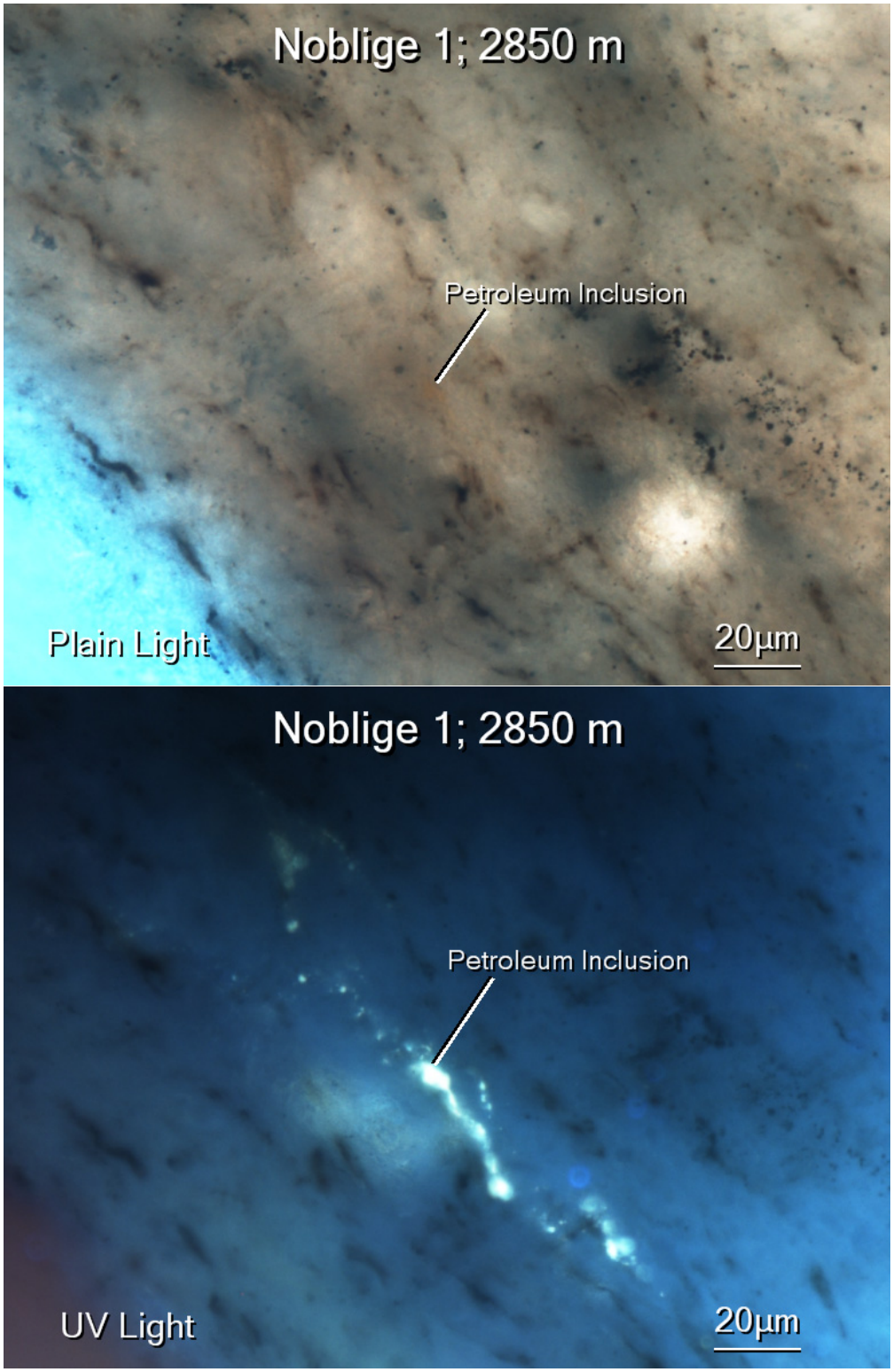



Figure 13: Photomicroscopy from Noblige 1

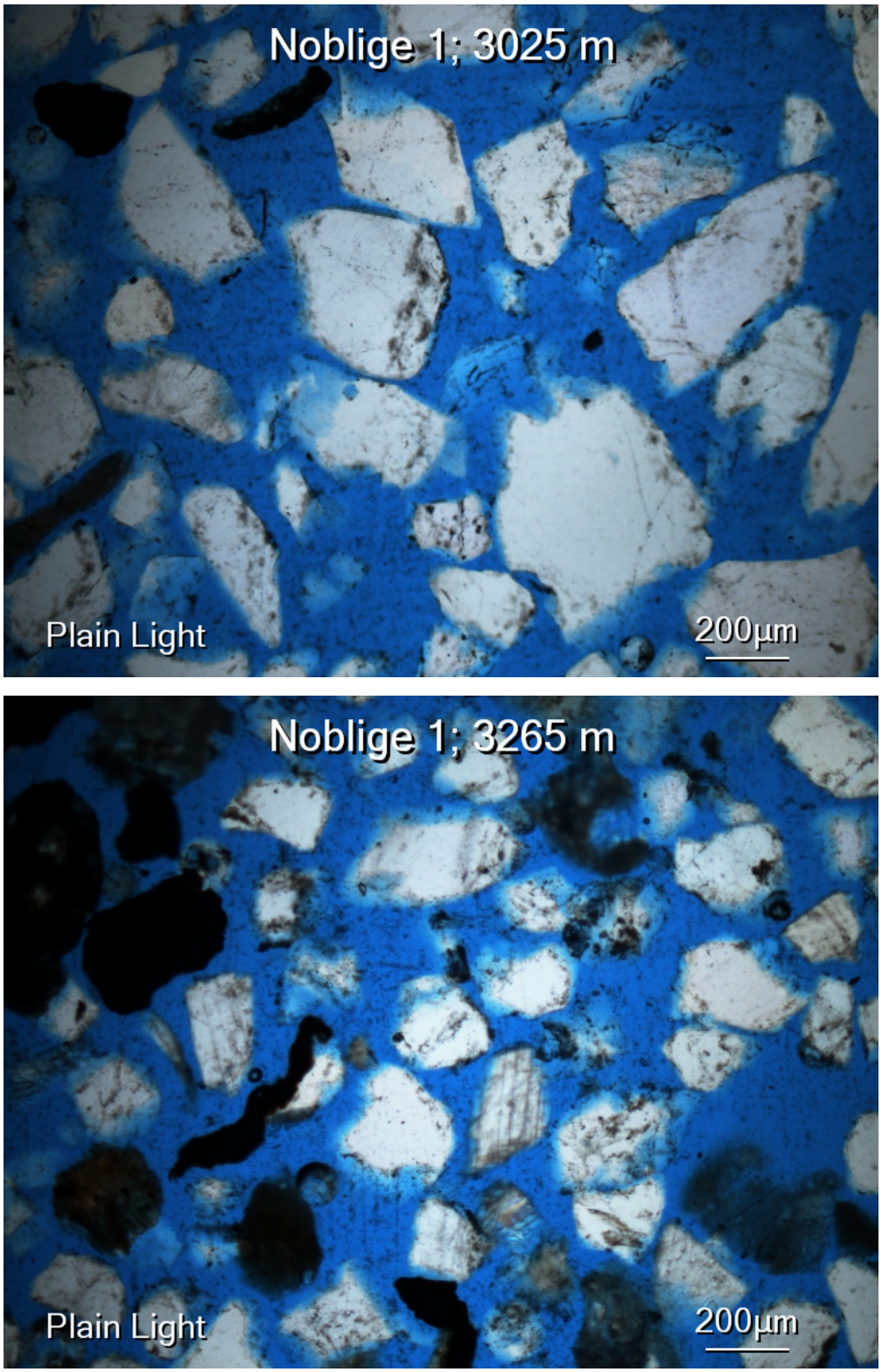



Figure 14: Photomicroscopy from Noblige 1

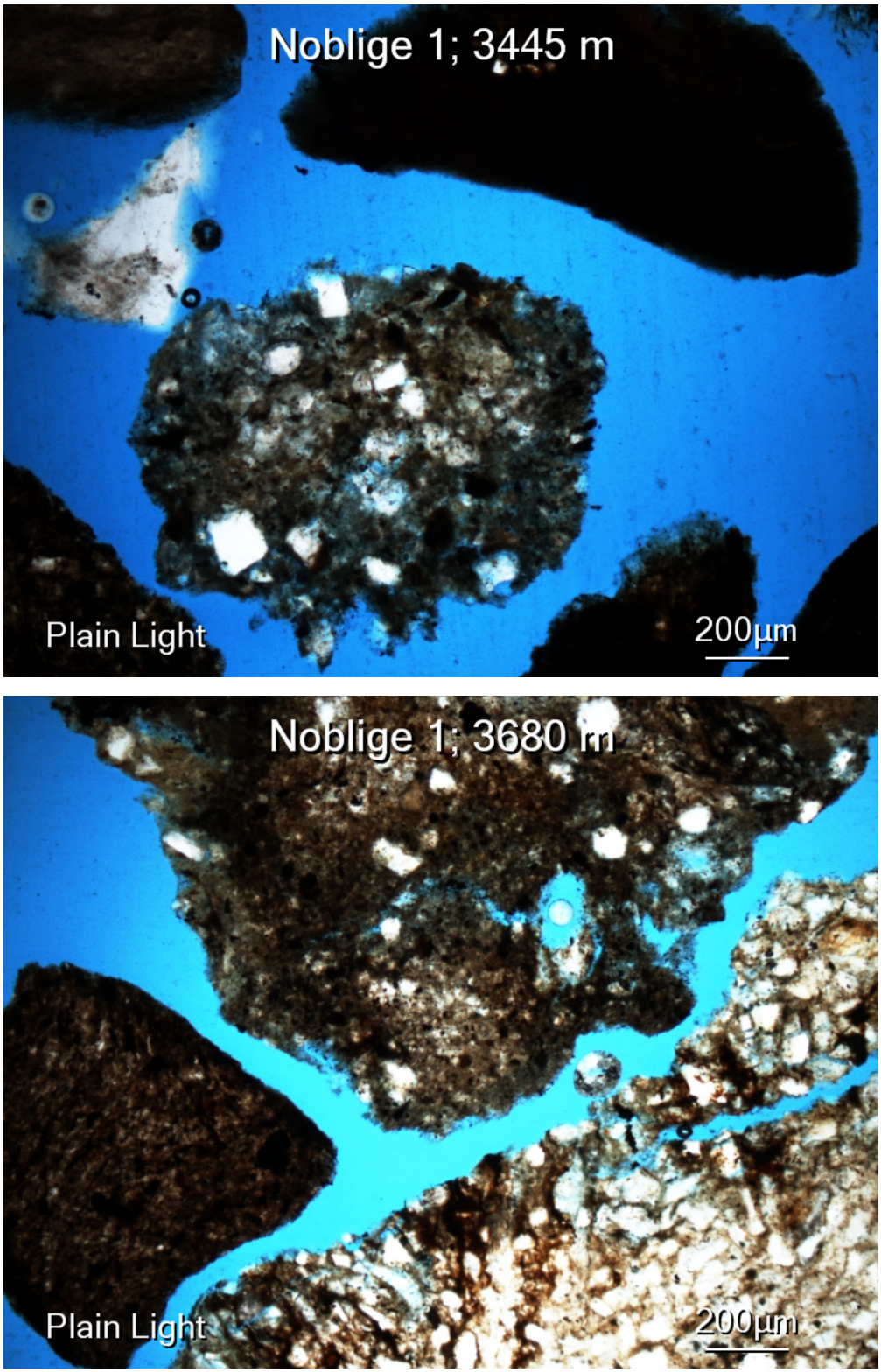



Figure 15: Photomicroscopy from Noblige 1

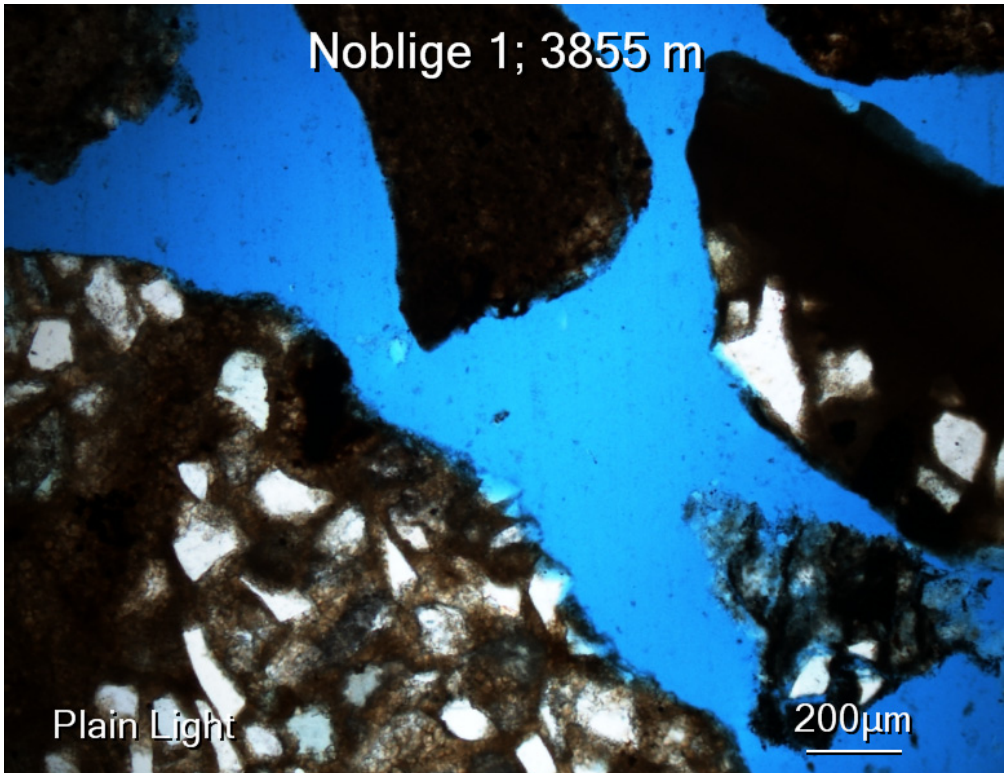



Figure 16: Photomicroscopy from Noblige 1

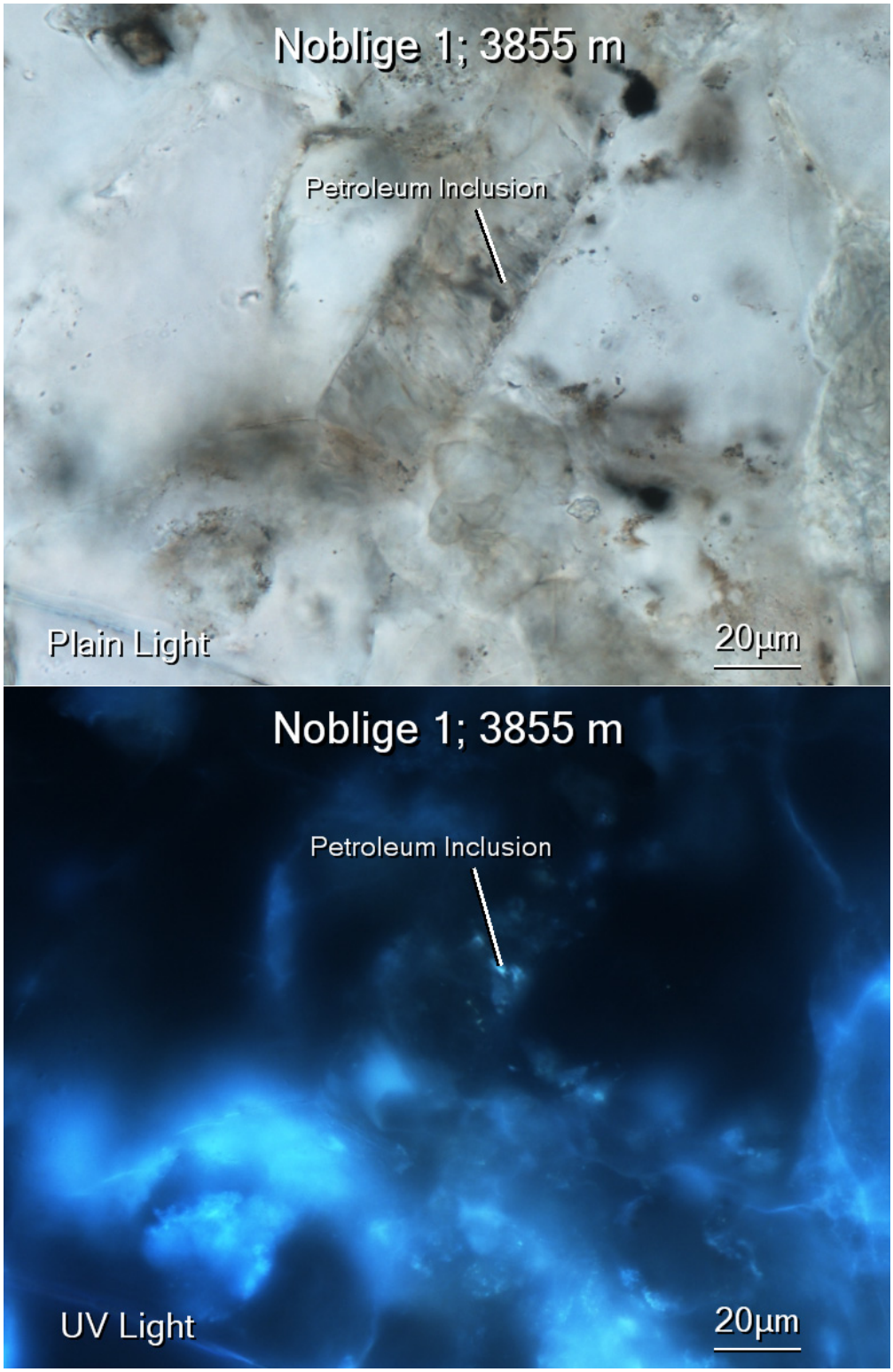



Figure 17: Photomicroscopy from Noblige 1

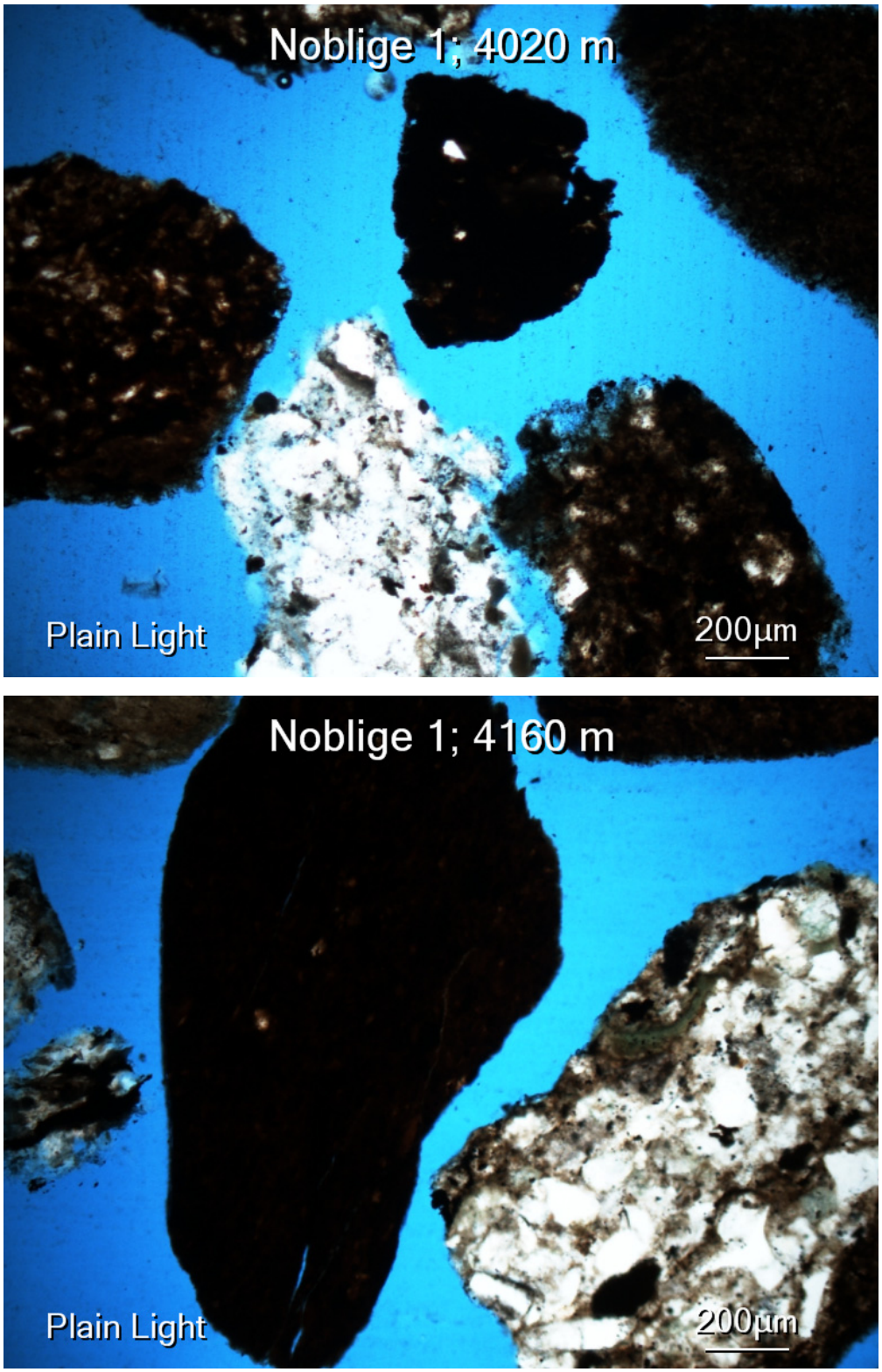



Figure 18: Photomicroscopy from Noblige 1

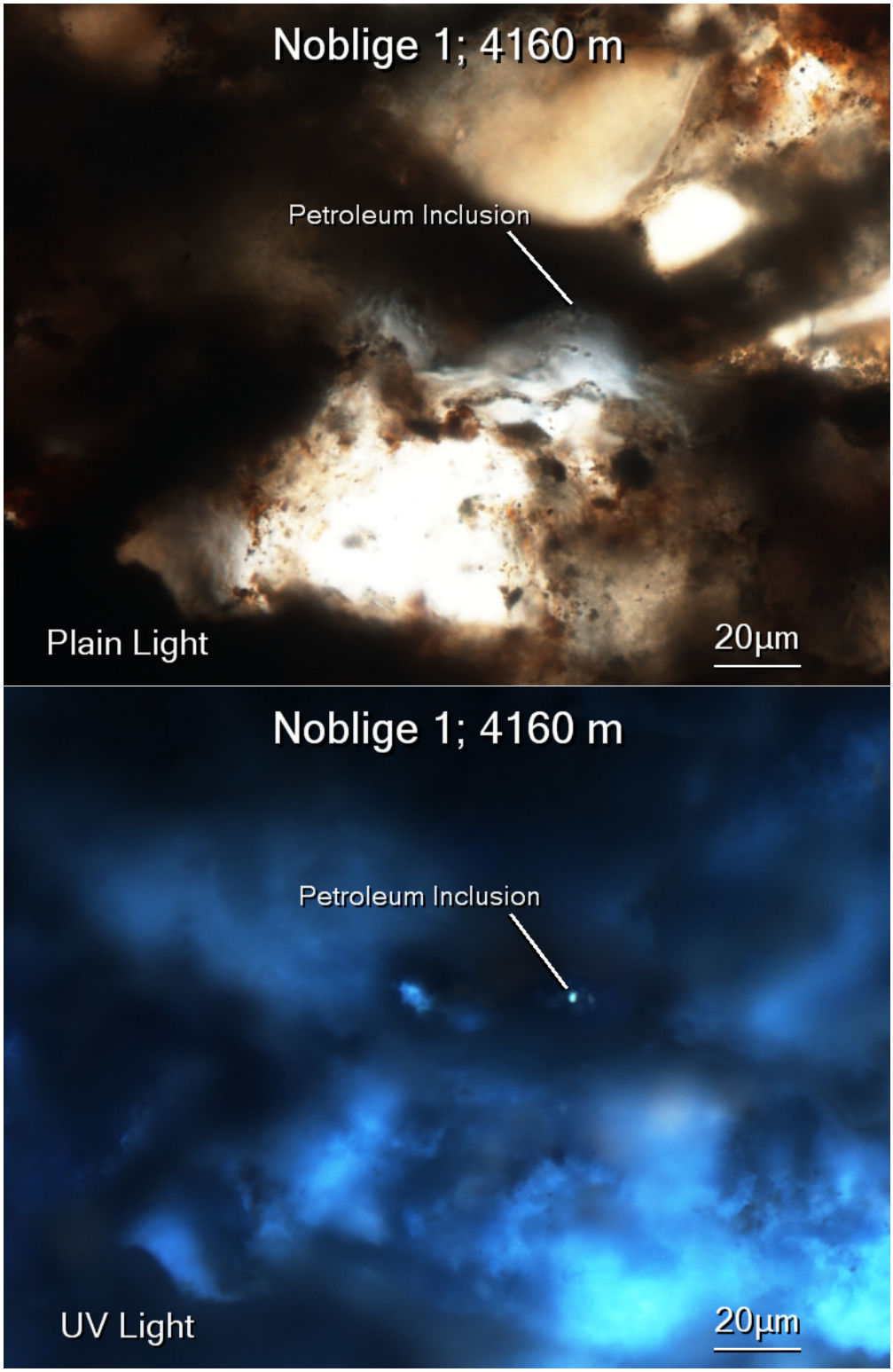



Figure 19: Photomicroscopy from Noblige 1

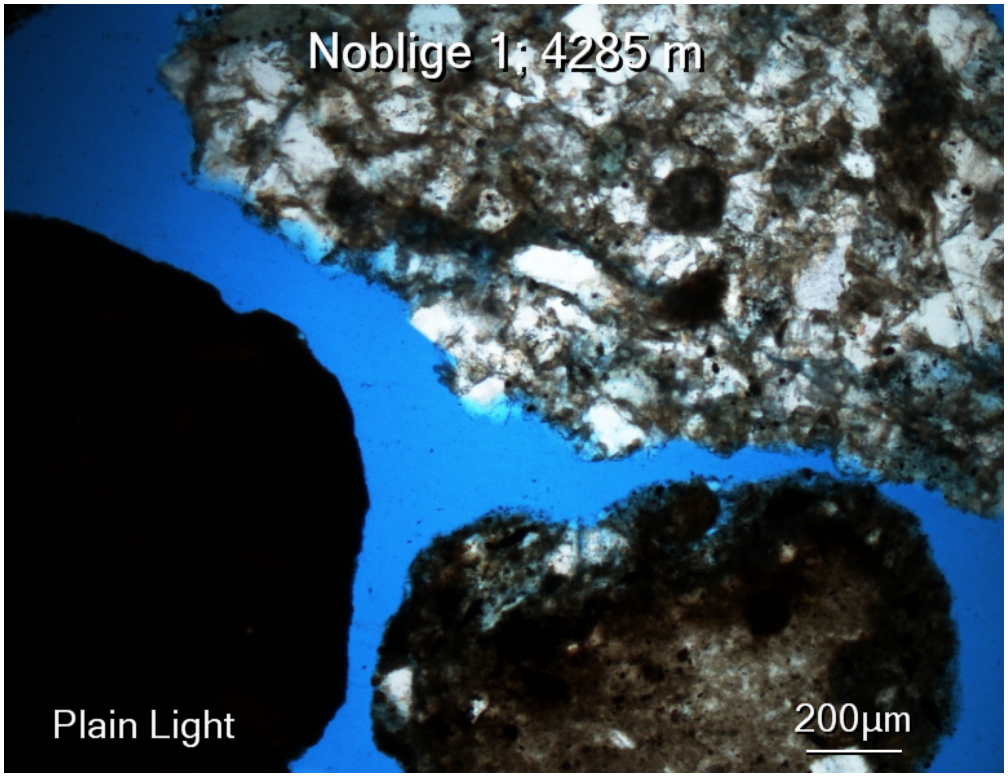



Figure 20: Photomicroscopy from Noblige 1

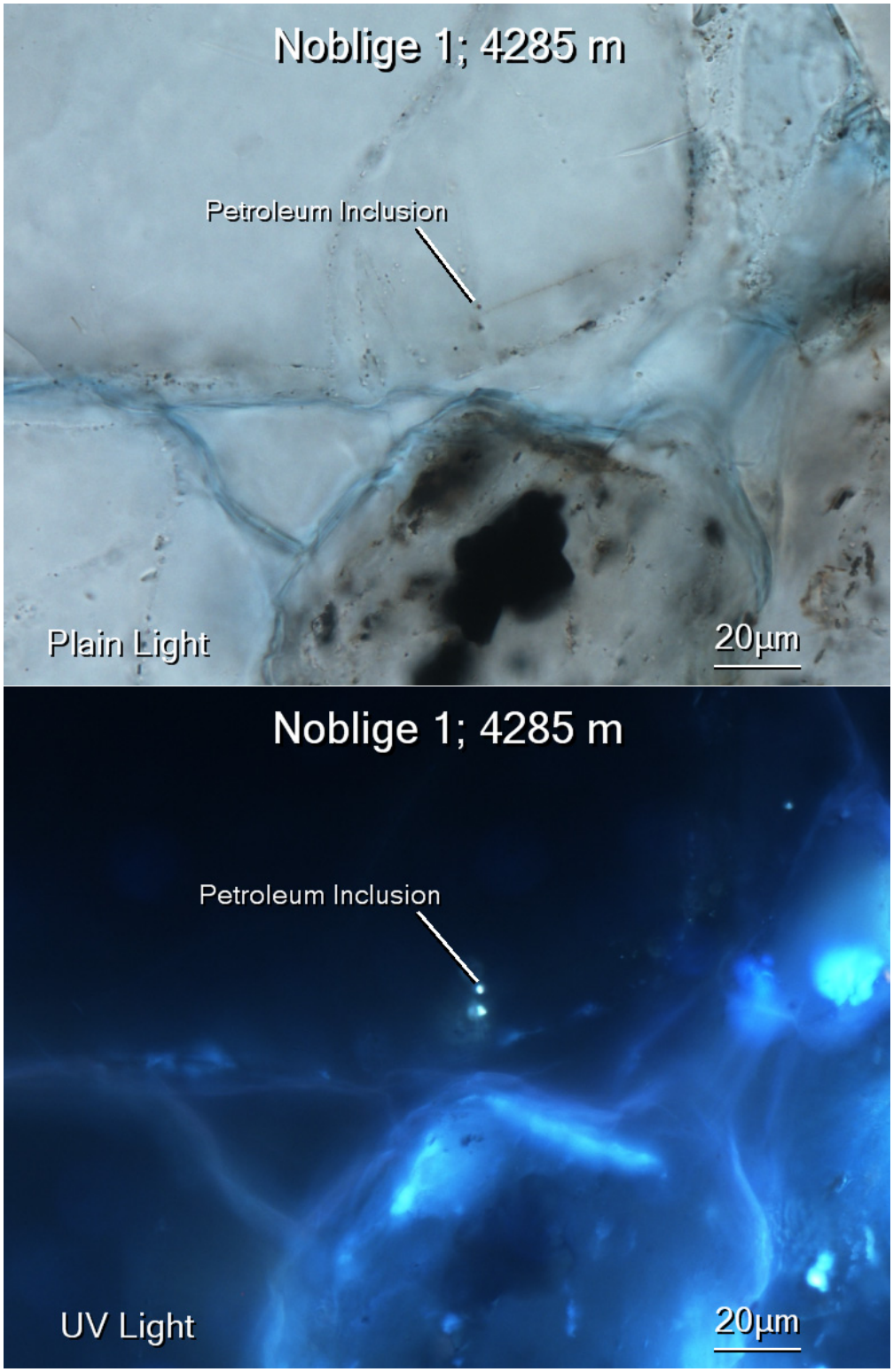



Figure 21: Photomicroscopy from Noblige 1

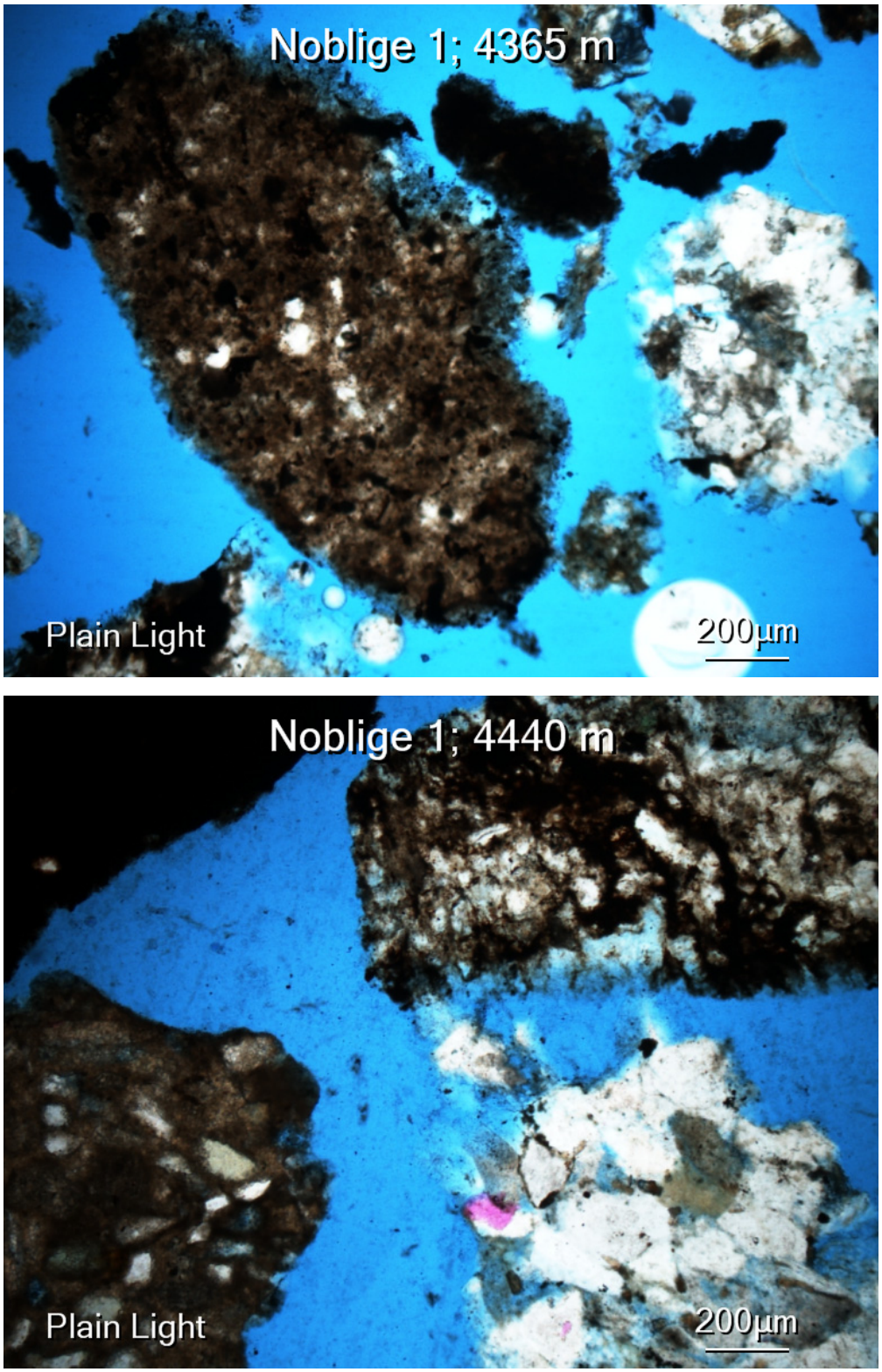



Figure 22: Photomicroscopy from Noblige 1

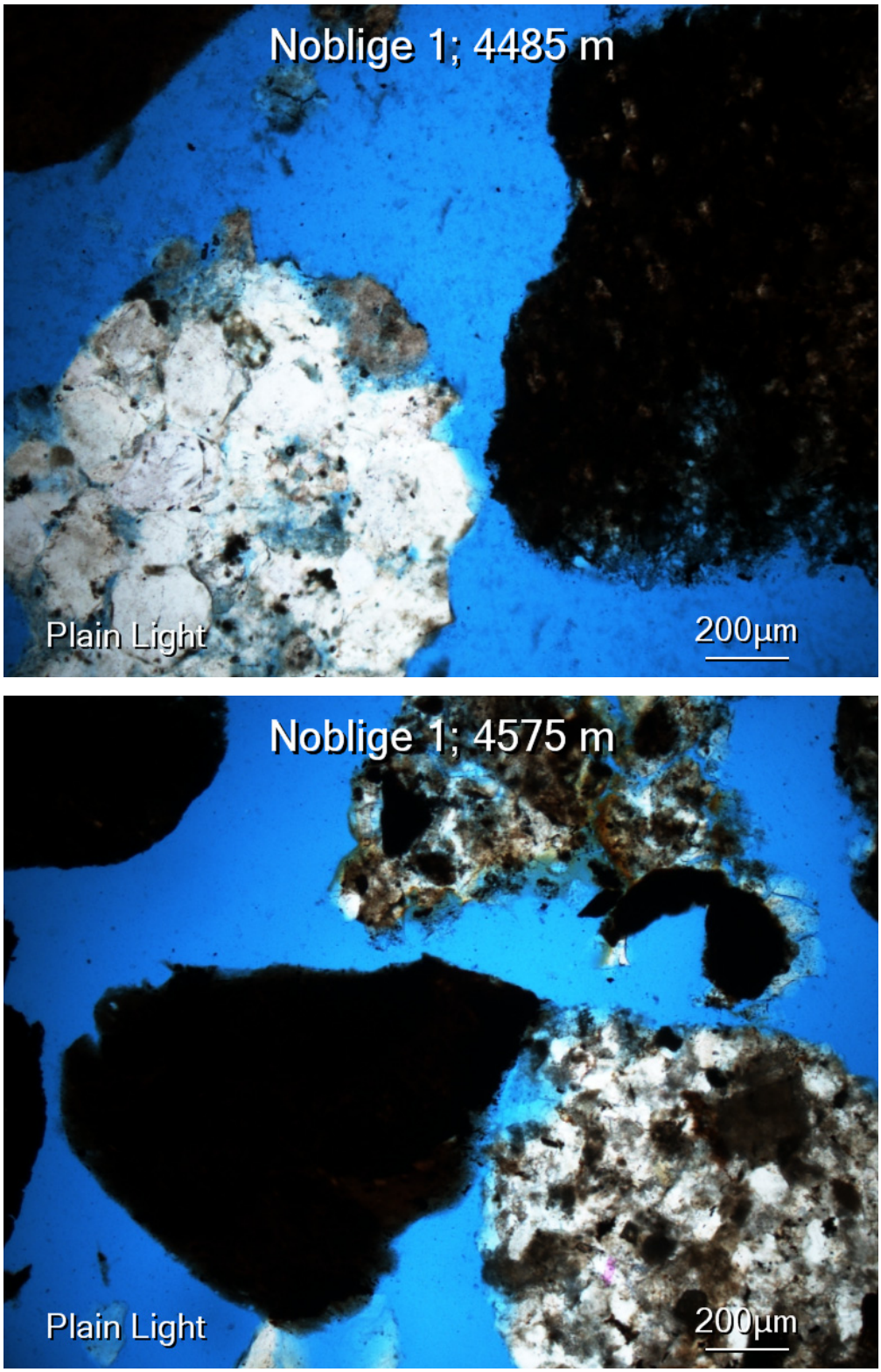



Figure 23: Photomicroscopy from Noblige 1

# Appendices

# A Interpretation of Fluid Inclusion Stratigraphy (FIS) Data

## A.1 FIS Analysis

### A.1.1 Introduction to FIS Analysis

Fluid Inclusion Stratigraphy involves the rapid, complete analysis of volatiles trapped as fluid inclusions in rock samples using quadrupole mass analyzers attached to an automated, high-vacuum sample introduction system. The technique documents the presence and relative bulk abundance of ionized volatile fragments with mass/charge ratio of $1 \leq m/z \leq 180$ that have been released from fluid inclusions by crushing of natural samples. This includes most geologically important inorganic species as well as organic species with less than or equal to 13 carbon atoms. The resulting analysis of the petroleum fraction is comparable to the low molecular weight fraction of a whole-oil gas chromatographic - mass spectrometric (GCMS) analysis (without devolatilization of the gas fraction); hence, the major classes of hydrocarbons (e.g., aromatics, naphthenes and paraffins) are represented. Unlike GCMS, where the quadrupole is front-ended with a GC, boiling point separation is not achieved and all species are analyzed simultaneously. Hence, significant interference can occur among species with the same mass to charge ratio. However, what FIS lacks in compound specificity, it makes up for in sensitivity and speed, allowing detection of petroleum in samples that are well beyond the reach of standard GCMS methodologies.

Prior to analysis, samples of rock material are freed of significant interfering contamination by washing, picking and magnetic separation as necessary to remove drilling fluids, lost circulation materials, other solid mud additives such as gilsonite, and metallic particles from the drillstring. Cleaned samples are loaded with appropriate standards into specially designed autosamplers and are heated in a vacuum oven for a minimum of 24 hours. This is done to remove adsorbed organic and inorganic volatile material that could interfere with the analysis. The autosampling device is placed in the vacuum system and evacuated to appropriate high vacuum. Bulk fluid inclusion volatiles are afterwards instantaneously released from each sample in a sequential manner by automated mechanical crushing. Volatile organic and inorganic species are dynamically pumped through quadrupole mass analyzers where they are ionized, separated according to their mass/charge and recorded.

Fluid Inclusion Stratigraphy is unique in several ways: 1) the methodology and theoretical framework are the result of a long-standing research and development effort, 2) the cumulative experience and database of documented case histories are the most extensive in the world and 3) the technology represents the most rapid analytical capability of its kind available. The resulting dataset can provide a nearly continuous log of present and past pore fluid chemistry through the stratigraphic section penetrated by a well, and, given adequate sample coverage, the data can be mapped in two or three dimensions.

### A.1.2 Introduction to FIS Data Interpretation

The following sections provide guidelines for interpreting Fluid Inclusion Stratigraphy (FIS) data that were developed during evaluation of a large number of wells from many geologic and structural environments over the years. This methodology was followed in preparing the annotated depth plots found at the front of this report and is adequate for most circumstances. There are two levels of interpretation to be considered:

1. Interpretation of FIS data by itself (basically describing what volatiles are present and in what relative proportion).
2. Interpretation of the significance of FIS data in a geologic context to answer a specific petroleum system question.

These guidelines concentrate on addressing the first level of interpretation, both because potential geologic scenarios are too variable to be thoroughly considered here, and because the end user is in the best position to judge the ultimate significance of these data after integrating the FIS data set with other information. When interpreting FIS data, the following statements apply:

1. FIS interpretations are generally qualitative.
2. Chemical relationships displayed in FIS data are either obvious or they are unreliable as exploration tools.
3. FIS interpretations are usually simple, but may be equivocal without supporting information.

### A.1.3 FIS Data Consists of Two Parts

There are two parts to a conventional FIS data set, and each must be evaluated in detail.

1. Stratigraphic profiles of critical species and species ratios with depth (Sections 2.1 & 2.2).
2. Individual mass spectra for each sample (Appendix C).

A mass spectrum is a graphical display of the log of the ion current (measured on the mass spectrometers' detectors) as a function of the mass-to-charge ratio (m/z) of the detected ions (this will become clearer after reading the sections below). The amplitude of the ion current is proportional to the quantity of each type of ion, which, in turn, is proportional to the abundance of the species in the original gas mixture. Discrete peaks occur because the charged substances have discrete masses and discrete charges (usually single and positive).

There is a tendency for end users to concentrate on interpreting the first part of the data set (depth plots) and ignore the second (individual mass spectra). However, as will be shown, evaluation of individual FIS mass spectra is as important to the overall FIS interpretation as pattern-recognition of whole-oil chromatograms is to evaluating oil families. Imagine taking a single species present in a chromatogram and plotting it as a function of depth in the reservoir without ever considering its relationship to other species that are present. Certainly useful information results, but not nearly as much as could be offered by looking at the overall species distribution in the chromatogram in addition to the absolute abundance of a species or the ratio of two species as a function of depth. Similarly, both FIS depth plots and individual mass spectra are important to the final interpretation.

## A.2 FIS Mass Spectra

### A.2.1 Understanding FIS Mass Spectra

FIS data are collected on quadrupole mass spectrometers. These instruments distinguish among positively charged species using an electrodynamic field produced by application of combined RF and DC voltages to two pairs of metal rods in the filter section. A species

with a specific ratio of mass to charge (m/z) will have a dynamically stable trajectory within the field formed by the voltages on the rods, while all other species are filtered out. By continuously varying the applied voltages, a range of charged substances can be sequentially stabilized and allowed to traverse the length of the filter assembly to the detector. FIS data currently provided consists of measured responses on m/z 1-180. This mass range allows detection of all volatile inorganic species as well as organic compounds with up to 13 carbon atoms ($C_{13}$). Detection is accomplished either with a Faraday cup, which reads ion currents directly from the filter without amplification, or by an electron multiplier, which amplifies the single charge of a given ion into a current.

In order for species to be detected they must be charged (ionized). This is accomplished by bombarding volatiles released from fluid inclusions with electrons that are thermionically emitted from a hot filament. Energy transference from electrons to neutral particles generally results in positively charged parent ions, while excess energy obtained by a molecule in the initial ionizing collision results in fragmentation of the parent molecule into several species. For a single parent molecule, the resulting mass spectrum is known as a fragmentation pattern. The distribution of ions from a given species can generally be predicted by considering all combinations of molecules and isotopic variants. The following example illustrates this concept.

Molecular carbon dioxide has a formula $CO_2$ and most common molecular mass of 44. In detail, the mass of a given molecule of $CO_2$ can be 44, 45, 46, 47, 48 or 49 because both carbon and oxygen have two significant, naturally occurring isotopes ($^{12}C$, $^{13}C$, $^{16}O$, and $^{18}O$). Hence, the fragmentation pattern of $CO_2$ would be expected to contain the singly charged species $CO_2^+$, $CO^+$, $C^+$ and $O^+$ with all possible isotopic permutations (14 possible masses). Additionally, doubly charged species can be produced. These species, although much rarer, have m/z of exactly half of their singly charged counterparts (e.g., $^{12}C^{16}O^{16}O^{++}$ has m/z of 44/2 = 22). Some peaks associated with doubly charged ions appear midway between two integer m/z locations (e.g., $^{13}C^{16}O^{16}O^{++}$ has m/z of 45/2 = 22.5). In general, instrument parameters favor the production of singly charged species. The relative frequency at which a given species will be produced and detected reflects natural isotopic abundance, ion production statistics and instrument parameters. In the above example of $CO_2$, the representative fragmentation pattern shown in Table V has been reported.

Table V: Partial Fragmentation Pattern for Carbon Dioxide

| **Mass** | **Species** | **Abundance** | **Mass** | **Species** | **Abundance** |
|---|---|---|---|---|---|
| 6 | $^{12}C^{++}$ | 0.0005 | 28 | $^{12}C^{16}O^{+}$ | 15 |
| 8 | $^{16}O^{++}$ | 0.00046 | 29 | $^{13}C^{16}O^{+}$ | 0.15 |
| 12 | $^{12}C^{+}$ | 6.3 | 30 | $^{12}C^{18}O^{+}$ | 0.029 |
| 13 | $^{13}C^{+}$ | 0.063 | 31 | $^{13}C^{18}O^{+}$ | 0.0029 |
| 16 | $^{16}O^{+}$ | 13 | 44 | $^{12}C^{16}O^{16}O^{+}$ | 100 |
| 18 | $^{18}O^{+}$ | 0.0088 | 45 | $^{13}C^{16}O^{16}O^{+}$ | 1.2 |
| 22 | $^{12}C^{16}O^{16}O^{++}$ | 0.52 | 46 | $^{12}C^{18}O^{16}O^{+}$ | 0.38 |
| 22.5 | $^{13}C^{16}O^{16}O^{++}$ | 0.0047 | 47 | $^{13}C^{18}O^{16}O^{+}$ | 0.0034 |
| 23 | $^{12}C^{18}O^{16}O^{++}$ | 0.0012 | 48 | $^{12}C^{18}O^{18}O^{+}$ | 0.00054 |
| | | | 49 | $^{13}C^{18}O^{18}O^{+}$ | 0.000043 |

In spite of the usage in the previous paragraph, the term "parent peak" is generally given to the most intense peak of the mass spectrum of a single compound, while the term "molecular peak" is given to the singly charged ion with the same atomic mass as that of the pure compound. In the example above, both the parent and molecular peaks of $CO_2$ occur at m/z = 44. It is frequently the case, however, that the most intense peak is not the molecular peak. For instance, many normal paraffins with three or more carbon atoms (n-propane and greater) have parent peaks at m/z = 43, 57 or 71.

Complex volatile mixtures have mass spectra characterized by multiple, interfering ions on a given m/z, making it difficult or impossible to find a "clean" peak indicative of a specific species. Generally, higher m/z positions display more interference, but even low m/z have these overlaps (e.g. $HD^+$ and $^3He^+$ both appear at m/z = 3). This brings us back to one of the original points mentioned in the Introduction: mass spectra of multicomponent gas mixtures are qualitative in the sense that the absolute abundance of most species cannot be calculated. Nevertheless, similar compounds give similar fragmentation patterns that tend to be distinct from other classes of compounds. Because of this, the major classes of organic species (paraffins, naphthenes and aromatics) can be distinguished and their relative abundance estimated. Similarly, it is useful to consider the assemblage of anomalous peaks in a given mass spectrum, as these will often indicate the presence of compounds that are concentrated by similar subsurface processes (e.g., the water-soluble species benzene, toluene and acetic acid as the primary indicators of "proximal pay"). It is these assemblages that are most useful for distinguishing among major types of FIS mass spectra, as well as inferring the presence of a specific compound even where interfering ions are possible.

### A.2.2 Five Types of FIS Mass Spectra

FIS mass spectra can be classified into five end member types:

1. *Non-hydrocarbon* FIS Mass Spectra
2. *Gas-range Enriched* FIS Mass Spectra
3. *Liquid-range Enriched* FIS Mass Spectra
4. *Water-soluble Enriched* FIS Mass Spectra
5. *Sulfur-compound Enriched* FIS Mass Spectra

Mixtures and gradations among these ideal end members are common. In considering the fragmentation patterns of organic species, it is useful to keep in mind the general formulas for the three dominant hydrocarbon classes:

1. *Paraffins:* $C_nH_{2n+2}$
2. *Naphthenes:* $C_nH_{2n}$
3. *Aromatics:* $C_nH_{2n-6}$

*Non-Hydrocarbon FIS Mass Spectra*

Non-hydrocarbon spectra generally show four major clusters or "humps" centered at approximately m/z 15, 28, 42 and 55. The tallest three peaks in these spectra occur within the

first three clusters at m/z 18, 28 and 44, and are attributable largely to water and carbon dioxide (with possible contributions from nitrogen on m/z 28). Most of the other peaks in the m/z 2-46 range of non-hydrocarbon spectra can be attributed to inorganic species or very minor organic contributions. Water and carbon dioxide are the two most abundant volatile species in subsurface pore fluids, hence their predominance here. FIS analysis is a bulk extraction technique, hence, many generations of fluid inclusions are potentially analyzed simultaneously. Because hydrocarbon inclusions are always present in much lower abundance than aqueous inclusions in a given rock volume, water and $CO_2$ peaks will generally dominate all FIS mass spectra, even those displaying hydrocarbon enrichment.

The fourth cluster of peaks, centered on m/z 55, represents minor amounts of hydrocarbons that are present in nearly all samples, as most hydrocarbons have a significant contribution in the m/z 55-57 area. Note, however, that even the largest of these peaks is generally three orders of magnitude below the major non-hydrocarbon peaks. Also, note that m/z 55 is commonly more abundant than m/z 57. The m/z 55 peak represents a major contribution from naphthenes, while the m/z 57 peak is generally a primary paraffin peak. The relative enrichment of naphthenes over paraffins in aqueous-dominated (non-hydrocarbon) FIS spectra may reflect the relative solubility of these species in water, as the progression from least soluble to most soluble follows the general rule: paraffins<naphthenes<aromatics. It is probable that these minor species are dissolved within aqueous fluid inclusions. The solubility of even relatively insoluble $C_4$ paraffin in water can be several hundred parts per million, well within the detection limit of the FIS system.

### *Gas-Range Enriched FIS Mass Spectra*

Gas-enriched spectra are characterized by strong responses on $C_1$-$C_5$ hydrocarbons with dwindling responses in the $C_6$-$C_8$ range, and essentially no response in the $C_9$+ range. Drier gases may exhibit responses only in the $C_1$-$C_3$ range. Naturally occurring hydrocarbon gases tend to be dominated by short-chain paraffins; hence, these are the primary peaks to look for in identifying gas FIS spectra. Predominant peaks (parent and some significant subordinates with intensity of at least 10% of the parent) for low-molecular weight normal paraffins and naphthenes (cycloparaffins) are shown in Table VI.

Table VI: Partial Fragmentation Pattern for Gas-Range Hydrocarbons

| **Methane** | **Ethane** | **Propane** | **n-Butane** | **n-Pent** | **n-Hex** | **Cyclopent** | **Cyclohex** |
|---|---|---|---|---|---|---|---|
| 16(100%) | 28 | 29 | 43 | 43 | 57 | 42 | 56 |
| 15 | 27 | 28 | 29 | 42 | 43 | 70(30%) | 84(75%) |
| 14 | 30(25%) | 27 | 28 | 41 | 41 | 41 | 41 |
| 13 | 29 | 44(27%) | 27 | 27 | 56 | 55 | 55 |
| | 26 | 43 | 41 | 28 | 29 | 39 | 42 |
| | | 39 | 39 | 29 | 27 | 27 | 69 |
| | | 41 | 42 | 57 | 42 | 40 | 27 |
| | | | 58(9%) | 72(9%) | 39 | 29 | 39 |
| | | | | | 86(15%) | | |

Here, molecular peaks are shown with their intensities relative to the parent peak. Note that the molecular peaks for $C_4$-$C_6$ normal paraffins are not among the top five most intense peaks (a feature of fragmentation patterns that was mentioned previously). Considering the location of the above peaks, a gas-enriched mass spectrum should contain peak clusters at m/z 13-16, 26-30, 39-44 and 55-57. Note that this is precisely where the four peak clusters are located in the previously described non-hydrocarbon mass spectrum (where they were attributed largely to $CO_2$ and water, nitrogen and minor hydrocarbon contributions). The distinction lies in the relative proportion of these species. Gases can typically contain 90% $C_1$ and 95% $C_1$-$C_3$. Hence, FIS gas spectra typically have prominent $C_1$-$C_3$ clusters. The water triad at m/z 16-18, which commonly shows a pattern of monotonic increase from 16 to 18 in non-hydrocarbon spectra can become disturbed at high gas concentrations so that masses 15 and 16 become dominant, even to the point of being more intense than mass 18. Similarly, the 26, 27, 39, 41 and 43 peaks generally display significantly higher intensities than in non-hydrocarbon spectra. The ratio of mass 57 to mass 55 ($C_4$+ paraffins / $C_4$+ naphthenes) may become quite high, reflecting the paraffinic nature of many gases.

*Liquid-Range Enriched FIS Mass Spectra*

FIS spectra that contain significant quantities of liquid-range petroleum species display repetitive peak clusters corresponding to fragments with successive carbon numbers in the $C_7$-$C_{13}$ range as shown in Table VII.

Table VII: Partial Fragmentation Pattern for Liquid-Range Hydrocarbons

| **Carbon #** | **m/z Cluster** | **Parent (nC)** | **Molecular (nC)** |
|---|---|---|---|
| C7 | 95-101 | 43, 57, 41 | 100(14%) |
| C8 | 109-115 | 43, 57, 41 | 114(7%) |
| C9 | 123-129 | 43, 57, 41 | 128(8%) |
| C10 | 137-143 | 43, 57, 41 | 142(7%) |
| C11 | 151-157 | 43, 57, 41 | 156(4%) |
| C12 | 165-171 | 57, 43, 71 | 170(8%) |
| C13 | 179-185 | 43, 57, 41 | 184(5%) |

Note, again, that molecular peaks for high-molecular weight hydrocarbon species are generally only 5-15% of the parent peak. Also note that the three most intense peaks for the $C_7$-$C_{13}$ paraffins are usually the same, and represent some of the most intense peaks previously identified for the $C_4$-$C_6$ gas-range paraffins.

Only normal (straight-chain) paraffins have been considered in the above table. Typical $C_6$-$C_{10}$ (gasoline) fractions contain 40% paraffins, 50% naphthenes and 10% aromatics by volume. Typical $C_{11}$-$C_{13}$ (kerosene) fractions contain 30% paraffins, 50% naphthenes and 20% aromatics by volume. As the general formula for naphthenes suggests, molecular peaks are shifted downward by 2 m/z units (e.g., the $C_7$ naphthene molecular peak is at 98). Hence the major contribution at 43 for normal paraffins becomes 41 for naphthenes, 57 becomes 55, and so on. This is why the ratio of 57 to 55 is plotted in basic FIS data packages: to track the relative distribution of paraffinic and naphthenic compounds as well as the processes that fractionate them (e.g., dissolution in an aqueous phase; recall the solubility law for hydrocarbon species). Aromatic fragmentation patterns will be considered under the explanation of

water-soluble FIS mass spectra.

Natural liquid petroleum is a complex mixture containing hundreds of specific compounds within these classes. Thus, the qualitative nature of FIS mass spectra is reiterated. Major classes of organic compounds can be identified, distinguished and tracked semi-quantitatively, but specific compounds cannot be quantified except under special circumstances. From the foregoing discussion it becomes apparent that even though the FIS analytical procedure does not scan past the molecular peak of $nC_{12}$, contributions on low molecular weight species can include species well above $C_{13}$. The maximum carbon number contributing to the FIS mass spectrum is limited only by the volatility of the given compounds within the high vacuum system and their abundance. However, it is unlikely that $C_{20}+$ compounds contribute significantly to FIS responses, given their volumetrically low abundance and vapor pressures.

*Water-Soluble Enriched FIS Mass Spectra*

FIS mass spectra containing anomalous concentrations of water-soluble volatile species are perhaps the most interesting of the main spectral types. Key indicator species are acetic acid, benzene and toluene (see Table VIII). Other common compounds include methane, ethane and carbon dioxide (fragmentation patterns previously outlined).

Table VIII: Partial Fragmentation Pattern for Water-Soluble Species

| **Formic A.** | **Acetic A.** | **Propionic A.** | **Butyric A.** | **Benzene** | **Toluene** | **Xylenes** |
|---|---|---|---|---|---|---|
| 29 | 43 | 28 | 60 | 78(100%) | 91 | 91 |
| 46(61%) | 45 | 29 | 73 | 77 | 92(75%) | 106(65%) |
| 45 | 60(60%) | 74(79%) | 27 | 52 | 39 | 105 |
| 28 | 15 | 45 | 41 | 51 | 65 | 39 |
| 17 | 42 | 73 | 42 | 50 | 51 | 51 |
| 44 | 29 | 57 | 43 | 39 | 63 | 77 |
| | | | 88(3%) | | | |

Aromatics tend to have strong molecular peaks, unlike many paraffinic and naphthenic compounds. The species above are easily identified in mass spectra because major peaks occur within the valleys formed between the peak clusters of predominant paraffinic and naphthenic ions. These species (particularly aromatics) are present at some level in most FIS spectra that contain liquid-range hydrocarbons, because, as outlined above, aromatic species comprise 10-30% of most oils by volume. However, typically, aromatic peaks are 0.5-1 order of magnitude less intense than the adjacent paraffin/naphthene m/z cluster. Although there are no quantitative rules, aromatics are considered anomalous when visual aromatic peak heights becomes sub-equal to, or greater than, adjacent paraffin/naphthene peak clusters. Aromatic peak heights 1-2 orders of magnitude higher than the adjacent peak clusters are not uncommon in FIS spectra that indicate strong enrichment of water-soluble species.

Organic acids represent the most common organic species reported from formation water analyses, and of these, the mono-functional acids dominate. Acetic acid and propionic acid generally have the highest reported concentrations and abundance generally decreases with increased carbon number. As can be seen from the table above, some major peaks have potential interferences with $CO_2$. The most promising peaks for recognition of organic acids

are m/z 60 and, perhaps, 73-74. Organic acids are considered to be present in anomalous concentration when a distinct peak occurs at m/z 60. In the absence of organic acids this location generally lies in a "peak-height valley", even on hydrocarbon-enriched FIS mass spectra. In extremely enriched samples the intensity of the 60 peak is greater than all masses in the 60-180 m/z range.

Where anomalous, the assemblage of species outlined above are present in proportions much different (and greater) than their concentrations in typical petroleum. The commonality that they hold is their relatively high solubility in water compared to paraffinic and naphthenic compounds of similar molecular weight. For instance, benzene is about 100-300 times more soluble in water than n-hexane, and about 3 times more soluble than toluene. Acetic acid is completely miscible in water. Benzene concentrations of several 10's of ppm are typical of oilfield brines, while organic acid concentrations of several thousand ppm have been recognized. Hence, these species in FIS spectra are generally interpreted to be held in solution within aqueous inclusions, rather than present within a free hydrocarbon phase. The origins of these compounds are outlined in a later section, but the most interesting from an exploration standpoint involves stripping from present-day petroleum accumulations and transport via diffusion into the surrounding water-dominated pore network. Considering relative solubility rules, one would predict that the ratio of paraffins to naphthenes (e.g., inferred by a m/z ratio such as 57/55) would be low. In fact, this is generally the case; further evidence that it is relative solubility in water that is driving the distribution of these species in water-soluble enriched FIS mass spectra.

*Sulfur-Compound Enriched FIS Mass Spectra*

The final type of end-member FIS mass spectrum contains anomalous concentrations of sulfur compounds. The species $H_2S$, COS, $CS_2$ and $SO_2$ and/or native sulfur gas are key indicators, although not all may be present in a given sample (see Table IX).

Table IX: Partial Fragmentation Pattern for Sulfur Compounds

| $H_2S$ | COS | $S_2$(?) | $SO_2$ | $CS_2$ | $S_8$ |
|---|---|---|---|---|---|
| 34(100%) | 60(100%) | 64 | 64(100%) | 76(100%) | 64 |
| 32 | 32 | 32 | 48 | 32 | 256(60%) |
| 33 | 28 | | 32 | 44 | 160 |
| | | | | 78 | 128 |
| | | | | | 192 |
| | | | | | 258 |
| | | | | | 96 |
| | | | | | 32 |

As can be seen, sulfur compounds tend to have strong molecular peaks, and enrichment is indicated if some combination of the m/z peaks 34, 60, 64 and 76 display anomalous intensities. Because these m/z positions generally occur in abundance valleys, the same qualitative rules apply as for acetic acid; namely, if a discrete peak is observed at one of these primary ion locations, the species is considered anomalous. The peak intensity need not rise to the level of the adjacent paraffin peak, although in extreme cases, it may. The 60 peak has a major interference with organic acids as outlined in the previous section. Hence the presence of COS

is inferred (but not demonstrated) only in the presence of other sulfur species. The m/z 32 would appear to be a good one for indicating sulfur presence; however, this ion location suffers major potential interference from atmospheric oxygen ($O_2^+$).

Care must be taken when interpreting sulfur-enriched FIS spectra, because at first glance they resemble the water-soluble enriched spectra. Ideally, the distinction lies in the location of $CS_2$ at m/z 76 (as opposed to benzene at 78), $H_2S$ at m/z 34 and $S_2^+$ and/or $SO_2$ at m/z 64. $SO_2$ presence can be verified by the presence of a paired anomaly at 64 and 48. In practice, it is sometimes difficult to distinguish between sulfur-enrichment and water-soluble species enrichment when these species are not strongly anomalous, and combinations of the two spectra occur as well.

### A.2.3 Summary of the Five Spectral Types

The above is a relatively detailed account of the characteristics of the five major classes of FIS mass spectra. In the end, however, the best way to recognize and distinguish among spectral types is to compare them to the end-member examples presented herein and categorize them by eye. After examining a few examples of each, pattern recognition will become easy. Understanding the complexities outlined in the previous sections is important, but usually unnecessary for first-order interpretation of FIS mass spectra. To summarize:

*Non-hydrocarbon Spectra:* Characterized by four peak clusters centered on m/z 15, 28, 42 and 55; the first three being dominant. Most peaks are attributable to water and carbon dioxide.

*Gas-range enriched:* Characterized by strong responses on $C_1$-$C_5$ (m/z 12-72) and lesser intensities on higher molecular weight ion locations. Peak clusters may be more broad at m/z 12-30 and 37-46. Predominance of masses 15 and 16, and high 57/55 ratios is possible.

*Liquid-range enriched:* Characterized by the presence of $C_7$-$C_{13}$+ species as regularly-spaced peak clusters in the m/z 95-180 range, which are dominated by ions from paraffinic and naphthenic compounds. Aromatic species contribute subordinate peak clusters between the paraffin-naphthene peaks (although, typically only benzene, toluene and xylenes are resolved).

*Water-soluble enriched:* Characterized by methane, ethane, organic acids, benzene and toluene. Acetic Acid (m/z 60) and aromatic peak clusters (m/z 78, 91, 105) attain intensities near or greater than those of adjacent paraffin-naphthene peak clusters.

*Sulfur-compound enriched:* Characterized by the presence of $H_2S$, COS, $CS_2$ and $SO_2$ and/or native sulfur gas as indicated by anomalies on some combination of the m/z peaks 34, 48, 60, 64 and 76.

### A.2.4 Combinations of Spectral Types

Combined FIS spectra are common, and appear as superimposed end member types. Although combinations of all end member spectra have been noted, the most common are gas + liquids and liquids + water-solubles. Recall that FIS is a bulk technique and samples the entire fluid history of the pore system. Hence, mixed FIS spectra might be expected if the sample has experienced temporally distinct charges of petroleum (or brine) types or contained a heterogeneous (immiscible) fluid in the pore system at some time.

## A.3 Interpreting FIS Track Plots and Petrographic Data in a Geologic Context

Fluid inclusions are the only direct records of paleofluids existing in the subsurface, and as such, have the potential to record conditions accompanying geologic processes, including petroleum migration. By studying the subsurface distribution of paleofluid chemistries with FIS, one can obtain valuable and unique information on three major exploration topics:

1. Petroleum migration or paleocharge
2. Seals
3. Proximity to undrilled pay

and two major production topics:

1. Pay zone and bypassed pay delimitation
2. Reservoir compartmentalization.

The previous discussions have concentrated on identifying spectral types in FIS data. This is a necessary first interpretive step. The next task is to evaluate the significance of FIS depth trends in their own right (now knowing their spectral origins), and eventually, in light of other available information to answer specific questions, such as were enumerated above. Petrographic data from anomalous fluid inclusion zones are often critical elements of these higher order interpretations, as will be seen, which why petrographic follow-up work is conducted as a routine part of every FIS analysis (see Table of Petrographic Observations).

### A.3.1 Significance of FIS petroleum indications

The most basic question that FIS can address is "Is there any evidence for present or past petroleum in this borehole?" Documentation of an FIS hydrocarbon anomaly generally provides a positive answer to this question, but could indicate other processes as well. Possible explanations for an FIS hydrocarbon anomaly are discussed in the following paragraphs.

*Migration without trapping*

A migration pathway may be indicated when FIS responses are low or moderate, when contamination and recycled inclusions can be discounted, when quoted visual petroleum inclusion abundances are "rare" or "several" (see Table of Petrographic Observations), and when no other petrographic or log evidence of current petroleum charge is identified in the zone. There are a number of factors that influence inclusion abundance and, consequently, raw FIS response strength, including geologic setting, extent of diagenesis, rock type and permeability. However, it has been demonstrated that both visual petroleum inclusion abundance and FIS strength within many porous reservoir rocks is proportional to hydrocarbon saturation or paleosaturation in a relative sense. Because migration occurs at average bulk-volume petroleum saturations below those encountered in charged reservoirs, FIS signal strength and visual inclusion abundance are generally lower along migration pathways than in charged reservoirs from the same area.

*Current Charge*

A zone that displays strong FIS hydrocarbon indications and high visual petroleum inclusion abundance (i.e., common, abundant or extremely abundant) may reflect penetrated pay, but could also indicate paleo-charge or, in some cases, a migration pathway (e.g., where inclusion abundance is enhanced by extensive microfracturing). A provisional interpretation of current charge is strengthened if residual petroleum (especially live oil stain) is identified in thin section, and particularly if water-soluble petroleum species (so-called "proximal pay indicators"; see below) are recorded in FIS data (e.g., in the seal overlying the anomaly, in the water leg underlying the anomaly, or in low permeability zones within the reservoir section itself). Any independent indications (e.g., from electric logs or mudlog gas shows) provide further encouragement.

*Paleo-charge*

Intervals of strong FIS response, high visual inclusion abundance (i.e., common, abundant or extremely abundant) and significant bitumen (e.g., dead oil stain or asphaltic residue) without accompanying water-soluble anomalies or independent evidence of current charge, may represent a paleo-column, but could also represent current charge or in rare cases a migration pathway. The interpretation of paleo-charge is favored if a valid DST has shown the interval to be currently wet.

*Recycled inclusions*

Very rarely, detritus that is generated from previous sedimentary rock may contain inherited petroleum inclusions. These inclusions must be recognized, as they clearly do not provide any useful information about the current petroleum system(s). Petrographic or microthermometric criteria can often be used to argue the origin of these inclusions, for instance, the presence of petroleum inclusions along recycled quartz overgrowths, or measured homogenization temperatures that are too high to have been produced during the current burial history. Associated FIS depth trends are usually erratic and poorly compartmentalized, and inclusion abundance is typically low. Inherited inclusions may be restricted to specific geologic units that derived detritus from a particular provenance, and are not found in intercalated chemical precipitates (e.g. bedded carbonates or diagenetic cements).

*Heavy bitumen stain*

In some instances, pore-occluding bitumen may contribute to FIS signals. Here, solid petroleum behaves as any other cement, and is capable of trapping residual hydrocarbons as bitumen-hosted fluid inclusions. These may be invisible due to the opacity of the solid petroleum host. Petroleum species may also desorb from pore-occluding bitumen during crushing, much as they do from mature kerogen (see below). Bitumen-sourced FIS responses may be inferred when strongly anomalous zones contain low visible petroleum inclusion abundance but have significant amounts of bitumen (e.g., common, abundant or extremely abundant). Abundant pore-filling bitumen in porous rock implies significant petroleum saturation at some time, so low visual petroleum inclusion abundance is unexpected (and not commonly encountered). In such cases it is possible either that the size of the inclusions are below the resolution of the light microscope ($< 1$ micron), that grain surface conditions (e.g., wettability) did not favor trapping of inclusions, or that the section was diagenetically quiescent during and after charging (i.e., little or no cementation or microfracturing).

*Mature Source Rock*

Mature source rock can contribute to FIS responses. Here, the signal is the combined effect of species desorbed from freshly crushed kerogen surfaces and conventional fluid inclusions that represent trapped in-situ generated petroleum. The chemistry and strength of FIS responses in source rocks tend to reflect kerogen type and maturity, at least in a general sense. Hence, mature gas-prone kerogen with limited liquids potential typically gives dry gas responses, while mature source rocks with liquid-prone or mixed kerogen types (including some coals) tend to have significant responses on both gas and liquid-range petroleum species. Furthermore, as maturation proceeds, FIS hydrocarbon responses progress from low (immature) to high (mature) to low again or dry gas (overmature). These trends are very qualitative, and FIS response in source intervals should not be used as a substitute for classical source rock analysis techniques. An in situ origin (local generation) is suggested for FIS responses if petrographic data from the anomalous zone reveals low permeability rock containing significant quantities of mature kerogen (common, abundant or extremely abundant). Liquid-prone kerogen is likely to be mature if it exhibits moderate to strong orange fluorescence. Coal-related FIS responses are often quite waxy, may be enriched in aromatics, and typically have large relative contributions from higher molecular weight species (i.e., flat spectral profiles).

*Contamination*

Except in rare cases, contamination is not a significant issue in FIS data. Pre-analytical washing and vacuum heating procedures are sufficient to remove most surface-adsorbed organic compounds that are volatile under FIS analytical conditions, including natural fluids such as residual oils, as well as elements of the mud system, including oil based mud. Insoluble organic additives (particularly natural materials like gilsonite) pose a greater threat, as they may not be removed by standard treatment, and can give responses similar to indigenous kerogen or bitumen. Infrequently, an organic-based mud system will contribute to FIS response, and in rare instances may be dominant. This tends to occur in recently drilled, unconsolidated mud-rich sections, which are difficult to wash without complete loss of sample. Contamination has also been suspected in some diapiric or bedded salt sections, where drilling encapsulation of these species is facilitated by the easily dissolved and precipitated halite. Processed contaminants often have a distinctive (and unnatural looking) chemistry, which might include extreme light end depletion, very low aromatics (particularly benzene, which may be removed for environmental reasons) or extremely high toluene (possibly residue from soxhlet extraction). Petrographic criteria can generally be used to assess the likelihood of contamination in a given anomalous FIS zone.

### A.3.2 Petroleum Type and Quality

Interpreted petroleum type and quality is based predominantly on the characteristics of individual mass spectra from each depth as already discussed (sample spectra are located in Appendix C). Three factors are considered: the maximum carbon number detected, the qualitative abundance of low molecular weight alkanes relative to high molecular weight alkanes (including the general slope of the imaginary line connecting the $C_1$-$C_{13}$ alkanes), and the presence or absence of species or ratios indicative of bacterial or thermal alteration (including souring processes). It is important to note that the interpreted petroleum type assumes a single, uniform petroleum inclusion population. The actual migration or charging history, on the other hand, may have involved multiple pulses with different composition (e.g., oil and

gas) and the relative abundance of these inclusions will influence the bulk spectra. Additionally, total inclusion abundance will affect the spectra insofar as higher molecular weight species represent a smaller volumetric proportion of petroleum and are also less volatile, hence decrease below instrumentation detection limits before low molecular weight species. Consequently, some samples with low oil inclusion abundance generate wet gas mass spectra, for instance. Optical inclusion abundance and characteristics should be consulted, where provided, to verify the interpreted petroleum type (see Table of Petrographic Observations). With the above limitations in mind, the following petroleum types are identified on the basis of spectral characteristics:

*Dry gas:* mostly $C_1$ with lesser $C_2$-$C_3$ and no higher hydrocarbons.

*Wet gas:* $C_1$-$C_9$ may be present, but $C_6$+ species are in minimal abundance. The alkane slope is extreme.

*Gas-condensate:* $C_1$-$C_{11}$ may be present. The alkane slope is quite steep, reflecting a very gas-enriched phase.

*Volatile oil:* $C_1$-$C_{13}$ present. Slight gas-range enrichment is observed and the alkane slope is moderate to steep.

*Oil:* $C_1$-$C_{13}$ is present. The alkane slope may be flat to moderate.

Biodegradation is suggested if sulfur compounds such as $H_2S$, COS, $CS_2$, $S_2$ (+/- $SO_2$) and/or thiols are present in addition to petroleum species. Ratios of paraffins to naphthenes may be low as well, as bacteria typically prefer to metabolize alkanes compared to other classes of petroleum compounds. Petrographic data may provide further evidence for biodegradation in the form of low-gravity petroleum inclusions. Bacterial activity is generally restricted to maximum burial temperatures below 65-70°C; hence FIS evidence of biodegradation is most commonly observed in rocks that are currently below this temperature.

Thermal alteration of liquid petroleum species can produce spectra very similar to those generated from biodegraded hydrocarbons, because the products of two common processes, bacterial sulfate reduction (BSR) and thermochemical sulfate reduction (TSR), are essentially identical. The best distinction is made from current bottom-hole temperature data, which, if above 140°C or so may be indicative of TSR, and if below 70°C or so is more consistent with BSR. Potential interpretive problems arise in the intervening temperature range, when deeply buried sediments are unroofed or when petroleum altered at shallow depths becomes buried to greater depth. Petrographic data may help, as pyrobitumen frequently accompanies TSR, while low-gravity liquid petroleum inclusions often occur in association with bacterially altered oils. Additional temperature or thermal maturity data (including fluid inclusion homogenization temperatures) may also be useful.

The presence of significant amounts of sulfur species can indicate a sour petroleum phase, where the souring process may in some cases be a reflection of the source rock, but could also reflect BSR or TSR. A study of TSR sour gas pools in Canada suggests that evaluating the relative proportion of products and reactants can provide a measure of sour gas potential. As TSR progresses, long-chain alkanes decrease while low molecular weight petroleum species increase along with $CO_2$, aromatics organic acids and the various sulfur compounds enumerated above. Ironically, $H_2S$ alone may not be as accurate an indicator of $H_2S$ content, as it is scavenged naturally (e.g., to form pyrite in iron-rich rocks) and by the metallic internal surfaces of the analytical system.

### A.3.3 Water-soluble Anomalies and Proximal Pay Indications

Water-soluble species, particularly benzene and toluene, have been used for decades to search for geochemical halos surrounding petroleum accumulations. The limitation of conventional techniques is that fluid samples are rarely intentionally collected from wet reservoirs. However, similar water-soluble species anomalies have been found in FIS data. Compounds generally include some subset of the following: methane, ethane, $CO_2$, acetic acid, benzene, toluene and xylenes, as well as low paraffin-to-naphthene and high aromatic-to-paraffin ratios. There are three dominant sources of this FIS volatile suite: maturation of kerogen-rich rock, thermal alteration of liquid petroleum, and diffusive stripping from a present-day charged petroleum reservoir proximal to the borehole. The latter of these three possibilities is the most important from an exploration standpoint, and is the FIS analog of the classic technique of analyzing formation fluids for benzene.

Criteria to distinguish among the three potential sources of water-soluble anomalies are often found during petrographic examination. A kerogen source may be inferred if the interval contains a substantial amount of mature kerogen, and where FIS responses include appreciable contributions from other hydrocarbon species (e.g., where water-soluble species are superimposed on an otherwise normal hydrocarbon response). Thermal alteration may be expected if pyrobitumen is present, and, particularly, if sulfur compounds are also detected in FIS data (see discussion above). These species may have resulted from thermochemical sulfate reduction at temperatures above 140°C. Extreme examples of this process are found in deep Devonian sour gas pools of the Western Canada Sedimentary Basin.

True "proximity to pay" (a.k.a., PTP) anomalies tend to occur in cuttings from shale rich lithologies, that are geometrically connected to penetrated or lateral pay. Examples include top or lateral lithologic or structural seals to a charged reservoir, and transition zones or water legs underlying petroleum. The signal is always a present-day feature and is thought to result from drilling encapsulation of penetrated pore fluids within easily sheared or thermally reconstituted lithologies. A significant amount of unpublished analytical data as well as a large body of empirical observation support this interpretation, although details of the process are still debated. Petrographic criteria are generally sufficient to interpret PTP signals, and these include absence of evidence for the other two possible origins, as well as presence of distinctively sheared, shale-rich cuttings.

PTP signals can be found along with direct FIS hydrocarbon indications in flushed reservoirs. Here, the water-soluble anomalies may be sourced from irreducible petroleum saturation with the paleo-reservoir, or may indicate an updip charge (possibly the leaked or structurally disturbed petroleum column that once resided at the well location).

PTP anomalies can be classified into two chemical subtypes: acetic acid + benzene dominant, and benzene dominant. Acetic acid is though to be sourced from high molecular weight compounds within the petroleum phase; hence, its presence suggests the nearby accumulation is oil or gas-condensate. Benzene without accompanying acetic acid suggests a drier petroleum phase, most likely wet gas. Dry gas generally does not give a PTP response because the key indicator species are not present in the petroleum phase, hence cannot be fractionated into nearby aqueous fluid.

When PTP anomalies are identified, a possible link to a nearby reservoir should be investigated. Many scenarios are possible, including an overlying penetrated charge, lateral production in a shallower section that is not under closure at the well location, or charge in remaining updip closure in a reservoir that tested wet at the well location.

### A.3.4 Seals

FIS seals are inferred at boundaries marking abrupt changes in FIS species strength or chemistry. The underlying assumption is that detected fluids are more or less synchronous on either side of the boundary and that some process has prevented free mixing of species across this barrier. In detail the boundary may represent a change in lithology, poroperm or a structural element. In the case of in-situ generated petroleum the boundary might represent a transition from poor to better source rock, or immature to mature source intervals. In the case of migrated petroleum the boundary might represent the extent of petroleum migration through porous rock, or the top seal to a present or past petroleum column. Basal compartment limits may represent seals or, in some cases, fluid contacts or paleocontacts (see below). In general, only the tops of FIS compartments are identified on interpreted FIS depth plots. If fluids were not synchronous on either side of the compartment boundary (e.g. a post-migration unconformity) then the seal interpretation would be in error. Seals may be selective or chromatographic, in which case low molecular weight species may migrate across the boundary, while higher molecular weight species do not.

### A.3.5 Microseepage

FIS microseeps are analogous to gas chimneys seen in seismic data, and surface manifestations of deeper charge identified in surface geochemical surveys. They are interpreted to result from near-vertical migration of light hydrocarbons followed by bacterial alteration in the shallow subsurface at temperature-depth conditions permissible for bacterial activity. Most bacteria are restricted to temperatures below 65-70°C; hence, anomalies may be observed in the upper 1-3 km of rock column, depending on the prevailing geothermal gradient. Key indictor species include light hydrocarbons, $CO_2$, possibly organic acids and aromatic compounds, and sulfurous volatiles, including $H_2S$, COS, $CS_2$, $S_2$ (+/- $SO_2$) and in some cases thiols. $H_2S$ is often sequestered within pyrite in iron-rich siliciclastics, hence is less common in shale-bearing lithologies. Inclusion formation in such low temperature environments may be aided by precipitation of bacterial carbonate. FIS microseeps are geometrically distinct, often beginning at the surface and abruptly disappearing at the appropriate temperature-controlled depth.

The presence of an FIS microseep appears to be a good indicator of deeper charge in the immediate vicinity, although weak seeps may represent regional signals within shallow aquifers. Data suggest that these anomalies overlie 75-80% of productive reservoirs, while only 10% of non-productive areas display similar signals. Hence, the presence of a strong seep within a dry hole might indicate deeper or nearby lateral charge in the area.

### A.3.6 Fluid Contacts

The basal boundary (abrupt or transitional) of any strong FIS compartment is a candidate for a present or past fluid contact, although the interpretation is often equivocal. The most compelling evidence for a present day contact occurs where hydrocarbon-dominant FIS signals (the petroleum leg) give way to water-soluble dominant signals (PTP in the water leg) and where visual petroleum inclusion abundance displays a parallel decrease. When inclusion abundance is high in the petroleum zone but PTP signals are not present in the water leg, it is possible that a paleo-charge is recorded. If the base of the anomaly corresponds to the base of the reservoir, or an abrupt decrease in reservoir quality, then the actual fluid contact (or

paleo-contact) may reside further downdip.

## A.4 Individual Track Plots

### A.4.1 Explanation and Significance of Individual Track Plots

The following is a synopsis of the significance of the different patterns of mass abundances and abundance ratios shown in Tracks 1-25. Note that not all species are quantified using their parent or molecular peaks (e.g., methane at $m/z = 15$) in order to minimize interfering contributions from other species.

### A.4.2 Ratios vs. Absolute Abundance

Both ratios of key ionized compounds as well as absolute abundances of key compounds (relative to a natural oil inclusion standard) are used in interpretation. Absolute abundances of species can be influenced by the efficiency of inclusion formation, the size distribution of the inclusions, the saturation and residence time of the fluid within the pore system and the relative proportion of fluid of a given composition that moved through that stratigraphic compartment. Chemical ratios, on the other hand, are not as susceptible to lithologic/diagenetic controls on inclusion formation/distribution, hence, may be better suited for displaying chemical compartments in some cases. They are also useful for enhancing some of the subtle trends within the data, and for characterizing chemical variability among petroleum inclusion compartments, which could be related to source, timing, or migration process. Ratio plots are not completely independent of inclusion abundance, as the intensity of mass spectrometer responses is somewhat non-linear with respect to ion concentration. Both types of plots should be considered during interpretation.

**Track 1:** Total Response - This represents the sum of the positive responses on all measured masses from $1 \leq m/z \leq 180$. These data are potentially useful for some data normalization schemes, or for estimating the relative percentage of a given compound in the analyzed sample. Note that responses are generally dominated by water and carbon dioxide, and that absolute quantification is not possible because water cannot be quantitatively analyzed with this system. The polar nature of water causes it to adhere to metallic surfaces inside the instrument resulting in false readings by the detector. However, two characteristics of the total response are noteworthy. First, total responses are often orders of magnitude greater for samples yielding proximity spectra than for other samples originating outside the hydrocarbon zone, even though the lithologies are usually clay rich, hence low in natural inclusion abundance. This is one line of evidence that leads us to hypothesize that proximity samples are dominated by drilling induced inclusions which trap some of the present day formation fluid. Secondly, inferred petroleum migration compartments are often characterized by high total responses. This suggests that both organic and inorganic inclusions are anomalously represented within these compartments. The significance of this correlation is not fully understood, but may document a fracture forming process occurring during focused movement of basinal fluids, including petroleum. If so, it may eventually provide additional information about the nature and mechanisms of secondary petroleum migration.

**Track 2:** $m/z = 44$ Dominant peak for carbon dioxide ($CO_2^+$), with possible minor contribution from $C_3^+$ hydrocarbon fragments and acetic acid. Anomalous values have been noted associated with pan-evaporative dolomitization of limestones in China and Oman. $CO_2$ response is often

high in proximity samples which show elevated levels of acetic acid. $CO_2$ is generally present in anomalous concentrations in FIS microseeps, where it is a product of bacterial alteration of seeping light hydrocarbons.

**Track 3:** $m/z = 34$ - Dominant peak for hydrogen sulfide ($H_2S^+$). Anomalous values associated with petroleum may indicate sour oil or gas. $H_2S$ is also noted at times in association with shallow dry gas of probable biogenic origin (including FIS microseeps) and with some proximity zones. $H_2S$ is probably not quantitatively analyzed due to rapid scavenging by metallic surfaces of the analytical system.

**Track 4:** 34/(34+15) - $H_2S$/($H_2S$+methane). Not frequently used, but ratio tends to be elevated in sour gas zones.

**Track 5:** 4/(4+2) - Helium fraction $^4He^+/(^4He^+ + H_2^+)$; ratioed to mass $m/z = 2$ to indicate the presence of anomalous He. Helium anomalies have been found in association with unconformities, thrust faults which sole in crystalline rocks, arkosic detritus sourced from such crystalline rocks (e.g., granite wash), gas sourced from old, radioactive shales and mafic hypabyssal volcanic rocks. An abrupt change in helium abundance has been documented within Precambrian rocks worldwide. It is possible that this reflects a fundamental evolutionary step in the Precambrian atmosphere.

**Track 6:** Air Confidence - This represents the results of an algorithm which performs five tests for the presence of the air components nitrogen, oxygen, and argon. The plot is scaled in integer values from zero to five, corresponding to zero to five positive tests. Values in the 4-5 range indicate a high confidence for air. Some anomalies may represent small leaks in the vacuum system. Natural air inclusions have been recognized in vadose cements below paleoexposure surfaces, as well as in some aeolian sands and evaporites.

**Track 7:** 30/(30+15) - ethane/(ethane+methane). Except for very dry gas, petroleum migration zones generally show elevated ratios of ethane to methane, provided that the petroleum is transported as a separate phase. Petroleum transported as a dissolved solute species in aqueous solution (e.g., in the case of proximity) may have low ratios of ethane to methane, due to the relatively higher solubility of methane in solution.

**Track 8:** $m/z = 15$ - $CH_3^+$; mostly derived from methane, with minor contributions from all other paraffins and $NH_2^+$, if present. Used as a relatively clean peak for methane; response is nearly as great as for the methane molecular peak. Anomalies are associated with oil and gas migration as well as water zones carrying significant dissolved gas. Distinction between dry gas and oil is accomplished by comparing responses on higher molecular weight fragments (e.g., $m/z = 97$). Transport in aqueous solution is suggested by co-occurrence of other water-soluble hydrocarbons as well as high ratios of water soluble to water insoluble species (e.g., 60/57, 55/57, 77/71). Methane dominated dry gas of possible biogenic origin is often documented in offshore wells at depths above 1200 m. These zones also often indicate anomalous sulfur species, which might document the activity of sulfate-reducing bacteria. In rapidly buried, relatively young sections, (e.g., offshore Trinidad and Gulf Coast) biogenic gas inclusions may be detected to much greater depths. These are FIS microseeps and are thought to sourced from leakage of light petroleum from depth.

**Track 9:** $m/z = 30$ - Ethane molecular peak ($C_2H_6^+$). Use similar to that of methane ($m/z = 15$).

**Track 10:** $m/z = 60$ - Acetic aid ($CH_3COOH$), with possible contribution from COS in some environments. Acetic acid anomalies may be sourced from source rock maturation, thermal alteration of liquid petroleum or diffusive stripping from oil or gas-condensate accumulations (the latter are known as proximity-to-pay indications or PTP). It is thought that PTP represent samples of present day formation fluids, which are entrapped during drilling, probably through thermal and mechanical processes acting on clay-bearing lithologies in the neighborhood of the drill bit. Our understanding of the sources and sinks of organic acids and water-soluble aromatics, particularly benzene, suggest that the signal must be actively fed; hence, it is unlikely that we would see these signals preserved for geologic time in paleo-reservoirs, or along migration paths, although this has not been fully demonstrated. The strength of the signal is dependent on so many variables, including drilling conditions, lithology, formation fluid and oil chemistry, temperature, hydrodynamics, etc., that it is doubtful that quantitative assessment of distance from accumulation is possible. As with most FIS interpretations, documenting proximity is deemed significant, while its absence is not necessarily so, unless a particular area is well calibrated. Thermal processes within the reservoir in which liquid-range petroleum is broken down to lower molecular weight petroleum with one byproduct being organic acid probably source acetic acid, in the context described above. As such, the presence of organic acid anomalies with benzene and or toluene anomalies suggests that the accumulation has some liquid-range component, although a few barrels of condensate per MMCF of gas appears to be enough to provide a signal, at least in relatively low salinity formation fluids which are very close to pay zones. As mentioned above, other sources of organic acids are possible, including maturation of source rocks (particularly coals), severe thermal degradation of oil (particularly during thermochemical sulfate reduction) and stripping from residual oil in high Sw zones or recently flushed reservoirs; hence, the nearby reservoired hydrocarbons may very well be subeconomic. COS and acetic acid can be expected in some of the same environments, so the distinction between the two is not always possible. However, COS tends to be less water soluble, and has a higher affinity for the petroleum phase than acetic acid.

**Track 11:** $m/z = 78$ - Benzene ($C_6H_6^+$). High values are associated with samples containing inclusions with liquid-range petroleum, as well as samples displaying "proximity" signals. A distinction can be made between these two by looking at individual spectra, or by comparing the response on the relatively insoluble paraffins (e.g., $m/z = 57$ or 71). Note however, that some samples may indicate both oil inclusions and proximity to pay; and it is here that individual mass spectra must be studied. Such mixed spectra are indicative of some pay zones (particularly those with significant Sw, as well as zones through which petroleum has migrated, and are now water wet, but are presently in communication with the previously migrated petroleum. Benzene rich proximity signals without associated acetic acid may indicate a nearby wet gas accumulation.

**Track 12:** $m/z = 91$ - Toluene ($C_7H_7^+$). This ion is interpreted in much the same way as benzene ($m/z = 78$). However, toluene has lower water solubility, so tends to be less anomalous or even absent from some proximity zones.

**Track 13:** 60/(60+57) - Acetic acid/(acetic acid + paraffins). This ratio tends to deflect to higher values in water bearing zones and shallow microseeps and to lower values in petroleum inclusion zones. Very high values are associated with proximity zones. Acetic acid has tremendous water solubility, while paraffins are relatively insoluble in water.

**Track 14:** 78/(78+91) - benzene/(benzene+toluene). This ratio is of limited utility in many cases, as these species are often not abundant enough to provide a coherent depth plot. In some cases, oil inclusion zones tend to deflect toward lower values, while proximity zones tend to deflect toward higher values. This is because oils typically have benzene to toluene ratios of about 0.5, while benzene has about 3 times higher solubility than toluene in water. Water washed oils will have lower ratios as will oils that have lost lighter ends through a semi-permeable seal.

**Track 15:** $m/z = 57$ - Paraffin fragment ($C_4H_9^+$). Anomalous values are associated with zones of oil and wet gas inclusions. Paraffins have lower solubility than other hydrocarbon classes, hence ratioing to these can define migration and reservoir processes (see next entries).

**Track 16:** 57/(57+15) - Paraffins/(paraffins+methane). This ratio plot displays the proportion of $C_4$ and greater paraffins relative to methane. The ratio will generally deflect to higher values in oil inclusion zones and toward lower values in dry gas zones. The ratio will also generally decrease within proximity zones due to the high solubility of methane relative to $C_4^+$ paraffins in aqueous solution.

**Track 17:** $m/z = 97$ - Alkylated naphthenes fragment ($C_7H_{13}^+$); basically naphthenes with methyl chains. This species tends to be anomalously high in petroleum inclusion zones which contain an appreciable liquid component (e.g., oils and condensates).

**Track 18:** 57/(57+55) - Paraffins/(paraffins+naphthenes). This ratio can be used for several purposes. Very low values are indicative of biodegraded oil, because bacteria prefer the paraffinic fraction. Low values are also documented in some proximity zones, due to the limited solubility of paraffins relative to naphthenes in aqueous solutions. Very high values are typical of dry gas zones as gases tend to be enriched in paraffins, although this trend must be used with caution. It is better to observe the relative change in this ratio with depth: If it decreases from baseline through a petroleum inclusion zone, liquid petroleum is more likely; if it increases, a lighter fraction might be expected. Again, these are generalizations which must be used cautiously. It is always best to follow up FIS work with thin section petrography to further investigate the characteristics of the entrapped petroleum phase. This ratio may also be used to identify transition zones from low to high Sw, and low-contrast pay zones. In general, we find that residual oil within water-rich zones under pay intervals tends to have higher ratios, probably due to the washing of more soluble naphthenes from the petroleum prior to entrapment. However, the water leg itself may have low ratios due to preferential concentration of naphthenes in the water phase.

**Track 19:** 97/(97+91) - Alkylated naphthenes/(alkylated naphthenes + toluene). This ratio tends to deflect toward higher values in zones containing liquid petroleum inclusions and toward lower values in proximity zones. Alkylated naphthenes are relatively water insoluble as compared to toluene.

**Track 20:** 77/(77+71) - $C_6^+$ aromatics/($C_5^+$ paraffins+$C_6^+$ aromatics). This ratio tends to deflect toward higher values in zones of proximity and toward lower values in zones containing liquid petroleum inclusions. Both trends reflect the relative solubility of aromatics (high) and paraffins (low).

**Track 21:** $m/z = 64$ - $C_5^+$, $S_2$ and $SO_2$. Volatilized native sulfur has been noted in conjunction with sour gas pools in Canada, and, along with other chemical indicators may indicate sour gas risk. In some cases, mass 64 appears to be concentrated in water legs to these pools, or

wet reservoir sections that are plumbed to a deeper source of these species. It has also been found in conjunction with FIS microseeps.

**Track 22:** $m/z = 76$ - $CS_2$ and $C_6^+$ hydrocarbons. $CS_2$ has been found in conjunction with biodegraded hydrocarbons, in association with FIS microseeps and as a byproduct of thermochemical sulfate reduction.

**Track 23:** 97/(15+97)*1000 - Alkylated naphthene/(alkylated naphthene + methane) - This track can be used to illustrate the relative proportions of low and high molecular weight species. The track deflects to higher values in oily or light end depleted zones and to lower values in gassy zones.

**Track 24:** $C_5 - C_{13}$ Presence - This algorithm records the highest molecular weight range hydrocarbon group present in each individual spectra, and provides a quick visual record of zones containing the corresponding petroleum compounds. For example, if the $C_5$ group is the highest molecular weight range hydrocarbon group present in a given sample, a ranking of 5 is assigned; if $C_6$ is the highest carbon number represented, then a ranking of 6 is assigned, and so on until a ranking of 13 is assigned if the presence of species in the $C_{13}$ range is detected. Mathematically, the algorithm tests for the presence of a group (i.e., carbon number) by scanning the spectra for a coherent signal comprised of at least two out of three of the major peaks associated with the particular molecular weight range.

**Track 25:** $C_{6-13}/C_{1-5}$ - A semi-quantitative parameter relating the abundance of liquid-range hydrocarbons to gas-range hydrocarbons. The ratio can be used in a qualitative sense to construct "psuedo GOR's".

### A.4.3 Mass Assignments

In addition to the Tracks 1-25 described above, mass spectra over the range $1 \leq m/z \leq 180$ are presented for each individual sample in Appendix C. The following descriptions contain additional information about species assignments for individual masses:

- $m/z = 2$ - Hydrogen ($H_2^+$); largely from $H_2O$, which makes up most of the evolved fluid in almost all samples.
- $m/z = 3$ - Deuterated hydrogen and helium-3 (HD and $^3He^+$).
- $m/z = 12$ - Carbon ($C^+$).
- $m/z = 14$ - Nitrogen ($N^+$) and $CH_2^+$; Nitrogen in conjunction with argon and oxygen anomalies suggests air. If not an analytical artifact (episodic burps of atmosphere leak into the analytical chamber), the presence of air may indicate a vadose zone below a subaerial exposure, or the presence of aeolean sand. If response on mass $m/z = 14$ exceeds that on masses $m/z = 13$ and $m/z = 15$ then nitrogen is likely present. $CH_2^+$ will generally be accompanied by relatively larger responses on $m/z = 15$ ($CH_3^+$), and $m/z = 16$ ($CH_4^+$) (due to it's fragmentation origin from $CH_4$, for instance). The most convincing distinction between analytical artifact and paleo-air occurs when several closely spaced samples have air anomalies, or when several replicate analyses of the same sample give the same result.
- $m/z = 16$ - Molecular peak for methane ($CH_4^+$), but major interference by $O^+$ fragment of water.

- $m/z = 17$ - Dominated by $OH^+$ fragment from water
- $m/z = 18$ - Dominated by water parent peak ($H_2O^+$)
- $m/z = 22$ - Doubly charged carbon dioxide ($CO2^{2+}$); minor contribution from neon ($^{22}Ne^+$)
- $m/z = 28$ - Dominated by diatomic nitrogen ($N_2^+$) and $CO^+$ fragment from carbon dioxide. Minor $C_2^+$ hydrocarbon contribution
- $m/z = 32$ - Oxygen ($O^+$) and sulfur ($S^+$). If $m/z = 32$ is larger than $m/z = 31$ and $m/z = 33$, oxygen is likely. If sulfur is present other likely peaks, such as $m/z = 34$ ($H_2S$), $m/z = 48$ ($SO^+$) and $m/z = 64$ ($S_2^+$, $SO_2^+$) should be checked. Oxygen can be a possible paleoexposure indicator when used in conjunction with other peaks (see discussion on Air Confidence, and Nitrogen).
- $m/z = 40$ - Argon ($Ar^+$) with possible significant interference by $C_3^+$ hydrocarbon fragments. High value of $m/z = 40$ relative to adjacent $m/z = 39$ and $m/z = 41$ peaks suggests argon.
- $m/z = 48$ - Sulfate fragment ($SO^+$); also, $C_4^+$
- $m/z = 55$ - Naphthene fragment ($C_4H_7^+$). High values are found in petroleum inclusion bearing intervals. Naphthenes have intermediate solubility between aromatics and paraffins. This $m/z$ is usually ratioed to $m/z = 57$ (see below).
- $m/z = 71$ - Paraffin fragment ($C_5H_{11}^+$). Same use as $m/z = 57$.
- $m/z = 77$ - Aromatic fragment ($C_6H_5^+$). Same general use as for benzene and toluene.
- $m/z = 85$ - Paraffin fragment ($C_6H_{13}^+$). Same use as $m/z = 57$.
- $95 \leq m/z \leq 103$ - peaks centered within this range are mostly $C_7 - C_8$ fragments
- $110 \leq m/z \leq 115$ - peaks centered within this range are mostly $C_8 - C_9$ fragments
- $122 \leq m/z \leq 126$ - peaks centered within this range are mostly $C_9 - C_{10}$ fragments
- $134 \leq m/z \leq 138$ - peaks centered within this range are mostly $C_{10} - C_{11}$ fragments
- $148 \leq m/z \leq 152$ - peaks centered within this range are mostly $C_{11} - C_{12}$ fragments
- $160 \leq m/z \leq 164$ - peaks centered within this range are mostly $C_{12} - C_{13}$ fragments
- $175 \leq m/z \leq 180$ - peaks centered within this range are mostly $C_{13} - C_{14}$ fragments

# B Reference Spectra

In order to insure consistent and high-quality results during routine Fluid Inclusion Stratigraphic Analysis and the intercomparability of wells analyzed weeks, months or even years apart, a number of machine-dependent parameters are monitored on a daily basis through the analysis of internal analytical standards. Information recorded during these analyses are used to evaluate the performance of individual components of the stratigraphic analyzers. Additionally, this information permits characterization of any systematic fluxuations that may have affected species sensitivity during the course of an FIS Analysis and are, in fact, used quantify these effects during post-analytical data reduction. The natural materials used as internal standards are described briefly below.

## B.1 Oil Inclusion Reference Standards

Oil inclusion reference materials (petroleum inclusion-bearing siliceous carbonate rock fragments from the Kindblade Fm., Lawton, Oklahoma), are analyzed 11 times during each analytical run. The results are given in Figure 24. Ideally, spectra should show a whole-oil like signature with good representation of ionized fragments out to at least $m/z \approx 150$. Daily variation occurs due to inhomogenieties in inclusion abundance and distribution within individual samples of this natural rock, as well as from minor instrumental fluctuations.

## B.2 Frac Sand Hydrocarbon Background Standards

Clean quartz sand, devoid of hydrocarbons, is analyzed 22 times during each analytical run. The results are given in Figures 25 and 26. Ideally, spectra should show no structured responses on $m/z > 60$.

## B.3 Cooked Frac Sand Hydrocarbon Background Standards

Clean quartz sand which has been heated to 1000°C to remove a large percentage of the fluid inclusion population is analyzed 11 times during each analytical run. The results are given in Figure 27. Ideally, these spectra should show approximately an order of magnitude less total response than those from the preceeding "Frac Sand Standard", as well as an increase in air components (e.g., nitrogen at $m/z = 28$; oxygen at $m/z = 32$; argon at $m/z = 40$) resulting from entrapment of air into evacuated cavities during the heating treatment. These spectra should also show little to no structured response for $m/z > 60$.

## B.4 Kindblade Trackplots

Selected peaks from oil inclusion inclusion reference standards used to monitor internal standardization and normalization procedures.

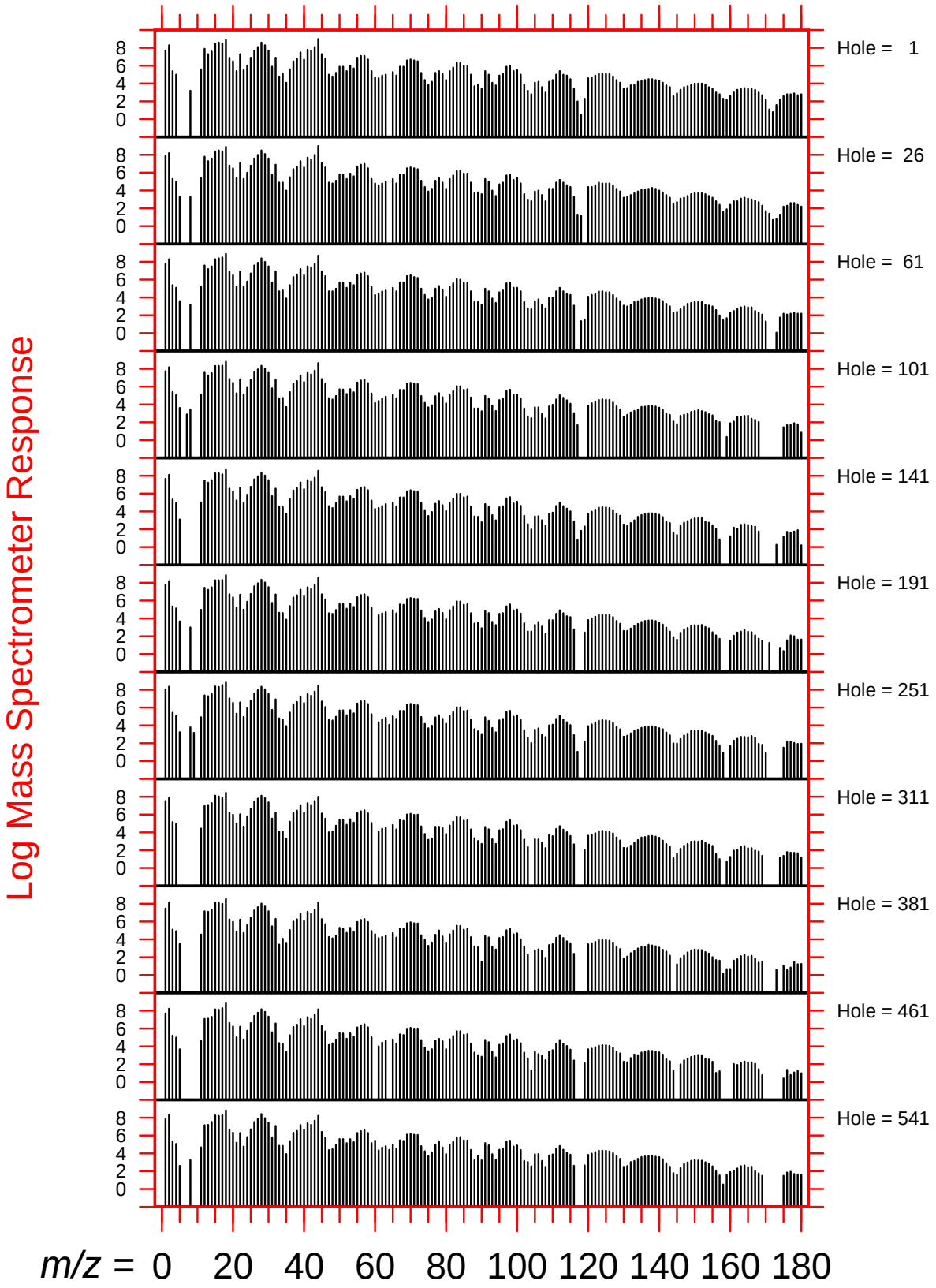



Figure 24: Oil Spectra

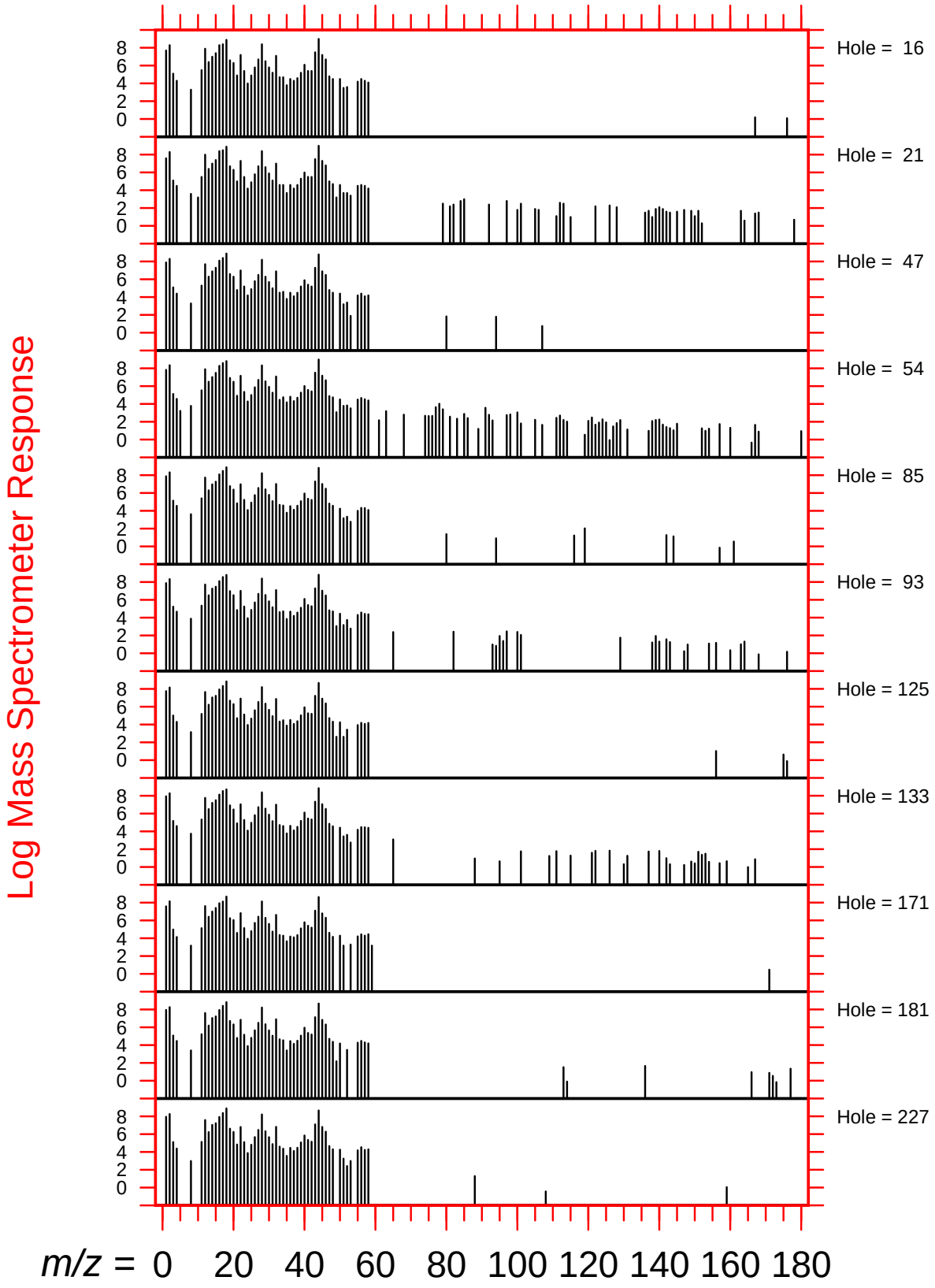



Figure 25: Frac Sand Spectra

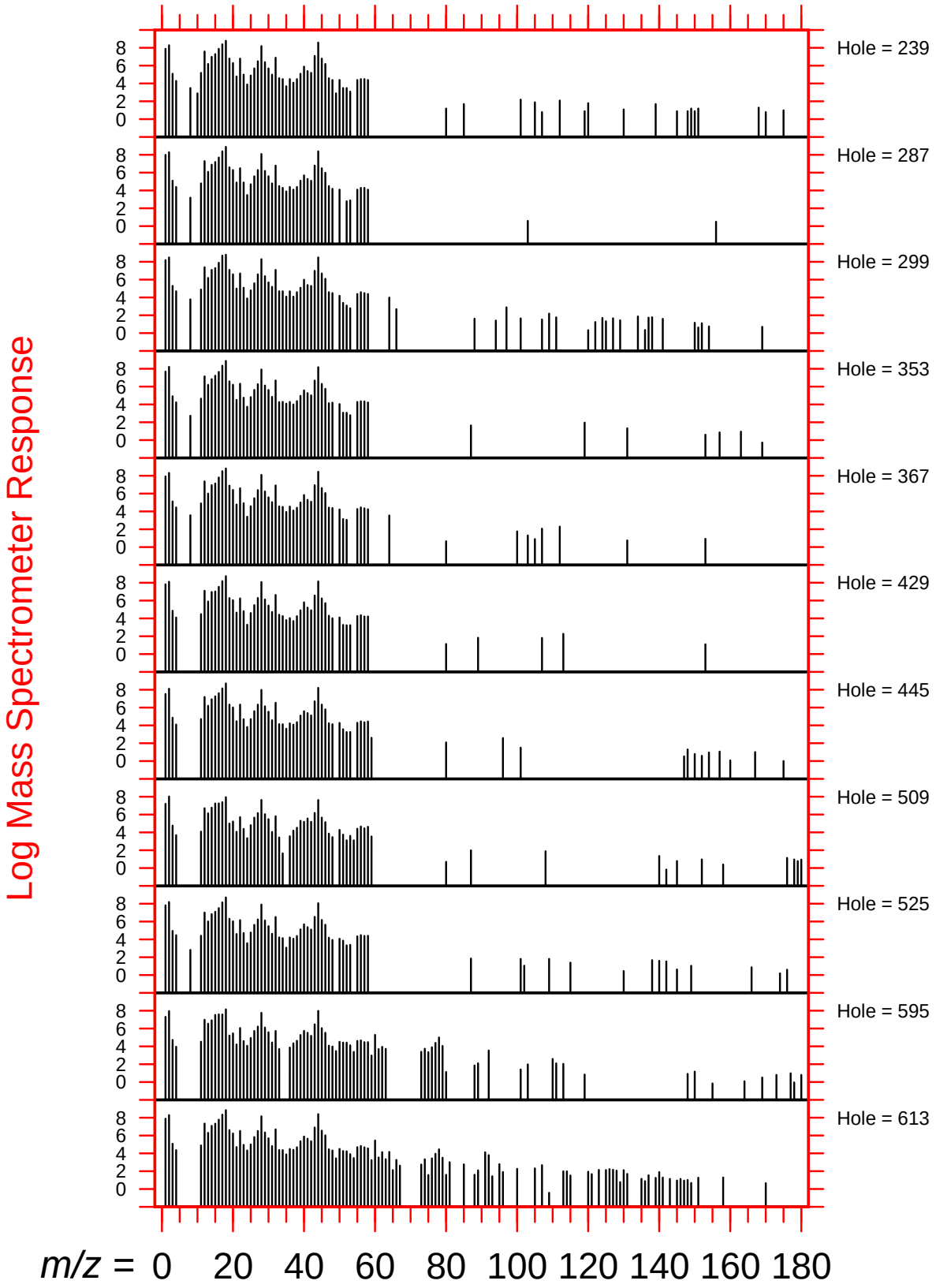



Figure 26: Frac Sand Spectra

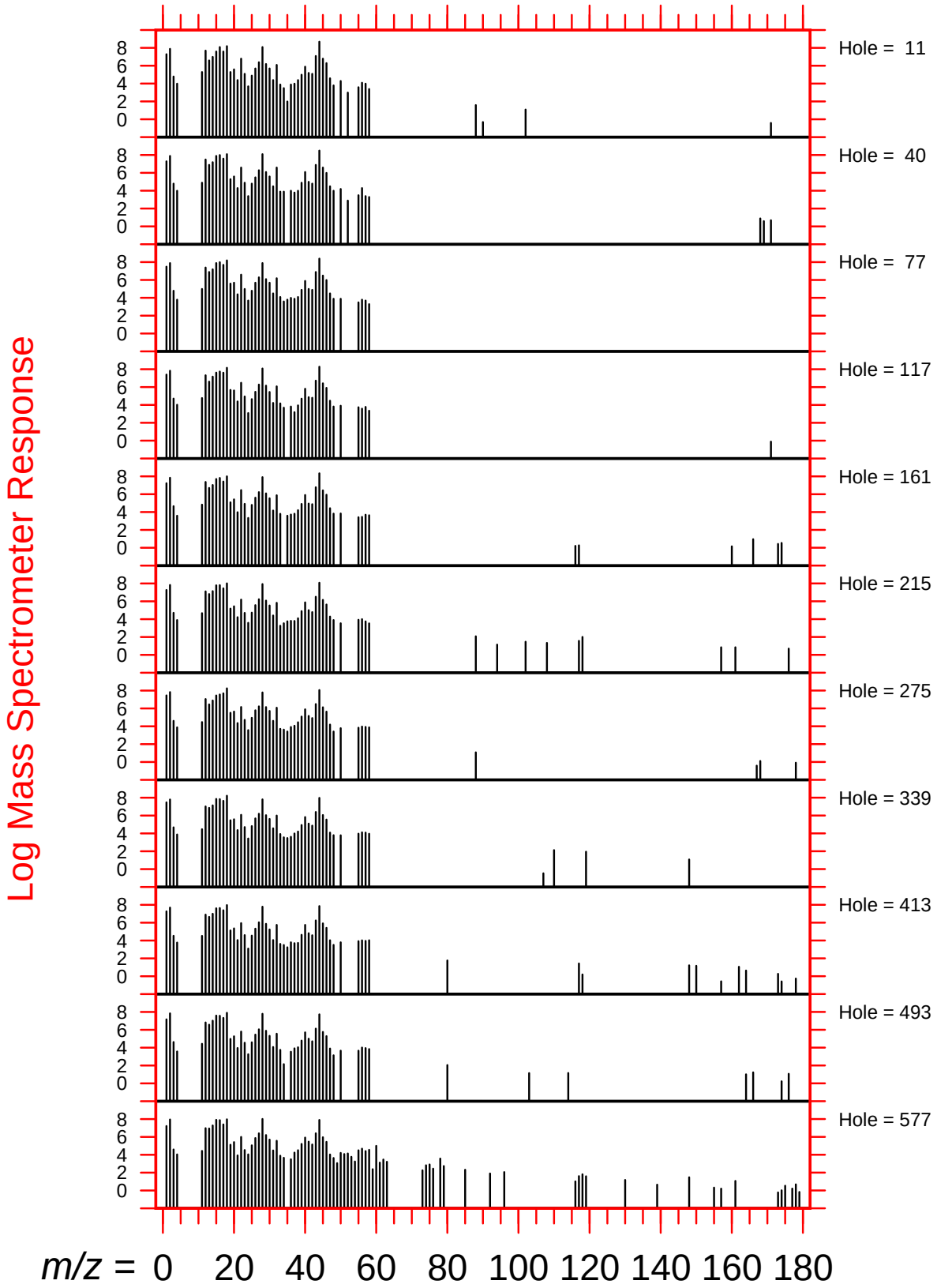



Figure 27: Cooked Frac Sand Spectra

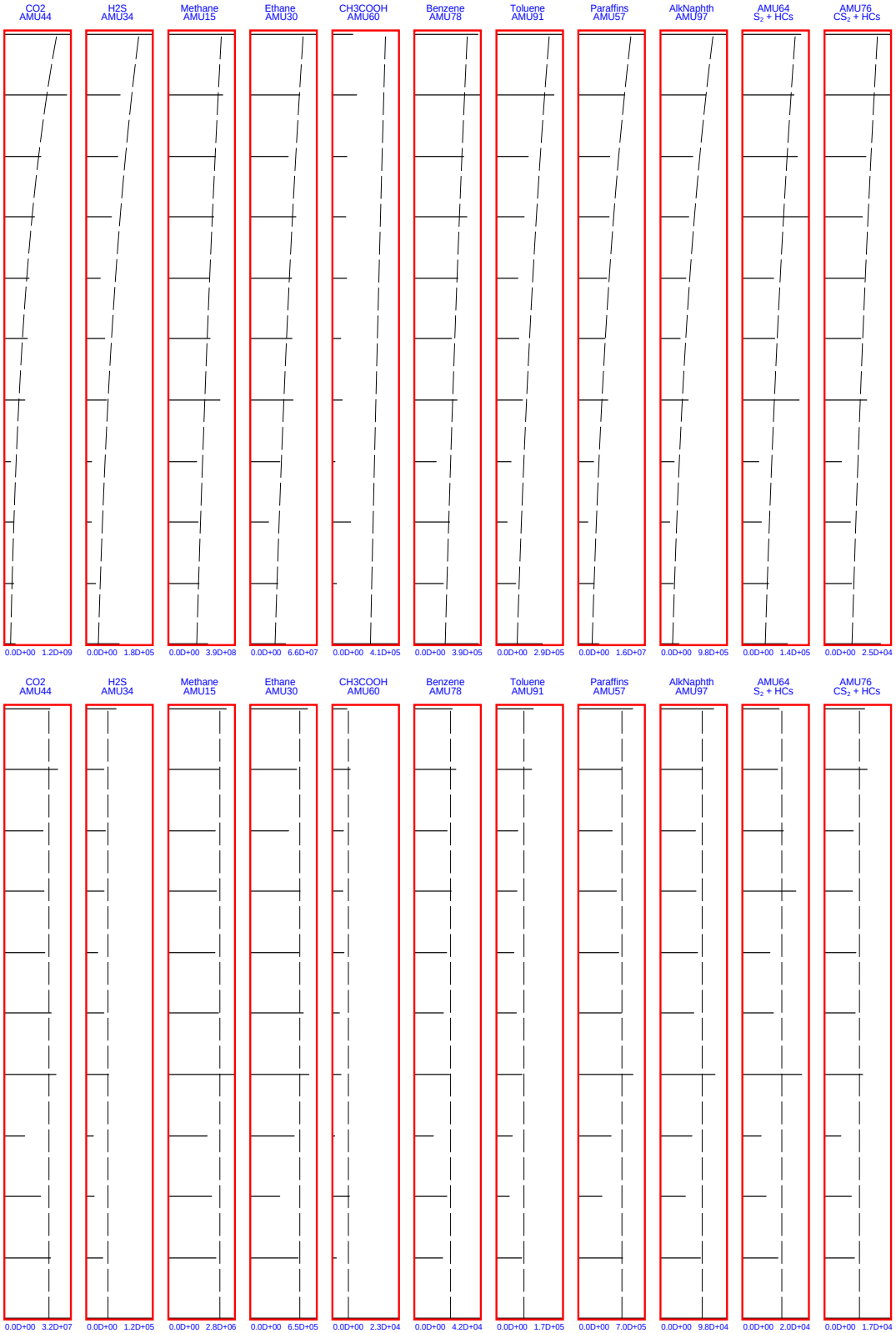
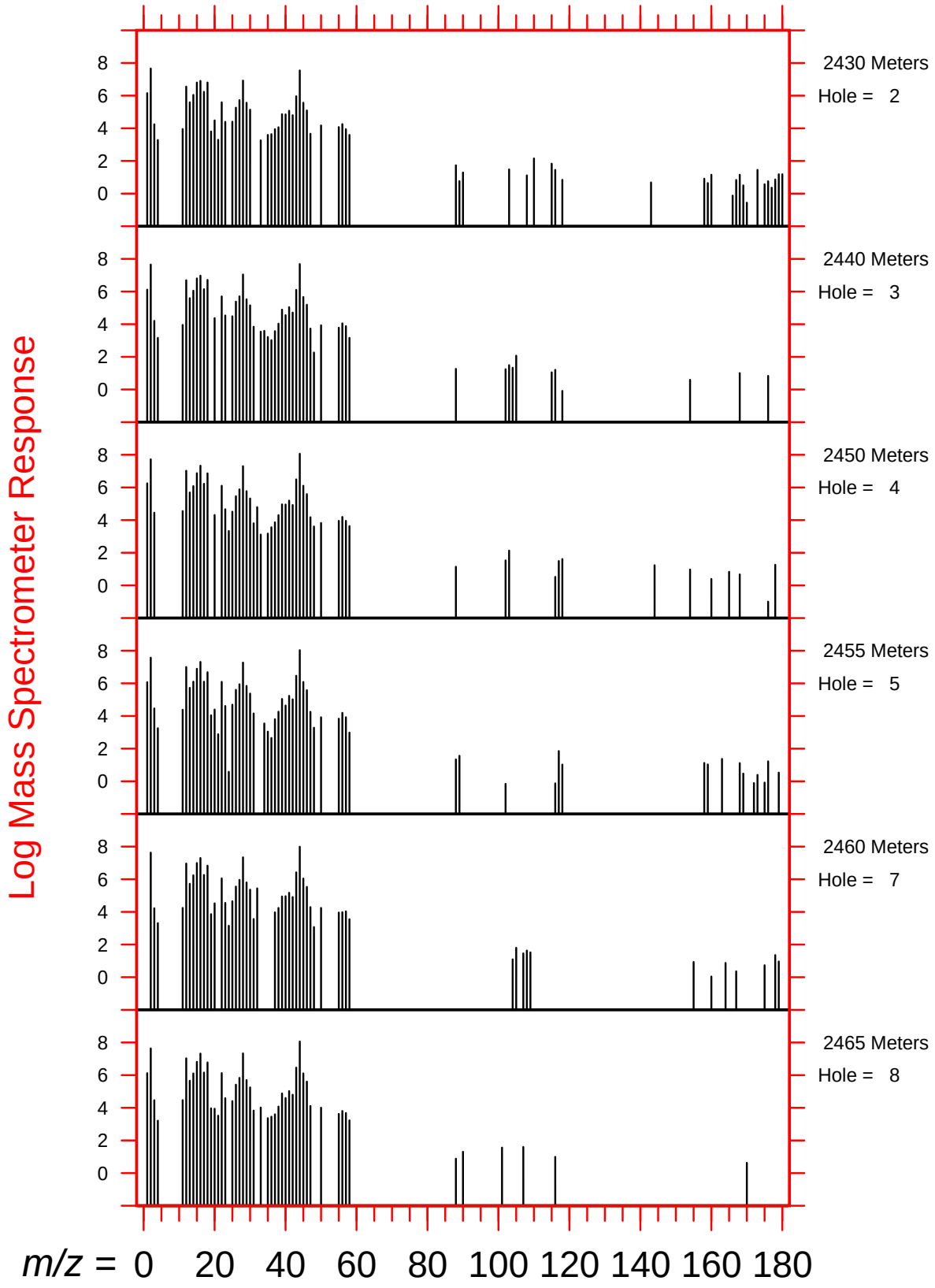
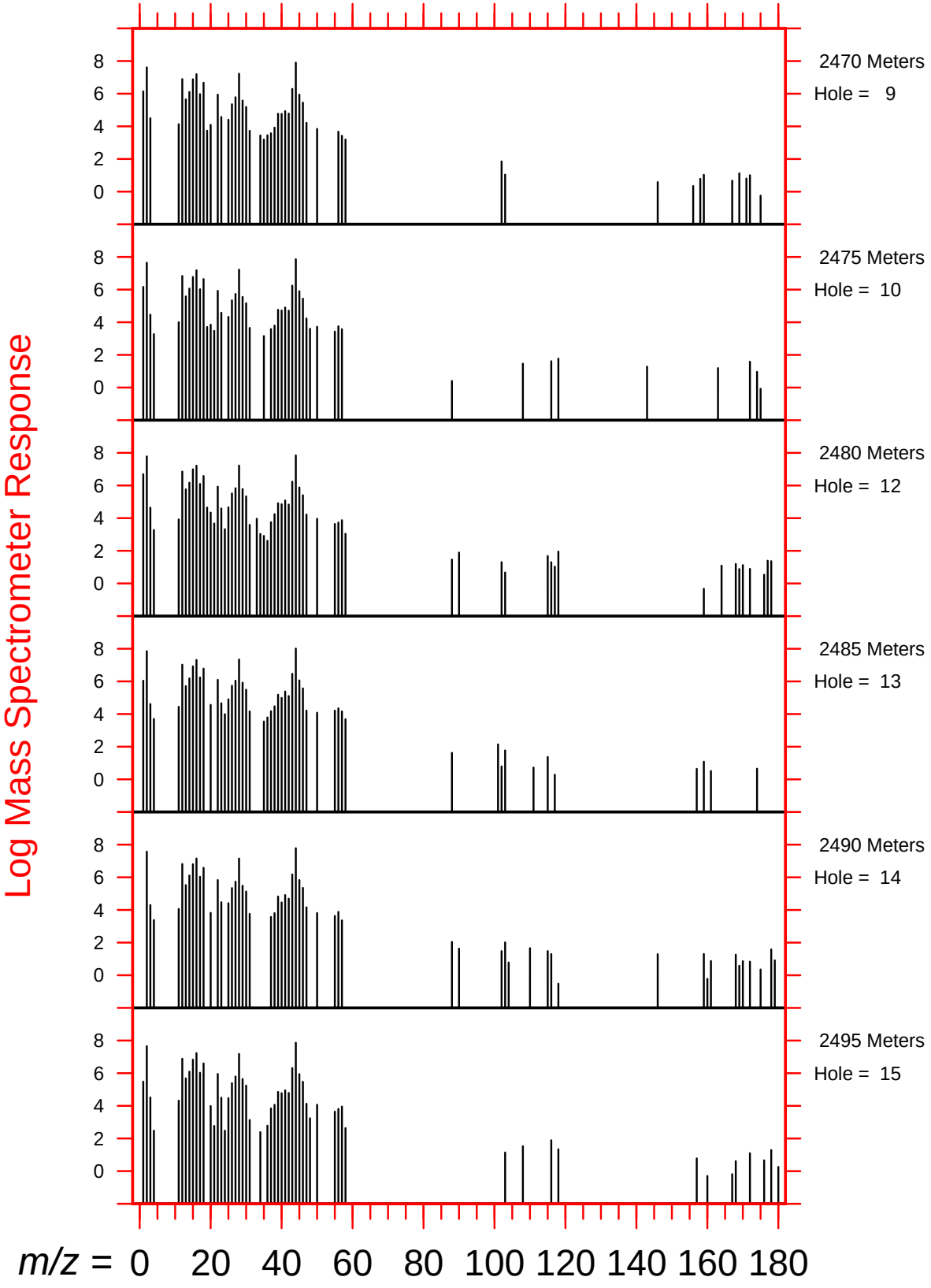


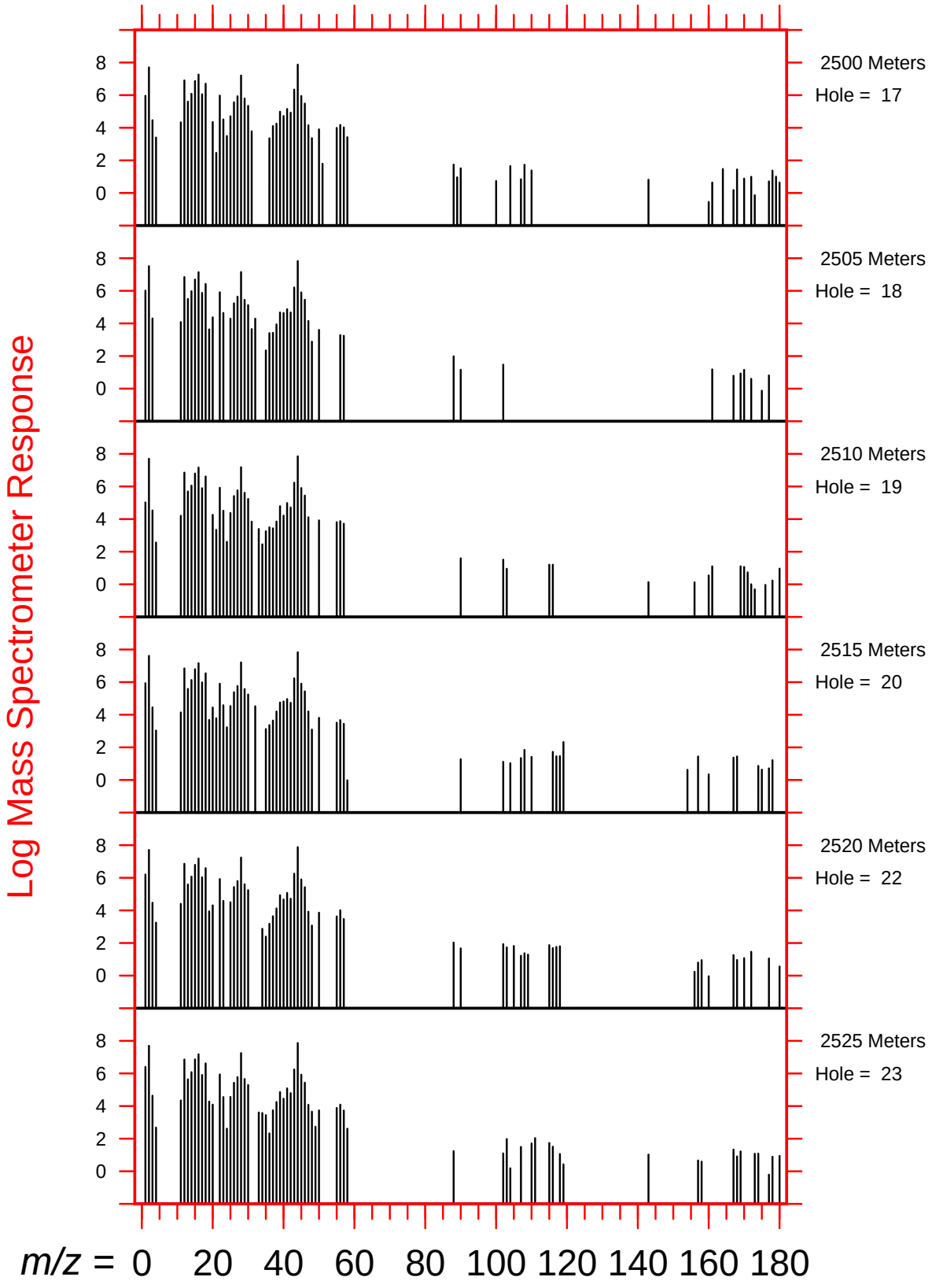

Figure 28: Kindblade Oil Standards Before (top) and After (bottom) Correction

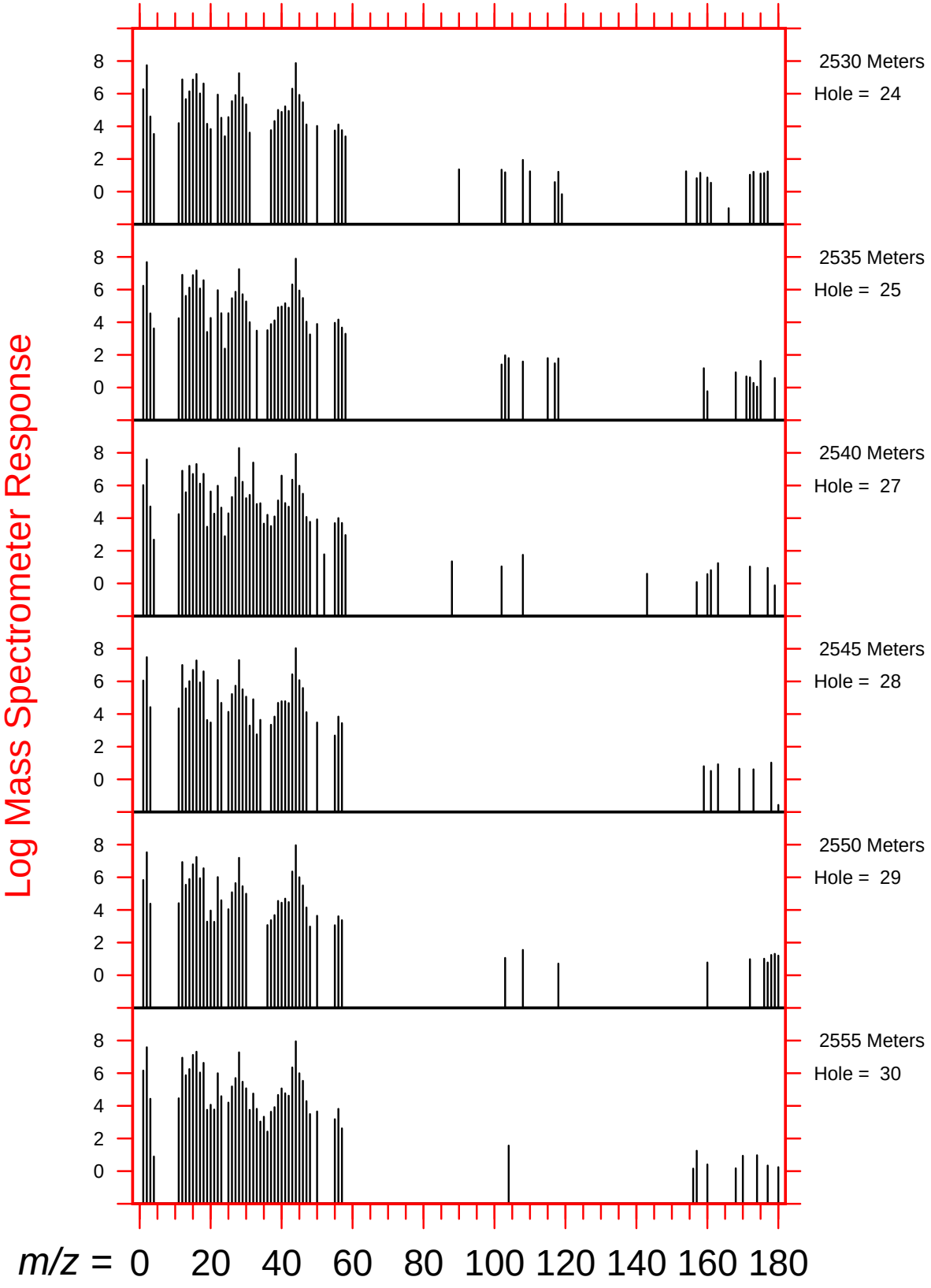
# C Individual Spectra

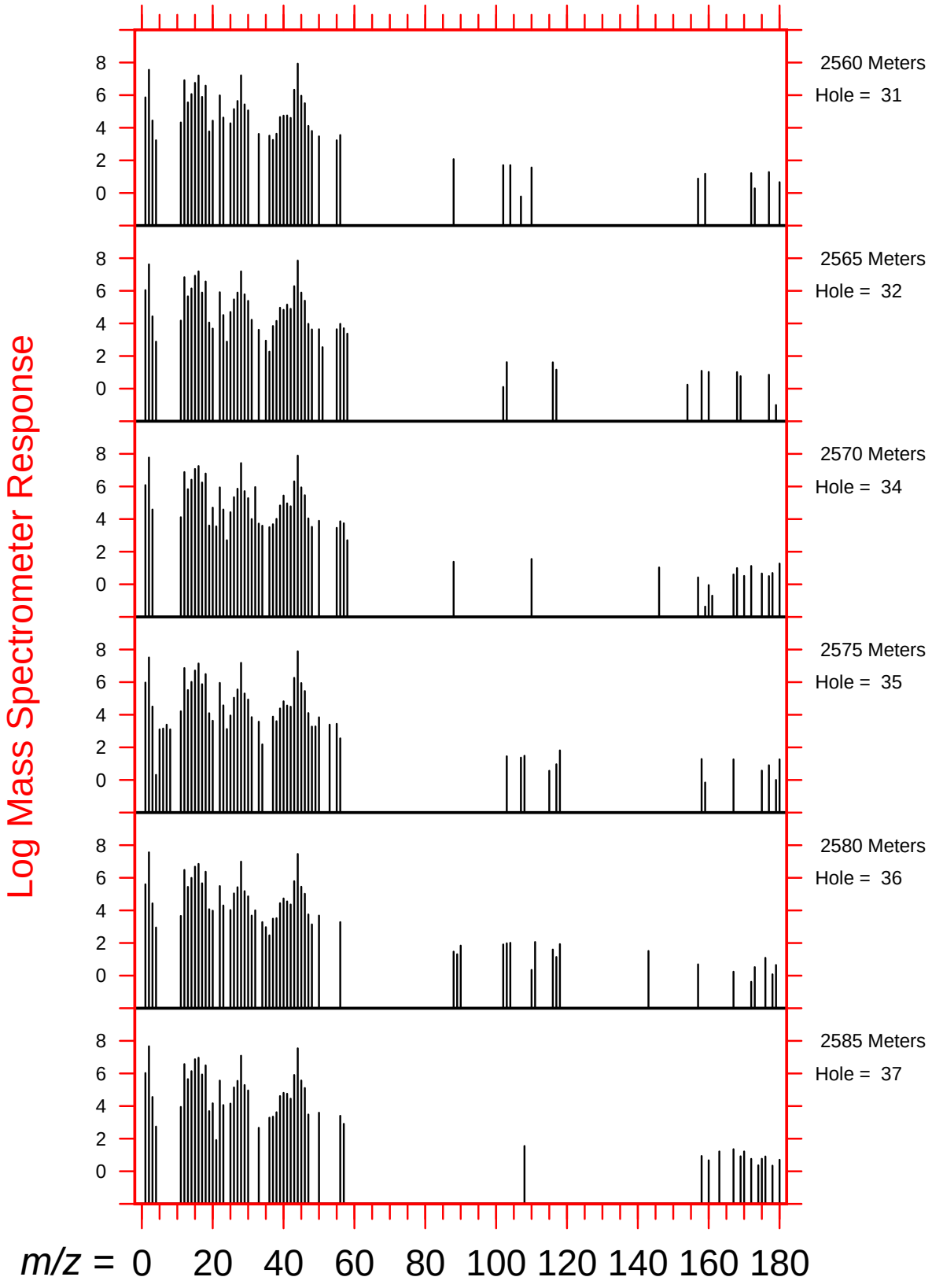
Individual spectra for each sample from Noblige 1 are shown on the following pages. Each spectrum is indexed according to depth and indicates the log of the millivolt response for atomic mass units (AMU, $m/z$) from $2 \leq m/z \leq 180$.

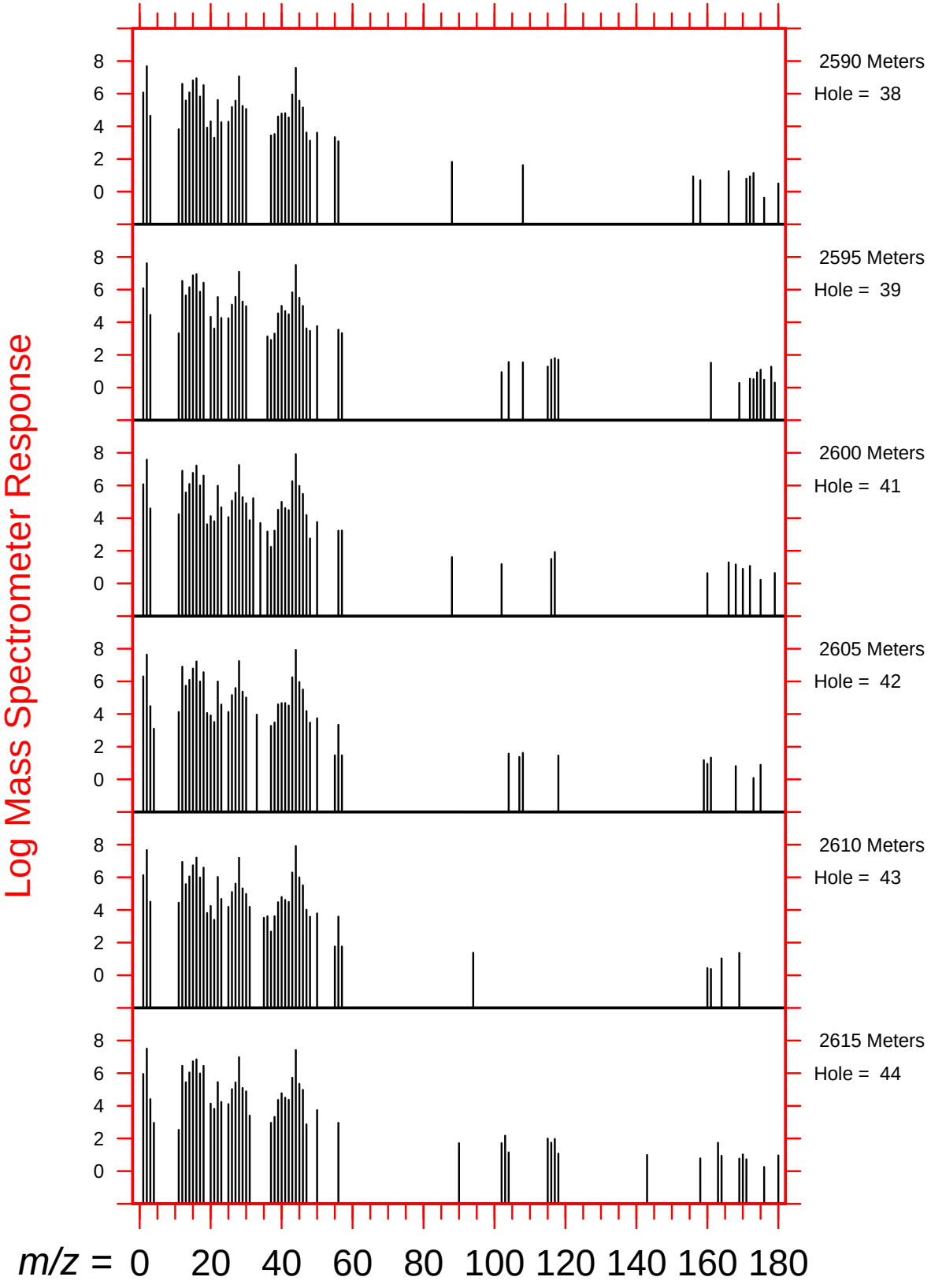

Log Mass Spectrometer Response
2430 Meters
Hole = 2
2440 Meters
Hole = 3
2450 Meters
Hole = 4
2455 Meters
Hole = 5
2460 Meters
Hole = 7
2465 Meters
Hole = 8
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

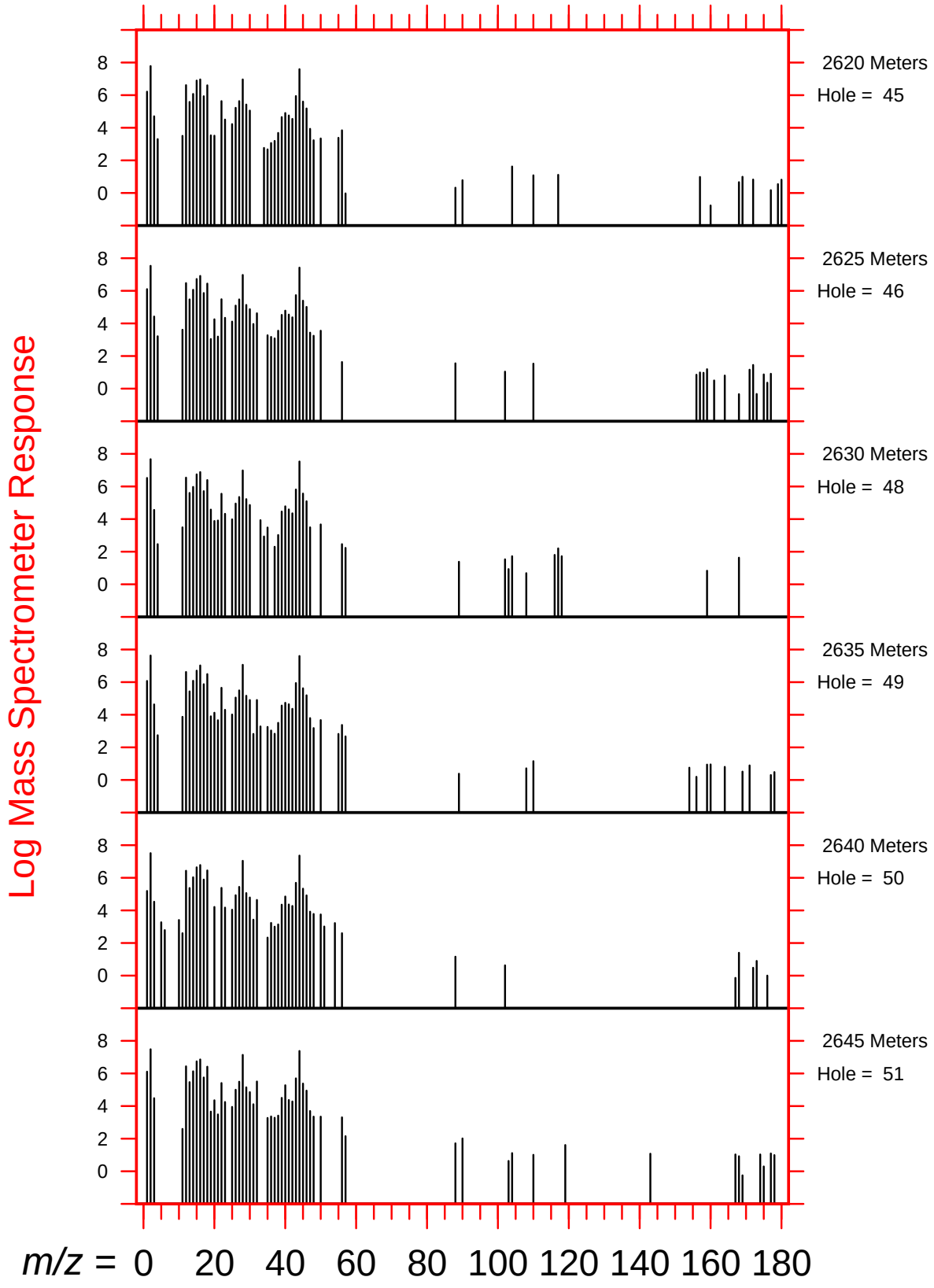

Log Mass Spectrometer Response
2470 Meters
Hole = 9
2475 Meters
Hole = 10
2480 Meters
Hole = 12
2485 Meters
Hole = 13
2490 Meters
Hole = 14
2495 Meters
Hole = 15
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

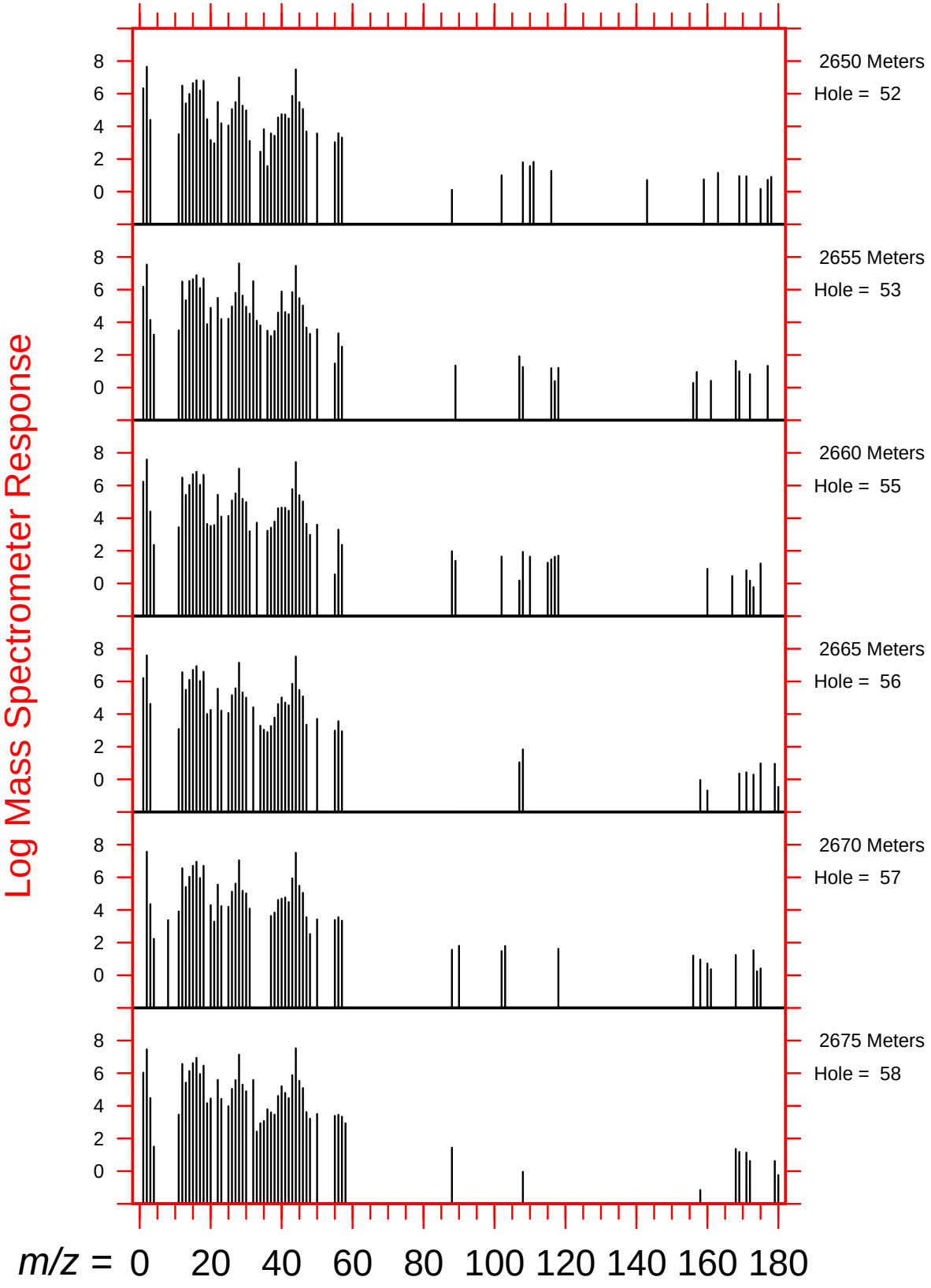

Log Mass Spectrometer Response
2500 Meters
Hole = 17
2505 Meters
Hole = 18
2510 Meters
Hole = 19
2515 Meters
Hole = 20
2520 Meters
Hole = 22
2525 Meters
Hole = 23
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

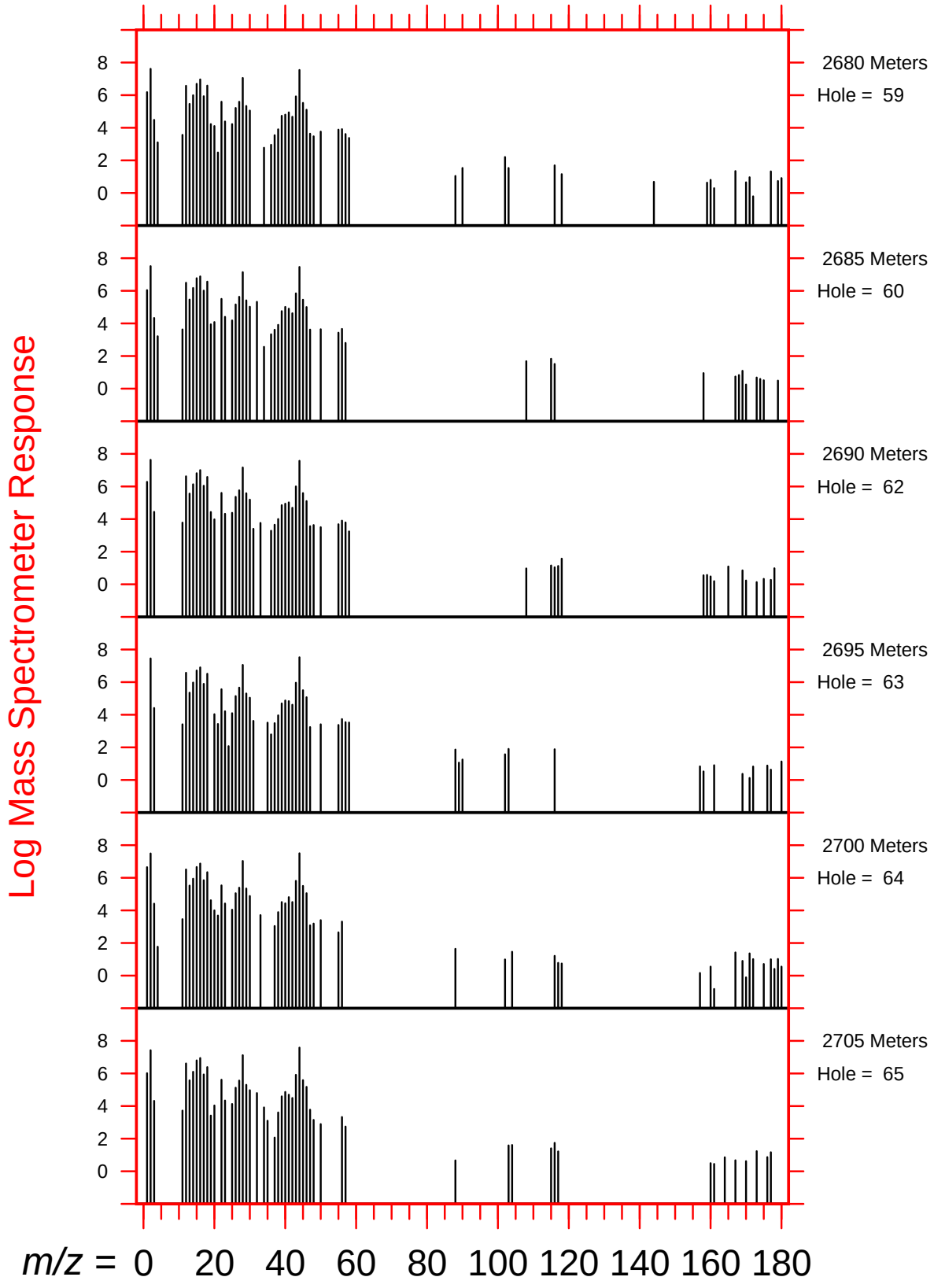

Log Mass Spectrometer Response
2530 Meters
Hole = 24
2535 Meters
Hole = 25
2540 Meters
Hole = 27
2545 Meters
Hole = 28
2550 Meters
Hole = 29
2555 Meters
Hole = 30
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

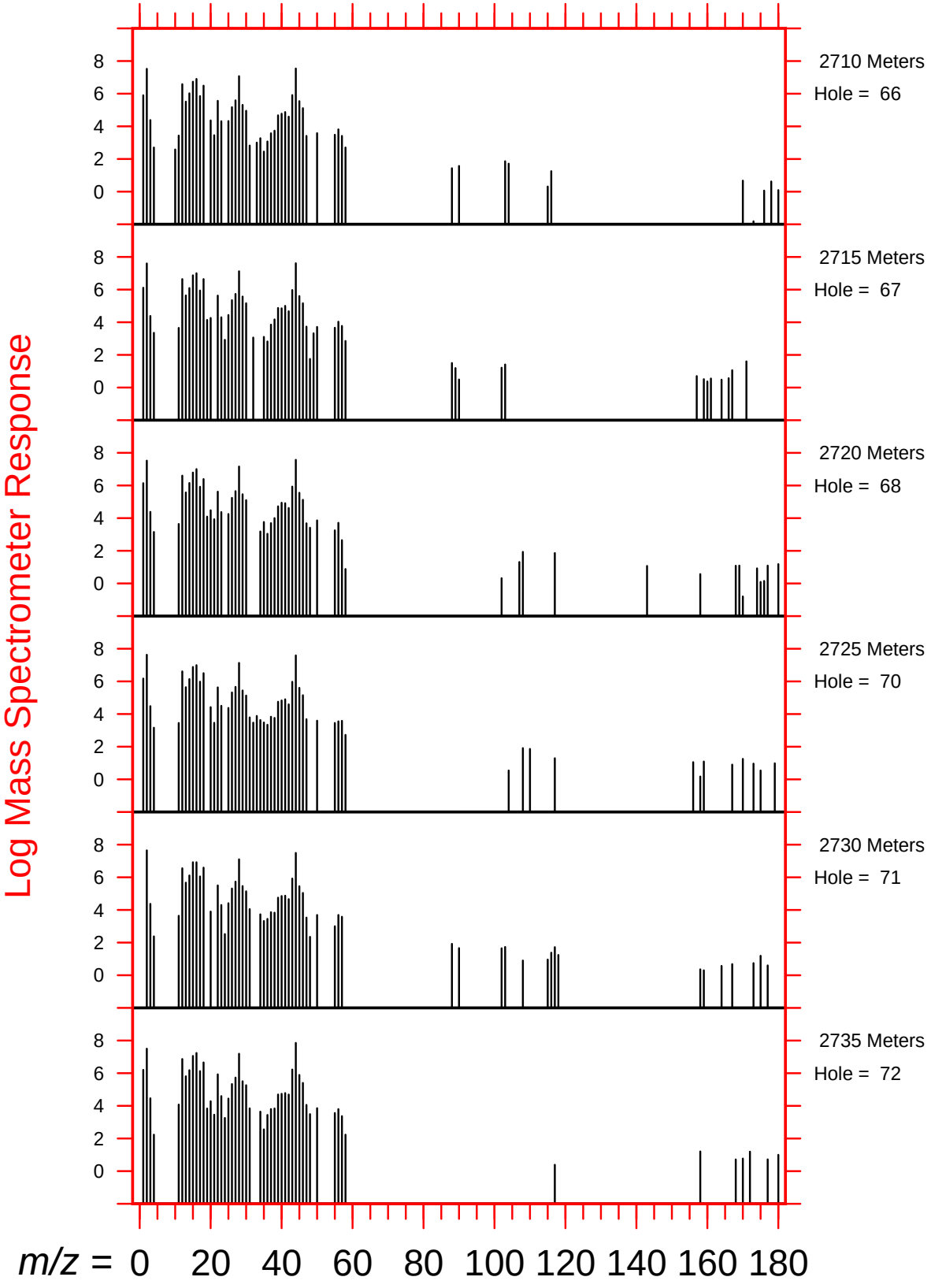

Log Mass Spectrometer Response
2560 Meters
Hole = 31
2565 Meters
Hole = 32
2570 Meters
Hole = 34
2575 Meters
Hole = 35
2580 Meters
Hole = 36
2585 Meters
Hole = 37
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

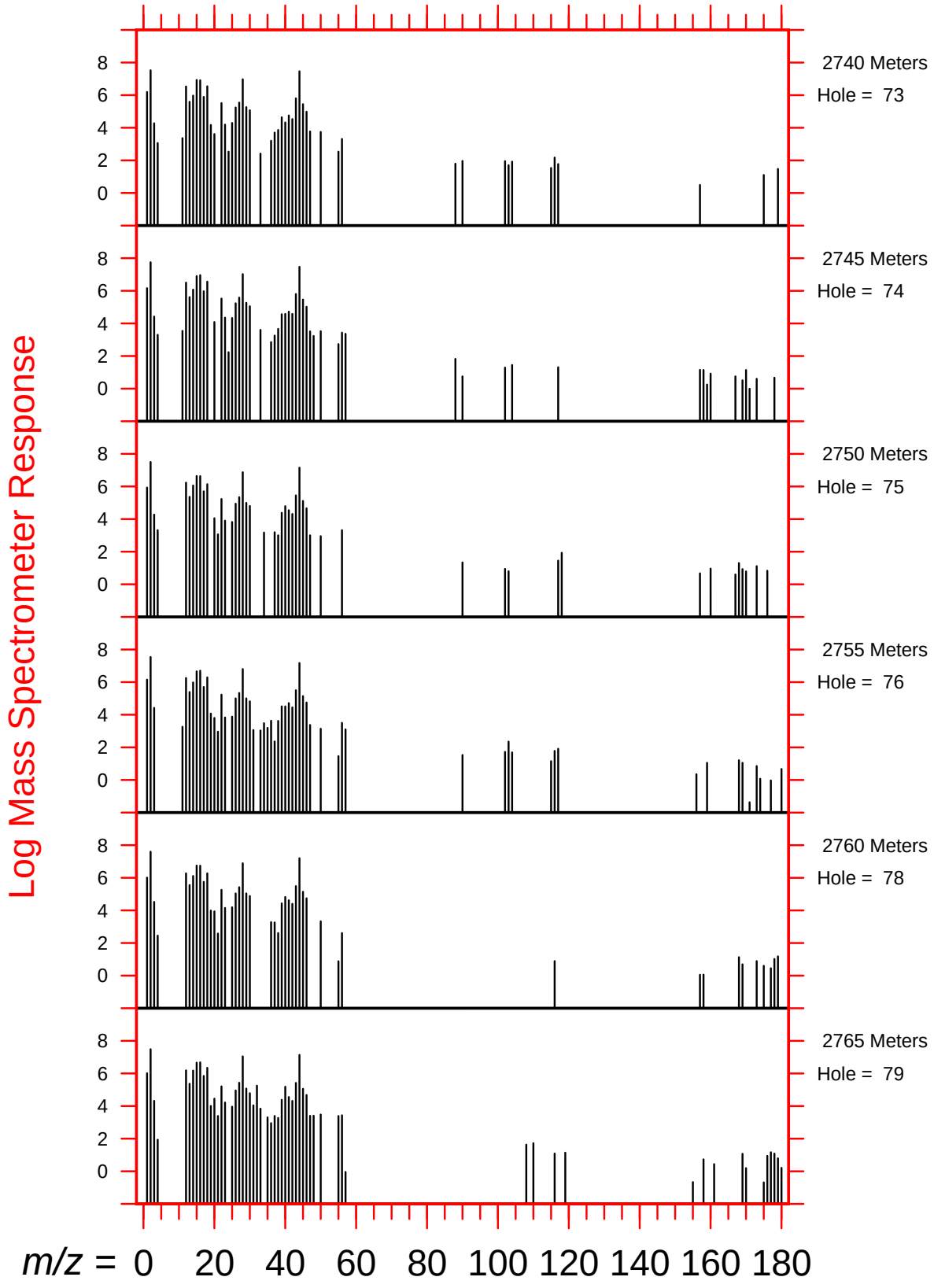

Log Mass Spectrometer Response
2590 Meters
Hole = 38
2595 Meters
Hole = 39
2600 Meters
Hole = 41
2605 Meters
Hole = 42
2610 Meters
Hole = 43
2615 Meters
Hole = 44
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

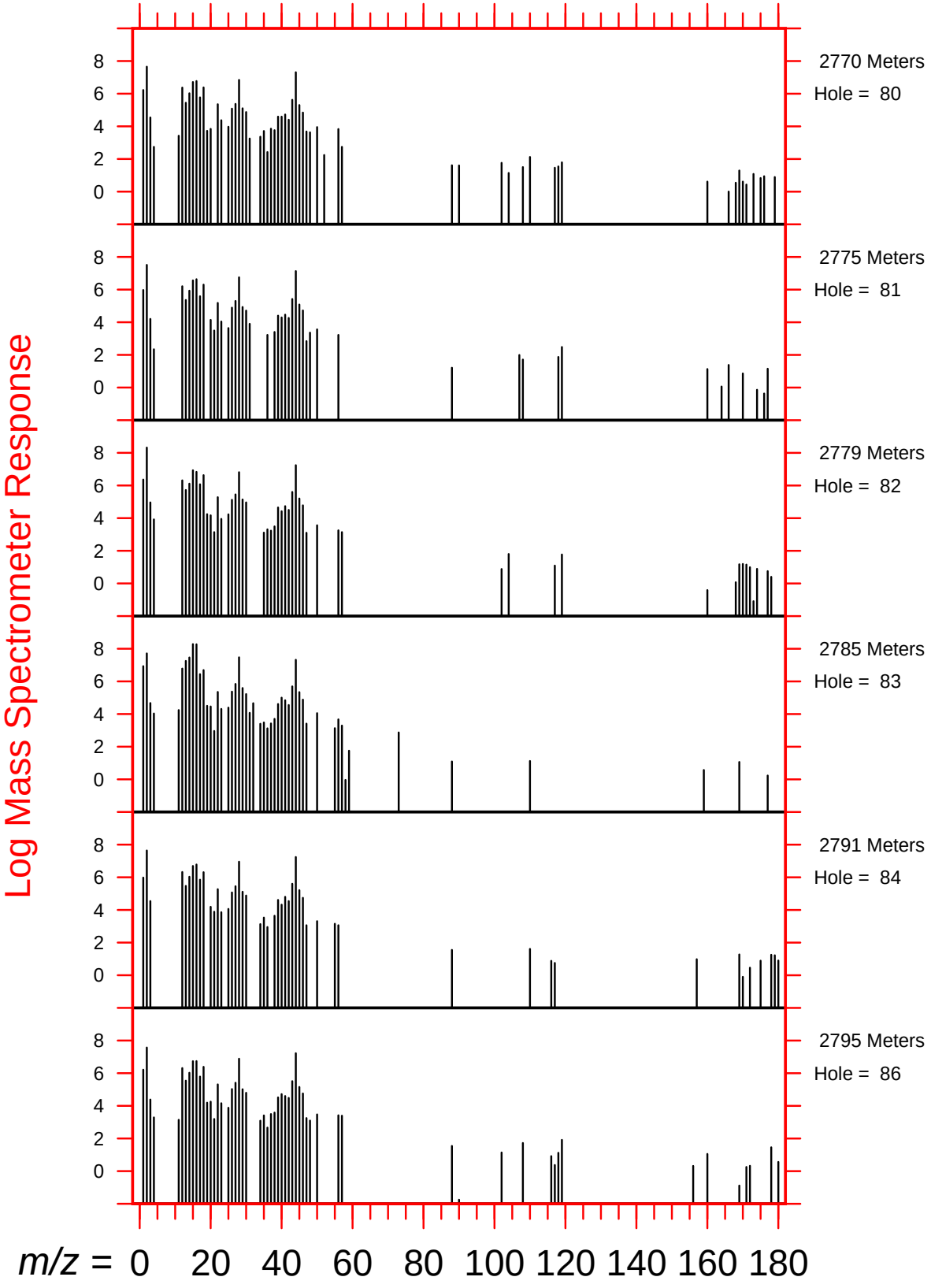

Log Mass Spectrometer Response
2620 Meters
Hole = 45
2625 Meters
Hole = 46
2630 Meters
Hole = 48
2635 Meters
Hole = 49
2640 Meters
Hole = 50
2645 Meters
Hole = 51
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

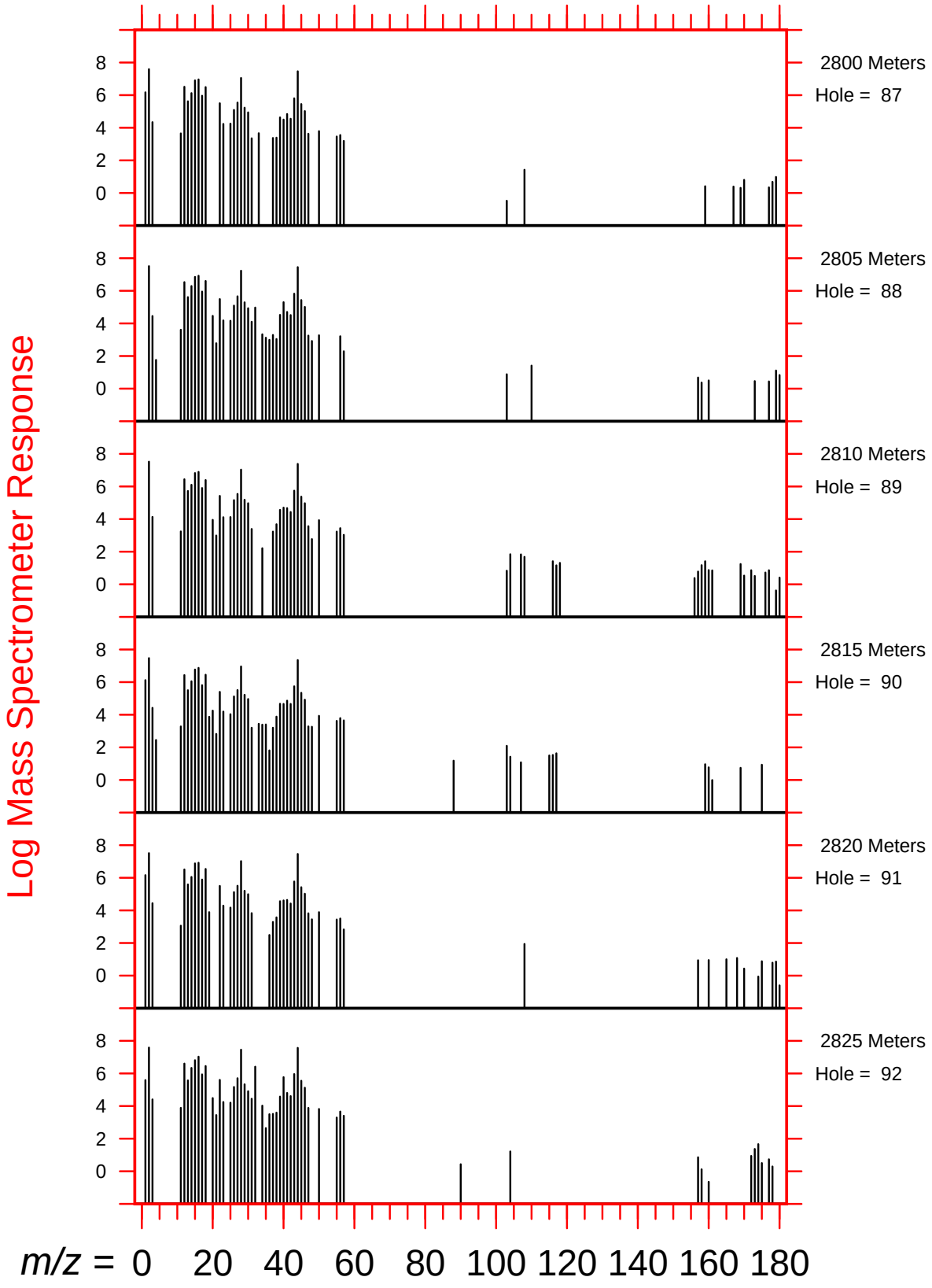

Log Mass Spectrometer Response
2650 Meters
Hole = 52
2655 Meters
Hole = 53
2660 Meters
Hole = 55
2665 Meters
Hole = 56
2670 Meters
Hole = 57
2675 Meters
Hole = 58
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

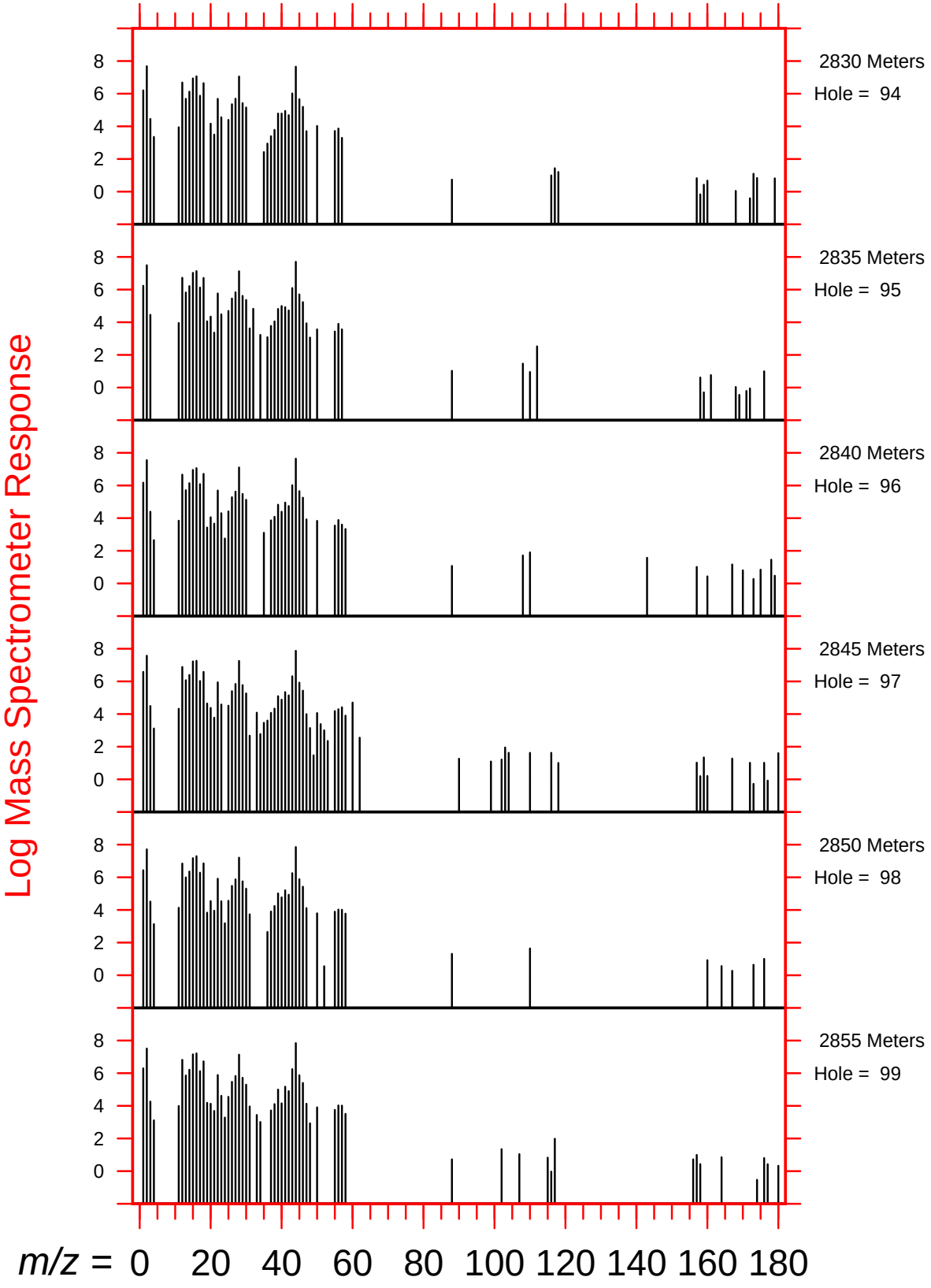

Log Mass Spectrometer Response
2680 Meters
Hole = 59
2685 Meters
Hole = 60
2690 Meters
Hole = 62
2695 Meters
Hole = 63
2700 Meters
Hole = 64
2705 Meters
Hole = 65
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

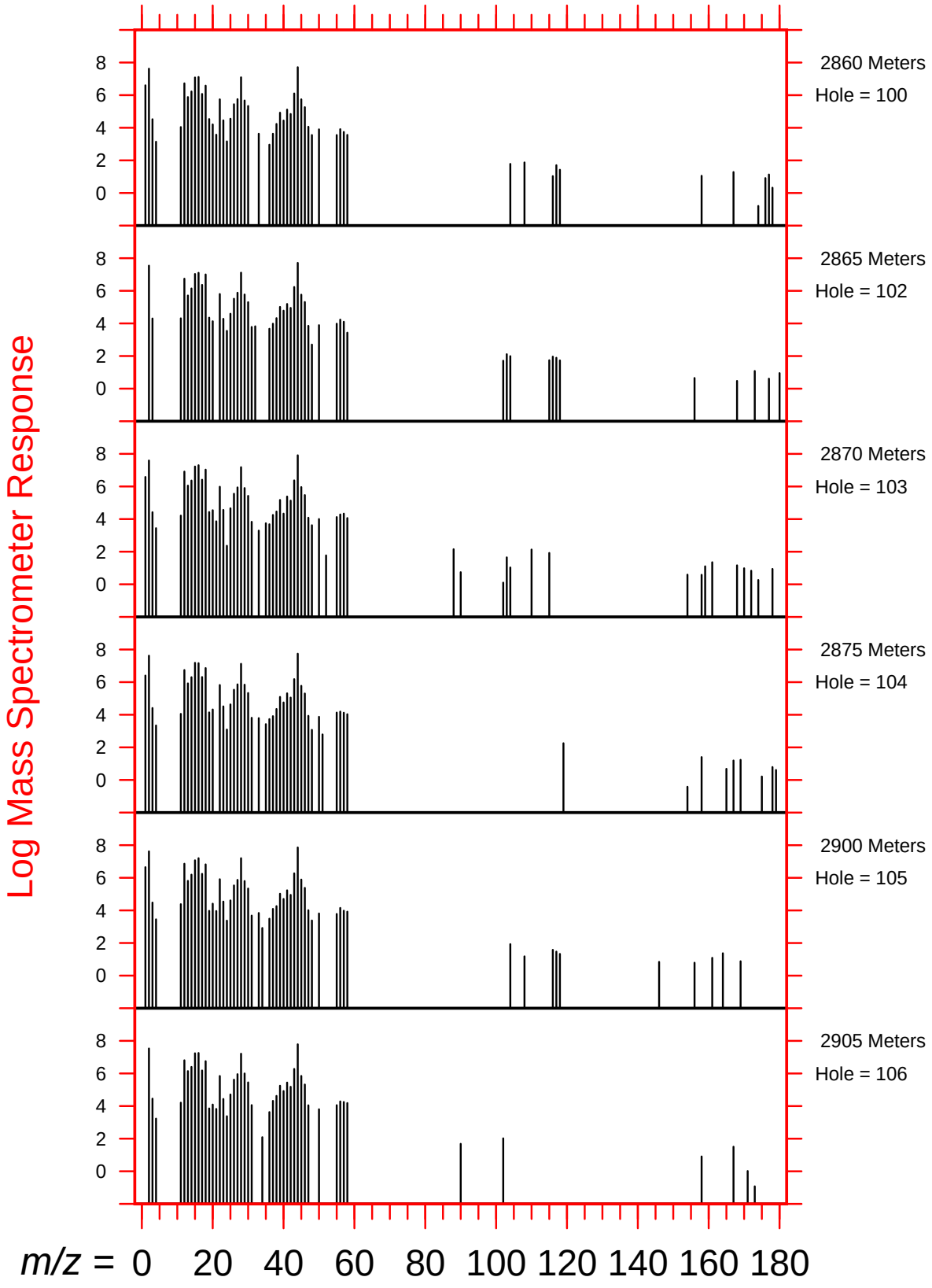

Log Mass Spectrometer Response
2710 Meters
Hole = 66
2715 Meters
Hole = 67
2720 Meters
Hole = 68
2725 Meters
Hole = 70
2730 Meters
Hole = 71
2735 Meters
Hole = 72
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

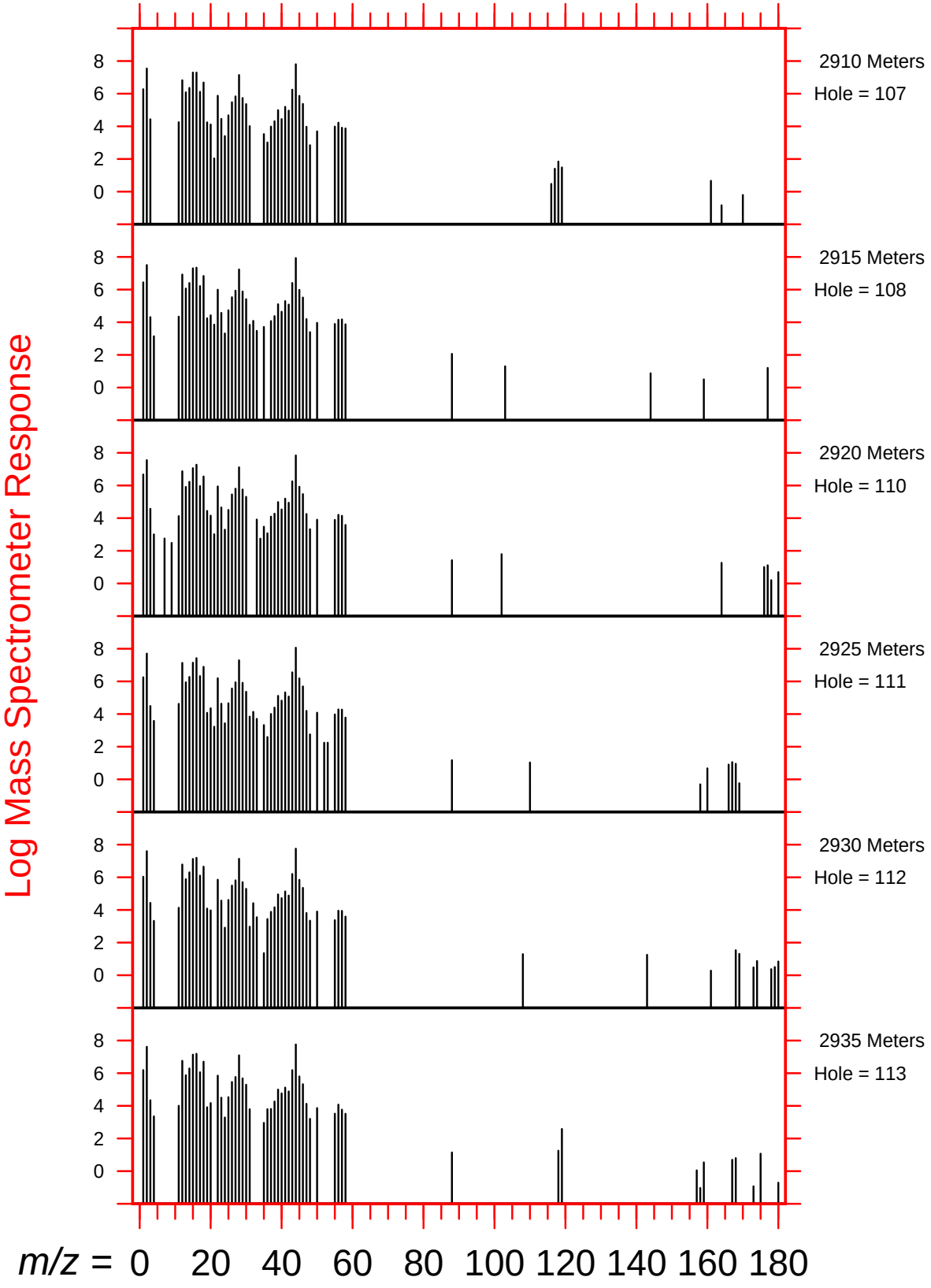

Log Mass Spectrometer Response
2740 Meters
Hole = 73
2745 Meters
Hole = 74
2750 Meters
Hole = 75
2755 Meters
Hole = 76
2760 Meters
Hole = 78
2765 Meters
Hole = 79
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

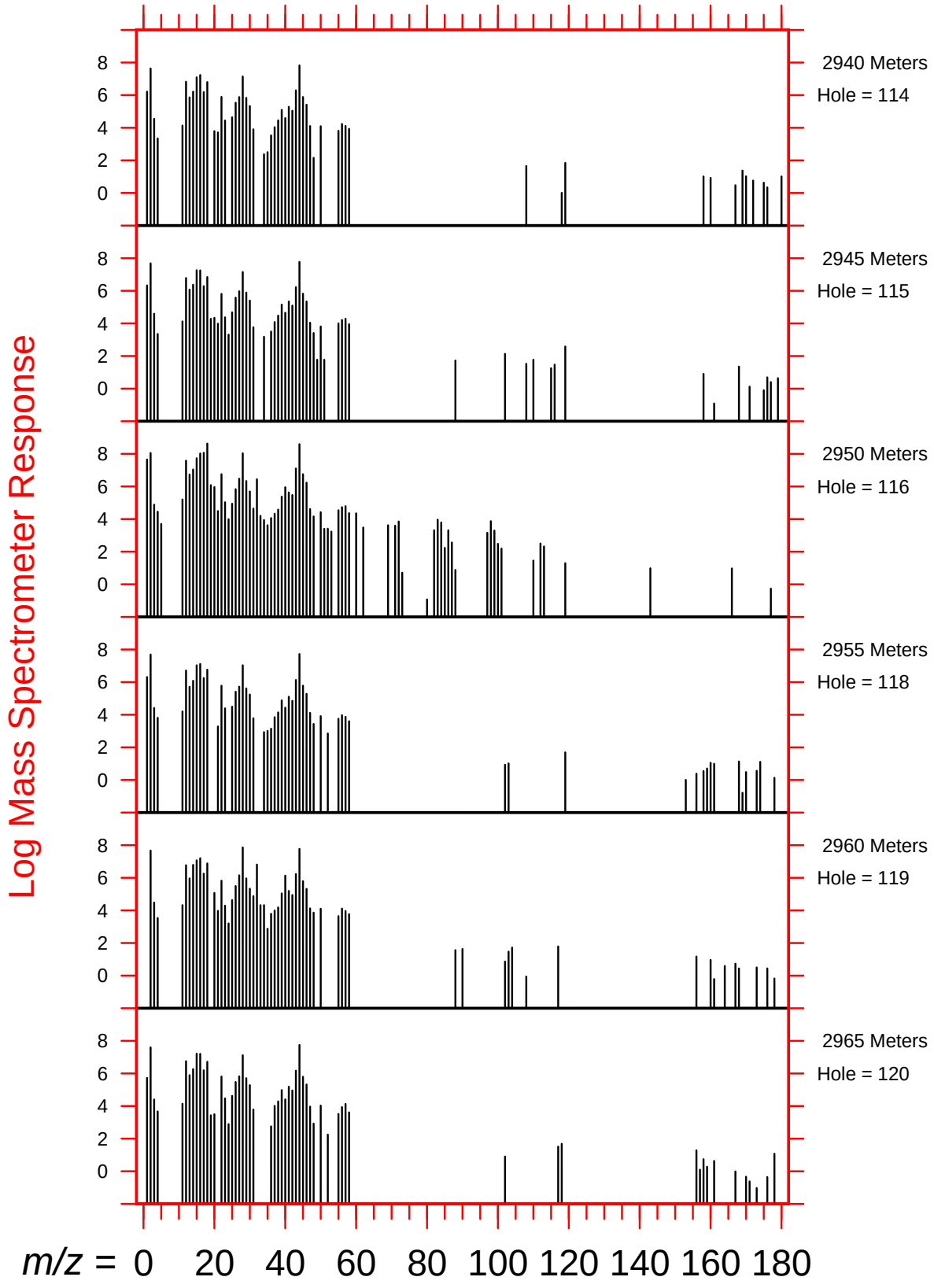

Log Mass Spectrometer Response
2770 Meters
Hole = 80
2775 Meters
Hole = 81
2779 Meters
Hole = 82
2785 Meters
Hole = 83
2791 Meters
Hole = 84
2795 Meters
Hole = 86
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

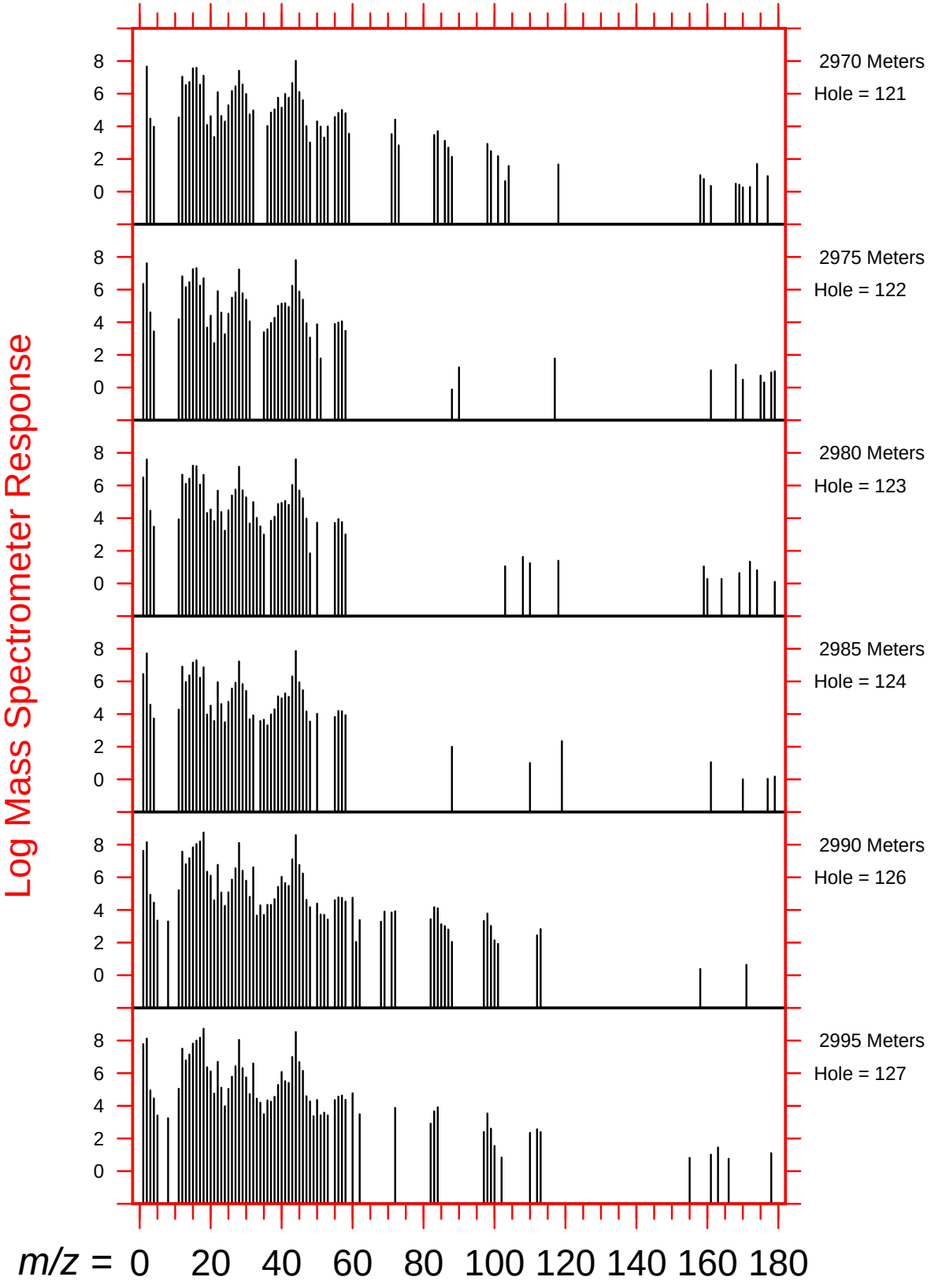

Log Mass Spectrometer Response
2800 Meters
Hole = 87
2805 Meters
Hole = 88
2810 Meters
Hole = 89
2815 Meters
Hole = 90
2820 Meters
Hole = 91
2825 Meters
Hole = 92
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

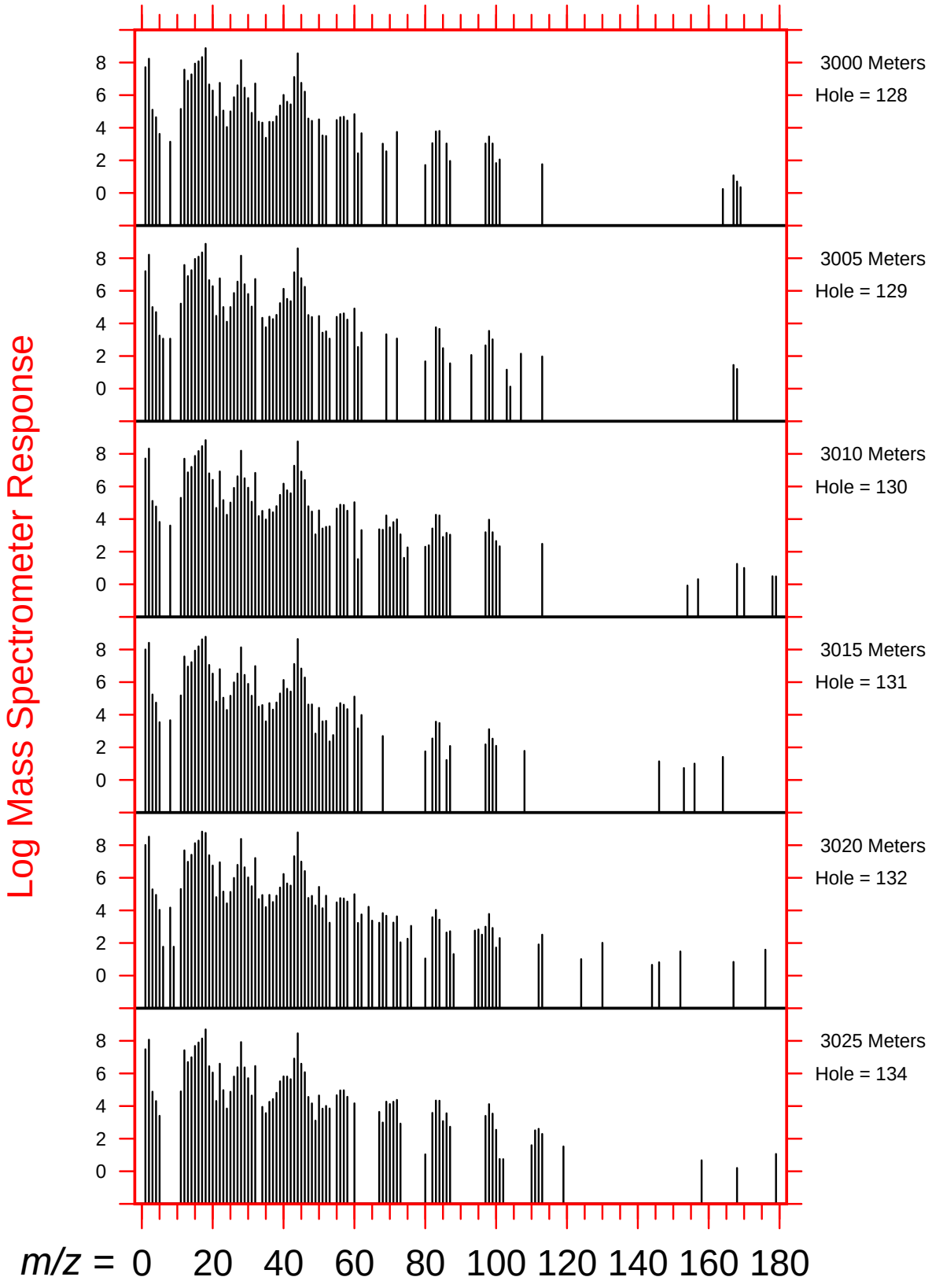

Log Mass Spectrometer Response
2830 Meters
Hole = 94
2835 Meters
Hole = 95
2840 Meters
Hole = 96
2845 Meters
Hole = 97
2850 Meters
Hole = 98
2855 Meters
Hole = 99
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

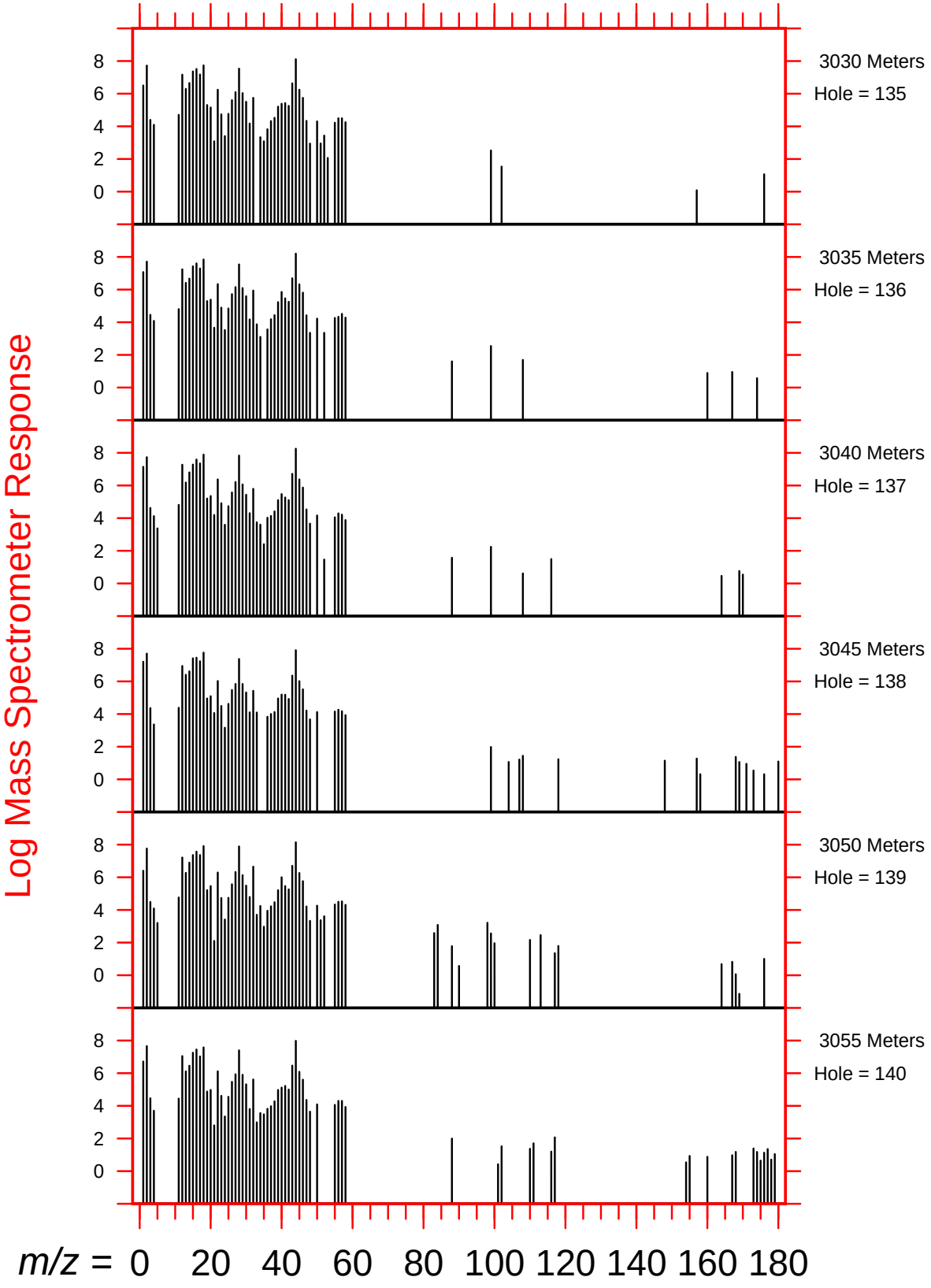

Log Mass Spectrometer Response
2860 Meters
Hole = 100
2865 Meters
Hole = 102
2870 Meters
Hole = 103
2875 Meters
Hole = 104
2900 Meters
Hole = 105
2905 Meters
Hole = 106
m/z = 0 20 40 60 80 100 120 140 160 180

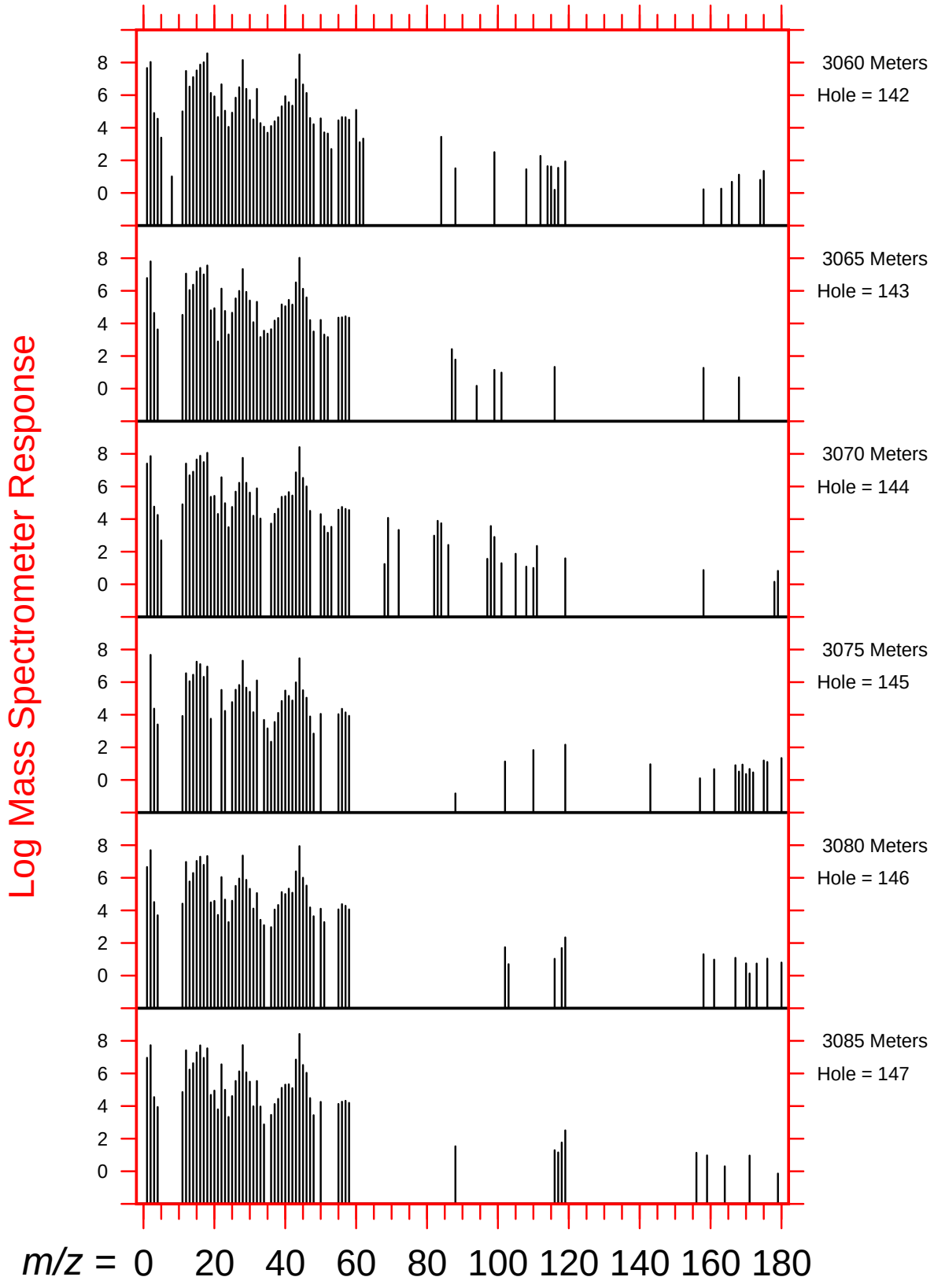

Log Mass Spectrometer Response
2910 Meters
Hole = 107
2915 Meters
Hole = 108
2920 Meters
Hole = 110
2925 Meters
Hole = 111
2930 Meters
Hole = 112
2935 Meters
Hole = 113
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

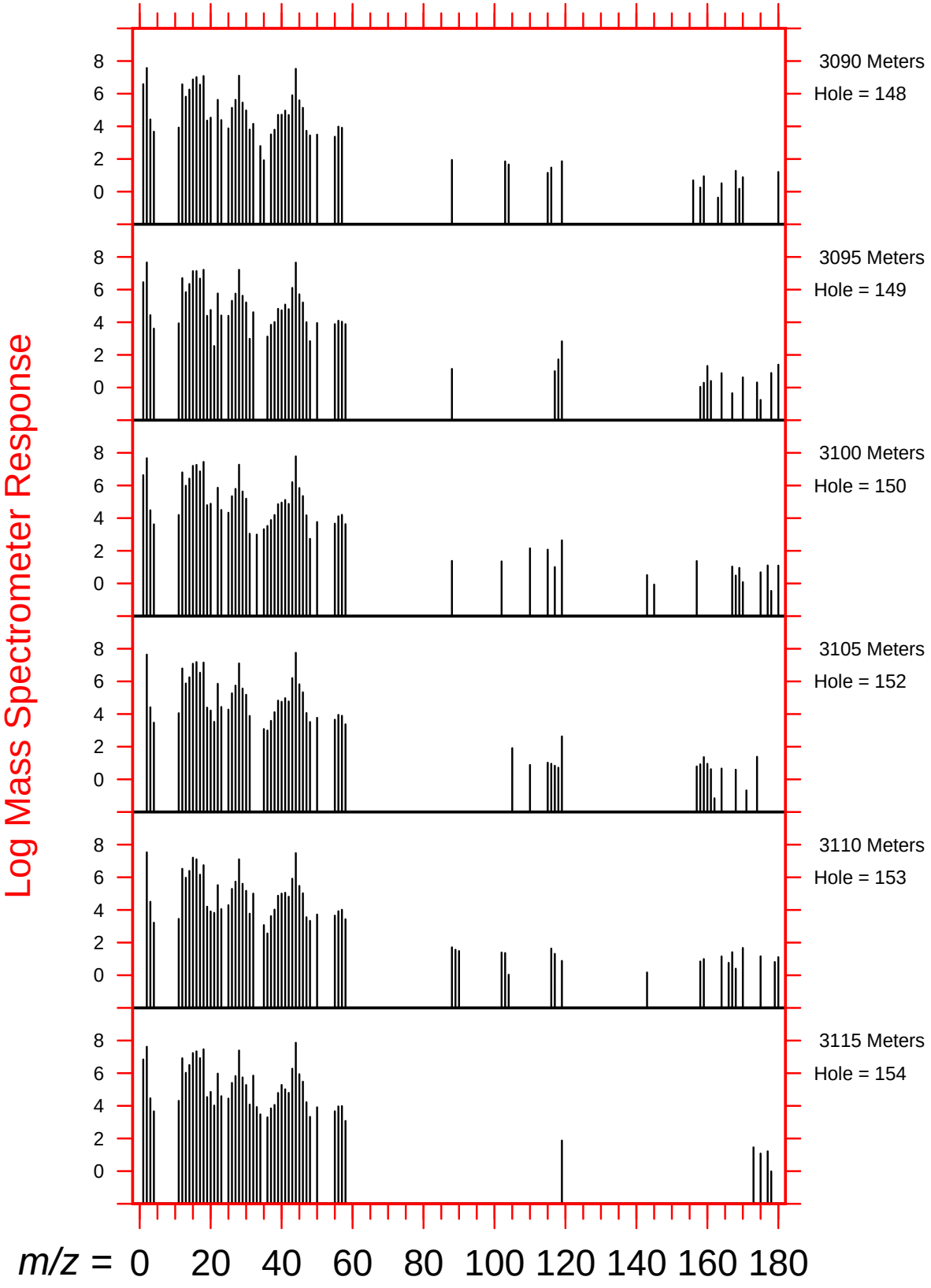

Log Mass Spectrometer Response
2940 Meters
Hole = 114
2945 Meters
Hole = 115
2950 Meters
Hole = 116
2955 Meters
Hole = 118
2960 Meters
Hole = 119
2965 Meters
Hole = 120
m/z = 0 20 40 60 80 100 120 140 160 180

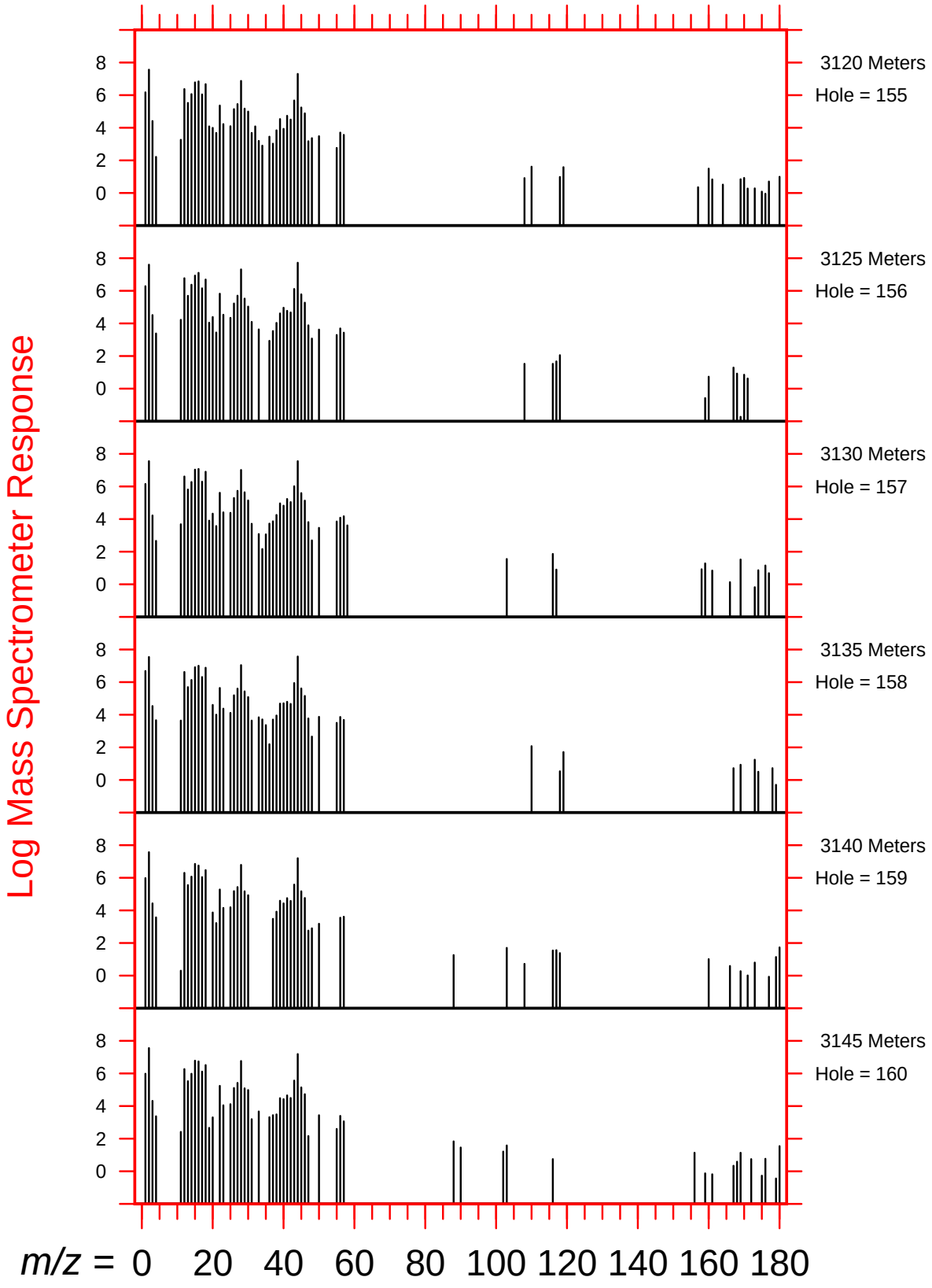

Log Mass Spectrometer Response
2970 Meters
Hole = 121
2975 Meters
Hole = 122
2980 Meters
Hole = 123
2985 Meters
Hole = 124
2990 Meters
Hole = 126
2995 Meters
Hole = 127
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

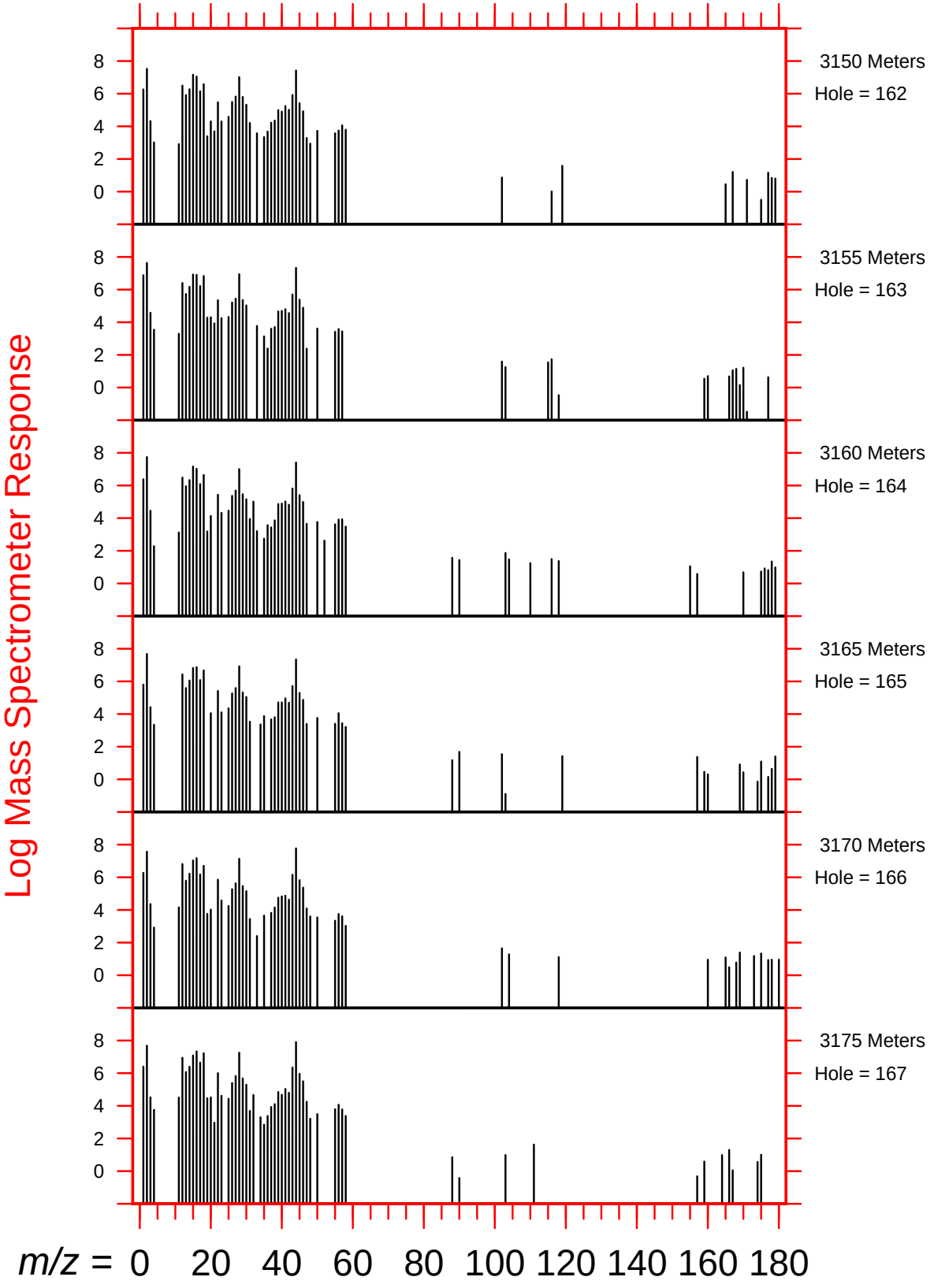

Log Mass Spectrometer Response
3000 Meters
Hole = 128
3005 Meters
Hole = 129
3010 Meters
Hole = 130
3015 Meters
Hole = 131
3020 Meters
Hole = 132
3025 Meters
Hole = 134
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

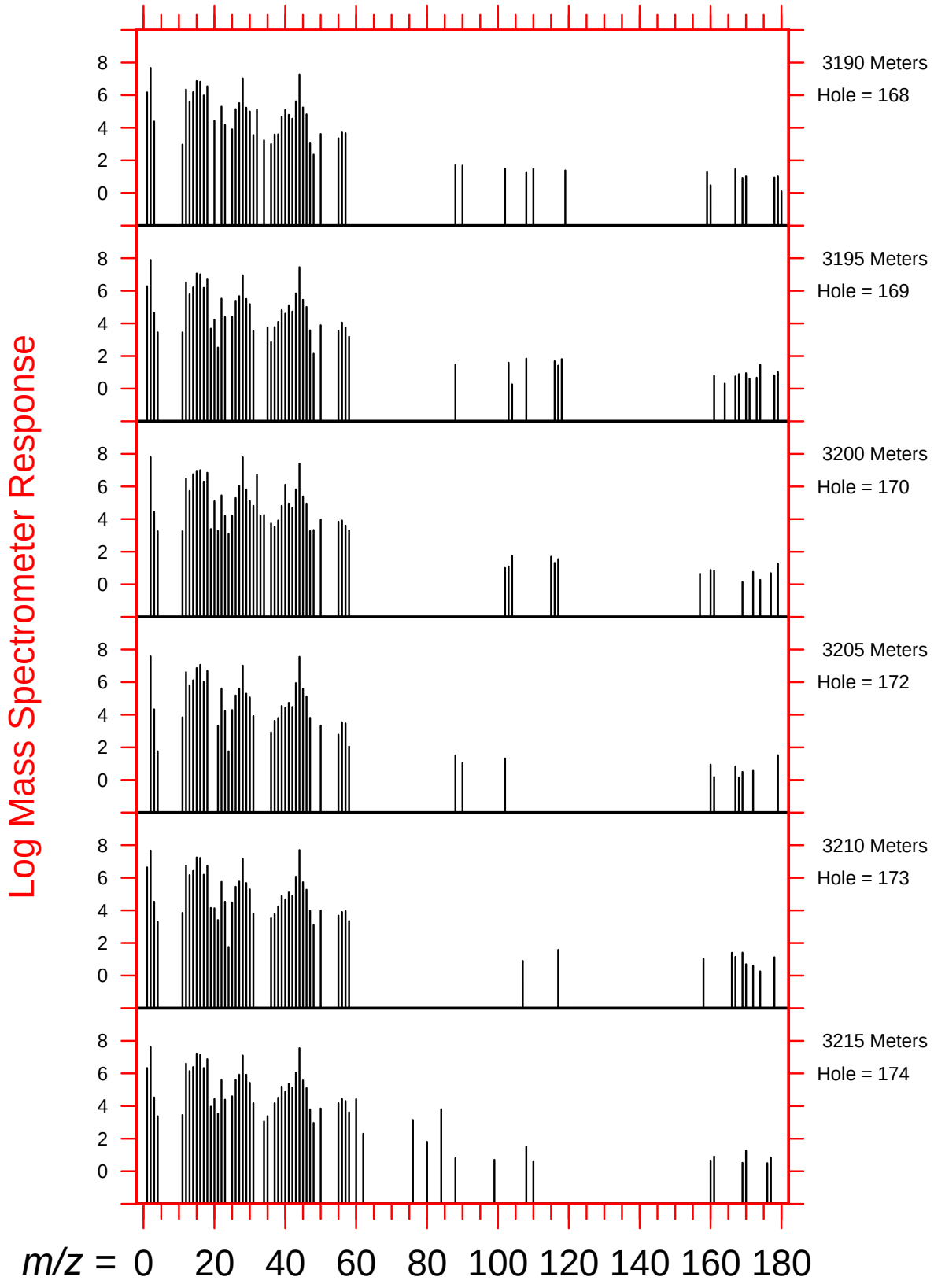

Log Mass Spectrometer Response
3030 Meters
Hole = 135
3035 Meters
Hole = 136
3040 Meters
Hole = 137
3045 Meters
Hole = 138
3050 Meters
Hole = 139
3055 Meters
Hole = 140
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

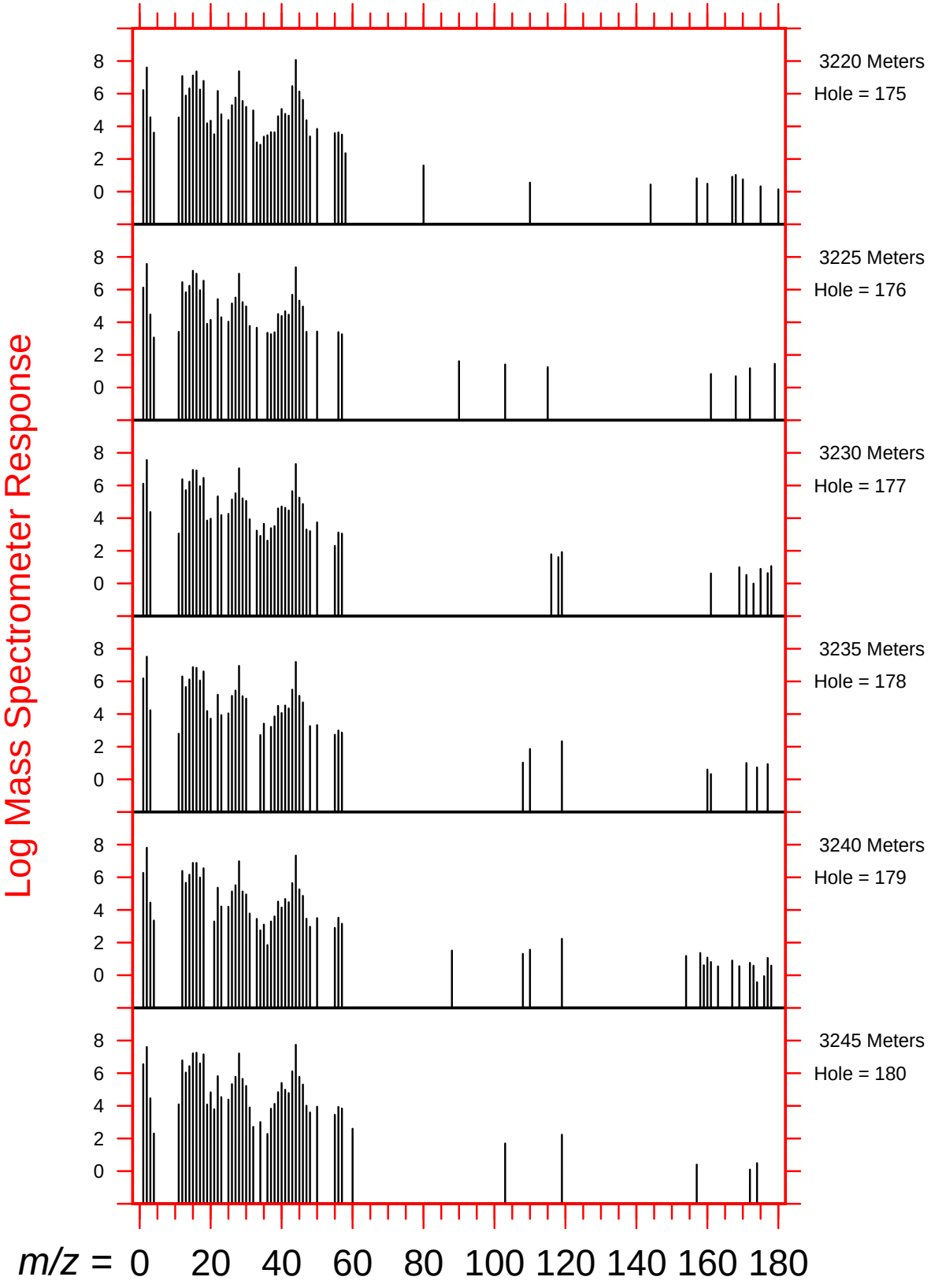

Log Mass Spectrometer Response
3060 Meters
Hole = 142
3065 Meters
Hole = 143
3070 Meters
Hole = 144
3075 Meters
Hole = 145
3080 Meters
Hole = 146
3085 Meters
Hole = 147
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

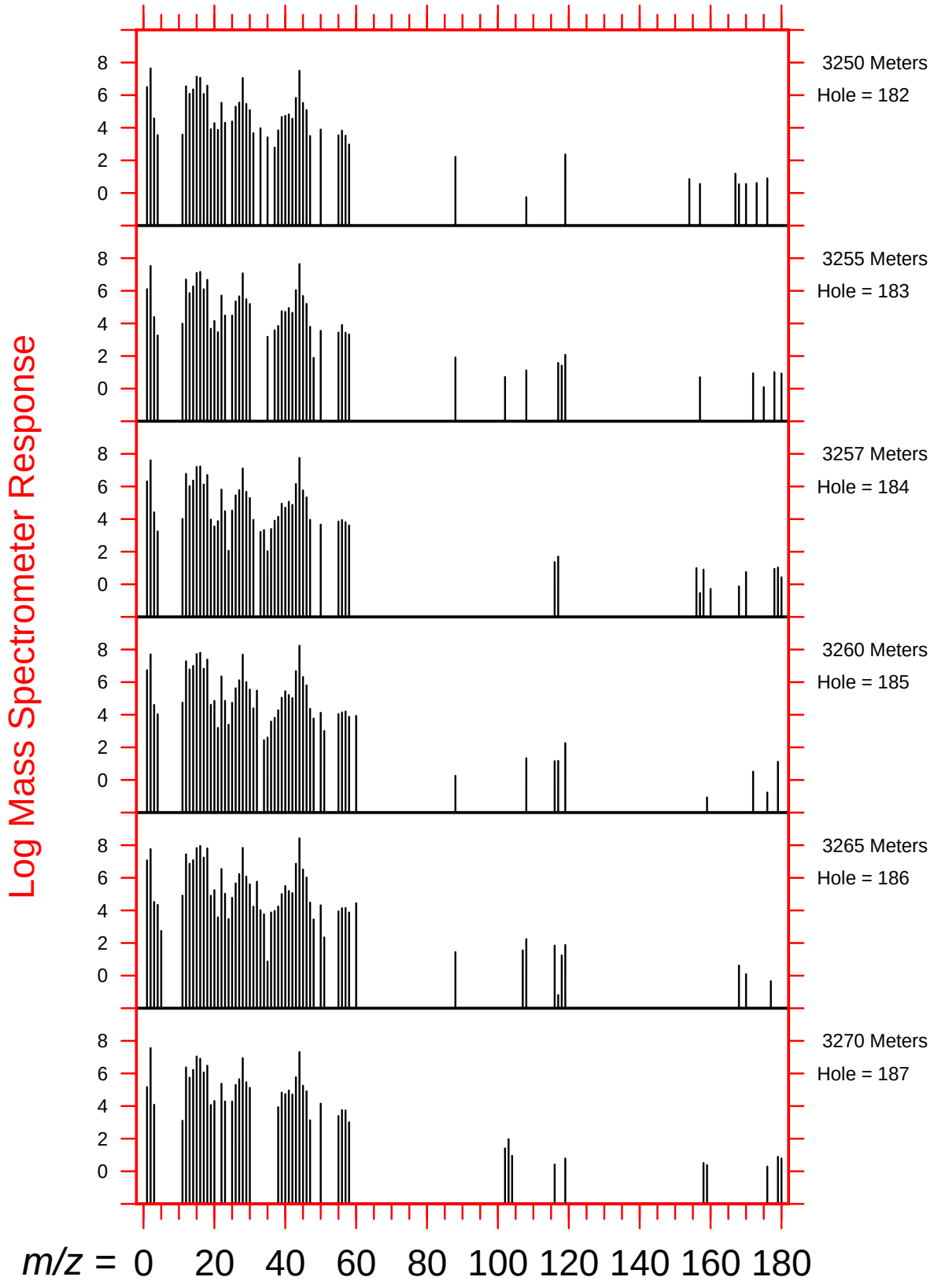

Log Mass Spectrometer Response
3090 Meters
Hole = 148
3095 Meters
Hole = 149
3100 Meters
Hole = 150
3105 Meters
Hole = 152
3110 Meters
Hole = 153
3115 Meters
Hole = 154
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

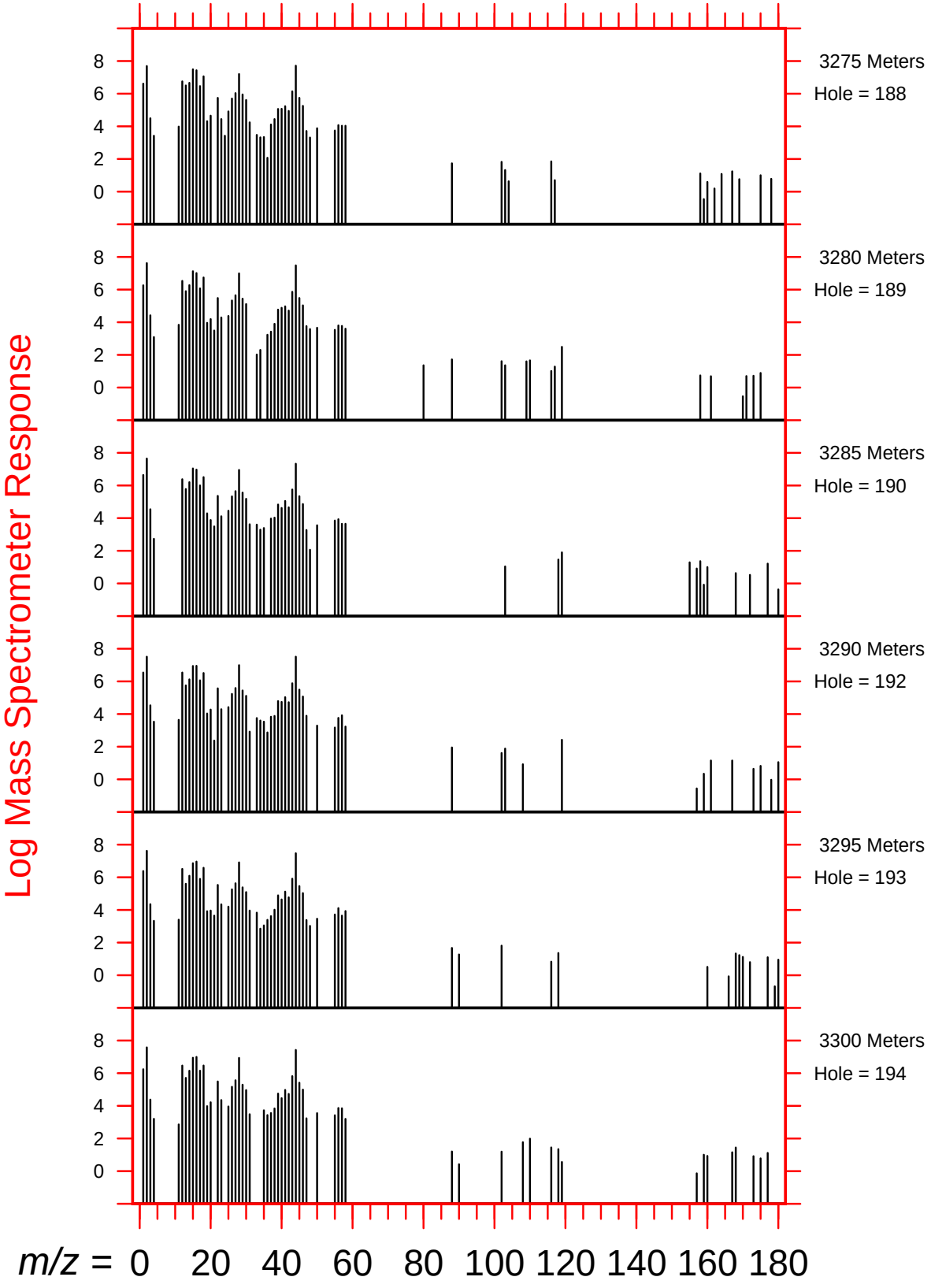

Log Mass Spectrometer Response
3120 Meters
Hole = 155
3125 Meters
Hole = 156
3130 Meters
Hole = 157
3135 Meters
Hole = 158
3140 Meters
Hole = 159
3145 Meters
Hole = 160
m/z = 0 20 40 60 80 100 120 140 160 180

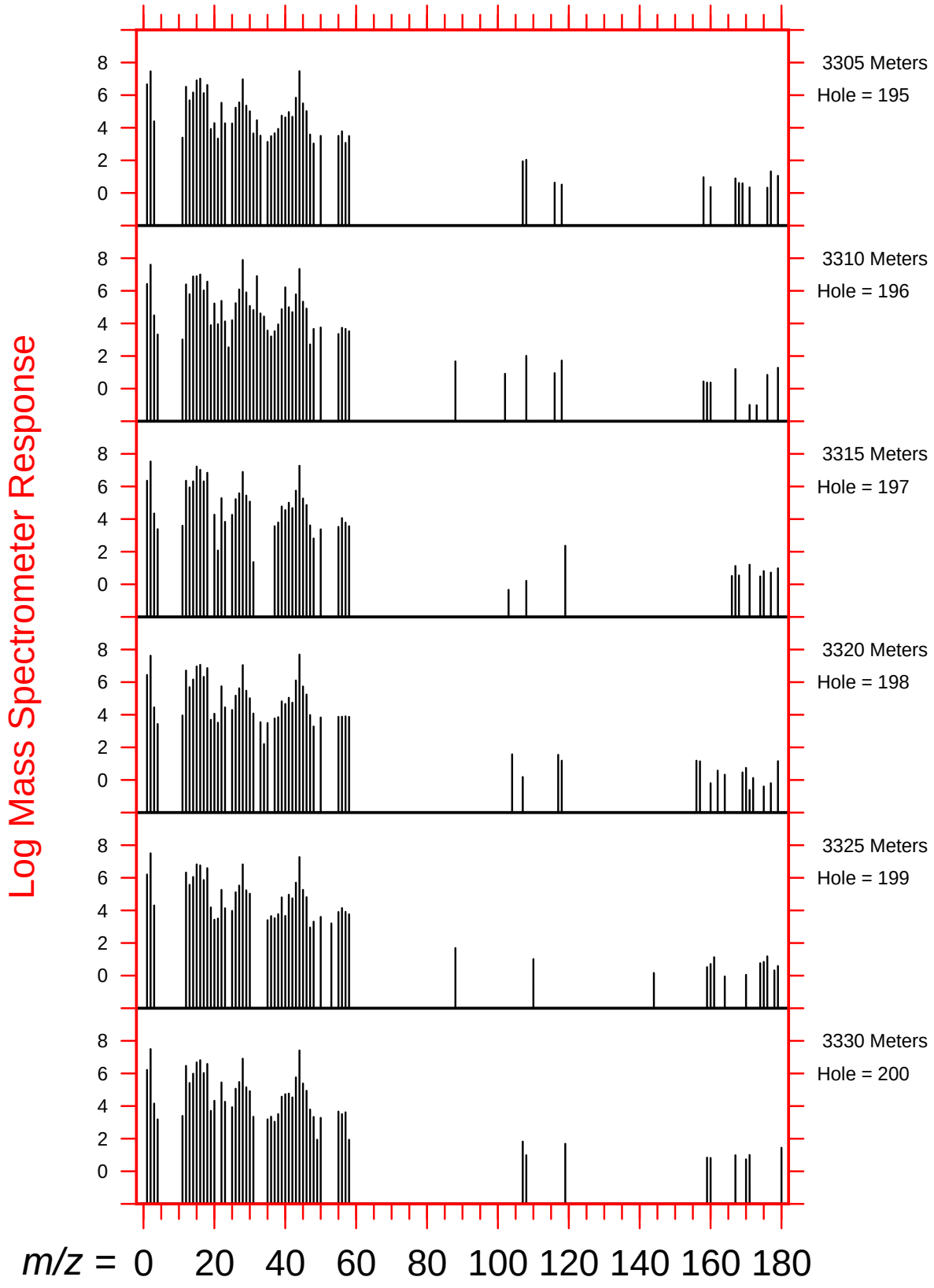

Log Mass Spectrometer Response
3150 Meters
Hole = 162
3155 Meters
Hole = 163
3160 Meters
Hole = 164
3165 Meters
Hole = 165
3170 Meters
Hole = 166
3175 Meters
Hole = 167
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

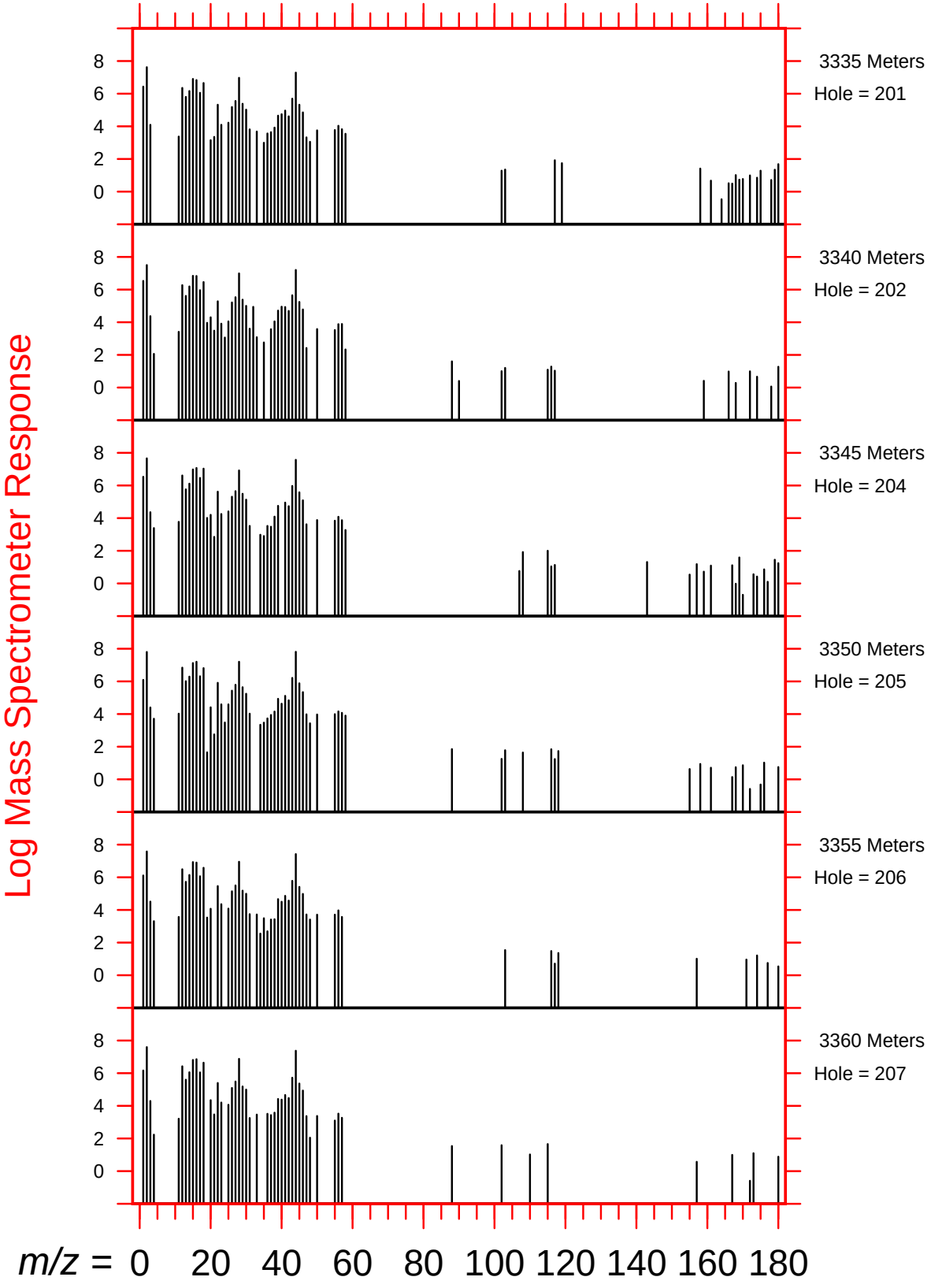

Log Mass Spectrometer Response
3190 Meters
Hole = 168
3195 Meters
Hole = 169
3200 Meters
Hole = 170
3205 Meters
Hole = 172
3210 Meters
Hole = 173
3215 Meters
Hole = 174
m/z = 0 20 40 60 80 100 120 140 160 180

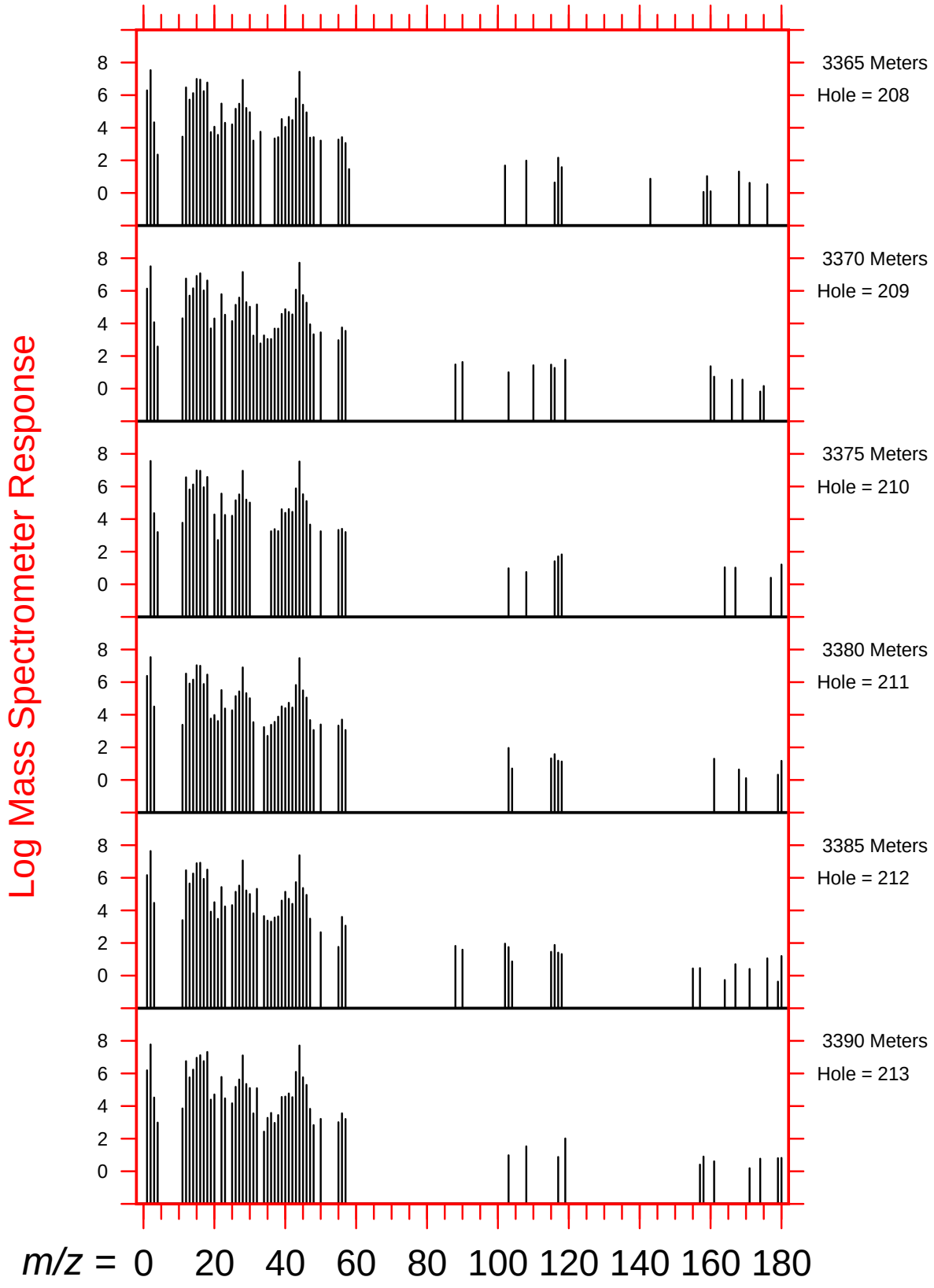

Log Mass Spectrometer Response
3220 Meters
Hole = 175
3225 Meters
Hole = 176
3230 Meters
Hole = 177
3235 Meters
Hole = 178
3240 Meters
Hole = 179
3245 Meters
Hole = 180
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

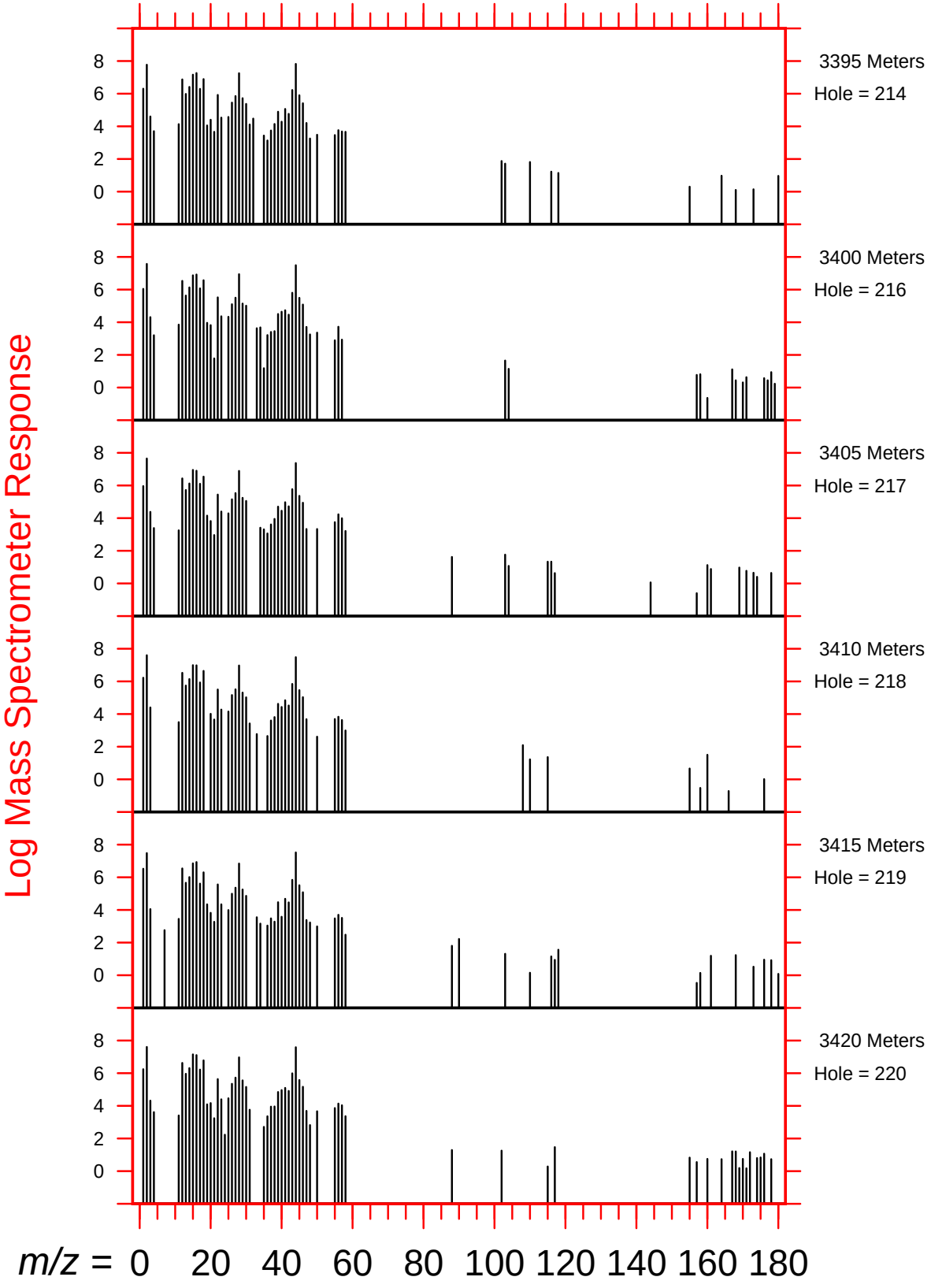

Log Mass Spectrometer Response
3250 Meters
Hole = 182
3255 Meters
Hole = 183
3257 Meters
Hole = 184
3260 Meters
Hole = 185
3265 Meters
Hole = 186
3270 Meters
Hole = 187
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

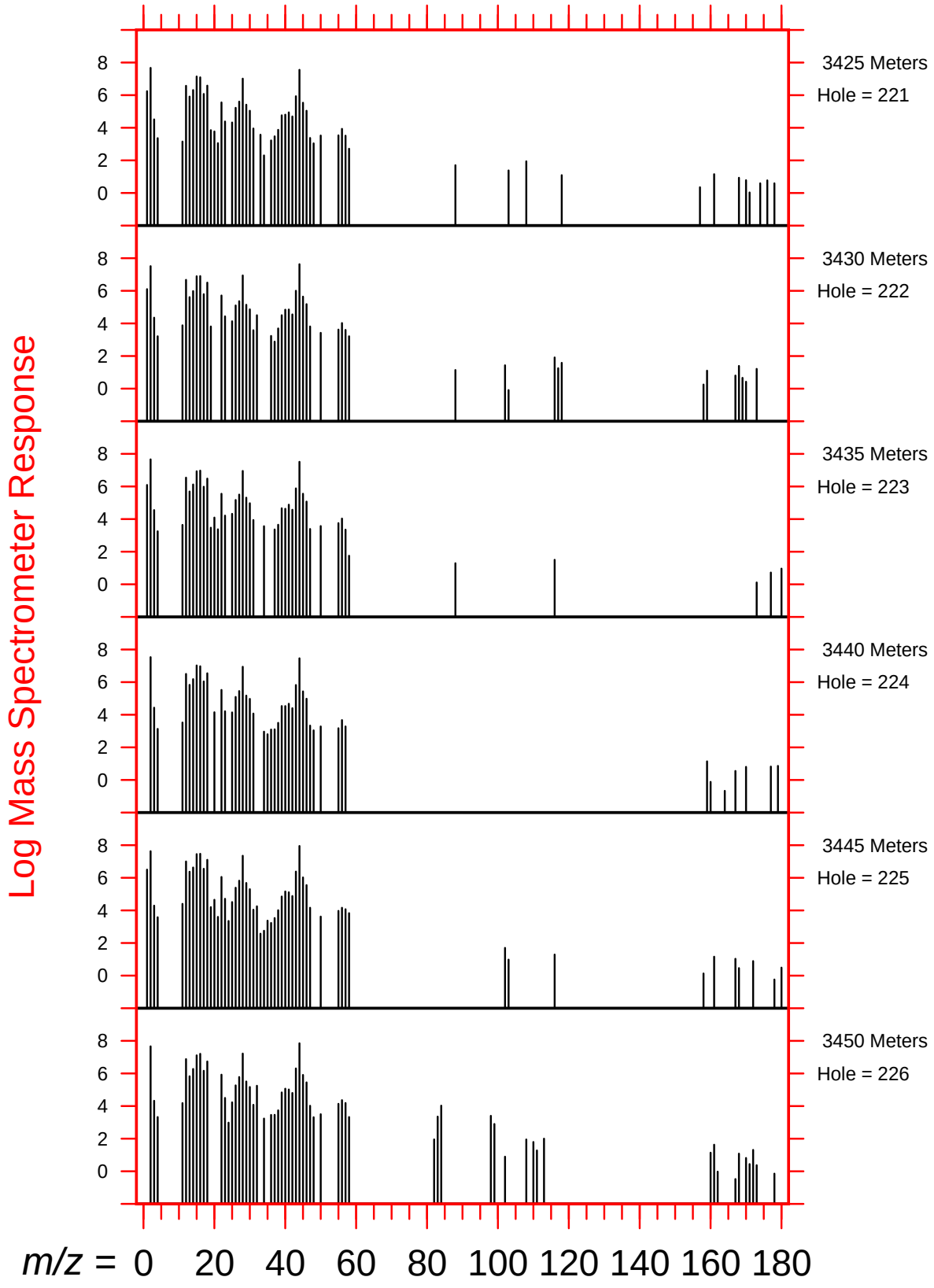

Log Mass Spectrometer Response
3275 Meters
Hole = 188
3280 Meters
Hole = 189
3285 Meters
Hole = 190
3290 Meters
Hole = 192
3295 Meters
Hole = 193
3300 Meters
Hole = 194
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

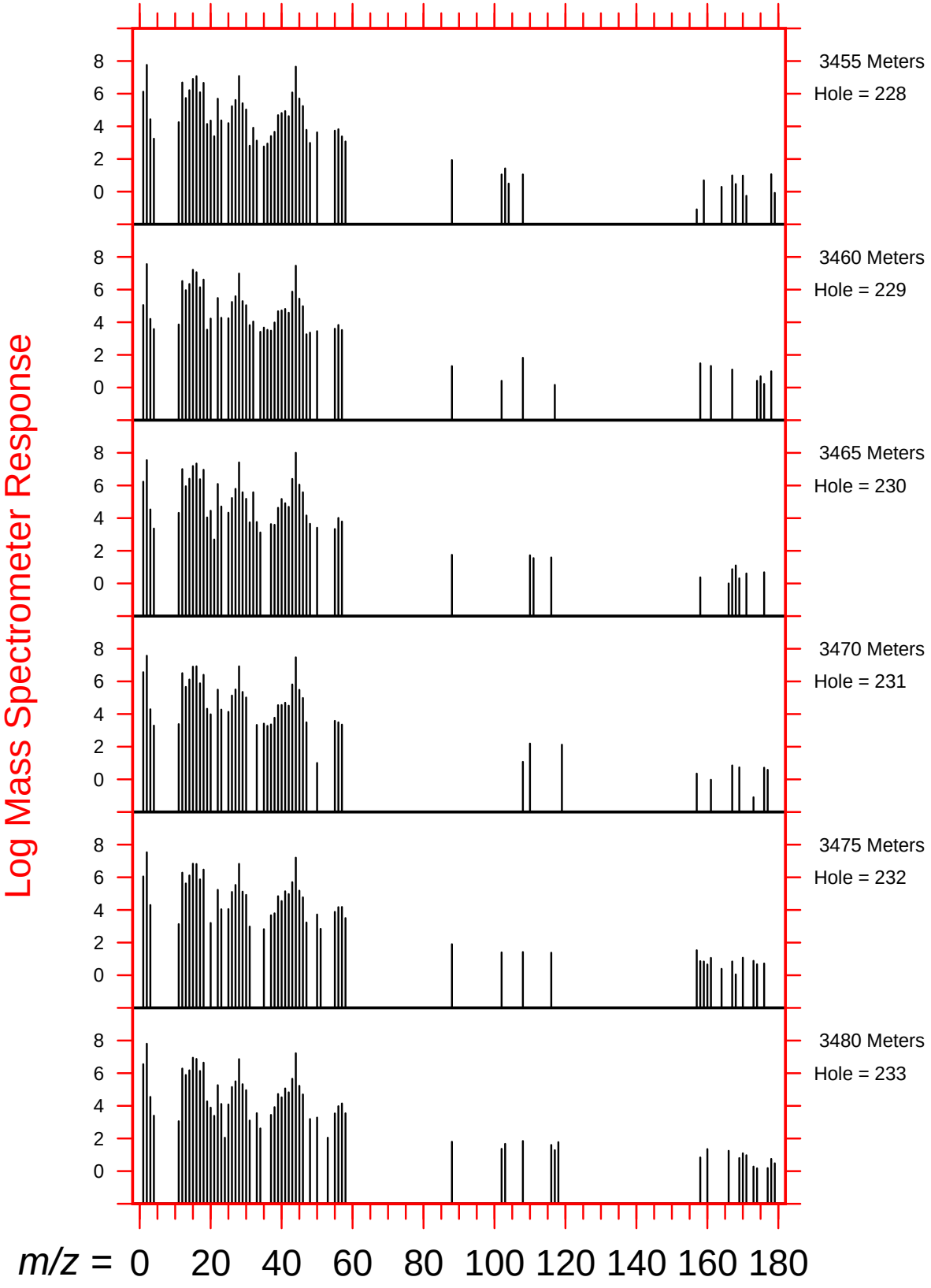

Log Mass Spectrometer Response
3305 Meters
Hole = 195
3310 Meters
Hole = 196
3315 Meters
Hole = 197
3320 Meters
Hole = 198
3325 Meters
Hole = 199
3330 Meters
Hole = 200
m/z = 0 20 40 60 80 100 120 140 160 180

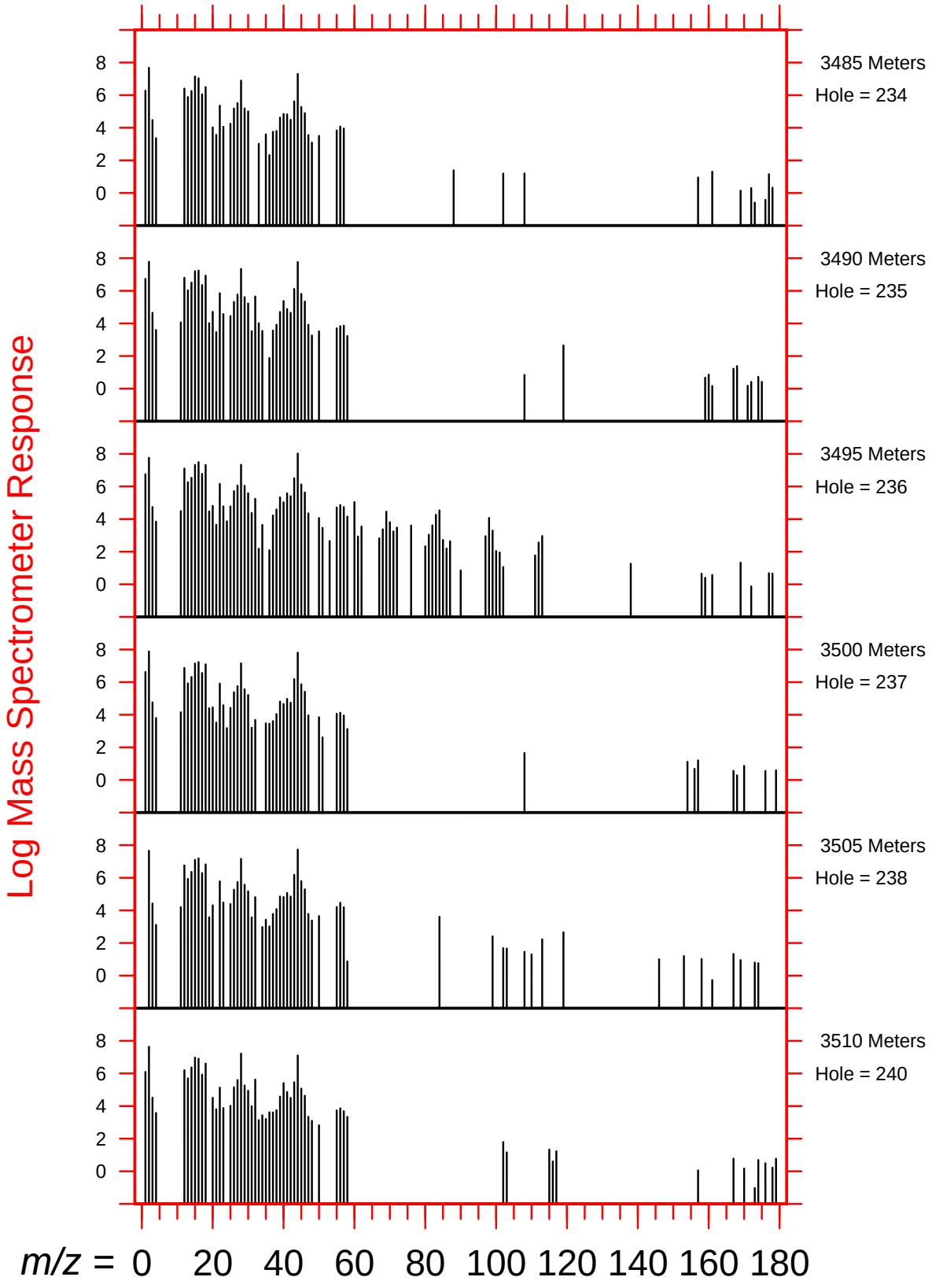

Log Mass Spectrometer Response
3335 Meters
Hole = 201
3340 Meters
Hole = 202
3345 Meters
Hole = 204
3350 Meters
Hole = 205
3355 Meters
Hole = 206
3360 Meters
Hole = 207
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

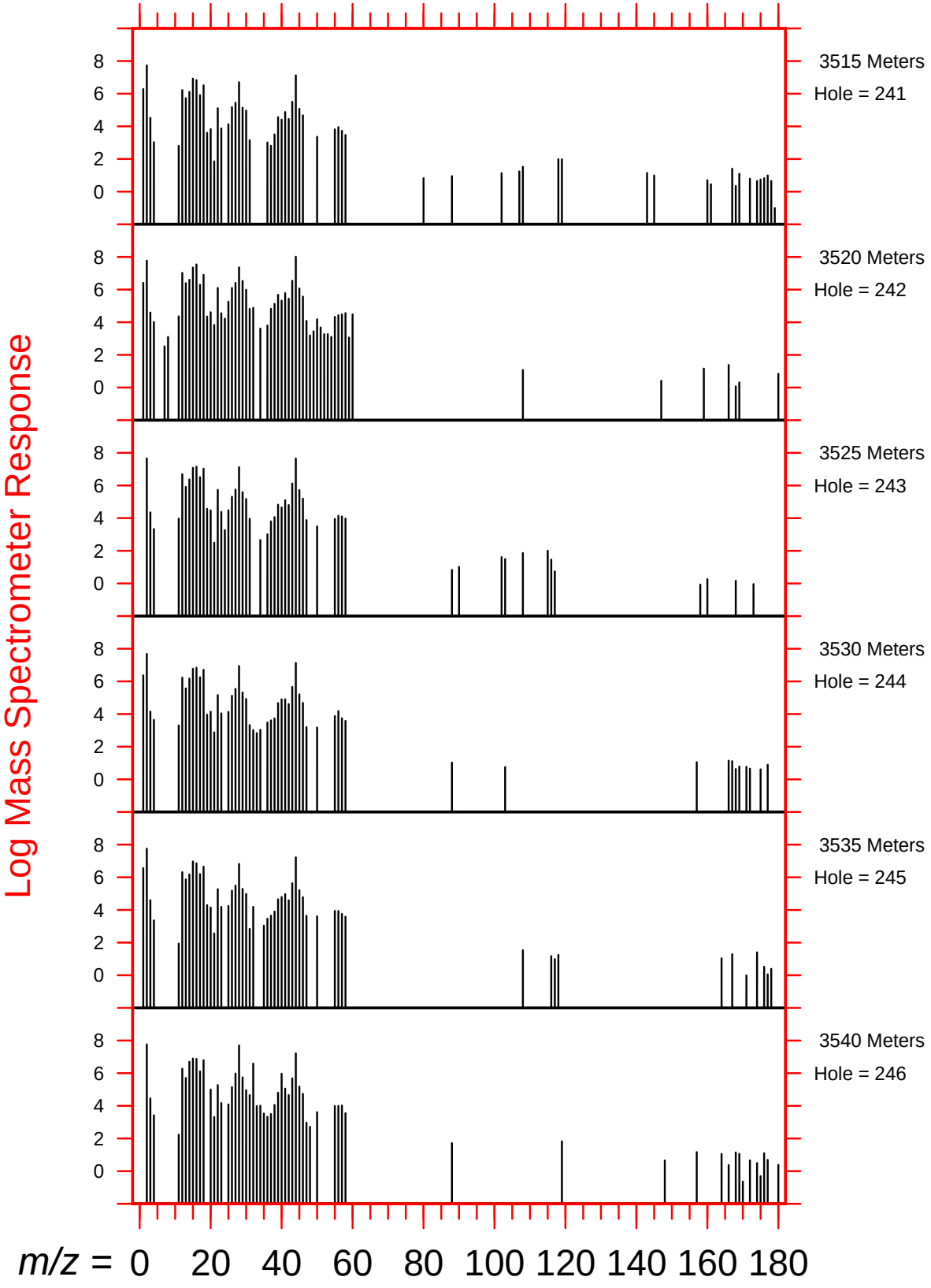

Log Mass Spectrometer Response
3365 Meters
Hole = 208
3370 Meters
Hole = 209
3375 Meters
Hole = 210
3380 Meters
Hole = 211
3385 Meters
Hole = 212
3390 Meters
Hole = 213
m/z = 0 20 40 60 80 100 120 140 160 180

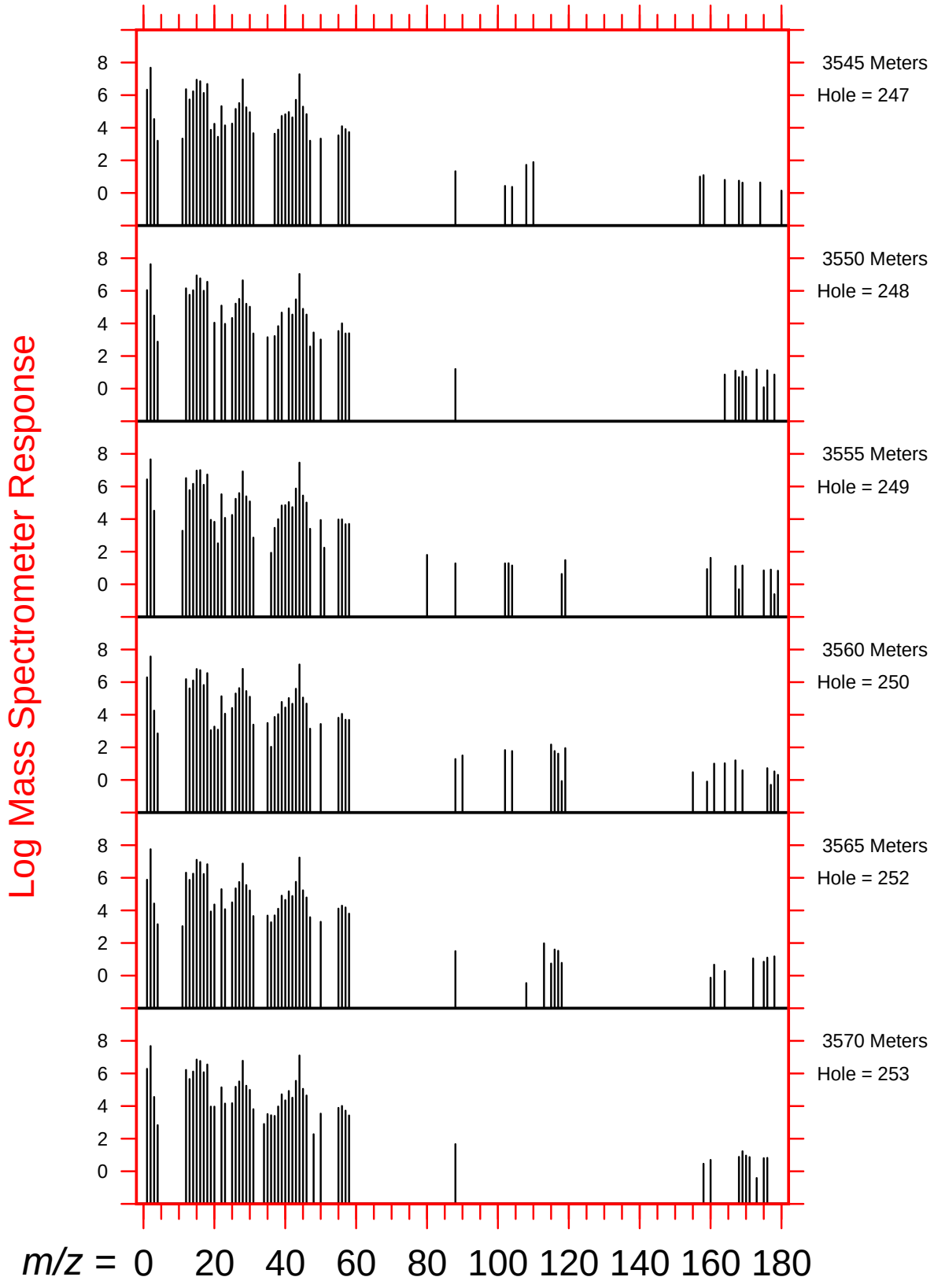

Log Mass Spectrometer Response
3395 Meters
Hole = 214
3400 Meters
Hole = 216
3405 Meters
Hole = 217
3410 Meters
Hole = 218
3415 Meters
Hole = 219
3420 Meters
Hole = 220
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

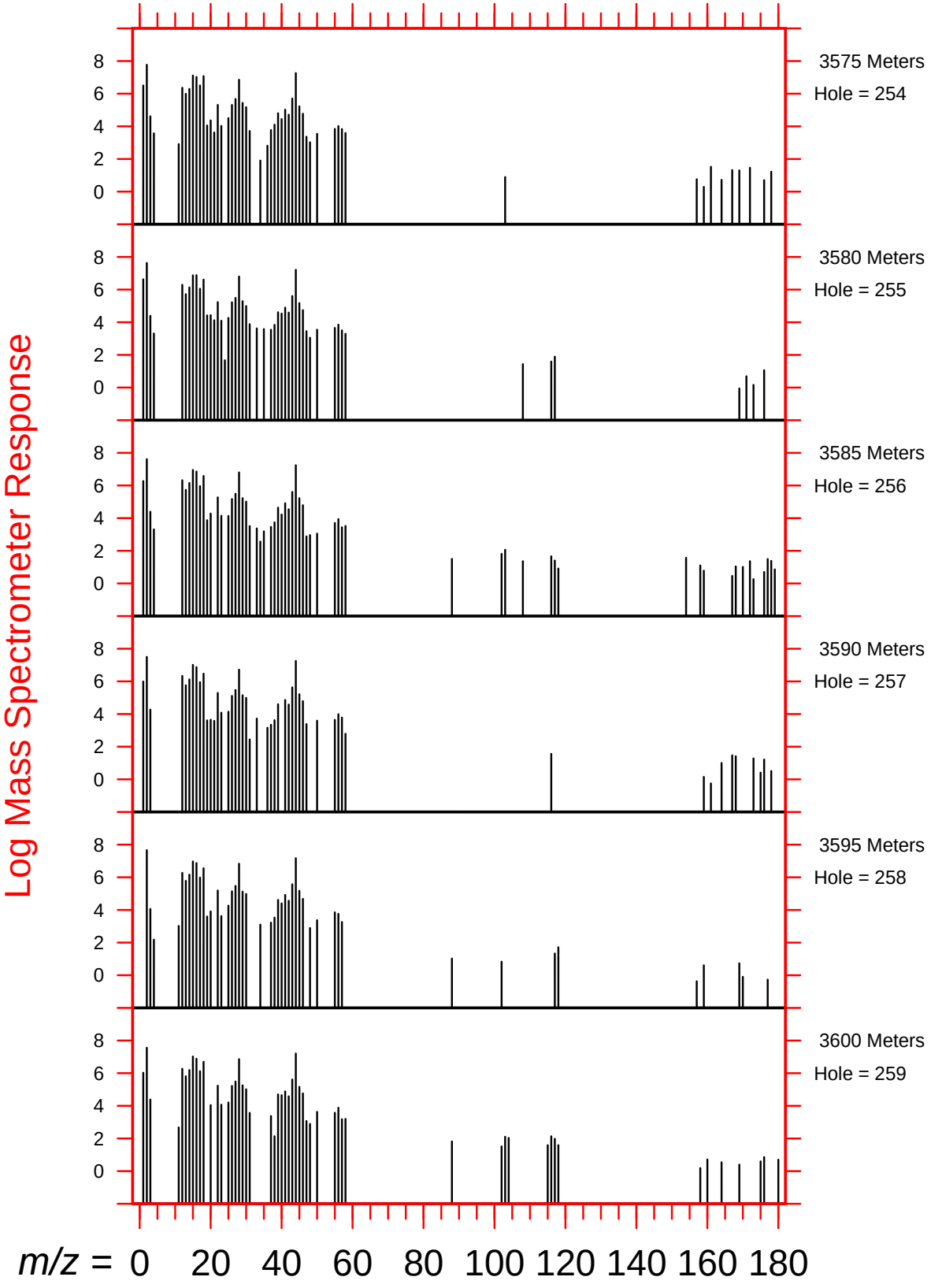

Log Mass Spectrometer Response
3425 Meters
Hole = 221
3430 Meters
Hole = 222
3435 Meters
Hole = 223
3440 Meters
Hole = 224
3445 Meters
Hole = 225
3450 Meters
Hole = 226
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

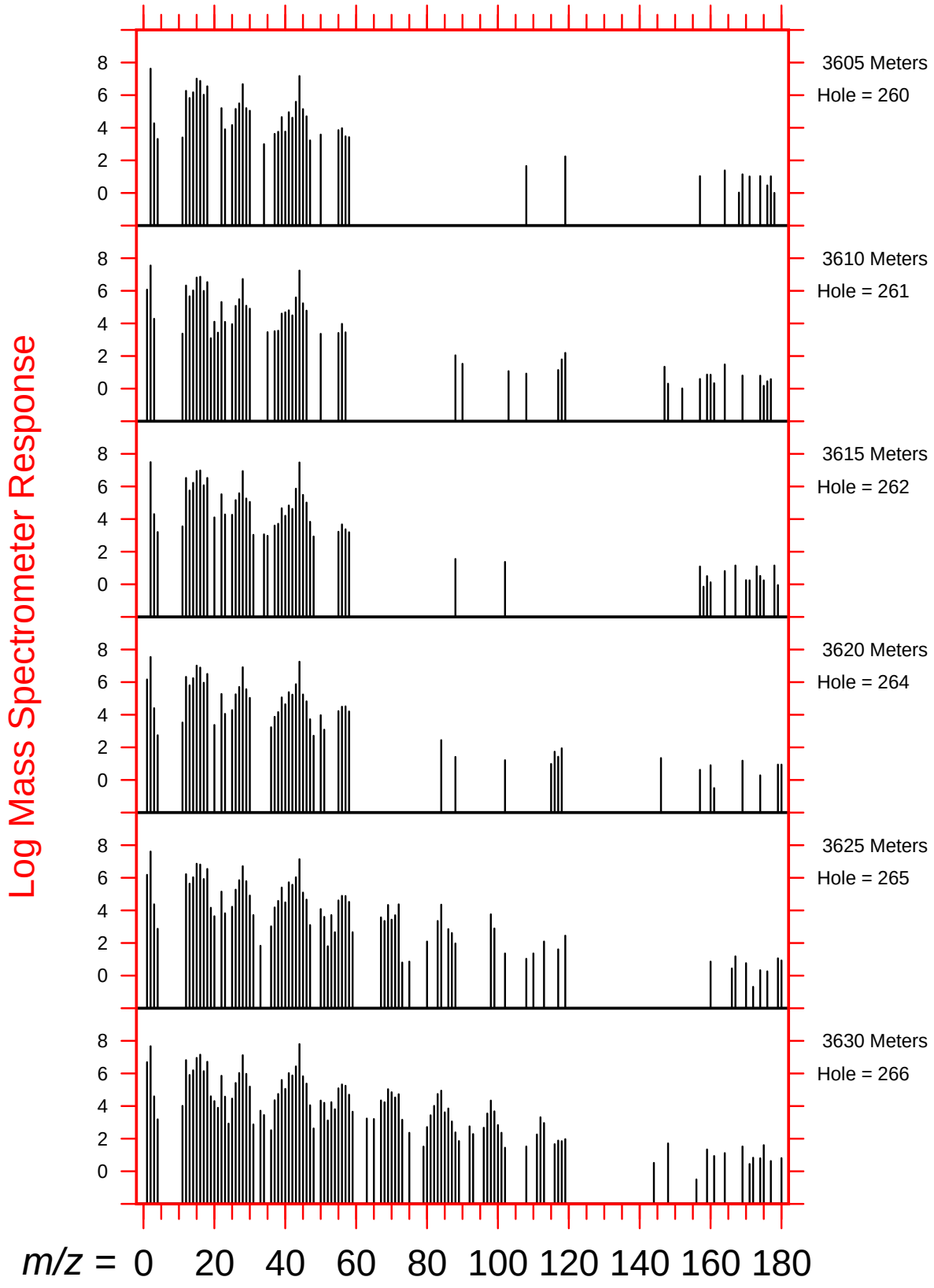

Log Mass Spectrometer Response
3455 Meters
Hole = 228
3460 Meters
Hole = 229
3465 Meters
Hole = 230
3470 Meters
Hole = 231
3475 Meters
Hole = 232
3480 Meters
Hole = 233
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

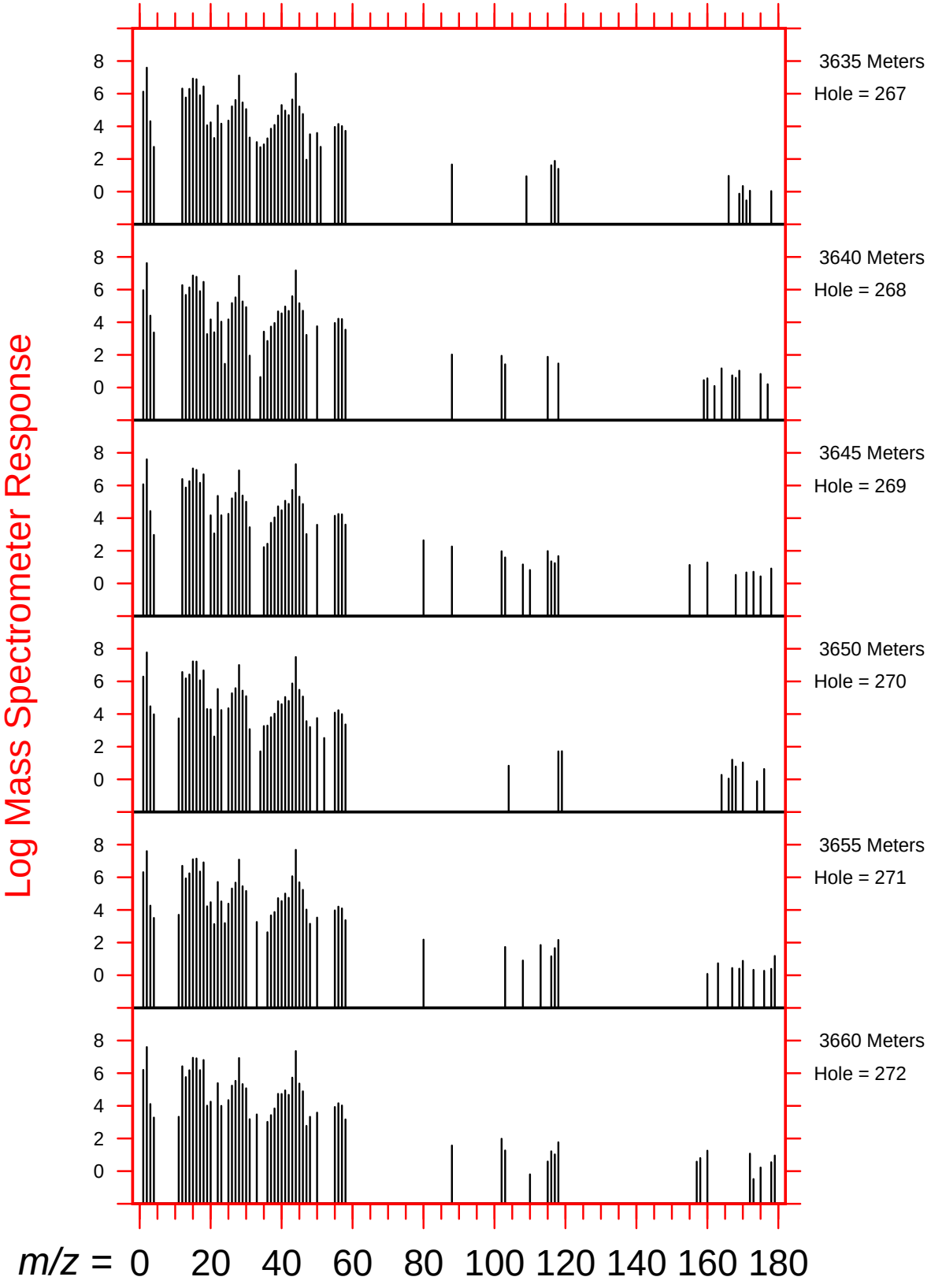

Log Mass Spectrometer Response
3485 Meters
Hole = 234
3490 Meters
Hole = 235
3495 Meters
Hole = 236
3500 Meters
Hole = 237
3505 Meters
Hole = 238
3510 Meters
Hole = 240
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

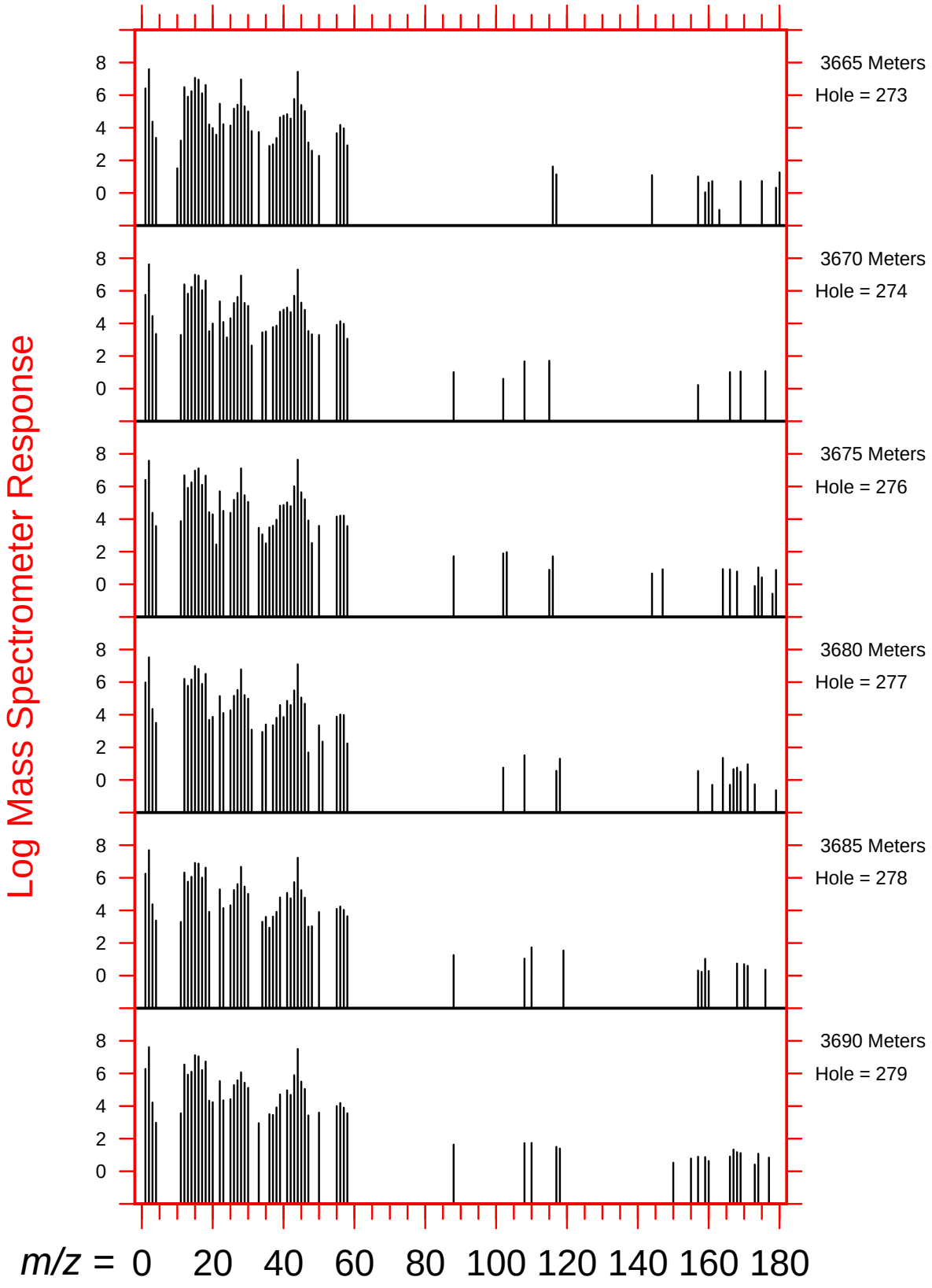

Log Mass Spectrometer Response
3515 Meters
Hole = 241
3520 Meters
Hole = 242
3525 Meters
Hole = 243
3530 Meters
Hole = 244
3535 Meters
Hole = 245
3540 Meters
Hole = 246
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

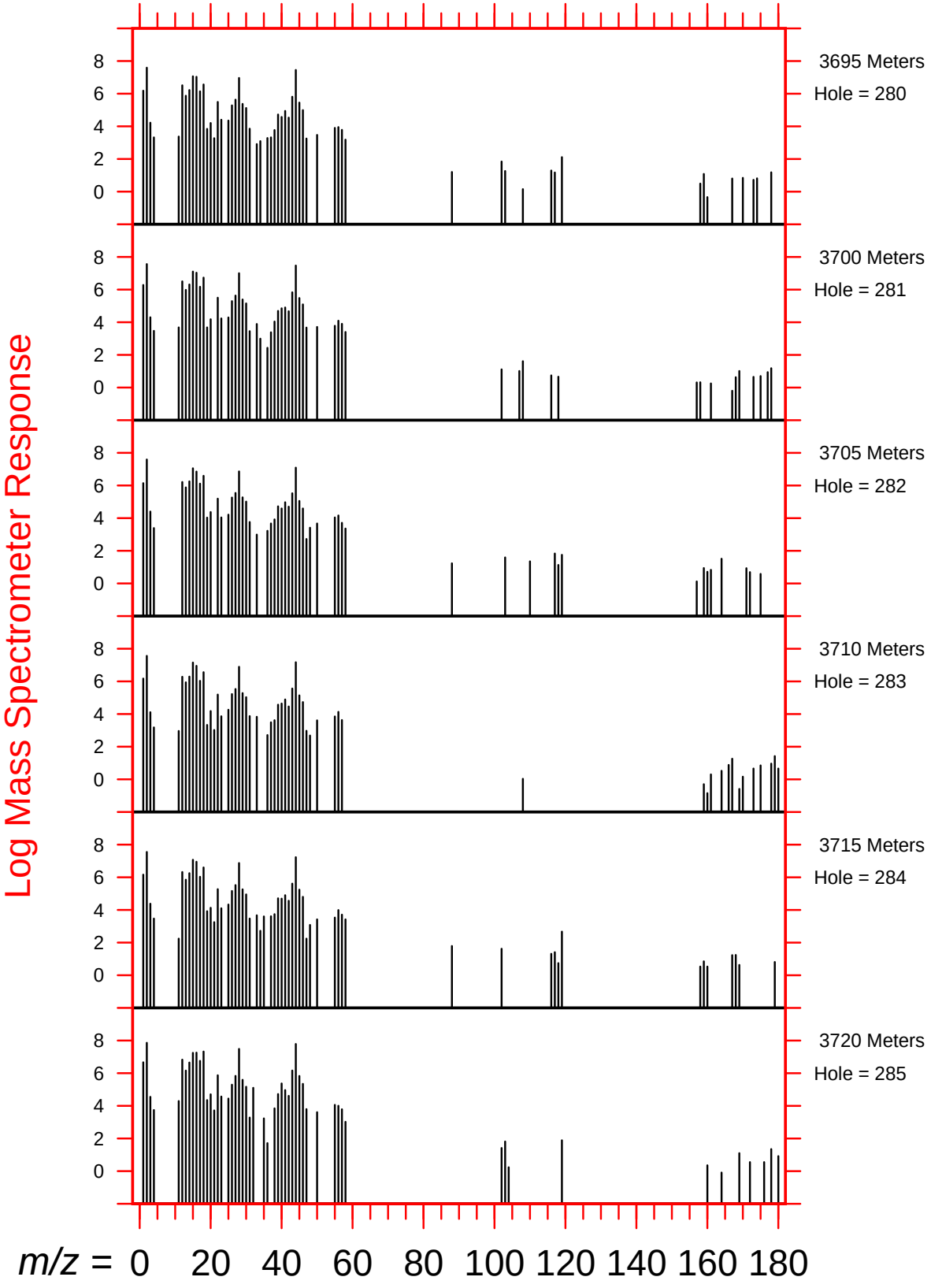

Log Mass Spectrometer Response
3545 Meters
Hole = 247
3550 Meters
Hole = 248
3555 Meters
Hole = 249
3560 Meters
Hole = 250
3565 Meters
Hole = 252
3570 Meters
Hole = 253
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

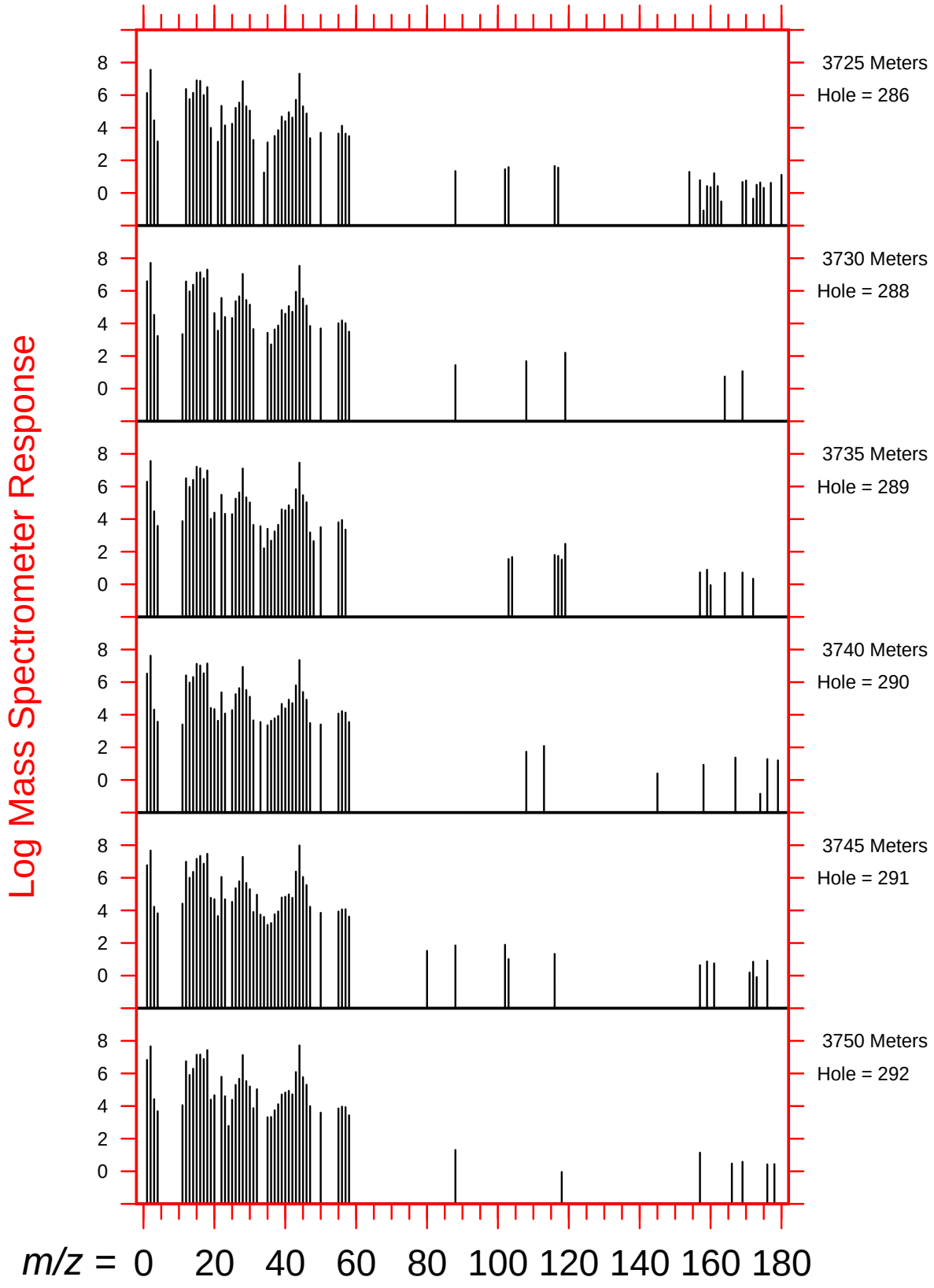

Log Mass Spectrometer Response
3575 Meters
Hole = 254
3580 Meters
Hole = 255
3585 Meters
Hole = 256
3590 Meters
Hole = 257
3595 Meters
Hole = 258
3600 Meters
Hole = 259
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

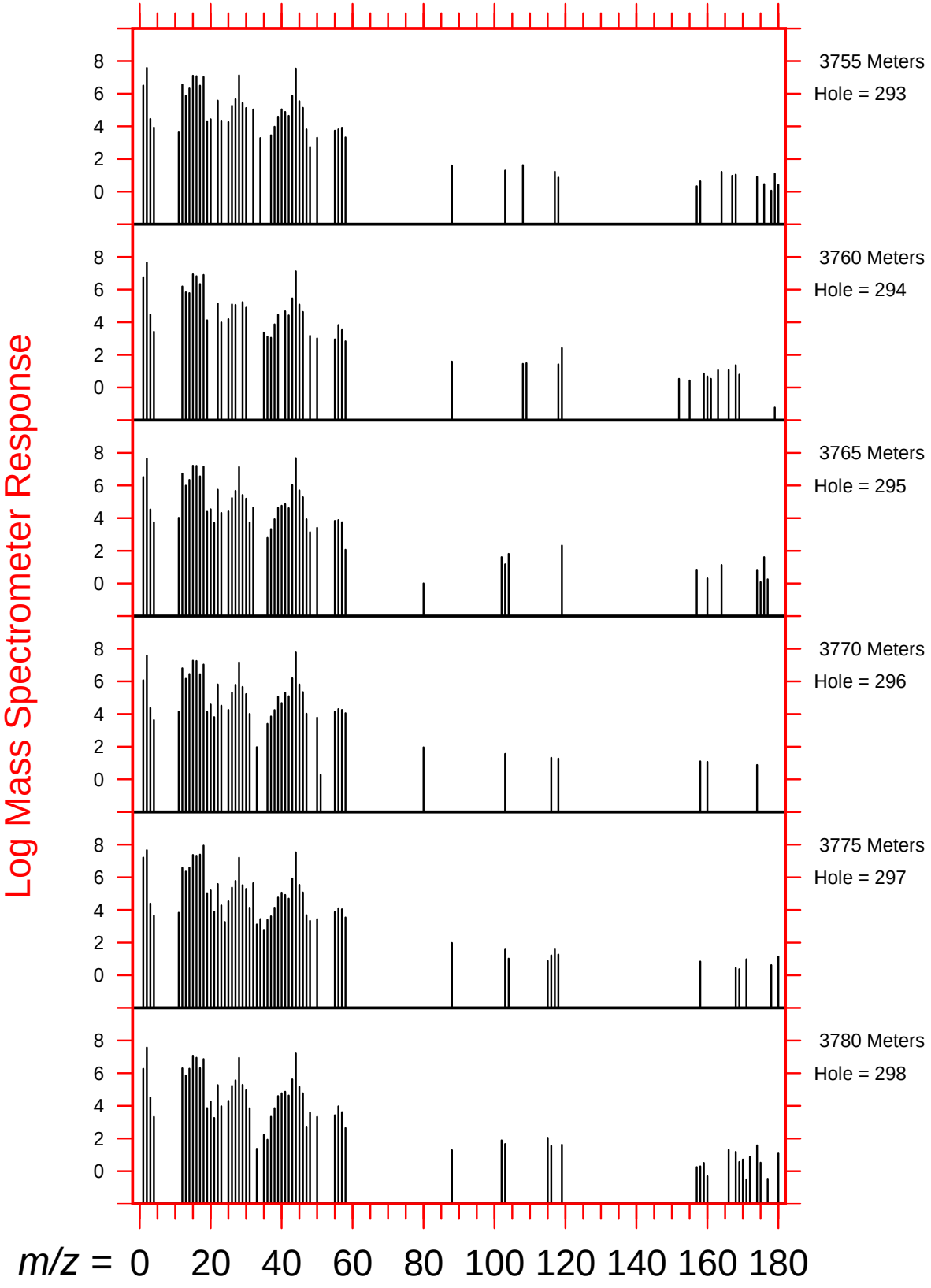

Log Mass Spectrometer Response
3605 Meters
Hole = 260
3610 Meters
Hole = 261
3615 Meters
Hole = 262
3620 Meters
Hole = 264
3625 Meters
Hole = 265
3630 Meters
Hole = 266
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

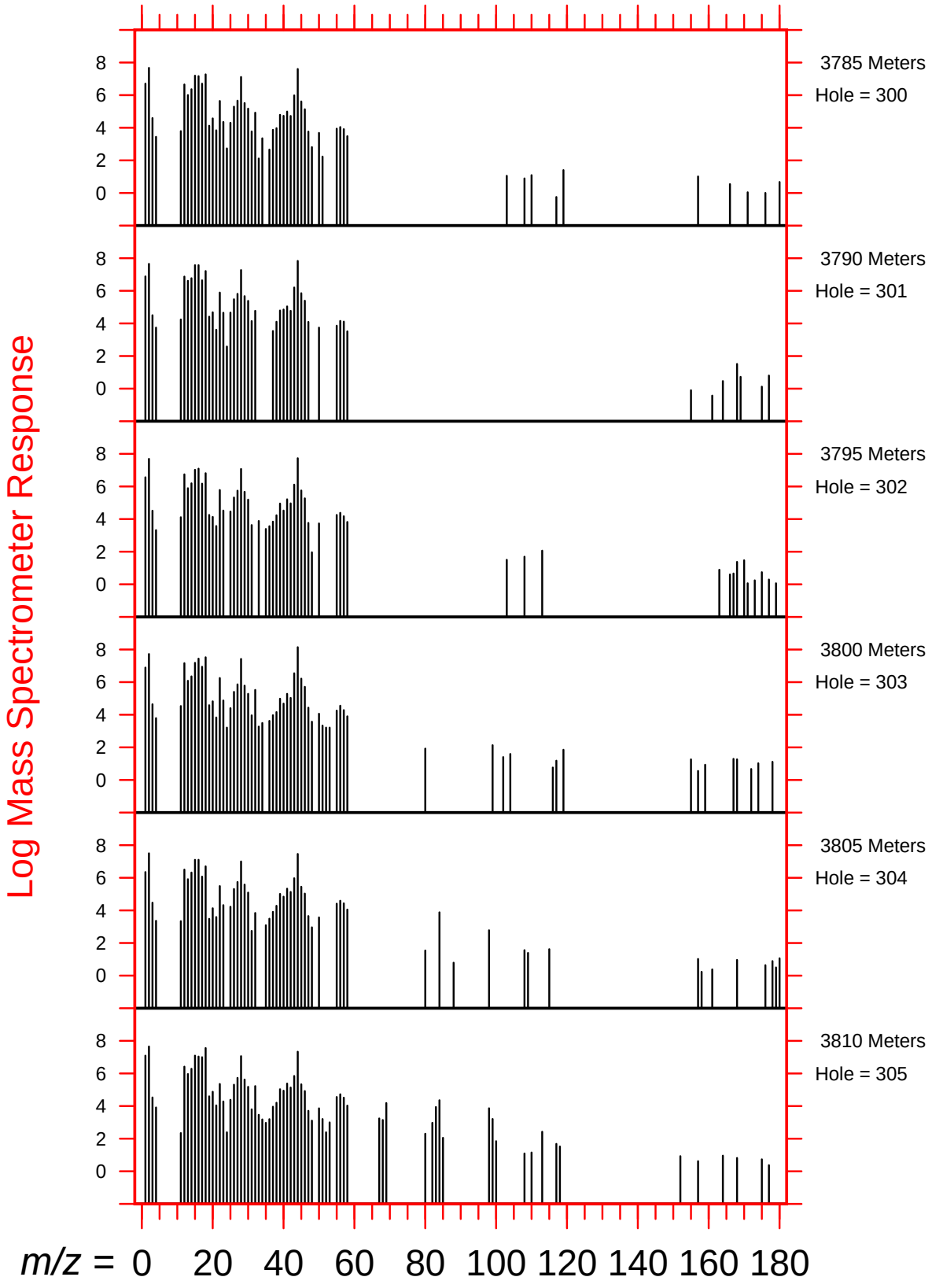

Log Mass Spectrometer Response
3635 Meters
Hole = 267
3640 Meters
Hole = 268
3645 Meters
Hole = 269
3650 Meters
Hole = 270
3655 Meters
Hole = 271
3660 Meters
Hole = 272
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

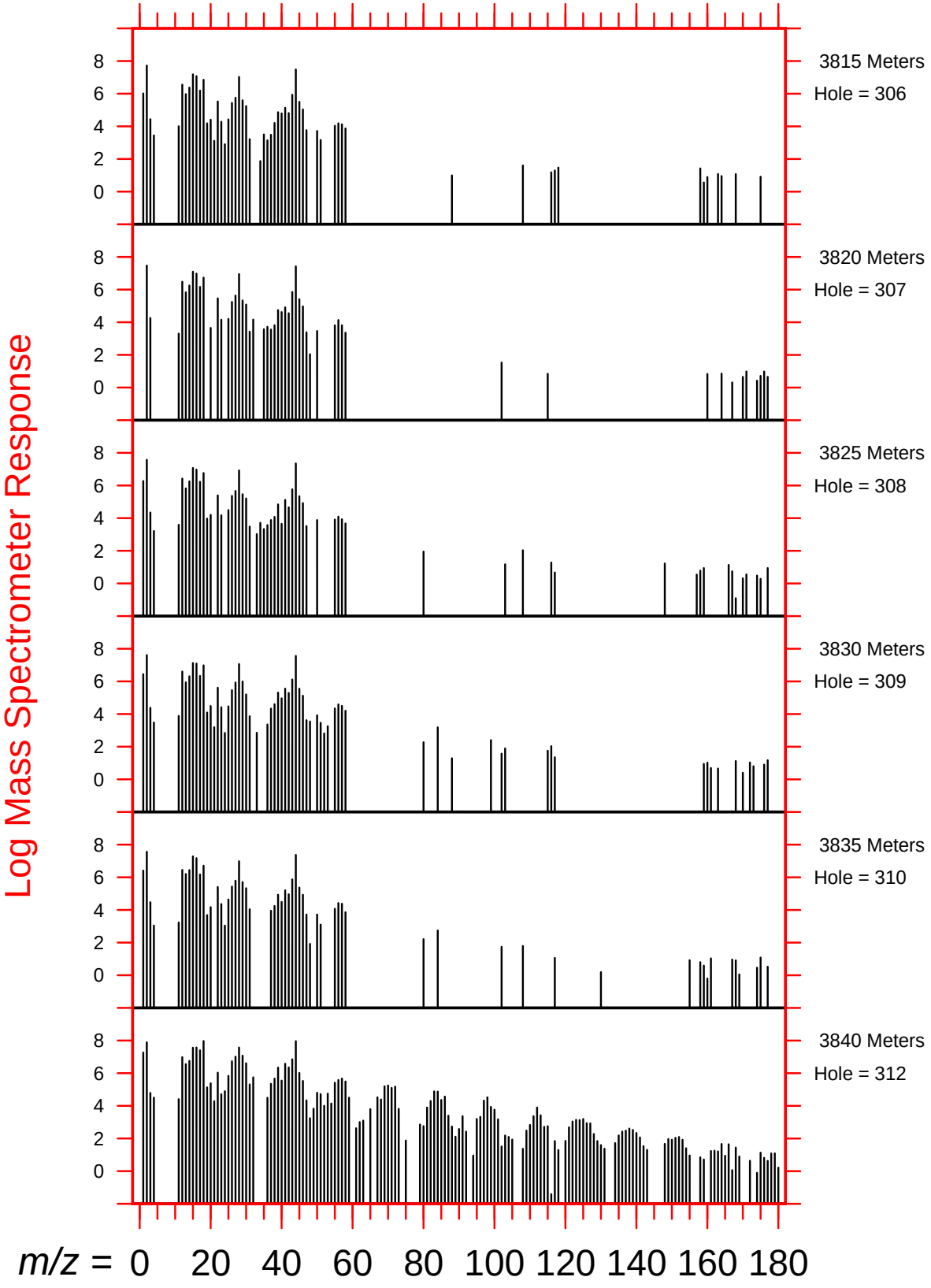

Log Mass Spectrometer Response
3665 Meters
Hole = 273
3670 Meters
Hole = 274
3675 Meters
Hole = 276
3680 Meters
Hole = 277
3685 Meters
Hole = 278
3690 Meters
Hole = 279
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

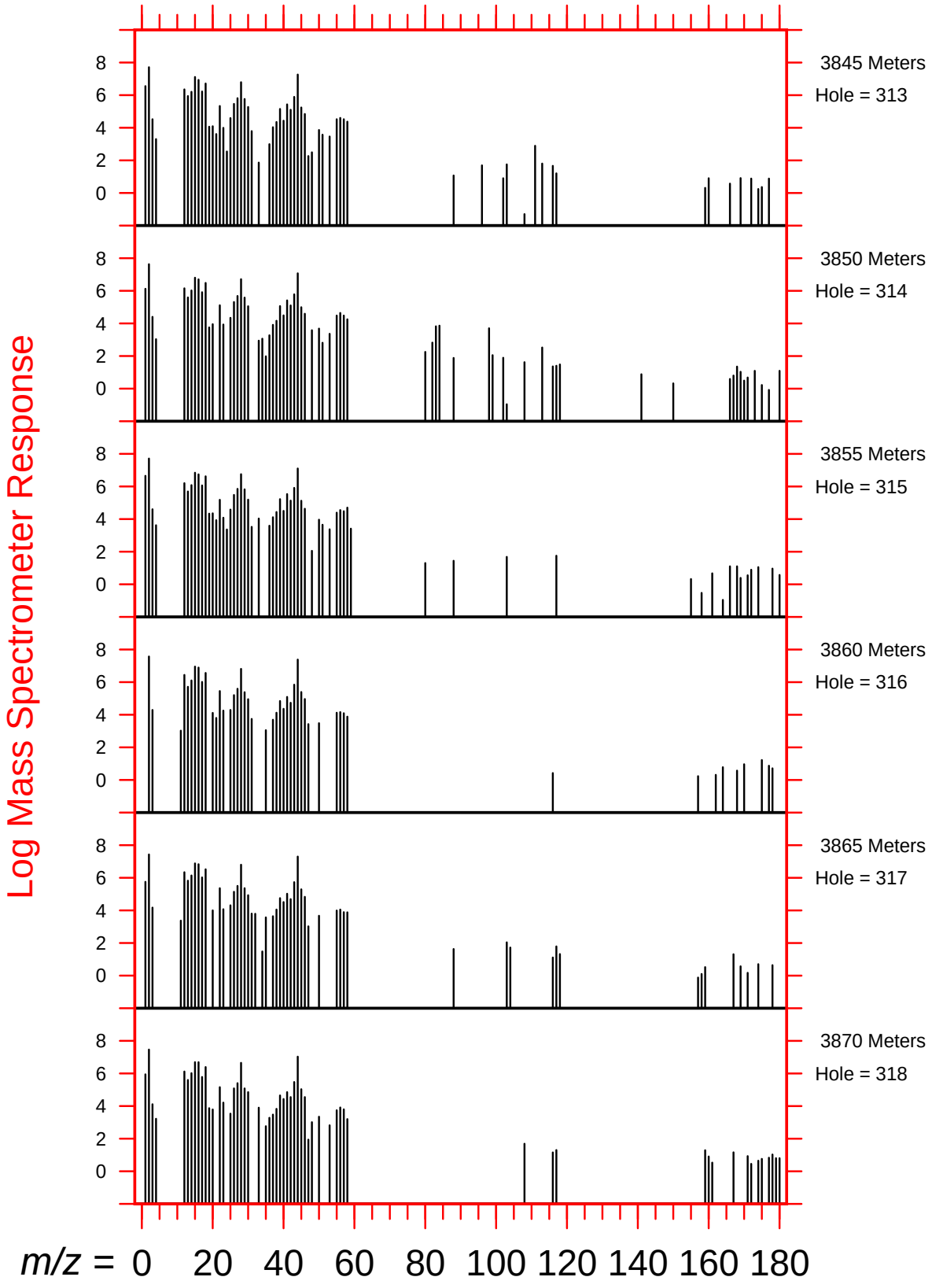

Log Mass Spectrometer Response
3695 Meters
Hole = 280
3700 Meters
Hole = 281
3705 Meters
Hole = 282
3710 Meters
Hole = 283
3715 Meters
Hole = 284
3720 Meters
Hole = 285
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

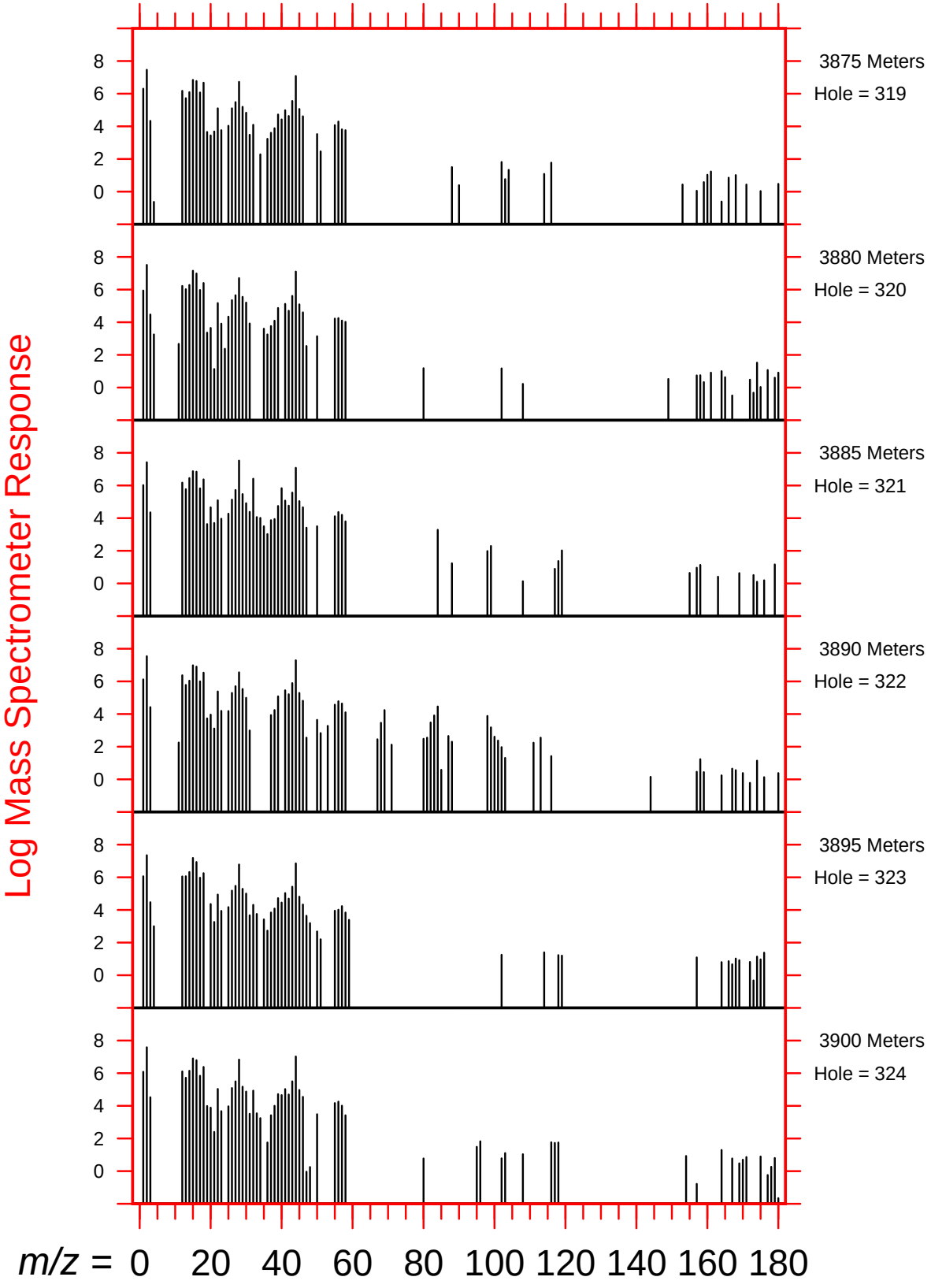

Log Mass Spectrometer Response
3725 Meters
Hole = 286
3730 Meters
Hole = 288
3735 Meters
Hole = 289
3740 Meters
Hole = 290
3745 Meters
Hole = 291
3750 Meters
Hole = 292
m/z = 0 20 40 60 80 100 120 140 160 180

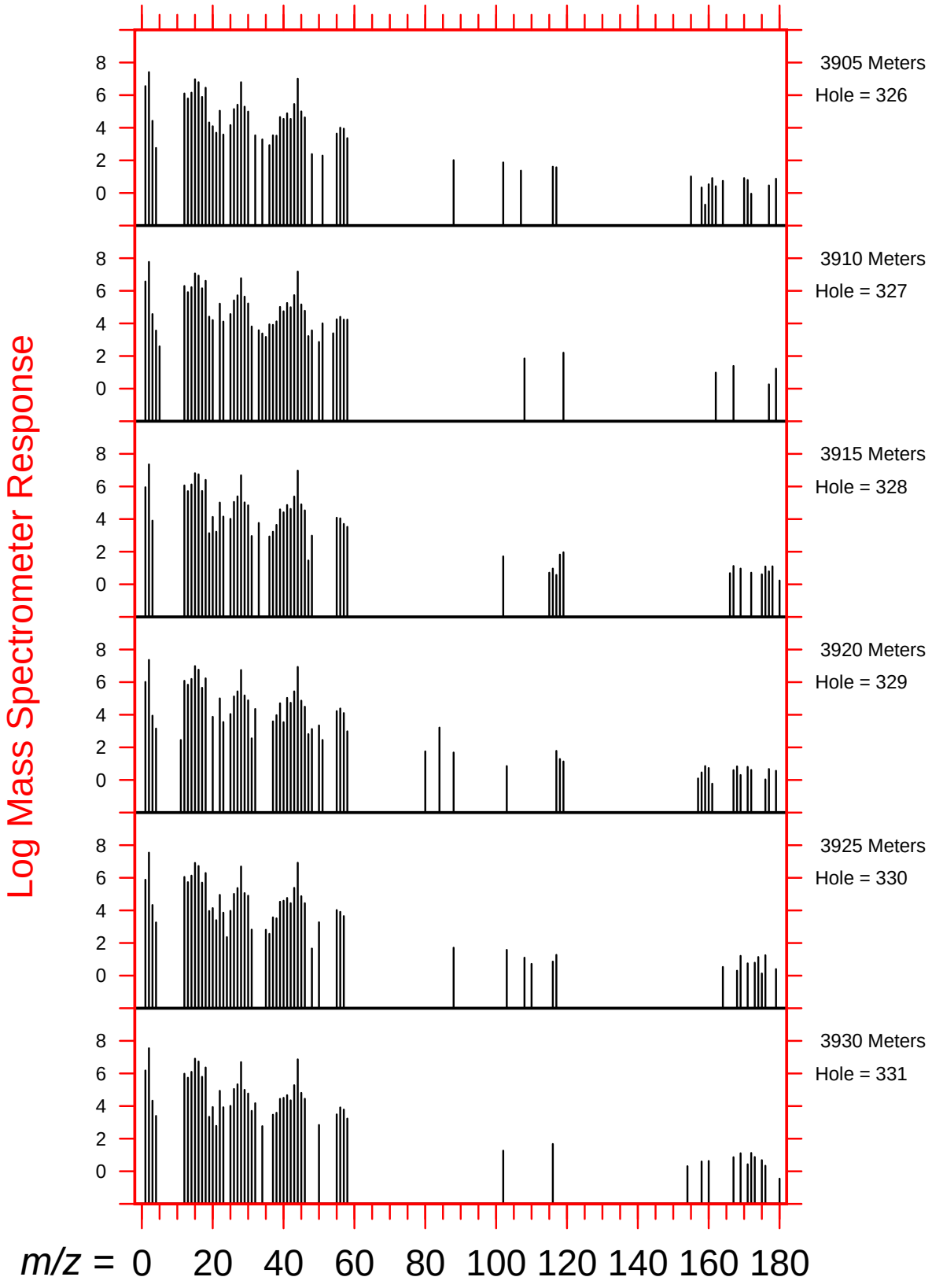

Log Mass Spectrometer Response
3755 Meters
Hole = 293
3760 Meters
Hole = 294
3765 Meters
Hole = 295
3770 Meters
Hole = 296
3775 Meters
Hole = 297
3780 Meters
Hole = 298
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

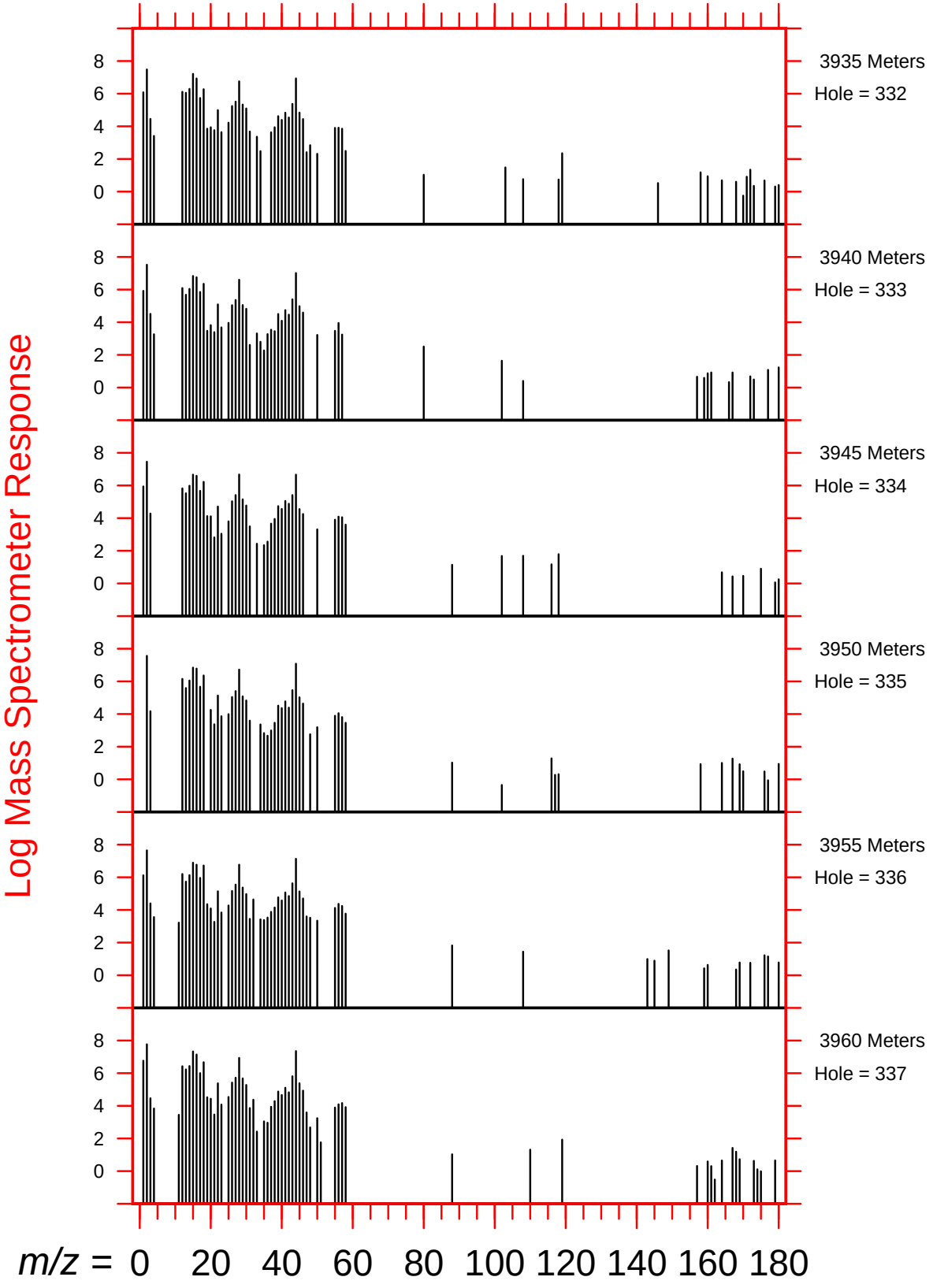

Log Mass Spectrometer Response
3785 Meters
Hole = 300
3790 Meters
Hole = 301
3795 Meters
Hole = 302
3800 Meters
Hole = 303
3805 Meters
Hole = 304
3810 Meters
Hole = 305
m/z = 0 20 40 60 80 100 120 140 160 180

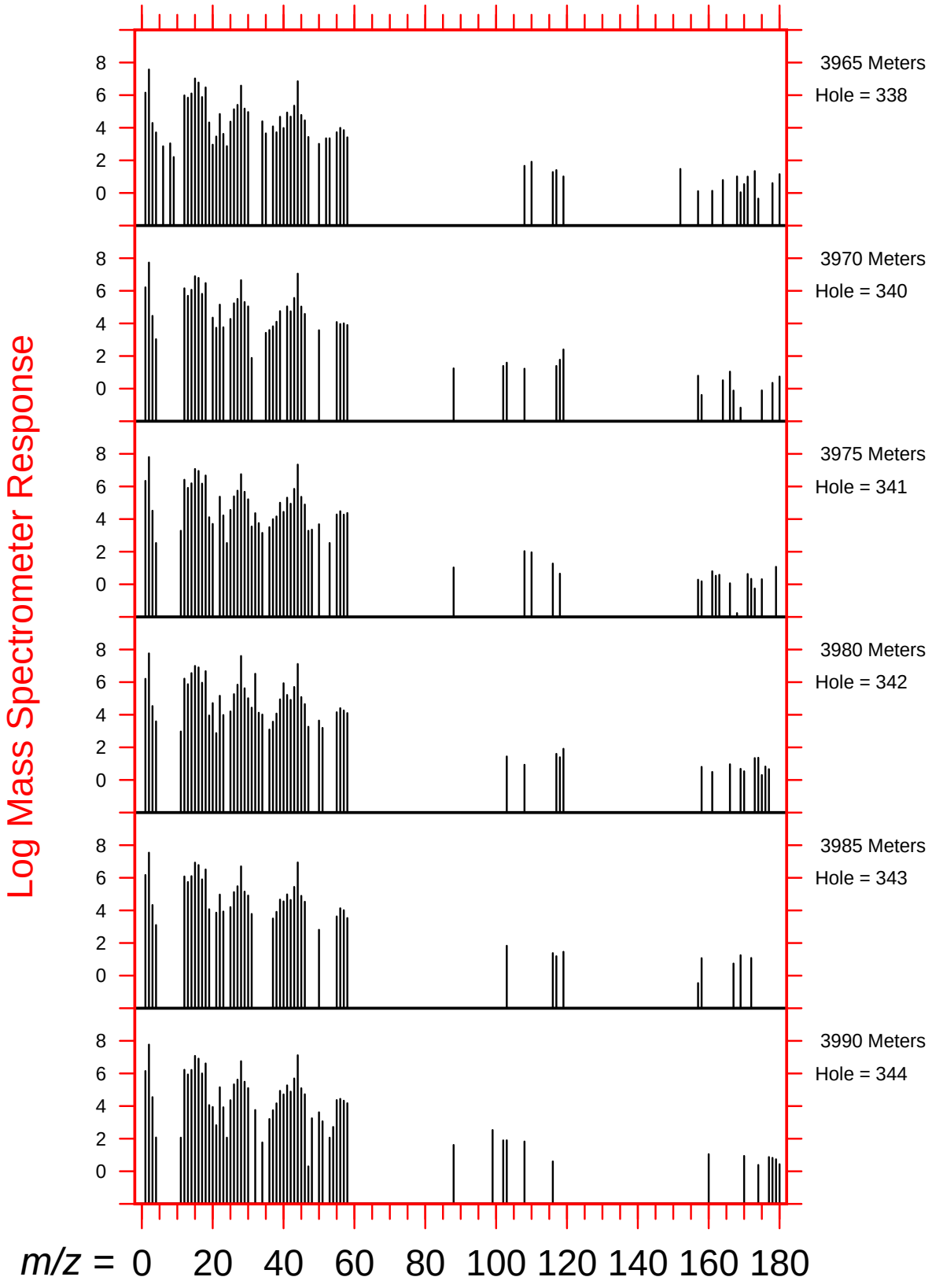

Log Mass Spectrometer Response
3815 Meters
Hole = 306
3820 Meters
Hole = 307
3825 Meters
Hole = 308
3830 Meters
Hole = 309
3835 Meters
Hole = 310
3840 Meters
Hole = 312
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

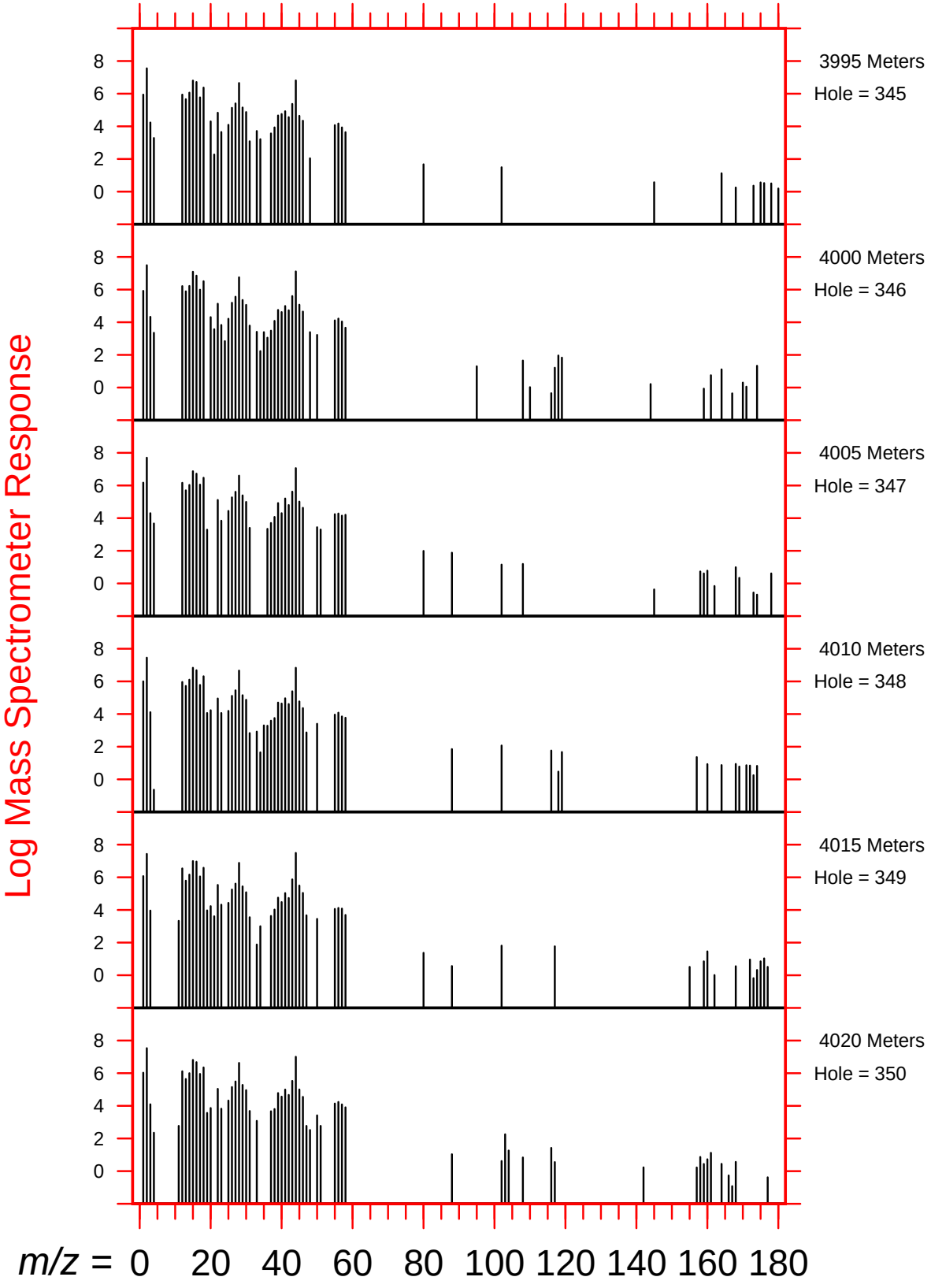

Log Mass Spectrometer Response
3845 Meters
Hole = 313
3850 Meters
Hole = 314
3855 Meters
Hole = 315
3860 Meters
Hole = 316
3865 Meters
Hole = 317
3870 Meters
Hole = 318
m/z = 0 20 40 60 80 100 120 140 160 180

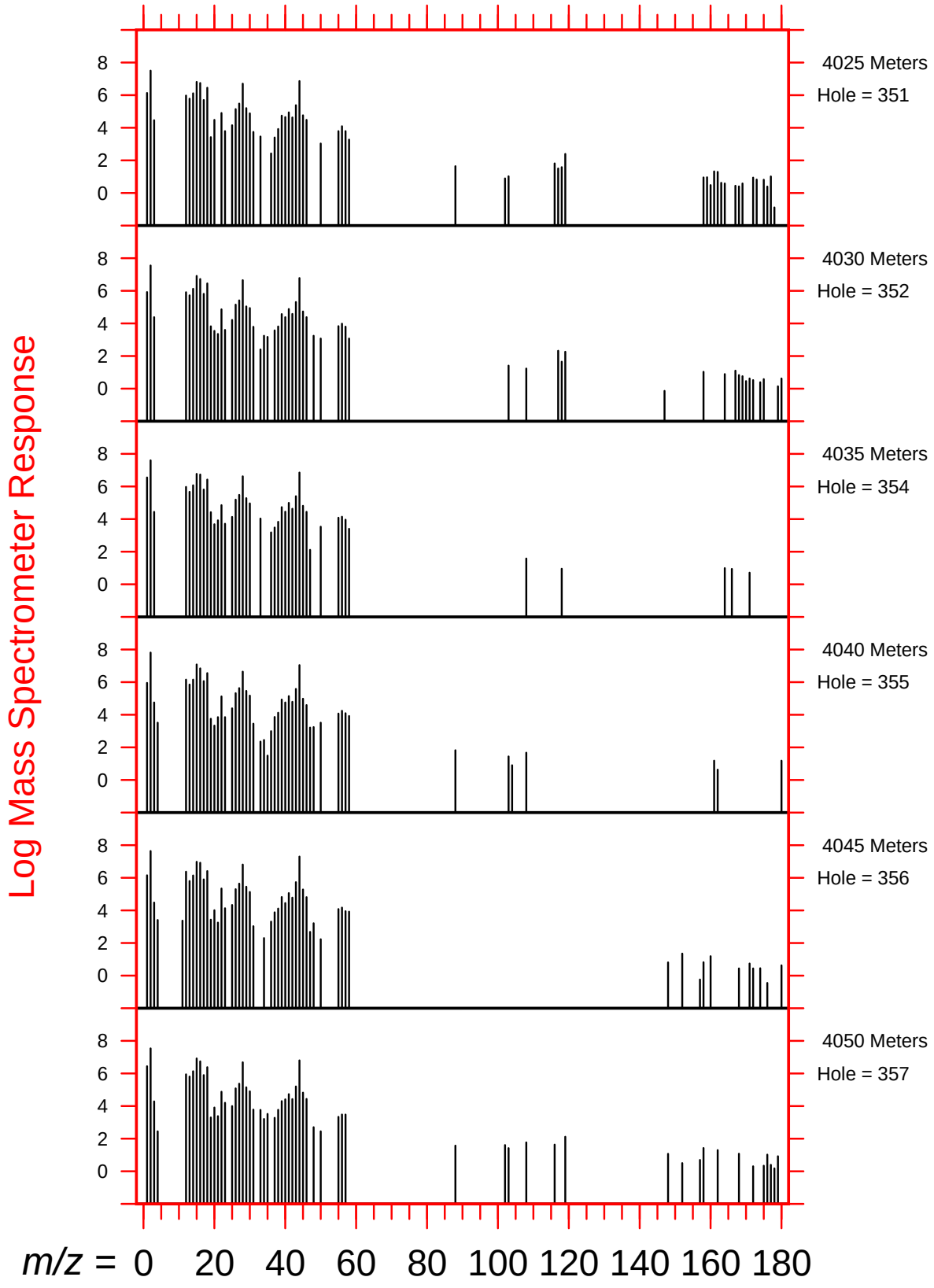

Log Mass Spectrometer Response
3875 Meters
Hole = 319
3880 Meters
Hole = 320
3885 Meters
Hole = 321
3890 Meters
Hole = 322
3895 Meters
Hole = 323
3900 Meters
Hole = 324
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

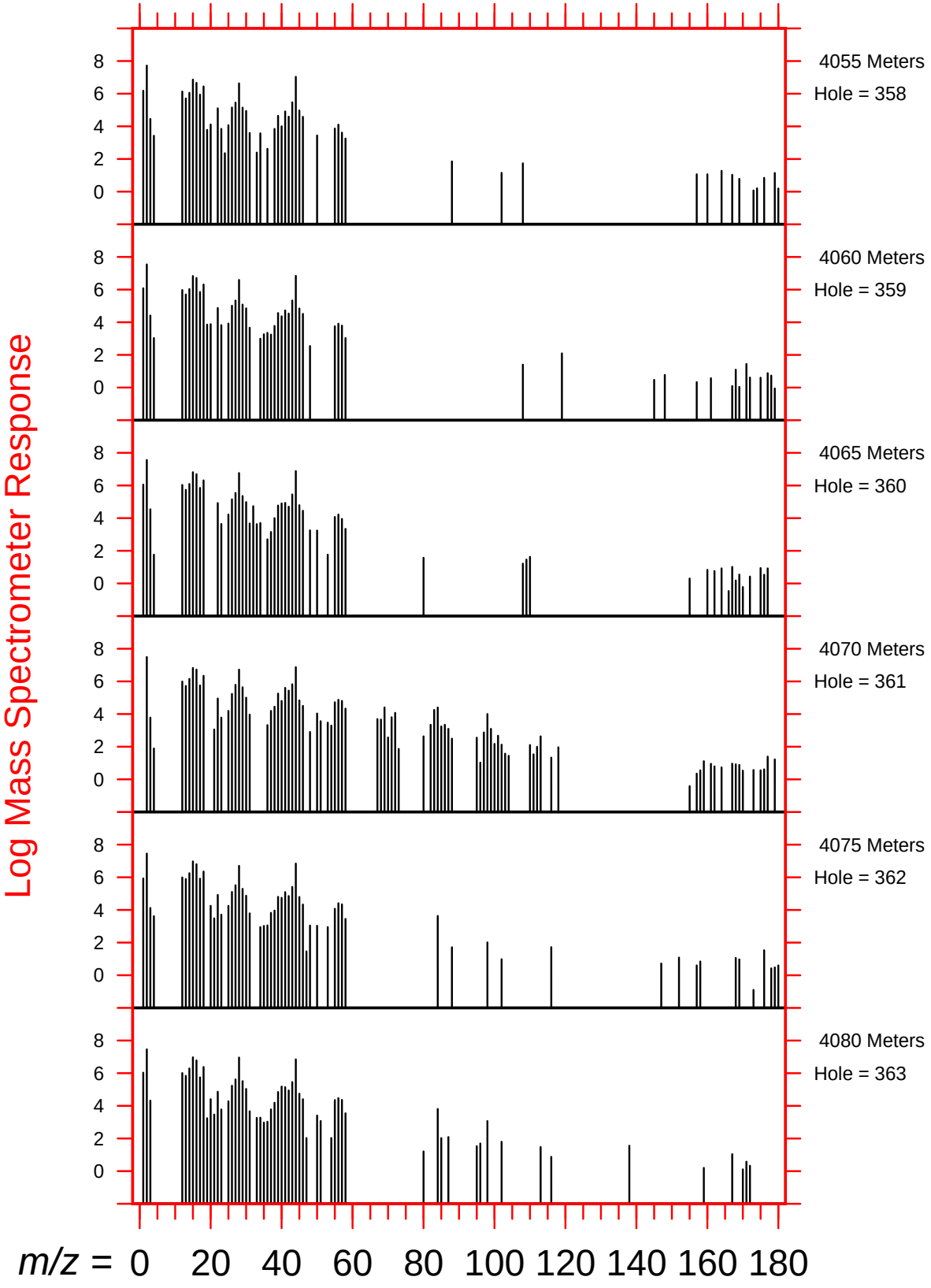

Log Mass Spectrometer Response
3905 Meters
Hole = 326
3910 Meters
Hole = 327
3915 Meters
Hole = 328
3920 Meters
Hole = 329
3925 Meters
Hole = 330
3930 Meters
Hole = 331
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

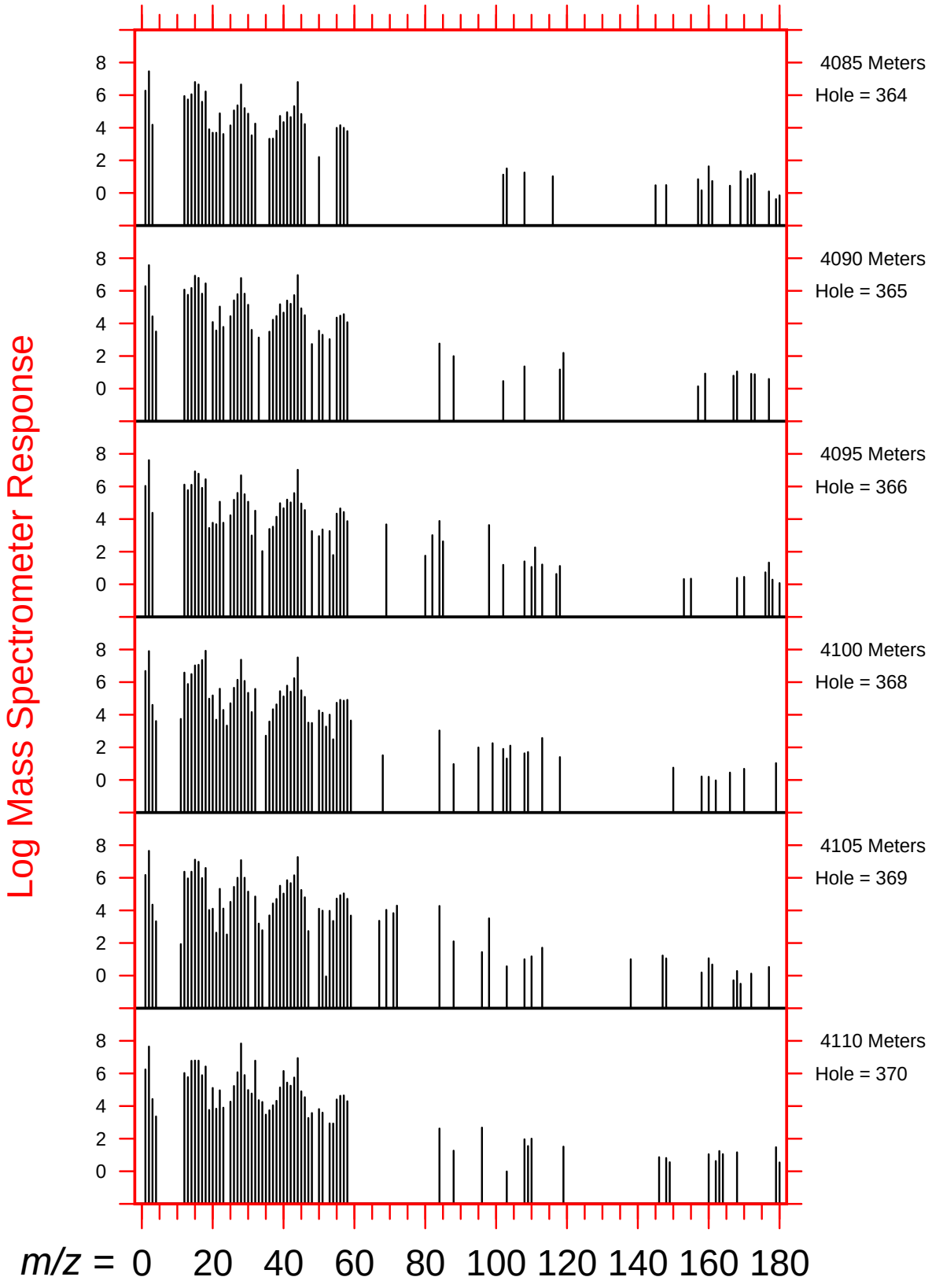

Log Mass Spectrometer Response
3935 Meters
Hole = 332
3940 Meters
Hole = 333
3945 Meters
Hole = 334
3950 Meters
Hole = 335
3955 Meters
Hole = 336
3960 Meters
Hole = 337
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

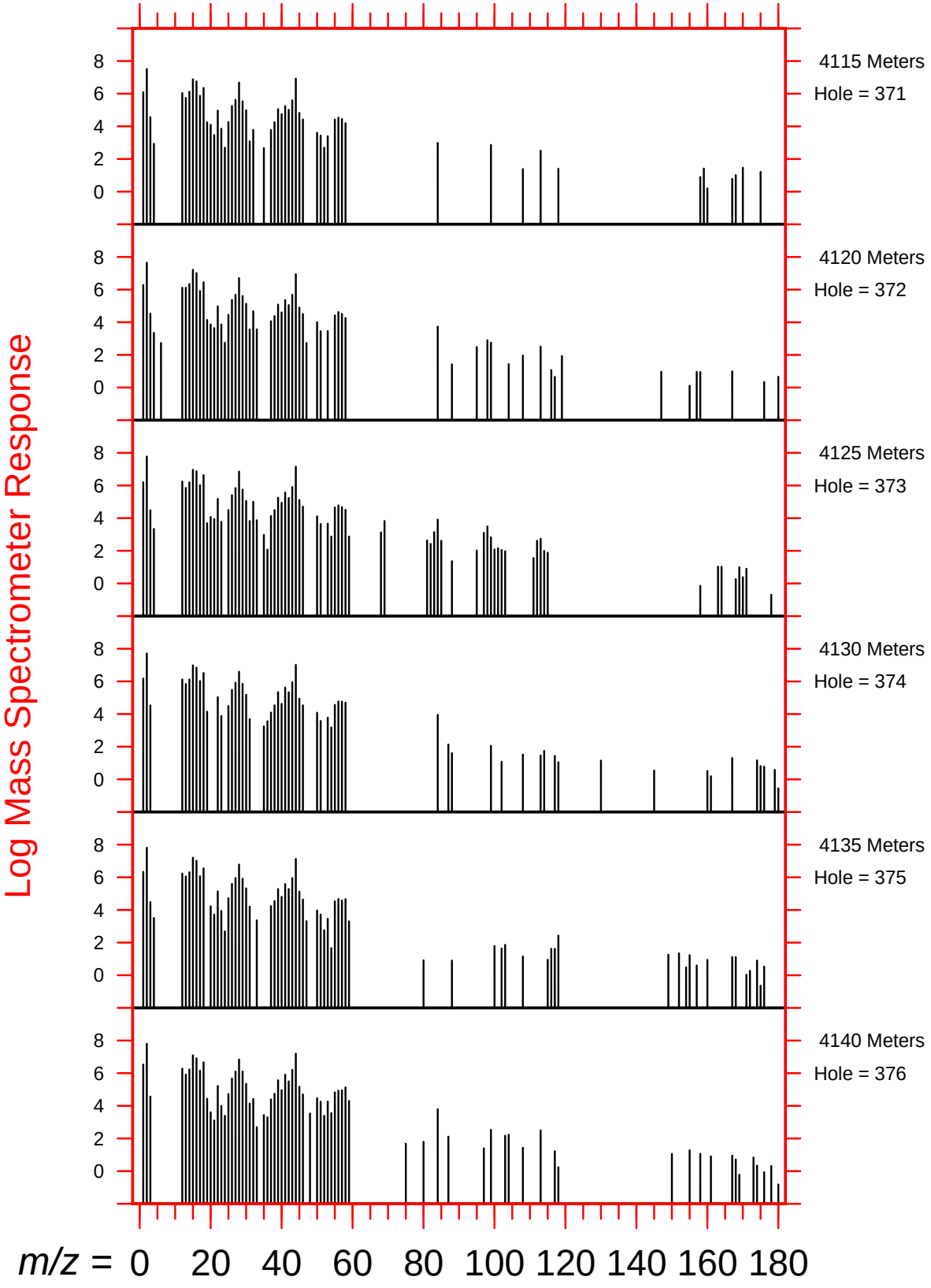

Log Mass Spectrometer Response
3965 Meters
Hole = 338
3970 Meters
Hole = 340
3975 Meters
Hole = 341
3980 Meters
Hole = 342
3985 Meters
Hole = 343
3990 Meters
Hole = 344
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

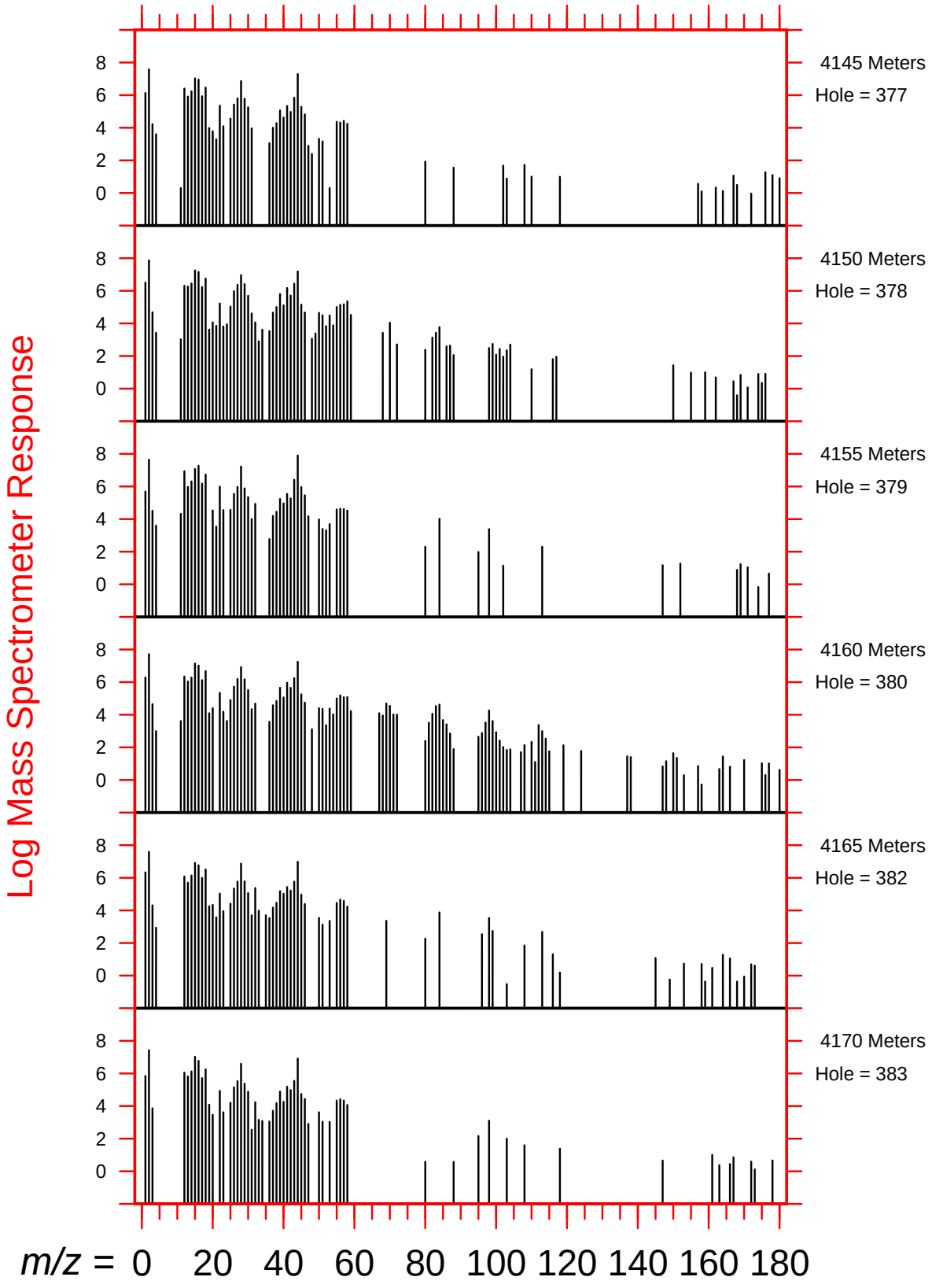

Log Mass Spectrometer Response
3995 Meters
Hole = 345
4000 Meters
Hole = 346
4005 Meters
Hole = 347
4010 Meters
Hole = 348
4015 Meters
Hole = 349
4020 Meters
Hole = 350
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

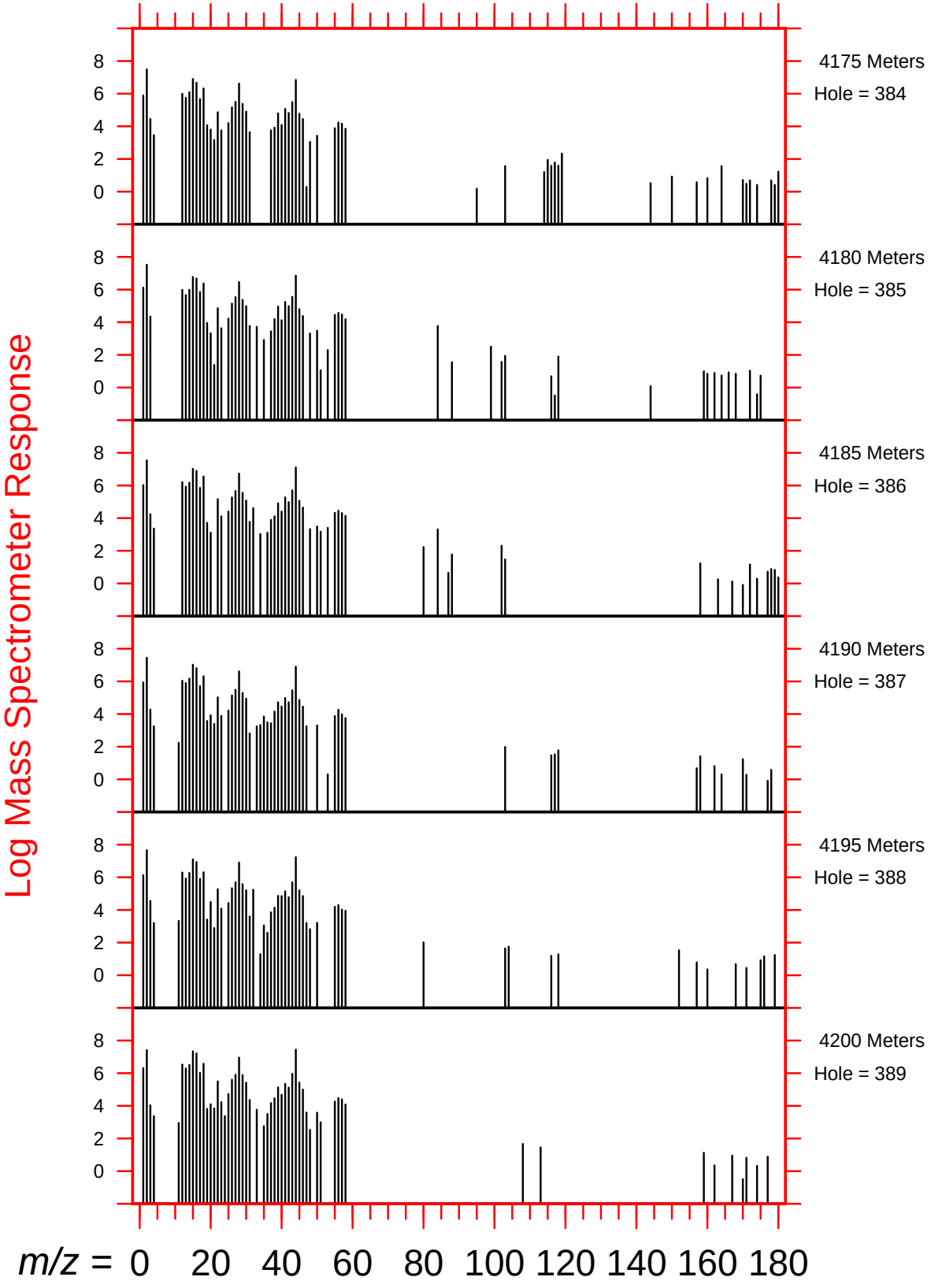

Log Mass Spectrometer Response
4025 Meters
Hole = 351
4030 Meters
Hole = 352
4035 Meters
Hole = 354
4040 Meters
Hole = 355
4045 Meters
Hole = 356
4050 Meters
Hole = 357
m/z = 0 20 40 60 80 100 120 140 160 180

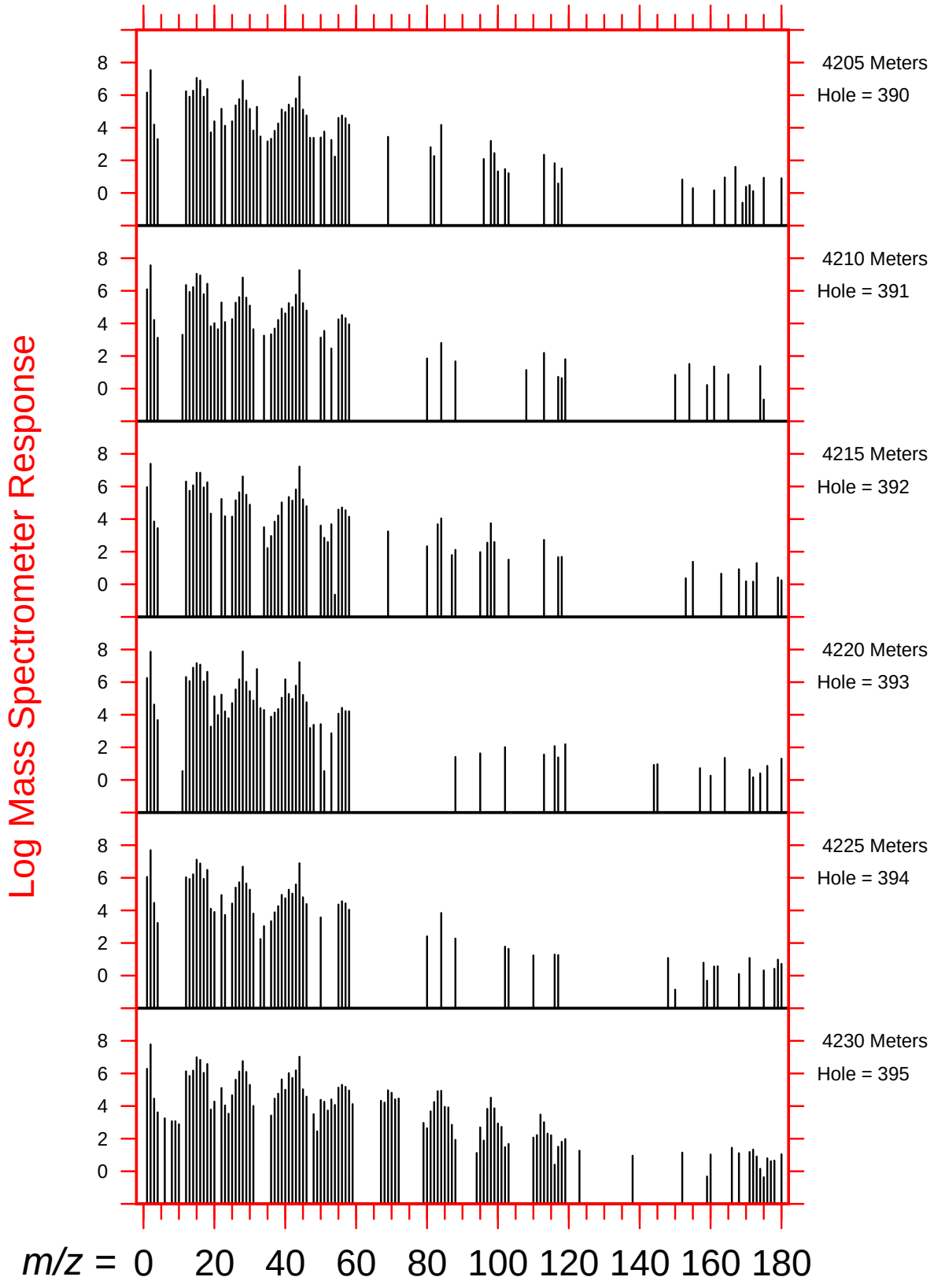

Log Mass Spectrometer Response
4055 Meters
Hole = 358
4060 Meters
Hole = 359
4065 Meters
Hole = 360
4070 Meters
Hole = 361
4075 Meters
Hole = 362
4080 Meters
Hole = 363
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

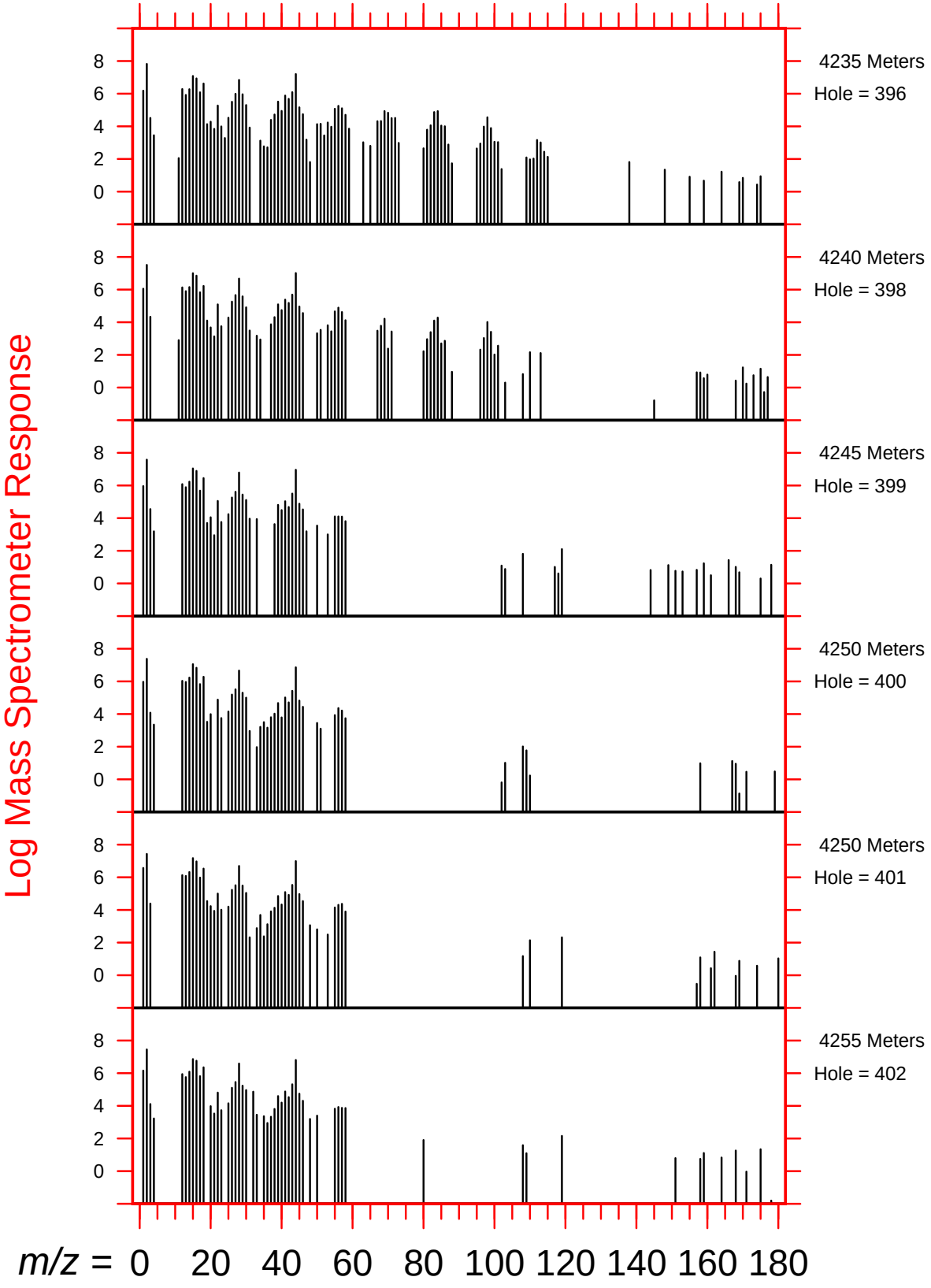

Log Mass Spectrometer Response
4085 Meters
Hole = 364
4090 Meters
Hole = 365
4095 Meters
Hole = 366
4100 Meters
Hole = 368
4105 Meters
Hole = 369
4110 Meters
Hole = 370
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

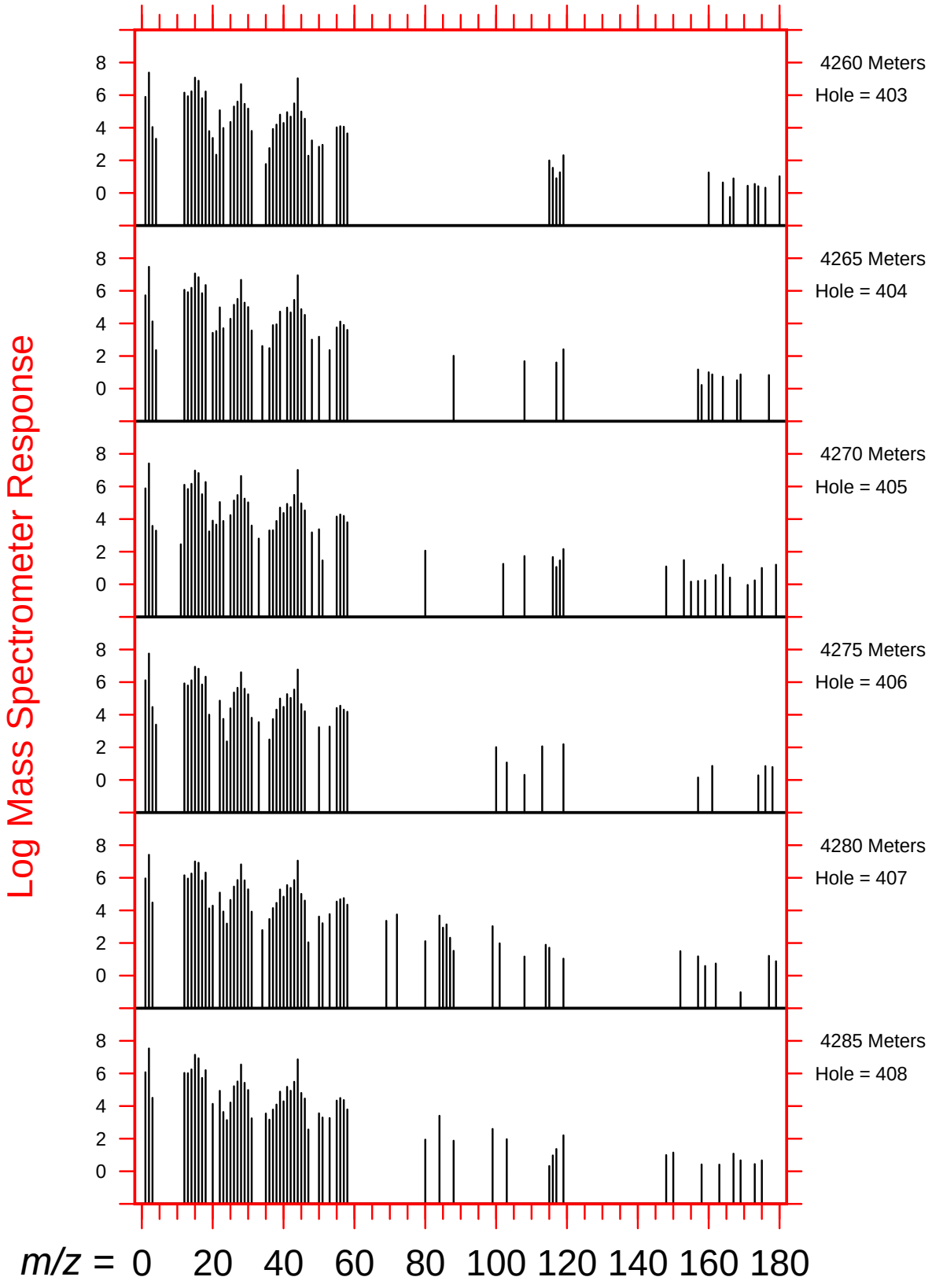

Log Mass Spectrometer Response
4115 Meters
Hole = 371
4120 Meters
Hole = 372
4125 Meters
Hole = 373
4130 Meters
Hole = 374
4135 Meters
Hole = 375
4140 Meters
Hole = 376
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

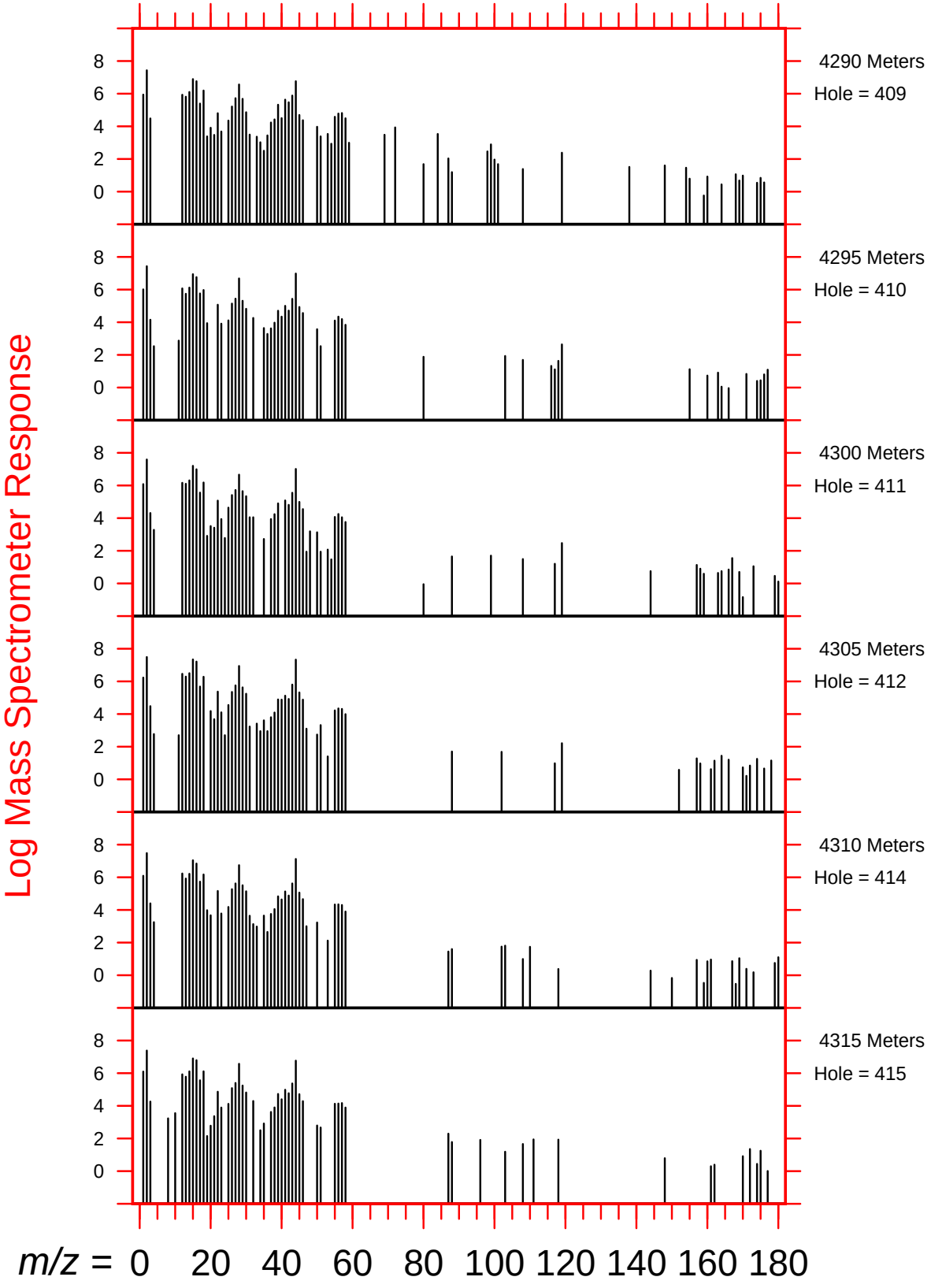

Log Mass Spectrometer Response
4145 Meters
Hole = 377
4150 Meters
Hole = 378
4155 Meters
Hole = 379
4160 Meters
Hole = 380
4165 Meters
Hole = 382
4170 Meters
Hole = 383
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

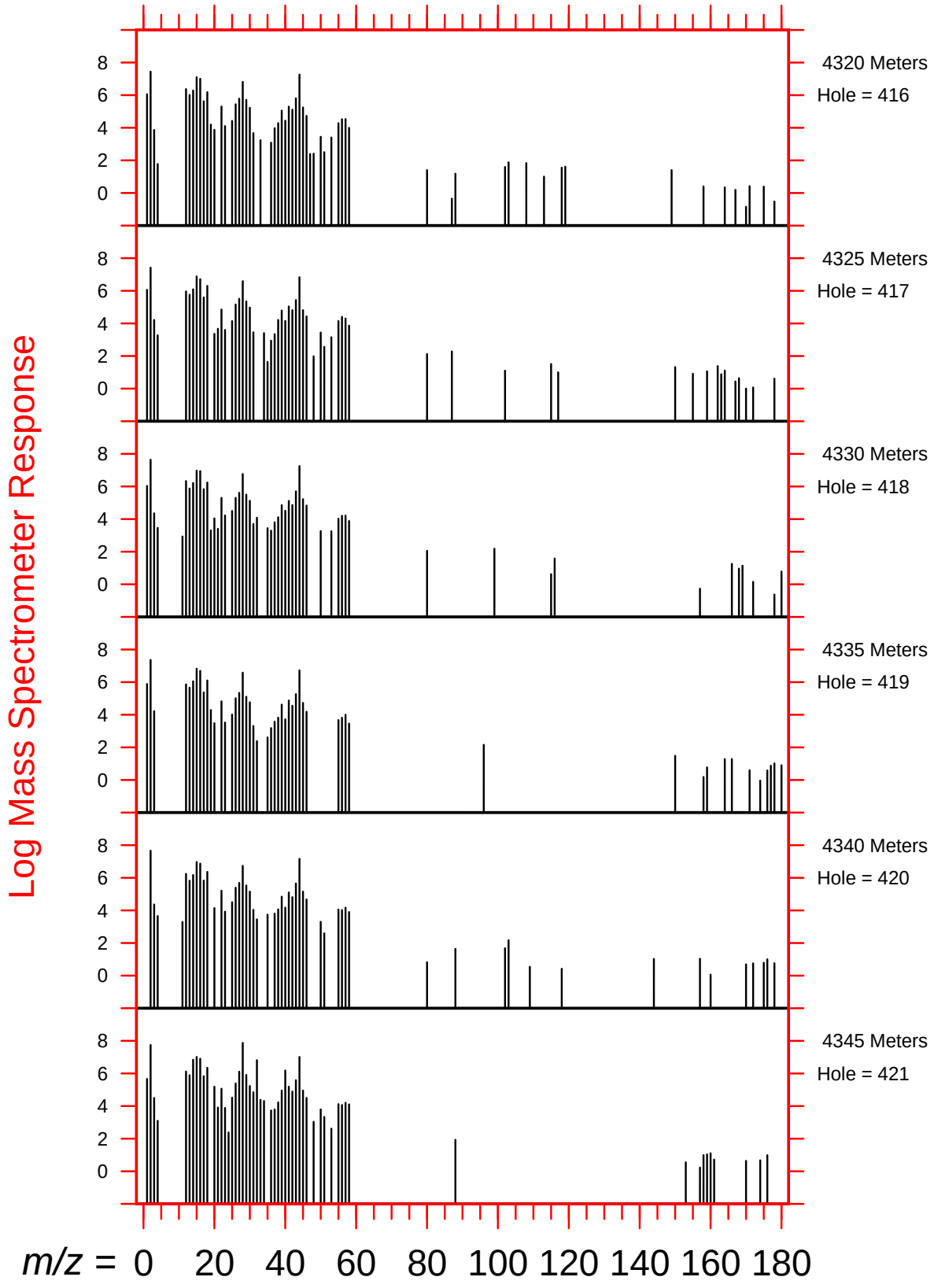

Log Mass Spectrometer Response
4175 Meters
Hole = 384
4180 Meters
Hole = 385
4185 Meters
Hole = 386
4190 Meters
Hole = 387
4195 Meters
Hole = 388
4200 Meters
Hole = 389
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

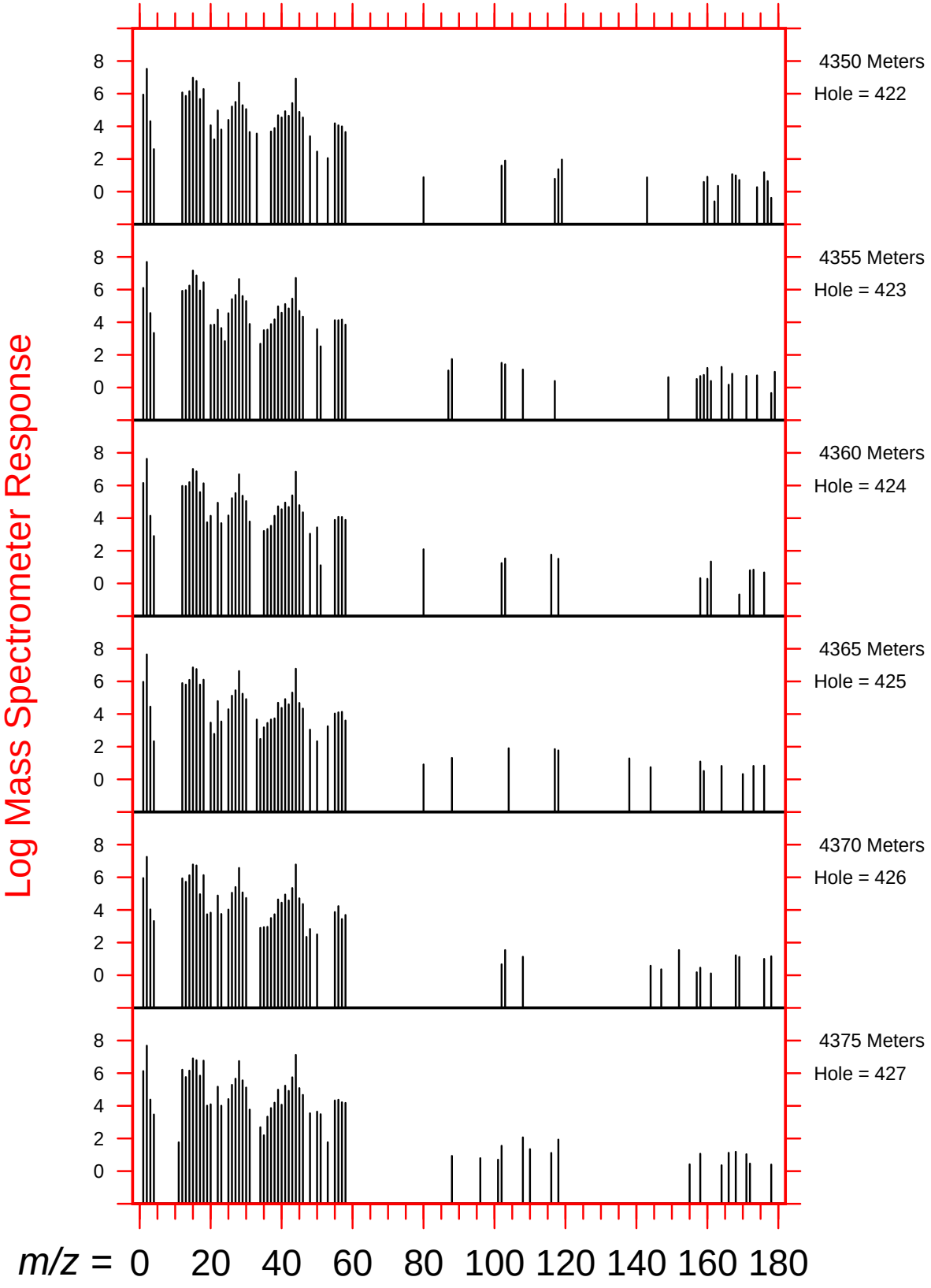

Log Mass Spectrometer Response
4205 Meters
Hole = 390
4210 Meters
Hole = 391
4215 Meters
Hole = 392
4220 Meters
Hole = 393
4225 Meters
Hole = 394
4230 Meters
Hole = 395
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

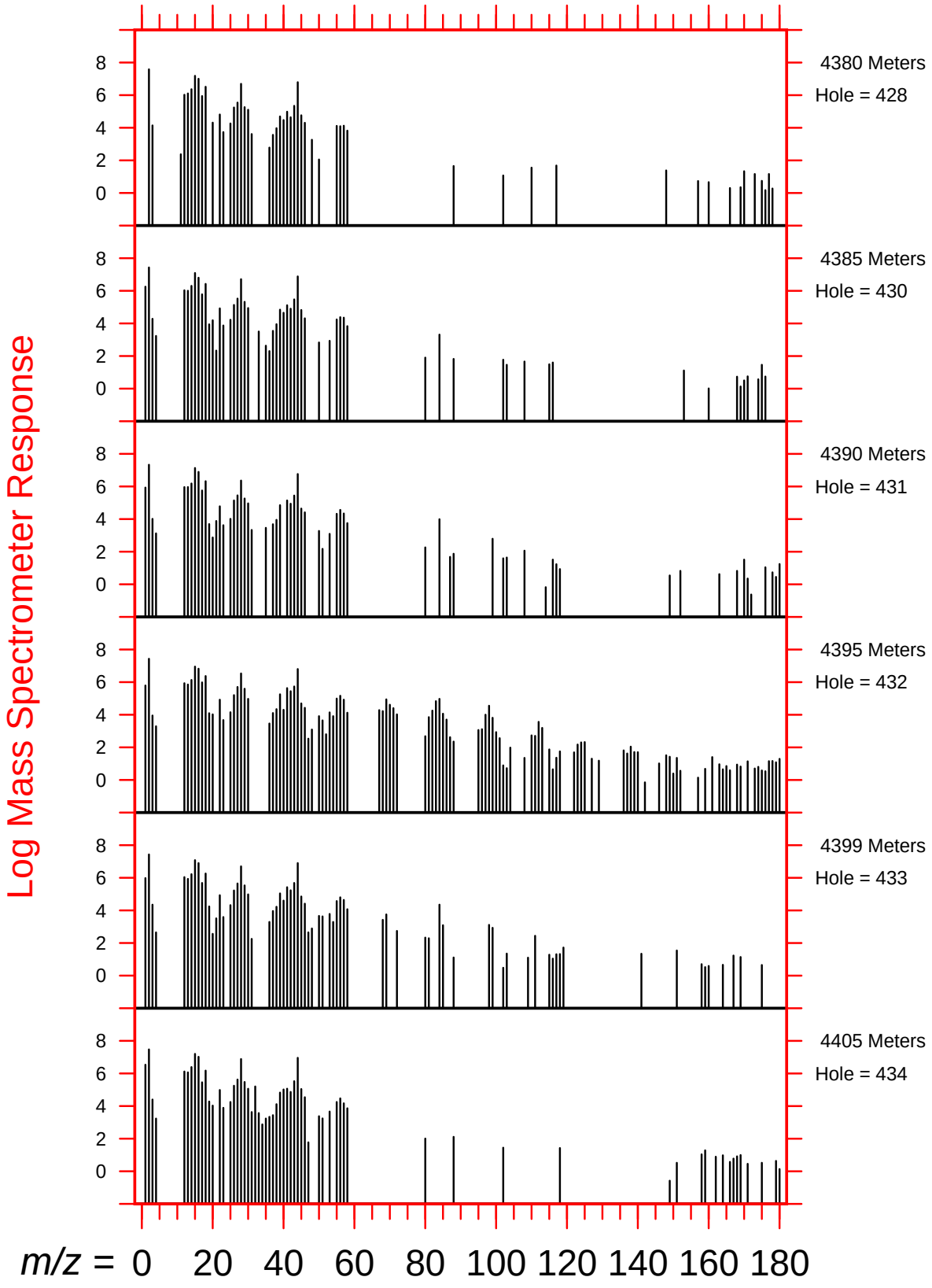

Log Mass Spectrometer Response
4235 Meters
Hole = 396
4240 Meters
Hole = 398
4245 Meters
Hole = 399
4250 Meters
Hole = 400
4250 Meters
Hole = 401
4255 Meters
Hole = 402
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

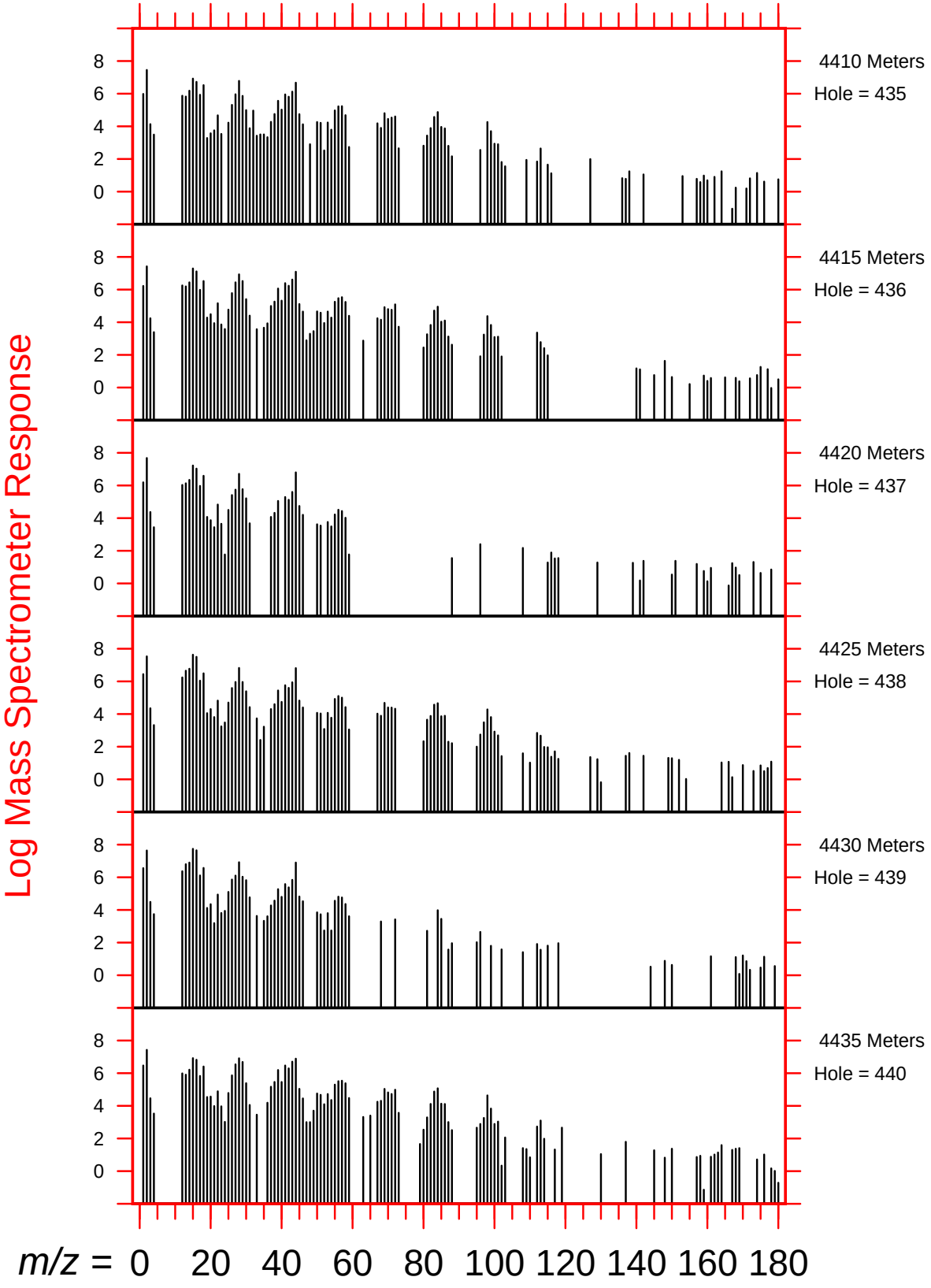

Log Mass Spectrometer Response
4260 Meters
Hole = 403
4265 Meters
Hole = 404
4270 Meters
Hole = 405
4275 Meters
Hole = 406
4280 Meters
Hole = 407
4285 Meters
Hole = 408
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

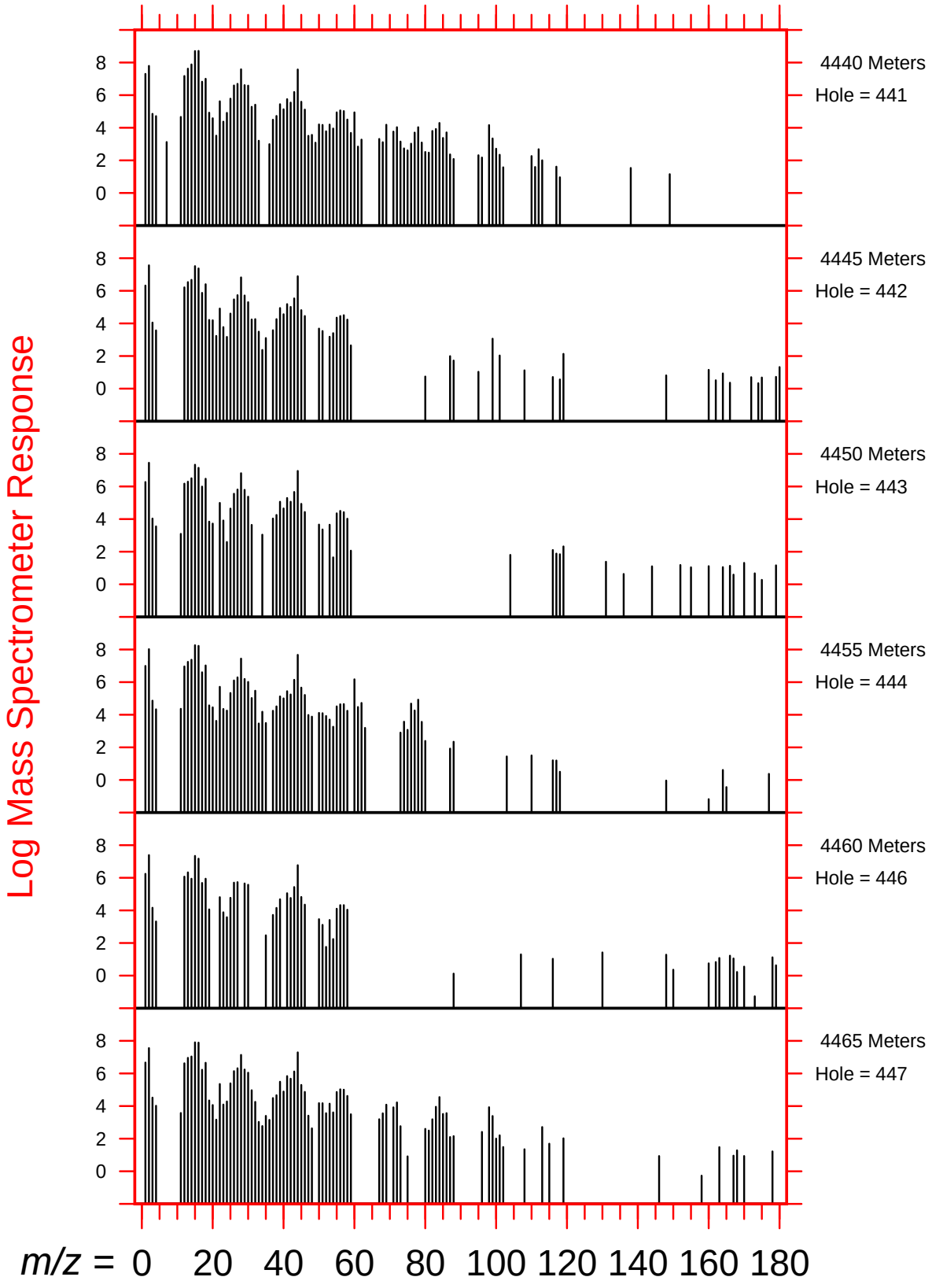

Log Mass Spectrometer Response
4290 Meters
Hole = 409
4295 Meters
Hole = 410
4300 Meters
Hole = 411
4305 Meters
Hole = 412
4310 Meters
Hole = 414
4315 Meters
Hole = 415
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

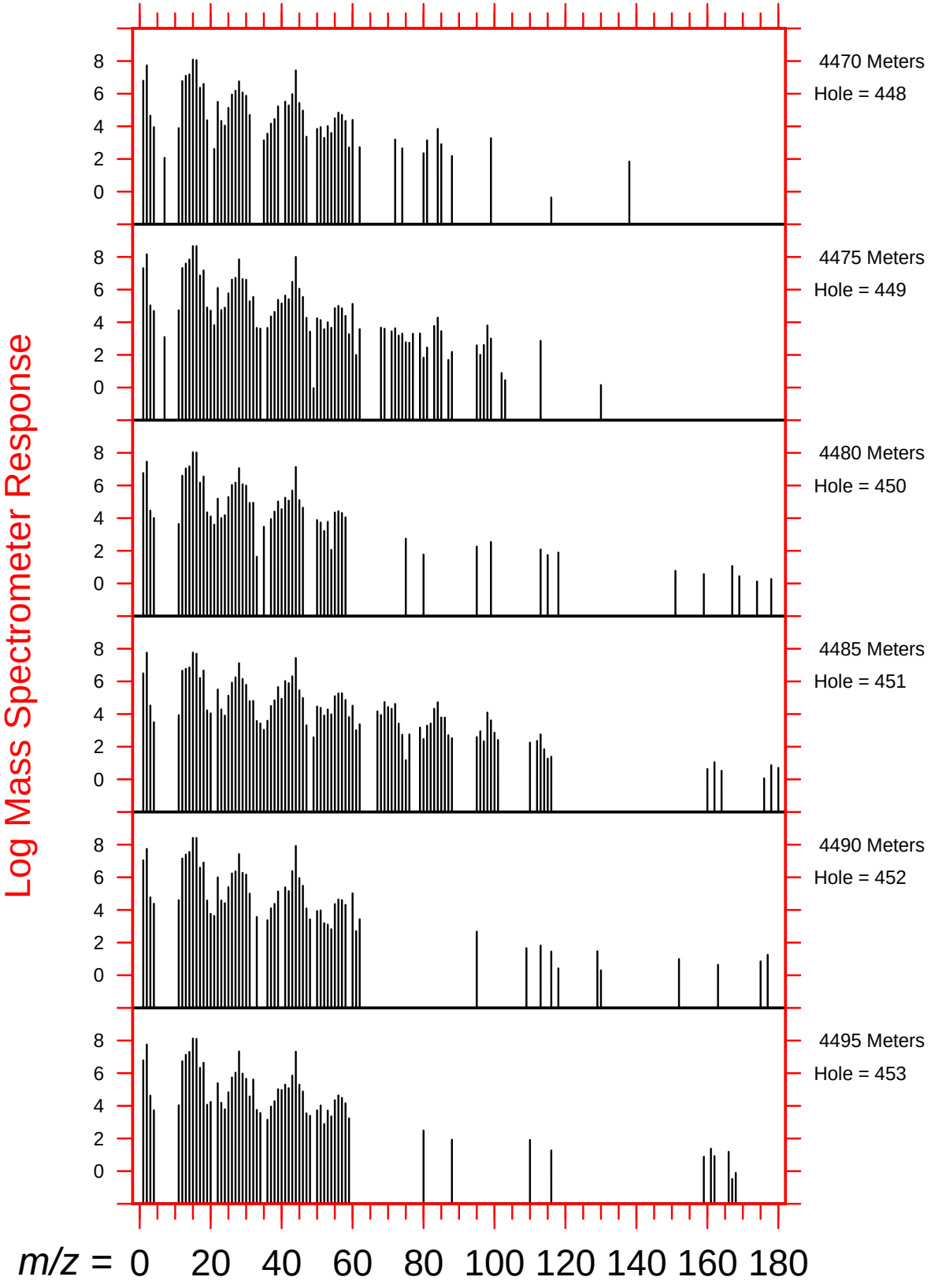

Log Mass Spectrometer Response
4320 Meters
Hole = 416
4325 Meters
Hole = 417
4330 Meters
Hole = 418
4335 Meters
Hole = 419
4340 Meters
Hole = 420
4345 Meters
Hole = 421
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180

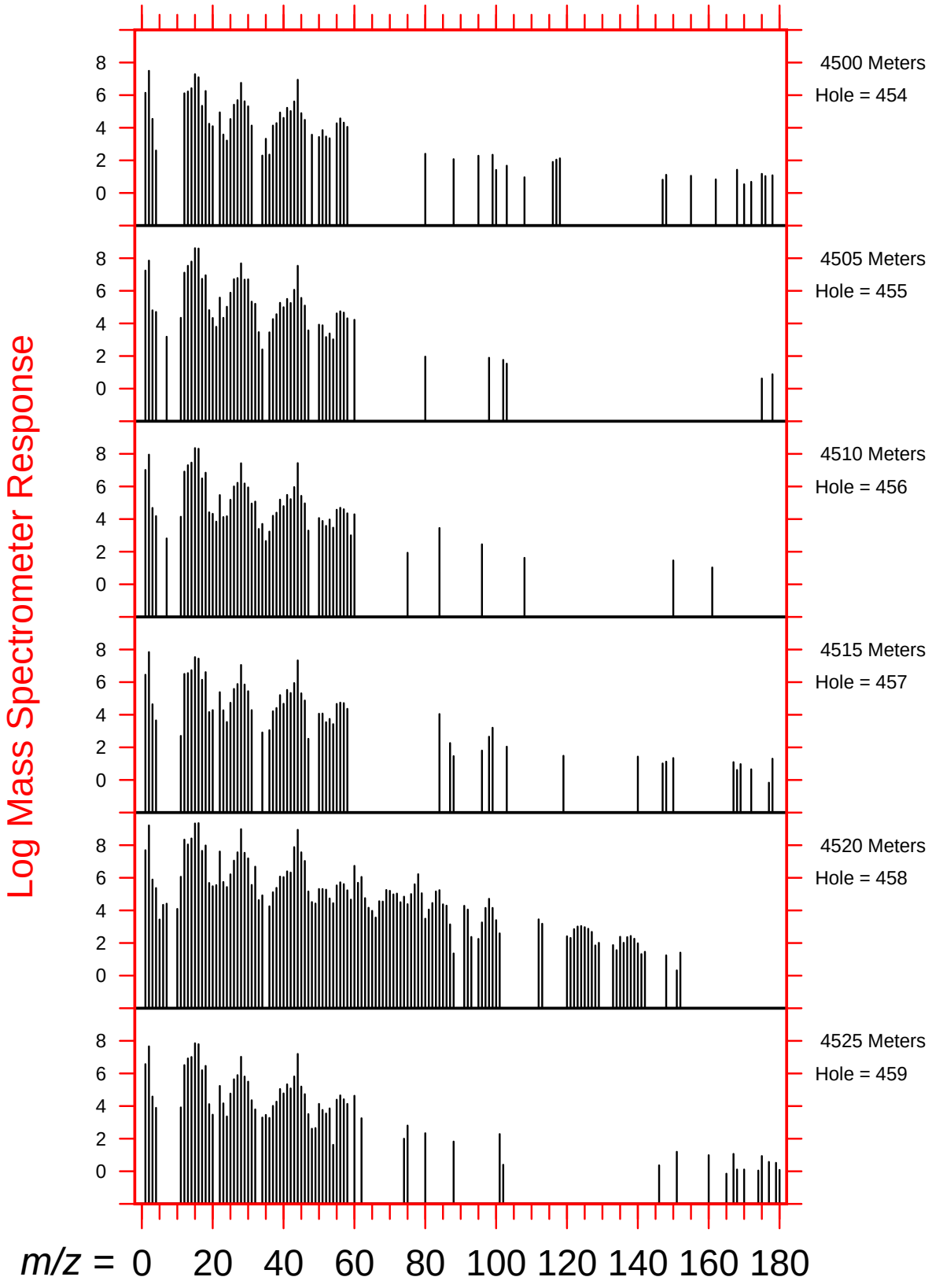

Log Mass Spectrometer Response
4350 Meters
Hole = 422
4355 Meters
Hole = 423
4360 Meters
Hole = 424
4365 Meters
Hole = 425
4370 Meters
Hole = 426
4375 Meters
Hole = 427
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

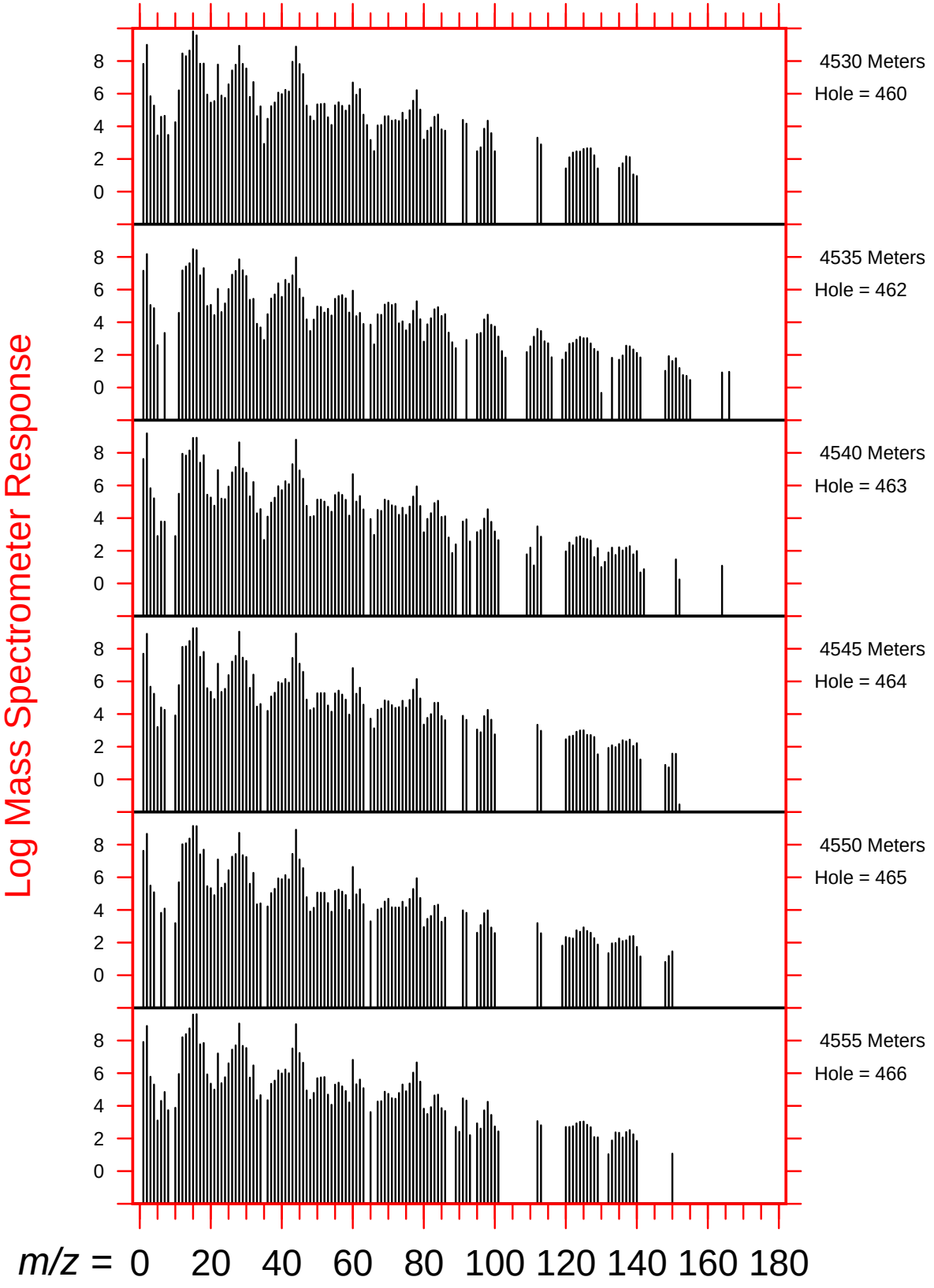

Log Mass Spectrometer Response
4380 Meters
Hole = 428
4385 Meters
Hole = 430
4390 Meters
Hole = 431
4395 Meters
Hole = 432
4399 Meters
Hole = 433
4405 Meters
Hole = 434
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

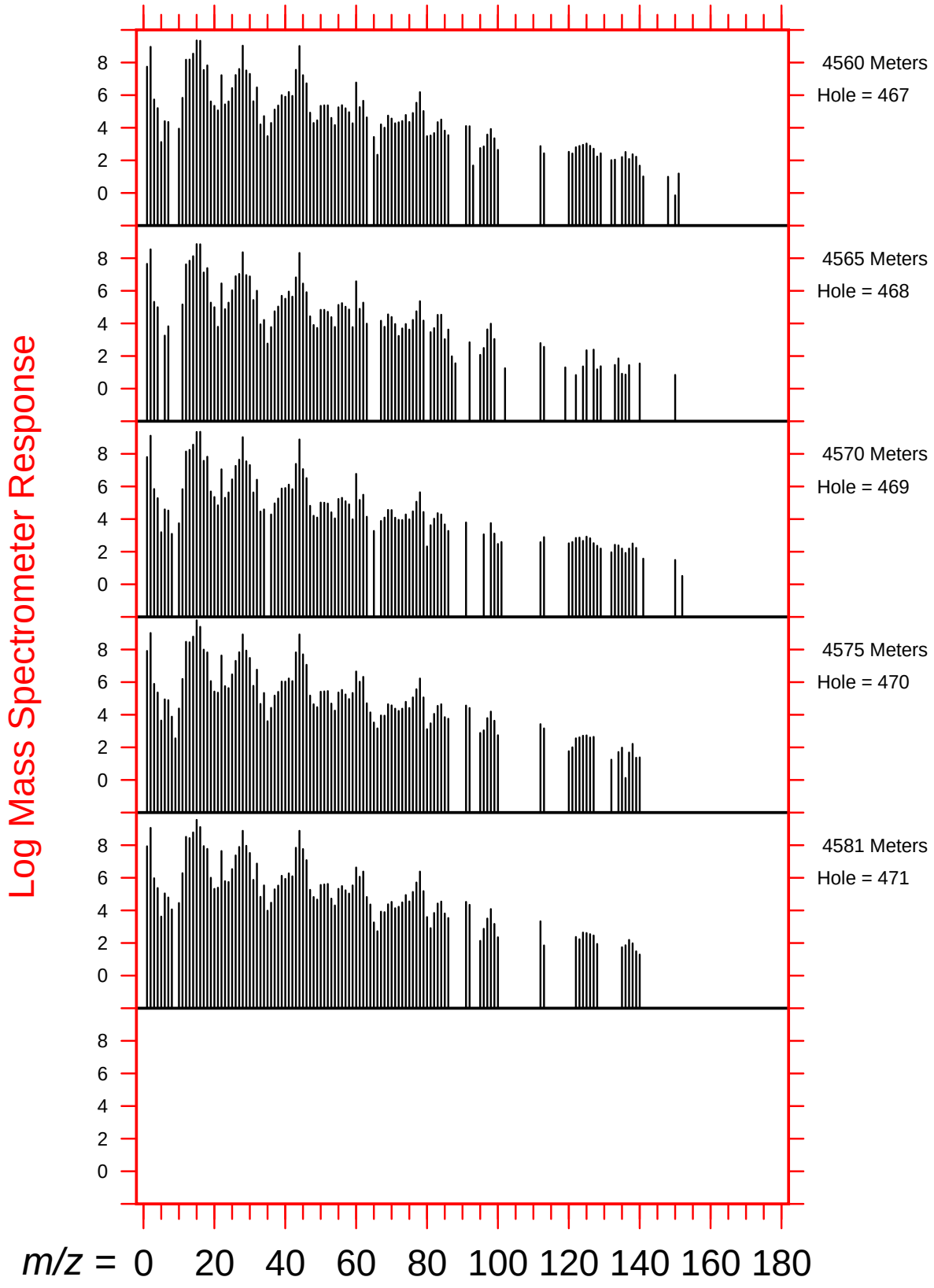

Log Mass Spectrometer Response
4410 Meters
Hole = 435
4415 Meters
Hole = 436
4420 Meters
Hole = 437
4425 Meters
Hole = 438
4430 Meters
Hole = 439
4435 Meters
Hole = 440
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180


Log Mass Spectrometer Response
4440 Meters
Hole = 441
4445 Meters
Hole = 442
4450 Meters
Hole = 443
4455 Meters
Hole = 444
4460 Meters
Hole = 446
4465 Meters
Hole = 447
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180


Log Mass Spectrometer Response
4470 Meters
Hole = 448
4475 Meters
Hole = 449
4480 Meters
Hole = 450
4485 Meters
Hole = 451
4490 Meters
Hole = 452
4495 Meters
Hole = 453
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180


Log Mass Spectrometer Response
4500 Meters
Hole = 454
4505 Meters
Hole = 455
4510 Meters
Hole = 456
4515 Meters
Hole = 457
4520 Meters
Hole = 458
4525 Meters
Hole = 459
0 2 4 6 8
m/z = 0 20 40 60 80 100 120 140 160 180


Log Mass Spectrometer Response
4530 Meters
Hole = 460
4535 Meters
Hole = 462
4540 Meters
Hole = 463
4545 Meters
Hole = 464
4550 Meters
Hole = 465
4555 Meters
Hole = 466
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180


Log Mass Spectrometer Response
4560 Meters
Hole = 467
4565 Meters
Hole = 468
4570 Meters
Hole = 469
4575 Meters
Hole = 470
4581 Meters
Hole = 471
0
2
4
6
8
m/z = 0 20 40 60 80 100 120 140 160 180

# Vitrinite Reflectance Measurement

## VITRINITE REFLECTANCE MEASUREMENT

## NOBLIGE-1



| Sample Details | | Mean | Range | Std Dev | N° of Readings | Sample Description Including Liptinite Fluorescence, Maceral Abundances, Mineral Fluorescence |
|---|---|---|---|---|---|---|
| 3030-3035m | $2_v$max | 0.46 | 0.37-0.61 | 0.053 | 25 | Common sporinite and sparse liptodetrinite yellow to orange, rare cutinite yellow. (Argillaceous siltstone>>sandstone> claystone>carbonate>coal. Coal rare, V, vitrite. Dom common, L>I>V. Liptinite and inertinite common, vitrinite sparse. Mineral fluorescence moderate orange. Iron oxides rare. Pyrite sparse). |
| Ctgs | $2_I$max | 1.37 | 1.04-1.92 | 0.246 | 10 | |
| 3334.7m | $2_v$max | 0.52 | 0.40-0.64 | 0.054 | 25 | Fluorescing liptinite absent. (Calcareous claystone and carbonate with traces of coal. Coal rare, V, vitrite. Dom abundant, V>>I. Vitrinite abundant, inertinite rare, liptinite absent. Mineral fluorescence moderate orange. Iron oxides rare. Pyrite rare). |
| SWC | $2_I$max | 1.58 | - | - | 1 | |
| 3405-3410m | $2_v$max | 0.53 | 0.43-0.65 | 0.049 | 25 | Sparse sporinite and rare liptodetrinite yellow to orange, rare cutinite yellow. (Argillaceous sandstone>>siltstone> claystone >carbonate>shaly coal>coal. Shaly coal rare, V>L>I, clarite>duroclarite>vitrite. Coal rare, V, vitrite. Dom common, V>L>I. Vitrinite sparse to common, liptinite sparse, inertinite rare. Mineral fluorescence mostly none weak to orange in fine grained sediments. Iron oxides rare. Pyrite sparse). |
| Ctgs | $2_I$max | 1.15 | 0.80-1.48 | 0.175 | 10 | |
| 3483.0m | $2_v$max | 0.53 | 0.42-0.60 | 0.046 | 25 | Abundant sporinite and sparse liptodetrinite yellow to orange, sparse cutinite yellow. (Carbonaceous shale and shaly coal with traces of siltstone. Shaly coal abundant, V>I>L, vitrite> clarodurite>inertite. Dom major, V>I>L. All three maceral groups abundant. Mineral fluorescence weak orange. Iron oxides rare. Pyrite sparse). |
| SWC | $2_I$max | 1.32 | 1.12-1.64 | 0.163 | 10 | |
| 3630-3635m | $2_v$max | 0.56 | 0.43-0.70 | 0.063 | 25 | Sparse sporinite and rare liptodetrinite yellow to orange, rare cutinite yellow. (Argillaceous sandstone>claystone>siltstone> shaly coal>coal. Shaly coal common, V>I>L, clarite>vitrite. Coal rare, V. vitrite. Dom common, I>V>L. All three maceral groups sparse. Mineral fluorescence weak orange in fine grained material. Iron oxides rare. Pyrite sparse). |
| Ctgs | $2_I$max | 1.57 | 1.16-2.36 | 0.355 | 10 | |
| 3709.0m | $2_v$max | 0.68 | 0.59-0.76 | 0.039 | 25 | Sparse sporinite and liptodetrinite dull orange, rare cutinite dull orange. (Fine claystone. Dom abundant, I>V>L. Inertinite and vitrinite common, liptinite sparse to common. Material transitional between vitrinite and semifusinite abundant. Mineral fluorescence weak orange. Iron oxides rare. Pyrite rare). |
| SWC | $2_I$max | 1.29 | 0.84-1.74 | 0.358 | 10 | |
| 3805-3810m | $2_v$max | 0.63 | 0.54-0.76 | 0.049 | 25 | Sparse sporinite and rare liptodetrinite orange to dull orange, rare cutinite orange. (Argillaceous sandstone>siltstone> claystone>carbonate>coal>shaly coal. Coal sparse, V>L>I, vitrite>clarite. Shaly coal rare, V>L, clarite. Dom sparse to common, V>L>I. All three maceral groups sparse. Mineral fluorescence weak orange. Iron oxides rare. Pyrite rare). |
| Ctgs | $2_I$max | 1.64 | 0.90-3.08 | 0.606 | 10 | |

**VITRINITE REFLECTANCE MEASUREMENT**

**NOBLIGE-1**



| Sample Details | | Mean | Range | Std Dev | N° of Readings | Sample Description Including Liptinite Fluorescence, Maceral Abundances, Mineral Fluorescence |
|---|---|---|---|---|---|---|
| 3882.0m | $2_v$max | 0.68 | 0.55-0.74 | 0.047 | 25 | Abundant sporinite and sparse liptodetrinite orange to dull orange, common cutinite dull orange. (Fine claystone with traces of coal. Coal rare, V>I, vitrite>inertite. Dom abundant, L>I>V. Liptinite and inertinite abundant, vitrinite common. Mineral fluorescence weak orange. Iron oxides rare. Pyrite rare). |
| SWC | $2_I$max | 1.35 | 0.92-2.20 | 0.372 | 10 | |
| 3980-3985m | $2_v$max | 0.68 | 0.55-0.80 | 0.055 | 25 | Common sporinite and sparse liptodetrinite orange to dull orange, rare cutinite orange. (Argillaceous siltstone>sandstone> claystone>carbonate>coal. Coal rare, V>L>I, clarite>vitrite. Dom abundant, L>I>V. All three maceral groups common. Micrinite abundant in some vitrinite. Mineral fluorescence moderate orange. Iron oxides rare. Pyrite rare). |
| Ctgs | $2_I$max | 1.46 | 1.18-1.74 | 0.172 | 10 | |
| 4138.0m | $2_v$max | 0.68 | 0.60-0.78 | 0.041 | 25 | Common sporinite and sparse liptodetrinite orange to dull orange, rare cutinite dull orange. (Argillaceous siltstones and sandstones. Dom abundant, V>I>L. Vitrinite and inertinite abundant, liptinite common. Mineral fluorescence moderate orange. Iron oxides rare. Pyrite rare). |
| SWC | $2_I$max | 1.32 | 1.02-1.86 | 0.214 | 10 | |
| 4235-4240m | $2_v$max | 0.71 | 0.59-0.86 | 0.056 | 25 | Sparse sporinite and rare liptodetrinite orange to dull orange, rare cutinite orange. (Argillaceous siltstone>sandstone> claystone>carbonate>coal. Coal rare, V>L>I, clarite. Dom common, V>L>I. Vitrinite common, inertinite sparse to common, liptinite sparse. Mineral fluorescence moderate orange. Iron oxides rare. Pyrite sparse, locally abundant). |
| Ctgs | $2_I$max | 1.60 | 1.16-2.10 | 0.287 | 10 | |
| 4350.8m | $2_v$max | 0.72 | 0.70-0.73 | 0.015 | 2 | Fluorescing liptinite absent. (Calcareous claystone. Dom sparse, I>V. Inertinite sparse, vitrinite rare, liptinite absent. Mineral fluorescence patchy weak to moderate orange. Iron oxides rare. Pyrite rare). |
| SWC | $2_I$max | 1.73 | 1.16-2.44 | 0.314 | 25 | |
| 4450-4455m | $2_v$max | 0.74 | 0.61-0.87 | 0.062 | 25 | Sparse to common sporinite and sparse liptodetrinite orange to dull orange, rare cutinite dull orange. (Argillaceous siltstone> sandstone> claystone>artificial composites>coal>shaly coal. Coal rare, I>V>L, duroclarite>vitrinertite (I). Shaly coal rare, I>V>L, clarite=clarodurite. Dom common, I>L>V. Inertinite and liptinite common, vitrinite sparse. Mineral fluorescence weak to moderate orange. Iron oxides rare. Pyrite rare). |
| Ctgs | $2_I$max | 1.53 | 1.14-1.94 | 0.232 | 10 | |
| 4534.3m | $2_v$max | - | - | - | - | Fluorescing liptinite absent. (Sandstone with traces of claystone. Dom rare to sparse, I only. Inertinite rare to sparse, vitrinite and liptinite absent. Mineral fluorescence none. Iron oxides rare. Pyrite rare). |
| SWC | $2_I$max | 1.68 | 1.32-2.34 | 0.277 | 18 | |
| 4549.5m | $2_v$max | 0.71 | 0.61-0.81 | 0.052 | 13 | Sparse sporinite orange to dull orange, rare cutinite orange. (Argillaceous siltstones and sandstones with minor claystones. Dom common, I>L>V. Inertinite common, liptinite sparse, vitrinite rare to sparse. Mineral fluorescence weak to moderate orange. Iron |
| SWC | $2_I$max | 1.58 | 1.30-1.92 | 0.231 | 10 | |

**VITRINITE REFLECTANCE MEASUREMENT**

**NOBLIGE-1**



| Sample Details | | Mean | Range | Std Dev | N° of Readings | Sample Description Including Liptinite Fluorescence, Maceral Abundances, Mineral Fluorescence |
|---|---|---|---|---|---|---|
| | | | | | | oxides rare. Pyrite common). |
| 4575-4581m | $2_v$max | 0.76 | 0.62-0.92 | 0.071 | 25 | Sparse sporinite and rare liptodetrinite dull orange to weak brown, rare cutinite dull orange. (Argillaceous siltstone> sandstone>claystone>carbonate>artificial composites>coal> shaly coal. Coal rare, V>I>L, vitrite>clarite. Shaly coal rare, V<I, vitrinertite (V). Dom common, V>I>L. Vitrinite common, inertinite sparse to common, liptinite sparse. Mineral fluorescence weak to moderate orange. Iron oxides rare. Pyrite sparse, locally abundant). |
| Ctgs | $2_I$max | 1.62 | 1.10-1.98 | 0.223 | 10 | |

A coal measures section with most samples containing large well-defined vitrinite populations. The top of the section sampled lies at or very close to the top of the oil window. The vitrinite reflectance gradient is relatively low so that the deepest sample is mid-mature for oil generation indicating that the zone of oil generation is relatively thick in this well.

Liptinite is absent to common and is dominated by sporinite although cutinite is also a distinctive component.

Vitrinite is more abundant than inertinite in the coals, but within the dispersed organic matter inertinite tends to be more abundant than vitrinite.