THE UNIVERSITY OF CALGARY

Petroleum geology and geochemistry of the Manyberries oil field, southeastern Alberta

by

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ABSTRACT

The Manyberries oil field is located in the southeastern corner of Alberta (township 4-5, range 4-5W4) and contains medium to light gravity crude oil (33° to 45° API) in quartzose, fluvial sands of the Mannville Formation. The hydrocarbon trapping mechanism for the area is stratigraphic due to the unconformable nature of the overlying contact with the overlying Upper Mannville Formation.

Organic geochemical analysis determined that the oils from the Manyberries field have similar characteristics and are designated here as Family M oils. A comparison of Family M organic geochemical characteristics to other Upper Jurassic to Lower Cretaceous oil fields from southeastern Alberta and north-central Montana indicates that oils from Black Butte (southeastern Alberta), Whitlash, and Fred and George Creek oil fields (Montana) are similar the Manyberries oil, and hence are also classified as Family M oils.

The hydrocarbon source for the Family M oils has not been identified, but organic geochemical characteristics suggest a carbonate source rock within the Upper Devonian Saskatchewan Group of the Williston Basin at peak oil generation, implying long distance oil migration (>400km) from central Williston Basin and into southeastern Alberta.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Upper Jurassic and Lower Cretaceous reservoirs in Alberta and British Columbia contain an estimated $2000*10^6$ m^3 of oil with an additional $300*10^6$ m^3 of oil in Saskatchewan (Creaney et al., 1994). Most of this oil is stratigraphically trapped in marine and fluvial sandstone reservoirs.

Upper Jurassic-Lower Cretaceous strata of southeastern Alberta has been the focus of much hydrocarbon exploration over the past 50 years. This activity lead to the discovery of the Manyberries oil field in 1953. This field contains $20,619.7*10^3 m^3$ of medium to light gravity (30-40° API) crude oil (ERCB, 1993) in Late Jurassic to Early Cretaceous reservoirs. The Manyberries oil field oil quality is anomalous because most oils in Lower Cretaceous reservoirs in southeastern Alberta and southwestern Saskatchewan range between 10° to 30° API gravity. The reasons for these differences are unknown but may be related to variations in the level of biodegradation, hydrocarbon source rock differences or differences in thermal maturity.

Little work has been published regarding the controls on reservoir extent and trapping mechanisms in the Manyberries area. Previous studies have focused more on regional correlation of Upper Jurassic and Lower Mannville strata in southeastern Alberta (Hayes, 1982). Thus, the causes and controls on the anomalous accumulation of high API gravity oil in the Manyberries area are unknown.

1.2 Objectives

The primary focus of this study is to determine the factors (geological and geochemical) responsible for the accumulation of high API gravity crude oil in Upper Jurassic to Lower Cretaceous reservoirs in the Manyberries oil field, southeastern Alberta (figures 1and 2). A secondary objective is to examine oils from similar-aged reservoirs in oil fields adjacent to the Manyberries area (i.e. from southeastern Alberta, southwestern Saskatchewan, and north-central Montana) to make an oil-oil correlation to Manyberries and to characterize hydrocarbon migration in this region (Figure 1). This study will;

1) Characterize the organic geochemical characteristics of the oils from the Manyberries oil field, southeastern Alberta;
2) Develop a geological model for Upper Jurassic to Lower Cretaceous reservoirs in the Manyberries area;
3) Compare the geochemical characteristics of the Manyberries oils with other oils from coeval reservoirs from southern Alberta, southwestern Saskatchewan and north-central Montana;
4) Integrate geological and geochemical data to understand hydrocarbon migration fairway within the Manyberries area; and
5) Develop a regional scale model for hydrocarbon migration in southeastern Alberta and southwestern Saskatchewan.

1.3 Study Area

The primary focus for this study is the Manyberries oil field, which is located

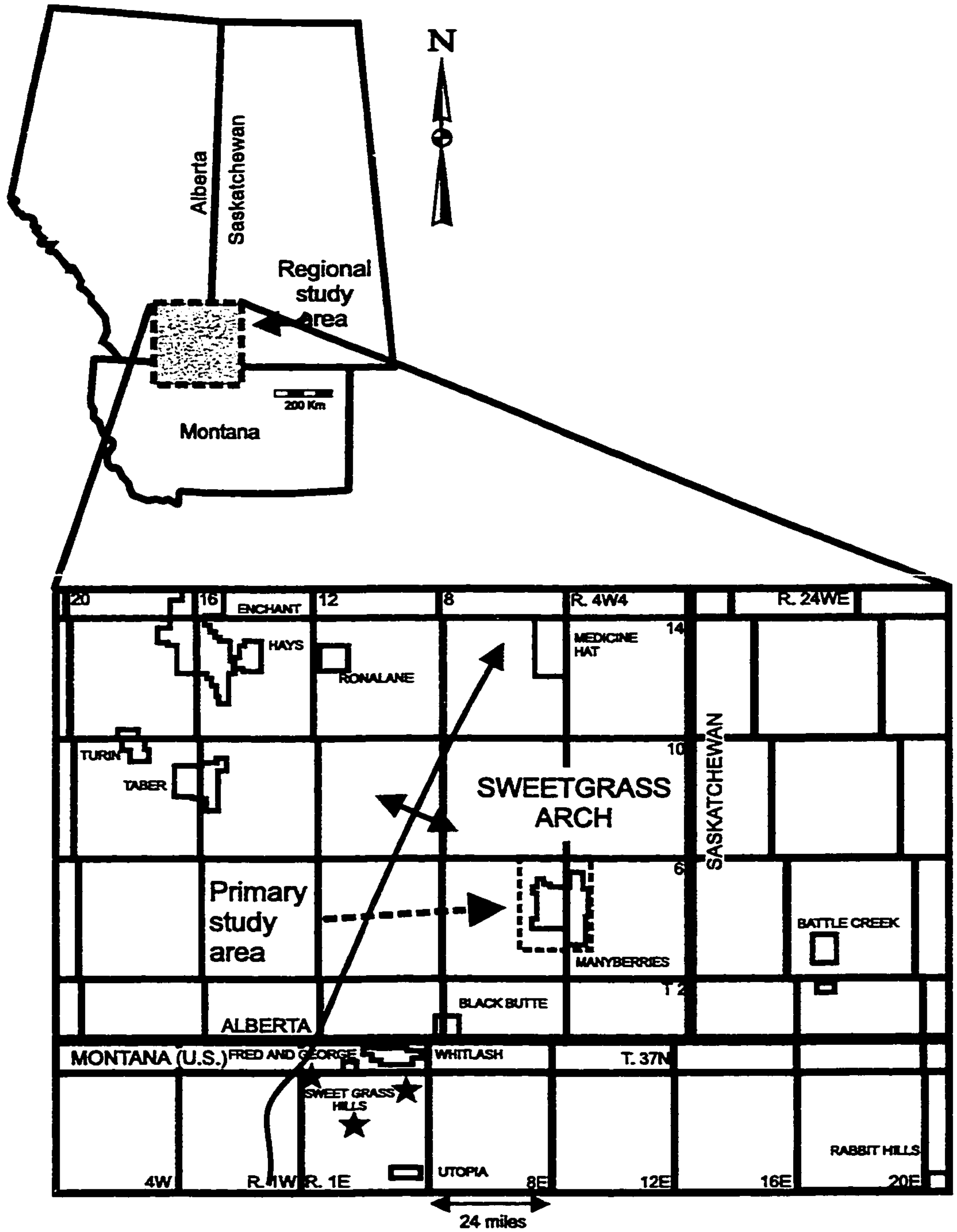


Figure 1. Maps showing the Manyberries and regional study areas (modified from Hayes, 1982). Stars indicate Sweet Grass Hills intrusions.

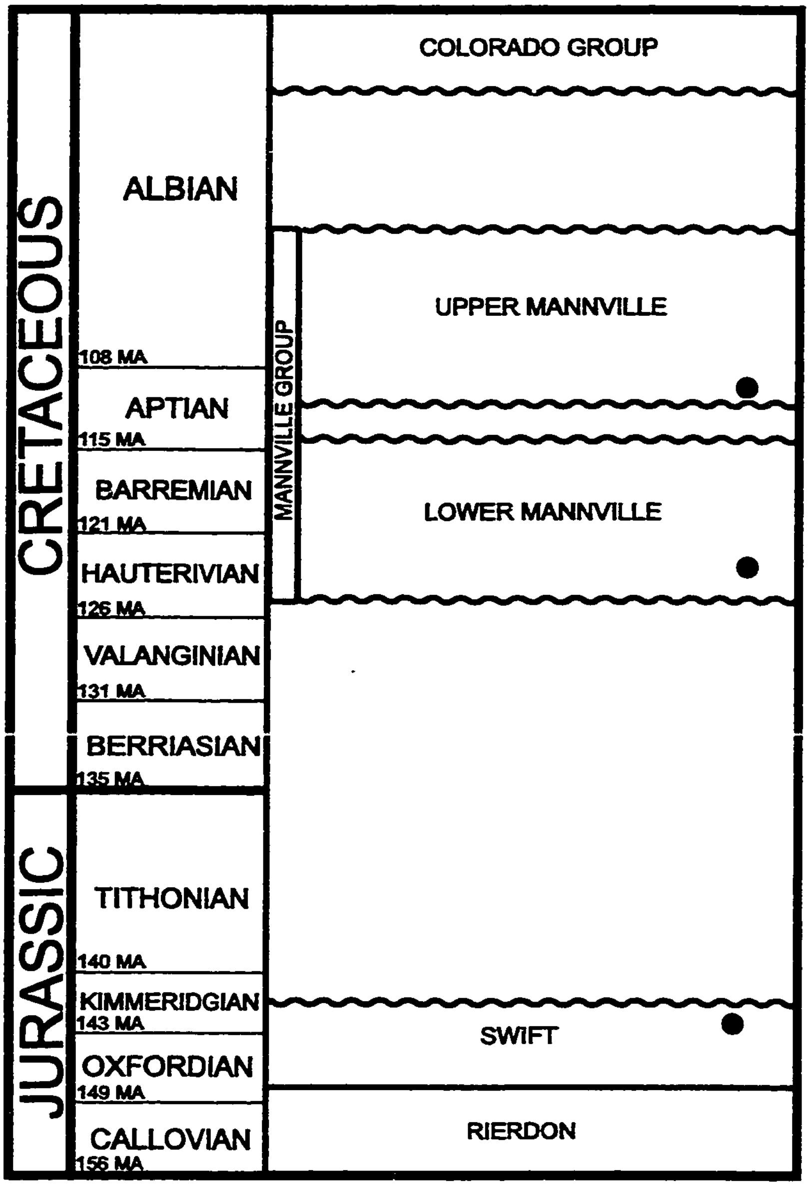


Figure 2. Generalized stratigraphic column for the Manyberries area (modified from Hayes 1986 and Leckie et al., 1997). Black circles on figure indicate oil-producing horizons in the Manyberries area.

between townships 4 to 6 ranges 4 to 5W2 (Figure 1). This study will also include a regional study defined by township 33N range 19E (Montana) in the southeast to township 15 range 20W2 (Alberta) in the northwest (Figure 1).

2. REGIONAL GEOLOGIC FEATURES

The Manyberries oil field is located in a structurally complex region. The Sweetgrass Arch, a major anticlinal structure, is located to the west of Manyberries (Torvell, 1958; Herbaly, 1974; Podruski, 1988) and the Sweetgrass Hills (Eocene alkaline intrusions) lie to the southwest (Marvin et al. 1980). The Manyberries field straddles two depositional basins, the Williston Basin to the east and the Alberta Basin to the west.

The Sweetgrass Arch in southeastern Alberta is a northeasterly plunging anticlinal structure that has been periodically active throughout most of the Phanerozoic (Podruski, 1988; Peterson, 1988). The present orientation of the Sweetgrass Arch is a result of the final compressional events of the Laramide Orogeny in the early Tertiary (Lorenz, 1983). The Sweetgrass Arch defines a northeasterly dip in the Manyberries area and also creates a major structural divide between the Alberta and Williston basins (Figure 3).

The Sweet Grass Hills are a series of intrusive stocks and dykes, composed of alkaline syenite, and ranging in age from 50 to 54 million years (Marvin et al., 1980). These intrusions coincide with extension in the southern Canadian Cordillera and emplacement of similar composition, igneous bodies in central Montana and southern British Columbia (Parrish et al., 1988; Ross et al., 1994)(Figure 3).

The Alberta Basin lies to the west of the Sweetgrass Arch and is defined as an asymmetrical, synclinal structure, bounded to the west by the Western Canadian Rocky Mountains and to the east by the Western Canadian Plains (Wright et al., 1994). It has evolved from a stable, cratonic platform during the Cambrian to Jurassic to a westward deepening Foreland Basin during the Middle Jurassic to Early Tertiary.

The Williston Basin is a large intracratonic basin centered over western North Dakota and eastern Montana and lies to the east of the Sweetgrass Arch area (Figure 3). The Williston Basin is bounded to the north and east by the Precambrian Shield, and to

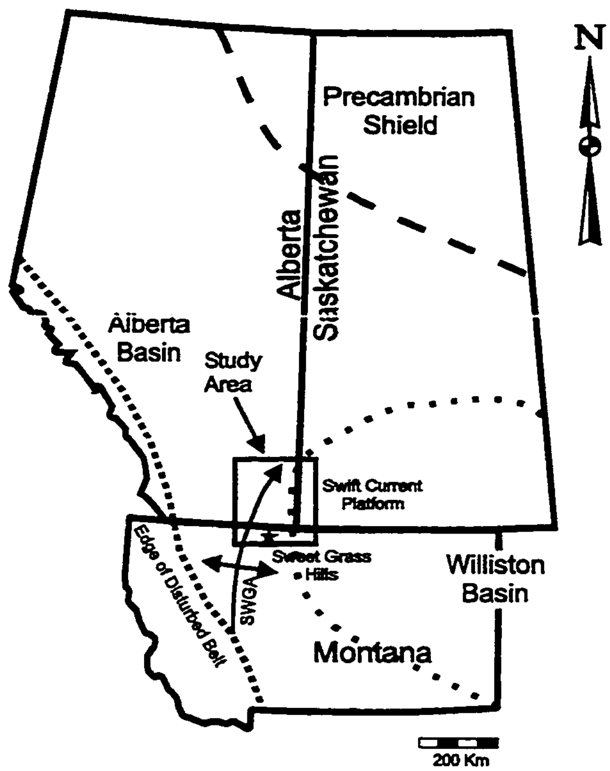


Figure 3. Major regional and local geologic features near the study area.

the south by the Black Hills Uplift and the Transcontinental Arch (not shown in Figure 3). (Wright et al., 1994). The Williston Basin reaches 4 kilometres in depth and is composed of sediments ranging in age from Cambrian to Tertiary (Wright et al., 1994).

3. PREVIOUS WORK

3.1 Stratigraphy

Much has been published on Upper Jurassic and Lower Cretaceous stratigraphy in southeastern Alberta (Weir, 1949; Glaister, 1959; Brenner and Davies, 1974; Hayes, 1982; 1986, Poulton et al., 1994), north-central Montana (Cobban, 1945; Hayes, 1982; 1986) and southwestern Saskatchewan (Milner and Thomas, 1954; Christopher, 1974; Poulton et al., 1994, Leckie et al., 1997). The following is a brief overview of the Upper Jurassic and Lower Cretaceous stratigraphy adjacent to the Manyberries area.

3.1.1 Upper Jurassic Stratigraphy of Southeastern Alberta, Southwestern Saskatchewan, and north-central Montana

Due to the lack of out-cropping Upper Jurassic and Lower Cretaceous strata, little was described of these units until extensive hydrocarbon exploration began in the area in the late 1940's. Cobban (1945) was the first to describe the Jurassic section of the Sweetgrass Arch area in north-central Montana using both outcrop and drill cuttings. He described and mapped an Oxfordian, laterally extensive unit in north-central Montana that was composed of a dark grey, non-calcareous shale overlain by a fine-grained, glauconitic, flaggy sandstone, which he termed the Swift Formation (Figure 4).

Weir (1949) extended the Swift Formation into the subsurface of southern Alberta (Figure 4) and defined a northern erosional edge north of township 10. This study used combined data from wireline logs, drill cuttings and core to establish the stratigraphic link with exposed Upper Jurassic units in Montana.

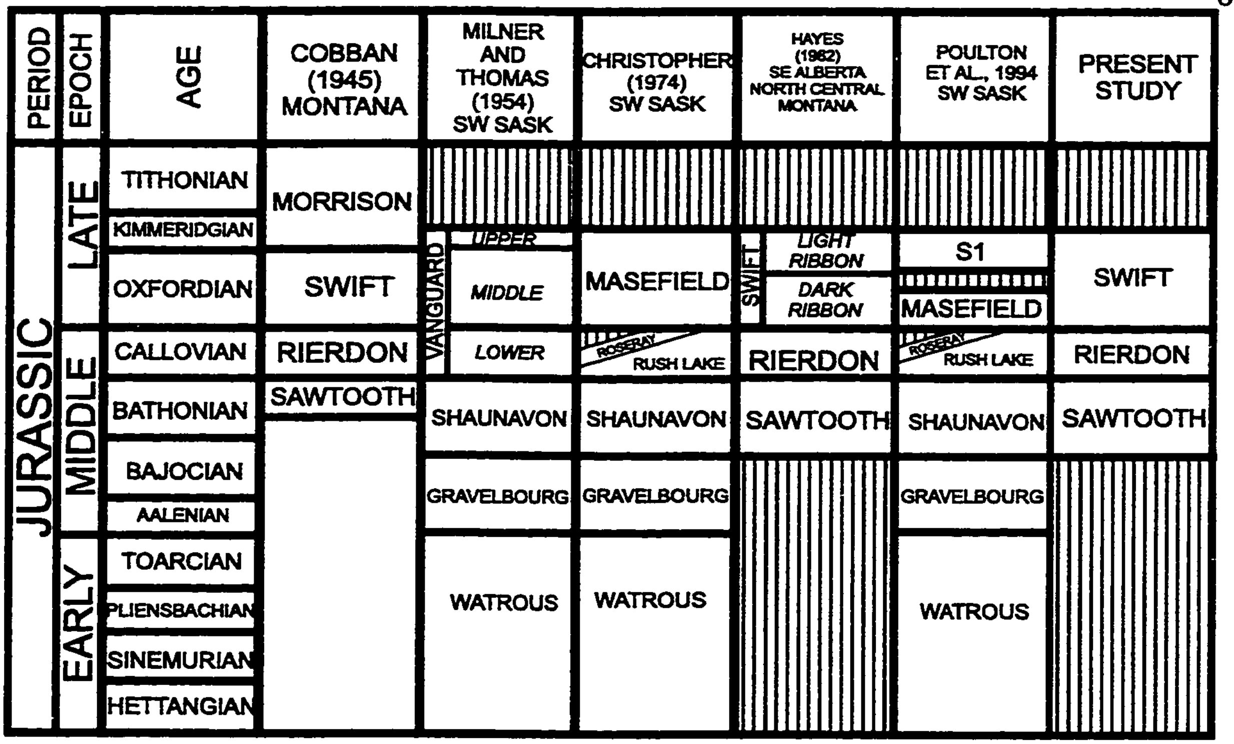


Figure 4 Abbreviated historical development of Jurassic lithostratigraphy in north-central Montana, southeastern Alberta and southwestern Saskatchewan (hatched region indicates periods of non-deposition or erosion).

Milner and Thomas (1954) were the first to characterize the Upper Jurassic section of the Vanguard Formation of southern Saskatchewan and described two informal Upper Jurassic members; the Middle and Upper members. The Middle member is composed of a sequence of intercalated sands and shales with traces of glauconite and chert and is thought to represent the lateral equivalent of the Swift Formation (Figure 4). The Upper Member of the Vanguard Formation is a sequence of variegated clay shales, calcareous sands and marly limestones. No fossils were present in this member but based on the stratigraphic relationship with underlying units and the overlying unconformable relationship with Lower Cretaceous deposits, this unit is considered to be Upper Jurassic.

Christopher (1974) raised the status of Vanguard Formation of southwestern Saskatchewan to the Vanguard Group. He describes this unit as composed of four units; the Middle Jurassic Rierdon Shale, and the Upper Jurassic Masefield Shale in the eastern part of study area and the Middle Jurassic Rush Lake Shale and Roseray Formation, and the Upper Jurassic, Masefield Shale in the western part of the study area. Christopher (1974) described the Masefield Shale as a marine deposit composed of a calcareous green-grey shale that coarsens upwards into a thin, calcareous, quartzose sand and correlated it with the Swift Formation of southeastern Alberta and north- central Montana (Figure 4; Cobban, 1945; Weir, 1949). Christopher (1974) also described a Lower Cretaceous unit, which he termed the S1 member of the Success Formation. This unit was described as an interlaminated sandstone and carbonaceous shale with a coarsening upward trend. Originally dated as Lower Cretaceous, the S1 Member has since been determined to be Upper Jurassic in age (Poulton et al., 1994; Leckie et al., 1997) and correlated to the Swift Formation (Hayes, 1982; Poulton et al., 1994).

Brenner and Davies (1974) developed a regional paleogeographic model for the deposition of the Swift Formation and equivalent units in Montana, Wyoming and southern Alberta. This model documents a large epicontinental seaway extending southward from the Arctic and a gradual northwesterly regression during the Oxfordian, that deposited marine bar sands over mud and carbonate clay facies. This regression is thought to have been the result of tectonic uplift of the Rocky Mountains to the west of the study area (Brenner and Davies, 1974).

Hayes (1982) described two informal members of the Upper Jurassic Swift Formation; the Light Ribbon Sand member and the Dark Ribbon Sand member based primarily rock colour. The gross composition ranges from 95 % mudstone and 5 % siltstone to almost 100% clean medium-grained sandstone. Common bedforms in the Swift range from lenticular bedded with single flat lenses to wavy bedding to cross-bedded sands with mud flasers. He constrained the age of the Swift Formation to Oxfordian based on extensive ammonite and microfaunal data from Brooke and Braun (1972) and Imlay (1980). Hayes (1982) indicated that the deposition of these units was the result of a forced regression due to tectonic activity in the developing thrust belt to the west.

The most recent analysis of Upper Jurassic stratigraphy is the synthesis by Poulton et al. (1994) for the Jurassic of the Western Canadian Sedimentary Basin. Poulton et al. (1994) included the S1 member of the Success Formation and the Masefield Shale, as Upper Jurassic units in southwestern Saskatchewan and correlates these units to the Swift Formation of Cobban (1945), Weir (1949) and Hayes (1982) (Figure 4).

In the present study, a simple classification scheme has been adopted, in that, no subdivision of the of the Swift Formation has been attempted.

3.1.2 Lower Cretaceous Stratigraphy of Southeastern Alberta, Southwestern Saskatchewan, and north-central Montana

Glaister (1959) was the first to examine the Lower Cretaceous Mannville Group in the southern Alberta subsurface. This study divided the Mannville Group into the Lower

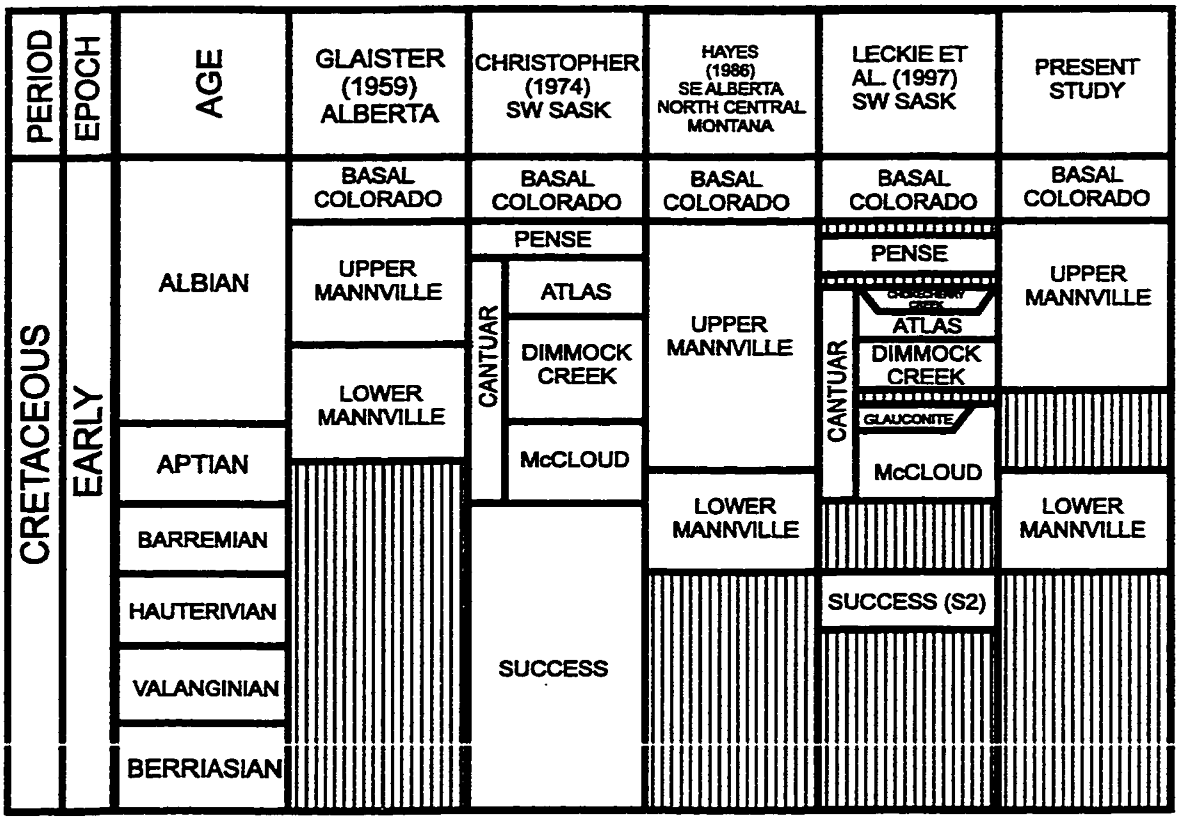


Figure 5. Abbreviated historical development of Lower Cretaceous lithostratigraphy in north-central Montana, southeastern Alberta and Southwestern Saskatchewan. (hatched region indicates periods of non-deposition or erosion)

Mannville Formation and Upper Mannville Formation (Glaister, 1959) based on wireline logs, core and drill cuttings (Figure 5). Glaister (1959) divided the Lower Mannville Formation into two basal quartzose sandstone members, the Cut Bank and Sunburst Sandstone, with the top of the Lower Mannville Formation defined by the thin, limy mudstone "Calcareous" Member (these units are not indicated on Figure 5). The Upper Mannville is composed of kaolinitic subgreywacke sandstones interbedded with siltstones and shales. Both the Lower and Upper Mannville formations were found to be correlatable over southern and central Alberta (Glaister, 1959).

Christopher (1974) divided the Upper Jurassic-Lower Cretaceous, Mannville Group of southwestern Saskatchewan into three formations; the Success, Cantuar and Pense formations (Figure 5). The Success Formation is divided into two members, the S1 and S2 members. The S1 Member is composed of interlaminated quartzose sands and carbonaceous silts deposited in a continental setting. The S1 member of the Success Formation has since been correlated to the Upper Jurassic, Swift Formation (Hayes 1982; Poulton et al., 1994) and interpreted as a marine tidal flat deposit. The S2 Member is composed of trough cross-bedded, medium to fine-grained, quartzose sands and is interpreted to represent deposits from a vast braid-plain that covered most of southern Saskatchewan (Christopher, 1974). The Cantuar Formation is composed of three members (in stratigraphic order); the McCloud, Dimmock Creek and Atlas members. These deposits were shown to be associated with deep valleys eroded into the underlying Success Formation and Vanguard Group (Christopher, 1974). The McCloud Member is composed of medium-grained quartzose sandstone grading into a dark grey to black carbonaceous mudstone and is restricted to only the deepest regions of the Lower Cretaceous valley systems in the study area (Christopher, 1974). The McCloud member is the lateral equivalent to the Lower Mannville Formation of Alberta. The overlying Dimmock Creek and Atlas members of the Cantuar Formation are composed of kaolinite cemented sandstones with common biotite and chlorite. These deposits are interpreted to represent marine deltaic to fluviatile environments that largely buried a pre-Cantuar valley system that drained to the north (Christopher, 1974). The correlative of these units in Alberta is the Upper Mannville Formation (Christopher, 1974). Topping the Mannville Group is the Pense Formation composed of a black shale and bioturbated, sandy and muddy calcareous sands grading into the overlying shales of the Colorado Group (Christopher, 1974). The Pense Formation is inferred to be correlated with Upper Mannville of Southern Alberta (Christopher, 1974).

Hayes (1986) described and mapped the Mannville Group in southeastern Alberta and north-central Montana and divided it into the Lower and Upper Mannville formations (Figure 5). The Lower Mannville Formation in the study area is composed of medium to fine-grained, trough cross-bedded, quartzose sandstones which grade upward into grey-green siltstones and mudstones and documents a northerly directed drainage system, which fed the Whitlash Valley, and the Edmonton Valley systems (Hayes 1986). Medium to fine-grained, poorly sorted, fluvial sandstones, containing abundant volcanic rock fragments, feldspar and smectite, characterize the Upper Mannville Formation. In the absence of this fluvial unit, a thick, carbonaceous, green-grey mudstone is common (Hayes, 1986). No fossils were obtained from the Lower and Upper Mannville formations, but based on correlation with units described by Glaister (1959), and the overlying Albian Joli Fou Formation and the underlying Oxfordian Swift Formation, the Mannville Group is considered to be Barremain to Albian (Hayes, 1986).

Leckie et al. (1997) mapped and described Upper Jurassic to Lower Cretaceous stratigraphy of Southwestern Saskatchewan (Figure 5). These workers correlated the S2 member to the Dalhousie sandstone in the Foothills of Alberta and the Taber/Cutbank sandstone of southern Alberta. They also describe two informal units not recognized by Christopher (1974) in the Cantuar Formation: the Glauconite and the Chokecherry Creek members (Figure 5). The Glauconite is composed of quartz-rich, trough cross-bedded, medium to fine-grained sandstone overlain by the Dimmock Creek Member as described by Christopher (1974). The Glauconite member is thought to be correlative with the Glauconitic member of the Upper Mannville Formation of southwestern Alberta (James, 1985). The Chokecherry Creek member is a lithic to quartzose sandstone, medium to fine-grained, and interbedded with black shale. Mud drapes on cross-bedded foresets in the Chokecherry Creek member indicates a supratidal, marine setting (Leckie et al., 1997). The Chokecherry Creek member has no correlative unit in southern Alberta.

In the present study the Lower Cretaceous is divided into Lower Mannville and Upper Mannville formations utilizing a similar stratigraphic nomenclature as Hayes (1986) with an unconformity at the base of the Upper Mannville Formation, depicting the erosional nature of Pre-Upper Mannville valley systems in the area.

3.2 Organic Geochemistry

Over the past three decades much work has been done with respect to correlating the oils in Lower Cretaceous reservoirs of Western Canada Sedimentary Basin to proven hydrocarbon source rocks. Much of this early work focused on determining the origin of the Lower Cretaceous tar sand accumulations of northern Alberta (Deroo et al., 1977; Rubinstein et al., 1977; Leenheer, 1984; du Rouchet, 1985; Brooks et al., 1988). Recent oil-source rock correlation has focused on Lower Cretaceous conventional oils of southern Alberta, southwestern Saskatchewan and northern Montana (Creaney and Allan, 1990; Allan and Creaney, 1991;; Osadetz et al., 1992; Dolson et al., 1993; Osadetz et al., 1994; Creaney et al., 1994; Riediger et al., 1995; 1996; 1997A, 1997B, Karavas et al., in press). No detailed organic geochemical characterization of Lower Cretaceous oils of southeastern Alberta has been reported in the literature. Thus, the current understanding of the organic geochemistry of Lower Cretaceous oil families of Alberta, Saskatchewan and Montana is summarized here in an attempt to outline the growth in knowledge for the oil family classifications in this area, and to provide the geochemical background for the present study.

3.2.1 Origin of Lower Cretaceous Tar-Sands in Alberta

The initial characterization of oils from Lower Cretaceous reservoirs was attempted by Deroo et al. (1977). They grouped the Lower Cretaceous tar sands and conventional oils of central and northeastern Alberta into a single oil family, based on sulphur content and saturated hydrocarbon and aromatic hydrocarbon distribution. The source for these oils was suggested to be from Lower Cretaceous shales, rich in marine or non-marine organic matter. Although the Lower Cretaceous units were suggested to be the major contributors of hydrocarbons to these deposits, Deroo et al. (1977) suggested that a minor amount of these accumulations was derived from Paleozoic source rocks. These Paleozoic oils migrated up-dip to the post-Paleozoic unconformity and then along the basal Lower Cretaceous sands. They also postulated that the tar sands and heavy oil deposits of northern Alberta were originally conventional oils that were degraded by bacterial activity.

Rubinstein et al. (1977) examined the northeastern Alberta tar-sand deposits and agreed with Deroo et al. (1977) that they were the result of biodegradation of conventional oils. They did not suggest a likely hydrocarbon source rock interval for the tar sands nor did they suggest a migration fairway for these oils.

Leenheer (1984) proposed that the Lower Cretaceous heavy oil/ tar sand deposits resulted from the long distance migration of oil derived from the Bakken/Exshaw Formation. These studies used a comparison of gasoline range fraction (C_5 to C_8), and saturate fraction (C_{15}+) gas chromatography, and biomarker analysis for Bakken/Exshaw extracts and heavy oils/tar sands samples. A correlation between tricyclic terpane distributions for the Bakken extracts and heavy oil deposits was made, suggesting that the Bakken and equivalents were the primary source for the heavy oil deposits.

Masters (1984) suggested the Lower Cretaceous Clearwater Shale member of the Lower Mannville Formation as the source for much of the Lower Cretaceous heavy oil/tar sand deposits, however no geochemical data was presented to support this interpretation. Moshier and Waples (1985) discounted this suggestion due to the limited volume of thermally mature, oil-prone Lower Cretaceous, hydrocarbon source rock. They examined a limited suite of drill cuttings from Lower Cretaceous shales and concluded that these shales were of insufficient quality and thermal maturity to have generated the vast quantity of hydrocarbons in the tar sand deposits.

du Rouchet (1985) suggested that the heavy oil/tar accumulations were derived from Triassic-Jurassic shales in the Deep Basin of western Alberta. This idea was based primarily on saturate fraction gas chromatographic similarities between Triassic oils in northeastern British Columbia and Lower Cretaceous heavy oils of Central Alberta. He also noted an association of Triassic oil-stained rock with overlying Lower Cretaceous oil-stained rock in the Peace River region. He believed that this indicated vertical migration of Triassic-derived oils into the Lower Cretaceous reservoirs, creating the

Peace River tar sand deposit. A broad region of non-deposition in these Lower Cretaceous sands truncates the Peace River deposits to the east and forced migrating oils to be relayed to the underlying, weathered, Paleozoic carbonates. These oils then moved up-dip towards northeastern Alberta accessing porous Lower Cretaceous sands and have been subsequently biodegraded.

Brooks et al. (1988) discounted the Exshaw/Bakken source for the tar-sands as outlined by Leenheer (1984) based primarily on the presence of 28,30 bisnorhopane and diasterane distributions (C_{27}, C_{28} and C_{29}) in Athabasca heavy oil deposits. These occurrences do not fit with Bakken extract data published by Leenheer (1984), from the Alberta and Williston basins and as such this source was discounted as the primary source for the heavy oil/tar sand deposits. Instead they postulated a Mesozoic clastic source but did not say which interval nor do they indicate a migration fairway for these oils.

3.2.2 Origin of conventional oils in Lower Cretaceous reservoirs, Alberta Basin (Alberta and northwestern Montana)

Creaney and Allan (1990) attempted the first major characterization of conventional oil families in the Alberta Basin, using biomarker analysis. These authors identified ten marine hydrocarbon source rocks in Alberta. Of these, only four (Upper Devonian Duvernay Formation, the Devonian/Mississippian Exshaw Formation, the Middle Triassic Doig Formation and the Lower Jurassic Nordegg Formation) were thought to be effective contributors to Lower Cretaceous reservoirs (Creaney and Allan, 1990; Figure 6). The distribution of oil in Lower Cretaceous reservoirs generated by each of these source rocks is controlled by the location of their subcrop edge relative to the overlying Lower Mannville Formation (Figure 6).

These ideas were further expanded by Allan and Creaney (1991), integrating oil and source rock biomarker evidence as key elements in understanding the effective sources for Lower Cretaceous oils in Alberta. They attributed most of the oil in Lower Cretaceous reservoirs to the Duvernay, and Exshaw formations, and the Nordegg Member. The Doig Formation is considered a closed hydrocarbon system because the overlying Lower Jurassic Nordegg Member seals most of the Triassic section in the Alberta Basin.

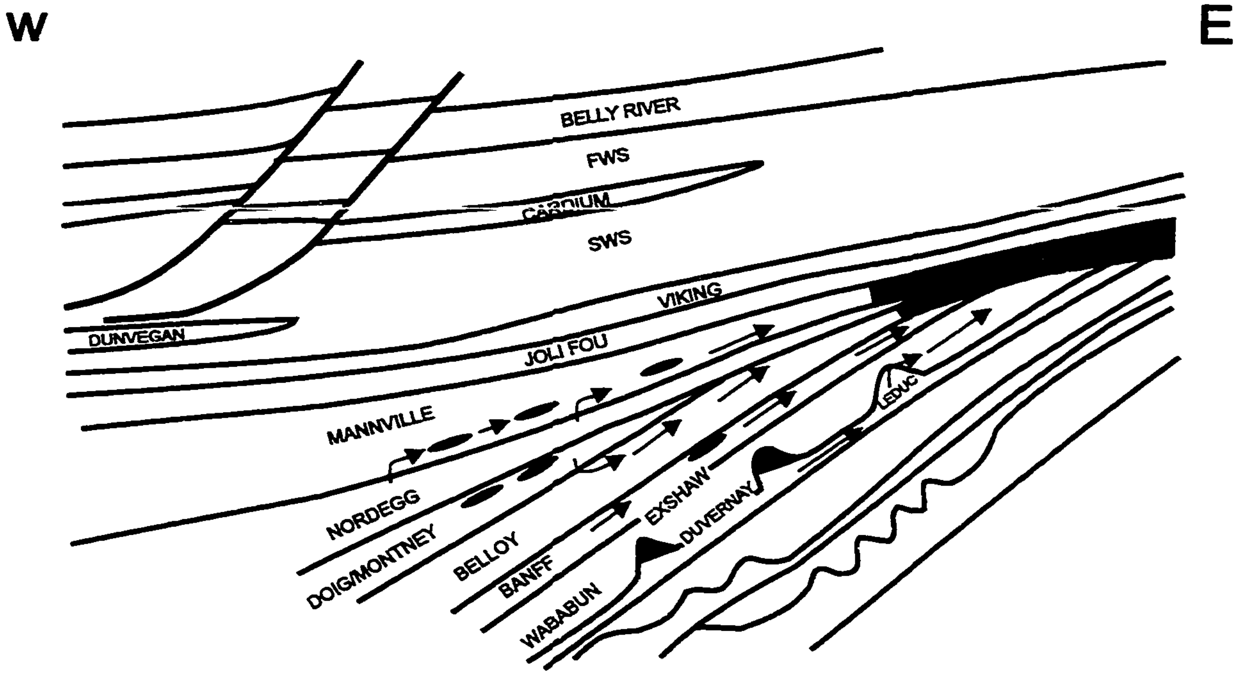


Figure 6. Oil migration in the Alberta Basin as outlined by Creaney and Allan (1990). SWS and FWS represent the Second White Specks and First White Specks of the Colorado Group respectively.

Dolson et al. (1993) integrated biomarker analysis and geology in an attempt to understand the controls on the migration and origin of oils in the Cutbank Field, northwestern Montana. These authors correlate the Cutbank Field oils to the Lower

Mississippian Exshaw Formation. The oils from the Cutbank Field were generated in southwestern Alberta by the thermally mature Exshaw/Bakken Formation, and then migrated up-section to Jurassic strata via vertical fractures in the Mississippian Madison Formation. The Jurassic section acted as a regional seal and allowed for migration up-dip towards the south (Figure 7). North of the Cutbank area the Jurassic section is eroded

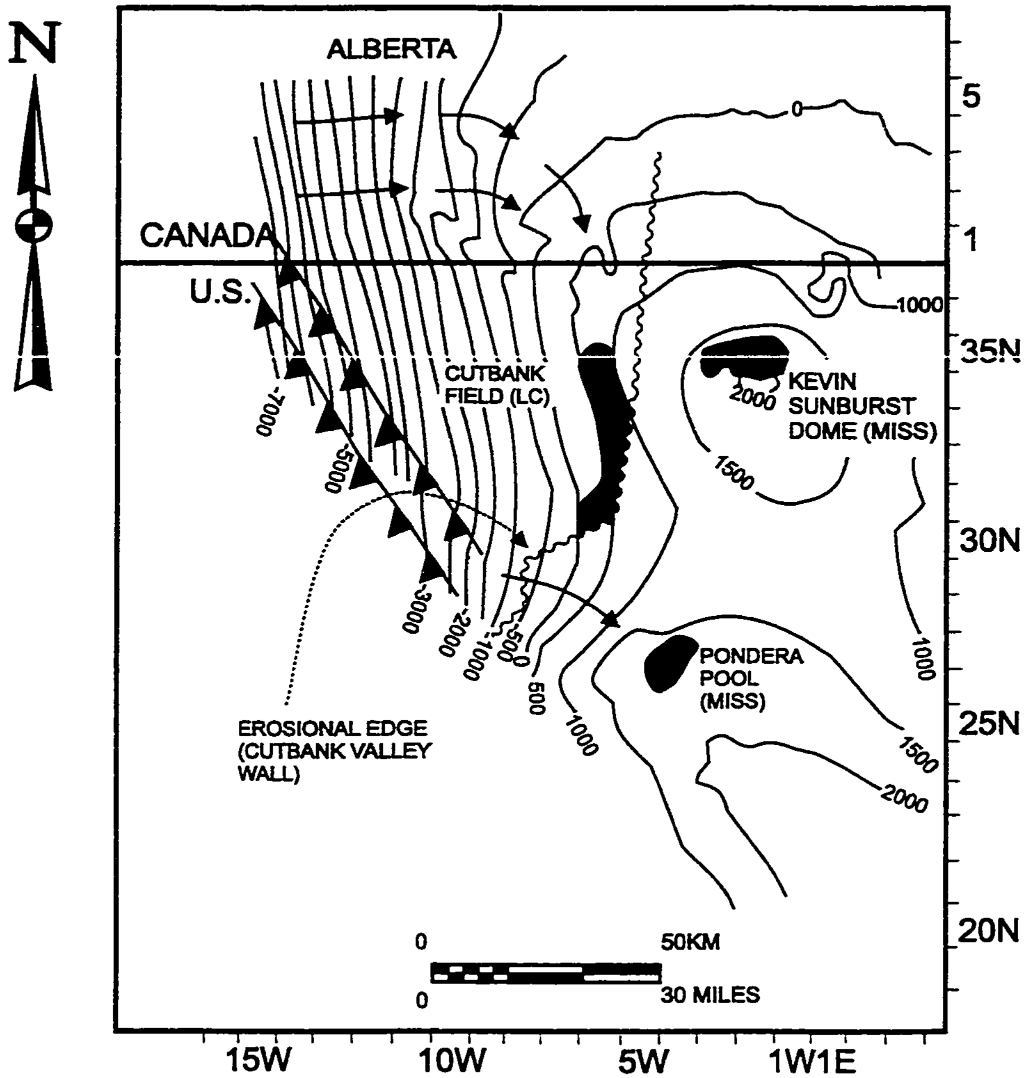


Figure 7. Oil migration in the Cutbank field of northwestern Montana (Dolson et al., 1993). North of the Cutbank area the Jurassic section is eroded creating a seal breach and allowing migrating oils to access Lower Cretaceous Cutbank sands. MISS represents Mississippian reservoir and LC represents Lower Cretaceous reservoir (Note structure contours depicted in map are for the top of the Mississippian).

Creaney et al. (1994) synthesized data on oil families in Western Canada. Lower Cretaceous reservoirs were determined to be charged by the Duvernay Formation in east-central Alberta, the Exshaw Formation for most of northeastern, eastern and southern Alberta, the Lodgepole Formation in southern Saskatchewan and the Nordegg Formation in northwestern Alberta.

Riediger et al. (1995) correlated oils in Lower Mannville reservoirs from the Provost field, east-central Alberta to a number of source rocks, including the Duvernay, and Exshaw formations and the Ostracode Member of the Lower Mannville Formation

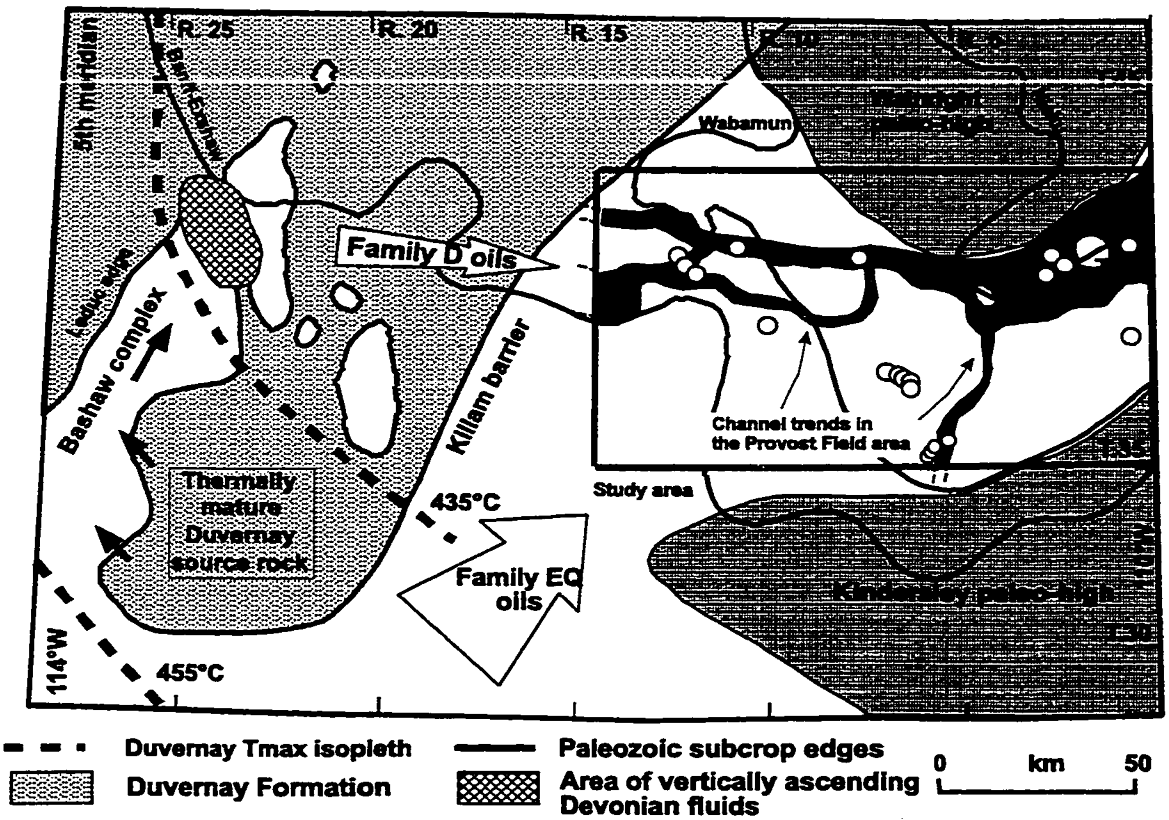


Figure 8. Hydrocarbon migration model for the Provost area after Riediger et al. (submitted). Open arrows indicate oil migration directions for Family EQ and D oils in Lower Cretaceous channel sands (dark grey) in the Provost area. Crosshatched area indicates cross-formational flow in from Devonian to Lower Cretaceous strata as indicated by Rostron and Toth (1997).

(Figure 8). The Ostracode Member is thought to contribute hydrocarbons to reservoirs in this area, based on the existence of "Q" compounds in the saturated hydrocarbon fractions of most Provost oils. These compounds have only been documented in Ostracode Member rock extracts (Riediger et al., 1997A). Oil migration in this area is controlled primarily by local seals and sub-crop edges which directly affect the distribution of Duvernay-derived oils relative to Exshaw-derived oils (Riediger et al., 1995). This evidence is further supported by high salinity anomalies in Devonian and Mannville strata in the Provost area, indicating strong upward migration of more saline, Devonian fluids into Lower Mannville strata of the area (Rostron and Toth, 1994; 1997). Recent work by Riediger et al. (submitted), suggests that Lower Mannville channels in southern Alberta may have acted as long distance carrier beds for Family EQ oils (mixed Exshaw and Ostracode Zone-derived oils) which were derived from southwestern Alberta into the Provost area.

Riediger et al. (1996) characterized oils from the Long Coulee oil field in southern Alberta (Figure 9) and documented the existence of a new oil family (Family F oils) in the Lower Mannville characterized by a high C_{28}/C_{29} regular sterane ratio, high saturated to aromatic hydrocarbon ratio and a high diasterane to regular sterane ratio. This oil family is unlike any previously documented in the Alberta Basin, however Riediger et al. (1997B) and Karavas et al. (1997) suggest that Family F oils are derived from the Middle Jurassic Rierdon Formation of southern Alberta (Figure 10).

Thus, there are at least 5 oil families in the Lower Cretaceous of Alberta derived from the Duvernay (Family D), the Exshaw (Family E), an unnamed Nordegg derived oil, the Rierdon (Family F), the Ostracode (Q), and a mixed Ostracode/Exshaw Formation derived oil (Family EQ) (Figure 10).

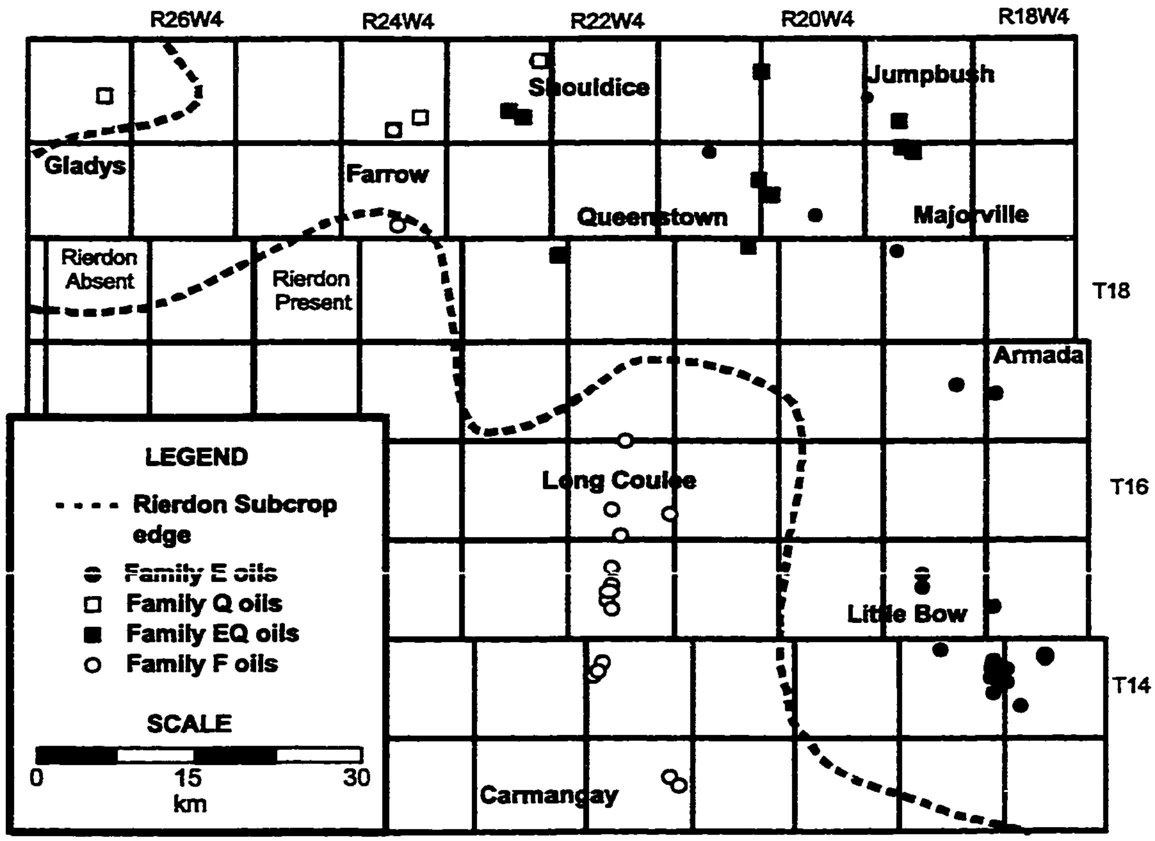


Figure 9. Study area for Riediger et al. (1996) and Karavas et al. (in press). Symbols indicated in legend are for various Lower Cretaceous oil families in southern Alberta.

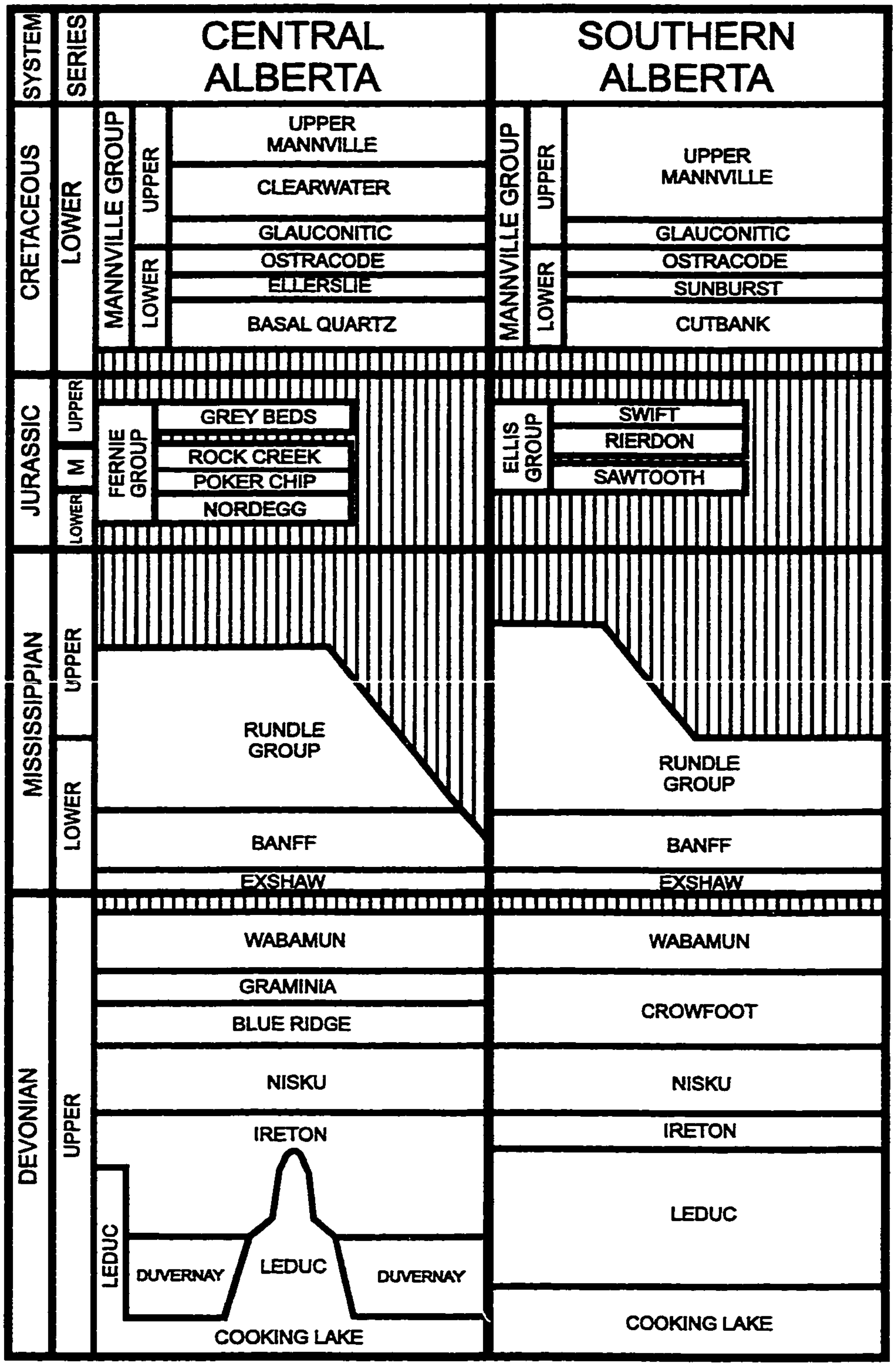


Figure 10. Generalized stratigraphic column of potential hydrocarbon source rocks (shaded) for oils in the Lower Mannville for southern and central Alberta (Riediger et al., 1997B).

3.2.3 Origin of conventional oils in Mesozoic reservoirs, Williston Basin

Williams (1974) classification of oils from the Williston Basin divided them into three families (I, II, and III) based on gasoline fraction (C_5 to C_8), saturate fraction (C_{15+}) gas chromatography and carbon isotopic data (δC^{13}) on the saturated hydrocarbon fraction and whole oil. Based on this work he considered that oil in the Mesozoic reservoirs of southwestern Manitoba was derived from the Upper Devonian to Early Mississippian Bakken Formation (Exshaw equivalent). These oils were suggested to have migrated northeast and up-dip from mature sources in the central Williston Basin towards the Paleozoic subcrop edge, and then vertically into overlying Mesozoic reservoirs.

Brooks et al. (1987) analyzed 34 oils from southeastern Saskatchewan and southwestern Manitoba, and identified three distinct oil families (A, B, and C). These oil families were distinguished on the basis of gross composition, and C_{15+} saturated hydrocarbon fraction composition using gas chromatography and gas chromatography-mass spectrometry. The Family A oils were derived from an Ordovician source, Family B oils are correlated to the Bakken Formation and Family C oils were generated by the Lower Mississippian Madison Group. Oils from Mesozoic reservoirs in southwestern Saskatchewan are correlated to the Family C oils, implying up-dip migration to the northeast, from a mature Madison source in North Dakota.

Osadetz et al. (1992) undertook a similar oil family study for southeastern Saskatchewan and southwestern Manitoba, and successfully correlated the Family C oils of southeastern Saskatchewan to the Lower Mississippian Lodgepole Formation, delineating it as the most effective source for oil in Paleozoic and Mesozoic reservoirs in the area (Figure 11).

Osadetz et al., (1994) examined the sources for oils in Mesozoic reservoirs in southwestern and west-central Saskatchewan. Using the guidelines of Brooks et al. (1987) and Osadetz et al. (1992), it was found that the majority of oils in Middle Jurassic to Lower Cretaceous reservoirs are similar to Family C oils of Osadetz et al. (1992), suggesting that the Lower Mississippian Lodgepole Formation was the primary source for Mesozoic oils in southwestern Saskatchewan (Figure 11). In that study no migration fairway was delineated for the oils but Creaney et al. (1994) imply that oils derived from the Lodgepole Formation migrated from mature sources in the deeper sections of the Williston Basin into these Mesozoic aged reservoirs in southwestern Saskatchewan.

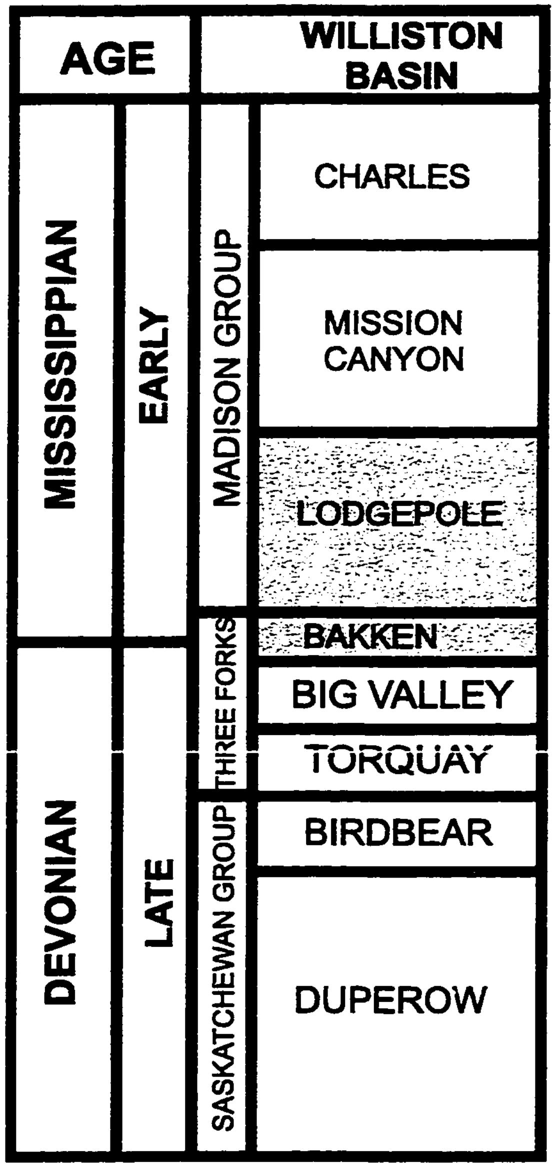


Figure 11. Representative stratigraphic column of potential hydrocarbon source rocks (shaded) for the oils in Mesozoic reservoirs of southern Saskatchewan (Brooks et al., 1987; Osadetz et al., 1992; and Osadetz et al., 1994).

4. METHODS

4.1 Geological Techniques

In the construction of a geologic model for the Upper Jurassic-Lower Cretaceous reservoirs of the Manyberries area, a variety of subsurface geological techniques were used, including geophysical well log interpretation, core analysis, stratigraphic cross-section construction, and isopach and structure mapping. Geophysical well logs were used to make stratigraphic correlations, pick formation contacts, delineate oil reservoirs and characterize the depositional environment for reservoir units. The main well logs used were, gamma ray, neutron /density porosity, spontaneous potential and resistivity. Geological correlation based solely on geophysical well logs proved to be difficult due to similar log responses for different stratigraphic units. Therefore, 27 wells with core were logged (Appendix 1) and lithologies were compared to geophysical well log signature to correctly characterize the well log signature for stratigraphic units.

Using the data from well logs and cores analyzed (Figure 12), stratigraphic cross sections were constructed (Appendix 2; see Figure 12 for cross-section locations). The top of the Middle Jurassic Rierdon Formation was selected as the stratigraphic datum to most readily illustrate deposition and erosion during the Upper Jurassic and Lower Cretaceous. These sections illustrate the lateral continuity of Upper Jurassic to Lower Cretaceous reservoirs in the area and were used to characterize specific formation tops (Appendix 3). This information was then used to construct a formation top database for 371 wells in the study area. This database then was used to construct isopach maps for

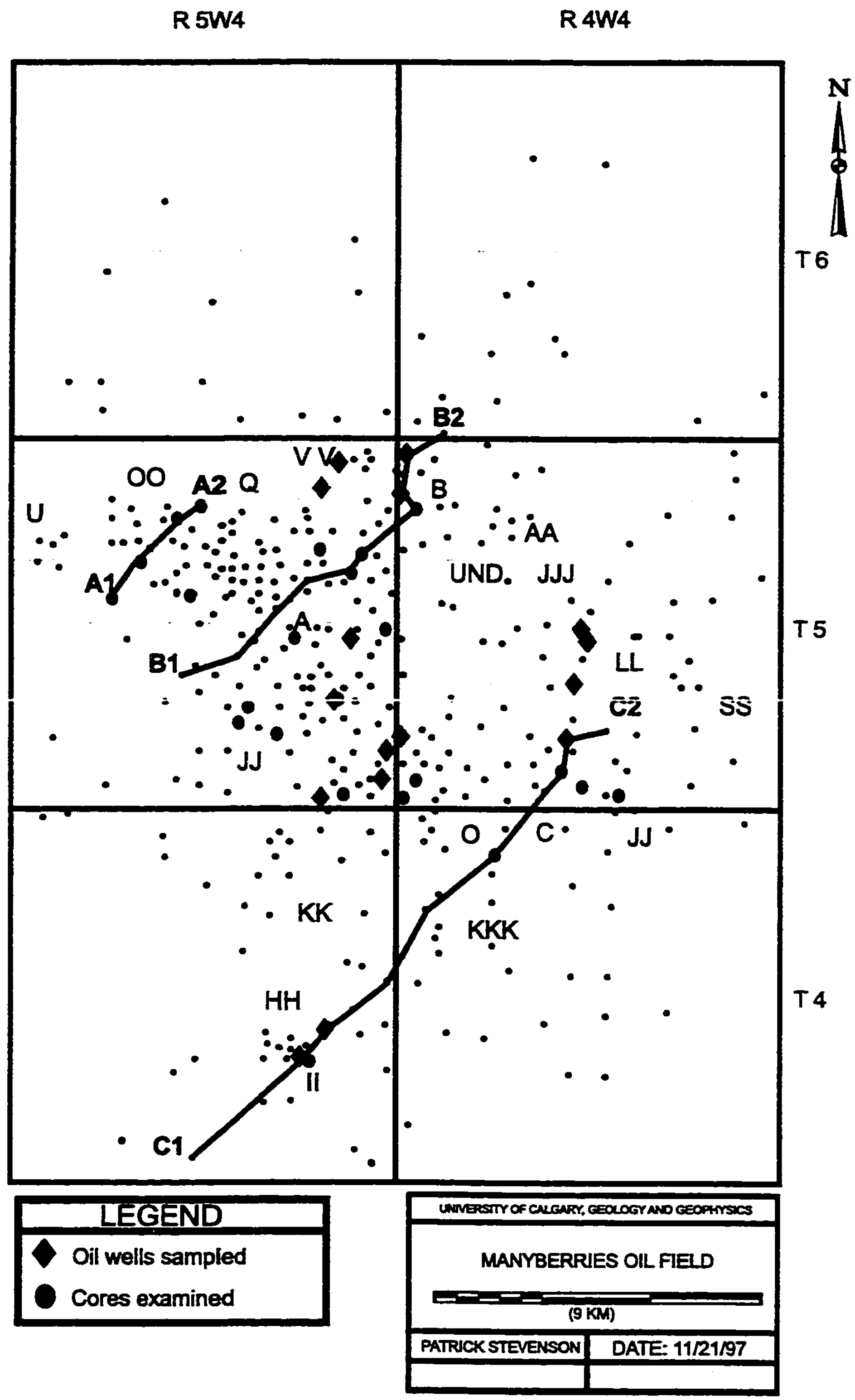


Figure 12. Wells used and pool locations and the position of stratigraphic cross-sections (Appendix 2). Diamonds denote oil sample locations sampled and circles denote cores examined.

the Swift, Lower Mannville and Upper Mannville formations and structure maps for the top of the Rierdon Formation. These maps were constructed with the use of Mcad Contour ® mapping software.

4.2 Geochemical Techniques

4.2.1 Oil Sampling Technique

Twenty six 200 ml oil samples from wellheads at Manyberries (Figure 12; Table 1), Medicine Hat, Black Butte, Whitlash, Fred and George Creek and Utopia oil fields were obtained for organic geochemical analysis (Table 1; Figure 12). These samples are representative of the range of API gravity and stratigraphic zone of production. API gravity data was obtained from IPL Petrodata Cards on microfilm at the Department of Geology and Geophysics petrofiche library. Duplicate samples were taken in case of breakage during transportation. All samples were stored in glass containers in a cool area (<20°C) during transportation and were then taken to the Organic Geochemistry Lab at the Geological Survey of Canada (GSC), Calgary for analysis and permanent storage.

An additional 12 oil samples already in storage at the Organic Geochemistry Lab at GSC (Calgary) were also included in this study and are listed in Table 1. Oil field locations sampled for this study are shown on (Figure 13).

4.2.2 Sulphur Analysis

The total sulphur content (wt. %) was determined for all oils collected using a LECO SC32 sulphur analyzer. Approximately 10 ml of whole oil was analyzed in a sulphur analyzer at 1400°C for 120 seconds. Duplicate oil samples were run in order to obtain average values.

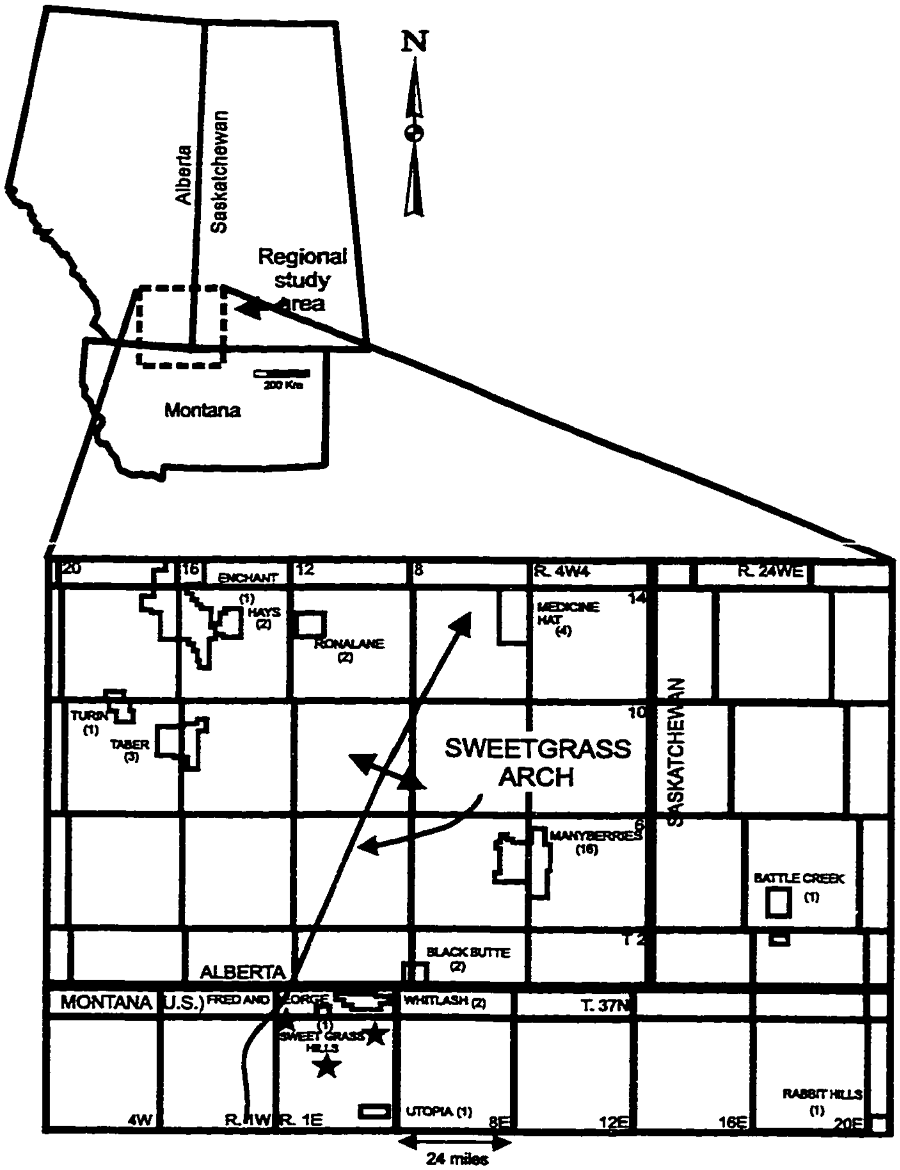


Figure 13. Oil fields sampled for study. The number of samples collected from each field is given in brackets. See Table 1 for sample locations.

Table 1. Wells sampled within the study area (abbreviations are as follows; LM = Lower Mannville Formation, UM = Upper Mannville Formation, Swift = Swift Formation, Med Hat = Medicine Hat, PZONE = production zone and n/a = not available)

WELL LOCATION	SAMPLE #	FIELD	P ZONE	API GRAVITY(°)	POOL	PERFORATION DEPTH (m)
10-36-4-5W4	2127	Manyberries	Swift	37.1	Sunburst KK	1053-1059
12-13-5-5W4	2128	Manyberries	LM/Swift	35.9	Sunburst JJ	1122.5-1130
16-01-5-5W4	2129	Manyberries	LM	31.6	Sunburst KK	1118.5-1126
2-2-5-5W4	2130	Manyberries	LM	33.4	Sunburst KK	1077.9-1088
4-7-5-4W4	2131	Manyberries	Swift	29	Sunburst KK	1133-1142
5-12-5-5W4	2132	Manyberries	Swift	35.9	Sunburst JJ	1097.5-1105
12-15-5-4W4	2133	Manyberries	UM	35.1	Sunburst LL	1156.2-1158
16-9-5-4W4	2134	Manyberries	UM	36.5	Sunburst LL	1170.5-1173
2-9-5-4W4	2135	Manyberries	UM	36.5	Sunburst C	1161.8-1166
8-14-4-5W4	2136	Manyberries	LM	38.1	Sunburst HH	1071-1074.7
14-11-4-5W4	2137	Manyberries	LM	37.5	Sunburst II	1063-1066
12-31-5-4W4	2138	Manyberries	LM	40.5	Sunburst B	1172.5-1175.5
12-36-5-5W4	2139	Manyberries	LM	39.5	Sunburst VV	1156.8-1161.8
2-35-5-5W4	2140	Manyberries	LM	39.5	Sunburst VV	1181.7-1184.2
4-31-5-4W4	2141	Manyberries	LM	40.5	Sunburst B	1189.5-1193.5
16-16-5-4W4	2146	Manyberries	UM	37.1	Sunburst LL	1166.0-1167.5
12-15-13-5W4	2142	Med Hat	UM	19.5	Glauconitic C	832-846
13-35-12-5W4	2143	Med Hat	UM	19.1	Glauconitic C	838.2-849.0
4-35-12-5W4	2144	Med Hat	UM	15.3	Glauconitic C	828.8-844.5
6-15-13-5W4	2145	Med Hat	UM	17.4	Glauconitic C	830-836
9-20-1-8W4	2365	Black Butte	LM	23.6	Mannville B	936.5-940
16-20-1-8W4	2366	Black Butte	LM	23.6	Mannville B	936.0-941
22-18-34N-20E	1406	Rabbit Hills	Sawtooth	20	n/a	1244.7-1248.1
6-23-05-27W3	1329	Battle Creek	Gravelbourg	33	n/a	1358.8-1360.6
15-22-3-26W3	726	Battle Creek	Madison	10.5	n/a	1385.0-1386.8
7-9-9-17W4	1917	Taber	LM	18.1	Taber A	989-998
10-4-10-16W4	1923	Taber	LM	19	Taber N	979-986
2-29-9-16W4	1924	Taber	LM	19	Taber N	1066-1078
6-36-11-17W4	1922	Turin	LM	31.9	Mannville D	1008-1021
16-35-12-13W4	1937	Ronalane	Sawtooth	31.1	Sawtooth K	930-936
11-16-13-12W4	2002	Ronalane	Sawtooth	30.2	Sawtooth C	917-918
1-28-13-14W4	1993	Hays	LM	32.1	Sawtooth B	952-955
15-5-13-14W4	1986	Hays	Sawtooth	18.3	Sawtooth B	973-975
2-31-12-15W4	2001	Enchant	LM	n/a	Ellis K	964-965
NE-14-37N-3E	2474	Whitlash	Swift	39	n/a	838-843
NE-26-37N-2E	2475	Whitlash	LM	39	n/a	774-789
NE-35-37N-2E	2476	Fred+George	LM	39	Sunburst B	771-775
NE-14-33N-4E	2477	Utopia	Swift	33	n/a	656-661

4.2.3 Distillation and Fractionation

The whole oil was first separated into fractions (Gasoline Range (C_5 to C_8), Saturate Fraction (C_{15+}), Aromatics and Resins and Asphaltenes) to better aid in Gas Chromatography (GC) and Gas Chromatography/Mass Spectrometry (GC/MS) analysis. This separation is achieved by a combination of simple distillation and liquid chromatography. The gasoline range (C_5 to C_8) was separated by a simple distillation process using 25 g of whole oil, with the gasoline range fraction boiled off at temperatures under 210°C. This fraction was collected in a cleaned weighed flask and used in gas chromatography of the gasoline range hydrocarbons. After the gasoline range fraction was separated, the remaining oil (>210°C fraction) was fractionated into four components; saturated hydrocarbons, aromatic hydrocarbons, NSO compounds and asphaltenes. The first step was to remove the asphaltene fraction, which was accomplished by adding a small volume of chloroform and a large volume of pentane (30 ml) to the distilled sample to precipitate the asphaltenes. The deasphaltened sample was then fractionated using open column liquid chromatography. The column was packed with one-third silica gel and two-thirds alumina adsorbent with an adsorbent to sample mass ratio of 100:1. The sample was then dissolved in 3.5 ml/g of distilled pentane and added to the column. The saturate fraction was then collected for GC analysis and gas chromatography-mass spectrometry (GC-MS). Eluting a 1:1 mixture of pentane and dichloromethane with remaining sample collected the aromatic fraction. The aromatic fraction was then collected but no analysis of this fraction was attempted. The resin fraction was then fractionated from the remaining sample using 4 ml of methanol/gm of support. Residual asphaltenes were then removed using 4 ml/g of

Table 2. Gross Composition Analysis; Manyberries, Black Butte, Whitlash and Fred and George Creek oil samples

WELL LOCATION	sample #	API gravity (°)	sulphur (wt%)	%saturates	%aromatics	%resins+ asphaltenes	saturate/ aromatic
10-36-4-5W4	2127	37.10	1.05	46.29	39.29	6.22	1.30
12-13-5-5W4	2128	35.90	1.11	51.93	40.02	7.40	1.30
16-01-5-5W4	2129	31.60	1.37	50.82	38.66	6.29	1.30
2-2-5-5W4	2130	33.40	1.15	53.11	36.05	5.98	1.50
4-7-5-4W4	2131	29.00	1.31	53.16	37.91	5.77	1.40
5-12-5-5W4	2132	35.90	1.04	51.51	38.69	6.79	1.30
12-15-5-4W4	2133	35.10	1.06	51.43	36.58	7.48	1.40
16-9-5-4W4	2134	36.50	1.09	52.37	35.77	6.72	1.50
2-9-5-4W4	2135	36.50	1.04	51.30	36.77	7.12	1.40
8-14-4-5W4	2136	38.10	1.00	53.40	36.52	6.90	1.50
14-11-4-5W4	2137	37.50	1.03	52.11	36.54	6.49	1.40
12-31-5-4W4	2138	40.50	1.15	49.95	38.18	7.64	1.30
12-36-5-5W4	2139	39.50	1.14	48.79	38.66	7.99	1.30
2-35-5-5W4	2140	39.50	1.06	51.85	37.25	8.89	1.40
4-31-5-4W4	2141	40.50	1.06	49.18	37.25	7.80	1.30
16-16-5-4W4	2146	37.10	1.07	51.73	37.25	7.75	1.40

support of chloroform and combined with previously collected asphaltene fraction. The four fractions collected were weighed to determine the relative percentages of saturated hydrocarbons, aromatic hydrocarbons, resins and asphaltenes (Table 2). This procedure follows that of Fowler et al. (1995). The remaining whole oil and fractions are in permanent storage at the GSC (Calgary).

4.2.4 Gas Chromatography (GC)

The gasoline fraction (C_5-C_8) was analyzed using a HP 5890A gas chromatograph. An example of a gasoline range chromatogram with identified peaks is shown in Figure 14 and all gasoline range gas chromatograms are provided in Appendix 4 (note, only Manyberries, Black Butte (#2365 n/a), Whitlash, Fred and George Creek samples are included in Appendix 4. C_5-C_8 GC's for Medicine Hat, Rabbit Hills, Battle Creek, Taber, Turin, Ronalane, Hays, Enchant, Whitlash, and Utopia oil fields are in the database at GSC Calgary).

The C_{15+} saturate fraction was analyzed using a Varian 3700 FID gas chromatograph with a 25m OV-1 column. The column temperature was raised from 60 to 260°C at a rate of 4° C/min. This procedure follows that of Fowler et al. (1995). All C_{15}+ gas chromatograms are provided in Appendix 5. (Note, only Manyberries, Black Butte, Whitlash, and Fred and George Creek samples are included in Appendix 5 and SFGC's from Medicine Hat, Rabbit Hills, Battle Creek, Taber, Turin, Ronalane, Hays, Enchant, Whitlash, and Utopia oil fields are in database at GSC Calgary). Pristane and phytane were the only compounds measured from the SFGC's used in this study (see Figure 15 for peak identification).

4.2.5 Gas chromatography-Mass Spectrometry (GC-MS)

A VG 70SQ hybrid MS-MS equipped with a VG 11-25 data acquisition system was used to obtain GC-MS data for each oil sample. An ion source (70 eV) was attached to the gas chromatograph to cause molecular fragmentation. The column used in this apparatus was a 25m DB-5 column, which was temperature programmed from 50°-310°C at a rate of 4° C/min. The carrier gas used for the GC-MS was 0.2 ml/min of He. Data was collected by multiple ion detection (MID), monitoring ions at m/z (mass/charge ratio) 177.1638, 191.1794, 217.1950, 218.2028, 231.2106 and 259.2262. All saturate fraction GC-MS data (m/z 191, 217, and 218 mass fragmentograms only) for the Manyberries, Black Butte, Whitlash and Fred and George Creek oil samples are provided in Appendix 6. GC-MS data for Medicine Hat, Rabbit Hills, Battle Creek, Taber, Turin, Ronalane, Hays, Enchant, Whitlash, and Utopia oil fields GC-MS data is available from GSC Calgary.

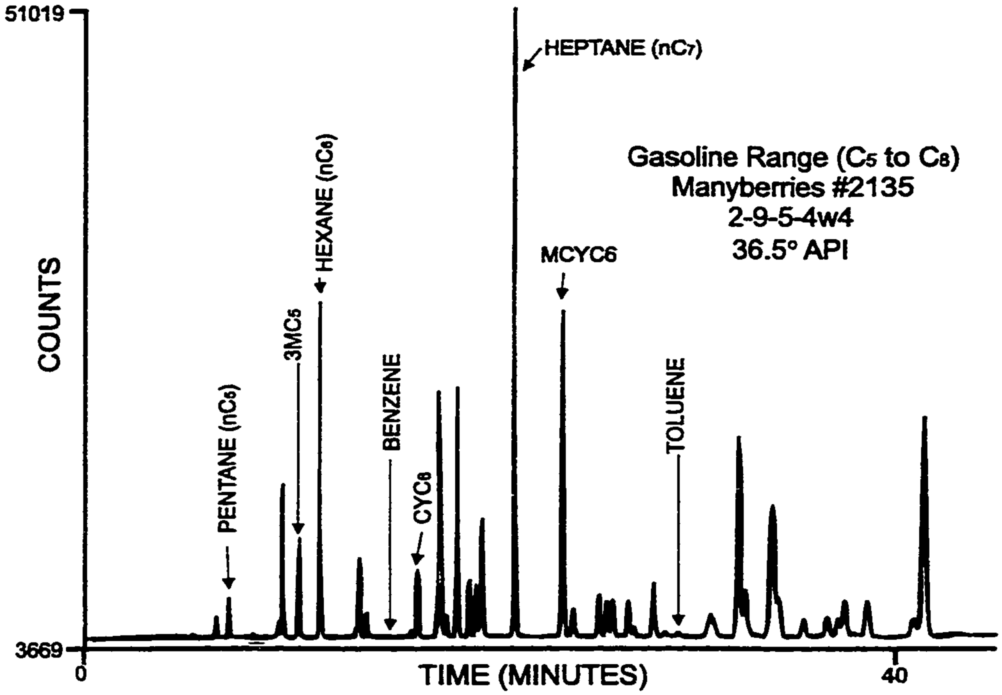


Figure 14. Representative gasoline range (C_5-C_8) gas chromatograph for sample # 2135 (2-9-5-4W4). Peak $3MC_5$=3-methyl pentane, CYC_6 =cyclohexane, $MCYC_6$ = methyl-cyclohexane.

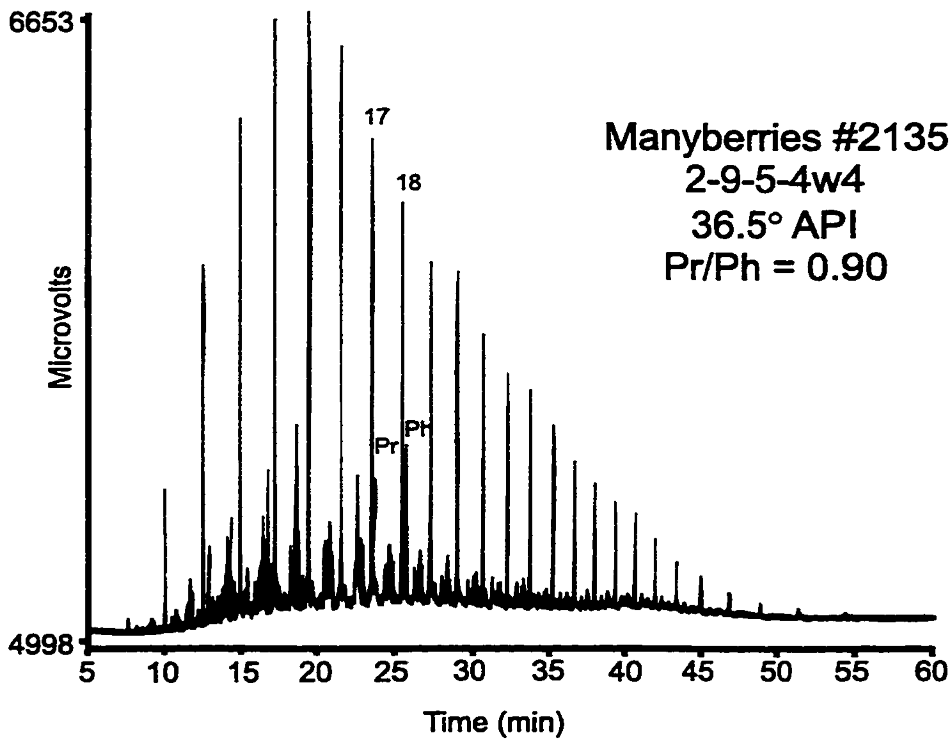


Figure 15. Representative saturate fraction (C_{15+}) gas chromatograph for lab # 2135 (2-9-5-4W4). Pr = pristane; Ph = phytane; 17= nC_{17}: 18=nC_{18}.

4.2.5.1 Biomarker Peak Measurement

Biomarker peak height from mass fragmentograms; m/z 191, 217, and 218 were used to calculate biomarker ratios. The biomarker peaks measured from the m/z 191 fragmentograms include C_{23} tricyclic terpane, C_{24} tetracyclic terpane, C_{26} tricyclic terpanes, 18α(H)-trisnorneohopane (Ts) and 17α(H)-trisnorhopane (Tm), C_{29} 17 α(H) 21β(H) norhopane, C_{30} 17 α(H) 21β(H) hopane, C_{34} 17 α(H) 21β(H) tetrakishomohopane (22S), and C_{35} 17 α(H) 21β(H) pentakishomohopane (22S) (Figure 16; Table 3). Compounds measured from m/z 217 fragmentogram include; C_{21} 5α(H) 14β(H) 17β(H) pregnane, C_{27} 13β(H) 17α(H) 20S diasterane, C_{27} 5α(H) 14α(H) 17α(H) 20R sterane, and C_{29} 5α(H) 14α(H) 17α(H) 20S, and 20R steranes (Figure 17). Compounds measured from m/z 218 include; C_{27}, C_{28} and C_{29} 5α(H) 14β(H) 17β(H) 20S, and 20R steranes and from these peaks an average was attained for each carbon number for use in calculation of the relative abundance of steranes C_{27}, C_{28} and C_{29} (Figure 18). This procedure follows that of Fowler et al. (1995).

Table 3. Biomarkers measured for this study (A, Terpanes: for representative m/z191 see Figure) and (B, Steranes: for m/z 217 and 218 see Figure and 18)

(A) Terpanes: m/z 191

1	C_{23} tricyclic terpane
2	C_{24} tetracyclic terpane
3	C_{26} tricyclic terpanes
4	18α(H)-trisnorneohopane (C_{27})
5	17α(H)-trisnorhopane (C_{27})
6	17 α(H)21β(H) norhopane (C_{29})
7	17 α(H)21β(H) hopane (C_{30})
8	17 α(H)21β(H) tetrakishomohopane (C_{34})
9	17 α(H)21β(H) pentakishomohopane (C_{35})

(B) Steranes: m/z 217 and m/z 218

A	C_{21} 5α(H),14β(H),17β(H)-pregnane
B	C_{27} 13β(H)17α(H)20S diasterane
C	C_{27} 5α(H)14α(H)17α(H)20R sterane
D	C_{29} 5α(H)14α(H)17α(H)20S sterane
E	C_{29} 5α(H)14α(H)17α(H)20R sterane
F	C27 5α(H)14β(H)17β(H)20R sterane
G	C27 5α(H)14β(H)17β(H)20S sterane
H	C28 5α(H)14β(H)17β(H)20R sterane
I	C28 5α(H)14β(H)17β(H)20S sterane
J	C29 5α(H)14β(H)17β(H)20R sterane
K	C29 5α(H)14β(H)17β(H)20S sterane

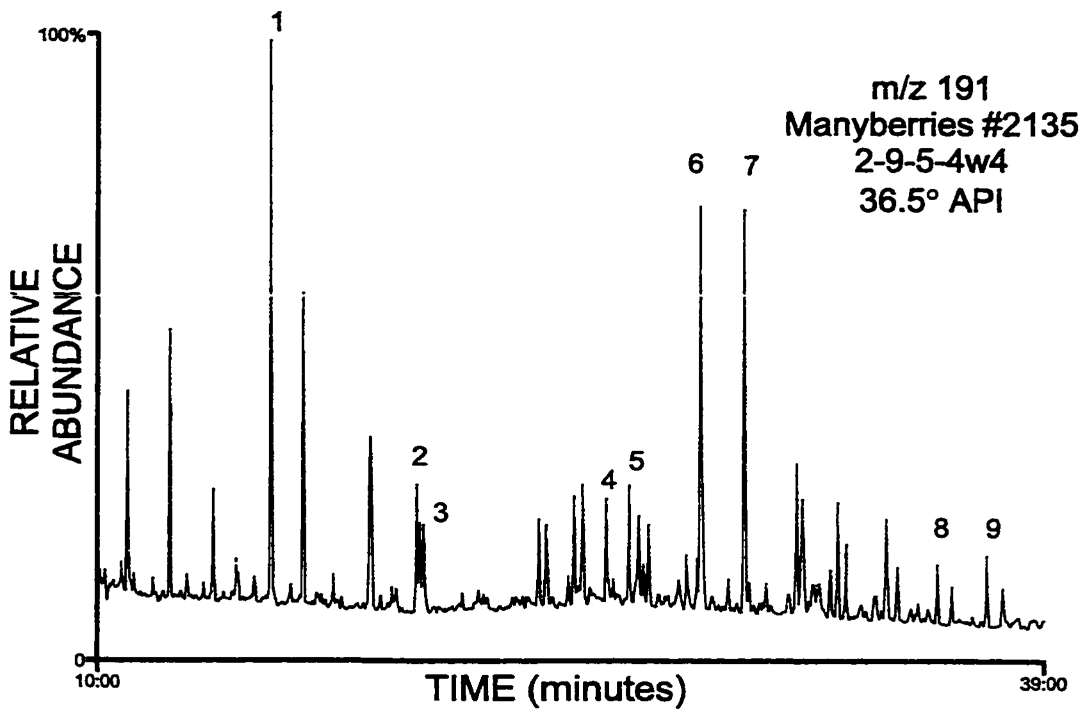


Figure 16. A representative m/z 191 mass fragmentogram from the Manyberries oil field, southeastern Alberta, sample # 2135 (2-9-5-4W4). For identification of peaks see Table 3.

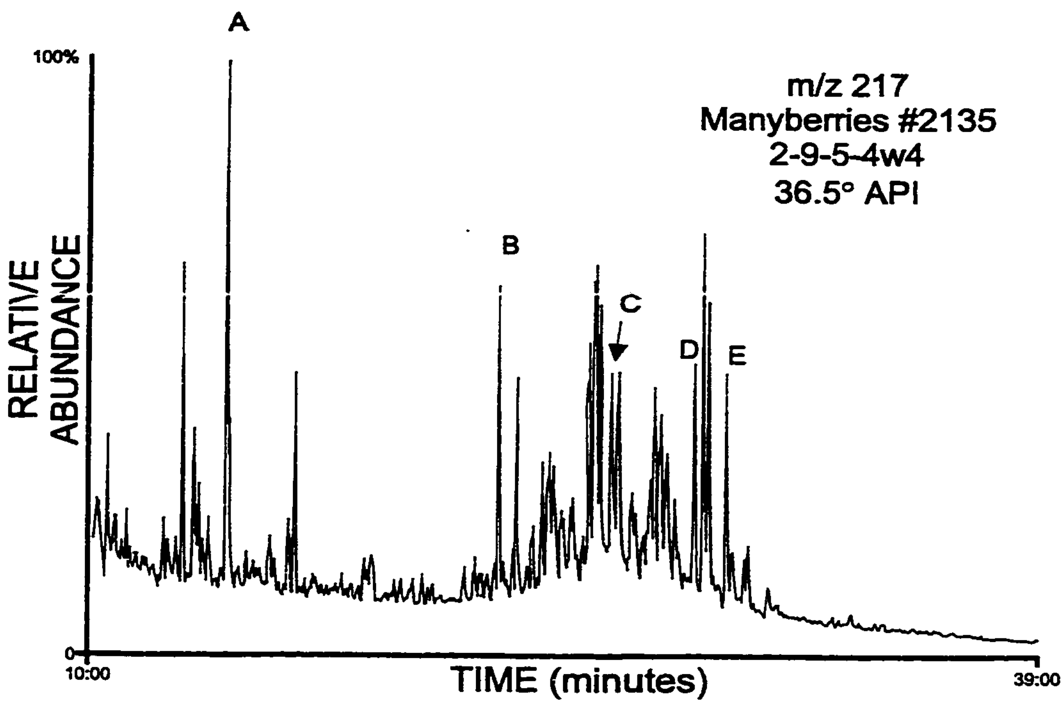


Figure 17. A representative m/z 217 mass fragmentogram from the Manyberries oil field, southeastern Alberta, sample # 2135 (2-9-5-4W4). For identification of peaks see Table 3.

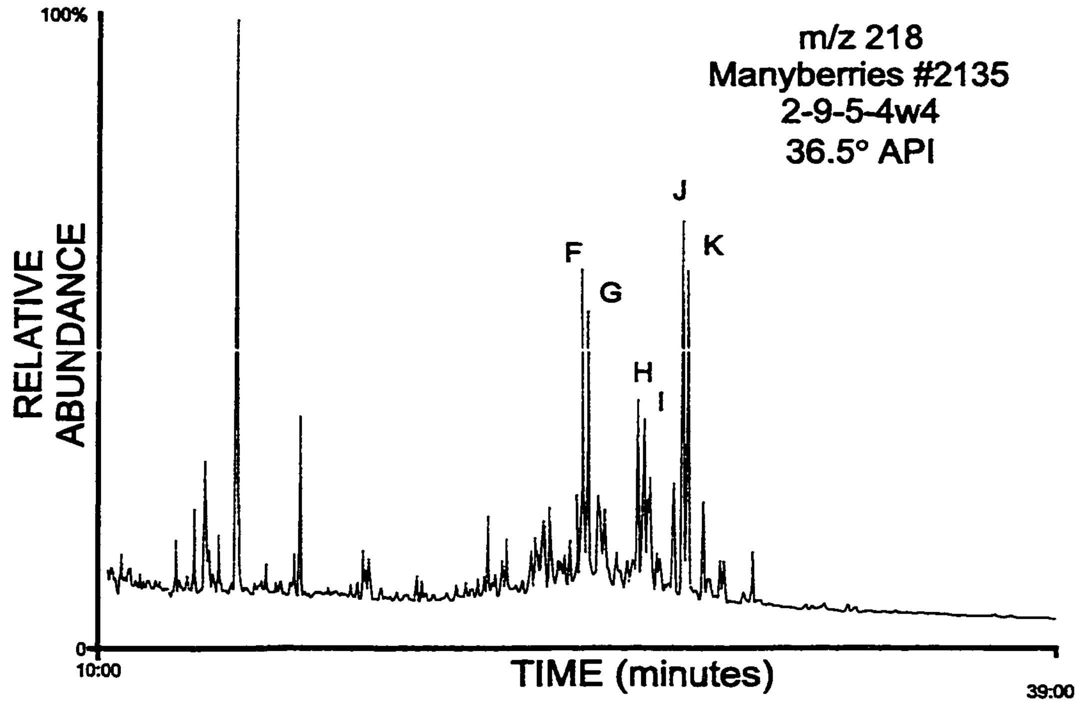


Figure 18. A representative m/z 218 mass fragmentogram from the Manyberries oil field, southeastern Alberta, sample # 2135 (2-9-5-4W4). For identification of peaks see Table 3.

5. UPPER JURASSIC AND LOWER CRETACEOUS STRATIGRAPHY AND STRUCTURE OF THE MANYBERRIES AREA, SOUTHEASTERN ALBERTA

The Upper Jurassic to Lower Cretaceous stratigraphy of southeastern Alberta is composed predominantly of a siliciclastic, shallow marine to fluvial non-marine succession (Cant, 1996). During the Early Cretaceous the area underwent several separate periods of erosion and deposition as the Swift Current Platform was uplifted creating a complex series of diachronous valley systems (Poulton et al., 1994). The geologic units that span this period of time host large oil accumulations in southeastern Alberta and thus are of great interest economically. In the Manyberries area there are three main oil reservoir units recognized within the Upper Jurassic to Lower Cretaceous section. These units are the Swift Formation, the Lower Mannville Formation, and the Upper Mannville Formation (Figure 2) which have all been informally termed by oil explorationists as the Sunburst Sandstone. The following will include a general discussion of the geologic characteristics, geophysical well log signature, thickness variations, reservoir characteristics, and hydrocarbon trapping mechanisms. Representative lithologic descriptions and geophysical log signatures are provided for each formation (Figures 19, 23,28,29). Lithologic descriptions of all cores examined and logged are presented in Appendix 1 and core locations are shown in Figure 12.

5.1 The Swift Formation

The Swift Formation conformably overlies the Middle Jurassic Rierdon Formation and is unconformably overlain by the Lower Cretaceous Mannville Group. It grades from dark grey to black, interlaminated sandstone and mudstone to a tan to light grey, very fine-grained quartzose sandstone (Figure 19). The bedding grades upward from lenticular bedded to ripple bedded foresets, with mud flasers giving the often quoted "ribbon sand " appearance (Hayes, 1982). Glauconite and disseminated pyrite are common at the base of the Swift and decrease in abundance upwards. Spherulitic siderite becomes increasingly common up-section, near the contact with the Mannville Group. Bioturbation is variable but consistently minor in the lower part of the Swift Formation and increases in intensity up-section. The most common bioturbation form is *Planolites* but *Chondrites* and *Teichichnus* can also be found. Brackish water dinoflagellate species taken from the lower part of the Swift Formation unit yield a Kimmeridgian age (Brooke and Braun, 1972). The Swift is interpreted as having been deposited in a fluctuating energy tidal flat environment with variable bottom water oxygenation levels (Dalrymple, 1992). This unit is the stratigraphic equivalent of the S1 member of the Success Formation in southwestern Saskatchewan as described by Christopher (1974) and Leckie et al. (1997) and equivalent to the Light and Dark Ribbon Sand members described by Hayes (1982)(Figure 5).

The well log signature for the Swift Formation is varied but generally feature-less and is difficult to correlate without core examination. Most commonly, the base of the Swift exhibits a high gamma ray count that decreases upward (Figure 19). Induction curves show an upward decrease in resistivity (Figure 19). Sonic and Density logs show an overall, subtle decrease in porosity up-section due to the weathering horizon development near the contact with Lower Mannville.

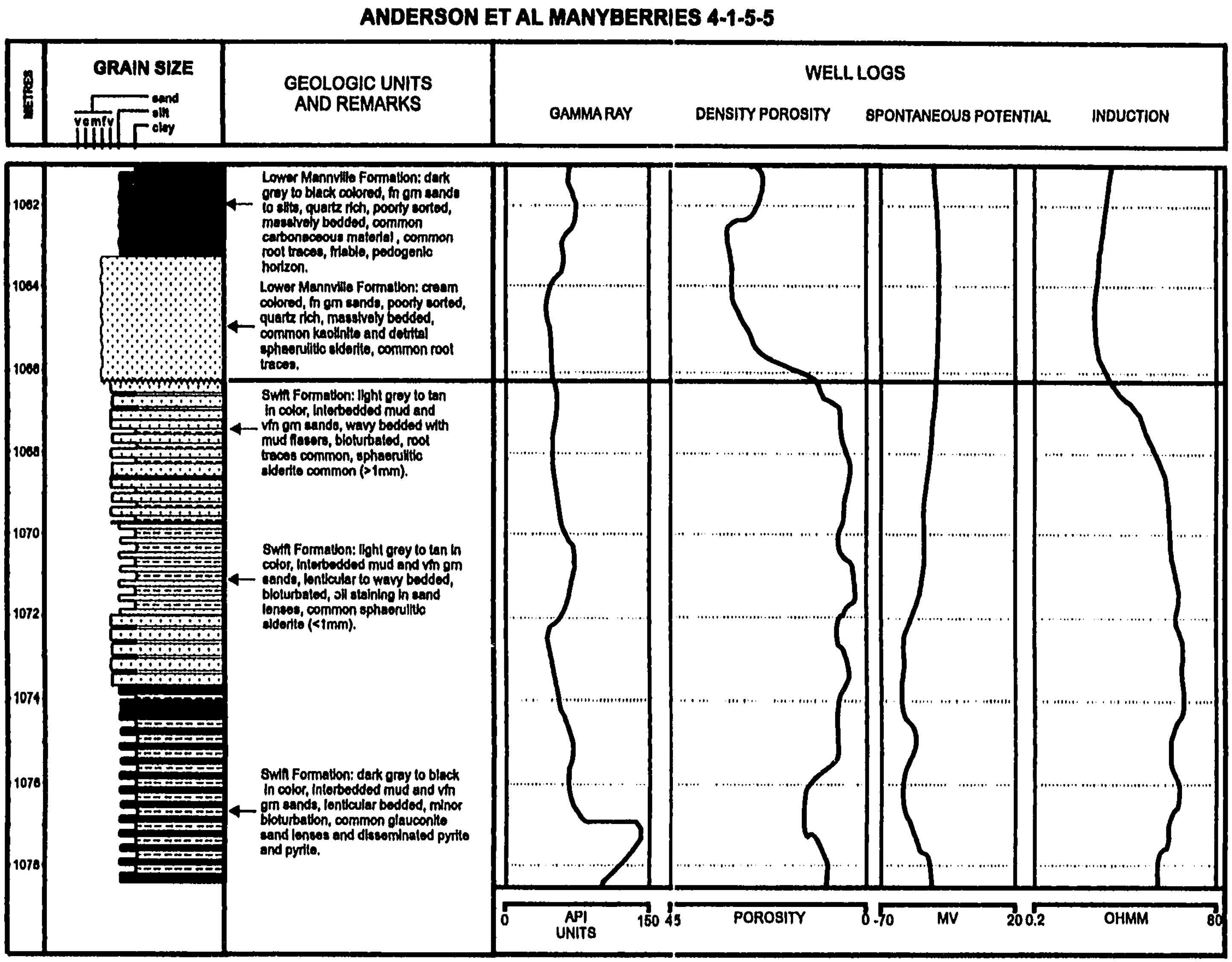


Figure 19. Representative lithology and well log signature for the Swift Formation.

The thickness of the Swift Formation, which ranges from 0 to greater than 30 metres (Figure 20) is controlled by both pre-Lower Mannville and pre-Upper Mannville erosion which incised into the Swift Formation creating "mesa" type topography (Figure 25). This relief on the Swift Formation is best documented in stratigraphic cross section B1-B2 (Appendix 2) where it has been eroded by pre-Upper Mannville valley incision.

5.1.1 Reservoir Characteristics of the Swift Formation

Porosity and permeability range from 4 to 23% and 0.95 to 70 millidarcies (md) respectively (Figure 21). Most of the permeability data are in the 0.01 to 10 md range (Figure 22), denoting poor reservoir quality for the Swift Formation. The interlaminated sandstone and mudstone nature of the Swift Formation is most likely the cause behind the poor permeability, creating the observed horizontal anisotropy and low petroleum production potential. Limited oil production (average 5 bbls/day) does come from the Swift Formation at Manyberries in the KK pool (an example of producing Swift lithology in the KK pool is from 4-1-5-5W4; Figure 19). At this locality thin (10-20 cm), cross-bedded, well-sorted, very fine-grained sandstones are developed (Figure 19). These deposits are only found in the KK pool area were Swift thickness is greater than 20 metres. Within this pool, porosity and permeability ranges from 13 to 23 % and 10 to 79 md respectively. Oil saturation values for Swift oil reservoir range from 2 to 16 %.

In summary, oil reservoir development in the Swift Formation requires at least 10 md permeability and 13% porosity, which is typical for a thin, cross-bedded, well -sorted, very fine-grained sandstone packages in the Swift Formation.

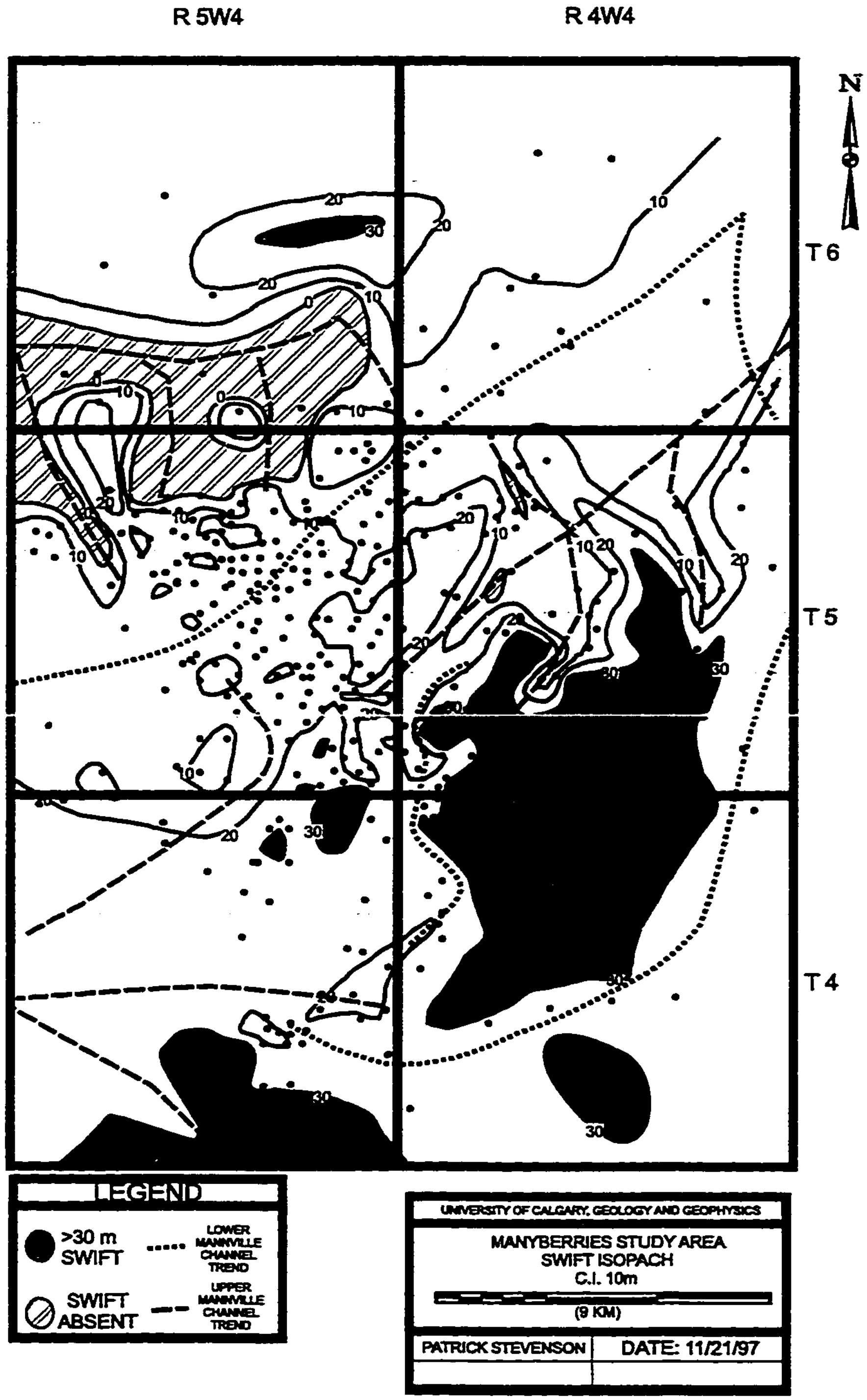


Figure 20. Isopach map of the Swift Formation. Note, the locations of Lower Mannville and Upper Mannville channel trends and their control on Swift thickness.

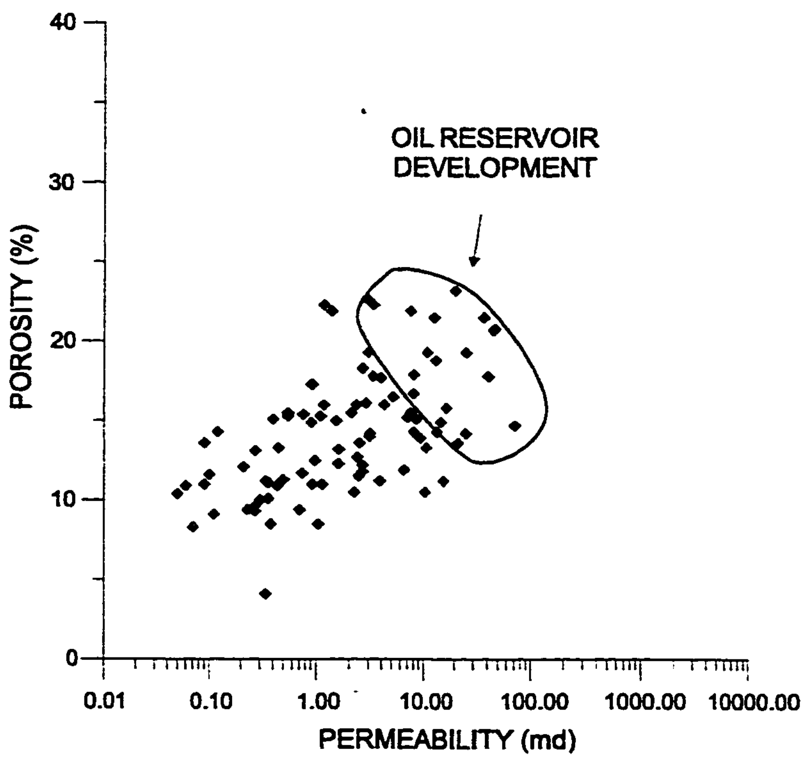


Figure 21. Porosity and permeability cross-plot for Swift Formation cores examined in this study. Note oil reservoir development only occurs in higher permeability and porosity cores.

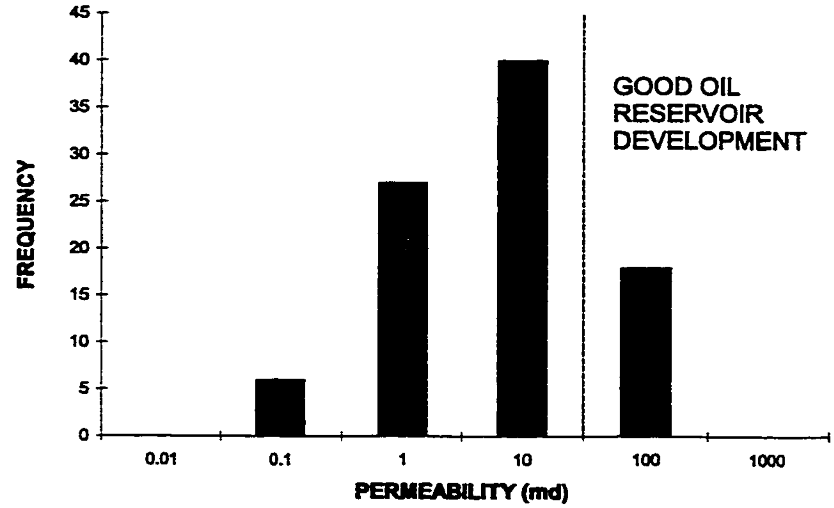


Figure 22. Histogram shows the range of permeability data from the Swift Formation in the Manyberries area. Note the data ranges for each category in the histogram, range from lowest to highest (e.g. the first category ranges from .01 to 0.1 md). Most data are less than 10 md, indicating generally poor reservoir potential for the Swift Formation.

5.2 The Lower Mannville Formation

The Lower Mannville Formation is composed of cream-coloured, fine-to medium-grained, moderately well-sorted, quartz-rich sandstones with a subordinate amount of chert grains and is kaolinite cemented (Figure 23). The Lower Mannville unconformably overlies the Swift Formation (Figure 23). Mud content increases, sorting decreases and root traces become increasingly more common up-section. Dominant bed forms grade upward from massively bedded to low-angle cross-bedded sandstones. No fossils were encountered in the cores examined but based on Hayes (1986) an early Barremian to early Aptian age is assumed for the Lower Mannville. Large cobbles of the Swift Formation are commonly found in the basal part of the Lower Mannville, indicating erosion of the underlying strata. Also in some areas (e.g. 10-10-5-5W4, see Appendix 1) the Lower Mannville Formation consists of a matrix supported conglomerate composed of mud clasts which typically has very poor reservoir characteristics. These conglomerates represent debris flow deposits shed off of pre-Lower Mannville topographic highs. The Lower Mannville in the Manyberries area is interpreted to represent a bedload braided river deposit that filled in pre-lower Mannville topography (Miall, 1992). This unit is correlative with the Lower Mannville in southeastern Alberta of Hayes (1986) and the S2 Member of Christopher (1974) and Leckie et al. (1997) in southwestern Saskatchewan.

Well log signatures for the Lower Mannville show a low gamma ray signature with blocky to funnel morphology, indicative of clean sand (Figure 23). Spontaneous potential logs show a marked decrease from 0 to –100 mv in the basal part of the Lower Mannville, which is associated with the development of good porosity (Figure 23).

logs for the Lower Mannville are generally greater than 10 ohms (deep induction) which is indicative of the presence of more resistive fluids (oil) (Figure 23).

The Lower Mannville ranges in thickness from 0 to greater than 20 m and exhibits a lenticular cross-sectional morphology with a linear, north-south longitudinal trend indicative of a valley fill sequence (Figure 24). Thickness of the Lower Mannville is controlled primarily by erosion prior to Upper Mannville deposition (pre-Upper Mannville topography), which cut down into the Lower Mannville and into the underlying Swift Formations (Figure 24, 25). This erosion is widespread in the study area creating a large system of Upper-Mannville valleys in the northern part of the study area (Figures 24, 25). This incision left a number of large northeast-southwest to north-south trending bodies of Lower Mannville with "mesa" type topography (Figure 25). This type of topography is clearly demonstrated in stratigraphic cross-sections A1-A2, B1-B2 and C1-C2 (Appendix 2).

5.2.1 Reservoir characteristics of the Lower Mannville Formation

The most prolific oil reservoir in the Manyberries area is the Lower Mannville Formation. The Lower Mannville shows a large variation in porosity and permeability ranging from 5 to 32% and 0.05 to 10000 md, respectively (Figure 26; 27). This variability in reservoir characteristics is due primarily to variations in grain size and mud content within a braided river depositional environment associated with periodic changes

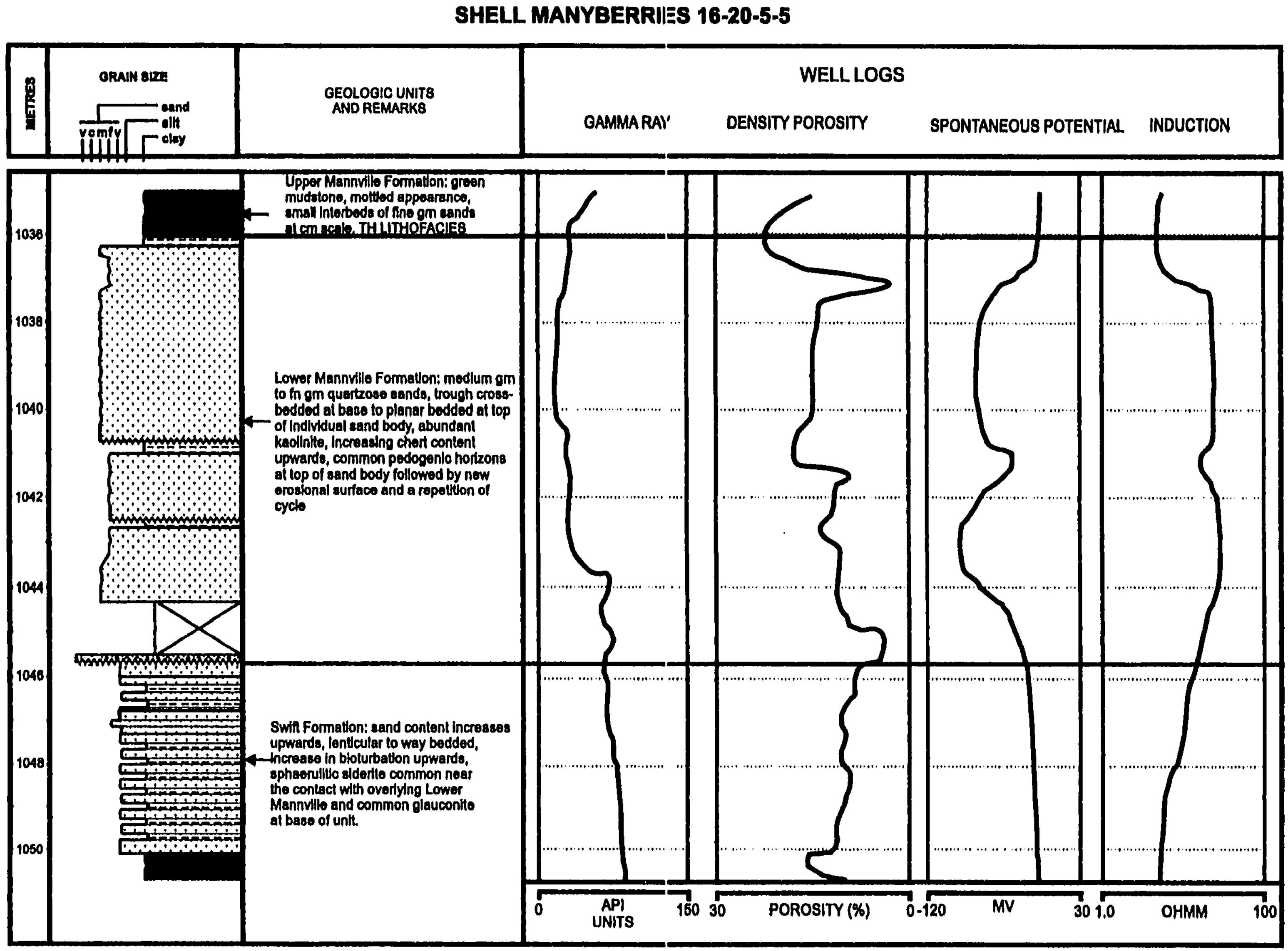


Figure 23. Representative lithology and well log signature for the Lower Mannville Formation.

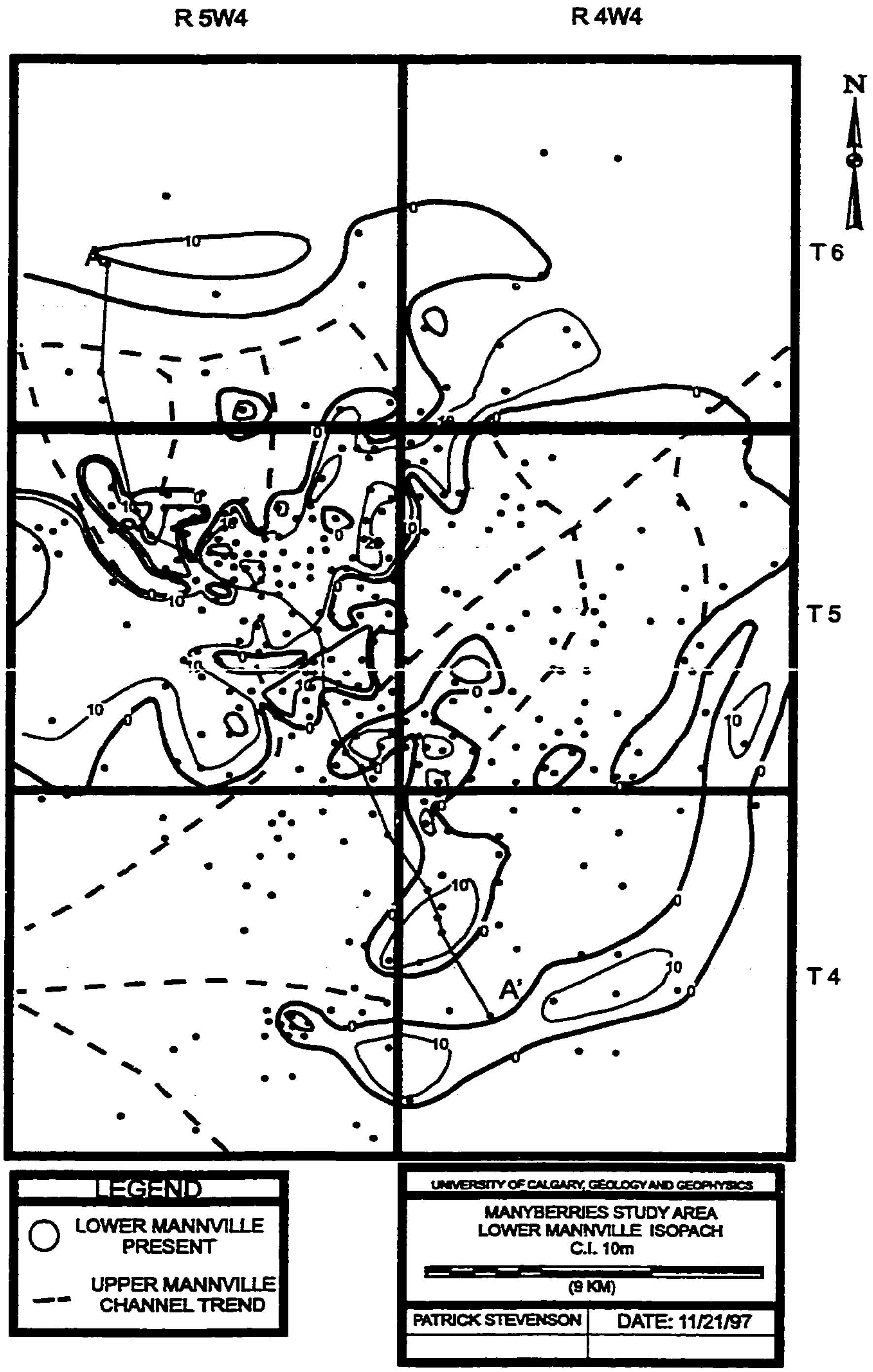


Figure 24. Isopach map of the Lower Mannville Formation. Pre-Upper Mannville channel trends is the dominant control on Lower Mannville thickness. Schematic cross-section location (Figure 25) is indicated by A- A'.

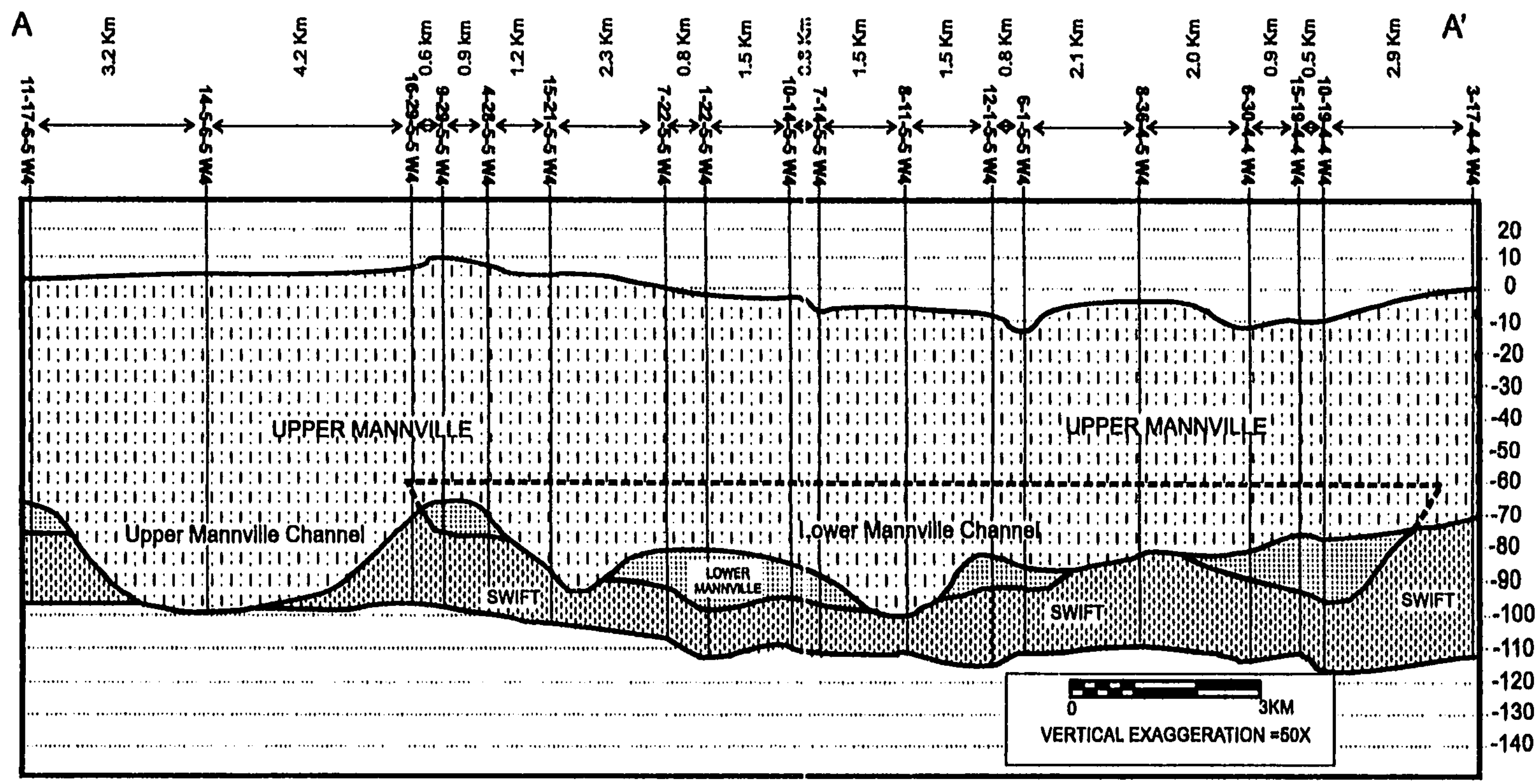


Figure 25. Schematic geologic cross- section in Manyberries area from northwest to southeast (A-A') displaying erosional topography on Lower Mannville surface. Note incision into underlying Swift by broad Lower Mannville channel. Structural datum for cross- section is 30 m above sea level.

in flow regime (Miall, 1992). These changes are most evident at 10-10-5-5W4 (Appendix 1) were a debris flow deposit comprises the Lower Mannville section and effectively reduces porosity and permeability. Porosity and permeability also decrease up-section in the Lower Mannville braidplain deposits because of a decrease in bed load competency (grain size decrease and an increase in mud content) (Miall, 1992) and to the unconformable nature of the overlying Upper Mannville. Oil saturation in the Lower Mannville Formation is consistently high in the Manyberries field, commonly exceeding 25% of total pore volume. High oil saturation values can be attributed to high porosity, which for a productive oil reservoir in the Lower Mannville often will exceed 17%.

5.3 The Upper Mannville Formation

The Upper Mannville Formation rests unconformably on the Lower Mannville Formation. The Upper Mannville is laterally continuous throughout the Manyberries area, in-filling pre-existing topographic lows created by pre-Lower Mannville erosion and pre- Upper Mannville erosion. The Upper Mannville is a complex unit exhibiting two distinct, informal lithofacies associations within the study area (VF and TH lithofacies; Figures 28, 29). Facies development is dependent on pre-existing topography. The VF lithofacies is found only in valley systems that incised into the underlying Rierdon Formation, removing the Swift and Lower Mannville formations in the northern part of the study area. The TH lithofacies (Figure 29) is found in regions with remnant Swift and Lower Mannville strata.

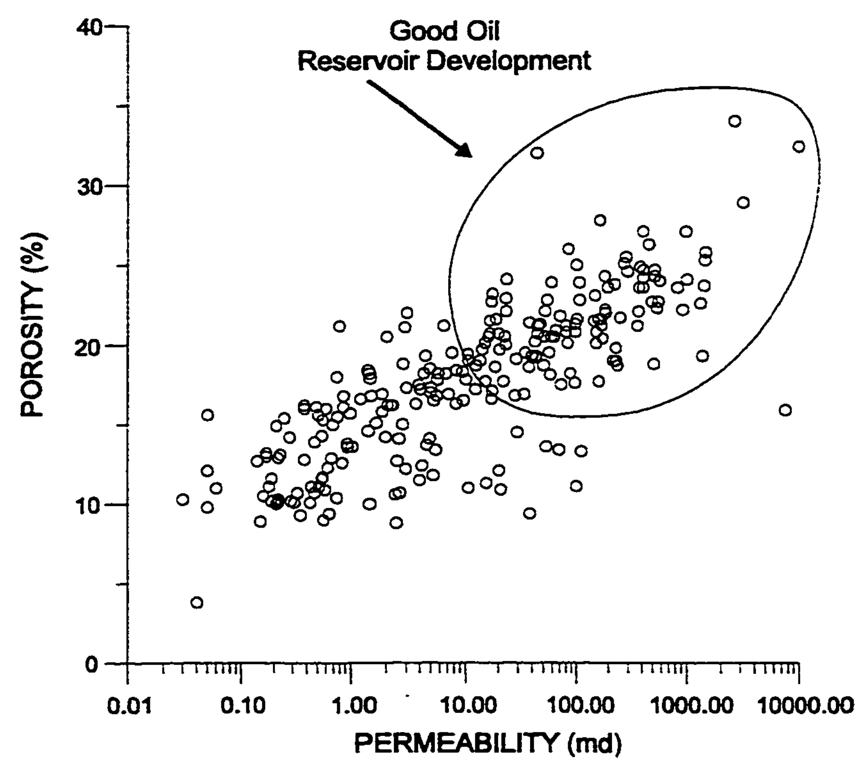


Figure 26. Porosity and permeability cross-plot from cores examined for the Lower Mannville Formation in the Manyberries area, showing good reservoir development.

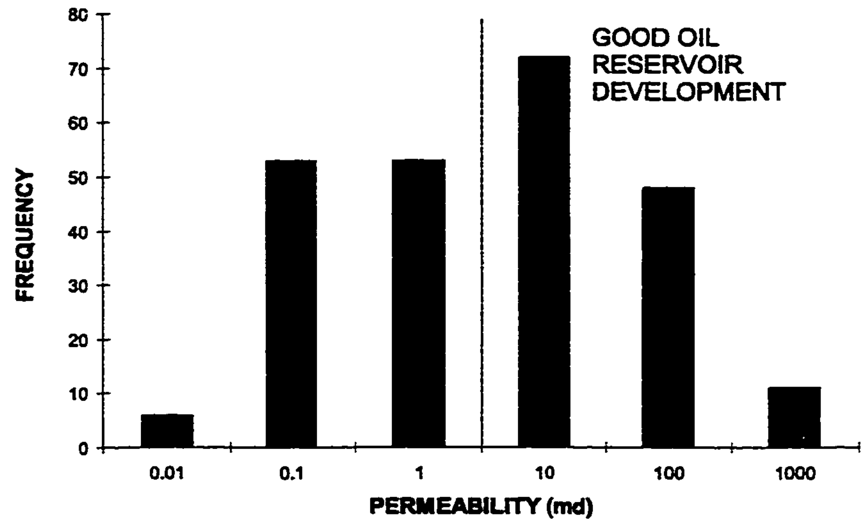


Figure 27. Histogram shows the range of permeability data from the Lower Mannville Formation in the Manyberries area. Note the data ranges for each category in the histogram, range from lowest to highest (e.g. the first category ranges from .01 to .1 md). Most data is greater then 10 md indicating good reservoir potential in Lower Mannville.

A good example of the VF lithofacies occurs at 16-28-5-5W4, (Figure 28) where the Upper Mannville grades upwards from a parallel-bedded mudstone to a dark grey, carbonaceous, fine-grained, silty sandstone with ripple cross-beds followed by a green to cream colored, poorly sorted, medium-grained, trough cross-bedded, lithic sandstone containing abundant quartz, chert, rock fragments, feldspars and kaolinite (Figure 28). Accessory components in the VF lithofacies are carbonaceous material and siderite concretions. At the base of the lithic sandstone are siderite clasts (<3 cm in diameter) suggesting an erosional contact with the underlying silty sandstone. No fossils were recovered from this unit but Hayes (1986) documents similar Upper Mannville lithic sandstone and imply an Aptian-Albian age.

A good example of the TH lithofacies occurs at 16-20-5-5W4 (Figure 23) and 10-4-5-4W4 (Figure 29) where it consists of a pedogenically altered, root-mottled, mudstone composed of smectite (Figure 29) which is commonly interbedded with a silty sandstone as described for VF lithofacies (Figure 28). The smectitic mudstone is quite extensive over paleo-topographic highs with a thickness in excess of 10 m (see 6-20-5-5W4; Appendix 1) and is generally not found in Upper Mannville valleys. Hayes (1986) documented a similar smectitic mudstone at 6-1-1-11W4 in the Upper Mannville section and also documents rooted horizons in this mudstone. In the region of township 5, range 4W4 the base of the TH lithofacies commonly is a quartz-rich, fine-grained, well-sorted, heavily oil-stained sandstone rather than the smectitic mudstone. This sandstone is thought to represent a reworking of the underlying Swift Formation. This lithofacies is interpreted to represent an exposure surface that was flooded periodically as Upper

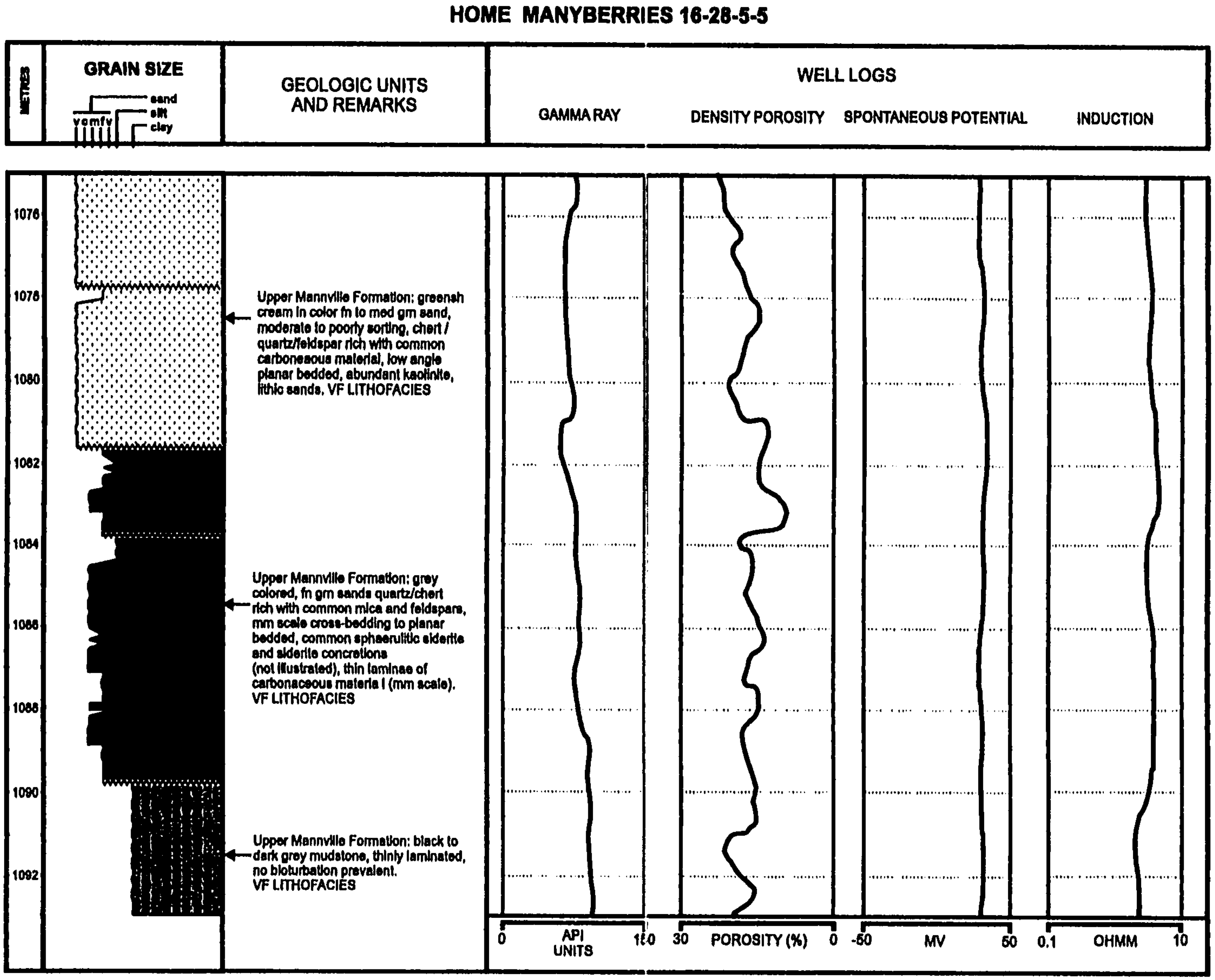


Figure 28. Representative lithology and well log signature for Upper Mannville VF lithofacies.

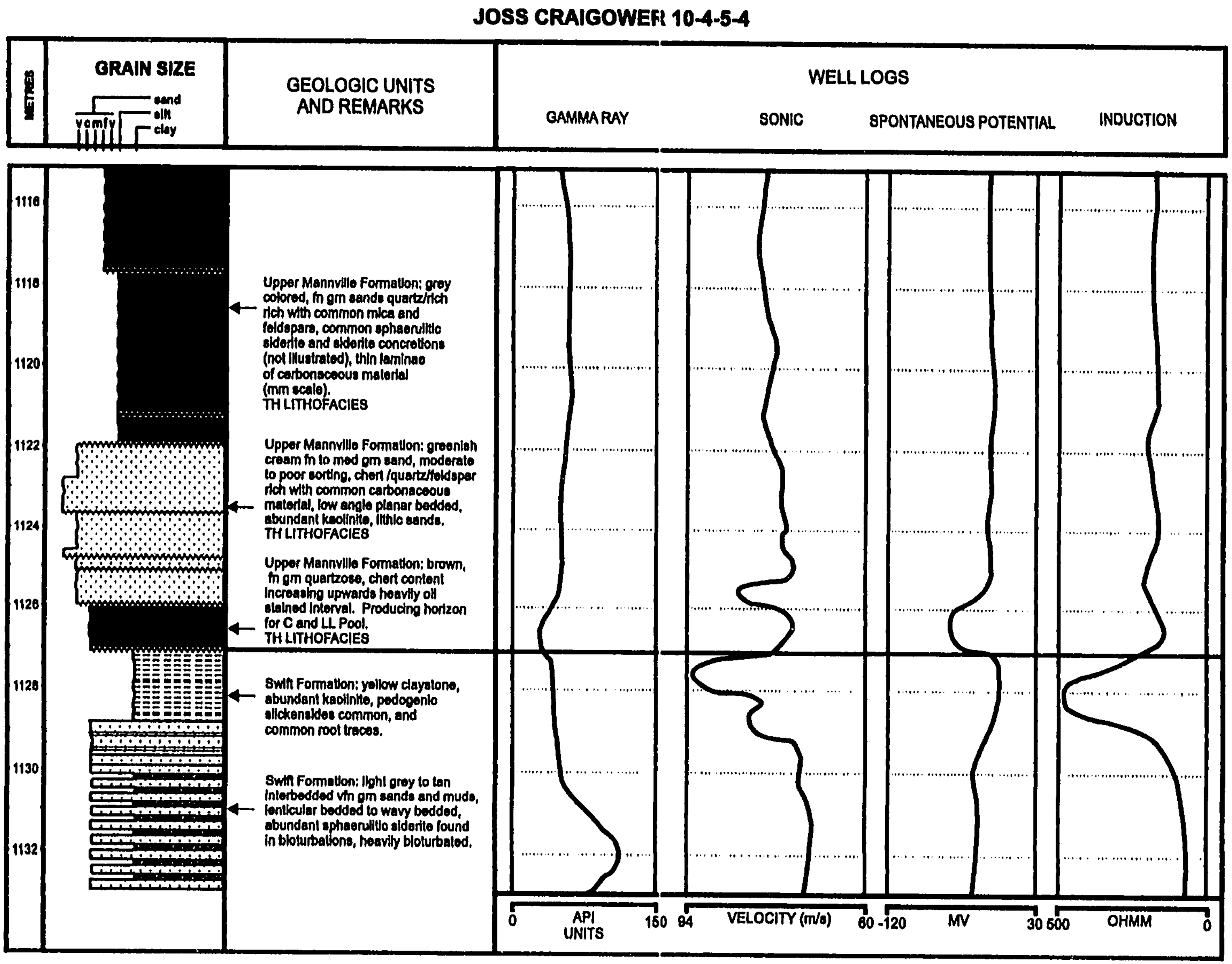


Figure 29. Representative lithology and well log signature for Upper Mannville TH lithofacies

Mannville valleys in the northern part of the study area filled. This created a vast floodplain type succession over Swift and Lower Mannville remnants. Generally both the VF and TH lithofacies succession are topped by a lithic sandstone unit which is interpreted as representing braided river deposits. As the pre-upper Mannville valley systems were in-filling, a large influx of sediment from the erosion of the thrust front, building to the west overwhelmed southern Alberta, creating thick sequences of lithic sandstones (Wood, 1996). This influx of sediment in-filled lows on pre-existing topography in the Manyberries area.

The well log signature for the Upper Mannville can be varied and easily mistaken for underlying strata. Generally the TH lithofacies unit will show a high gamma ray count relative to underlying Lower Mannville deposits (Figures 23; 28 and 29). The lithic sandstone of VF lithofacies and TH lithofacies unit shows a moderately low gamma ray signature with an overall fining-upward morphology (Figures 28; 29). High spontaneous potential signature and a low induction signature of 1 to 10 ohms are typical for the Upper Mannville units in the study area. Porosity logs show a varied but consistently low porosity signature attesting to high clay content in the Upper Mannville.

Thickness of the Upper Mannville in the Manyberries area ranges from less than 70 metres on pre-Upper Mannville topographic highs to greater than 100 metres in pre-Upper Mannville valley systems in the northern part of the study area (Figure 30). The orientation of Upper Mannville thickness trends show westward and northeastward directed valley trends which have cut into the underlying Lower Mannville and Swift formations (Figure 30) (cross-sections A1-A2, B1-B2 and C1-C2, Appendix 2) creating a

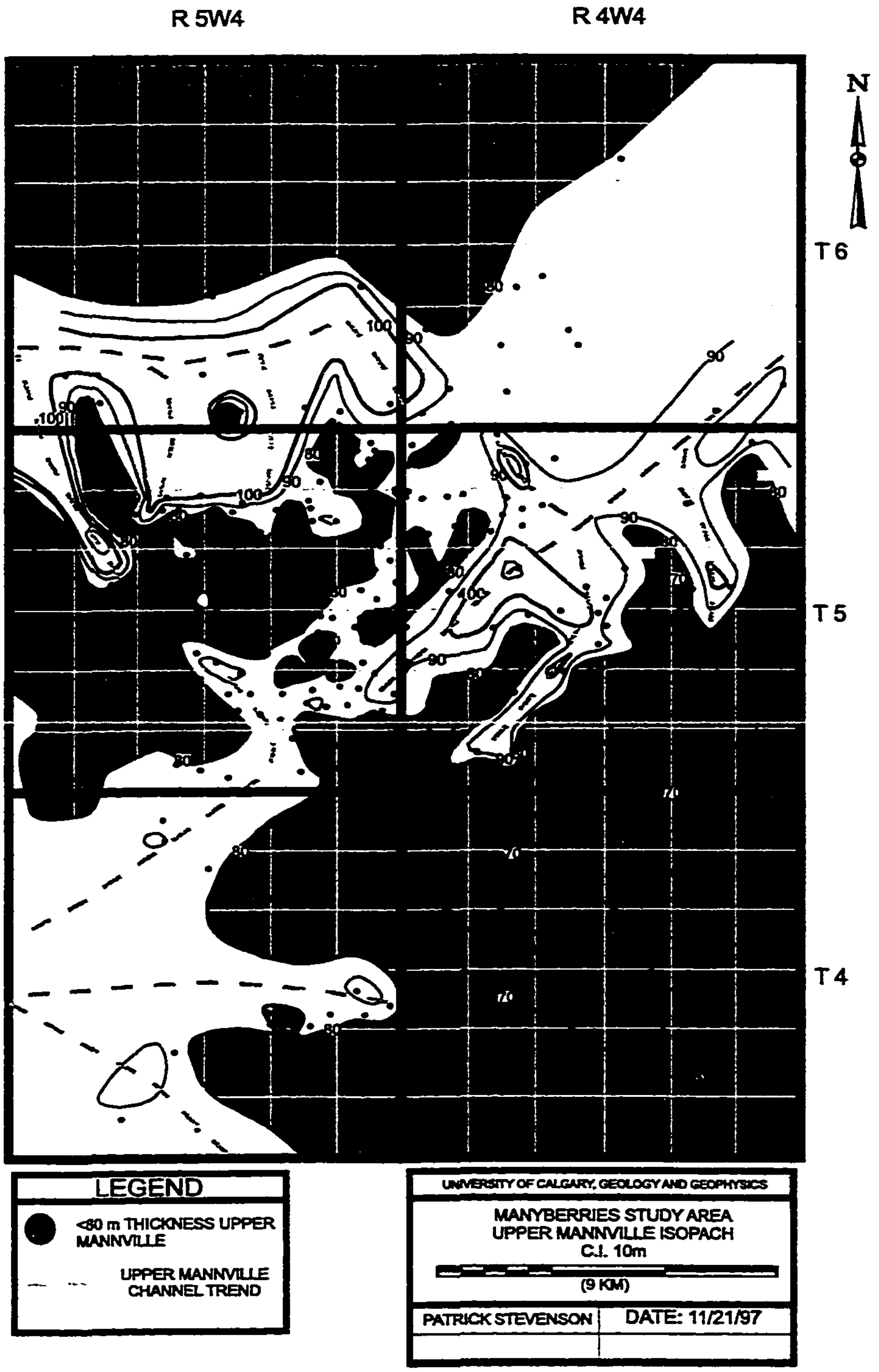


Figure 30. Isopach map of the Upper Mannville Formation. Note trends of Upper Mannville thickness greater than 80 m (white area) and their orientation away from pre-existing pre-Upper Mannville topographic highs (shaded areas). Areas where Upper Mannville thickness is less than 80m thickness corresponds to Swift Formation thicks (see Figure 20).

deep valley system in the northern part of the study area and a large remnant of Lower Mannville and Swift Formation to the southeast, northwest and over the Manyberries oil field (Figure 30). Thus, Upper Mannville deposition first, in-filled pre-existing topography in the area and then blanketed the whole area during a period of increased subsidence and sedimentation similar to that described by Wood (1996).

5.3.1 Reservoir Characteristics of the Upper Mannville Formation

Porosity and permeability range from 5.5 to 24 % and 0.01 to 240 md, respectively (Figure 31) with most of the permeability data ranging from 0.01 to 10 md (Figure 32). The predominantly low permeability and porosity is indicative of the poor reservoir quality for this unit. The likely cause for the low permeability characteristics is the high clay content occluding porosity. Hayes (1986) documented poor reservoir quality in similar Upper Mannville lithic sands in southeastern Alberta. Oil reservoir development in the Upper Mannville Formation is isolated to quartz- rich sands on pre-Upper Mannville topographic highs (TH lithofacies; Township 5 Range 4W4; Figure 29). These sandstones show porosity and permeability that range from 20 to 24% and 126 to 254 md respectively, with 13 to 26% oil saturation. These reservoirs are laterally discontinuous with limited occurrences in LL and C Pool and are generally less than a metre in thickness (see cross-section C1-C2; Appendix 2). Thus, the Upper Mannville Formation is a relatively minor oil reservoir in the Manyberries area and is restricted to the LL and C pool localities.

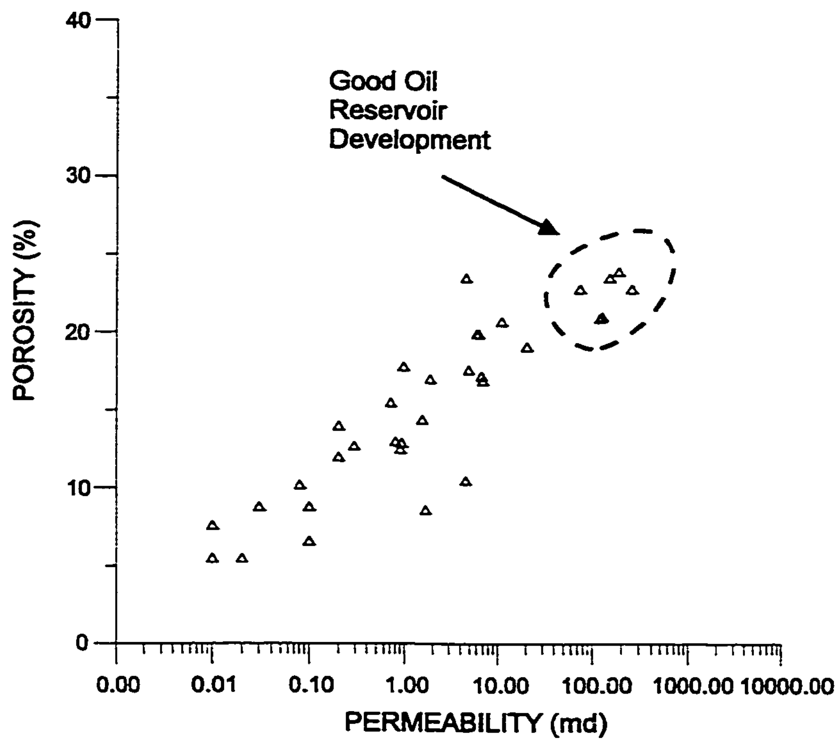


Figure 31. Porosity and permeability cross-plot for cores from the Upper Mannville Formation examined in the Manyberries area.

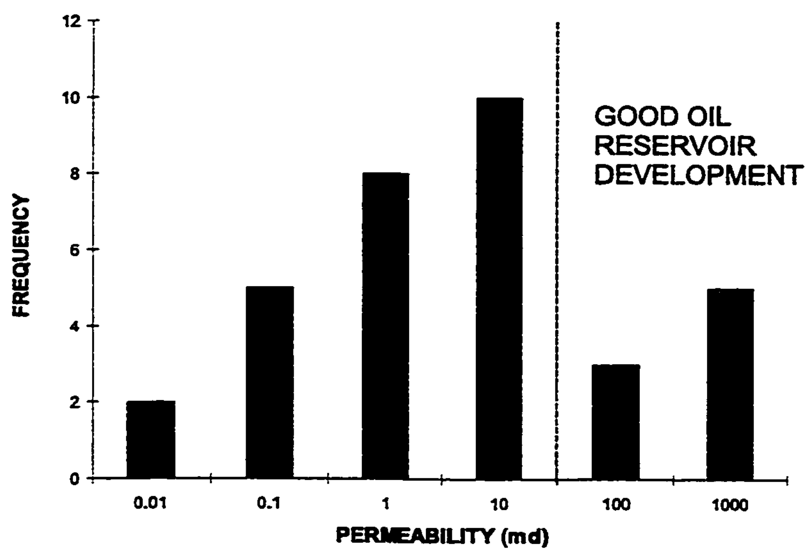


Figure 32. Histogram shows the range of permeability data from the Upper Mannville Formation in the Manyberries area. Note the data ranges for each category in the histogram, range from lowest to highest (e.g. the first category ranges from .001 to .01 md). Most data are less than 10 md indicating poor reservoir potential in Upper Mannville.

5.4 Structure in the Manyberries Area

The predominant structural trend in the Manyberries area strikes north-northwest to south-southeast with an average dip of 7.1 m/km towards the northeast (Figure 32). This structural trend is thought to have developed as a result of final uplift of the Sweetgrass Arch during the Laramide Orogeny in early Tertiary (Podruski, 1988). There is an increasing level of structural complexity grading from west to east with the development of small scale structural features and a major structural feature centered on section 8 township 6 range 4W4 (Figure 32). This structure is elliptical in shape and has 70 m of total relief relative to the surrounding structural fabric. There is no stratigraphic thickening in this region of the Upper Mannville, Lower Mannville or Swift formations and thus this feature must post-date the deposition of these units. This structural anomaly has an unknown origin and cannot be examined in further detail without the use of a seismic data and mapping of underlying horizons. However, based on the shape of the structure it is thought to be similar to previously described features formed by either salt dissolution in the underlying Paleozoic section (Oliver and Cowper, 1983) or a karst collapse feature in the Mississippian section (Hopkins, 1997).

5.5 Discussion

The primary oil reservoir for the Manyberries area is the Lower Mannville Formation averaging 17 % porosity and 214 md permeability. The hydrocarbon trapping mechanism in the Lower Mannville is dependent on a complex interplay of structure and stratigraphy, which will be discussed in section 5.5.1. Due to the limited occurrence of Swift and Upper Mannville reservoir lithologies, no further examination of trapping mechanism for these units will be discussed.

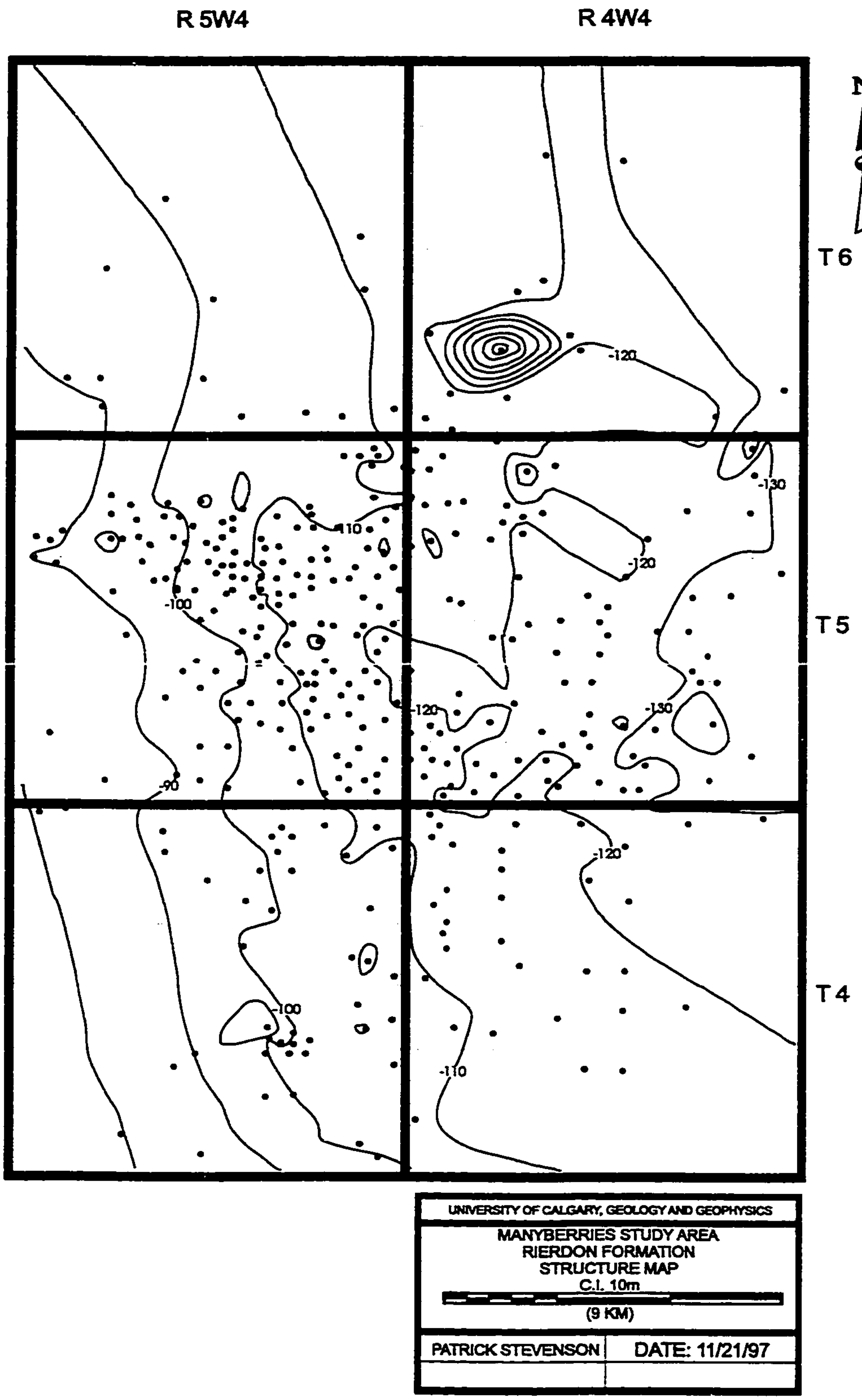


Figure 33. Structure map of the Rierdon Formation in the Manyberries area.

5.5.1 Trapping Mechanism in Lower Mannville oil reservoirs

The main hydrocarbon trapping mechanism for Lower Mannville oil reservoirs in the Manyberries area is stratigraphic with a minor component of structural control in individual pools. This discussion will focus on examples of the trapping mechanism affecting Manyberries OO, and II pools.

OO pool is located in the northeastern corner of the Manyberries oil field (Figure 34). The primary reservoir for OO pool is the Lower Mannville Formation. Pre-Upper Mannville valley incision truncates the Lower Mannville to the west and north of OO pool (Figure 25, 34) (see also stratigraphic cross-section A1-A2 in Appendix 2). In-filling this valley trend are low porosity and permeability deposits of the Upper Mannville VF lithofacies. Thus, considering the porosity and permeability contrast between Upper Mannville valley fill deposits and the Lower Mannville channel sands and the regional dip for the reservoir in the area towards the northeast, the lateral seal for hydrocarbon entrapment is the Upper Mannville Formation (Figure 25). Wood and Hopkins (1992) document a similar trapping mechanism in Upper Mannville Glauconitic Member reservoirs with similar lithic sandstones acting as the lateral seal for oil accumulation.

In II pool pre-Upper Mannville valley incision has truncated the Lower Mannville channel sands (Figure 34). These valley trends were subsequently filled with VF lithofacies creating a similar porosity and permeability contrast between Upper and Lower Mannville strata and as in OO pool, a similar hydrocarbon trapping mechanism.

In conclusion, the present hydrocarbon-trapping configuration in the Manyberries area was created by erosion of Lower Mannville channel sands (reservoir) by pre Upper Mannville incision along the western portion of the field area. Following this erosion poor permeability, Upper Mannville Formation lithic sands were deposited in these valley trends creating a lateral seal for hydrocarbon migration.

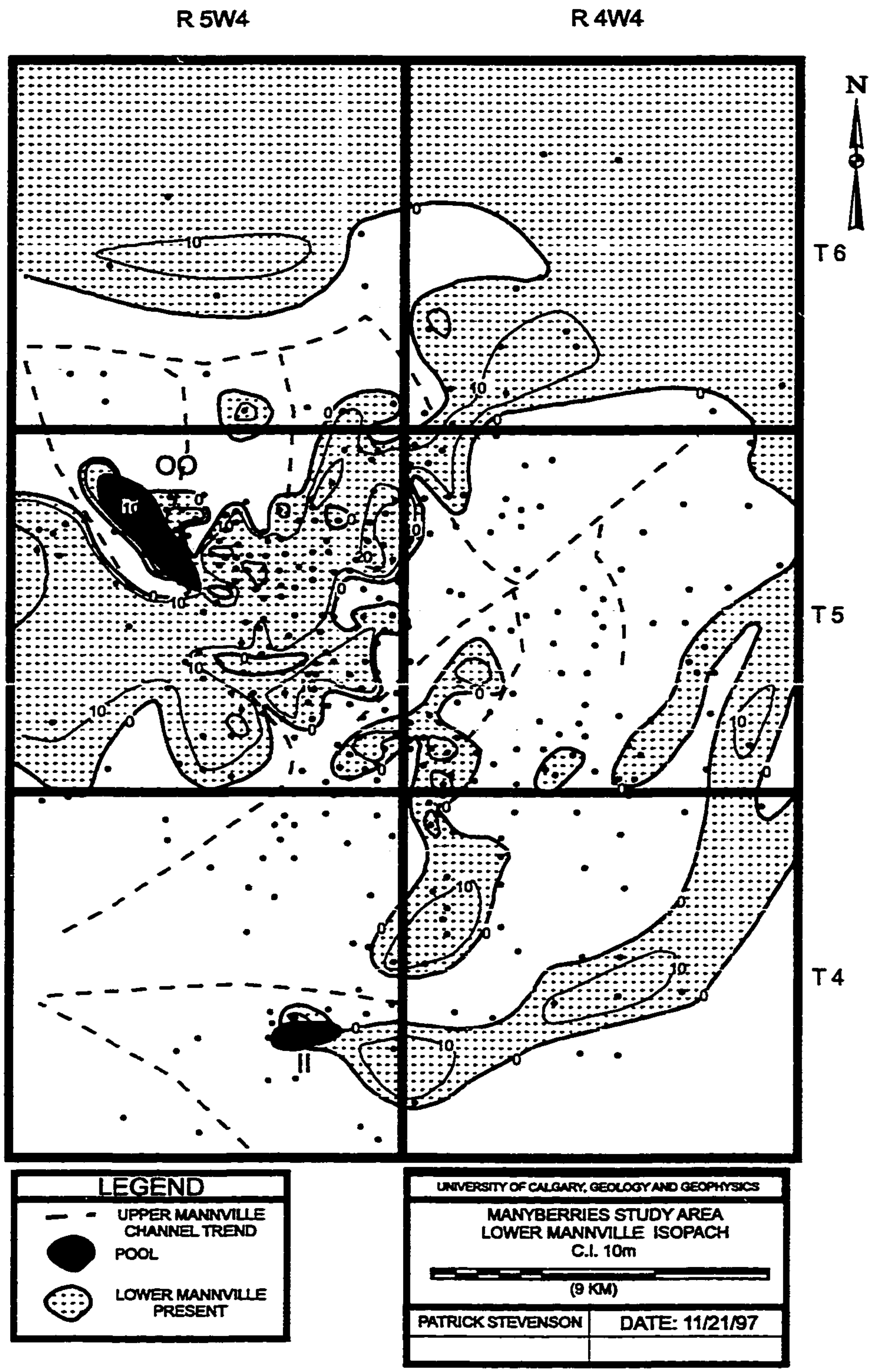


Figure 34. Isopach map of Lower Mannville Formation in the Manyberries area with OO, and II pools in grey. The Lower Mannville is truncated to the west of OO and II Pool, creating the stratigraphic trap.

6. ORGANIC GEOCHEMISTRY OF UPPER JURASSIC-LOWER CRETACEOUS OILS, MANYBERRIES OIL FIELD, SOUTHEASTERN ALBERTA

The analysis of bulk geochemical (gross composition, sulphur) and biological fossils (isoprenoid, terpane and sterane biomarkers) of an oil yields important information regarding the causes of oil quality variations. Oil quality is largely determined by four factors; the nature of the hydrocarbon source rock, which generated the oil, the level of catagenesis of the source rock that was the source for the oil, the extent of biodegradation that an oil accumulation has undergone, and the extent of thermal alteration of an oil after it enters the reservoir. These bulk geochemical and biomarker characteristics act as a "fingerprint" for an oil, which may be used to group oils into oil families (oil-oil correlation) and to identify their source rocks (oil-source correlation). The oil geochemistry is essential for understanding oil quality variations in a petroleum producing area, which in turn may be used to predict areas of better oil quality. Oil-oil and oil-source rock correlations allow inferences regarding petroleum migration and thus may indicate new areas of exploration potential.

In this chapter the bulk geochemical and biomarker characteristics will be used to "fingerprint" the oils from the Manyberries area and to indicate the geochemical nature of the source rock for the oils.

6.1 Gross Composition

The gross composition of the oils from the Manyberries area ranges from 46 to 53% saturates, 35 to 40 % aromatics and 5 to 9 % asphaltenes and resins (Table 1, p. 32). The saturated hydrocarbon to aromatic hydrocarbon ratio ranges from 1.3 to 1.5, (Table

1, p. 32). The sulphur content ranges from 1.0 to 1.3 weight percent sulphur (Table 1 p. 32).

6.2 Gasoline Range Analysis

The gas chromatograms of the gasoline range for each Manyberries oil sample is provided in Appendix 4 with a representative gasoline range GC given in Figure 14. Relevant gasoline range data are provided in Table 4. Gasoline range (C_5 to C_8) hydrocarbons give several important parameters and ratios to quantify the level of thermal maturity (heptane and isoheptane indices), biodegradation (3-methyl pentane/n-hexane and isopentane/n-pentane), and water-washing (3-methyl pentane/benzene and methylcyclohexane/toluene).

Table 4. Gasoline Range (C_5-C_8) ratios for Manyberries oils used in the study ($3MC_5$=3-methyl pentane, CYC_6 =cyclohexane, $MCYC_6$ = methyl-cyclohexane, nC_5 = pentane nC_6 = hexane)

SAMPLE #	Heptane	Isoheptane	$3MC_5/nC_6$	iC_5/nC_5	$3MC_5$/ benzene	$MCYC_6$/ toluene
2127	23.40	1.79	0.81	0.45	76.07	85.68
2128	26.60	1.92	0.63	0.36	355.20	53.01
2129	10.60	2.45	3.74	2.39	>1000	21.97
2130	11.00	2.40	> 1.0	1.19	>1000	>100
2131	3.20	3.35	> 1.0	5.10	>1000	2.92
2132	29.70	1.60	0.59	0.36	72.23	41.47
2133	31.70	1.69	0.67	0.34	>1000	>100
2134	32.90	1.73	0.62	0.33	>1000	>100
2135	33.10	2.03	0.60	0.30	92.00	57.41
2136	29.80	1.94	0.67	0.34	49.57	43.67
2137	28.80	2.13	0.68	0.35	46.99	31.70
2138	31.50	1.83	0.60	0.31	83.79	26.13
2139	30.50	1.93	0.57	0.32	36.22	20.62
2140	30.00	1.79	0.65	0.32	30.63	17.69
2141	26.80	2.09	0.66	0.34	>1000	44.83
2146	31.20	2.00	0.58	0.32	>1000	>100

Thompson (1983) classified the thermal maturity of a suite of oils from North America based on two gasoline range parameters, heptane and isoheptane values (Table 4). The heptane value = (n-heptane x 100)/(cyclohexane + 2-methylhexane + 1,1 dimethylcyclopentane + 2,3 dimethylpentane + 3-methylhexane + 1, cis-3 dimethylcyclopentane+ 1, trans-3-dimethylcyclohexane + 2,2,3 trimethylcyclopentane + 2,5 dimethylcyclohexane). The isoheptane value = (2-methylcyclohexane + 3-methylcyclohexane)/(1,cis-3-dimethylcyclopentane + 1, trans-3-dimethylcyclopentane + 1, trans-2-dimethylcyclopentane). Thompson (1983) used the heptane and isoheptane values to characterize oils into four main categories; normal oils with heptane values ranging from 18 to 22 and isoheptane values from 0.8 to 2.0, mature oils with heptane values ranging from 22 to30 and isoheptane values from 2.0 to 3.1, supermature oils with heptane values greater than 30 and isoheptane values greater than 3.1, and biodegraded oils with heptane values less than 18 and isoheptane values less than 3.1 (Table 5). The Manyberries oils show high heptane values ranging from 3.2 to 33.10 and isoheptane values, ranging from 1.60 to 3.35 (Table 4), which suggests that they are mature to supermature, based on the classification of Thompson (1983). The thermal maturity of the Manyberries oils will be further discussed in section 6.5.4.

Table 5. Oil classification scheme as defined by Thompson (1983)

Classification	Heptane Value	Isoheptane Value
Normal oil	18-22	0.8-2.0
Mature oil	22-30	2.0-3.1
Supermature oil	>30	>3.1
Biodegraded oil	<22	<.0.8

The Manyberries oil suite shows a range of 3-methyl pentane/n-hexane ($3MC_5/nC_6$) values of 0.30 to >1.0 and isopentane/n-pentane (iC_5/nC_5) values 0.31 to 5.1 (Table 4). These ratios have been shown by Osadetz et al. (1991) to be sensitive to bacterial attack whereby $3MC_5/nC_6$ and iC_5/nC_5 ratios greater than 1 indicate a biodegraded oil (Osadetz et al., 1991). Thus it is suggested here that the Manyberries oils have undergone a slight biodegradation of gasoline range compounds. Biodegradation of the Manyberries oils will be discussed in section 6.5.6.1.

The Manyberries oils show a range of 3-methyl pentane/benzene ($3MC_5$/benzene) values from 30.63 to >1000 and methylcyclohexane/toluene ($MCYC_6$/toluene) values ranging from 2.92 to >1000 (Table 4). Due to the high solubility of toluene and benzene, (McAuliffe, 1967) these parameters have been shown to be indicative of water washing and migration distance (Osadetz et al., 1991). Osadetz et al. (1991) indicates that $3MC_5$/benzene and $MCYC_6$/toluene ratios greater than 10 are indicative of a strongly water-washed oil (Osadetz et al., 1991). Thus it is suggested here that the oils from the Manyberries area have been water-washed. This concept with respect to the Manyberries oil will be more fully discussed in section 6.5.6.3.

6.3 C_{15+} Saturated Hydrocarbons

Gas chromatograms of C_{15+} saturated hydrocarbons are provided in Appendix 5 with a representative saturate fraction gas chromatogram given in Figure 15 (p. 34). Relevant ratios are listed in Table 6.

Two acyclic isoprenoids of particular use for characterizing oils are pristane (pr) and phytane (ph). The ratio of these two compounds (pr/ph) can be indicative of source rock depositional environment (Didyk et al., 1978; ten Haven et al., 1987; Peters and Moldowan, 1993). Generally, oils with a pr/ph ratio greater than 3.0 were derived from a terrestrial organic matter-enriched source rock, while a pr/ph from 1.0 to 0.6 indicates

Table 6. Acyclic isoprenoid and normal alkane ratios from C_{15+} saturate fraction gas chromatograms of the Manyberries oils

SAMPLE #	pr/ph	pr/nC$_{17}$	ph/nC$_{18}$
2127	0.84	0.30	0.38
2128	0.95	0.33	0.40
2129	1.00	0.36	0.40
2130	0.77	0.29	0.41
2131	0.95	0.34	0.40
2132	0.84	0.27	0.38
2133	0.78	0.29	0.42
2134	0.86	0.29	0.38
2135	0.90	0.31	0.37
2136	0.73	0.27	0.41
2137	0.79	0.29	0.39
2138	0.85	0.27	0.37
2139	0.92	0.33	0.41
2140	0.93	0.31	0.38
2141	0.85	0.28	0.37
2146	0.89	0.30	0.38

derivation from a source rock deposited under anoxic, hypersaline conditions. Palacas (1992) stated that oils with pr/ph ratios of less than or equal to 1 are derived from a carbonate source rock and pr/ph ratios greater than 1 are derived from a shale source. The Manyberries oil suite shows pr/ph ratios ranging from 0.73 to 1.0 which suggest derivation from a carbonate source rock, which was deposited under near anoxic conditions.

The ratio of acyclic isoprenoids to normal alkane (i.e. pristane/ C_{17} normal alkane (pr/nC_{17}) and phytane/ C_{18} normal alkane (ph/nC_{18})) is useful for assessing the degree of biodegradation in oils and relative thermal maturity. Generally, ratios of pr/nC_{17} and ph/nC_{18} which are >1 for an oil indicate that the oil has undergone biodegradation due to the preferential loss of normal alkanes relative to acyclic isoprenoids during biodegradation (Peters and Moldowan, 1993). All of the Manyberries oil samples have pr/nC_{17} and ph/nC_{18} ratios which are less than 1, indicating that none of these oils have had the C_{15+} fraction biodegraded.

6.4 Terpane and Sterane biomarker characteristics

Gas chromatography-mass spectrometry (GC-MS) analysis was used to examine the relative distributions of sterane and terpane biological fossils or biomarkers. Table 7 provides the biomarker ratios calculated from peak height measurements from m/z 191, m/z 217 and m/z 218 mass fragmentograms (see Figures 13, 14, and 15 for representative mass fragmentograms).

6.4.1 Terpanes (m/z 191 mass fragmentogram)

The relative abundance of terpane biomarkers is measured from m/z 191 mass fragmentogram (Figure 16) which are provided in Appendix 6 for oils from Manyberries, Black Butte, Whitlash and Fred and George Creek oil fields. The dominant terpane compound in the Manyberries oils is C_{23} tricyclic terpane (Figure 16). Generally, all Manyberries oils examined show a decline in the abundance of homohopane homologous series from C_{30} to C_{34} followed by an increase for C_{35} compound (Figure 16).

The Manyberries oils show high C_{23} tricyclic terpane /C_{30} homohopane (C_{23}/C_{30}h) ratio with values ranging from 0.98 to 1.65, C_{24} tetracyclic terpane/C_{26} tricyclic terpane (C_{24} tet/C_{26}) ratios range from 1.29 to 1.78, C_{29} norhopane/C_{30} hopane (C_{29}/C_{30}h) ratio range from 0.91 to 1.10, C_{35} homohopane /C_{34} homohopane (C_{35}/C_{34}) ratio range from

1.10 to 1.30, and 18 α(H)-trisnorhopane/ 17 α(H)-trisnorhopane (Ts/Tm) values range from 0.70 to 0.88. These terpane biomarker parameters will be discussed in further detail in section 6.5.

6.4.2 Steranes (m/z 217 and m/z218 mass fragmentogram)

The relative abundance of sterane biomarkers is measured from m/z 217 (Figure 17) and m/z 218 fragmentograms (Figure 18). All m/z 217 and m/z 218 mass fragmentograms for the samples from Manyberries, Black Butte, Whitlash and Fred and George Creek oil fields are provided in Appendix 6. The dominant sterane compound in the Manyberries oils is the C_{21} 5α(H) 14β(H) 17β(H)-pregnane. The Manyberries oils also show a general depletion in relative abundance of regular steranes with $C_{29} < C_{27} < C_{28}$, and a prominence of C_{27} diasteranes over C_{27} regular steranes.

The Manyberries oils show a high ratio of C_{21} pregnane/C_{29} regular sterane (C_{21}/C_{29}) ranging from 1.48 to 2.72, C_{27} diasterane/C_{27} regular sterane (D/R 27) ranges from 1.71 to 2.17. Regular steranes range from 33 to 37% for C_{27}, 19 to 21% for C_{28} and 39 to 46 % for C_{29}. The ratio of C_{28}/C_{29} ranges from 0.42 to 0.57 with a mean of 0.43 +/- 0.04. The ratio of C_{29} 5α(H) 14 α(H)17α(H) 20S to C_{29} 5α(H)14α(H)17α(H) 20R sterane (C_{29}S/R) ranges from 0.89 to 1.02. These sterane biomarker parameters will be discussed in further detail in section 6.5.

6.5 Discussion

The Manyberries oils display similar geochemical characteristics (i.e. weight % sulphur, gross composition, saturate fraction biomarker distributions) and represent a single oil family, designated here as Family M. These oil characteristics will be discussed

Table 7. Biomarker ratios calculated for all oil samples from the Manyberries oil field (see text for ratio identification)

	Terpanes (m/z191)			
sample #	C23/C30h	C24tet/C26	C29/C30h	TS/TM
2127	1.02	1.50	0.96	0.83
2128	0.98	1.43	0.96	0.80
2129	1.17	1.52	1.10	0.88
2130	1.06	1.38	0.91	0.81
2131	1.16	1.41	1.01	0.76
2132	1.17	1.46	0.91	0.74
2133	1.32	1.42	0.98	0.78
2134	1.17	1.48	0.98	0.77
2135	1.40	1.69	0.99	0.82
2136	1.65	1.63	0.99	0.88
2137	1.27	1.78	0.96	0.86
2138	1.26	1.29	0.95	0.72
2139	1.14	1.58	0.91	0.70
2140	1.06	1.39	0.95	0.76
2141	1.24	1.53	0.93	0.77
2146	0.98	1.71	0.98	0.78

	Steranes (m/z 217 and m/z 218)						
sample #	C21/C29	D/R27	C27%	C28%	C29%	C28/C29	C29S/R
2127	1.58	1.99	34.18	19.40	46.42	0.42	0.91
2128	1.48	1.74	35.03	20.38	44.59	0.46	0.92
2129	1.70	2.02	33.86	20.37	45.77	0.45	0.91
2130	1.69	1.95	36.52	19.36	44.12	0.44	0.89
2131	1.75	2.08	32.15	21.01	46.84	0.45	0.97
2132	1.77	1.87	34.96	20.31	44.73	0.45	0.93
2133	1.98	2.17	33.63	21.43	44.94	0.48	0.92
2134	1.72	2.04	33.77	19.53	46.70	0.42	0.89
2135	2.06	1.97	34.37	21.41	44.23	0.48	1.00
2136	2.72	2.03	37.67	22.67	39.67	0.57	1.00
2137	2.20	1.96	37.67	19.78	42.55	0.46	1.02
2138	1.66	1.88	35.39	20.13	44.47	0.45	0.92
2139	1.91	1.71	33.88	20.66	45.45	0.45	0.91
2140	1.55	1.80	33.29	20.74	45.97	0.45	0.93
2141	1.96	1.89	37.03	21.16	41.81	0.51	0.95
2146	1.50	1.74	32.57	21.33	46.10	0.46	0.94

in detail in section 6.5.1. Following this there will be a discussion of the potential hydrocarbon source rock intervals for the Family M oils in section 6.5.2, section6.5.2.1, section 6.5.2.2 and section 6.5.3. Variation in the thermal maturity of oils from the Manyberries area has implications for the level of catagenesis reached by the Family M source and area of oil generation, and these are discussed in section 6.5.4. The potential source area for the Family M oils will be discussed in section 6.5.5. Finally, the effects of post-expulsion alteration on the oils in the Manyberries area will be discussed in section 6.5.6.

6.5.1 Organic Geochemistry of the Manyberries area (oil-oil correlation)

The oils from the Manyberries area are grouped as a single oil family based on the similarities of their geochemical characteristics and are designated as Family M (see appendices 4, 5, and 6). Family M oils are typified by a high saturated to aromatic hydrocarbon ratio (>1.0), moderately low sulphur content (~1.0 %), a pristane/phytane ratio of greater than 0.6 and less than 1.0, C_{23} tricyclic terpane/C_{30} hopane ratio of greater than 1.0, C_{24} tetracyclic terpane/C_{26} tricyclic terpane ratio of greater than 1.0, C_{29} norhopane/C_{30} hopane ratio greater than 0.9, C_{35}/C_{34} homohopane ratio greater than 1.0, C_{21}/C_{29} sterane ratio greater than 1.4, C_{27} diasteranes/ C_{27} regular steranes ratio greater than 1.0, C_{28} sterane/C_{29} sterane mean ratio of 0.43 +/-0.04. A comparison of the Family M oils to other oil families in southern Alberta and southwestern Saskatchewan is provided in Chapter 7.

6.5.2 Oil-source rock correlation

The consistency of the biomarker characteristics among Family M oils suggests that they were all derived from the same or a very similar source rocks. We can use certain biomarker ratios to infer the nature of the source rock (lithology, depositional environment, and age). This information can then be used to identify and sample the stratigraphic units that are potential source rocks for the oils in question.

6.5.2.1 Lithology

The Family M oils have pr/ph <1, C_{24} tet/C_{26} ratio greater than 1, C_{29}/C_{30} ratio close to 1, C_{35}/C_{34} greater than 1 and C_{21}/C_{29} sterane greater than 1. These ratios for an oil have been shown by various workers to be indicative of derivation from a carbonate hydrocarbon source rock (McKirdy et al., 1983; Palacas et al., 1984; Zumberge, 1984; Connan et al., 1986; Mello et al., 1988; ten Haven et al., 1987; Clark and Philip; 1989; Waples and Machihara, 1991; Palacas, 1992; Riediger et al., 1993; and Peters and Moldowan, 1993)(Table 8). Most oils derived from carbonate source rocks also display C_{27} diasterane/C_{27} regular sterane ratio of less than 1, however the Family M oils have C_{27} diasterane/C_{27} regular sterane ratios greater than one, values more typical of oils derived from a shale source rock. However, some studies (e.g. Clark and Philip, 1989; Riediger et al., 1993) reported carbonate source rock extracts which display C_{27} diasterane/C_{27} regular sterane ratios greater than 1. Thus it is proposed that the biomarker distributions of the Family M oils are consistent with derivation from a carbonate source rock.

Table 8. Some characteristics of oil derived from a carbonate versus a shale hydrocarbon source rock

Characteristics	Shales	Carbonates	Reference
pr/ph	>1	<1	1, 10
C24tet/C26	<1	>1	1, 4, 7, 10
C29/C30h	<1	>1	2, 4, 8
C35/C34	<1	>1	3, 1, 5, 7
C21/C29	<1	>1	7, 10, 11
C27 dia/reg	>1	>1	2, 1, 6, 10, 11, 12

(1) Palacas et al. (1984), (2) Zumberge (1984), (3) McKirdy et al. (1983)
(4) Connan et al. (1986), (5) ten Haven et al. (1987), (6) Mello et al (1988)
(7) Clark and Philp (1989), (8) Waples and Machihara (1991)
(10) Palacas (1992), (11) Riediger et al. (1993)
(12) Peters and Moldowan (1993)

6.5.2.2 Age

Grantham and Wakefield (1988) found a correlation between the C_{28}/C_{29} sterane ratio and geologic time for normal marine source rocks. This idea was based on the examination of a suite of crude oils that were derived from hydrocarbon source rocks from Precambrian to Tertiary age. These authors found that the relative abundance of C_{28} steranes increased in abundance over geologic time, which parallels the diversification of phytoplankton (Figure 35). The Manyberries samples have a mean C_{28}/C_{29} ratio of 0.43 +/- 0.04 which places the age of the source rock of these oils as roughly late Devonian to early Mississippian in age (Grantham and Wakefield, 1988).

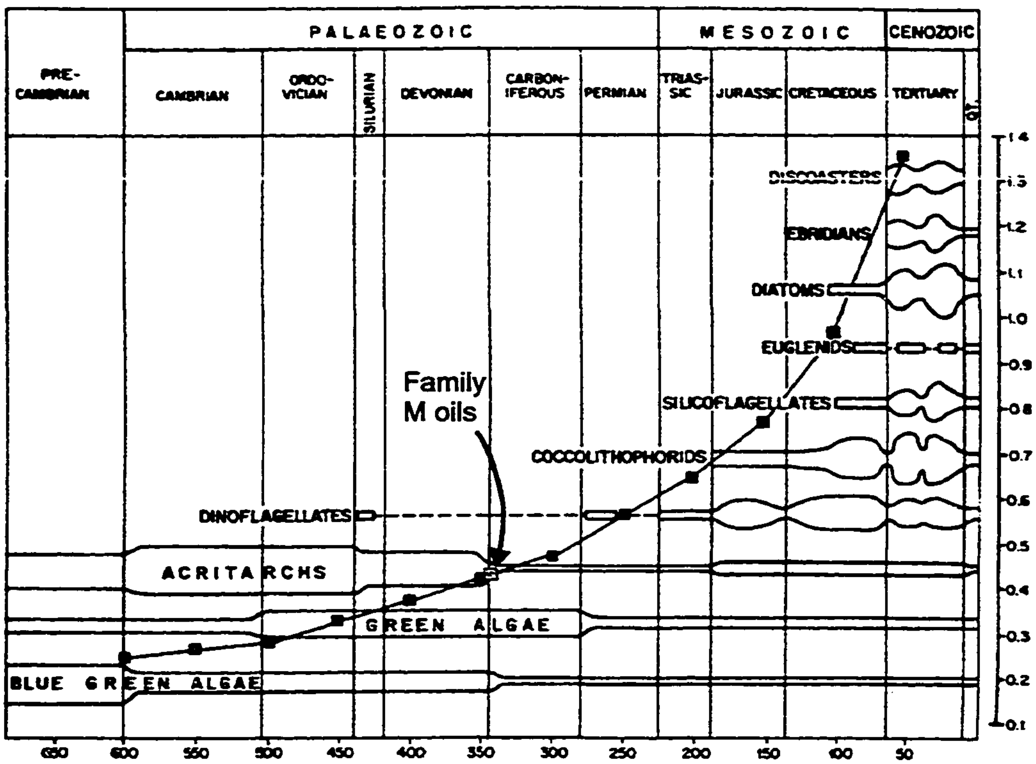


Figure 35. Geological distributions of important groups of phytoplankton compared to the mean C_{28}/C_{29} sterane ratio (right axis) of marine source rock derived crude oils (Grantham and Wakefield, 1988).

Thus, the biomarker characteristics of Family M oils suggest an organic rich, carbonate source rock, during the late Devonian to early Mississippian as the source for the Family M oils.

6.5.3 Potential Hydrocarbon Source rocks for Family M oils

Due to a lack of extract data from potential Upper Devonian to Lower Mississippian carbonate source rocks near the study area, no conclusive oil-source correlation can be made for the Family M oils at this time. However, by considering regional geologic features and lithologic data for this age range of stratigraphy, some inferences for the Family M source rock can be made.

The Manyberries oil field area lies on the eastern edge of the Sweetgrass Arch. If we consider that peak oil generation from potential Paleozoic source rocks within the Alberta and Williston basins was during late Cretaceous to early Tertiary time (Creaney et al., 1994; Burrus et al., 1995), and that the Sweetgrass Arch was a structural high during this time and constituted a oil migration "divide", we can infer that the Family M oils must have been derived from the Williston Basin. The best Williston Basin stratigraphic candidates as the source(s) of the Family M oils include the Upper Devonian Saskatchewan Group, the Upper Devonian to Lower Mississippian Three Forks Group or the Lower Mississippian Madison Group (Figure 36).

A potential source for the Family M oils is the Bakken Formation (Three Forks Group) a shale unit with TOC values ranging 12 to 28 %, HI values ranging from 176 to 658, and Tmax values ranging from 422 to 436 (Osadetz et al., 1992). Osadetz et al. (1992) document Bakken extract data from southeastern Saskatchewan as having the

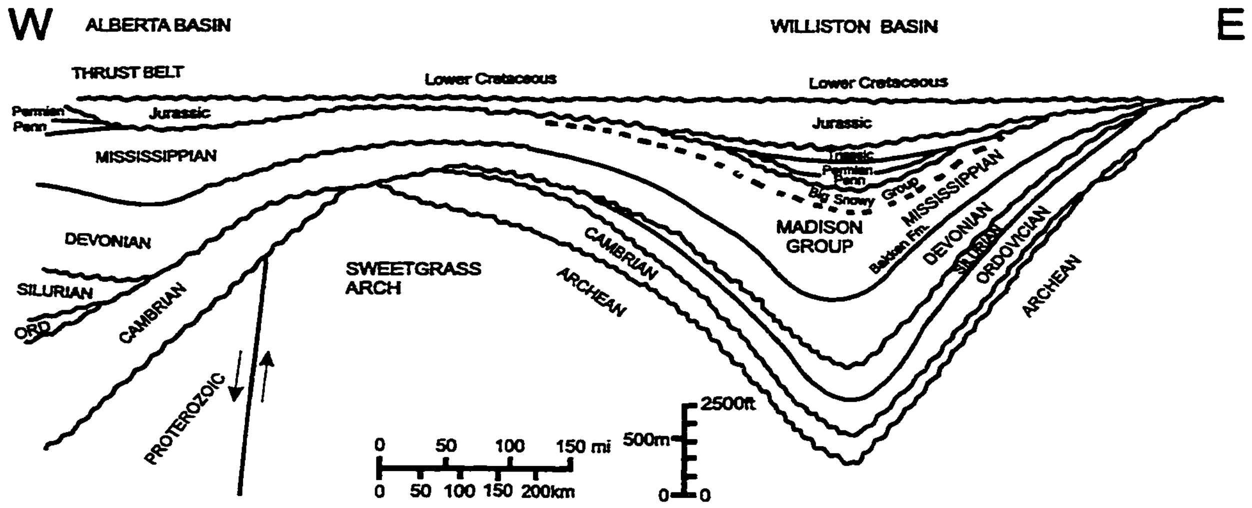


Figure 36. Regional geologic cross-section over the Sweetgrass Arch (eastern North Dakota to western Montana) modified after Peterson (1988).

following biomarker characteristics; pr/ph>1, C_{23}/C_{30} ratio of ~1, C_{24}tet/C_{26}tri ratio of~1, C_{29}/C_{30} ratio of >0.6, no C_{35} homohopane prominence, C_{27} dia/reg ratio of 1 and a moderately high abundance of C_{21} pregnane. These biomarker characteristics are quite different from the Family M characteristics (Figure 37) and thus an oil-source rock correlation cannot be made between the Bakken and the Family M oils.

Osadetz et al. (1992) documents the Lodgepole Formation (Madison Group) as the most effective hydrocarbon source rock in the Williston Basin. This statement is based on oil-source rock correlations between most of the Mississippian oils in southeastern Saskatchewan and Lodgepole extract data from the same area. The Lodgepole source rock from southeastern Saskatchewan has a total organic carbon (TOC) content ranging from 3.0 to 6.0%, HI values ranging from 503 to 640, and Tmax values ranging from 439 to 440 °C. These authors document the following biomarker characteristics for the Lodgepole extracts as having pr/ph<1, low C_{23}/C_{30} ratio (<1), low C_{29}/C_{30} ratio (<0.6),

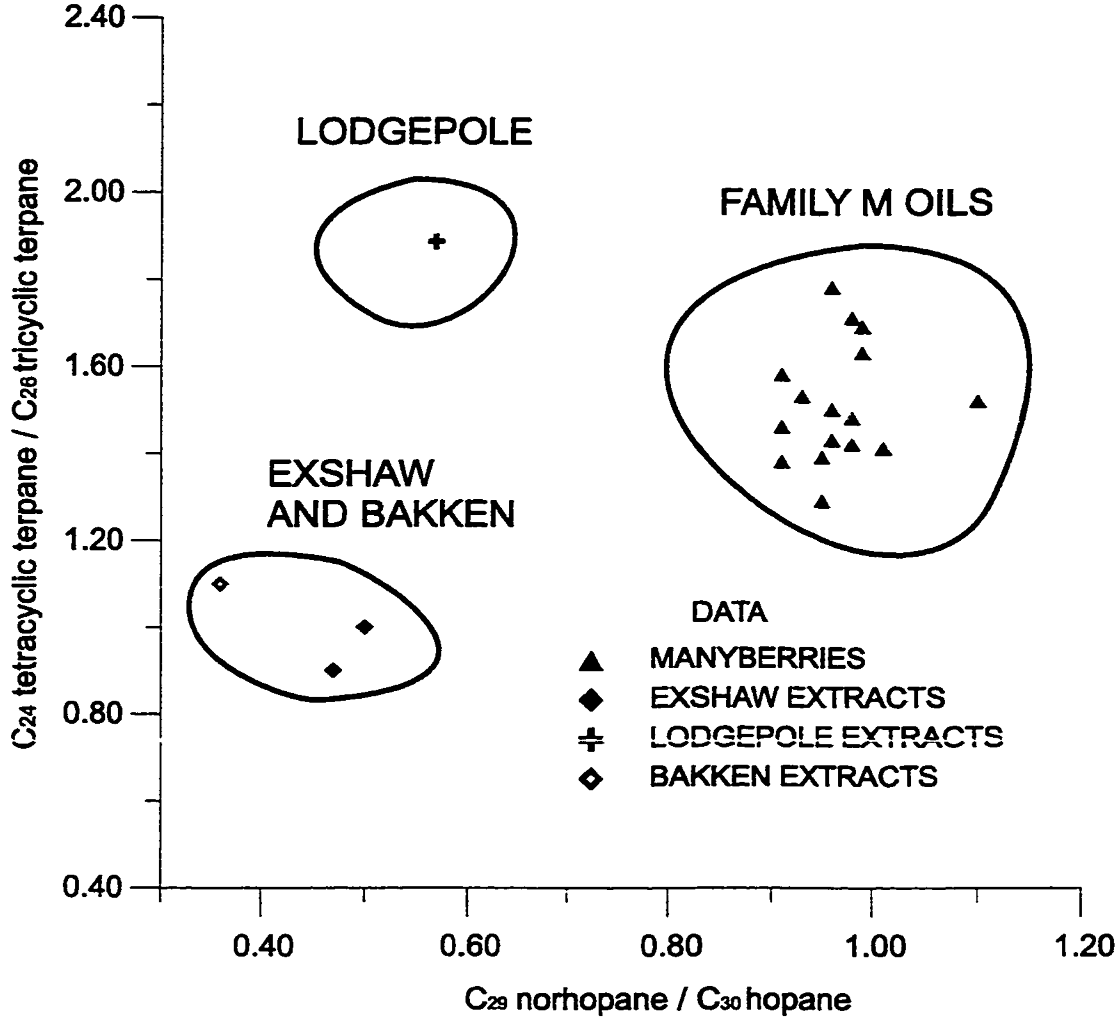


Figure 37. A cross-plot of C_{24} tetracyclic terpane/C_{26} tricyclic terpane versus C_{29} norhopane /C_{30} hopane for Lodgepole, Bakken and Exshaw Formation extracts from southeastern Saskatchewan (Osadetz et al., 1992) and southwestern Alberta (Dolson et al., 1993), compared to oils from the Manyberries area.

high C_{24}tet/C_{26}tri (>1.4), C_{35} homohopane prominence, low C_{27} dia/reg (<0.5), and low abundance of C_{21} sterane. These biomarker characteristics are quite different from those of Family M oils (Figure 37) and as such no oil-source rock correlation can be made between the Lodgepole and the Family M oils.

Thus, the Family M oils do not correlate to any established hydrocarbon source rocks in the Williston Basin and as such represent derivation from an undocumented source (Figure 37). As the biomarker data from Family M oils suggests generation from an Upper Devonian to Lower Mississippian carbonate source rock, the best stratigraphic candidate is the Saskatchewan Group, but unfortunately no source rock extracts are available from mature sources in the Saskatchewan Group. Switzer et al. (1994) document the Winterburn/Woodbend Group (Saskatchewan Group equivalent) in southern Saskatchewan as composed of carbonates deposited in supratidal to evaporitic setting. Martin Fowler (personal communication) documents organic rich intervals in the Saskatchewan Group with >10% TOC.

Thus, based on the biomarker model presented for the Family M oils, the potential source for the Manyberries oils is an organic rich, carbonate source rock deposited in the Williston Basin during the late Devonian to early Mississippian. Based on source rock extract data available from Williston Basin, no correlation between Family M oils and any prospective late Devonian to early Mississippian units could be made and as such the source for Family M oils is still unknown.

6.5.4 Thermal Maturity

During the conversion of kerogen to oil, non-reversible heat driven chemical reactions occur within the kerogen, which convert thermally metastable compounds to more thermally stable compounds. An example of such a reaction is the conversion of C_{29} 5α(H) 14α(H) 17α(H) 20R, sterane to C_{29} 5α(H)14β(H)17β(H) 20S sterane (C_{29}S/R). At a critical level of temperature and time this reaction will reach equilibrium ($C_{29}S = C_{29}$ R) and thus the ratio of C_{29}S to C_{29} R can be used as a measure of the level of catagenesis (Thompson, 1983; Mackenzie, 1984; Barnes et al., 1984; Peters and Moldowan, 1993 and Killops and Killops 1993). This rationale can also be used for oils, whereby the level of catagenesis (thermal maturity of the source rock that generated the oils in question can be estimated from these geochemical parameters. The relative degree of thermal maturity of the Family M oils, is assessed based on gasoline range parameters (heptane and isoheptane values) and biomarker characteristics (i.e. C_{29}S/R, Ts/Tm, and C_{27} dia/reg).

Isoheptane and heptane values for the Manyberries oils indicate that these oils are mature to supermature, based on the criteria of Thompson (1983)(Table 5). These values imply generation from a hydrocarbon source rock with an equivalent vitrinite reflectance greater than 1.0% Ro or late hydrocarbon generation (Thompson, 1983), with generation temperatures in excess of 138 ° C. Oil samples 2129, 2130 and 2131 show much lower

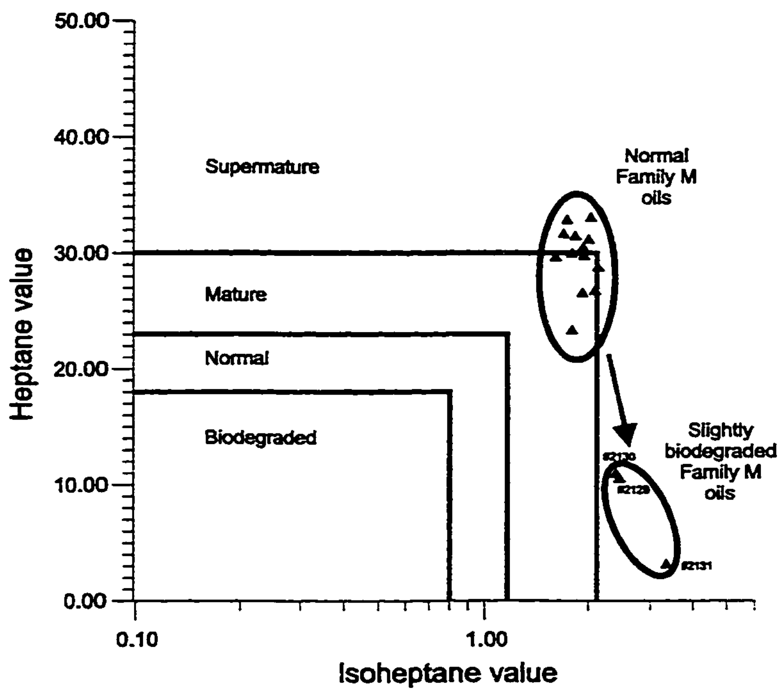


Figure 38. A cross-plot of the Manyberries oil suite heptane value versus isoheptane value and maturity fields as defined by Thompson (1983).

heptane values relative to the other samples. Thompson (1983) documents a similar situation in the Powder River Basin of Wyoming and attributed heptane value differences to biodegradation of originally supermature oil. Thus, the difference in heptane values between samples 2129,2130 and 2131 may be due to a slight biodegradation of gasoline range compounds (Figure 38) and will be discussed in section 6.5.6.3.

The ratio of C_{29} 5α(H) 14α(H) 17α(H) 20S, sterane and C_{29} 5α(H) 14β(H) 17β(H) 20R sterane (C_{29}S/R) has been determined by various authors to be a suitable parameter for the classification of oils in terms of their thermal maturity (Mackenzie, 1984; Siefert and Moldowan, 1986; Peters and Moldowan, 1993). Generally the C_{29} 5α(H) 14α(H) 17α(H) 20R isomer is less stable during the thermal evolution of a kerogen or an oil up to levels of 0.8 % Ro (Mackenzie, 1984). Thus, the ratio of C_{29}S/R increases with increasing thermal maturity to an equilibrium value of 1.0 at about 0.8% Ro. The Manyberries oils exhibit a range of C_{29} S/R from 0.89 to 1.00. These C_{29} S/R ratios suggest oil generation occurred at peak maturity (Mackenzie, 1984; Peters and Moldowan, 1993).

The ratio of 17α(H)-trisnorhopane (Tm) and 18α(H)-trisnorhopane (Ts) has been used by various authors as an indicator of source rock lithology and thermal maturity within oil families (McKirdy et al., 1983, 1984; Rullkotter et al., 1985; and van Graas, 1990). During catagenesis 17α(H)-trisnorhopane (Tm) is less stable than 18α(H)-trisnorhopane (Ts), (Siefert and Moldowan, 1978) and so the Ts/Tm ratio increases with increasing thermal maturity. The Manyberries oil samples show a range of Ts/Tm ratios from 0.70 to 0.88 suggesting oil generation occurred at peak maturity (van Graas, 1990; Peters and Moldowan, 1993).

The ratio C_{27} 13β(H) 17α(H) 20S diasterane to C_{27} 5α(H) 14α(H)17α(H) 20R regular steranes (C_{27} dia/reg) has been used as a thermal maturity parameter (Waples and Machihara, 1991; Peters and Moldowan, 1993). Diasteranes are more stable than regular steranes during catagenesis and at peak generation regular steranes may even be rearranged into diasteranes (Peters and Moldowan, 1993). Thus, the C_{27} dia/reg ratio increases with increasing thermal maturity. The C_{27} dia/reg ratio for the Manyberries oil samples range from 1.71 to 2.17 suggesting oil generation occurred at peak maturity (Waples and Machihara, 1991).

6.5.5 Source area for Family M oils

The thermal maturity of the Manyberries oil samples suggest catagenesis levels exceeding 0.8% Ro within the source rock. The Bakken Formation of the Williston Basin reached this level of catagenesis in deeper sections of the basin between 30 to 40 million years ago (Burrus et al., 1995). Thus, neglecting kinetic effects and differences in organic matter between the Bakken and the potential sources in the Upper Devonian to Lower Mississippian section, this level of catagenesis could only have been reached in deeper sections of the Williston Basin in North Dakota at least 40 million years ago. Thus, the Family M oils are suggested here to have been derived from the Upper Devonian to Lower Mississippian section in the deeper portion of the Williston Basin (Figure 39) during the Eocene, requiring a lateral migration distance of greater than 400 kilometres (Figure 39).

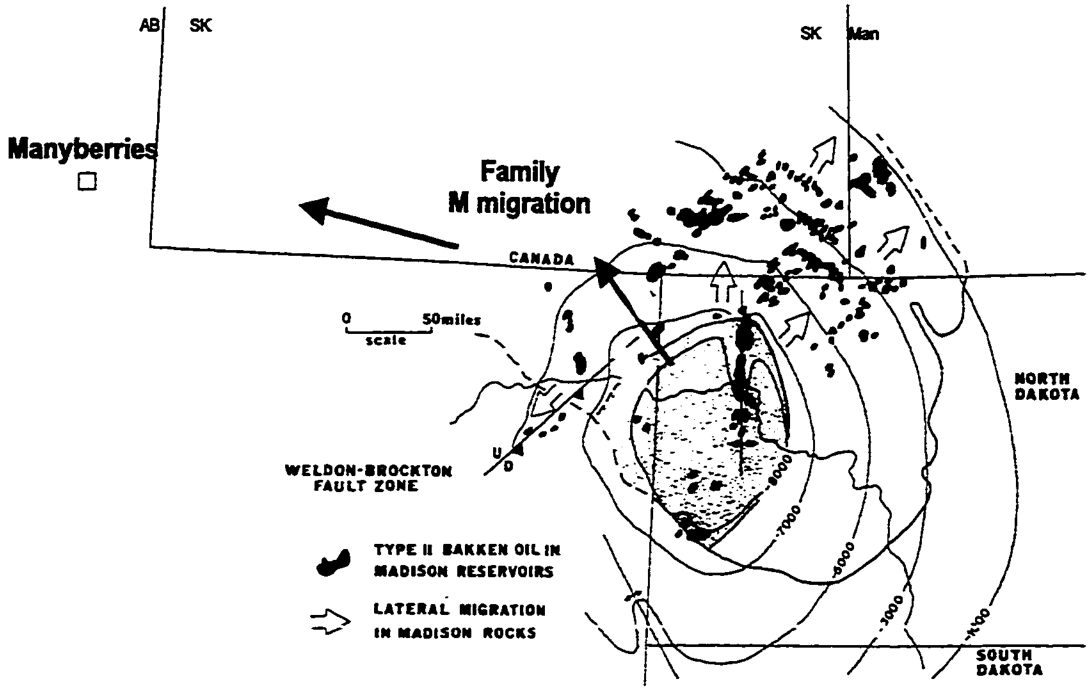


Figure 39. Thermally mature, Bakken Formation (shaded area) within the Williston Basin (Modified from Dow, 1974). Family M oils were likely generated from the shaded area and migrated into southeastern Alberta (Many) (solid arrow indicates migration). Subsea structure contours are for the top of Mississippian (C. I. 2000 ft).

6.5.6 Post-Expulsion effects on Family M oils

Following the generation and expulsion of oil from a hydrocarbon source rock a number of processes can affect the quality of the oil including water washing, gas deasphalting, and biodegradation. These effects can act to increase or decrease the API gravity and sulphur content of a crude oil, which are important with respect to economic considerations for oil production.

6.5.6.1 Water washing

Water washing is the dissolution of the more soluble gasoline range compounds (C_5 to C_8) in water. This process commonly occurs when oils have migrated long distances and have had extensive contact with water. The most soluble components of the gasoline range compounds are benzene and toluene (McAuliffe, 1967) and their absence in an oil can be taken to indicate that water washing has occurred. Water washing is common in Alberta and Williston Basin oils (Evans et al., 1971; Bailey et al., 1973 and Osadetz et al., 1991).

A cross-plot of the ratio of 3 methyl-pentane/benzene versus the ratio methylcyclohexane/toluene is used to quantify water washing (Osadetz et al., 1991)(Figure 40). The Manyberries oils exhibit extremely low concentrations of benzene and toluene suggesting significant water washing has occurred relative to oils examined by Osadetz et al. (1991)(Figure 40). Commonly this level of water-washing is accompanied by extensive biodegradation (Evans et al., 1971; Bailey et al., 1973 and Osadetz et al., 1991) but in the Manyberries oil, biodegradation is slight to nonexistent (see section 6.5.6.3). Thus, the water washing effect seen in the Manyberries suite of oils is not related to biodegradation but to migration or to an active hydrogeologic flow regime in the area.

6.5.6.2 Gas Deasphalting

Gas deasphalting is a process whereby asphaltenes in oils are precipitated by the addition of gaseous hydrocarbons (C_1 to C_6) to a crude oil creating higher API oil. Evans et al. (1971) and Bailey et al. (1973) have documented several cases of gas deasphalting in Western Canada. Gases derived from thermally mature sources have moved up-dip into an existing oil accumulation altering the composition of the oil by causing the precipitation of asphaltenes and creating anomalously light oil.

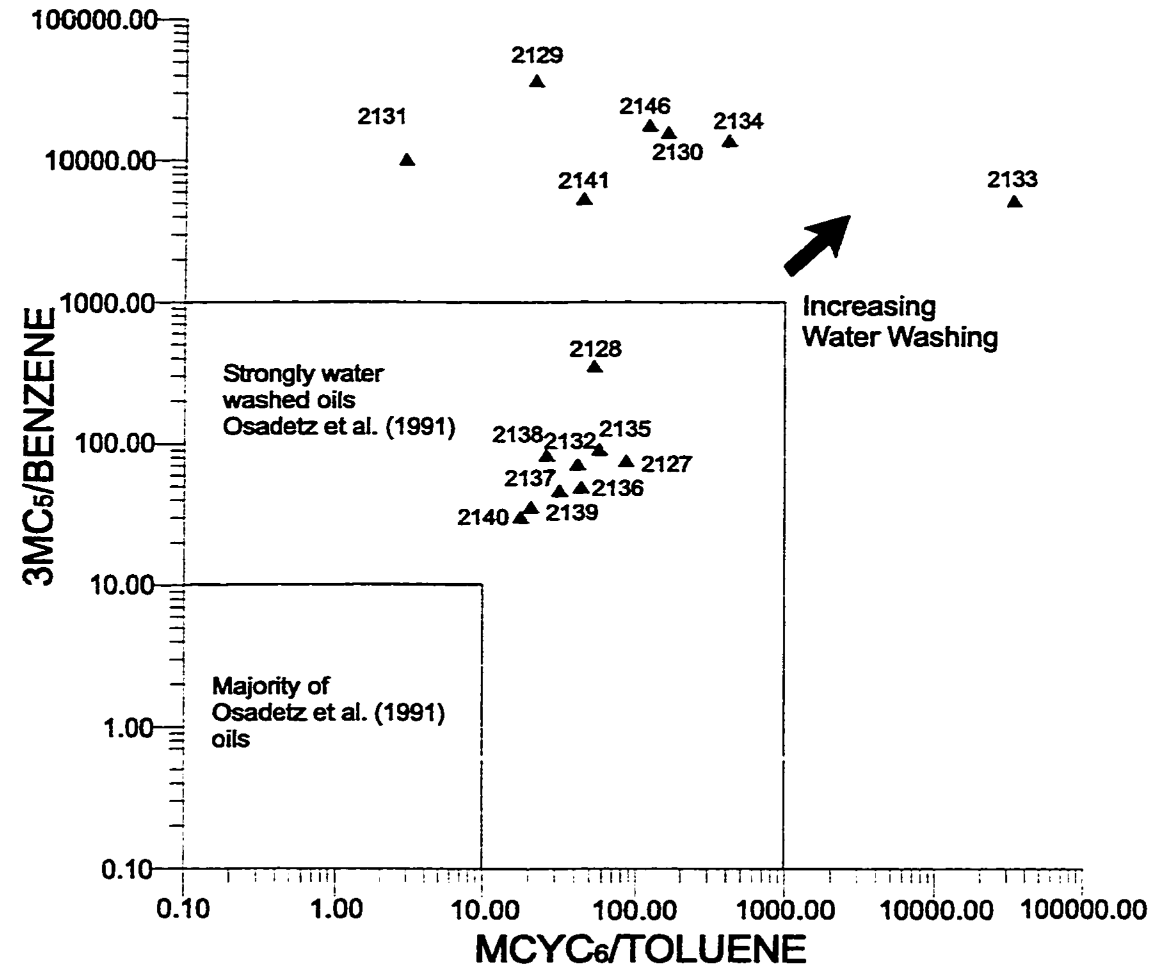


Figure 40. A cross plot of 3 methyl-pentane/benzene ($3MC_5$/ Benzene) versus the ratio methylcyclohexane/toluene ($MCYC_6$/Toluene) for the Manyberries suite of oils. Shaded areas represent the relative degree of water washing of oils examined by Osadetz et al. (1991).

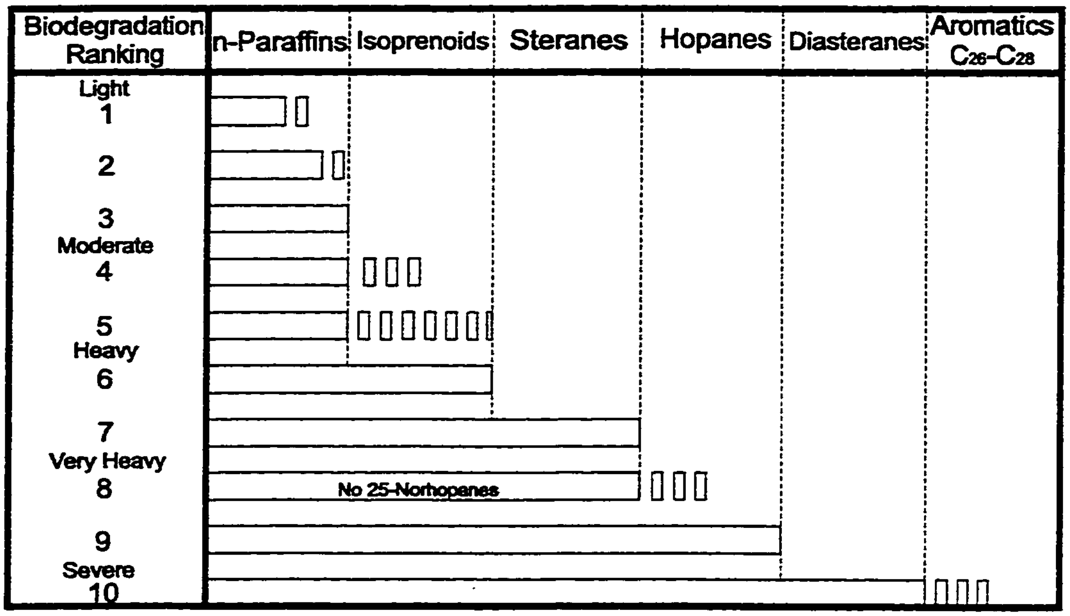
The oil reservoirs in the Manyberries area have anomalously high API gravity relative to other Lower Cretaceous oils in southern Alberta and southeastern Saskatchewan (Table 1), but show no evidence of asphaltene precipitation within Lower Mannville reservoirs and this is not thought to have been a significant process in the area. More likely, the cause for the high crude oil gravity is related to the source rock character and high thermal maturity of Family M oils.

6.5.6.3 Biodegradation

A common alteration process involved in the decrease in oil quality is biodegradation. Biodegradation is the microbial destruction of organic compounds in an oil, resulting in a decrease in crude oil API gravity, and an increase in its sulphur content. Several workers have quantified the relative level of biodegradation in oil by the sequential and systematic removal of compounds (Connan, 1984; Peters and Moldowan, 1993). This work is summarized in Table 9, which displays a relative scale of biodegradation from 1 to 10 (Table 9). A biodegradation level of 1 would show a slight destruction of n-paraffin's and would be classified as lightly biodegraded. Level 10 biodegradation would show destruction of C_{26} to C_{29} aromatic steroids and be classified as heavily biodegraded. The Manyberries oil samples are essentially unbiodegraded with the exception of samples 2129, 2130 and 2131. These samples show the lowest API gravity of the sample suite and a slight depletion of gasoline range (C_5 to C_8) n-alkanes and would be classified as a level 1 biodegraded oil (Peters and Moldowan, 1993). This level of biodegradation can be most easily seen in a cross plot of 3 methyl-pentane/hexane versus isopentane/n-pentane (Figure 41). It should be noted, however that the C_{15+} saturated hydrocarbons (GC) do not show any evidence of biodegradation, that is, there does not appear to be any loss of longer chain n-alkanes.

Considering that reservoirs in the Manyberries area are at less than 1200 m depth, that the oil is in contact with fresh water in close proximity to a local recharge area(Sweet Grass Hills), and reservoir temperatures average 35° C, it seems unusual that the oils in the Manyberries area would not be more extensively biodegraded. The lack of biodegradation could be due to a lack of oxygen, microbes or nutrients in the formation

Table 9. The effects of biodegradation on a typical mature oil (after Peters and Moldowan, 1993)



waters, which would effectively limit the destruction of organic compounds in the oil. Investigation of this phenomenon is beyond the scope of this study, however detailed work on formation water chemistry may help to establish the causes behind the lack of biodegradation in the area.

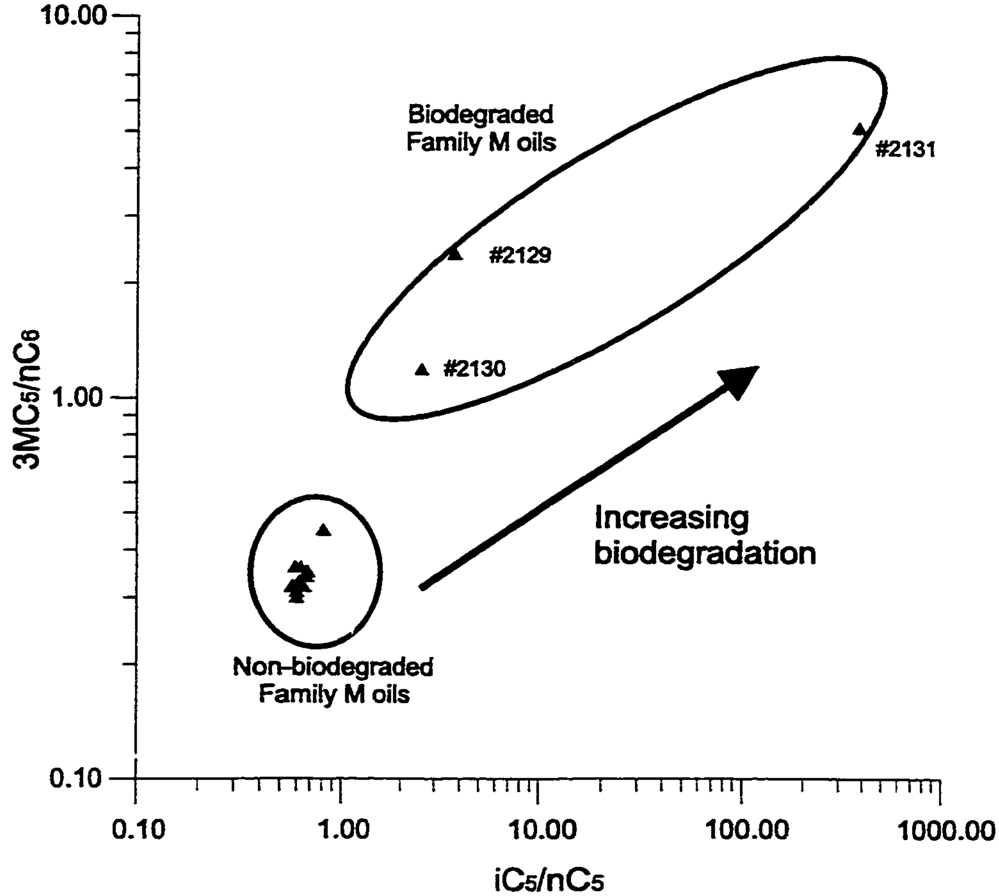


Figure 41. A cross plot of 3 methyl-pentane/hexane versus isopentane/n-pentane for the Manyberries oils. Three Family M oils show low level of biodegradation (losses of short-chain n-alkanes).

7. REGIONAL OIL-OIL CORRELATION

Family M oils from the Manyberries oil field will now be compared to other Mesozoic and Paleozoic oils from adjacent regions (Figure 42), in order to identify a possible correlation with these other oils. New oil data from Black Butte and Medicine Hat oil fields from southeastern Alberta, and Whitlash, Fred and George Creek and Utopia oil fields from north-central Montana are included because they are the most proximal oil fields to Manyberries and their geochemical characteristics have not been previously described (see Figure 42 for field locations). Oil data from recent oil classifications in southern Alberta (Family E; Riediger et al., 1997B), north-central Montana, and southwestern Saskatchewan (Family Csw; Osadetz et al., 1994) are compared to Family M oils of the Manyberries area. The geochemical differences among the three oil families (E, M, Csw) are illustrated using a number of bivariate plots of selected bulk geochemical and biomarker ratios (Table 10; Figure 43, 44 and 45). These figures illustrate that the Family M oils differ in their geochemical characteristics from oil families E and Csw, but are similar to oils from Black Butte, Whitlash and Fred and George Creek fields. The Medicine Hat, Utopia oils and oil sample #1329 from Battle Creek are similar to Family E oils (Riediger et al., 1997B).

7.1 Oil-oil correlation of Family M oils with oils from the Sweet Grass Hills area

The oils from Manyberries, Black Butte, Whitlash and Fred and George Creek oil fields are all similar in bulk geochemical and biomarker characteristics and are classified as Family M oils. These oils all show Pr/Ph ratios greater than 0.6, 1.0 (Figure 43),

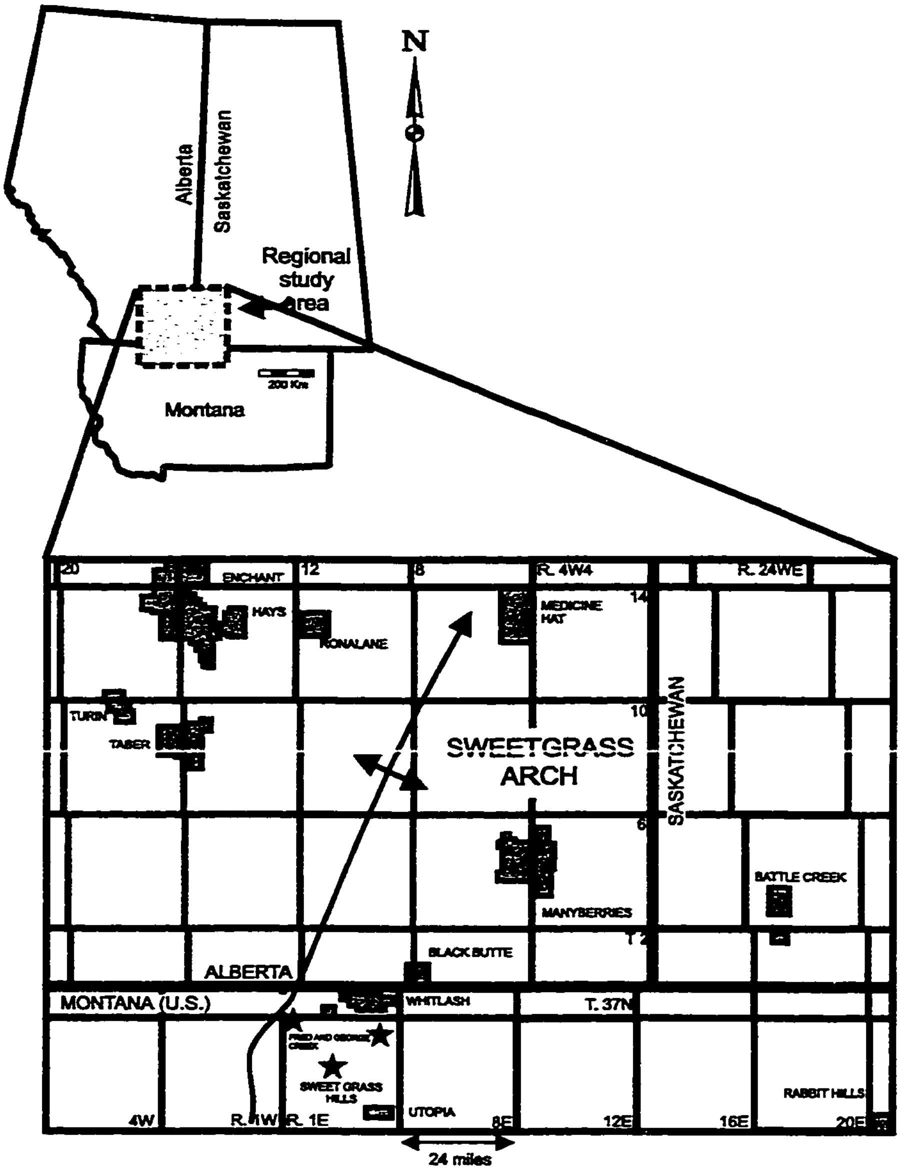


Figure 42. A map of oil fields sampled for regional oil-oil correlation.

Table 10. Bulk geochemical and biomarker ratios for oils used for regional oil-oil correlation (see Figure 42 for field locations)

		Oil	Terpanes				
sample #	Field	Family	$C_{23}/C_{30}h$	$C_{24}tet/C_{26}$	C_{29}/C_{30h}	C_{35}/C_{34}	TS/TM
2142	Med Hat	E	0.50	0.82	0.74	1.50	0.44
2143	Med Hat	E	0.47	0.90	0.64	1.33	0.37
2144	Med Hat	E	0.53	0.83	0.63	1.32	0.41
2145	Med Hat	E	0.51	0.91	0.63	1.26	0.42
2365	Black Butte	M	1.99	1.43	1.10	0.93	0.92
2366	Black Butte	M	1.12	1.38	1.00	1.00	1.03
1406	Rabbit Hills	Csw	0.23	2.20	0.81	1.21	0.41
1329	Battle Creek	E?	0.50	0.92	0.79	1.20	0.44
726	Battle Creek	Csw	0.44	1.92	0.81	1.01	0.41
1917	Taber	E	0.35	0.88	0.63	1.29	0.42
1923	Taber	E	0.18	1.00	0.61	0.80	0.46
1924	Taber	E	0.16	0.80	0.61	0.94	0.45
1922	Turin	E	0.20	1.20	0.65	0.73	0.50
1937	Ronalane	E	0.62	1.14	0.84	1.16	0.59
2002	Ronalane	E	0.55	1.18	0.71	1.29	0.57
1993	Hays	E	0.31	1.13	0.71	1.36	0.53
1986	Hays	E	0.32	1.00	0.69	1.30	0.50
2001	Enchant	E	0.47	0.91	0.81	1.37	0.52
2474	Whitlash	M	1.23	1.45	0.98	1.13	0.87
2475	Whitlash	M	0.99	1.48	0.96	1.19	0.91
2476	Fred+ George	M	1.06	1.04	1.00	1.11	0.67
2477	Utopia	E	0.48	1.25	0.86	1.28	0.44

		Oil			Steranes			
sample #	Field	Family	S/A	Pr/Ph	C_{21}/C_{29}	C_{27}dia/reg	C_{28}/C_{29}	C_{29} s/r
2142	Med Hat	E	0.5	0.72	0.69	1.05	0.54	0.89
2143	Med Hat	E	0.5	0.59	0.75	1.12	0.50	0.78
2144	Med Hat	E	0.4	0.63	0.78	0.98	0.52	0.96
2145	Med Hat	E	0.6	0.65	0.79	1.06	0.52	0.95
2365	Black Butte	M	1.1	0.67	3.24	2.59	0.45	1.06
2366	Black Butte	M	1.1	0.64	1.78	2.31	0.45	0.92
1406	Rabbit Hills	Csw	0.60	0.58	0.34	0.48	0.36	0.98
1329	Battle Creek	E?	0.87	0.67	0.45	0.83	0.44	0.91
726	Battle Creek	Csw	0.40	0.39	0.64	0.69	0.44	1.00
1917	Taber	E	0.76	0.69	0.76	0.96	0.43	0.86
1923	Taber	E	0.71	0.69	0.36	0.95	0.40	0.77
1924	Taber	E	0.52	0.59	0.32	0.85	0.42	0.84
1922	Turin	E	0.89	0.71	0.31	1.10	0.39	0.86
1937	Ronalane	E	0.99	0.67	0.75	1.50	0.40	0.79
2002	Ronalane	E	0.83	0.77	0.80	1.47	0.46	0.84
1993	Hays	E	0.84	0.61	0.55	1.52	0.53	0.92
1986	Hays	E	0.90	0.72	0.49	1.20	0.47	0.80
2001	Enchant	E	0.83	0.72	0.78	1.09	0.47	0.89
2474	Whitlash	M	1.68	0.81	2.51	2.32	0.44	1.00
2475	Whitlash	M	1.71	0.80	1.84	2.06	0.42	1.02
2476	Fred+ George	M	1.84	0.70	1.86	2.22	0.41	0.95
2477	Utopia	E	0.96	0.73	0.83	0.86	0.39	0.92

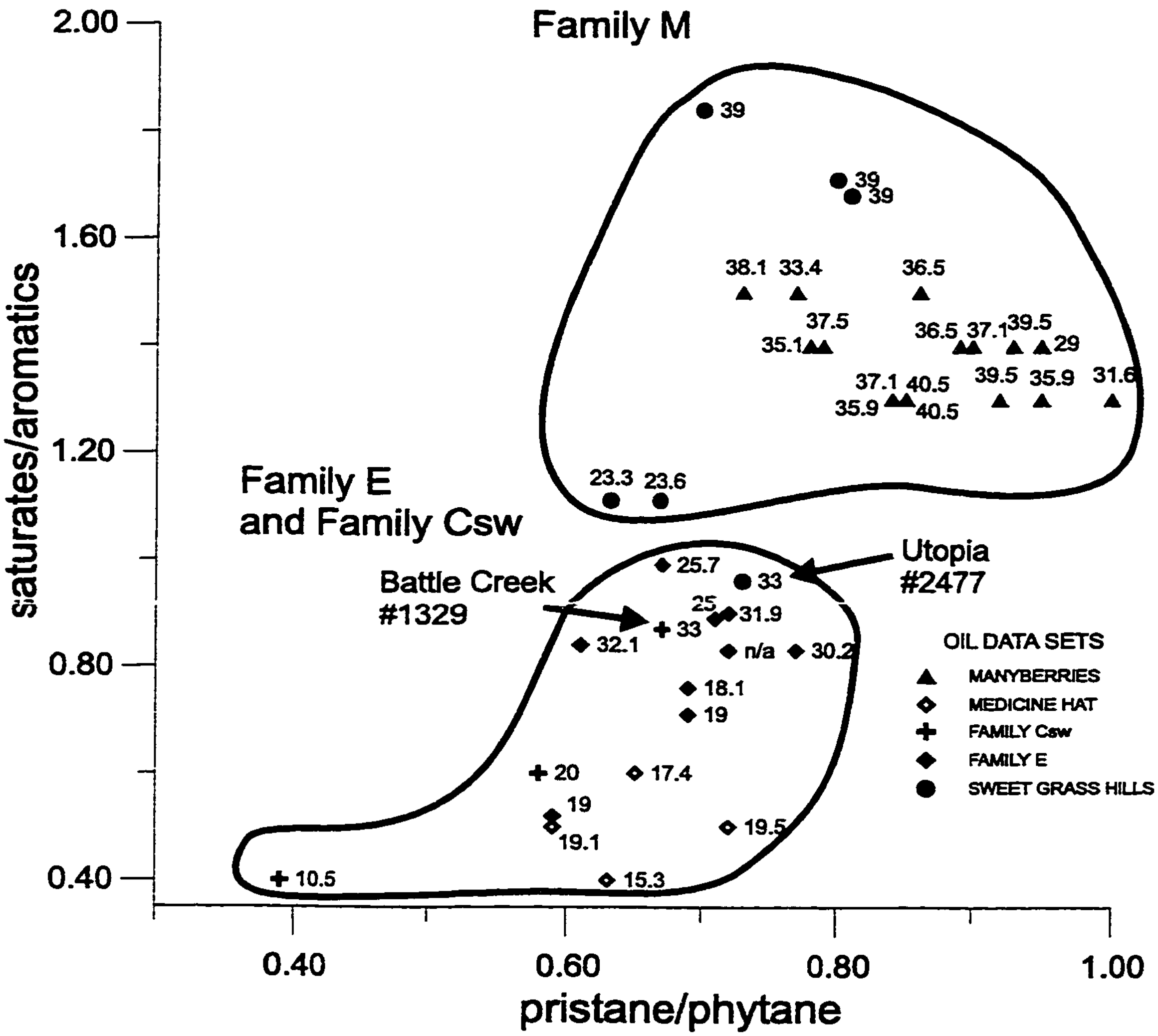


Figure 43. A cross-plot of pristane/phytane versus saturated /aromatic hydrocarbons for established oil families from southern Alberta (Riediger et al., 1997B), southwestern Saskatchewan (Osadetz et al., 1994) and Medicine Hat. Sweet Grass Hills oil data set is from Black Butte, Whitlash, Fred and George Creek and Utopia oil fields (API gravity is posted for individual oil sample points).

C_{23}/C_{30} ratio greater than 1.0, C_{27} diasterane/regular sterane greater than 1.0 (Figure 44), C_{24}tet/C_{26}tri ratios greater than 1 and C_{29}/C_{30} greater than 0.9 (Figure 45). However, there are slight differences in saturates/aromatics and pristane/phytane ratios in the oils from

Black Butte when compared to other Family M oils. The Black Butte oils have undergone slight biodegradation modifying the total concentration of saturated hydrocarbons and pristane. This is readily apparent when a comparison is made between saturate fraction C_{15+} gas

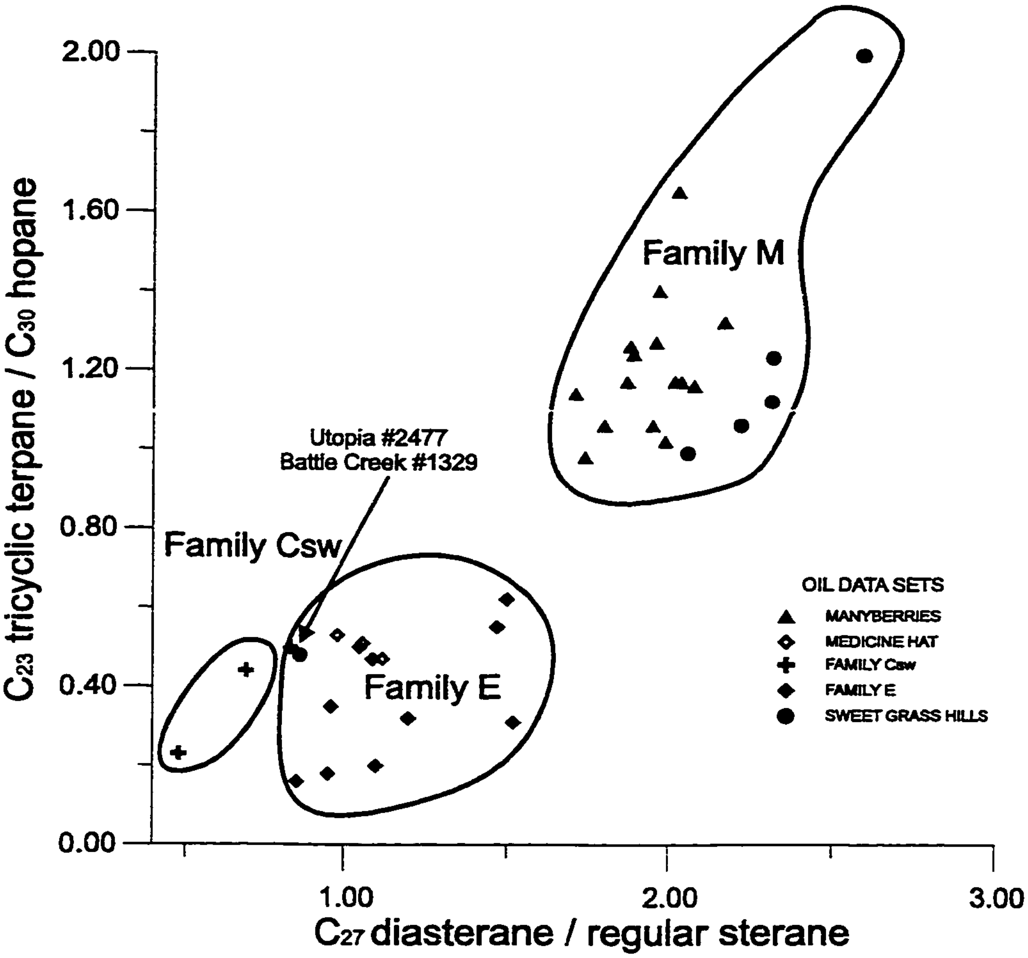


Figure 44. A cross-plot of C_{23} tricyclic terpane/C_{30} hopane versus C_{27} diasterane /C_{27} regular sterane for established oil families from southern Alberta (Riediger et al., 1997B), southwestern Saskatchewan (Osadetz et al., 1994) and Medicine Hat. Sweet Grass Hills oil data set is from Black Butte, Whitlash, Fred and George Creek and Utopia oil fields.

chromatograms from Manyberries sample 2135 and Black Butte sample 2366 (Figure 46). Sample 2366 shows the development of an unresolved complex mixture (UCM).

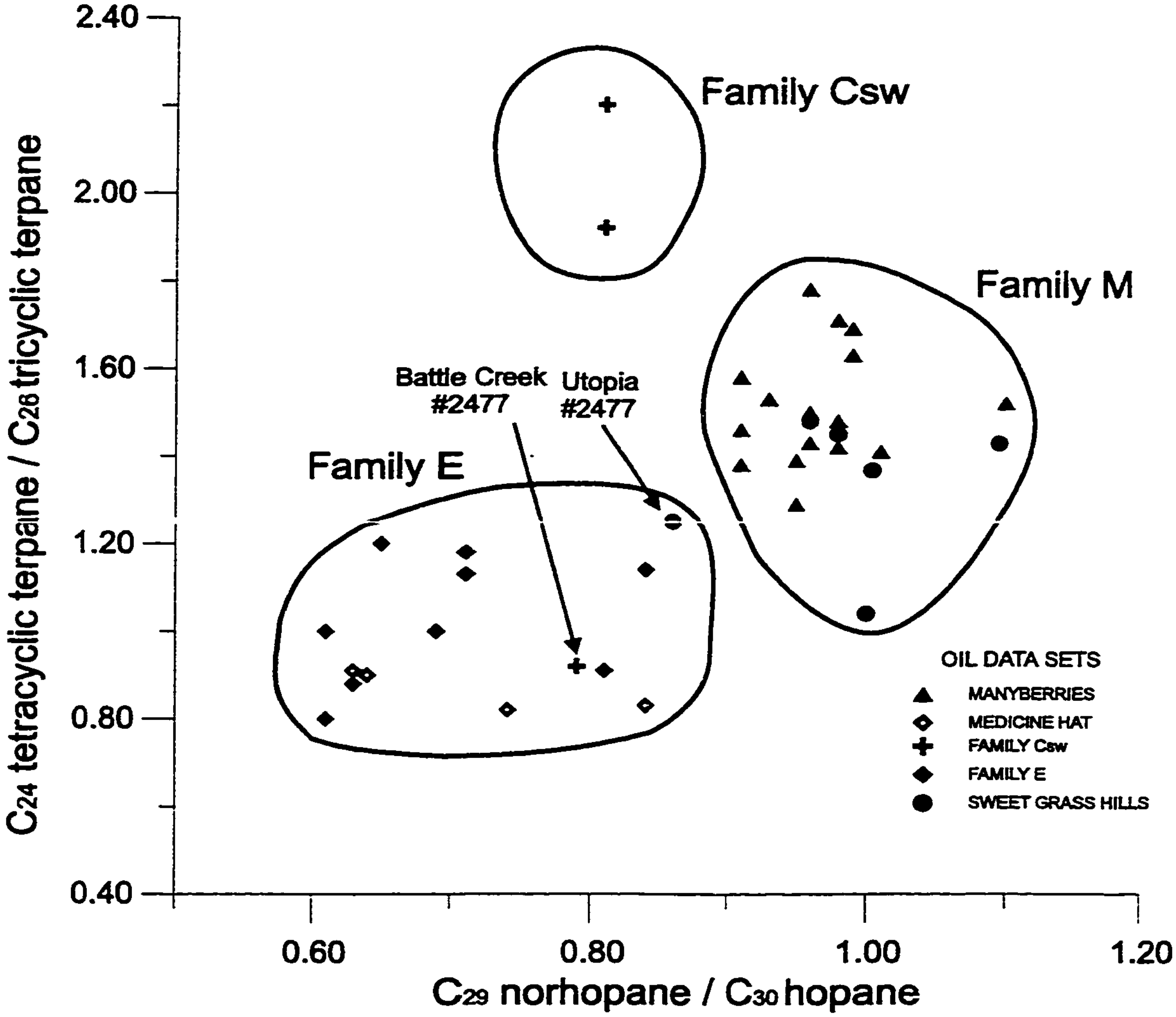


Figure 45. A cross-plot of C_{24} tetracyclic terpane/C_{26} tricyclic terpane versus C_{29} norhopane /C_{30} hopane for established oil families from southern Alberta (Riediger et al., 1997B), southwestern Saskatchewan (Osadetz et al., 1994), and Medicine Hat. Sweetgrass hills oil data set is from Black Butte, Whitlash, Fred and George Creek and Utopia oil fields.

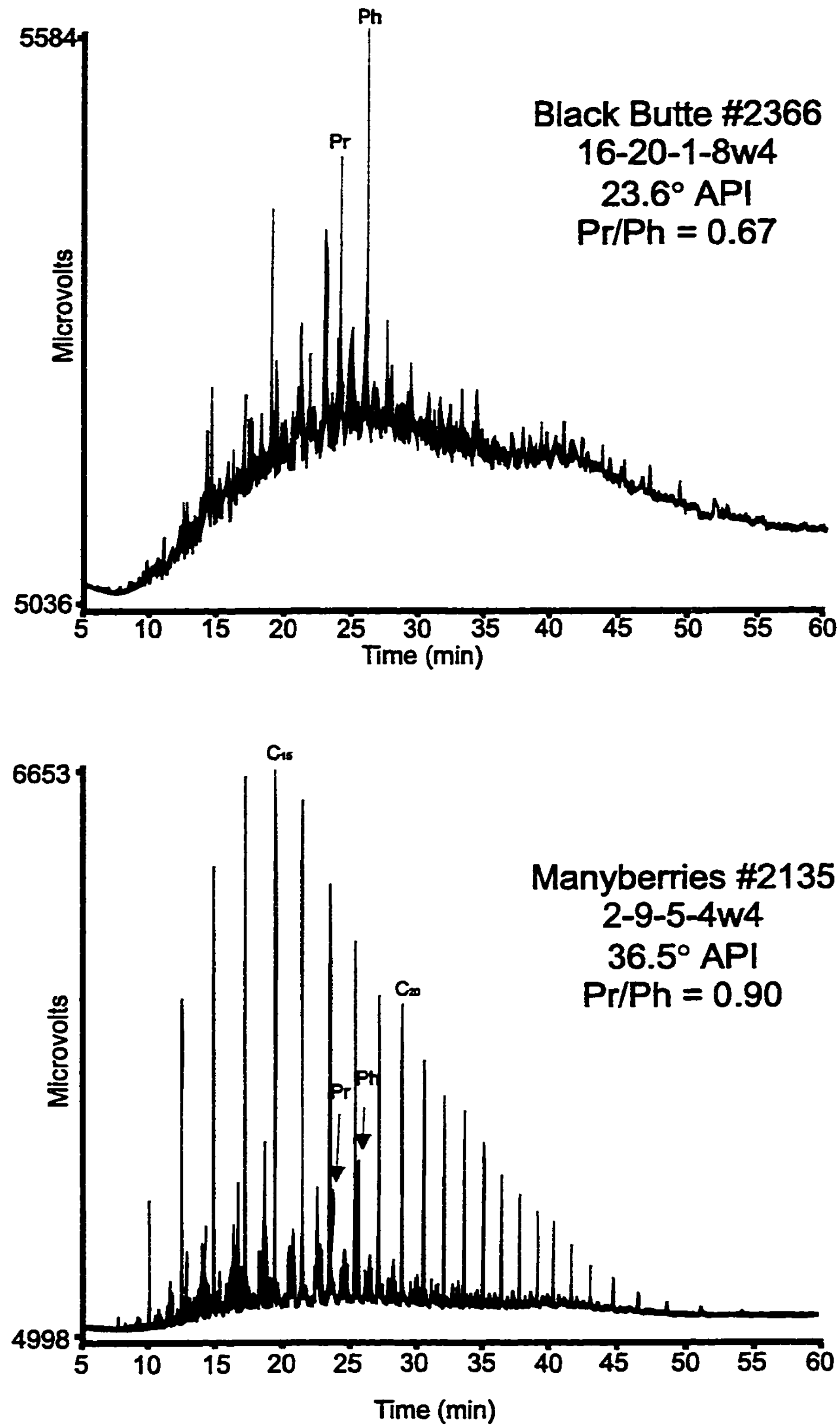


Figure 46. A comparison of saturate fraction C_{15+} gas chromatographs for oil samples from Manyberries (sample #2135) and Black Butte (sample #2365) oil fields. Pr=Pristane; Ph=Phytane.

hump and decreased abundance of C_{15} to C_{20} n-alkanes. These characteristics indicate that the Black Butte oils are biodegraded Family M oils relative to the Manyberries oil sample, which shows no development of a UCM hump (Figure 46).

7.2 Geochemical comparison of Family M and other oil families

Family M oils exhibits little similarity in bulk geochemical and biomarker characteristics to other established oil families in the region (Families E and Csw). Generally, saturate/aromatic ratios for Family E and Family Csw are greater than 1.0 (Figure 43; Table 11), pristane/phytane ratios for Family E, and Family Csw generally do not exceed 0.8 (Figure 43;Table 11), C_{23}/C_{30}h ratios are less than 1.0 for both Family E and Csw, C_{27} dia/reg ratio is greater than 1.0 for Family E and less than 1.0 for Family Csw (Figure 44; Table 11). C_{24}tet/C_{26} tri ratios for Family Csw are generally ~2.0 whereas Family E range from 0.8 to 1.1 (Figure 45; Table 11). C_{29}/C_{30} ratios for Family E, and Csw are generally less than 0.8 (Table 11). C_{21}/C_{29} ratios for Family Csw and Family E are less then 1.0 and C_{35}/C_{34} homohopane ratios are generally greater than or equal to 1.0.

In summary, the Family E oils of southern Alberta and Family Csw oils of southwestern Saskatchewan are not similar in geochemical characteristics to Family M oils of Manyberries and the Sweet Grass Hills area (Table 11). The Family E oils are correlated to the Exshaw Formation in southern Alberta (Riediger et al., 1997B)(Table 11) and the Family Csw oils are correlated to the Lodgepole Formation in central Williston Basin (Osadetz et al., 1994)(Table 11).

Table 11. Bulk geochemical and biomarker characteristics of oil families in regional study area

	Characteristics	Family M	Family Csw	Family E
	S/A	> 1.3	< 1.0	< 1.0
	Pr/Ph	> 0.7	< 0.6	< 0.8
TERPANES	C_{23}/C_{30} H	> 1.0	< 0.5	< 0.6
	C_{24} tet/C_{26} tri	> 1.3	~ 2.0	< 1.2
	C_{29}/C_{30}	~ 1.0	> 0.8	< 0.8
	C_{35}/C_{34}	> 1.1	> 1.0	>1.0
STERANES	C_{21}/C_{29}	> 1.5	< 0.7	< 0.8
	C_{27} dia/reg	> 1.7	< 0.7	>1.0
	C_{28}/C_{29}	~ 0.43	~0.4	~0.46

8. HYDROCARBON MIGRATION IN THE MANYBERRIES AREA AND SURROUNDING REGION

In general, during the process of filling a clastic reservoir with hydrocarbons, oil will migrate in successive fronts (Larter et al., 1991; England, 1994; Larter and Aplin, 1995). Early generated oil will fill the structurally highest area of a reservoir and over time more mature oil will be trapped down-dip of the earlier generated oil. Thus oils generated during later stages of catagenesis will be trapped closest to the source rock. The resulting trend in thermal maturity along an oil migration fairway has therefore been used to indicate migration direction and distances (England, 1994).

Considering that, (A) the Family M oils are only found in southeastern Alberta, (B) no hydrocarbon source rocks of Upper Devonian to Lower Mississippian age from the Alberta Basin correlate to Family M oils (Riediger et al., 1997B; Martin Fowler, personal comm.) and (C) the existence of the Sweetgrass Arch as a structural high during the early Eocene, it is suggested here that the Family M oils must have originated from mature Upper Devonian to Lower Mississippian sources in the Williston Basin and migrated into southeastern Alberta.

Using the methods of Larter et al. (1991), England (1994) and Larter and Aplin (1994), the assumption that the Family M oils have migrated from the Williston Basin, and reservoir geology, a generalized hydrocarbon migration model is postulated for the Manyberries area (section 8.1). With an understanding of oil migration of Family M oils within the Manyberries field, the other Family M oils (Whitlash, Black Butte and Fred and George Creek) will be examined to understand the regional hydrocarbon migration of Family M oils in southeastern Alberta (section 8.2).

8.1 Hydrocarbon Migration in the Manyberries Area

The predominant oil reservoir in the Manyberries area is the Lower Mannville Formation. Interpreted as fluvial channel sands, these deposits are thought to have been partially eroded prior to deposition of the Upper Mannville (Figure 25). Following this period of erosion, Upper Mannville lithic sands were deposited and in-filled pre-existing topographic lows and developed the hydrocarbon trapping mechanism for the area (Figure 25). Structural fabric in the area indicates a north-northwest/south-southeast striking and eastward dipping reservoir unit with a major structural anomaly centered over section 8, township 6, range 4W4 (Figure 33). This feature is located down-dip of the Manyberries oil accumulation and may represent the major factor behind oil accumulation in the area.

With the reservoir geology in mind, thermal maturity sensitive biomarkers can be used to delineate an overall filling direction for the Manyberries field. Using a cross-plot of C_{27} dia/reg and Ts/Tm (Figure 47), two oil groups of differing thermal maturity are delineated for the Manyberries field and are designated here as M1 and M2. The lower thermal maturity oils are the M1 oils, from B, JJ, and VV pools (Figure 47, 48). The higher maturity oils are the M2 oils, from KK, HH, II, LL and C pools (Figure 47, 48). The difference in maturity indicates a trend of increasing thermal maturity towards the southern and eastern part of the Manyberries oil field (Figure 48). This trend runs sub-parallel to the northeast dipping structure of the Lower Mannville Formation reservoirs, with the most mature oils of group M2 (HH and II pool) found in the structurally highest reservoirs (Figure 48). Most documented examples of hydrocarbon migration and accumulation show a maturity profile that increases down-dip, towards a mature source rock interval (England, 1994), however the Manyberries oils do not show this trend. The maturity data suggests a roughly southeast trending increase in thermal maturity indicating a northwesterly trending oil migration direction. This trend crosscuts Lower Mannville channel trends, the most porous and permeable units in the area. Considering that oil migration generally follows the most porous and permeable conduit, hydrocarbon

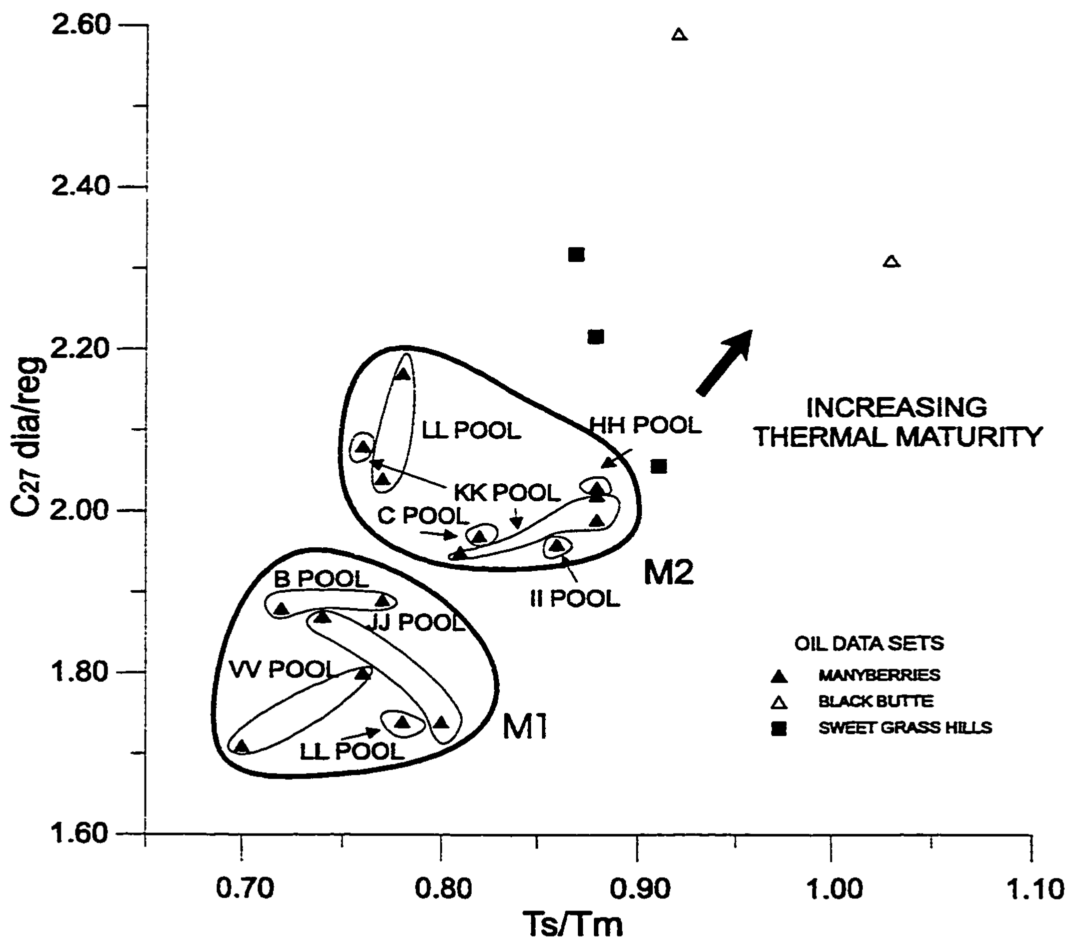


Figure 47. A cross plot of C_{27} diasterane/regular steranes versus Ts/Tm (maturity parameters) for all Family M oils. Two thermal maturity groups for the Manyberries oils are designated as M1 and M2.

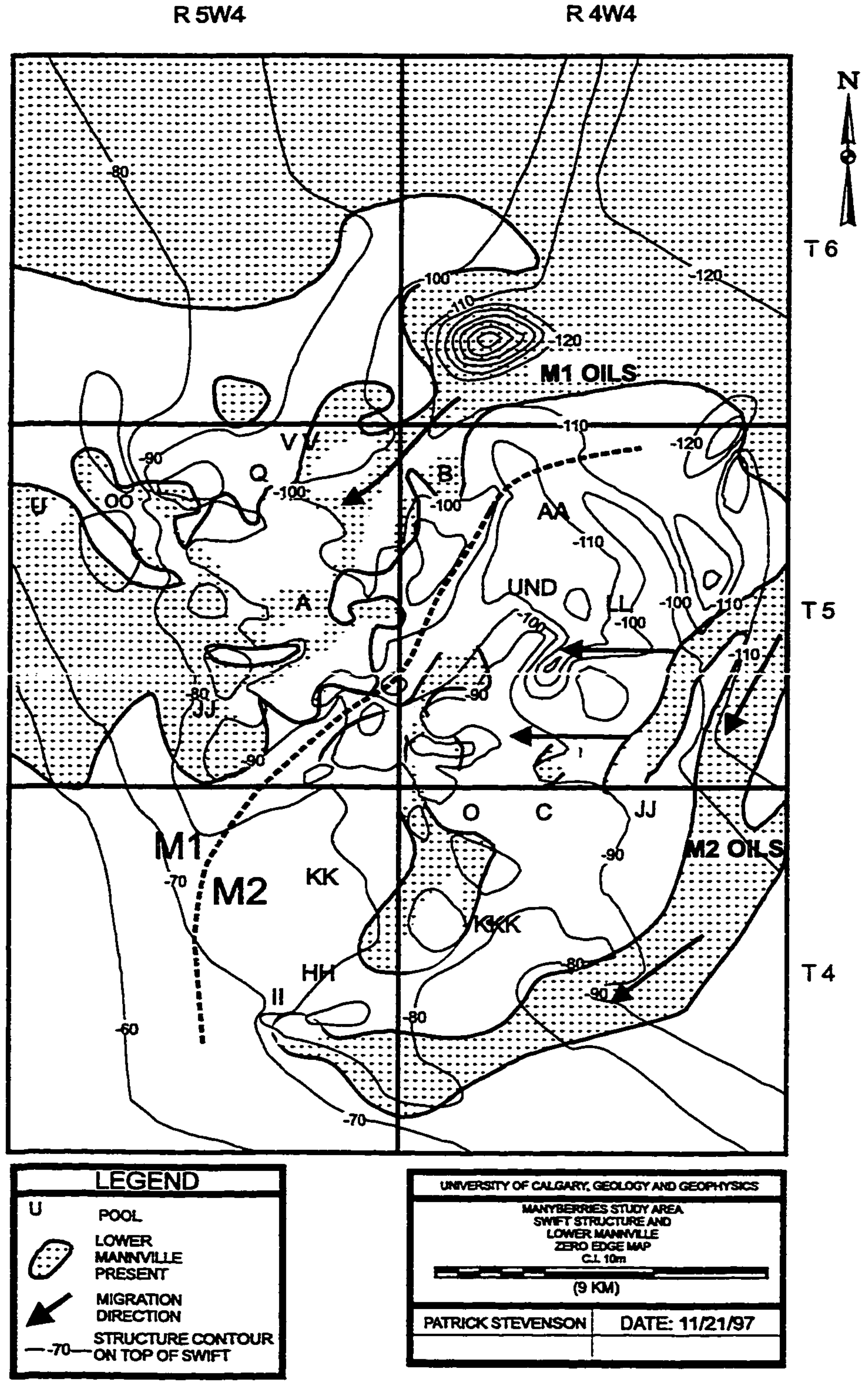


Figure 48. Possible migration pathways for oil in the Manyberries area. Lower Mannville present indicated by speckled pattern and Swift structure in black. Black arrows indicate potential migration pathways for oils in the area.

migration would preferentially follow Lower Mannville channel trends rather than migrating through less permeable Swift or Upper Mannville units(England,1994)(Figure 48).

Thus, the most likely possibility for hydrocarbon migration in the Manyberries area is oil migrated into the area from the east/northeast following Lower Mannville channel trends. Then following these channel trends M1 oils filled pools in the northernmost part of the Manyberries field to spill point (-110 structure contour on the top of the Swift Formation; Figure 48) and then the later generated M2 oils migrated into the eastern north-south directed channel filling pools in the southern/eastern part of the Manyberries field.

8.1.1 Possible scenario for hydrocarbon migration into the Manyberries area

Considering that the Family M oils were possibly generated by a thermally mature Upper Devonian to Lower Mississippian source in the Williston Basin, these oils have migrated a great lateral distance, through a thick package of Mississippian and Jurassic section to reach the Upper Jurassic and Lower Cretaceous reservoirs in the Manyberries area (Figure 49). This migration pathway is problematic given that the Lower Mississippian and Middle Jurassic strata near the Manyberries area are up to 300 m thick and as such would represent a significant barrier to vertical flow from the Devonian. Late Laramide faults have been documented in the Sweetgrass Arch area (Hayes, 1982; Peterson, 1988; Ross et al., 1994; Lopez, 1995) and the elliptical structural feature documented in section 5.4 (see Figure 48), may be related to fault activity in the area. This structural feature may have fractured Mississippian and Jurassic strata, allowing for the vertical migration of hydrocarbons into the area. Lies (1996) documents the possible vertical migration of fluids from the Paleozoic into Lower Cretaceous reservoirs based on regional water potential mapping in the Manyberries field. Bachu and Hitchon, (1996) also document vertical migration of fluids from Mississippian into Lower Cretaceous strata in the extreme southwestern corner of Saskatchewan.

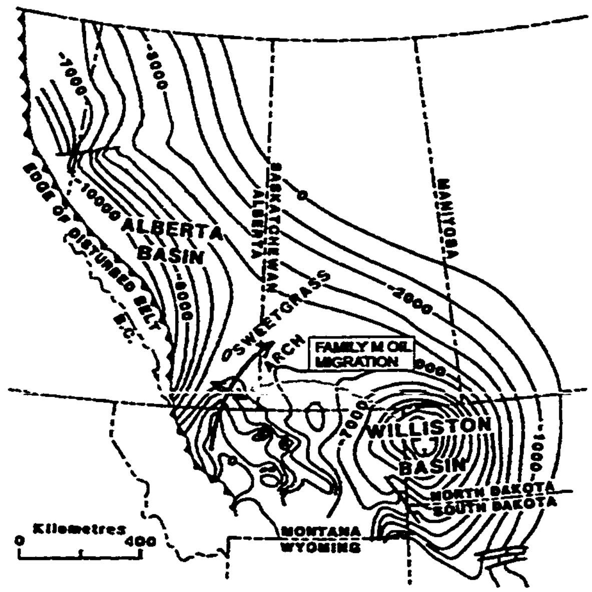


Figure 49. Potential Family M hydrocarbon migration pathway from central Williston basin into southeastern Alberta. Structure map on top of basement (C. I. 1000 ft; modified from Podruski, 1988).

Considering this documentation of the vertical movement of Paleozoic fluids into Mesozoic reservoirs it is proposed that a similar situation may have occurred in or near the Manyberries area. Thus, based on this documentation and the biomarker signature of Family M oils, it is suggested here that regional hydrocarbon migration out of the Williston Basin followed a conduit in the Paleozoic (Figure 49) and then accessed the Lower Mannville near the Manyberries area via normal faults which cut into the Jurassic and Lower Cretaceous section.

8.2 Family M oil migration in southeastern Alberta

The Family M oils from Manyberries, Black Butte, Whitlash and Fred and George Creek show an observed maturity increase with lower maturity Family M oils from Manyberries to medium maturity Family M oils from Fred and George Creek and Whitlash oil fields to possibly higher maturity Family M oils from Black Butte (Figure 50).

The maturity trend for the Family M oils in the oil fields of the Sweet Grass Hills area (Whitlash, Fred and George Creek and Black Butte) shows a general increase in thermal maturity down-dip which is in general agreement with the hydrocarbon migration model of England (1994). The Black Butte oils have been biodegraded, which can affect biomarker thermal maturity parameters (C_{29} S/R, Ts/Tm and C_{27} dia/reg) at a biodegradation level of 6 or more (Table 9). The oil from the Black Butte area has only been biodegraded to a level of 4 to 5 and thus the compounds used as thermal maturity parameters would be unbiodegraded. Thus, the thermal maturity trend for oils from the Sweetgrass Hills area indicates oil migration likely came from the northeast, following the general structural trend out of the Williston Basin (Figure 49). Based on present day structural trends in southeastern Alberta, and the suggestion that the likely source of the Family M oils is located in the Williston Basin to the east/southeast of the Manyberries area, one would expect the Manyberries oils to be more mature than Sweet Grass Hills and Black Butte oils. However, the opposite trend is observed. The reasons behind this observed discrepancy is unknown but may be due to a number of factors including the timing of fault activity and uplift in the area, and the regional migration conduit for Family M oils.

8.2.1 Possible scenario for Family M oil migration into Sweet Grass Hills area

Considering the discontinuous nature of the Lower Mannville Formation in the Manyberries area it is thought that this unit could not be the regional migration conduit for moving Family M oils into the Sweet Grass Hills area (Figure 50). The more likely conduit for regional oil migration is within the underlying Paleozoic strata.

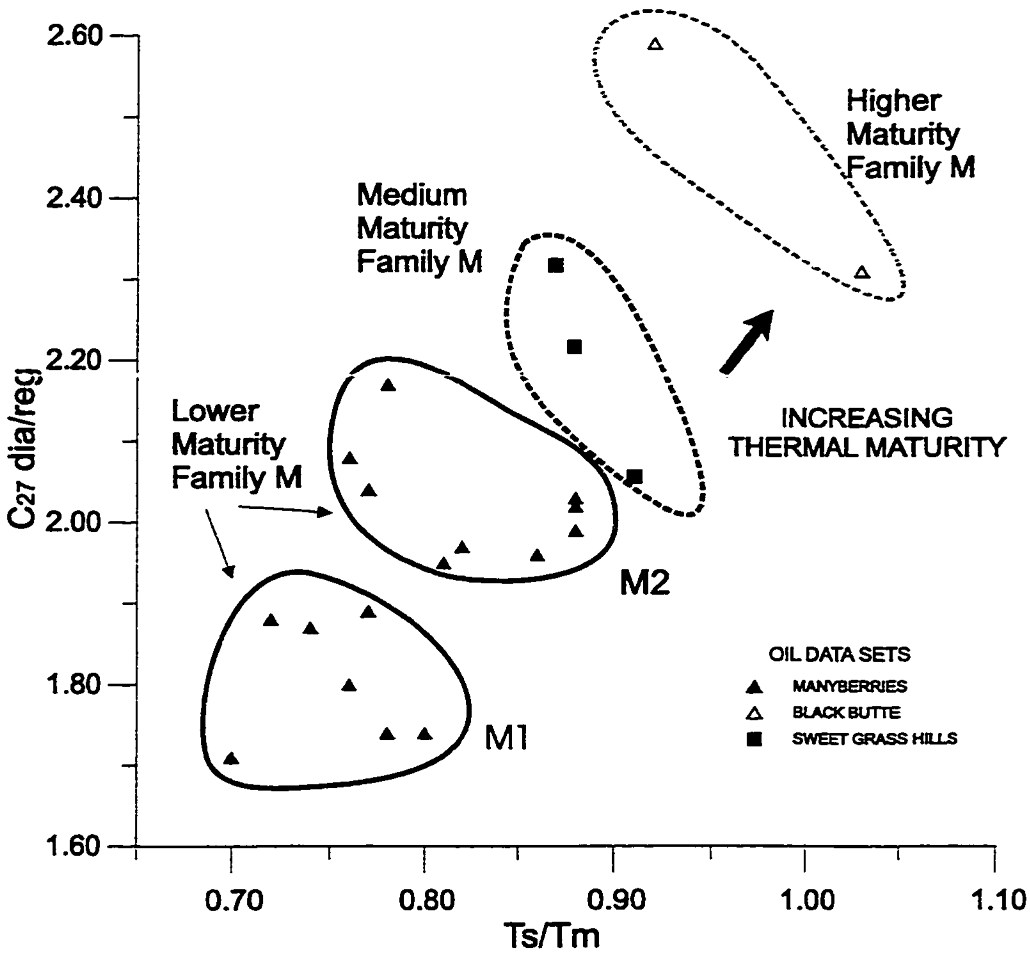


Figure 50. A cross plot of C_{27} diasterane/regular steranes versus Ts/Tm (maturity biomarker parameters) for Family M oils of Montana (Whitlash and Fred and George Creek) and southeastern Alberta (Manyberries and Black Butte).

Gussow (1955) speculated that oil migration in the area followed the weathered top of the Mississippian and moved towards the Sweet Grass Hills area out of the Williston Basin, but said nothing of how oil would get out of the Mississippian into the Lower Cretaceous. Northwest and northeast trending basement faults associated with Sweet Grass Hills intrusives have been interpreted in the subsurface by Grauman (1985) and Thompson (1985), Ross et al. (1994), and at the surface by Lopez (1995). These faults could potentially fracture strata overlying Paleozoic oil conduits enough to allow for the upward migration of oils and thus charge Upper Jurassic to Lower Cretaceous units. Further work is needed to establish the ability of Paleozoic units to act as the conduit for oil migration and to understand the controls on the distribution of Family M oils.

In summary, it is suggested that the Family M oils were most likely generated from the central Williston Basin (Figures 39; 49), then migrated up-dip in Paleozoic strata towards the Sweet Grass Hills area were the oils accessed Upper Jurassic to Lower Cretaceous reservoirs in the Sweet Grass Hills area through faults in the area (Figure 51).

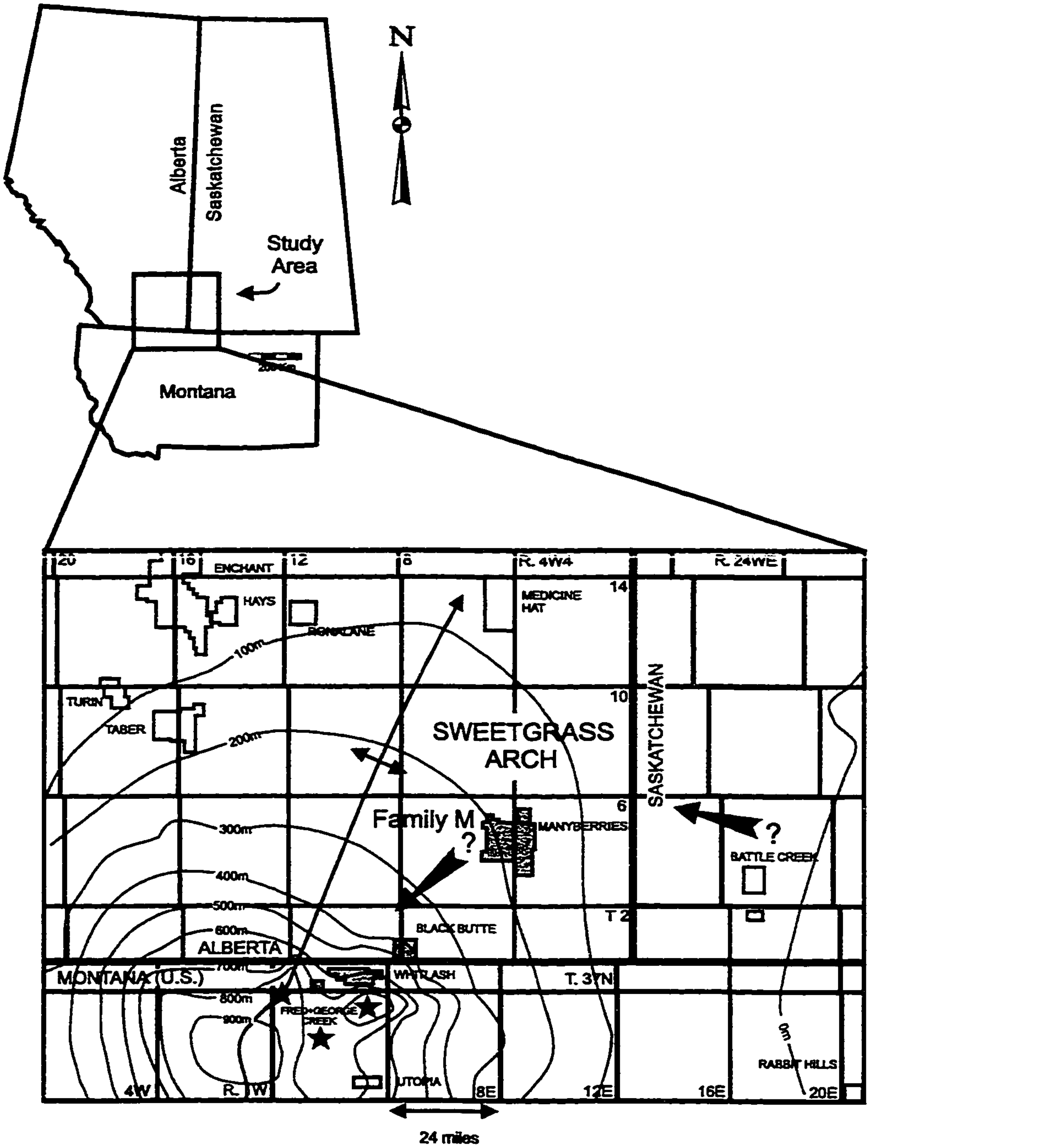


Figure 51. Structure map on Base of Fish Scales horizon (from sea level; C. I. 100 m)(Figure modified from Hayes, 1982; and Wright et al., 1994). Arrows indicate possible migration direction for Family M oils.

9. HYDROCARBON EXPLORATION POTENTIAL AND FUTURE WORK

The exploration for Family M oils should be considered for the southeastern corner of Alberta. The Lower Cretaceous Lower Mannville Formation and the underlying Paleozoic horizons should be considered as stratigraphic targets.

Stratigraphic traps for Family M oils in the Lower Mannville are proven from the Manyberries area. A southwesterly directed oil migration route for the Family M oils in southeastern Alberta has been shown from biomarker work. Thus, the Lower Mannville should be considered as an attractive target to explore for more Family M oils. This consideration should also take into account the development of structures near other potential Lower Mannville reservoirs that would allow for the vertical migration of Family M oils from the Paleozoic.

At present without a full understanding of the actual source rock interval and no identified Family M pools in the Paleozoic of southeastern Alberta, more work needs to be done to constrain potential source rock intervals, porosity development in these units and migration conduits for Family M oils in the area. Based on the ideas presented here and future work, Paleozoic units in southeastern Alberta could prove to be an attractive target for the exploration of Family M oils.

10. SUMMARY

In summary, the principal oil reservoir unit in the Manyberries area is the Lower Mannville Formation. This unit unconformably overlies the Swift Formation and is composed of a fine to medium-grained, massive to low angle crossbedded, quartzose sandstone grading upwards to a muddy, poorly sorted, rooted, silty sandstone and is interpreted to represent a braided river deposit. The Lower Mannville ranges in thickness from 0 to 25 metres and is characterized by a northeast-southwest to east-west trending lenticular morphology. Generally, the Lower Mannville Formation averages 17 % porosity and 214 mD permeability, indicating good oil reservoir potential. Post Lower Mannville erosion has truncated these deposits on the west and north side of the Manyberries field juxtaposing low permeability Upper Mannville Formation deposits and creating the hydrocarbon trapping mechanism in the area.

The oils from the Manyberries field have similar organic geochemical characteristics and are classified as a single oil family, Family M. The Family M oils are unlike any established oil family in southern Alberta or southwestern Saskatchewan. No oil source-rock correlation could be determined for the Family M oils, but based on biomarker characteristics of these oils, the hydrocarbon source rock is likely a thermally mature (peak oil generation) carbonate of Upper Devonian to Lower Mississippian age. Due to the thermal maturity of the Family M oils and the existence of the Sweetgrass Arch or a related structural high near the Manyberries area during the time of generation (early Tertiary), the Family M oils were likely generated in central Williston Basin and migrated laterally to southeastern Alberta. These oils then accessed Lower Mannville channel trends via faults that cut underlying Mississippian and Jurassic units, and penetrated the Upper Devonian. The Family M oils then migrated up-structure along these Lower Mannville channel trends and accumulated against Upper Mannville lithic channel sands in the Manyberries area.

Black Butte, Fred and George Creek and Whitlash oil fields, situated on the northeastern flank of the Sweet Grass Hills, also belong to Family M. Using biomarker maturity parameters, Family M oils from the Manyberries area were determined to have attained a lower level of thermal maturity relative to the other Family M oils in the area and their depth of production. Further work is needed to constrain oil migration models in the area. Based on geological work and initial biomarker work from southeastern Alberta it is thought that Family M oils migrated from central Williston Basin through the Paleozoic section following the regional structural fabric and then accessed the Upper Jurassic to Lower Cretaceous reservoirs in southeastern Alberta through faults that have fractured underlying Paleozoic and Middle Jurassic units.

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APPENDIX 1: CORES EXAMINED IN STUDY

LEGEND

LITHOLOGY

- SANDSTONE
- MUDSTONE
- SILTY-SANDSTONE
- MATRIX SUPPORTED CONGLOMERATE
- CALCAREOUS MUDSTONE

PHYSICAL STRUCTURES

- LENTICULAR BEDDING
- RIP-UP CLASTS
- LOW-ANGLE TABULAR BEDDED
- PLANAR BEDDING
- FAULT PLANE
- TROUGH CROSS BEDDED
- FLASER BEDDING
- Palsl PALESOL HORIZON
- WAVY BEDDED

ACCESSORY COMPONENTS

Kaol	KAOLINITE	Gl	GLAUCONITE		CARBONACEOUS MATERIAL
Lth	LITHIC	Mc	MICA		
Sid	SIDERITE		CHERTY		
	ROOTLETS	Py	PYRITE		

ICHNOFOSSILS

- PLANOLITES

SAMEDAN AO&G MANYBERRIES 6-30-4-4

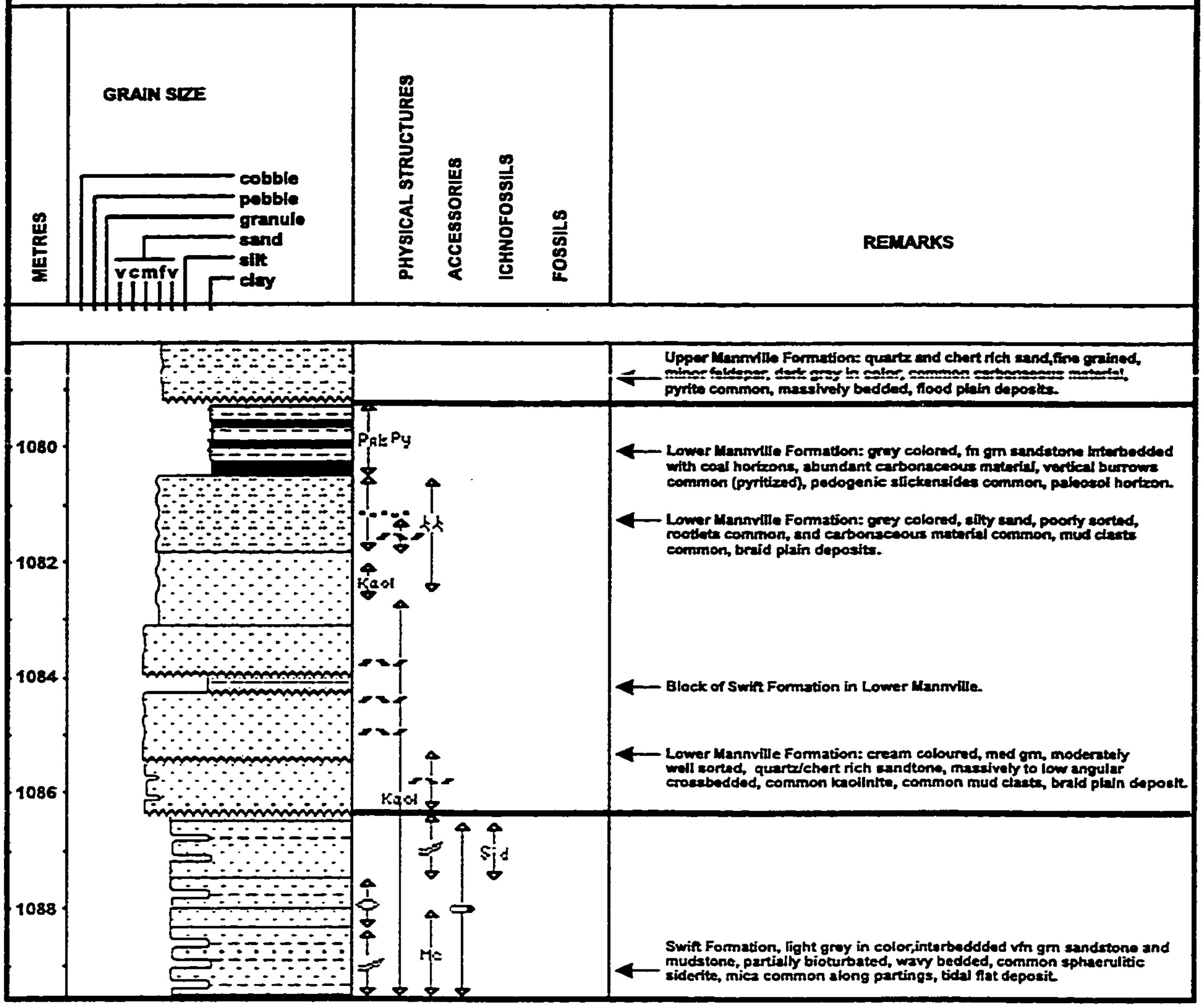
6-30-4-4w4

Date logged: July 29, 1997

Logged by: Patrick Stevenson

Ground: 992.4m KB: 995.9m

Remarks: Lower Mannville/ Swift Formation weathered horizon, slabbed no core analysis



SAMEDAN OAKWOOD MANYBERRIES 6-32-4-4

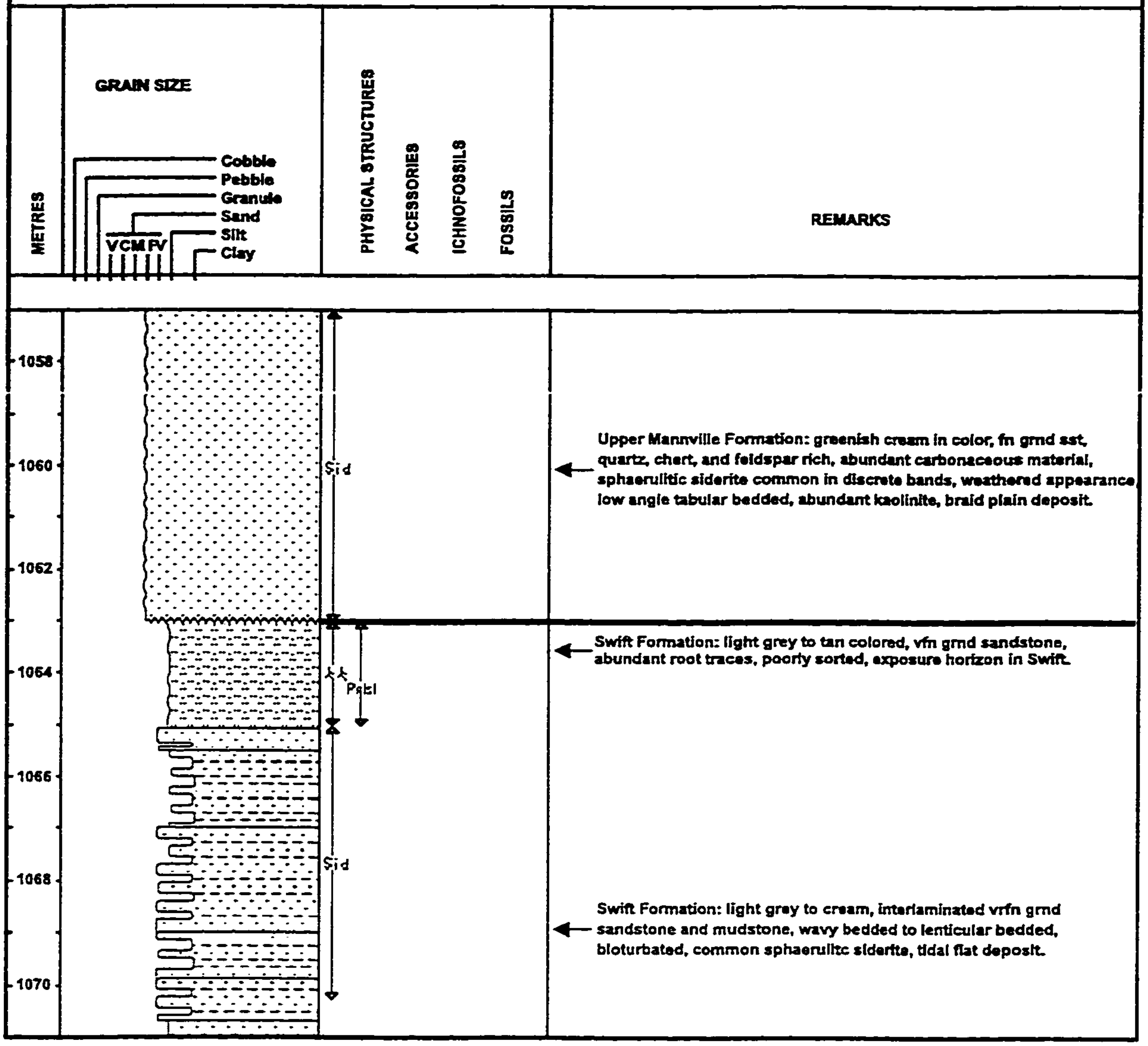
6-32-4-4w4

Date logged: March 11, 1996

Logged by: Patrick Stevenson

Ground: 976.60 M **KB:** 972.40 M

Remarks: Swift/Upper Mannville formation



HOME MANYBERRIES 14-11-4-5

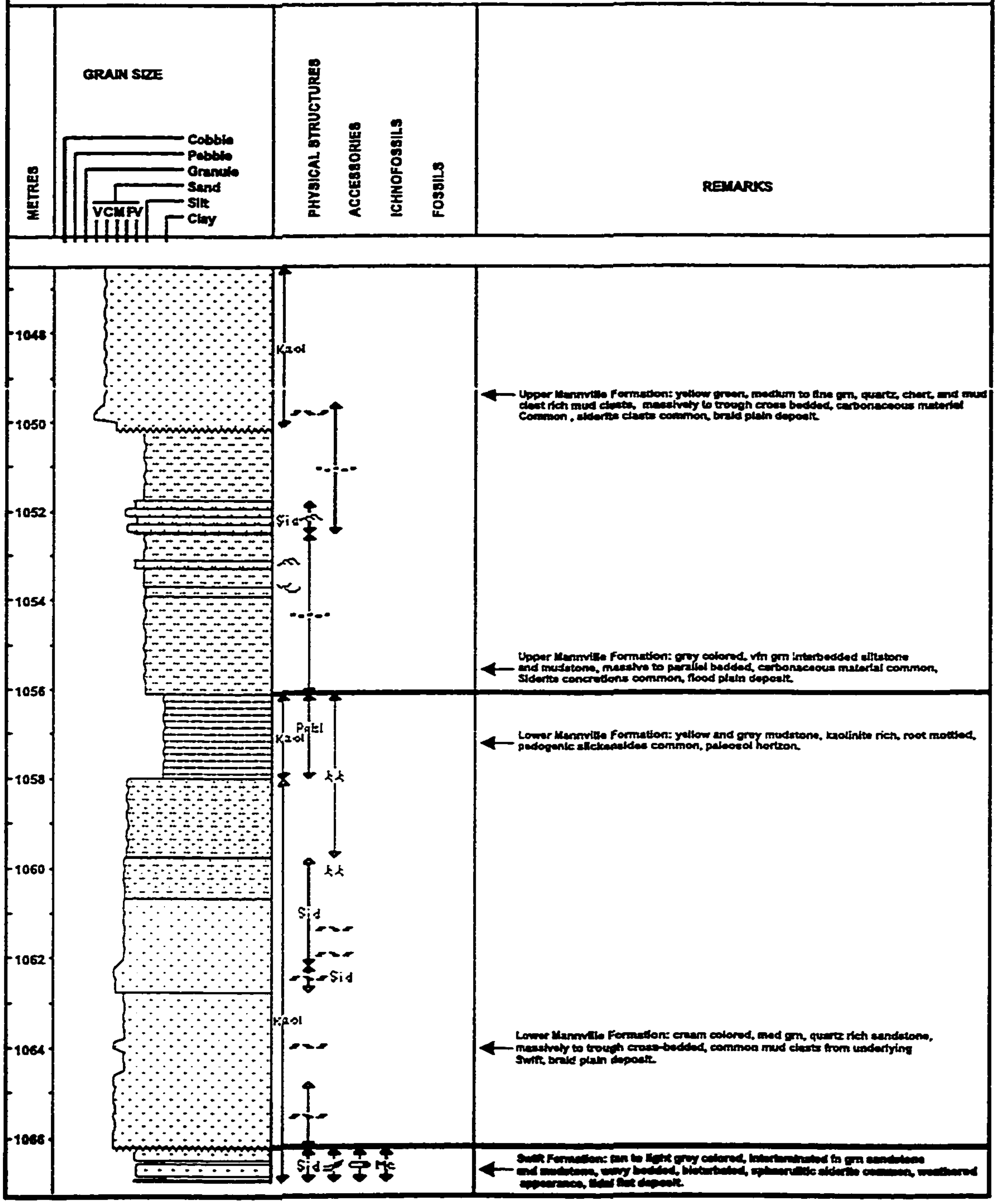
14-11-4-5w4

Date logged: July 29, 1997

Logged by: Patrick Stevenson

Ground: 1052.80 M   **KB:** 1056.20 M

Remarks: Upper Mannville succession with underlying Lower Mannville/Swift, slabbed core



HOME CMG MANYBERRIES 2-3-5-4

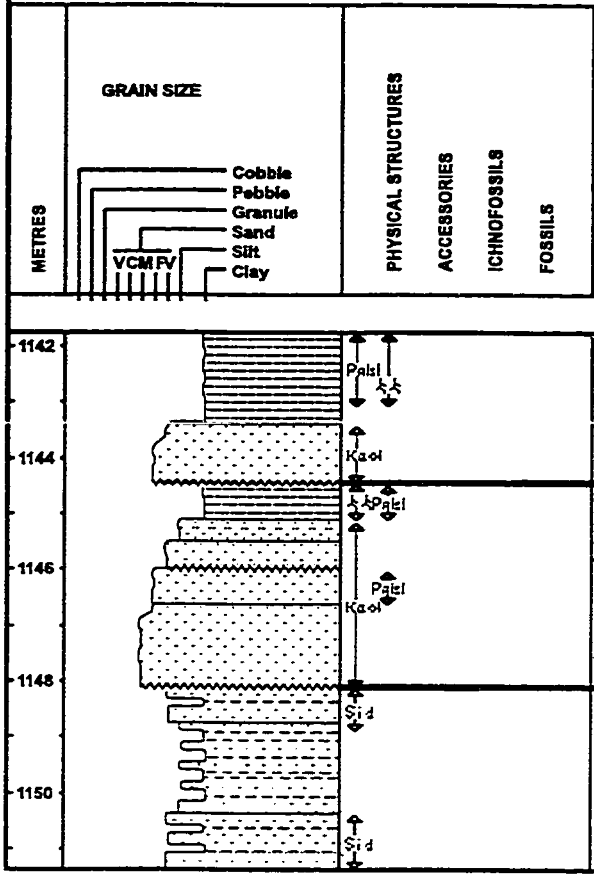
2-3-5-4w4

Date logged: March 7, 1996

Logged by: Patrick Stevenson

Ground: 1055.20 M   **KB:** 1051.90 M

Remarks: Lower Mannville Formation



REMARKS

Upper Mannville Formation: green mottled mudstone (smectitic), with common root traces, pedogenic slickensides common, flood plain deposit/ paleosol.

Upper Mannville Formation: grey colored, fine grnd sandstone, quartz rich, trough cross-bedded, dirty appearance, root mottled appearance, common mica

Lower Mannville Formation: dark grey colored, fn grnd sandstone, abundant, carbonaceous material, massively bedded, common rootlets, exposure surface.

Lower Mannville Formation: cream colored, med grnd quartz/chert rich sandstone, low angle cross-bedded, oil stained, common kaolinite, braid plain deposit.

Swift Formation: light grey to tan, interlaminated fn grnd sandstone, with mud flashers, common sphaerulitic siderite, leached appearance, tidal flat deposit.

Swift Formation: light grey to tan in color, vfn grnd sandstone interlaminated with mudstone, lenticular bedded, little bioturbation, common sphaerulitic siderite (>1mm), poor core recovery (brecciated), mica common along mudstone partings.

HOME MANYBERRIES 8-4-5-4

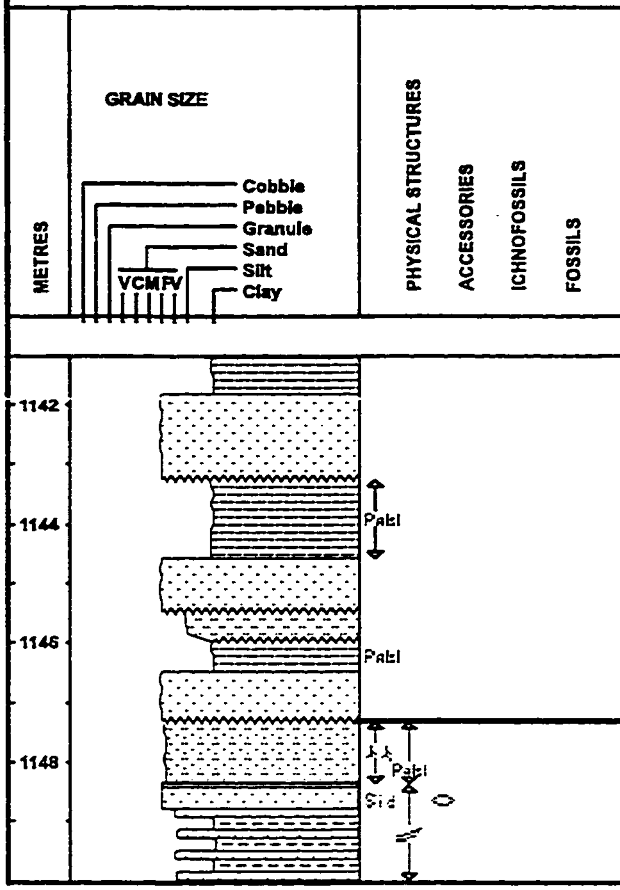
8-4-5-4w4

Date logged: March 11, 1996

Logged by: Patrick Stevenson

Ground: 1053.10 M **KB:** 1048.80 M

Remarks: Swift/Upper Mannville formation



REMARKS

- Upper Mannville Formation: root mottled, green, smectitic mudstone, flood plain/exposure horizon.
- Upper Mannville Formation: dark grey to black, fn grn sst, quartz/chert rich minor feldspar, parallel bedded, no mica, Flood plain deposit.
- Upper Mannville Formation: mottled green smectitic mudstone, pedogenic slickensides, flood plain/exposure Horizon.
- Upper Mannville Formation: fn grn sand, low angle tabular bedded, quartz and carbonaceous material rich, common Mica, flood plain deposit.
- Swift Formation: light grey to tan in color, vfn grnd sst interlaminated with mudstone, root traces common, weathered appearance, common sphaerulitic siderite, tidal flat deposit.

JOSS CRAIGOWER 10-4-5-4

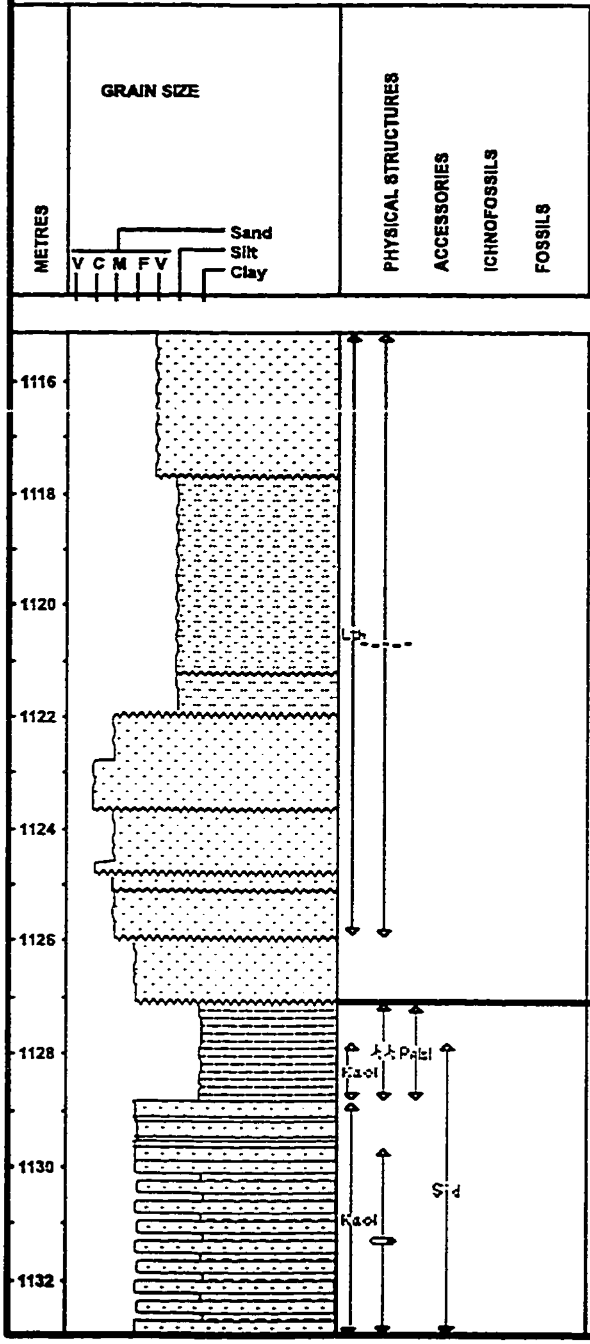
10-4-5-4w4

Date logged: March 7, 1996

Logged by: Patrick Stevenson

Ground: 1028.40 M   **KB:** 1031.75 M

Remarks: Upper Mannville Formation oil reservoir



REMARKS

Upper Mannville Formation, grey colored, fn grnd sands, quartz/chert rich with common mica and feldspars, common sphaerulitic siderite, thin laminae of carbonaceous material, braid plain deposit.

Upper Mannville Formation: dark grey to green, finely laminated silt and vfn grn sands, qtz/cht rich sands, minor mica, multiple siderite concretion horizons (not illustrated), flood plain deposit.

Upper Mannville Formation: fine to med grnd sst, poorly sorted to moderately sorted, chert and kaolinite rich with common carbonaceous material, low angle planar bedded, braid plain deposits.

Upper Mannville Formation: brown colored, fn grained, quartz rich minor chert increasing in content upwards, oil producing horizon for LL pool in Manyberries area, reworked Swift.

Swift Formation: yellow claystone, pedogenic slickensides and root traces common, paleosol horizon.

Swift Formation: light grey to tan colored, interbedded vfn sands and muds, lenticular to wavy bedded, common to abundant sphaerulitic siderite most commonly found in bioturbation, highly bioturbated, tidal flat deposit.

ANDERSON ET AL MANYBERRIES 4-6-5-4

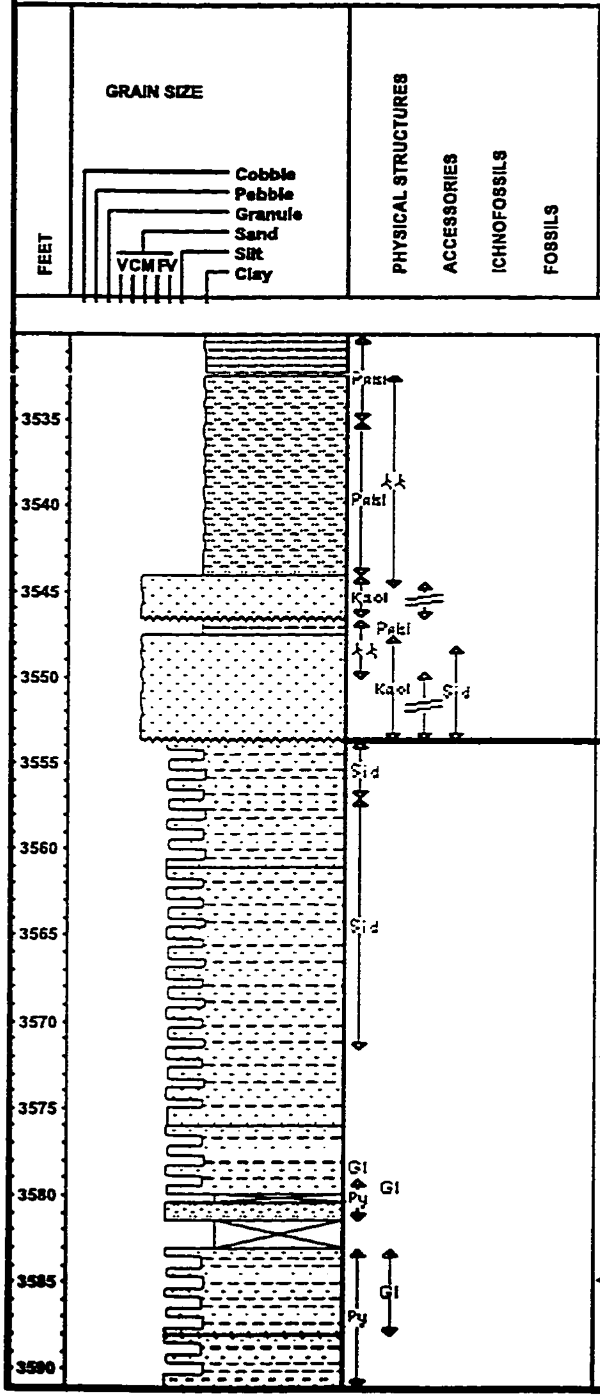
4-6-5-4w4

Date logged: February 15, 1996

Logged by: Patrick Stevenson

Ground: 3253.00 Ft KB: 3239.00 Ft

Remarks: Lower Mannville/Swift Formation



REMARKS

Lower Mannville Formation: grey colored, fine grn sandstone, poorly sorted, root mottled, kaolinite abundant, common pedogenic slickensides, abundant carbonaceous material, braid plain deposit.

Lower Mannville Formation: cream colored, quartz/chert rich sandstone, med grn, well sorted, kaolinite common, massively bedded to low angle cross-bedded, rare sphaerulitic siderite, braid plain deposit.

Swift Formation: light grey to tan in color, interbedded vfn grnd sand and muds, lenticular bedded, abundant bioturbation, size of sphaerulitic siderite increasing (.5 mm), tidal flat deposit/ exposure surface.

Swift Formation: light grey to tan in color, interbedded sandstone and mudstone, wavy bedded, common bioturbation, tidal flat deposit.

Swift Formation: dark grey to black colored, interbedded muds and vfn grnd sands, minor glauconite, wavy to lenticular bedded, bioturbation, tidal flat deposit.

ANDERSON ET AL MANYBERRIES 6-6-5-4

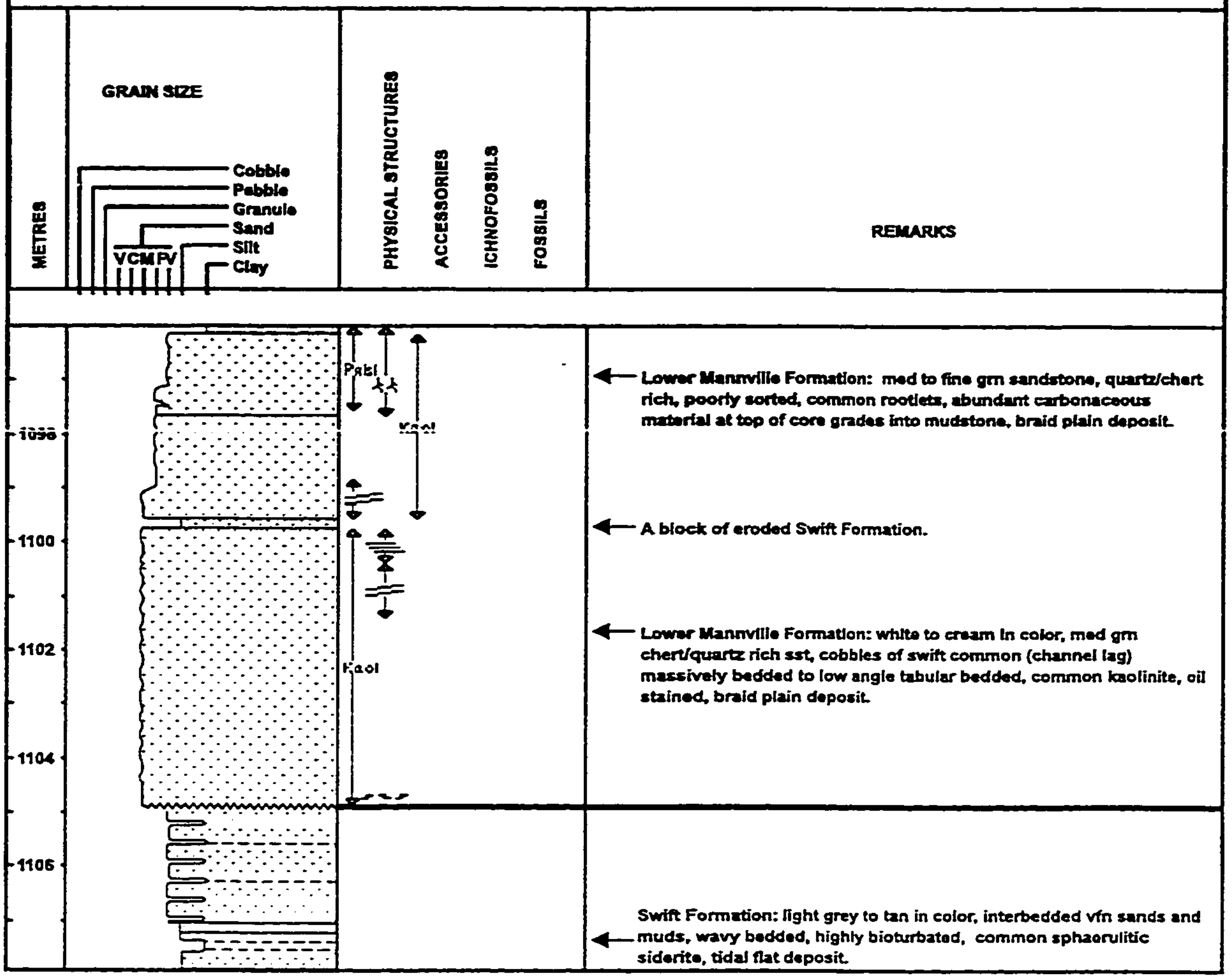
6-6-5-4w4

Date logged: February 14, 1996

Logged by: Patrick Stevenson

Ground: 1003.70 M   **KB:** 1007.90 M

Remarks: Lower Mannville/Swift Formation



TRI LINK ET AL MANYBERRIES 15-30-5-4

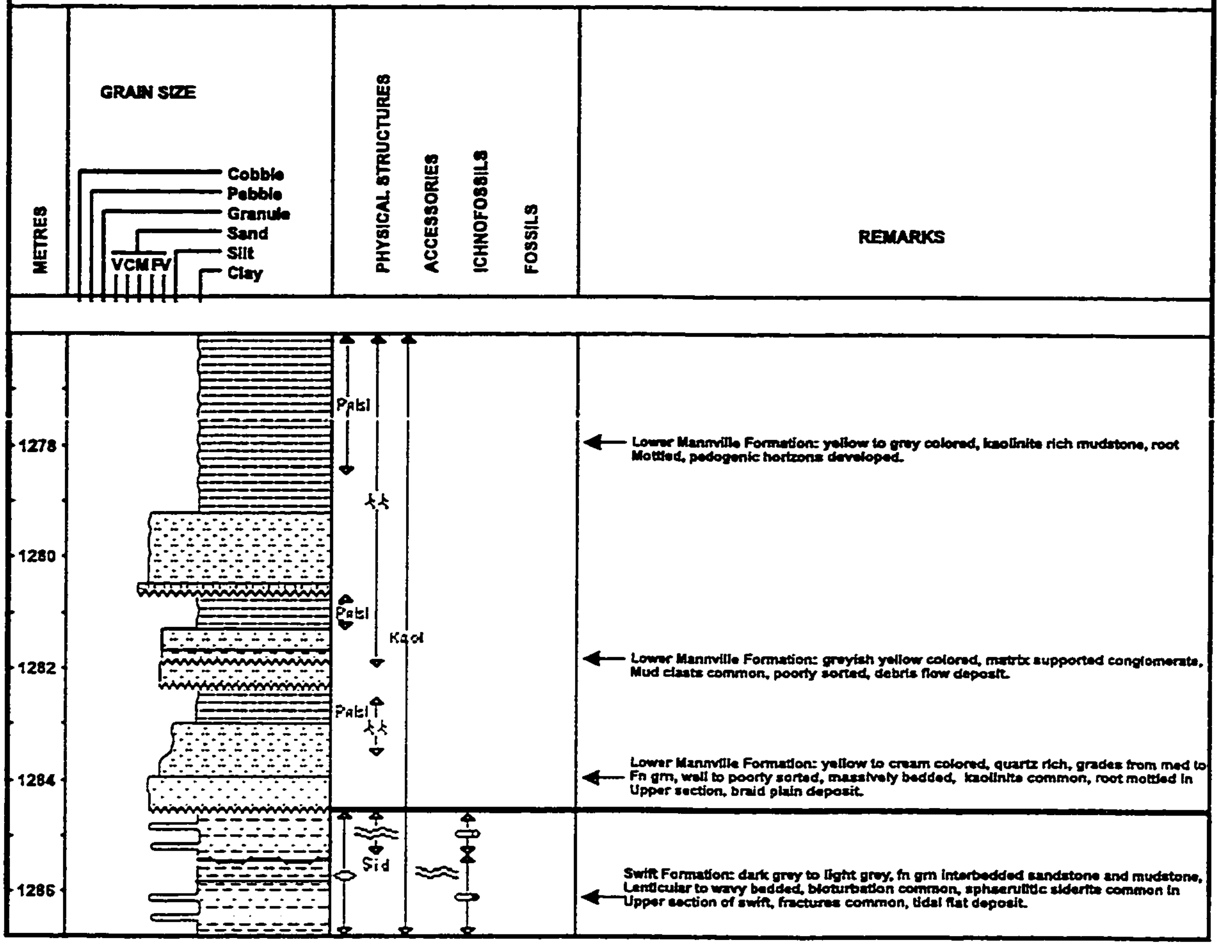
15-30-5-4w4

Date logged: June 19, 1997

Logged by: PATRICK STEVENSON

Ground: 1173.70 M **KB:** 1178.90 M

Remarks: Swift/Lower Mannville formation



LARIAT ET AL MANYBERRIES 4-31-5-4

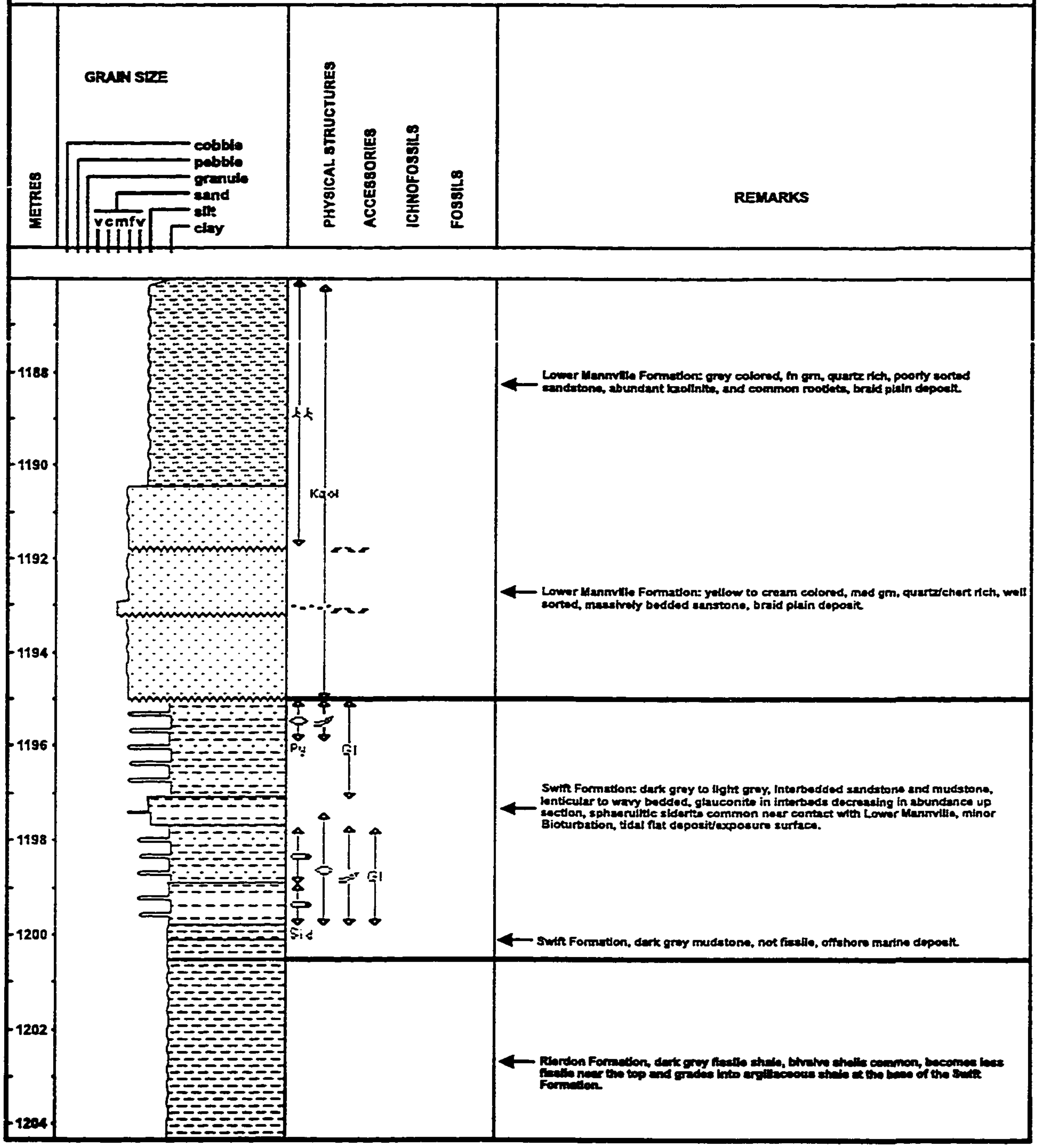
4-31-5-4w4

Date logged: July 24, 1997

Logged by: Patrick Stevenson

Ground: 1085.80 m KB: 1089.70 m

Remarks: Upper Rierdon to Lower Mannville formations, Slabbed, good core recovery except in reservoir interval



ANDERSON ET AL MANYBERRIES 4-1-5-5

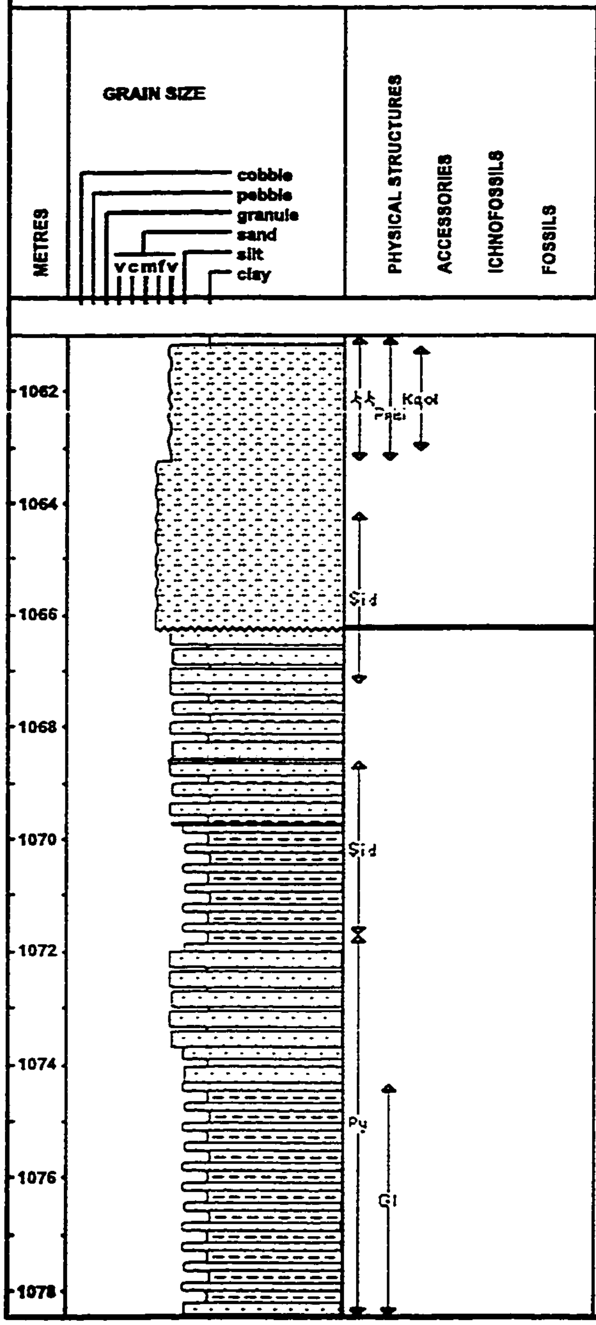
4-1-5-5w4

Date logged: March 7, 1996

Logged by: Patrick Stevenson

Ground: 977.50 m **KB:** 973.20 m

Remarks: Swift/Lower Mannville Formation



REMARKS

Lower Mannville Formation: dark grey to black, fn grn sandstone to claystone, common pedogenic slickensides, root traces, poor core recovery, possible paleosol horizon.

Lower Mannville Formation: grey, fn grnd sands, massively beddded, leached horizon, common detrital sphaerulitic siderite, root traces common, heavily burrowed, braid plain deposit.

Swift Formation: light grey to tan in color, interbiaminated vrfn grnd sands with mud flasers, root traces common, sphaerulitic siderite common (1mm in size), tidal flat deposit.

Swift Formation: light grey to tan, vfn grn sanstone interlaminated with mudstone, lenticular to wavy bedded, common biotubation, oil staining in sand lenses, tidal flat deposit.

Swift Formation: light grey to tan in color, vfn grn sands with mud flasers, moderately bioturbated, no glauconite, rare sphaerulitc Siderite, tidal flat deposit.

Swift Formation: dark grey to black interlaminated vfn grn sandstone and mudstone, lenticular bedded (sediment starved current ripples), minor bioturbation, rare glauconite and pyrite, mica common along mudstone partings, tidal flat deposit.

Swift Formation: dary grey to black interlaminated vfn grnd sandstone and mudstone, lenticular bedded, sediment starved current ripples, rare glauconite, rare bioturbation, tidal flat deposit.

HUBER WINTERSHALL MANYBERRIES

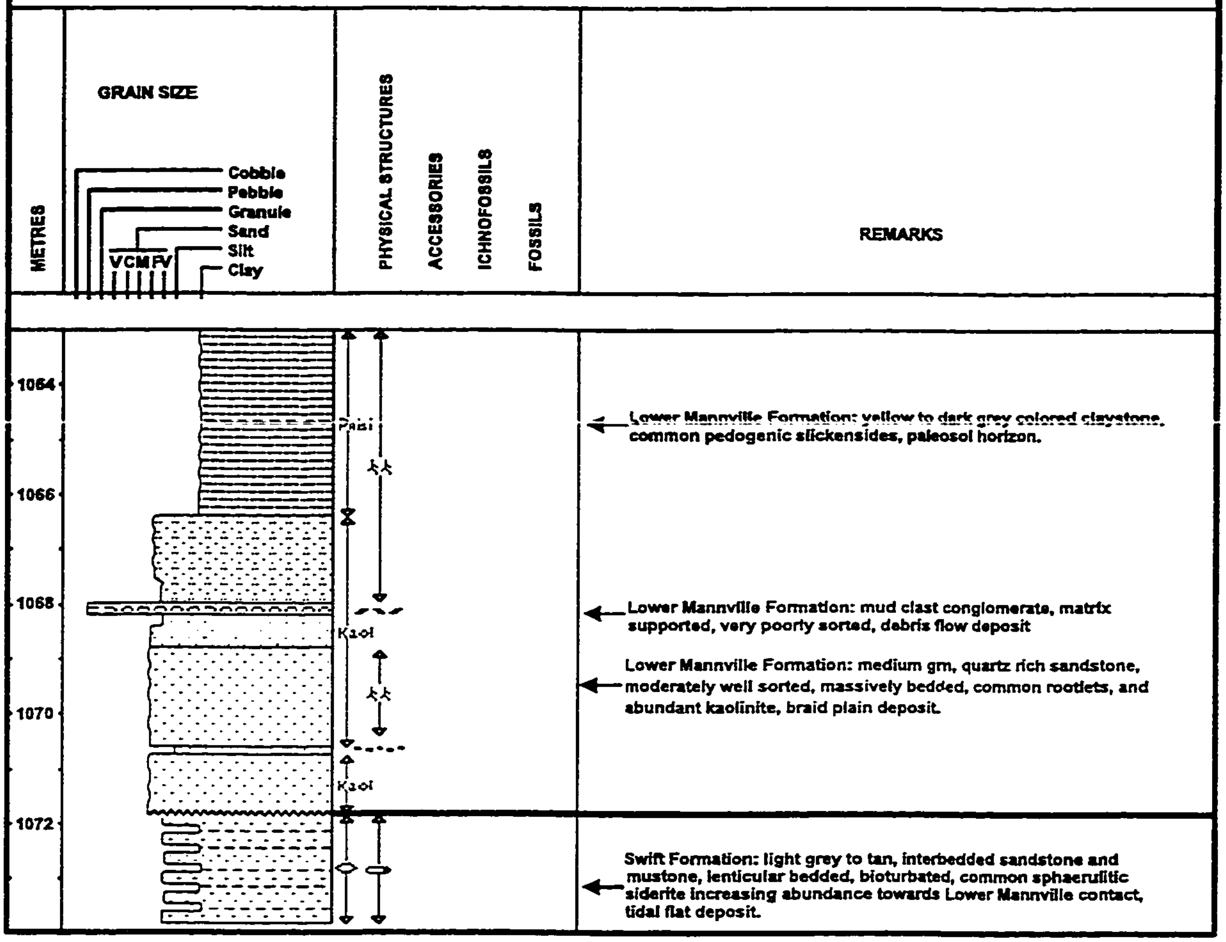
6-10-5-5w4

Date logged: November 3, 1997

Logged by: Patrick Stevenson

Ground: 977.8M **KB:** 982 M

Remarks: Lower Mannville/Swift Formation



HUBER WINTERSHALL MANYBERRIES 10-10-5-5

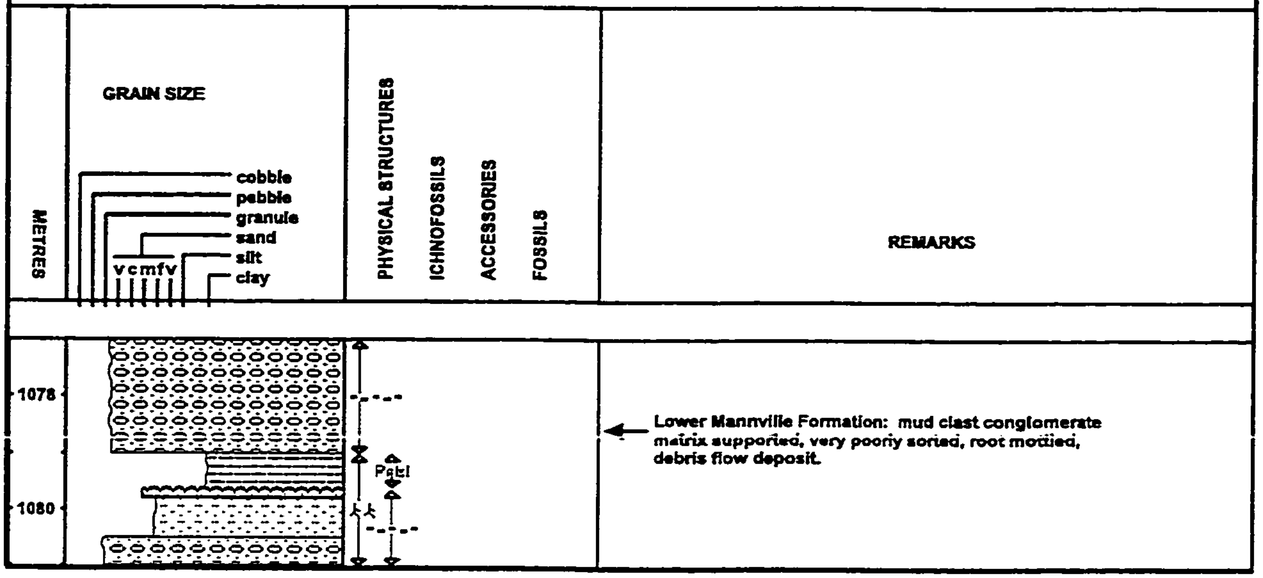
10-10-5-5w4

Date logged: November 4, 1997

Logged by: Patrick Stevenson

Ground: 987.90 m **KB:** 991.50 m

Remarks: An example of Lower Mannville Formation



HUBER ET AL MANYBERRIES 4-11-5-5

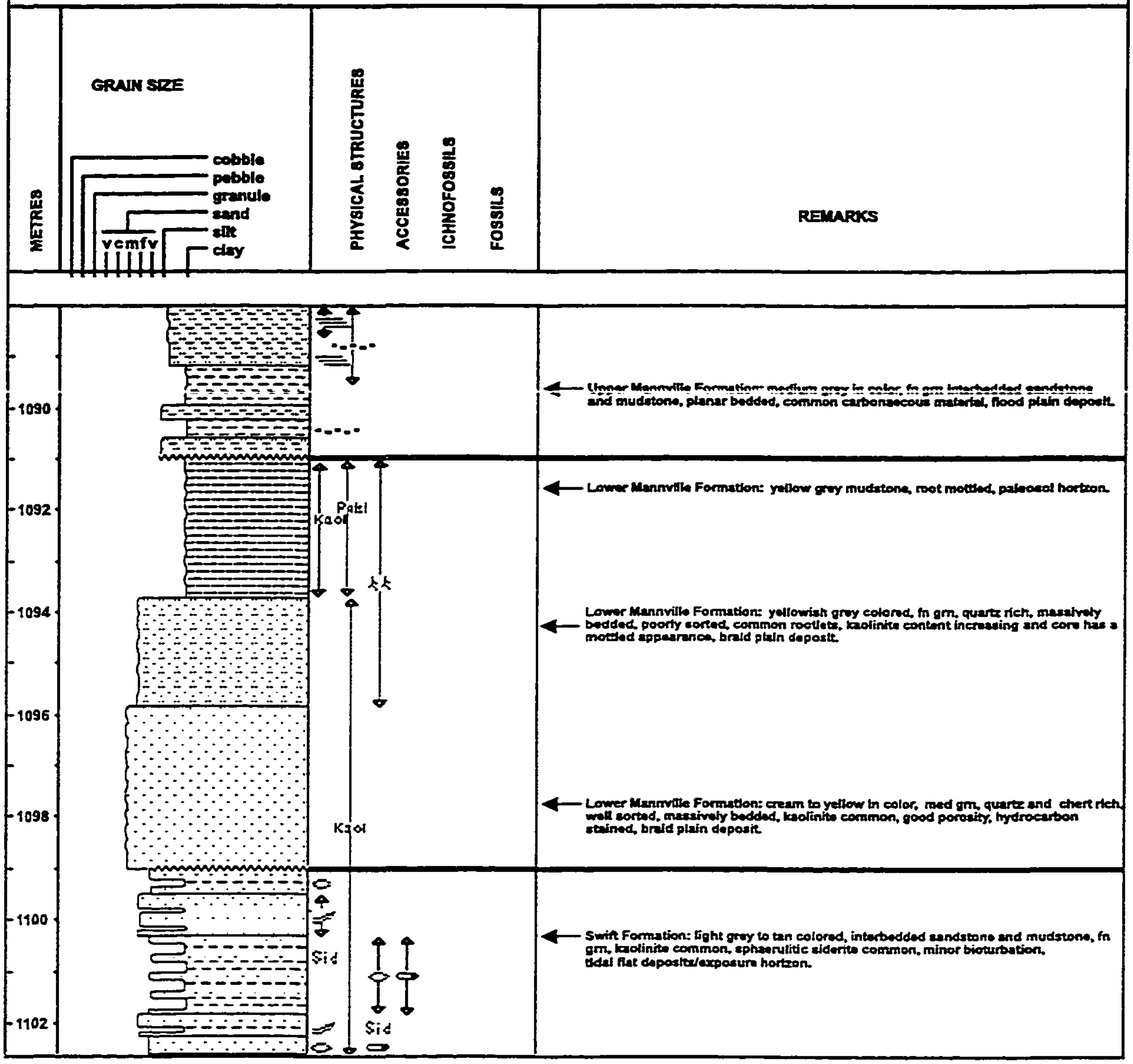
4-11-5-5w4

Date logged: July 28, 1997

Logged by: Patrick Stevenson

Ground: 1002.60 m **KB:** 1006.00 m

Remarks: Swift/Lower/Upper Mannville formations



ANDERSON ET AL. MANYBERRIES 13-12-5-5

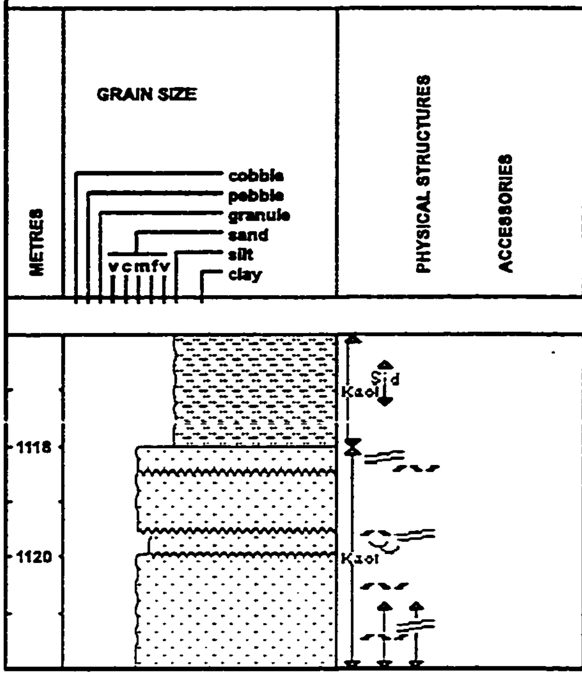
13-12-5-5w4

Date logged: July 28, 1997

Logged by: Patrick Stevenon

Ground: 1018.40 m **KB:** 1023.20 m

Remarks: Lower Mannville Formation, not slabbed, core analysis



REMARKS

Lower Mannville Formation: grey colored, quartz and kaolinite rich sand, poorly sorted, massively bedded, rootlets common, poorly developed pedogenic surface.

Lower Mannville Formation: cream colored, med grn, quartz/chert rich sand, common kaolinite, trough cross-bedded to low angle tabular bedded, mud clasts common, multiple scour surfaces, good porosity, good oil staining.

BRINKEROFF LOMALTA MANYBERRIES 15-14-5-5

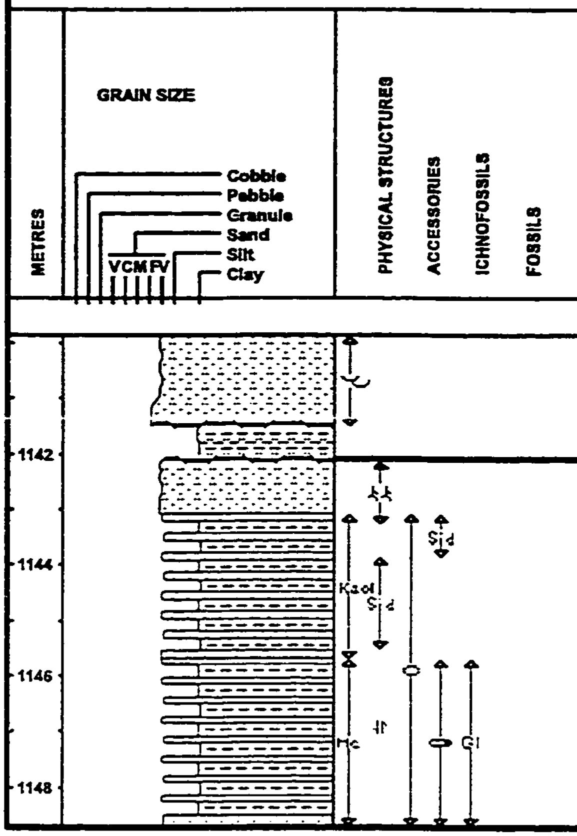
15-14-5-5w4

Date logged: July 28, 1997

Logged by: Patrick Stevenson

Ground: 1040.60 M **KB:** 1044.70 M

Remarks: Upper Mannville and Swift formation not slabbed, no core analysis



REMARKS

Upper Mannville Formation: grey colored, fn grn interbedded sandstone and mudstone, small scale trough cross beds, carbonaceous material common, flood plain deposit.

Upper Mannville Formation: faulted into contact with Swift, fault slickensides common at contact.

Swift Formation: light cream in color, vfn to fn grn, interlaminated sandstone and mudstone, lenticular to wavy bedded, bioturbation common, red colored fault plane associated with large amounts of sphaerulitic siderite (<1mm), tidal flat deposit.

Swift Formation: light grey to tan colored, interlaminated sandstone and mudstone, lenticular bedded to wavy bedded, minor to moderate bioturbation, common mica along mudstone partings, flecks, Pyrite, and fault slickensides, poor porosity and no hydrocarbon staining, core highly fractured, tidal flat deposit.

KANEB ET AL MANYBERRIES 2-16-5-5

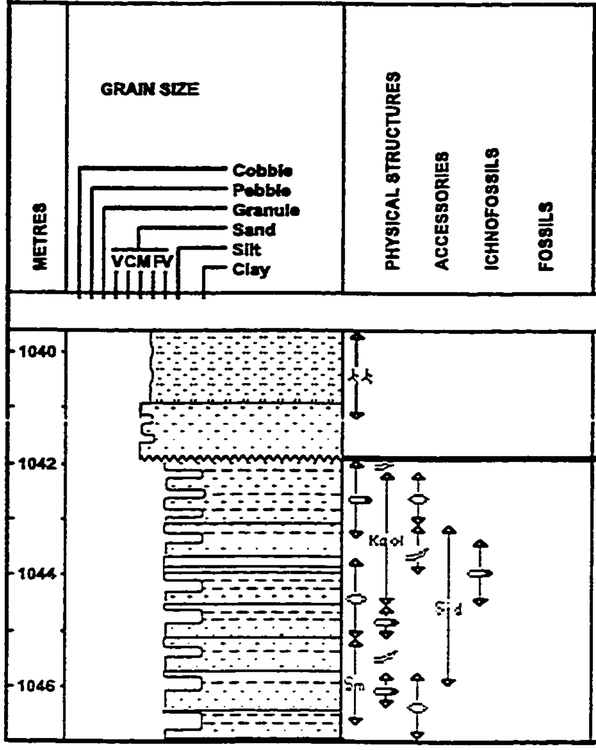
2-16-5-5w4

Date logged: July 30, 1997

Logged by: Patrick Stevenson

Ground: 961.30 M **KB:** 965.50 M

Remarks: Lower Mannville/Swift Formation, slabbed, core analysis



REMARKS

← Lower Mannville Formation: yellow grey, quartz rich, fn grn, massively bedded, poorly sorted abundant kaolinite, root mottled, braid plain deposit.

← Lower Mannville Formation: yellow to cream colored, quartz rich, medium grn, well sorted, massively bedded and abundant kaolinite, braid plain deposit.

← Swift Formation: light grey to tan in color, vfn to fn grn, interbedded sandstone and mudstone, lenticular to wavy bedded, bioturbated, sphaerulitic siderite common, tidal flat deposit/exposure horizon.

CLARION MANYBERRIES 6-20-5-5

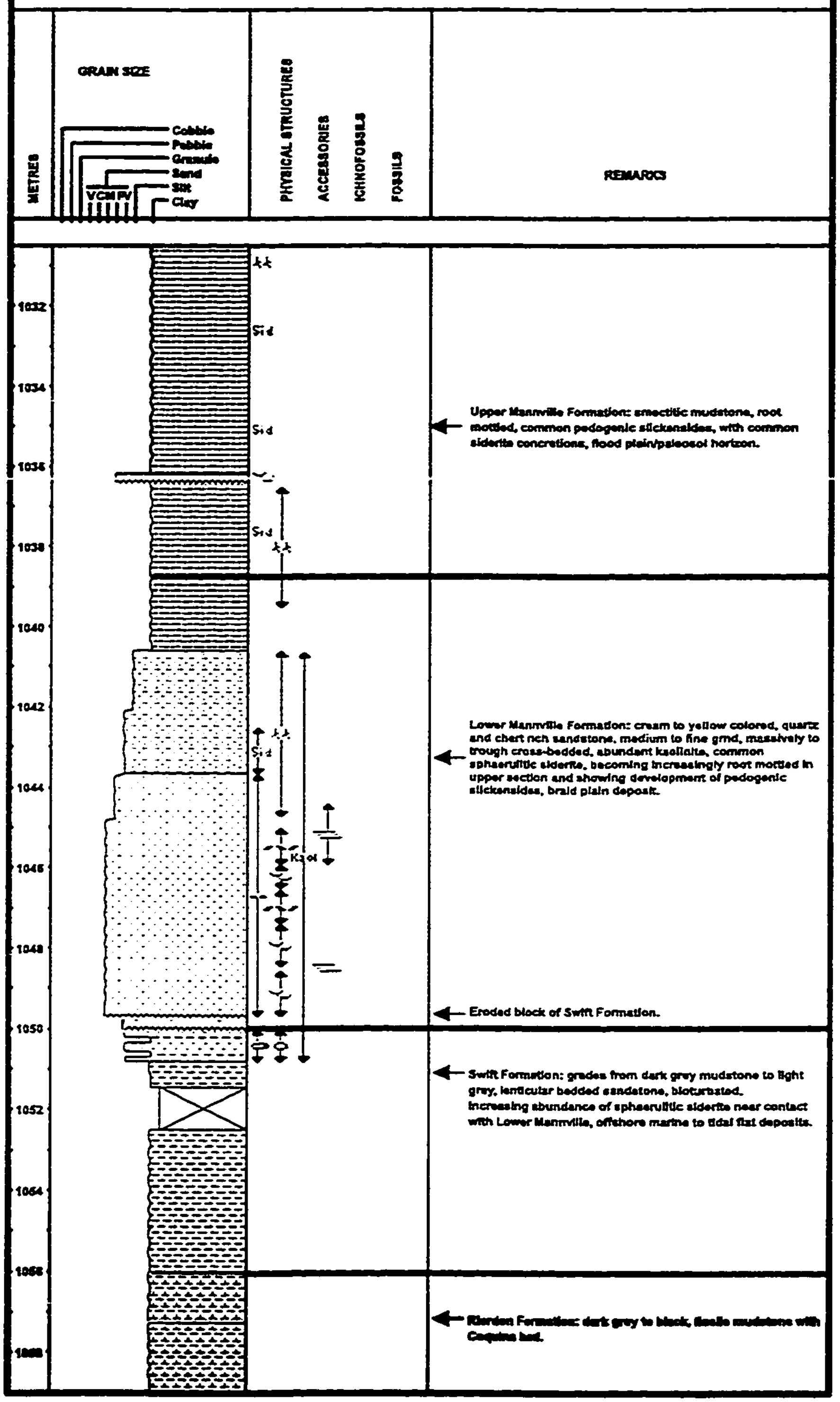
6-20-5-5w4

Date logged: November 3, 1997

Logged by: Patrick Stevenson

Ground: 957.80 M **KB:** 962.40 M

Remarks: Rierdon/Swift/Lower Mannville and Upper Mannville



SHELL MANYBERRIES 16-20-5-5

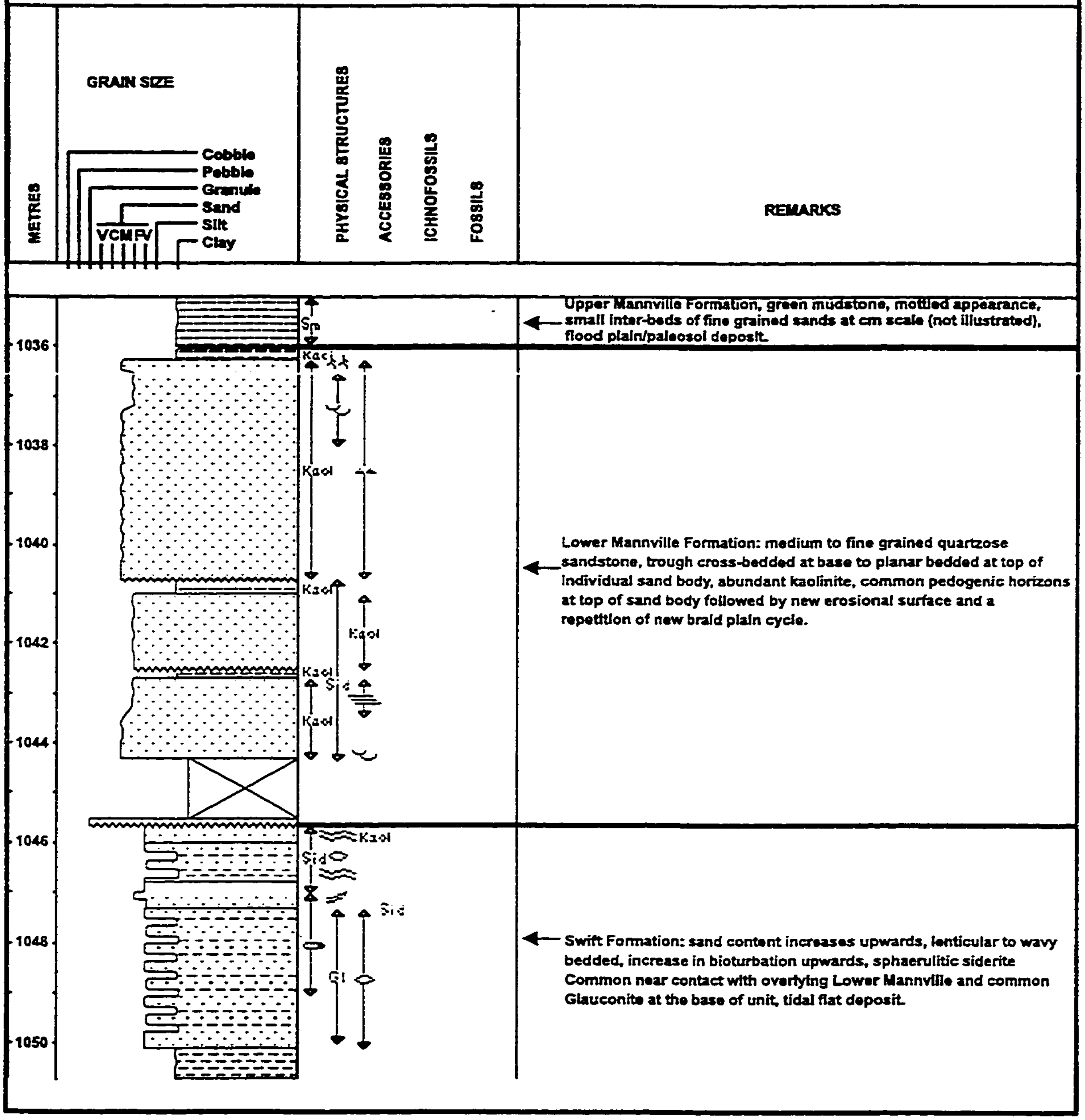
16-20-5-5w4

Date logged: November 3, 1997

Logged by: Patrick Stevenson

Ground: 962.80 M KB: 966.80 M

Remarks: Swift/Lower Mannville/and Upper Mannville formations



SHELL MANYBERRIES 8-21-5-5

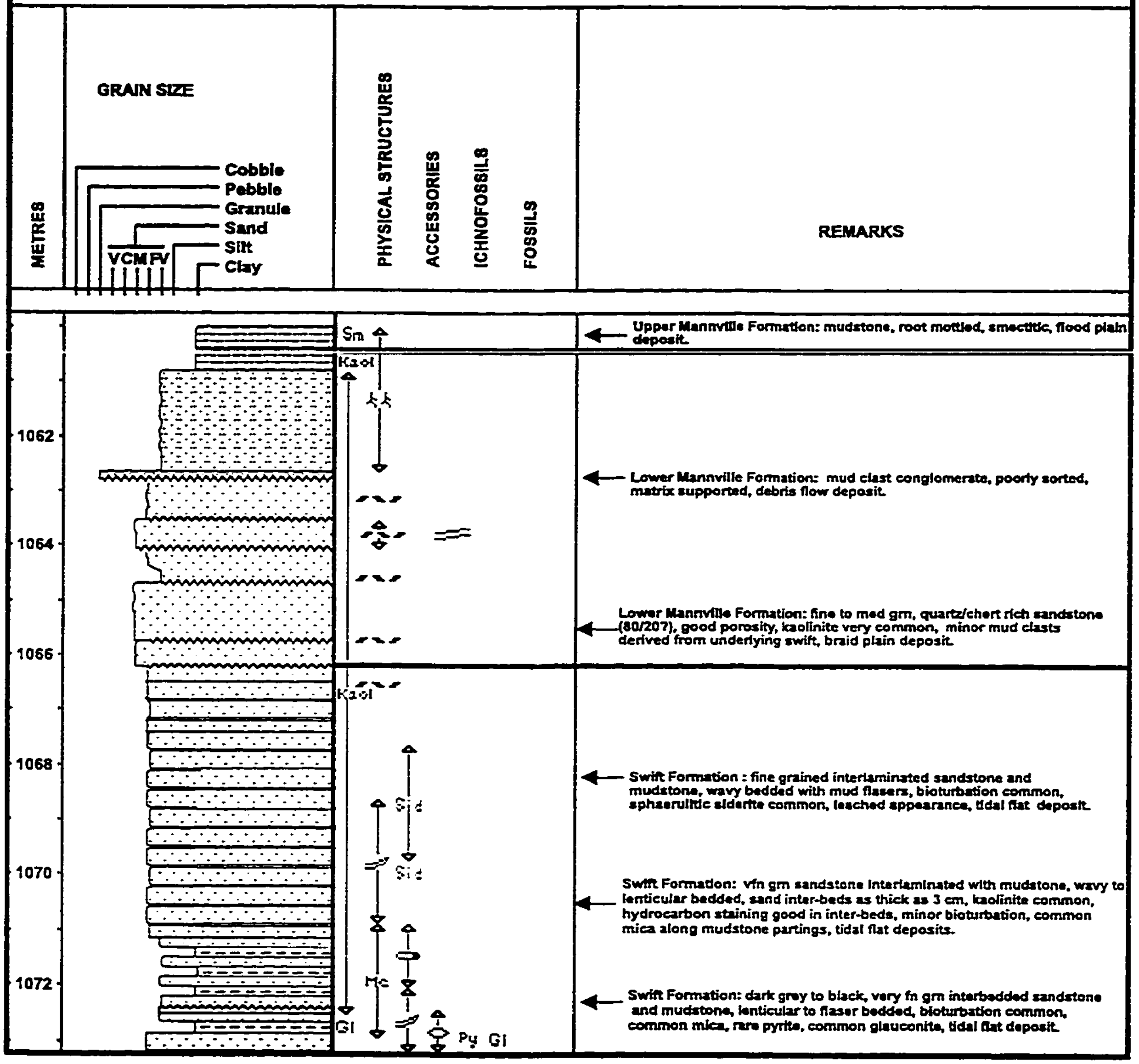
8-21-5-5

Date logged: July 25, 1997

Logged by: Patrick Stevenson

Ground: 977.80 M KB: 981.20 M

Remarks: Lower Mannville good core recovery, slabbed, core analysis



SHELL MANYBERRIES 13-24-5-5

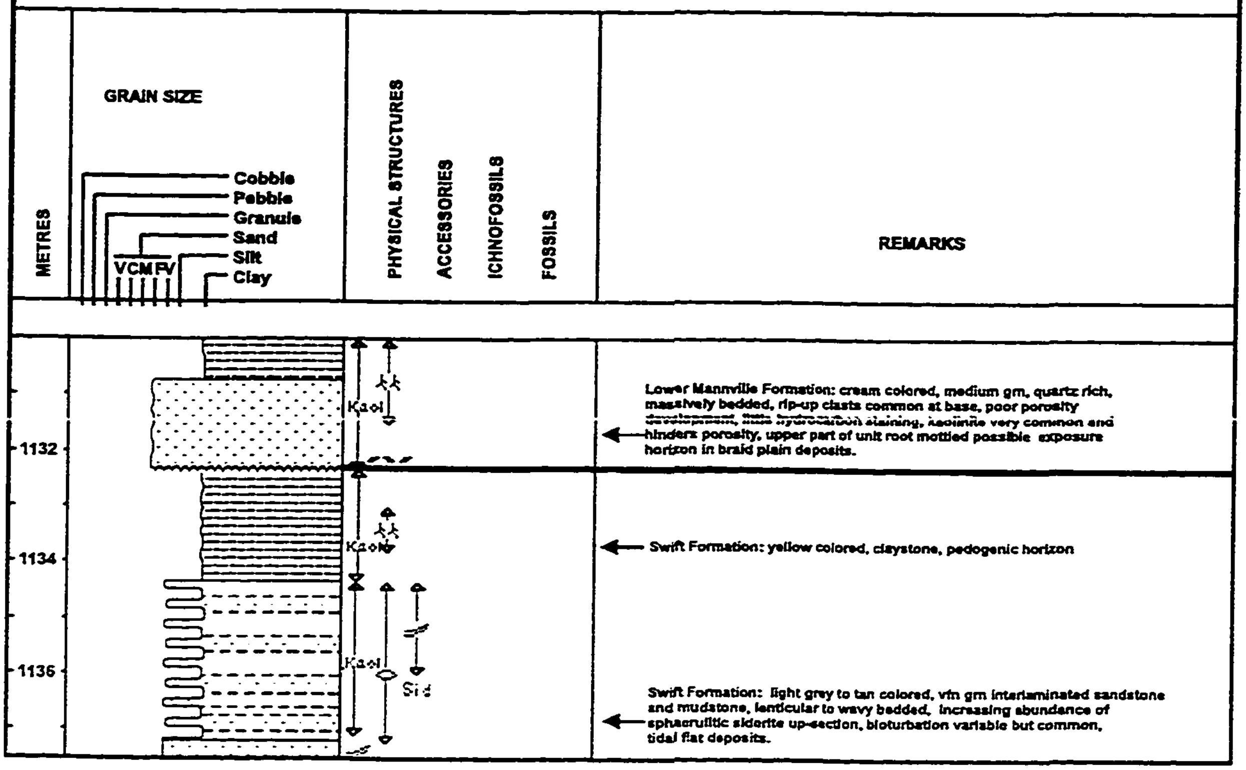
13-24-5-5w4

Date logged: July 23, 1997

Logged by: Patrick Stevenson

Ground: 1022.20 M **KB:** 1025.70 M

Remarks: Swift/Lower Mannville Formation core, slabbed, and core analysis



HOME ET AL MANYBERRIES 6-25-5-5W4

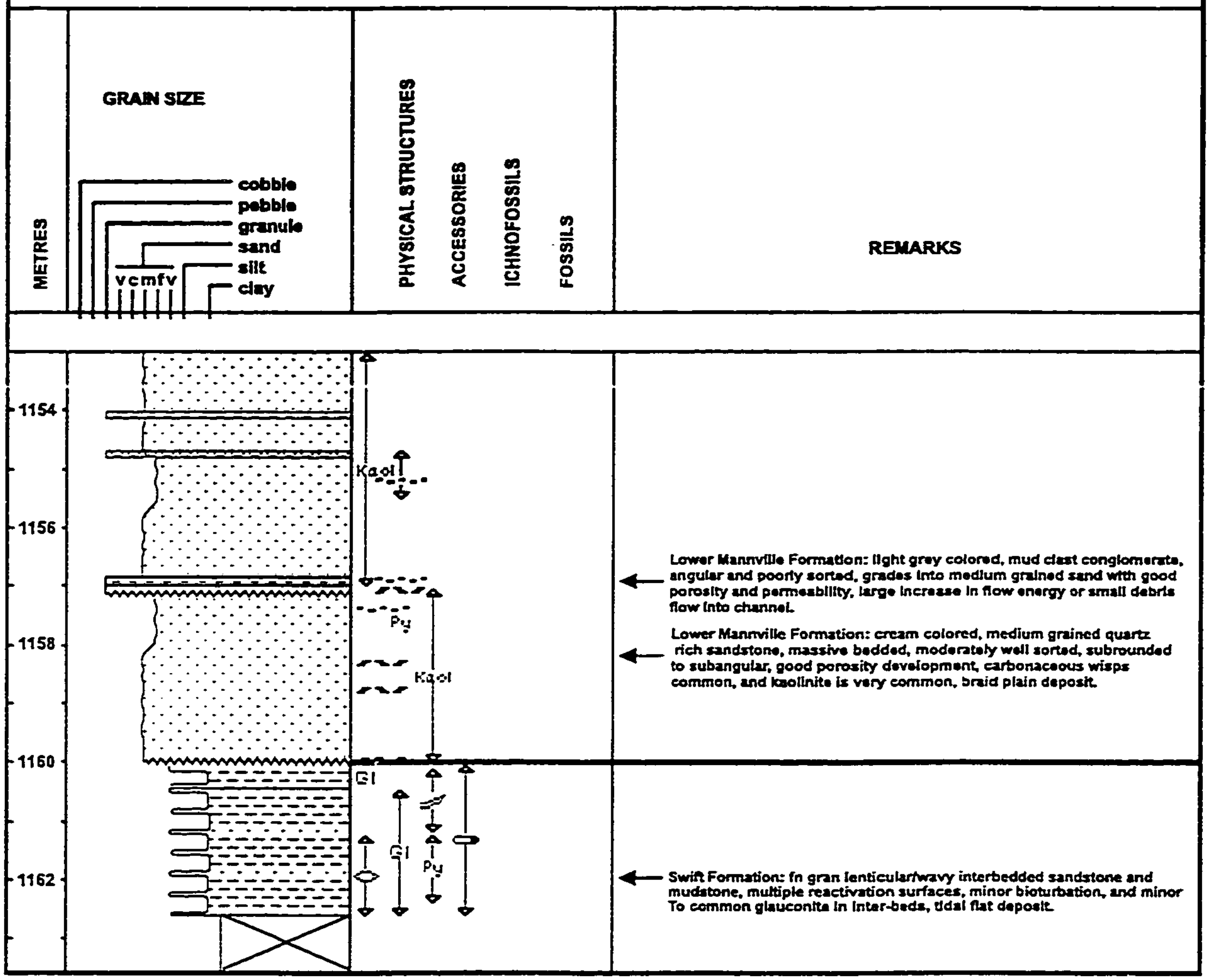
6-25-5-5w4

Date logged: July 24, 1997

Logged by: Patrick Stevenson

Ground: 1048.6m **KB:** 1052.6m

Remarks: Lower Mannville Formation, slabbed, good core recovery



SHELL CARLYLE MANYBERRIES 8-27-5-5w4

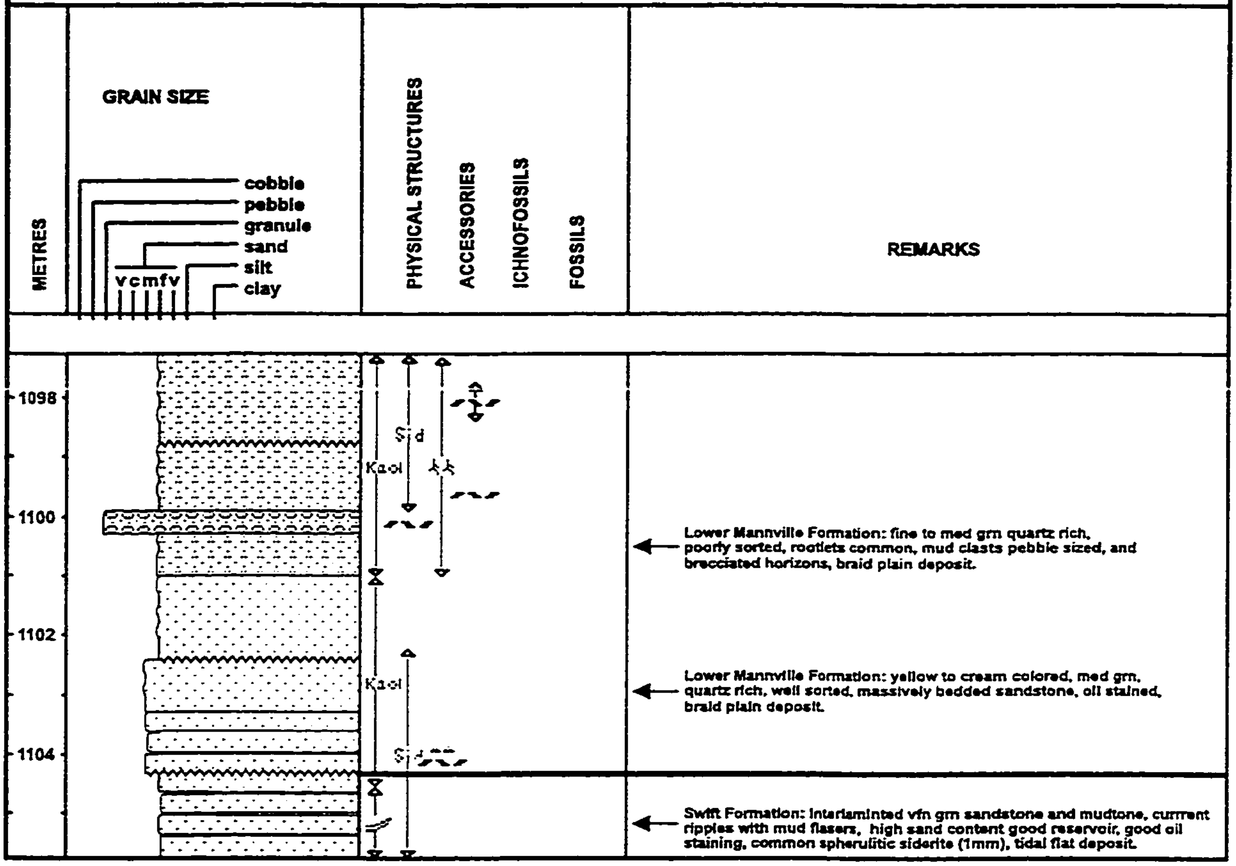
8-27-5-5w4

Date logged: July 25, 1997

Logged by: Patrick Stevenson

Ground: 998.7m **KB:** 1002.7m

Remarks: good example of Swift/Lower Mannville succession oil stained, slabbed, core analysis



HOME MANYBERRIES 10-28-5-5

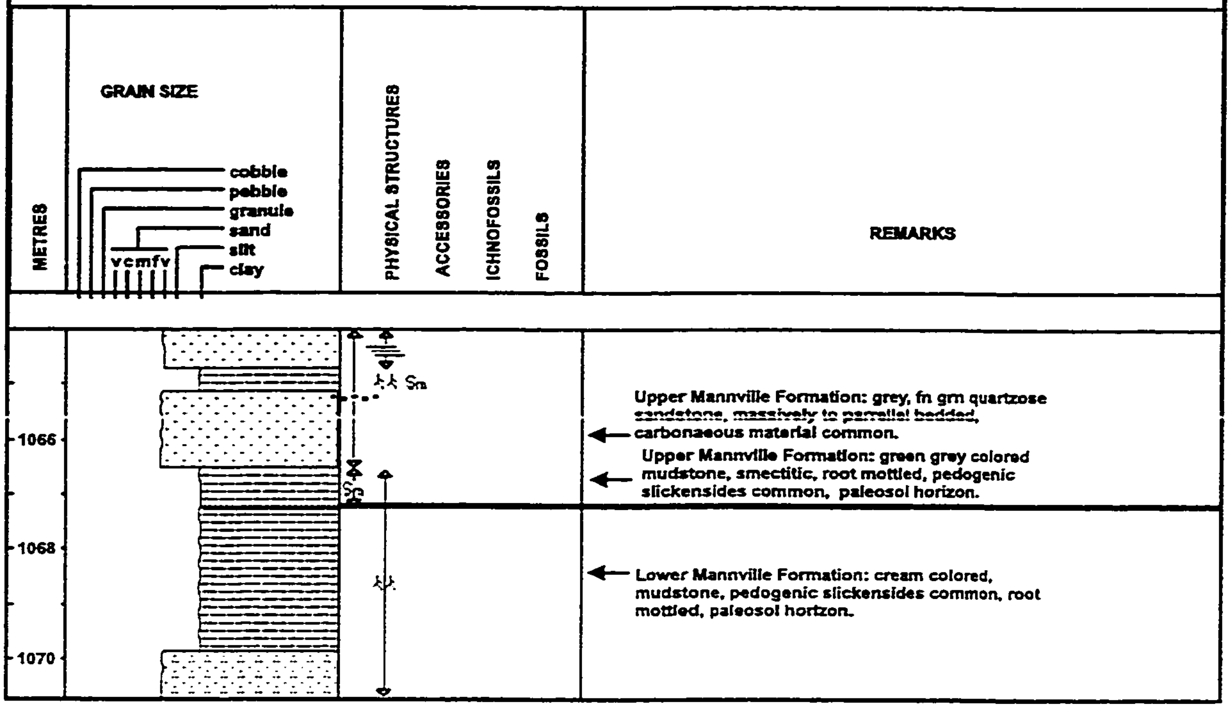
10-28-5-5w4

Date logged: November 3, 1997

Logged by: PATRICK STEVENSON

Ground: 983.80 m **KB:** 988.00 m

Remarks: Lower Mannville and Upper Mannville formations



HOME MANYBERRIES 16-28-5-5

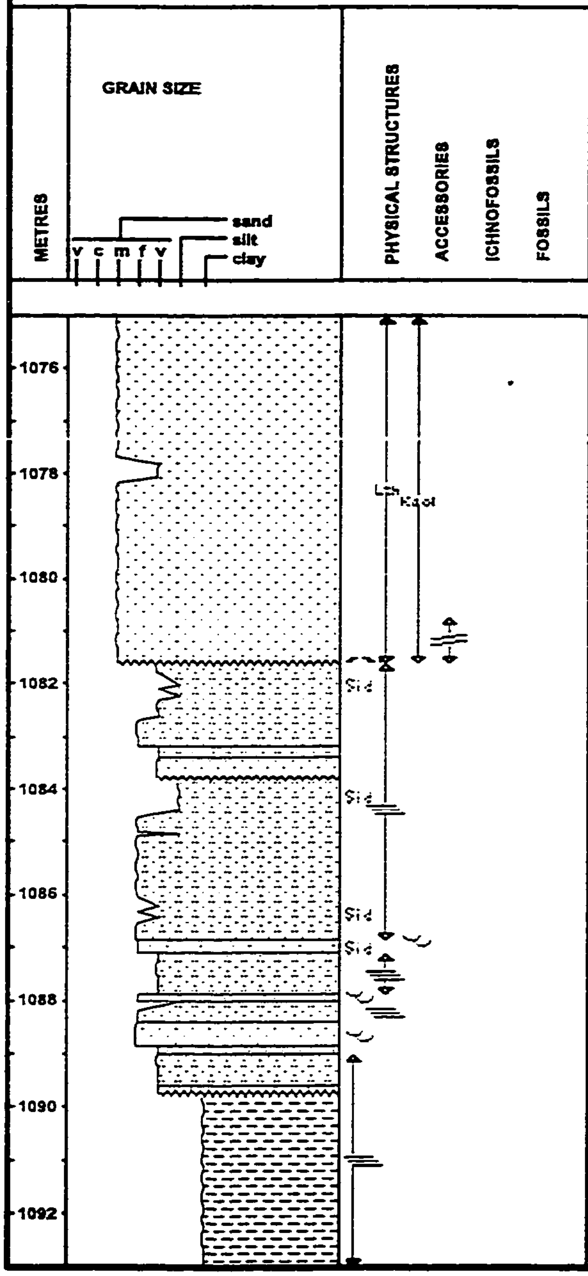
16-28-5-5w4

Date logged: June 18, 1997

Logged by: PATRICK STEVENSON

Ground: 991.20 m   **KB:** 995.00 m

Remarks: Upper Mannville Formation lithic sands



REMARKS

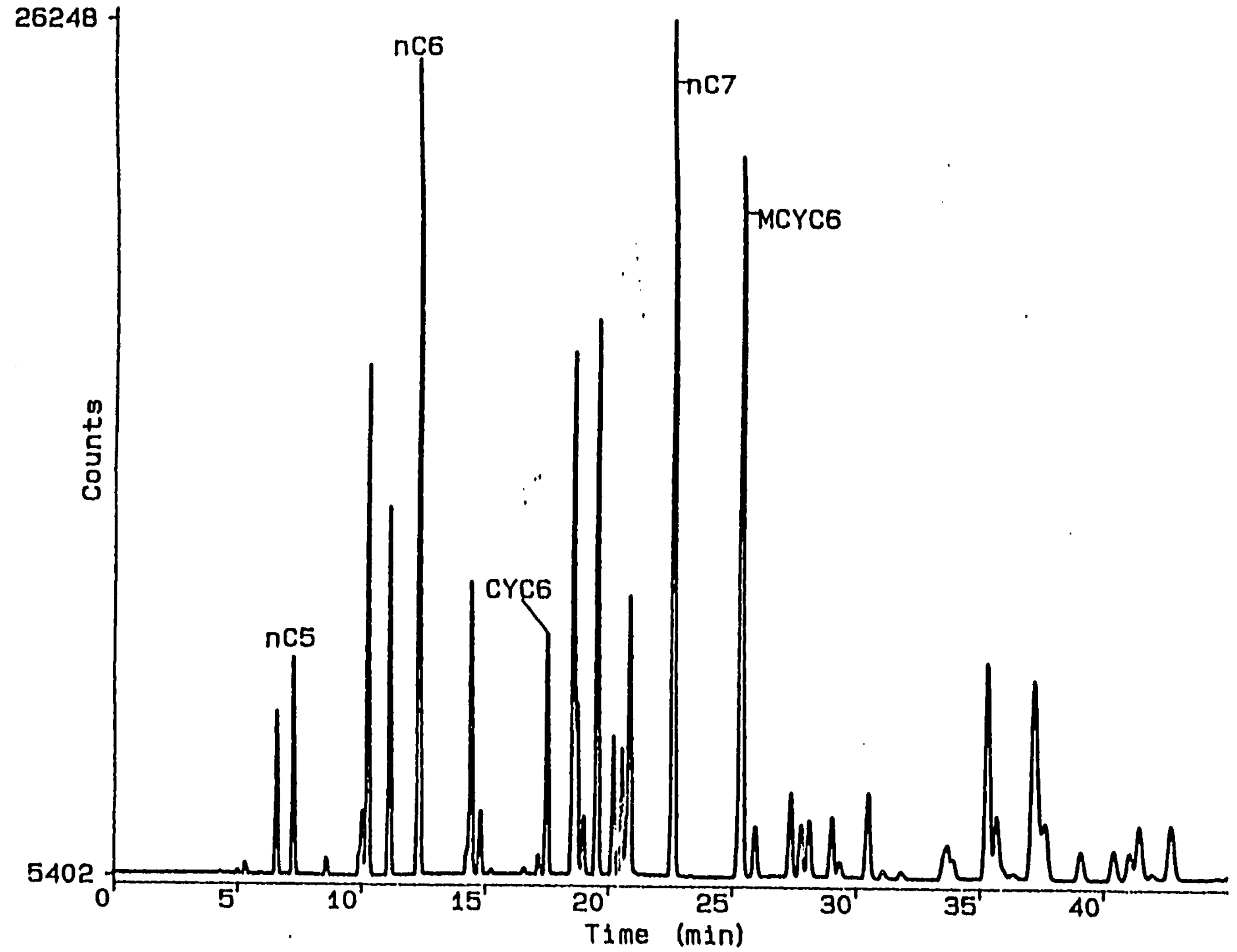
Upper Mannville Formation, medium grained, quartz/chert/feldspar/rock fragments common, common carboneaous material, poorly sorted, massively bedded, poor porosity, Lithic sands of pre-Upper Mannville valley fill, braid plain deposit.

Upper Mannville Formation, dark grey to green, interbedded fine grained sands and muds, cm scale cross-bedding to planar bedded, siderite concretion horizons common (10cm thick), meandering river valley fill deposits.

Upper Mannville Formation, black to to dark grey mudstone, thinnly laminated,no bioturbation prevalent, oxbow lake deposit of pre-Upper Mannville valley fill.

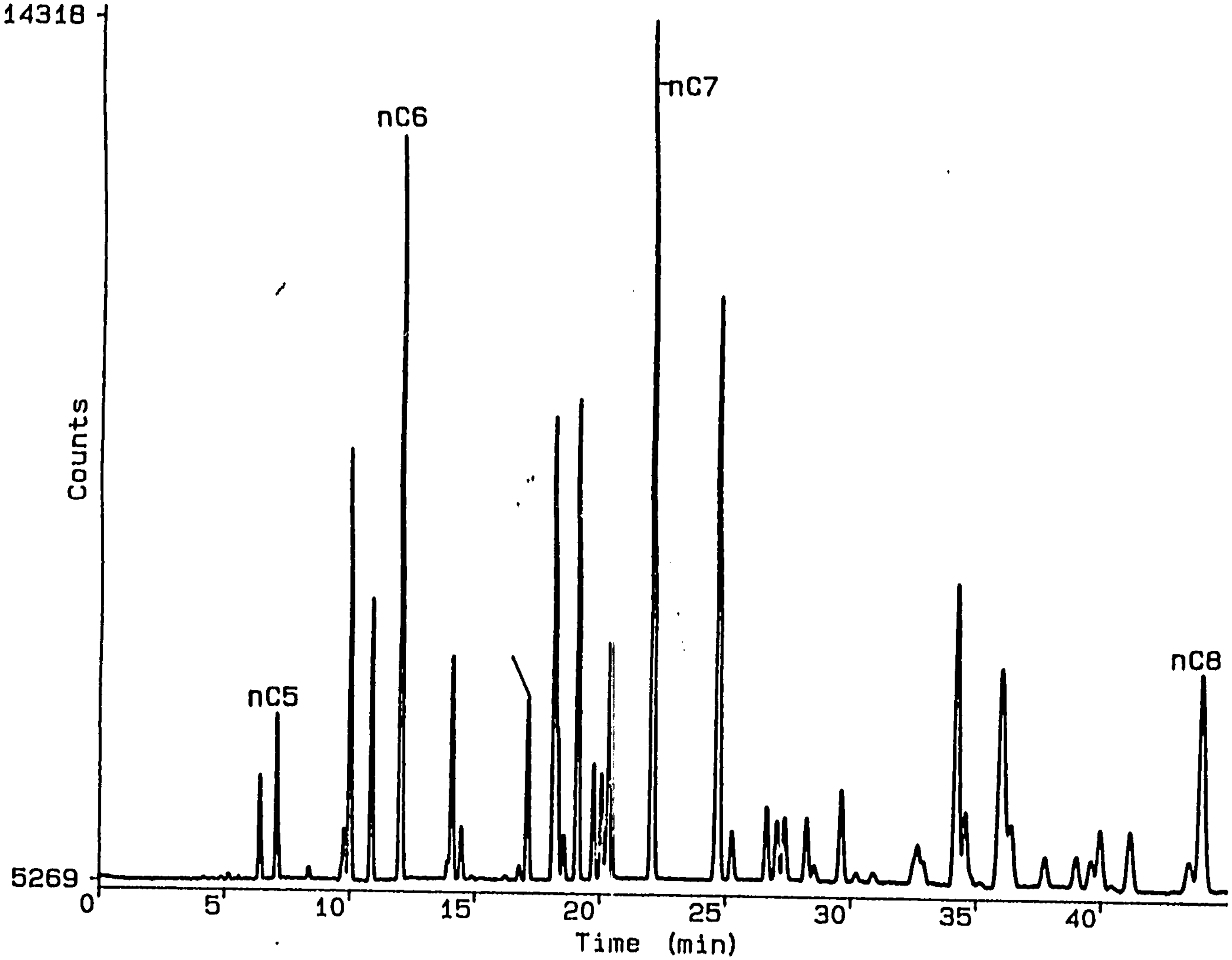
APPENDIX 4: GASOLINE RANGE GAS CHROMATOGRAPHY (C_5 TO C_8) DATA FOR FAMILY M OILS

Data file: /HP/ALTA546
Report: None --
Acquired: Mon May 6, 1996 9:25:51 am
Time range: 0.00-45.00



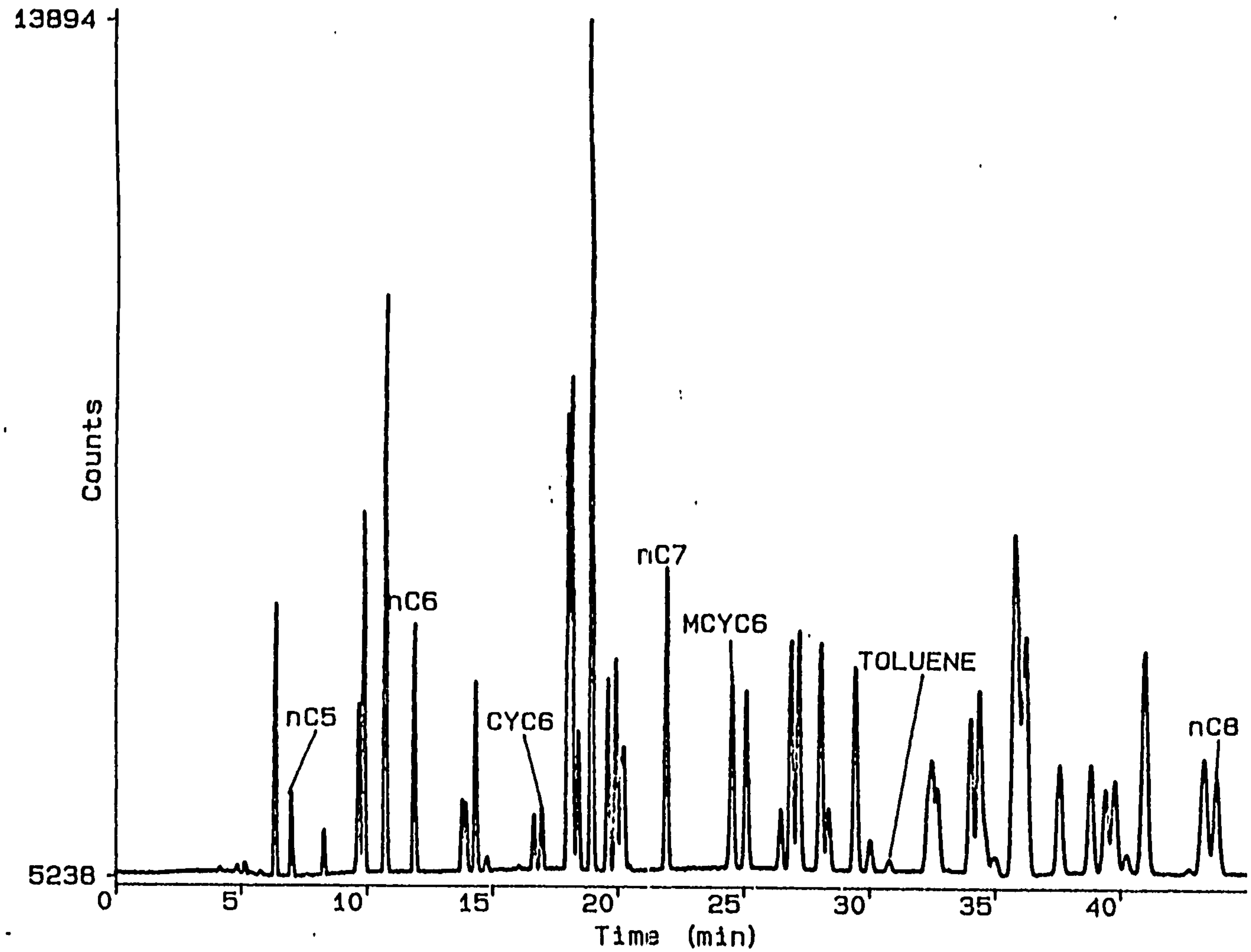
#2127 ANDERSON ET AL MANYBERRIES 10-36-4-5W4

Data file: /HP/ALTA547
Report: 15993
Acquired: Mon May 6, 1996 1:44:36 pm
Time range: 0.00-45.00



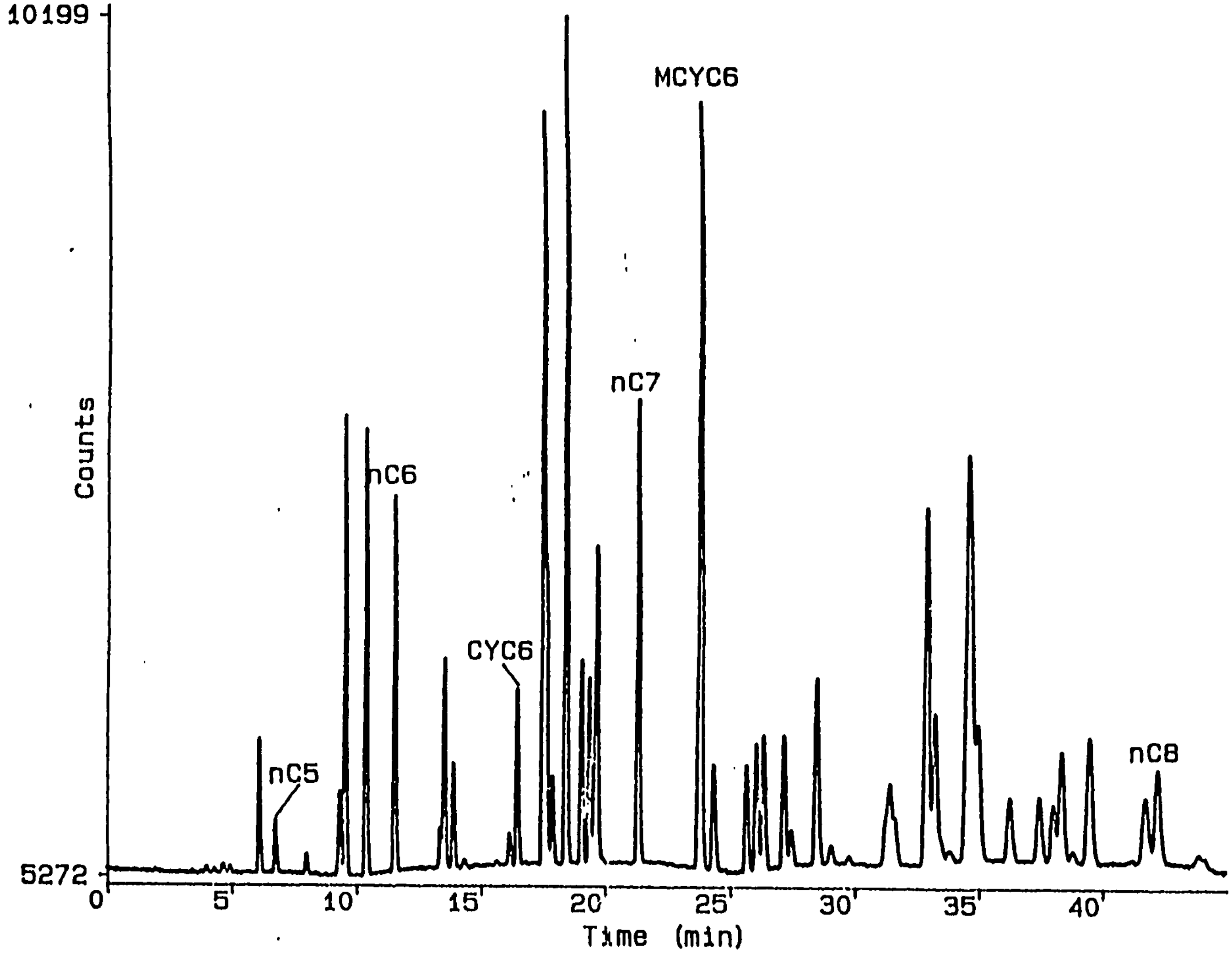
#2128 ANDERSON ET AL MANYBERRIES 12-13-5-5W4

Data file: /HP/ALTA548
Report: 16002
Acquired: Tue May 7, 1996 8:12:56 am
Time range: 0.00-45.00



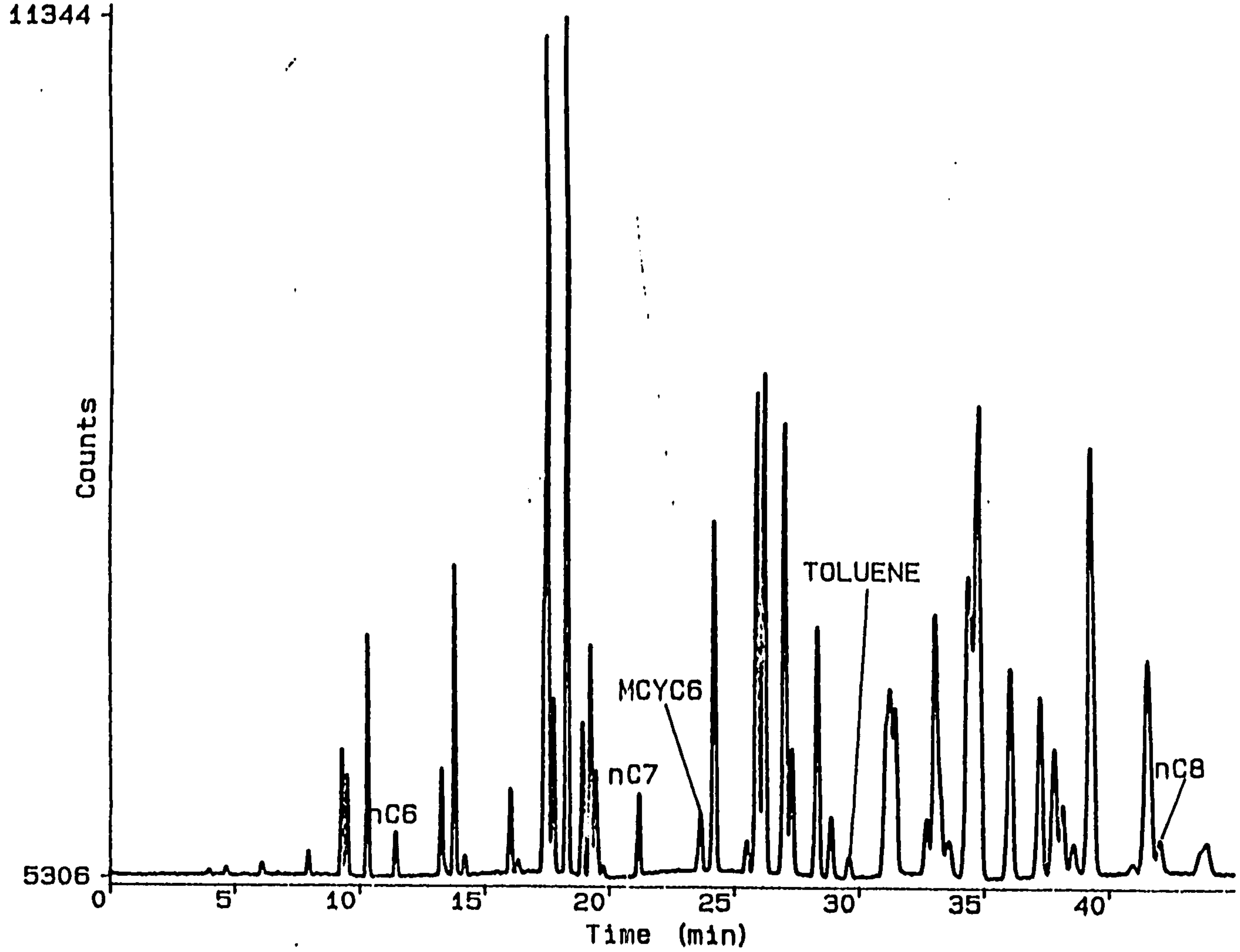
#2129 ANDERSON ET AL MANYBERRIES 16-01-5-5W4

Data file: /HP/ALTA549
Report: 16009
Acquired: Tue May 7, 1996 1:14:52 pm
Time range: 0.00-45.00



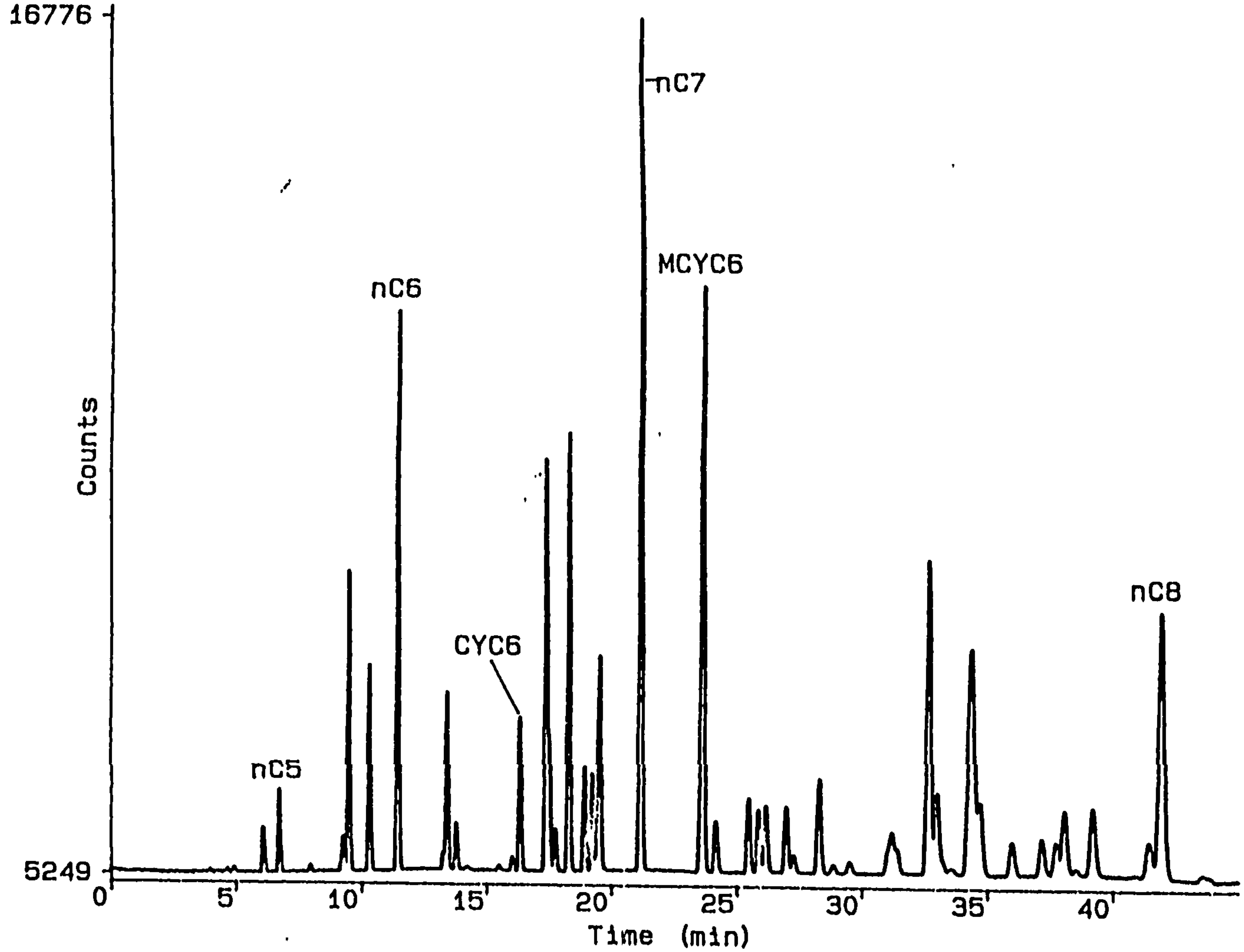
#2130 ANDERSON ET AL MANYBERRIES 2-2-5-5W4

Data file: /HP/ALTA550
Report: 16021
Acquired: Wed May 8, 1996 1:10:34 pm
Time range: 0.00-45.00



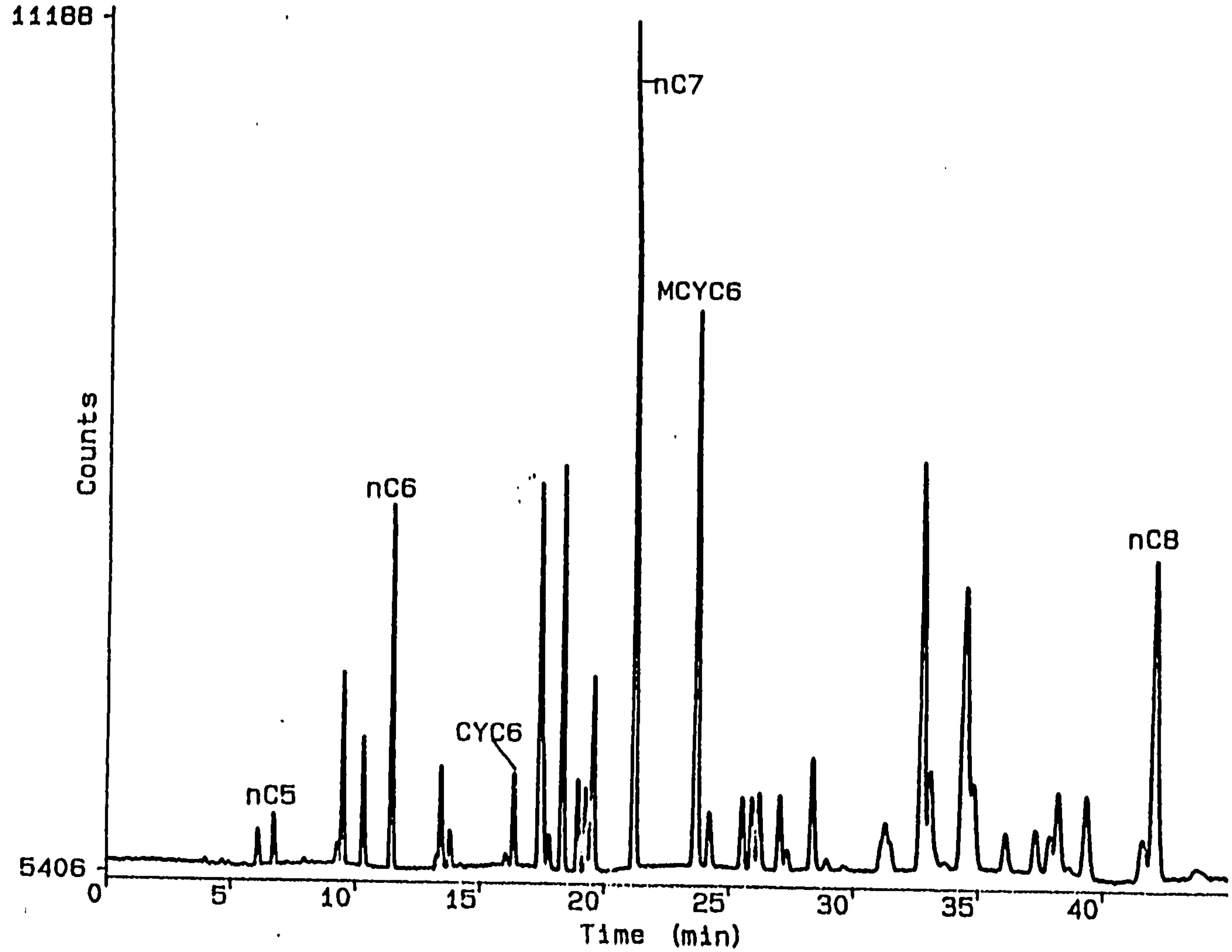
#2131 ANDERSON ET AL MANYBERRIES 4-7-5-4W4

Data file: /HP/ALTA551
Report: 16025
Acquired: Wed May 8, 1996 2:25:07 pm
Time range: 0.00-45.00



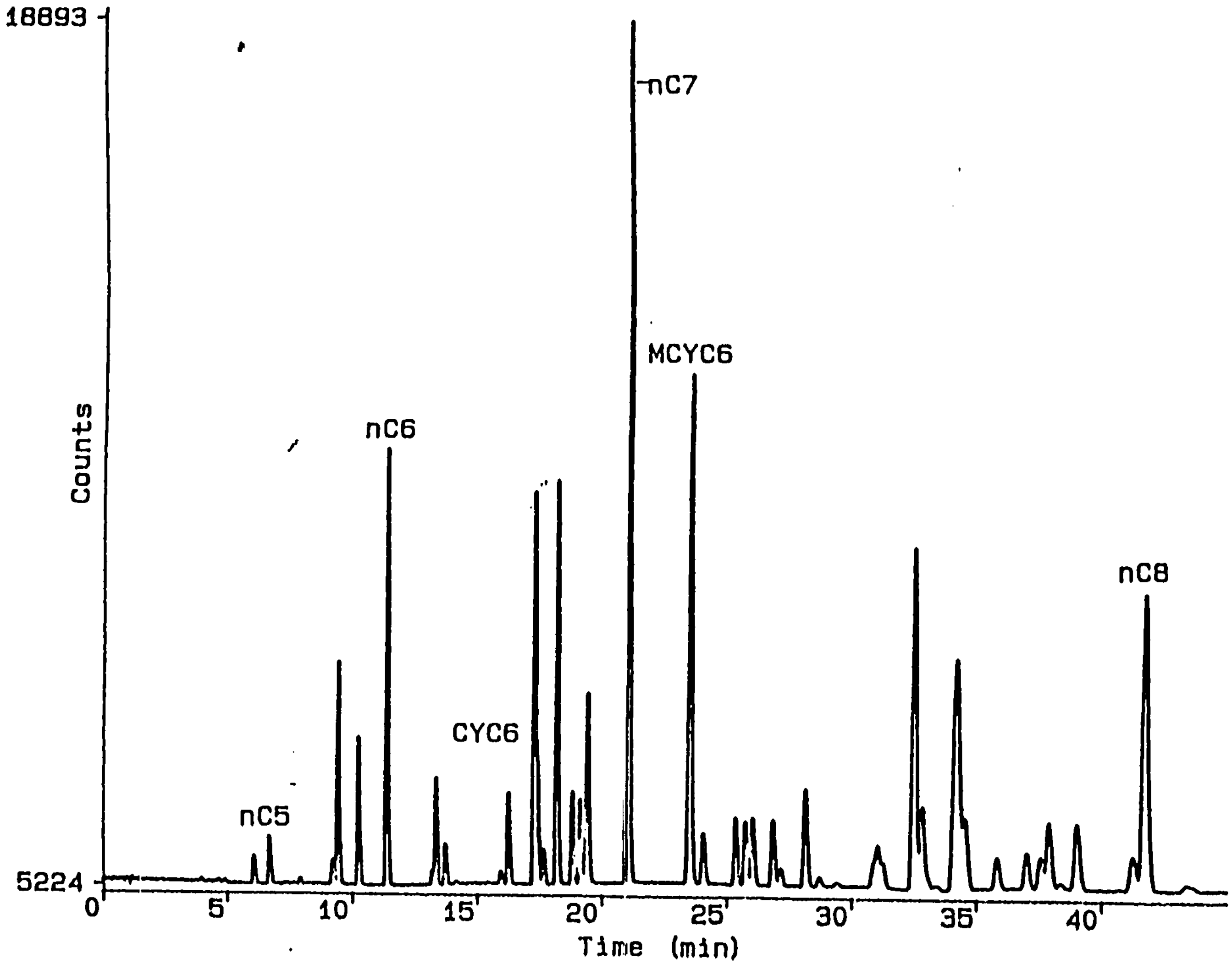
#2132 ANDERSON ETAL MANYBERRIES 5-12sb-5-5W4

Data file: /HP/ALTA552
Report: 16035
Acquired: Thu May 9, 1996 8:28:15 am
Time range: 0.00-45.00



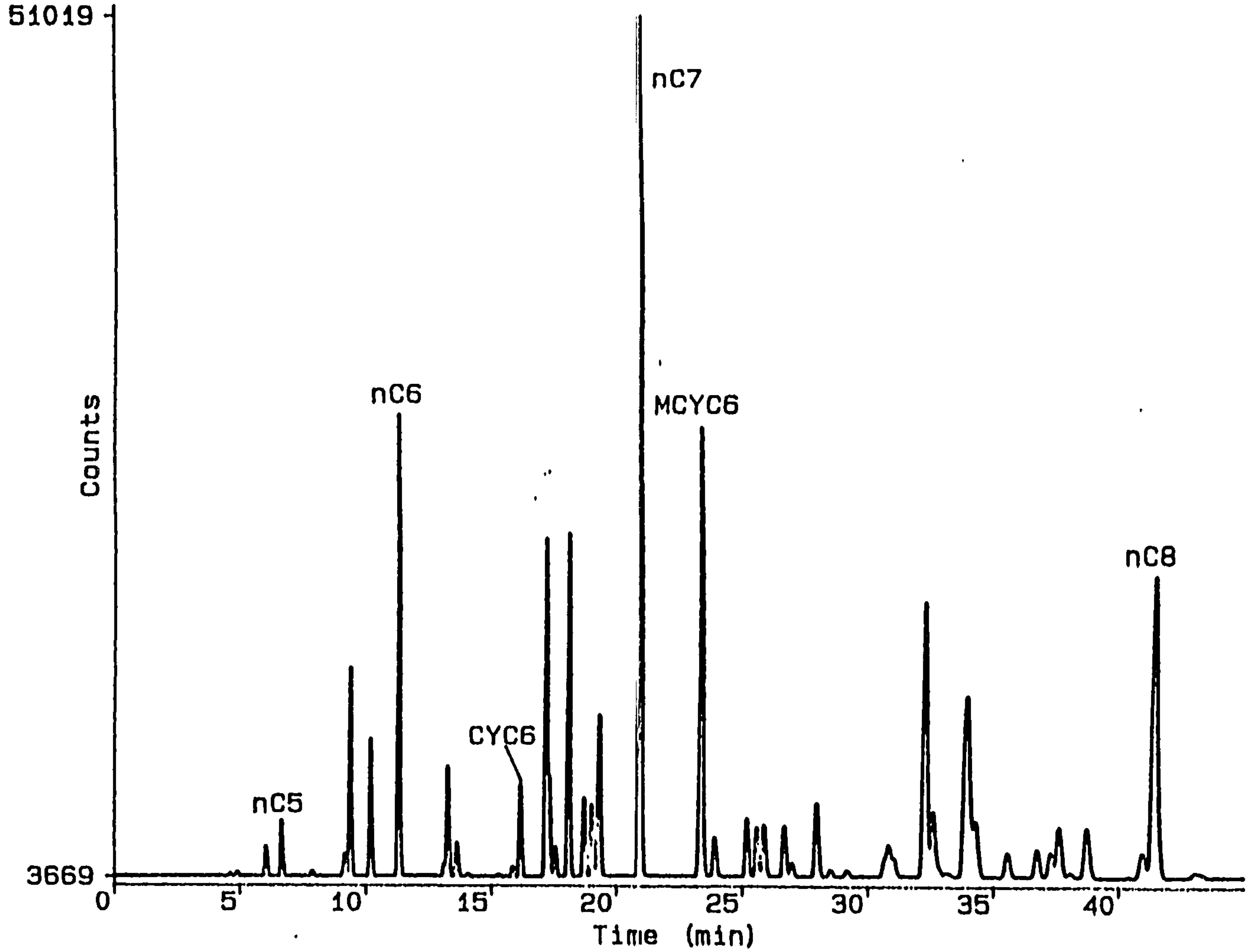
#2133 CIMARRON ETAL MANYBERRIES 12-15-5-4W4

Data file: /HP/ALTA553
Report: 16038
Acquired: Thu May 9, 1996 9:43:01 am
Time range: 0.00-45.00

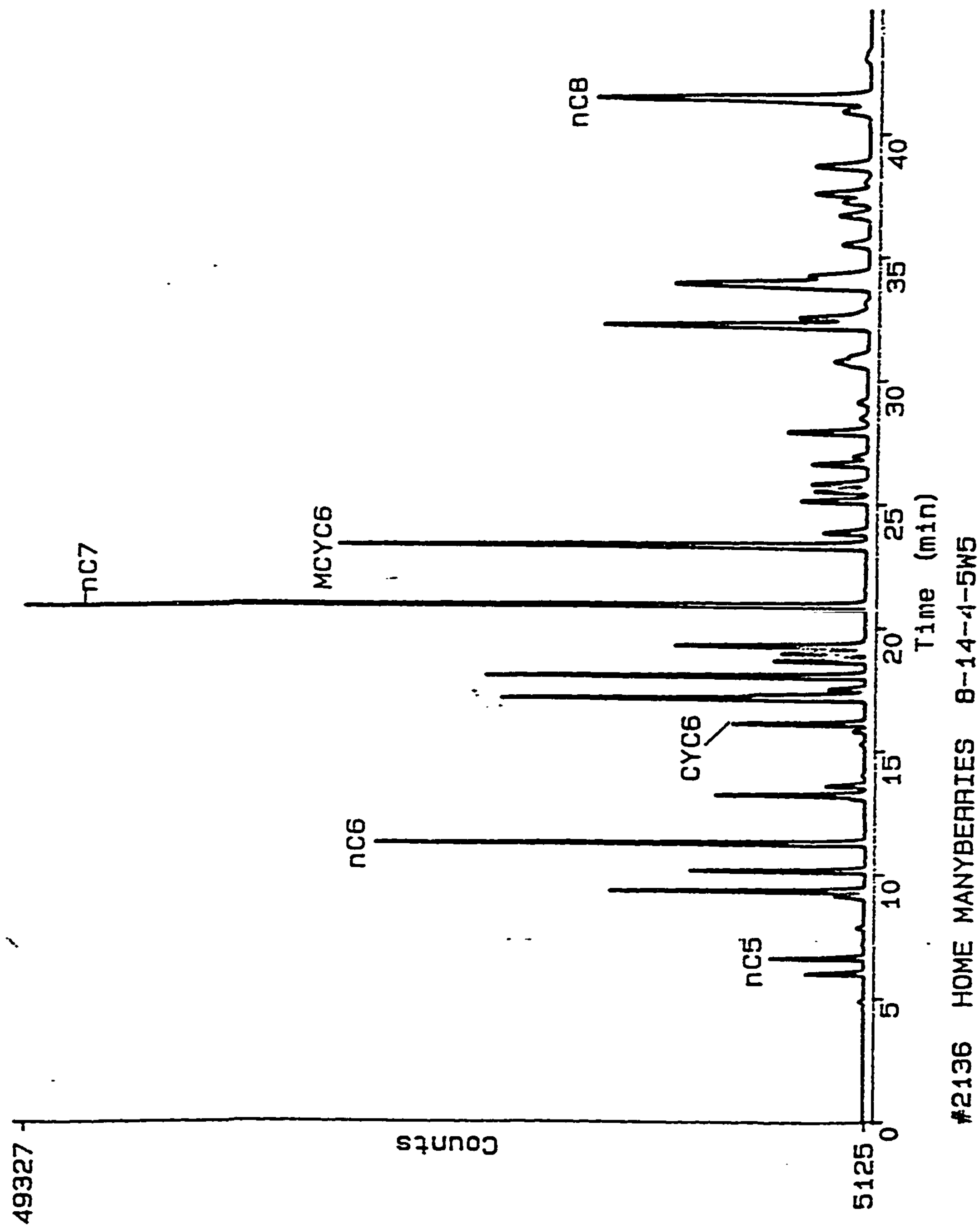


#2134 CIMARRON ETAL MANYBERRIES 16-9-5-4W4

Data file: /HP/ALTA554
Report: 15047
Acquired: Thu May 9, 1996 12:12:23 pm
Time range: 0.00-45.00

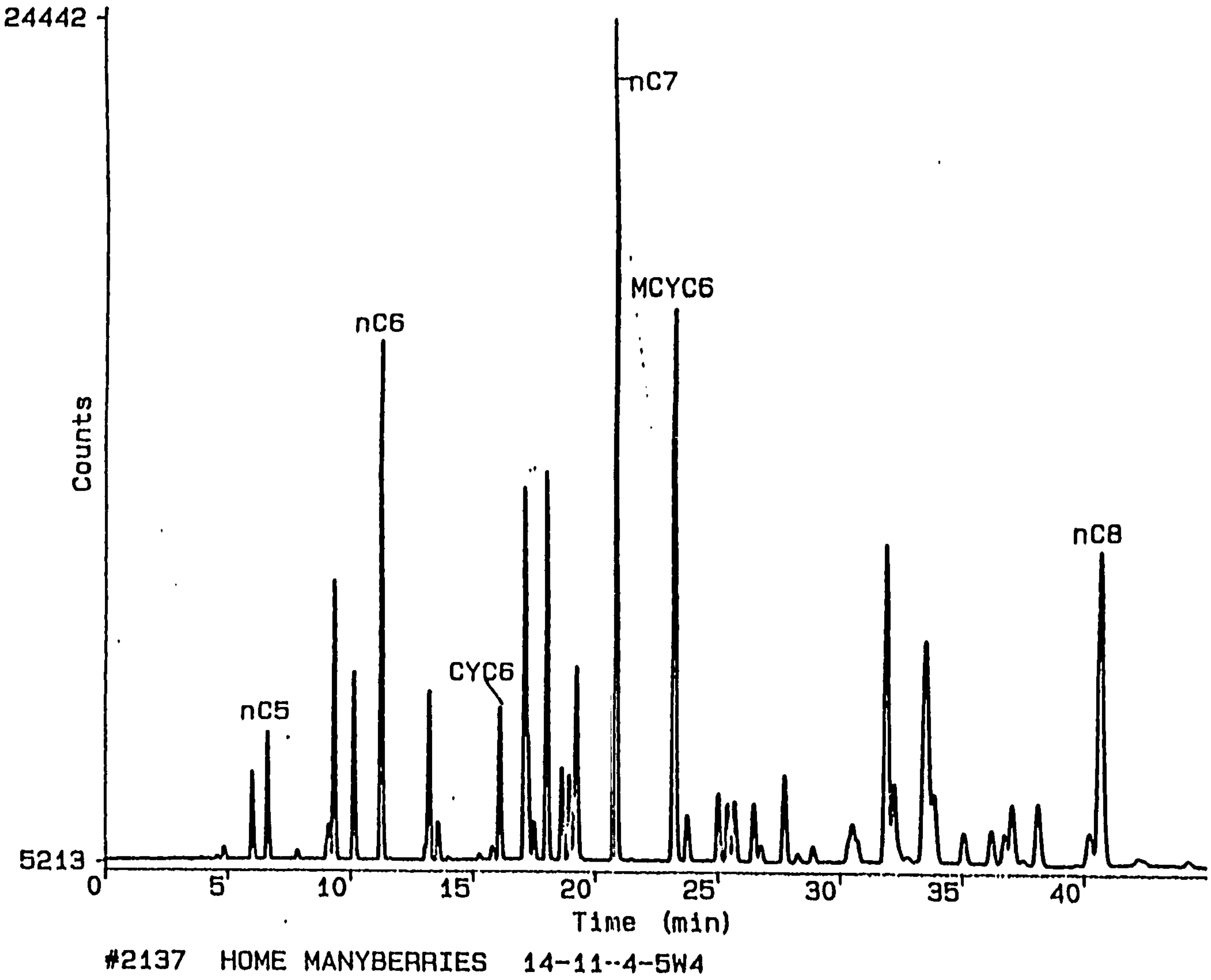


#2135 CIMARRON ETAL MANYBERRIES 2-9-5-4W4

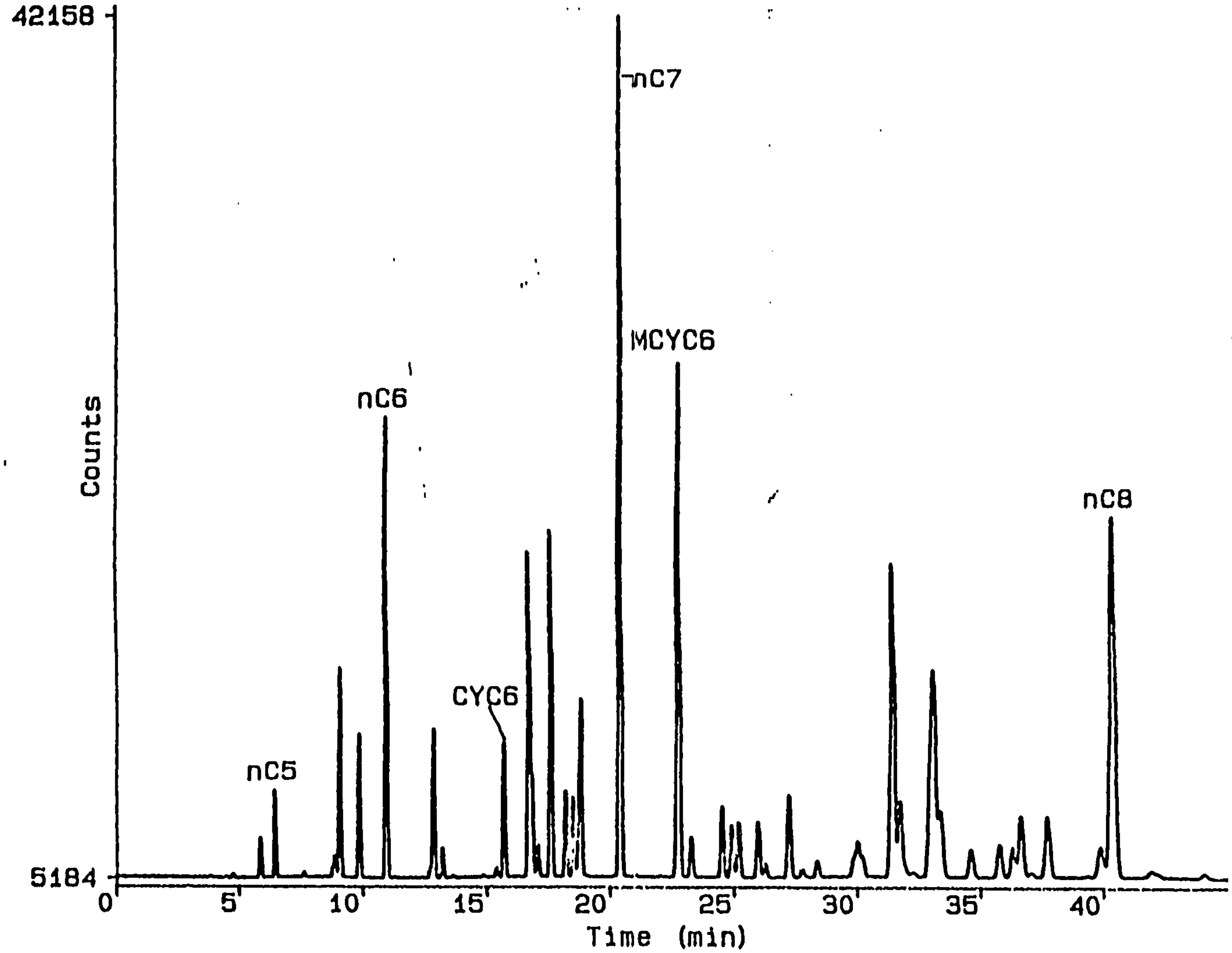


Data file: /HP/ALTA555
Report: 16060
Acquired: Thu May 9, 1996 2:46:45 pm
Time range: 0.00-45.00

Data file: /HP/ALTA556
Report: 16065
Acquired: Fri May 10, 1996 9: 41: 42 am
Time range: 0.00-45.00

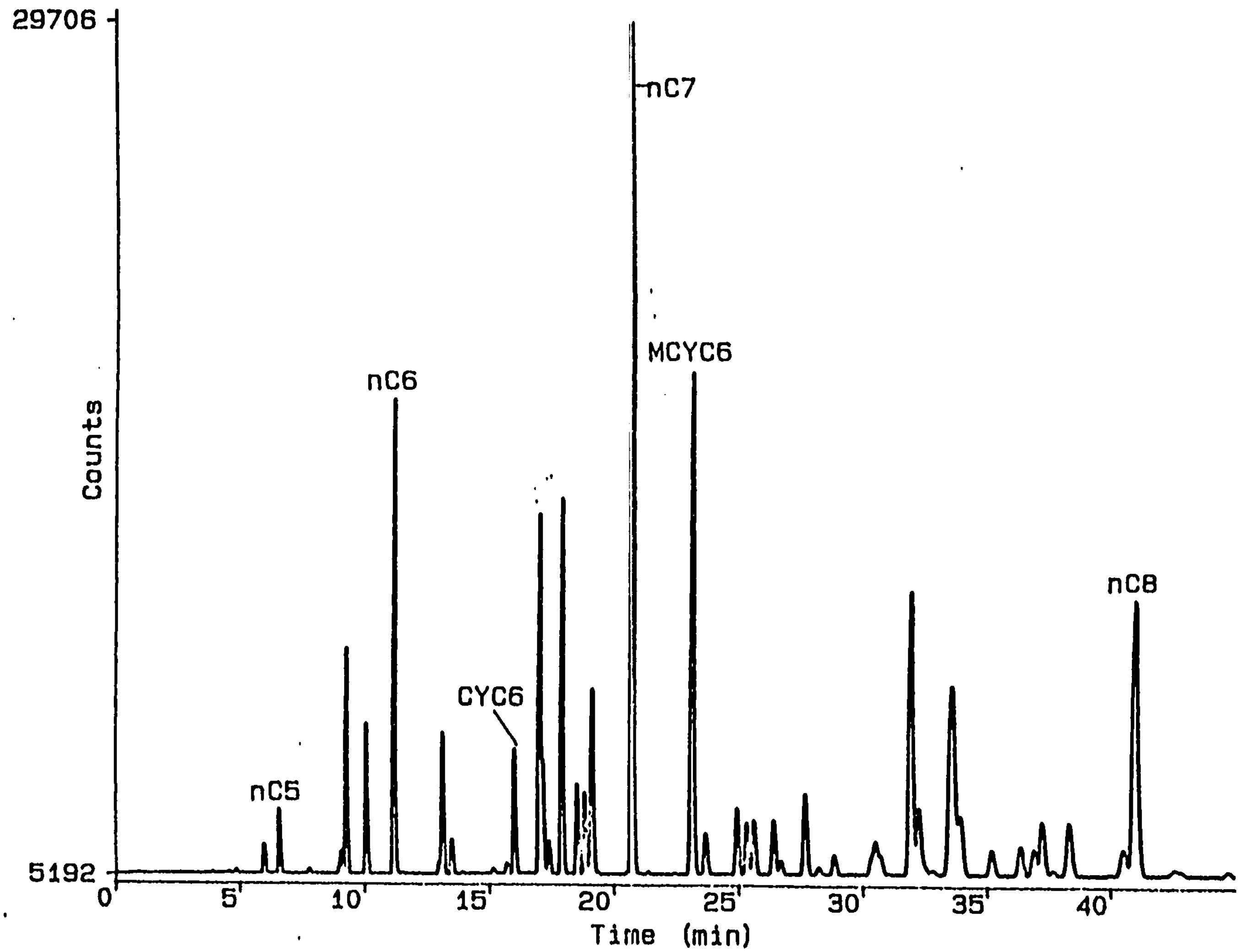


Data file: /HP/ALTA557
Report: 16066
Acquired: Fri May 10, 1996 10:56:28 am
Time range: 0.00-45.00



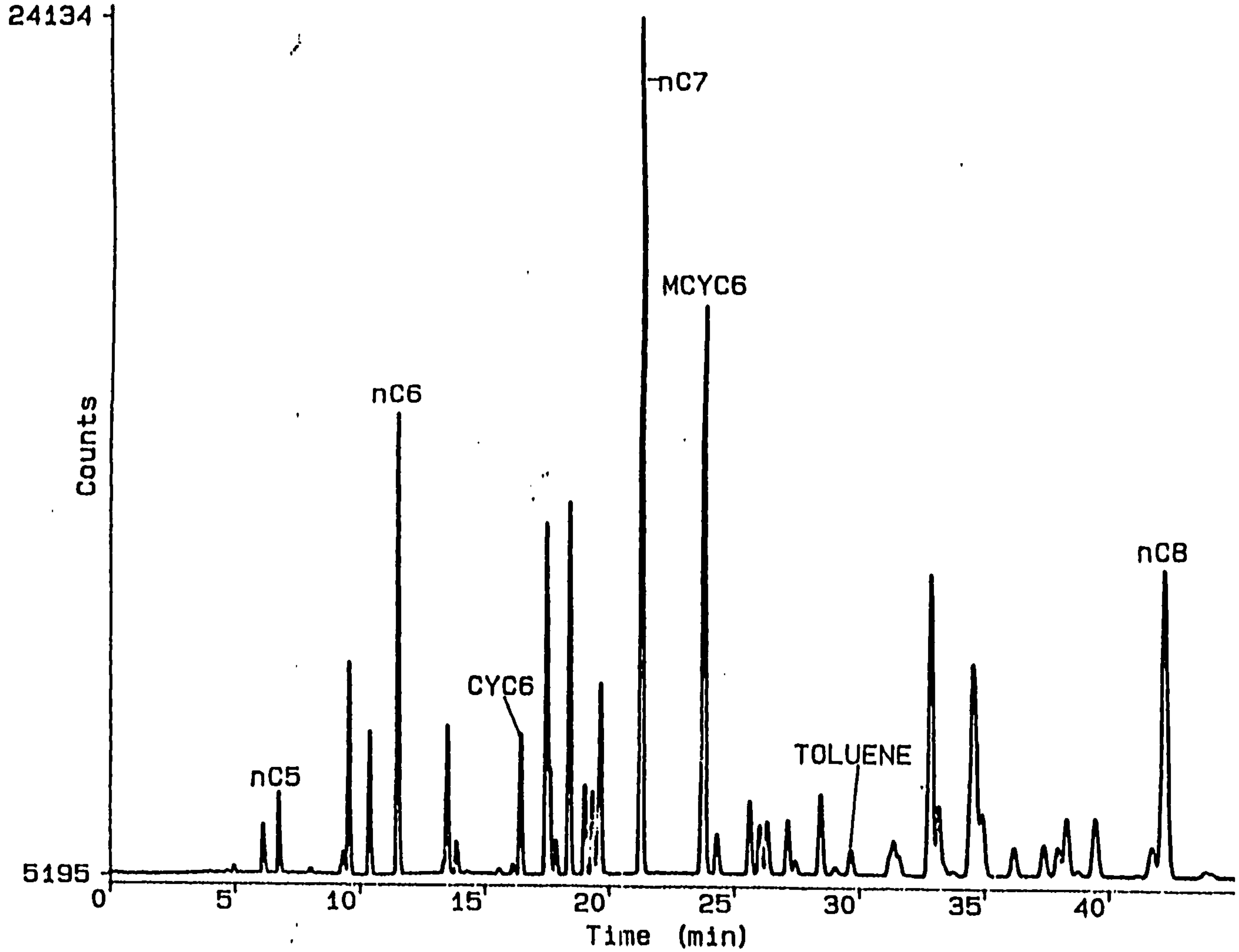
#2138 JORDAN ETAL MANYBERRIES 12-31-5-4W4

Data file: /HP/ALTA558
Report: 16067
Acquired: Fri May 10, 1996 12:10:51 pm
Time range: 0.00-45.00



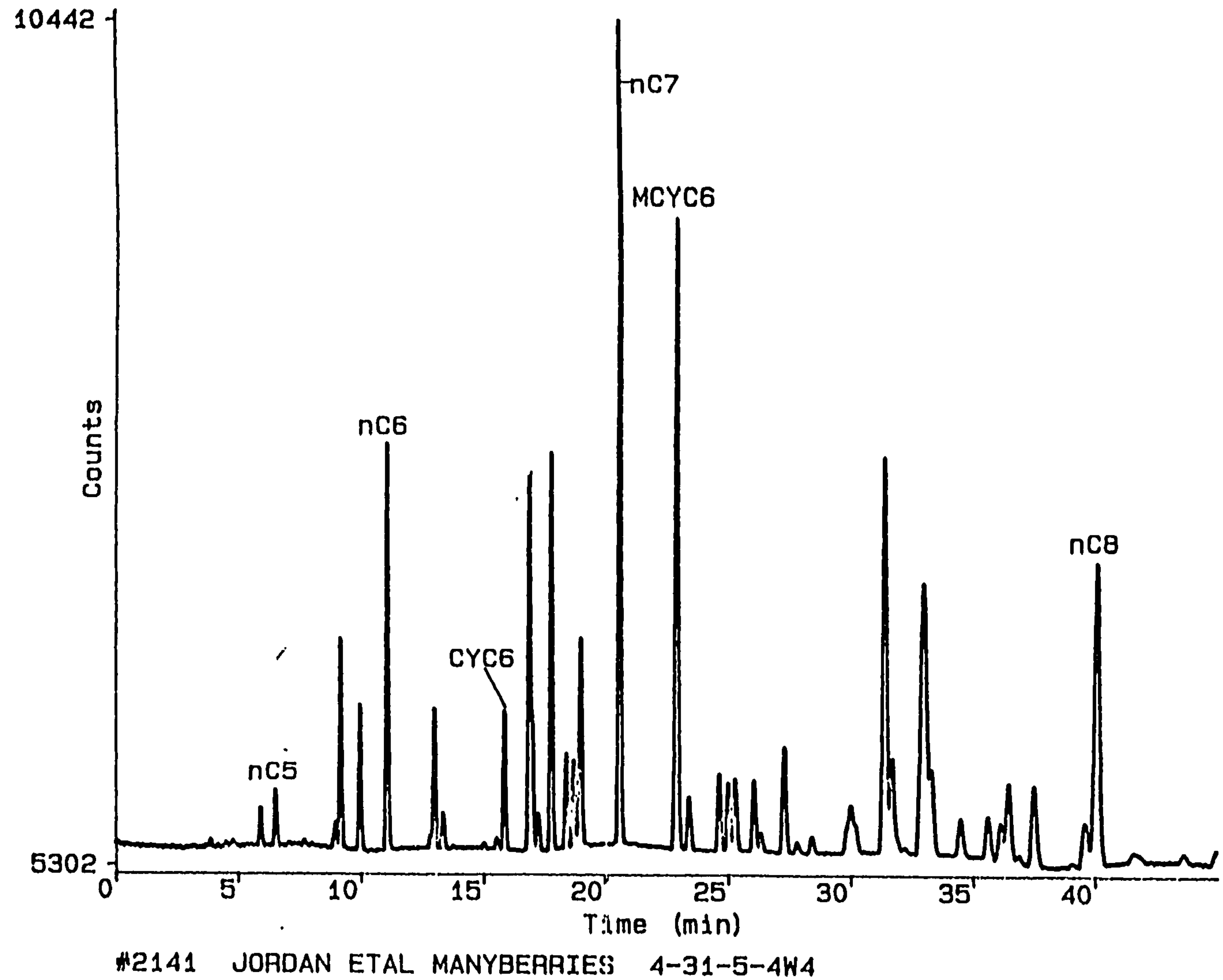
#2139 JORDAN ETAL MANYBERRIES 12-36-5-5W4

Data file: /HP/ALTA559
Report: 16085
Acquired: Fri May 10, 1996 2:39:55 pm
Time range: 0.00-45.00

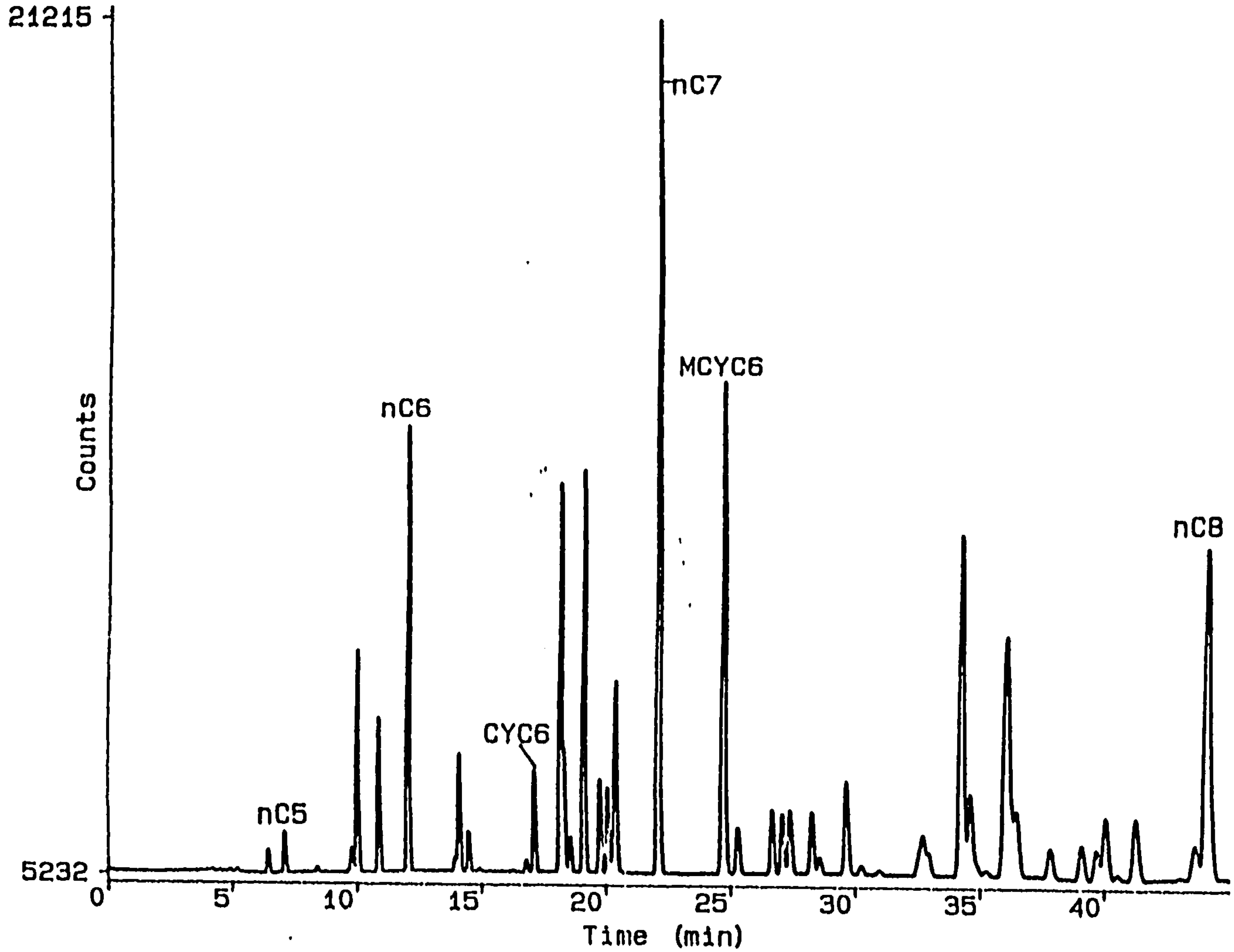


#2140 JORDAN MANYBERRIES 2-35-5-5W4

Data file: /HP/ALTA560
Report: None
Acquired: Mon May 13, 1996 10:01:22 am
Time range: 0.00-45.00

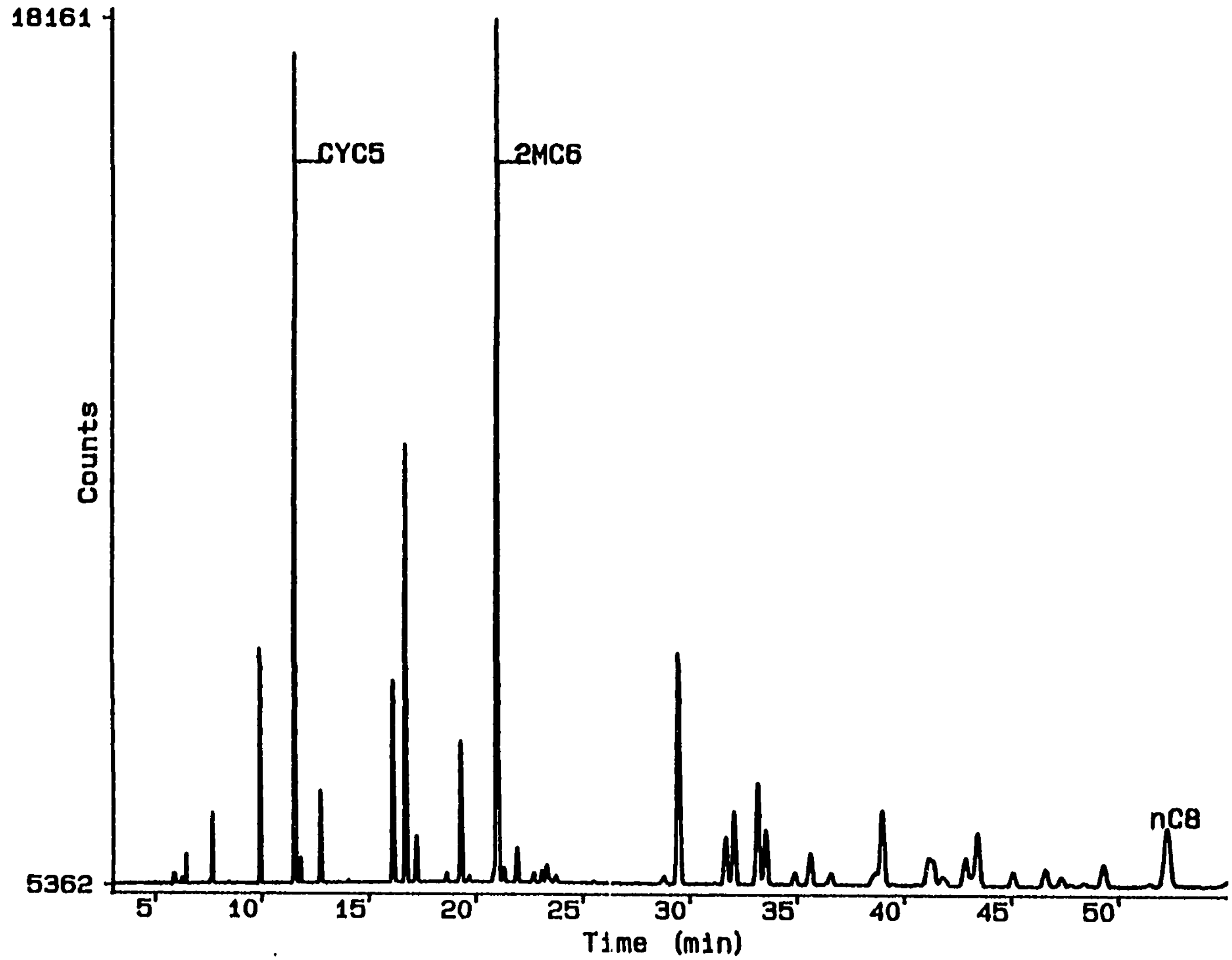


Data file: /HP/ALTA565
Report: 16116
Acquired: Tue May 14, 1996 10:59:38 am
Time range: 0.00-45.00

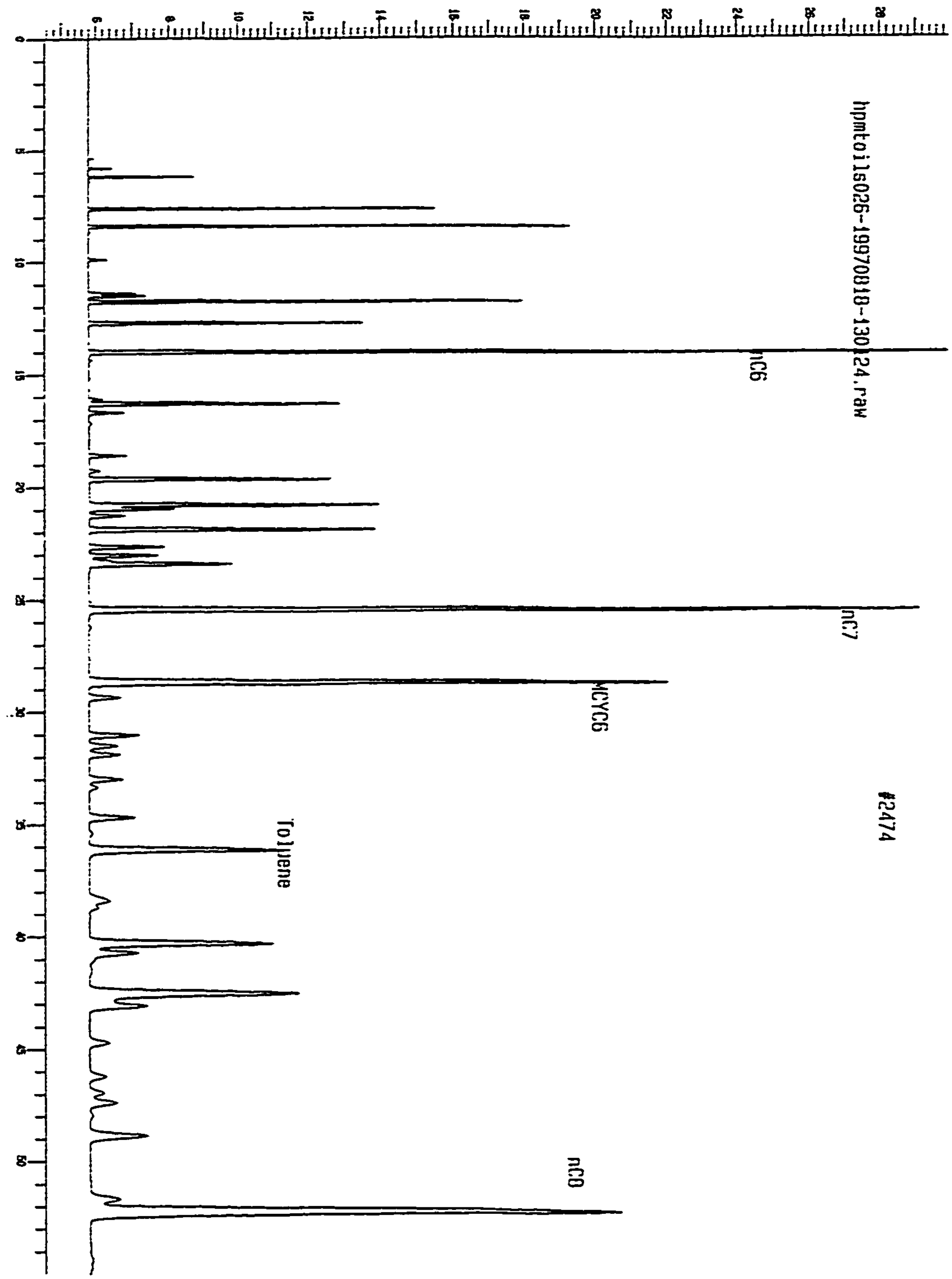


#2146 SAMEDAN MANYBERRIES 16-16-5-4W4

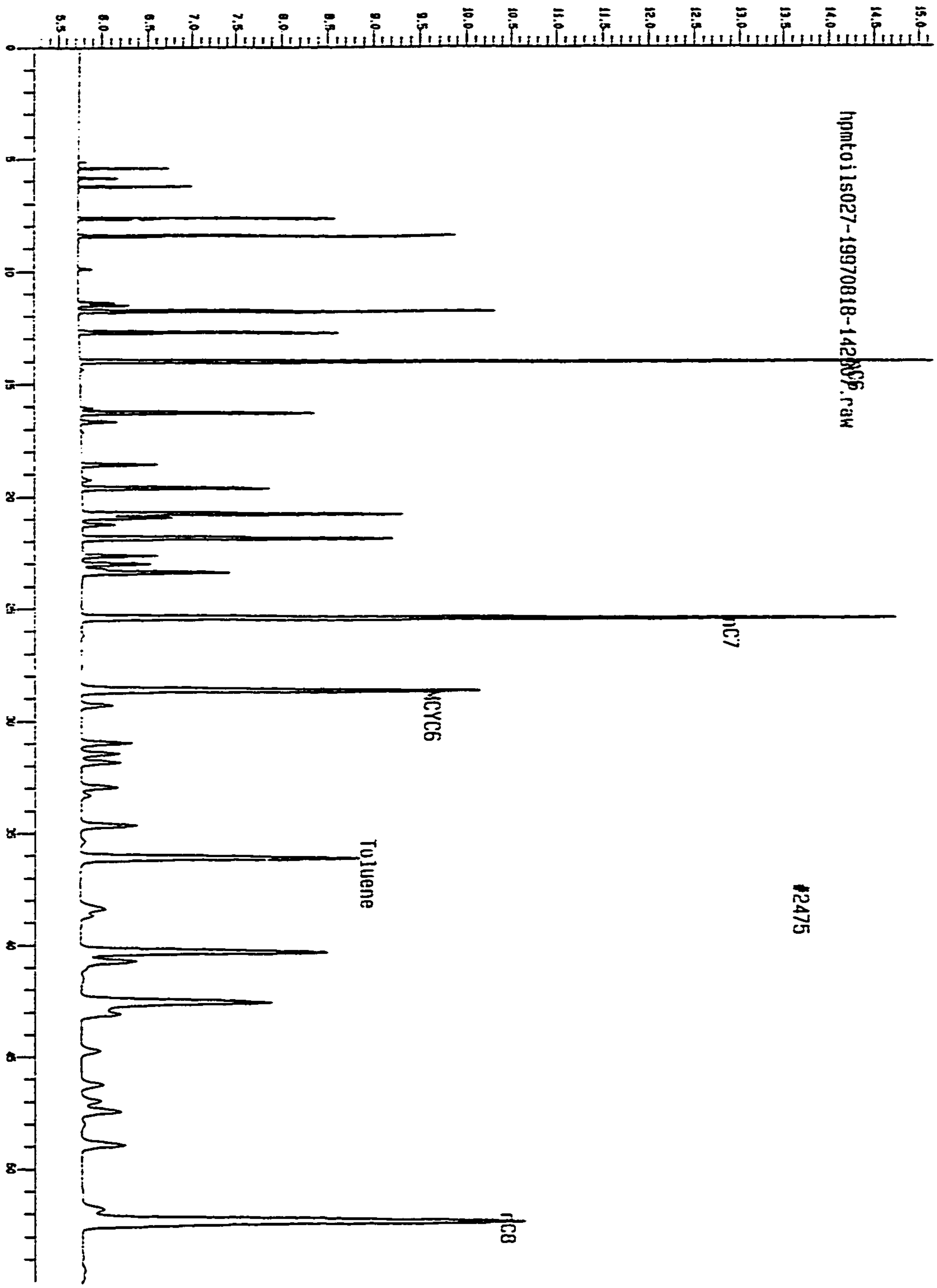
Data file: /HP/ALTA733
Report: None
Acquired: Wed Apr 30, 1997 1:41:54 pm
Time range: 3.00-55.00

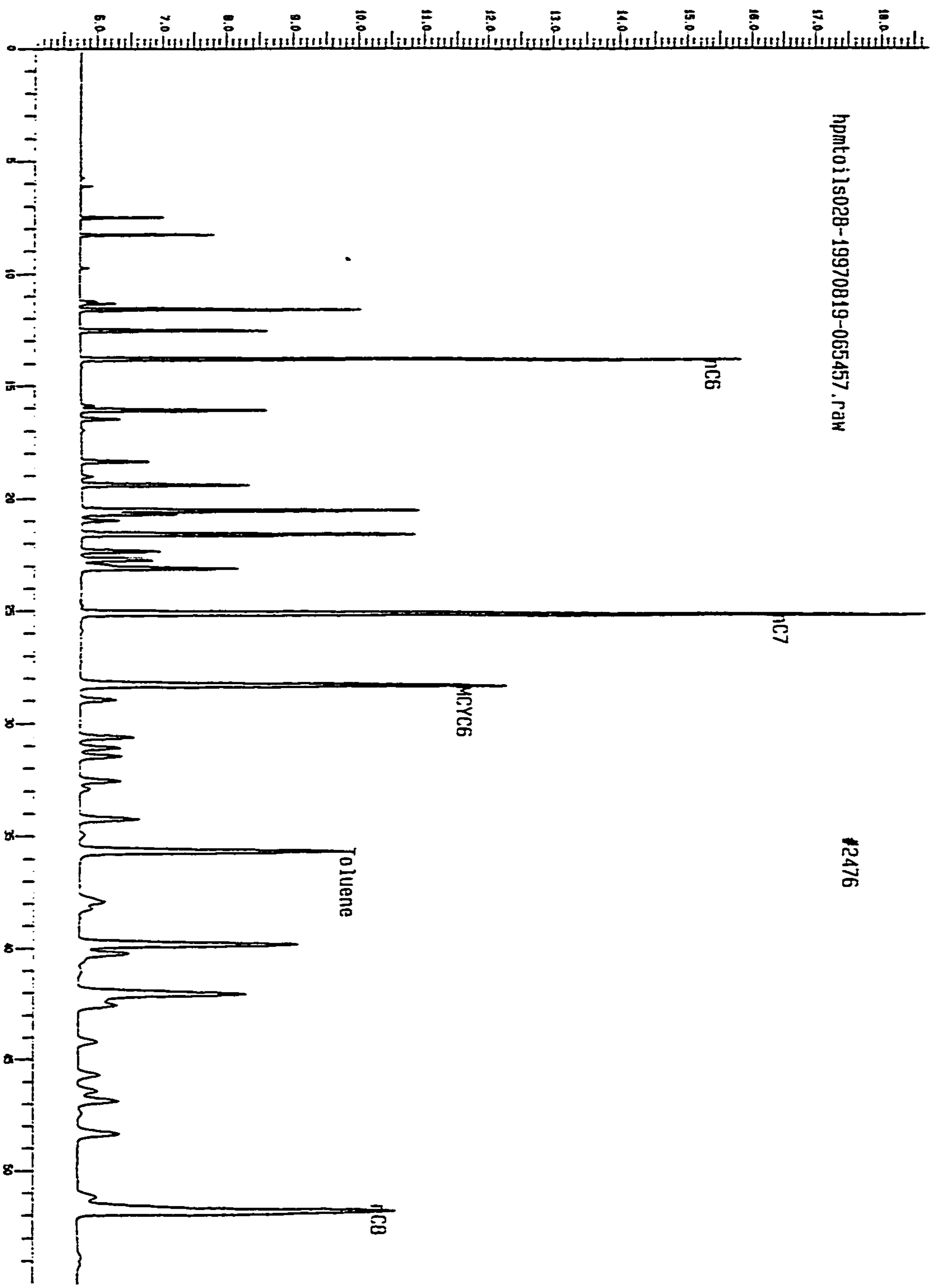


#2366 BLACK BUTTE 16-20-1-8W4 936-941 m



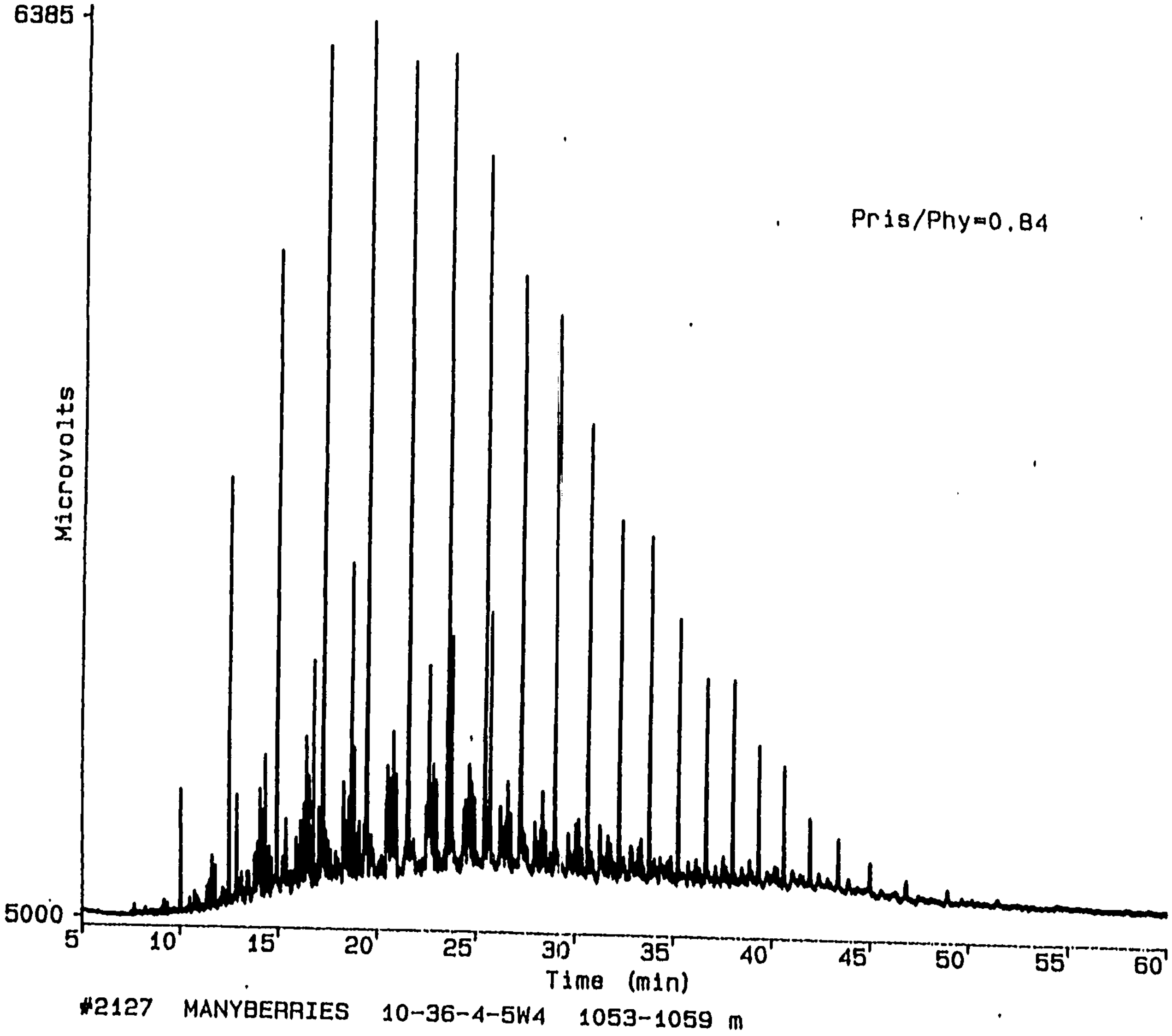
hpmtoils026-19970818-130124.raw
nC6
nC7
MCYC6
Toluene
nC8
#2474


nC6
nC7
MCYC6
Toluene
#2475
nC8

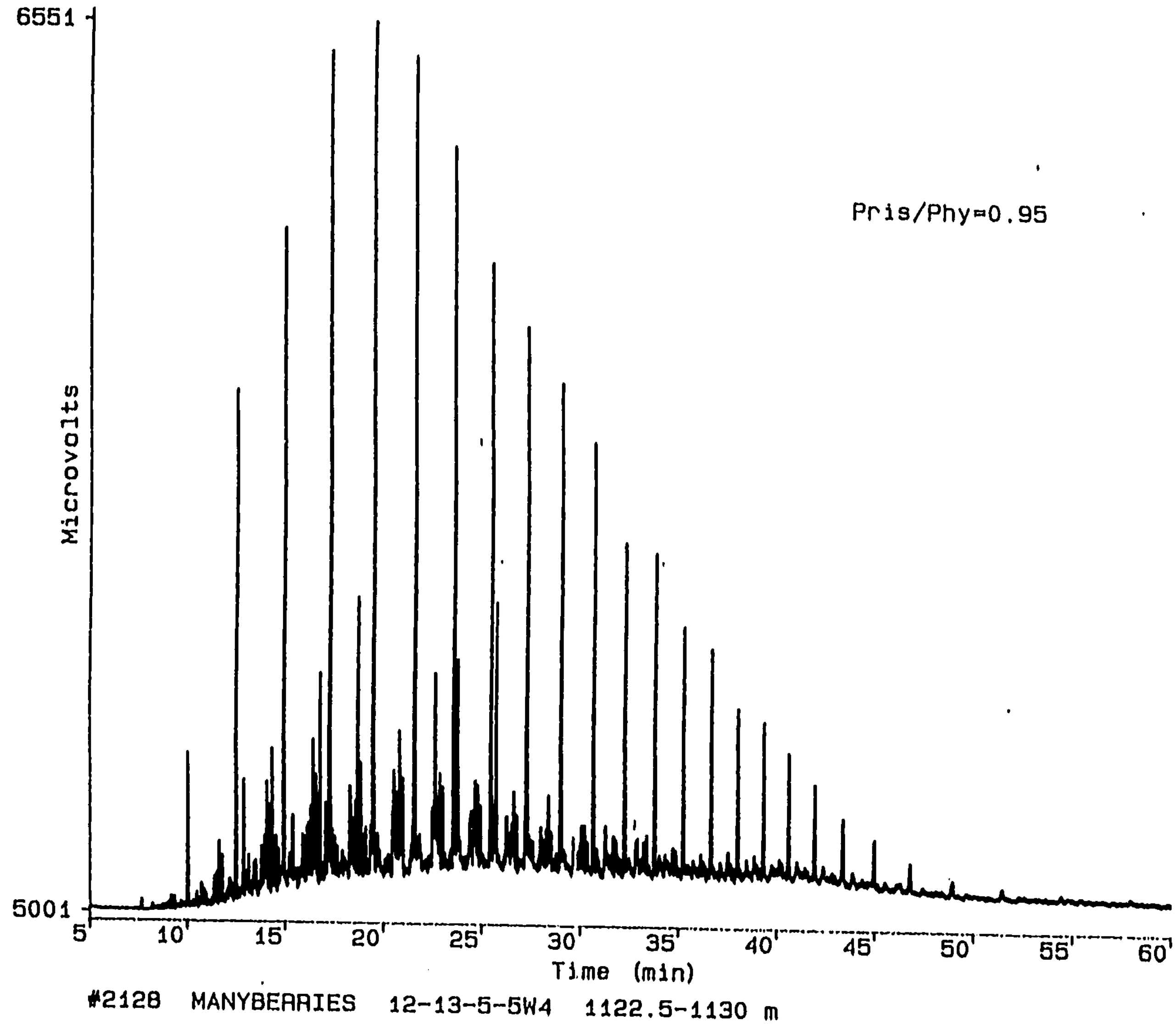

hpmtoils028-19970819-065457.raw
nC6
nC7
MCYC6
Toluene
#2476
nC8

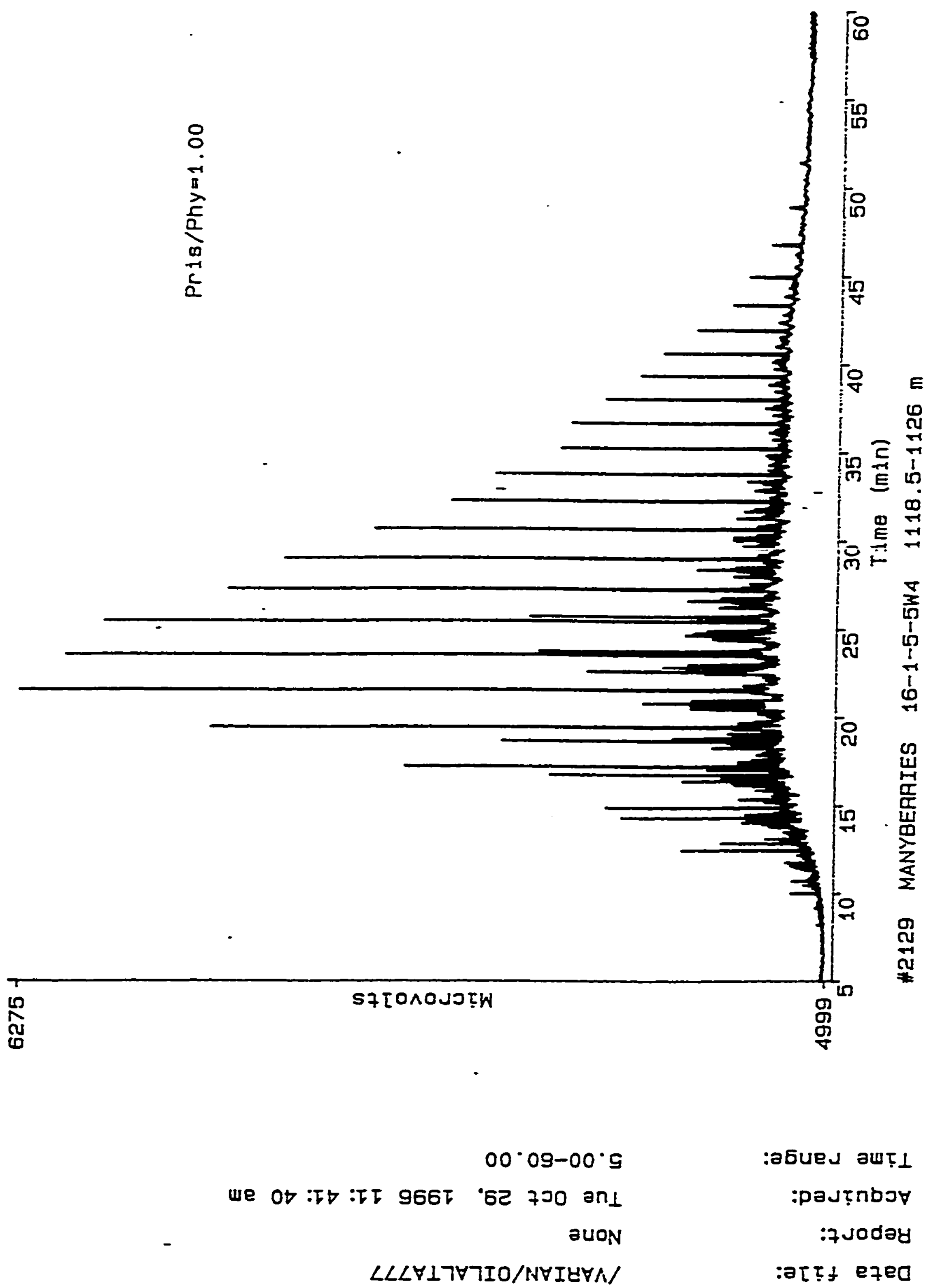
APPENDIX 5: C_{15+} SATURATE FRACTION GAS CHROMATOGRAPHY (GC) DATA FOR FAMILY M OILS

Data file:	/VARIAN/OILALTA775
Report:	None
Acquired:	Tue Oct 29, 1996 8:52:39 am
Time range:	5.00-60.00

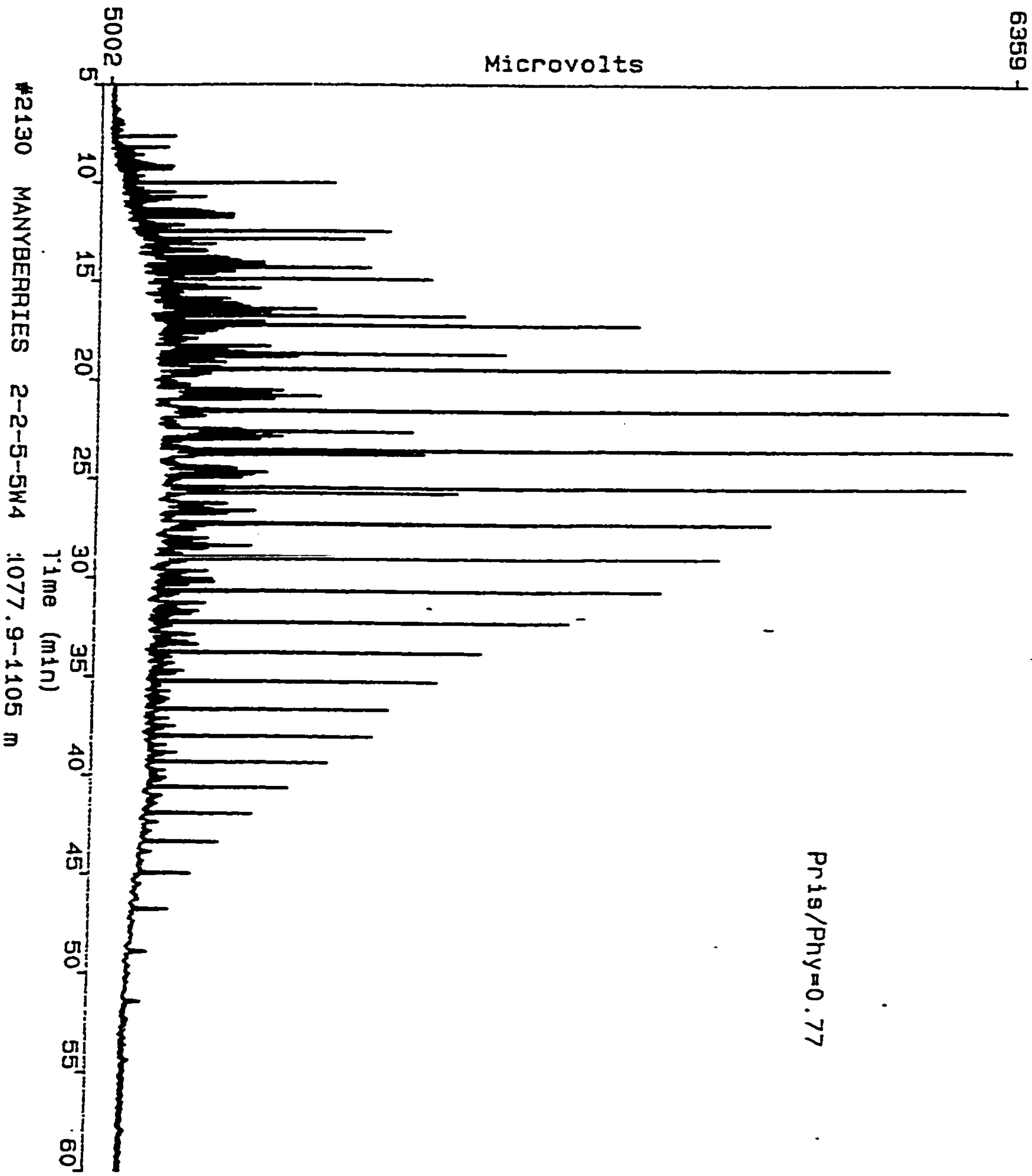


Data file:	/VARIAN/OILALTA776
Report:	None
Acquired:	Tue Oct 29, 1996 10:22:44 am
Time range:	5.00-60.00

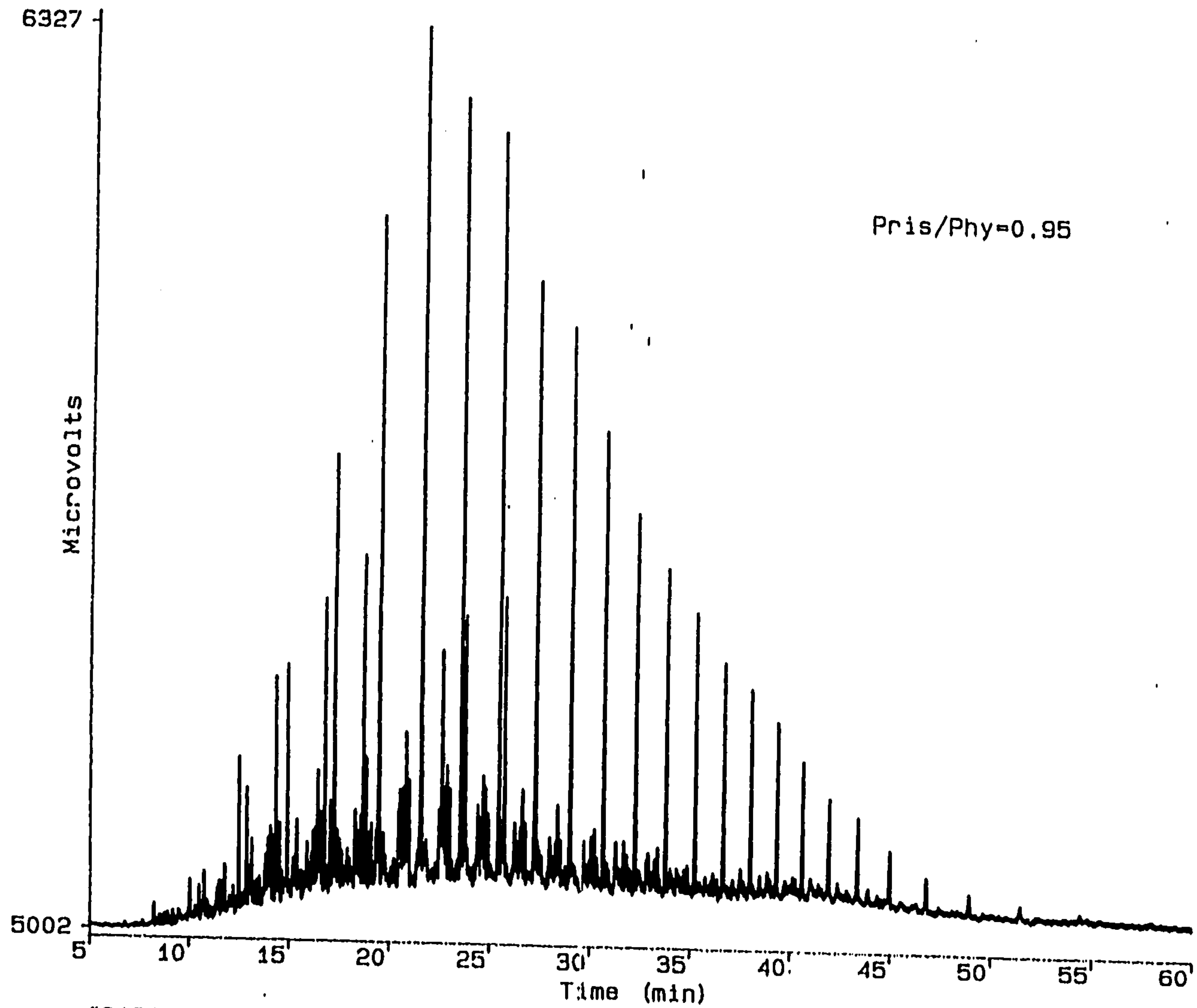



Pris/Phy=1.00
6275
Microvolts
4999
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)
#2129 MANYBERRIES 16-1-5-5W4 1118.5-1126 m
Data file: /VARIAN/OILALTA777
Report: None
Acquired: Tue Oct 29, 1996 11:41:40 am
Time range: 5.00-60.00

Data file: /VARIAN/OILALTA778
Report: None
Acquired: Tue Oct 29, 1996 1:02:37 pm
Time range: 5.00-60.00

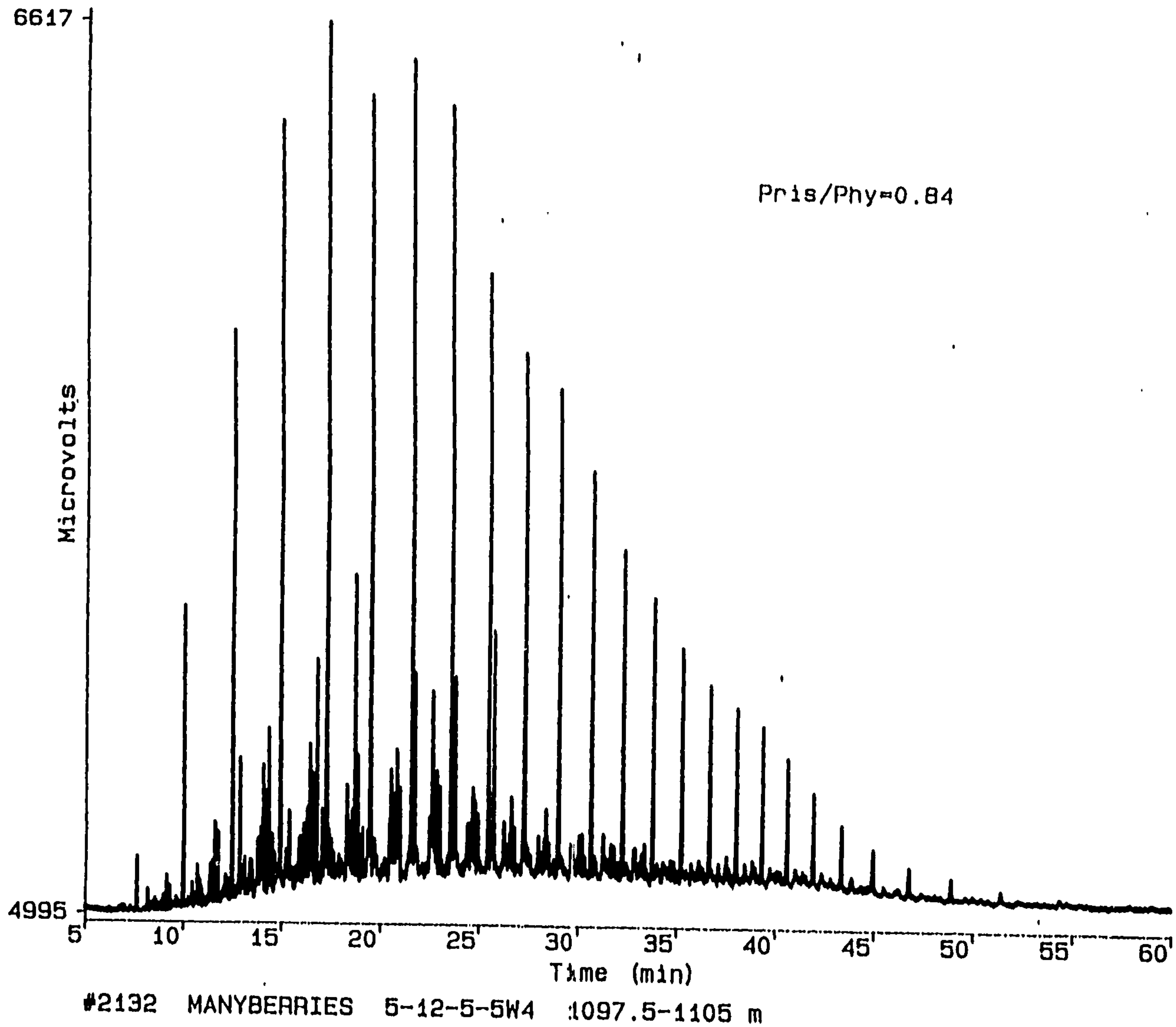


Data file:	/VARIAN/OILALTA779
Report:	None
Acquired:	Tue Oct 29, 1996 2:20:55 pm
Time range:	5.00-60.00



#2131 MANYBERRIES 4-7-5-4W2 1133-1142 m

Data file: /VARIAN/OILALTA780
Report: None
Acquired: Wed Oct 30, 1996 7:38:37 am
Time range: 5.00-60.00



Data file: /VARIAN/OILALTA781
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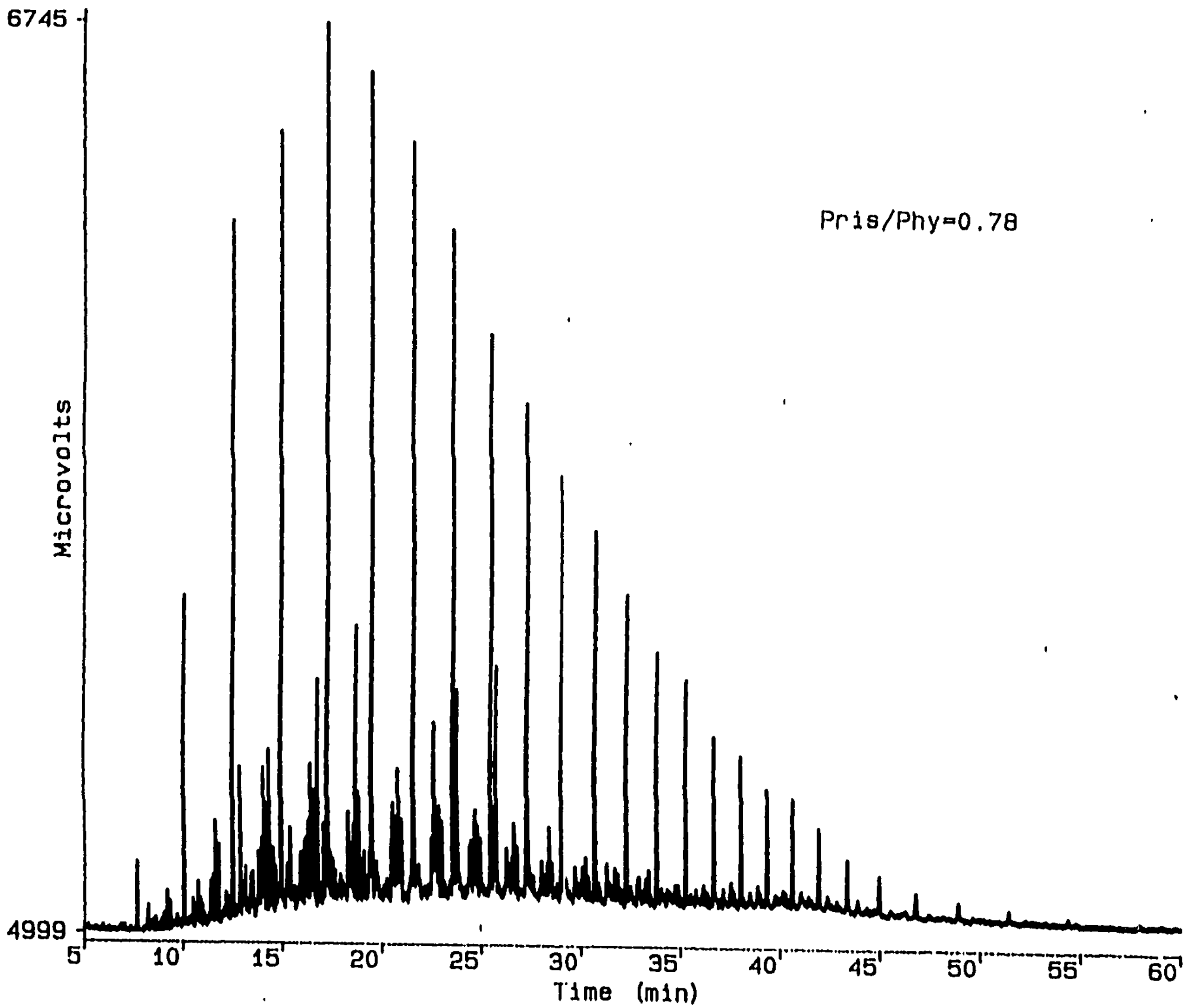
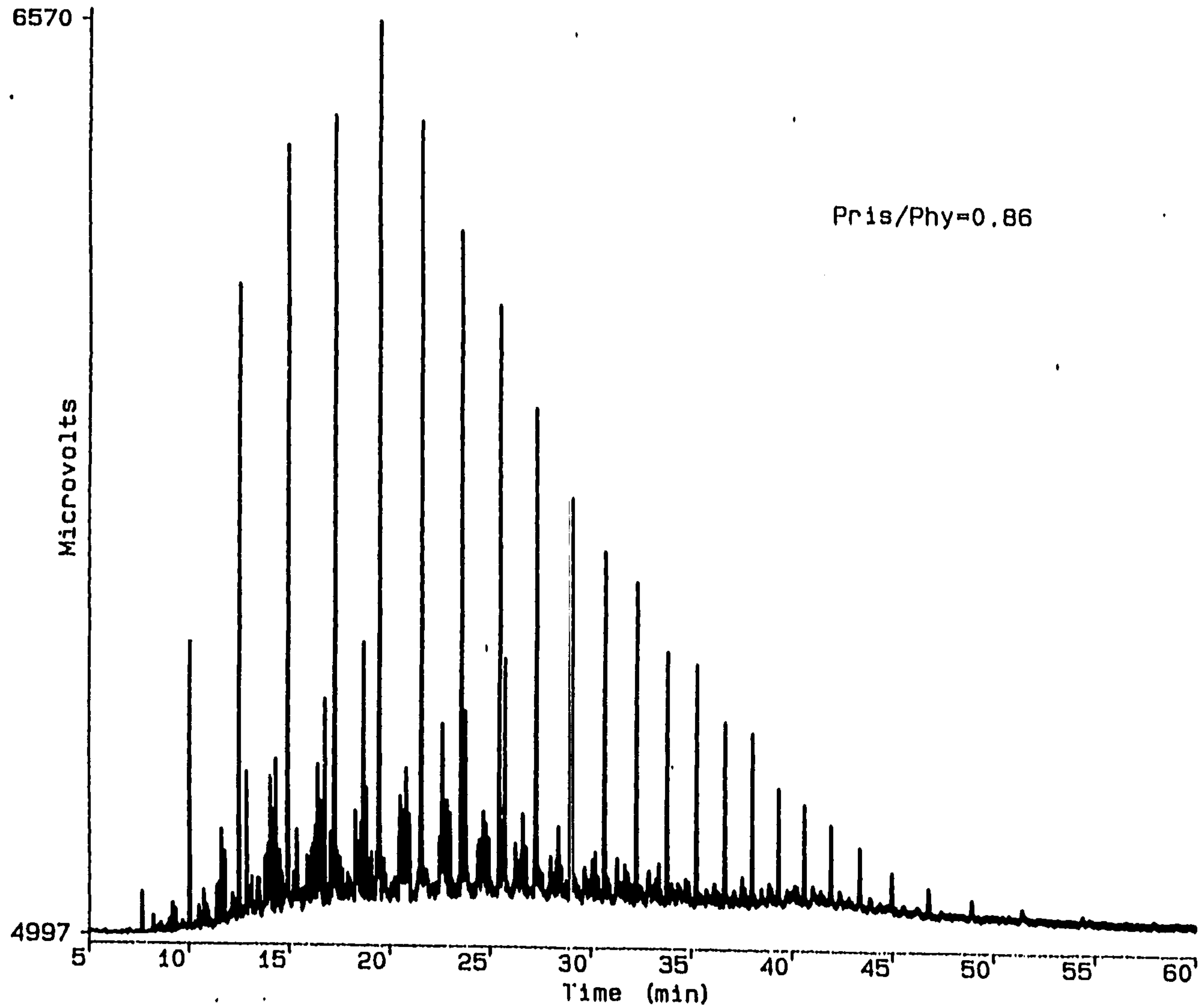
Time range: 5.00-60.00

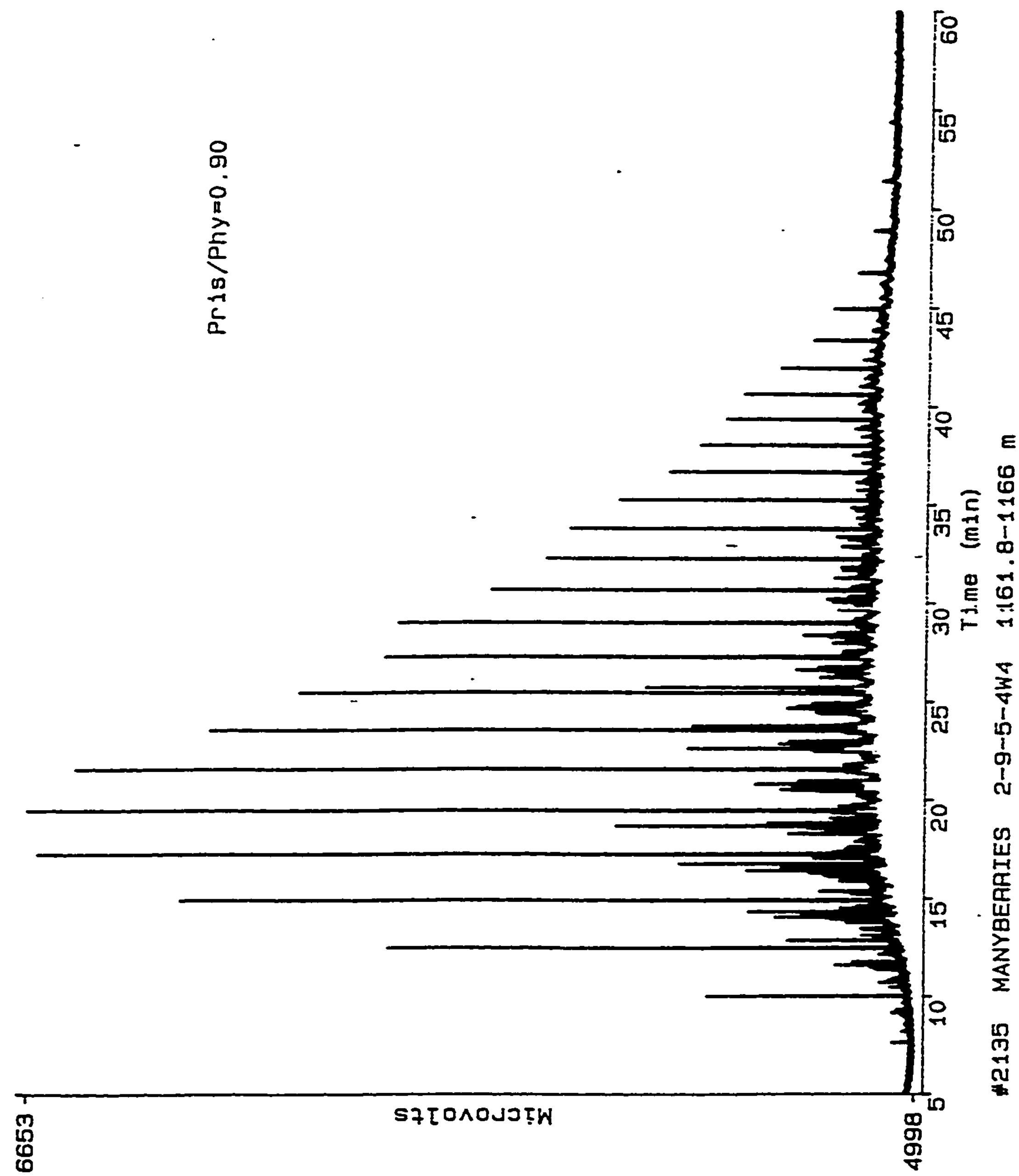


#2133 MANYBERRIES 12-15-5-4W4 1156.2-1158 m

Data file: /VARIAN/OILALTA782
Report: None
Acquired: Wed Oct 30, 1996 10:45:17 am
Time range: 5.00-60.00

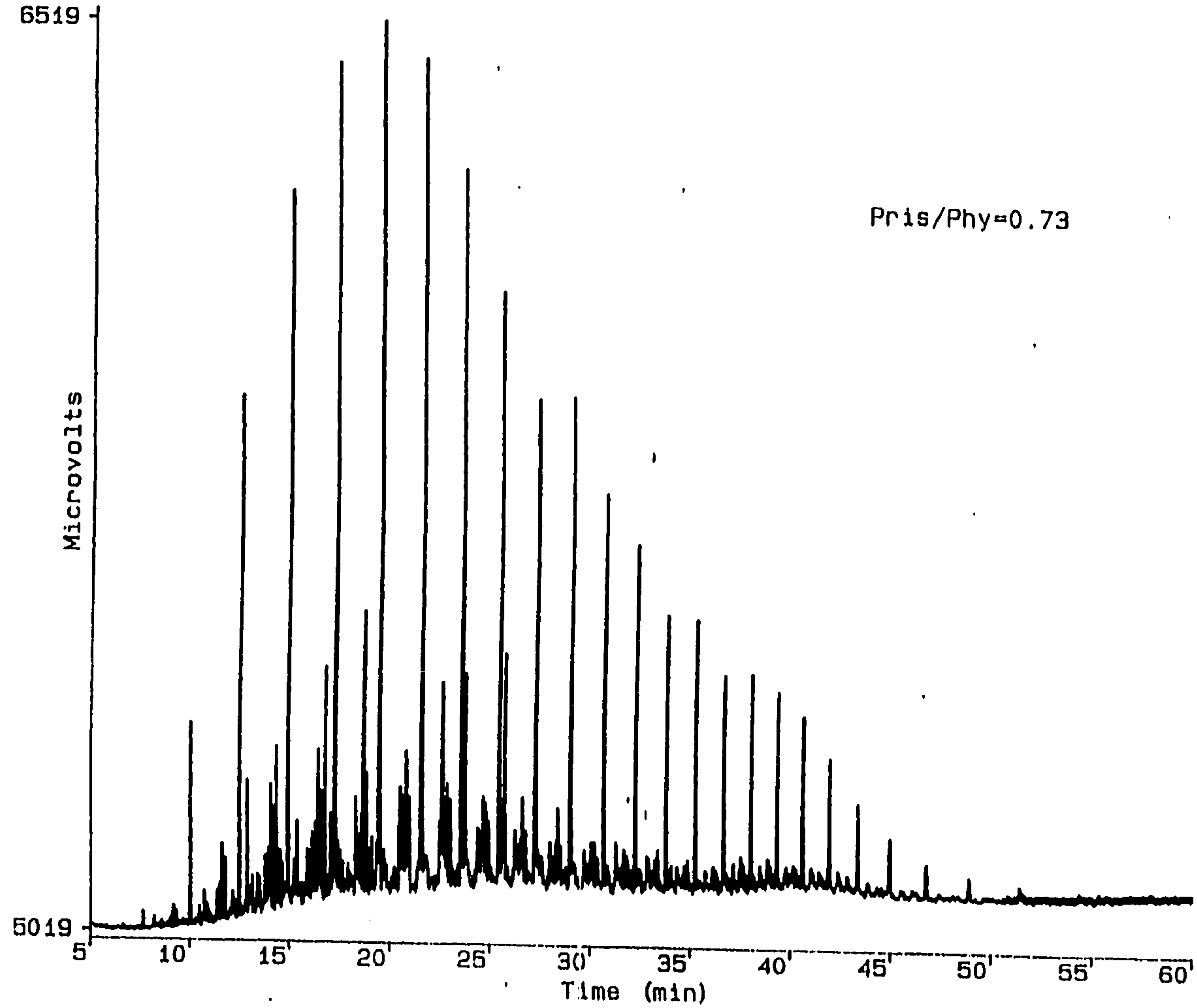


#2134 MANYBERRIES 16-9-5-4W4 1170.5-1173 m



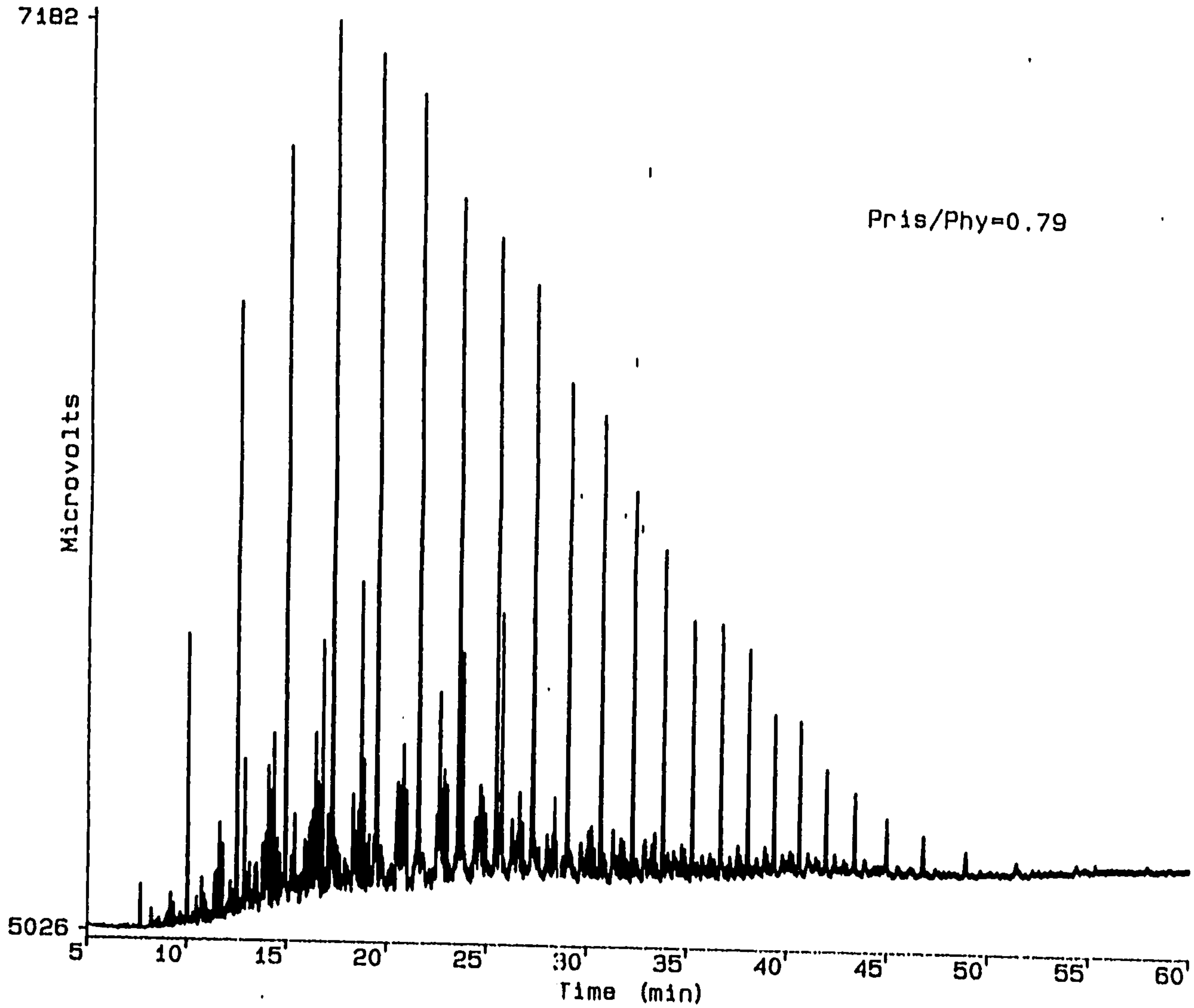
Data file: /VARIAN/OILALTA783
Report: None
Acquired: Wed Oct 30, 1996 1:14:17 pm
Time range: 5.00-60.00

Data file: /VARIAN/OILALTA784
Report: None
Acquired: Wed Oct 30, 1996 2:39:19 pm
Time range: 5.00-60.00



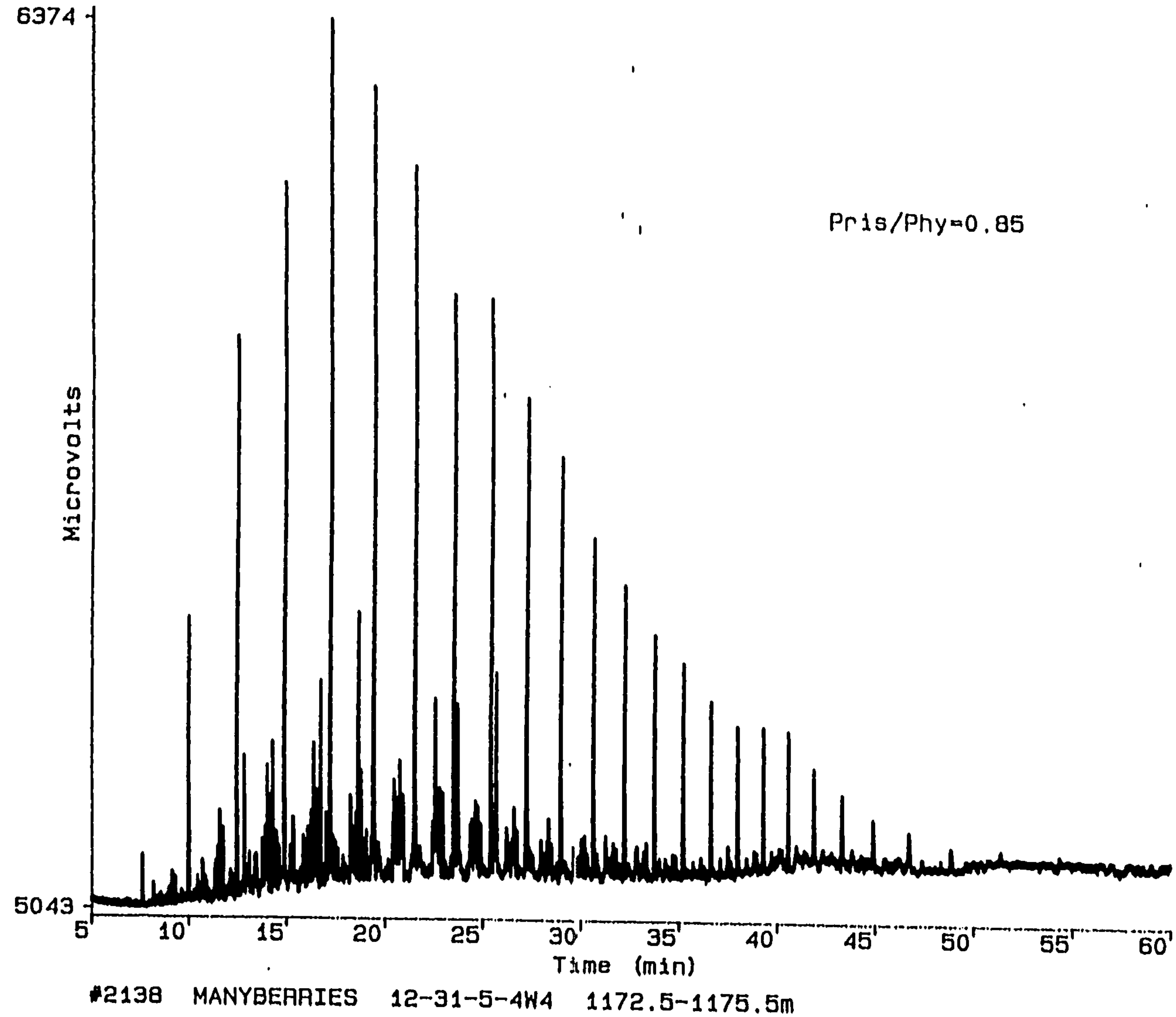
#2136 MANYBERRIES 8-14-4-5W4 1071-1075 m

Data file: /VARIAN/OILALTA785
Report: None
Acquired: Thu Oct 31, 1996 8:32:06 am
Time range: 5.00-60.00



#2137 MANYBERRIES 14-11-4-5W4 1063.6-1066 m

Data file:	/VARIAN/OILALTA786
Report:	None
Acquired:	Thu Oct 31, 1996 10: 35: 41 am
Time range:	5.00-60.00



Data file: /VARIAN/OILALTA787
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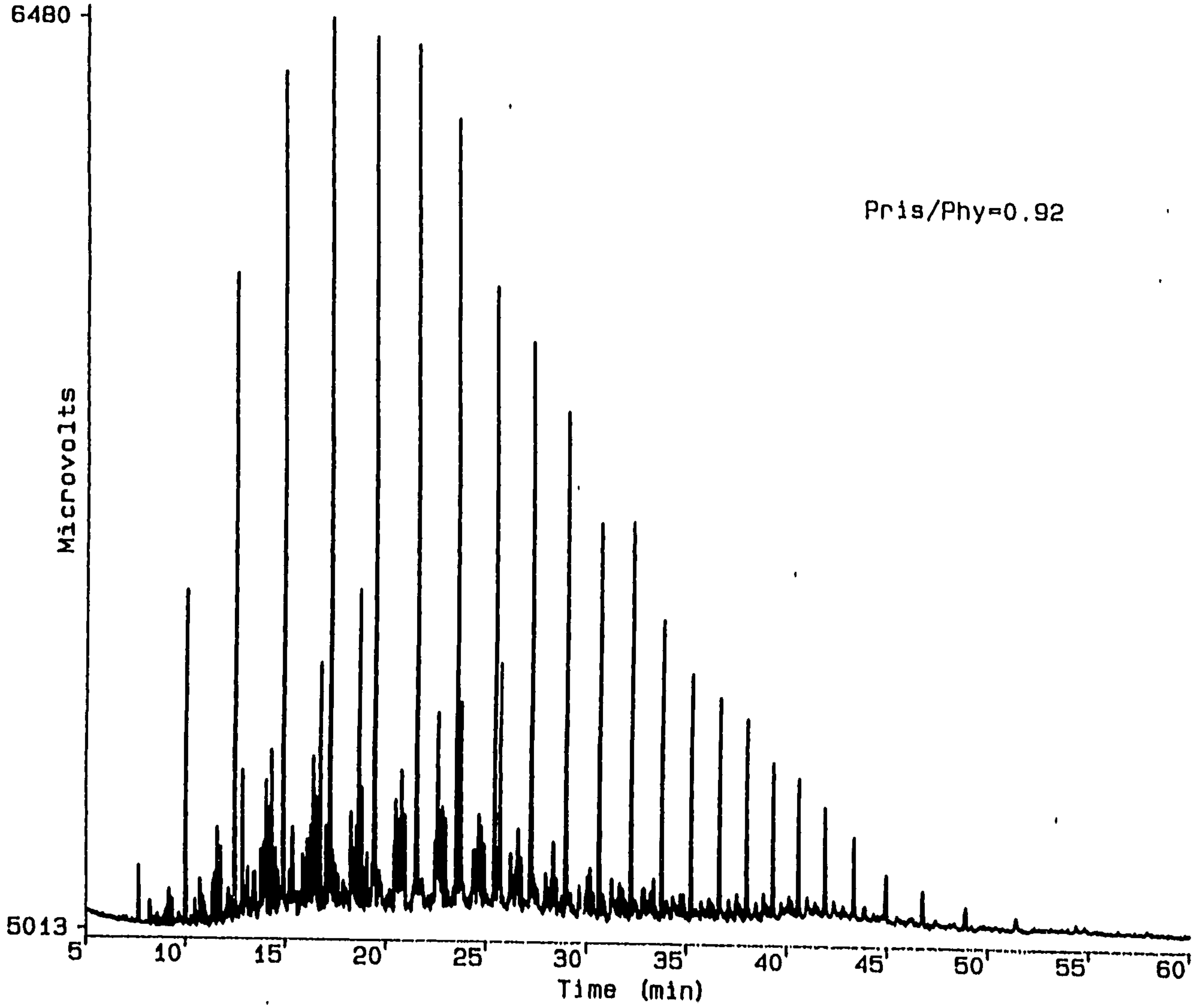

#2139 MANYBERRIES 12-36-5-5W4 1156.8-1161.8

Data file: /VARIAN/OILALTA788
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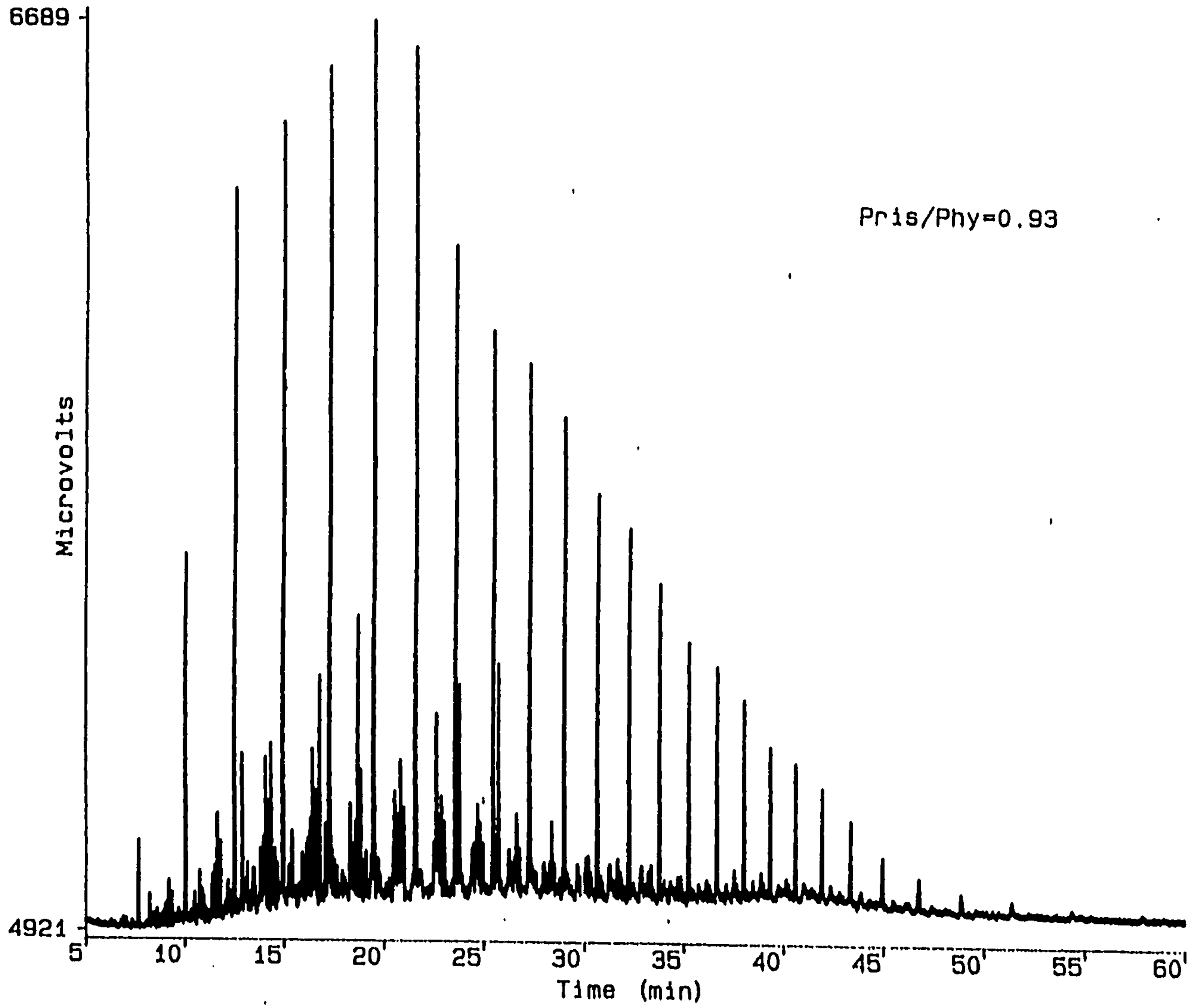
Acquired: Thu Oct 31, 1996 1:25:56 pm
Time range: 5.00-60.00



#2140 MANYBERRIES 2-35-5-5W4 1181.7-1184.2 m

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Report: None
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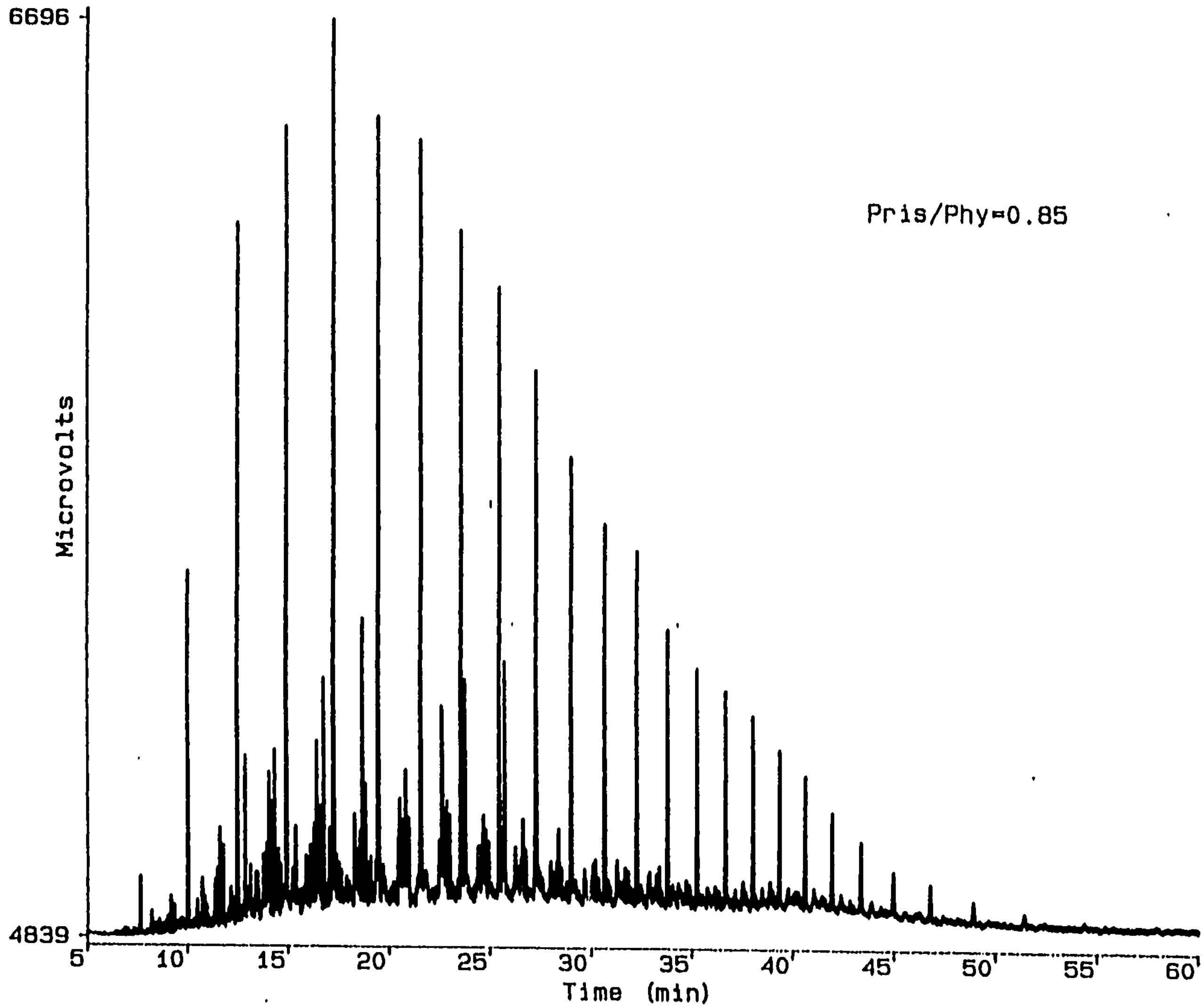
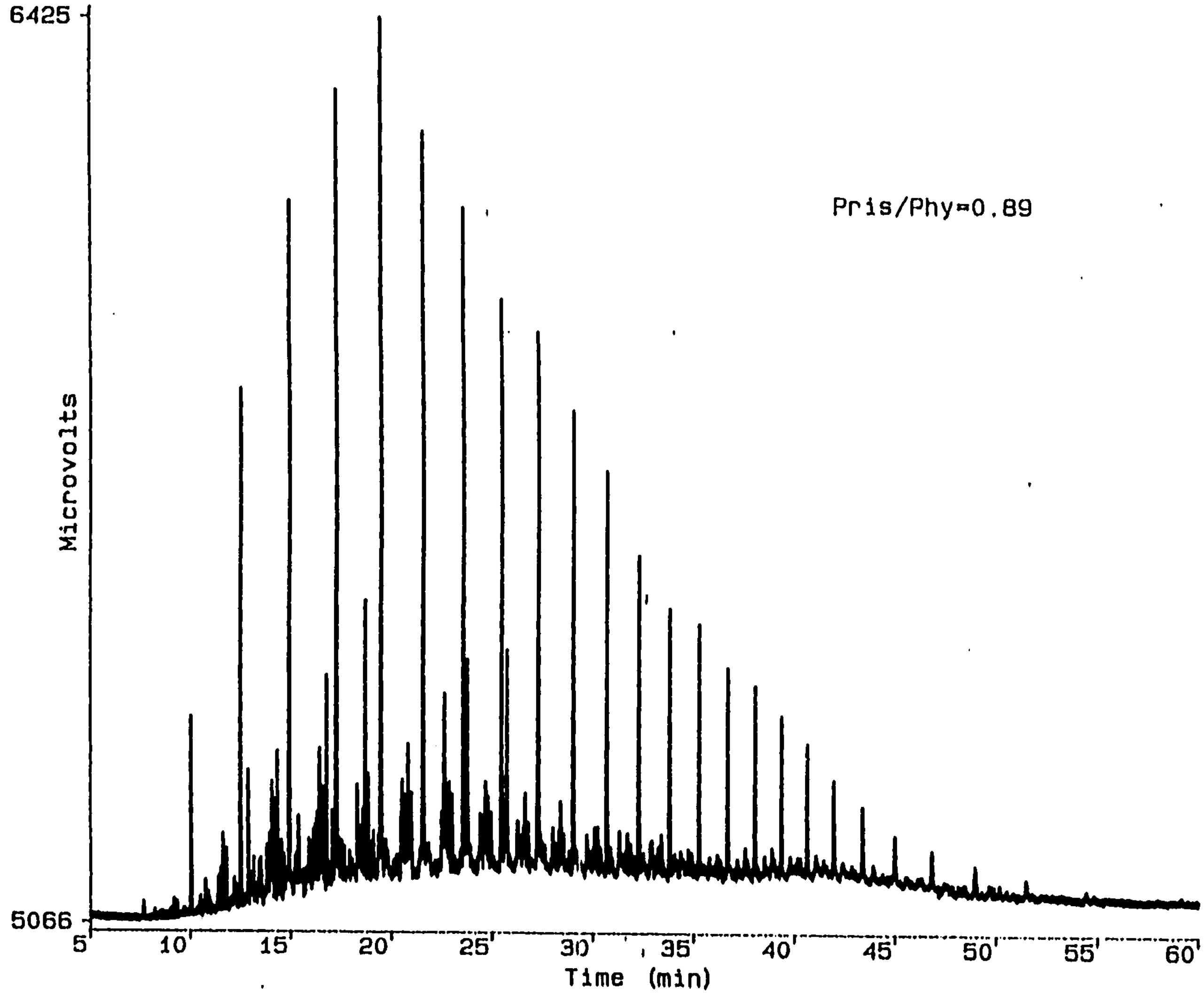
Time range: 5.00-60.00



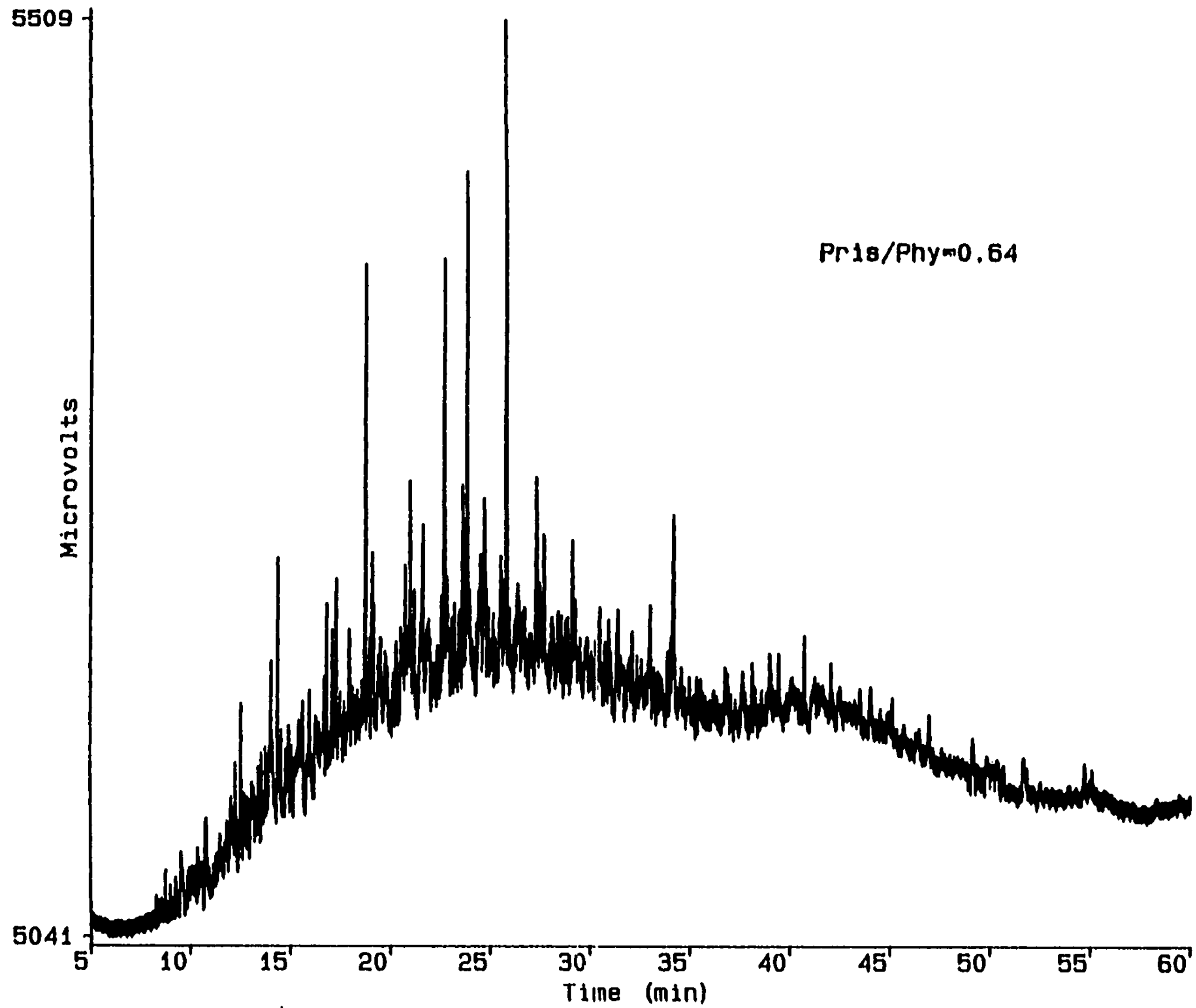
#2141 MANYBERRIES 4-31-5-4W4 1189.5-1193.5 m

Data file:	/VARIAN/OILALTA794
Report:	None
Acquired:	Mon Nov 4, 1996 8:46:36 am
Time range:	5.00-60.00



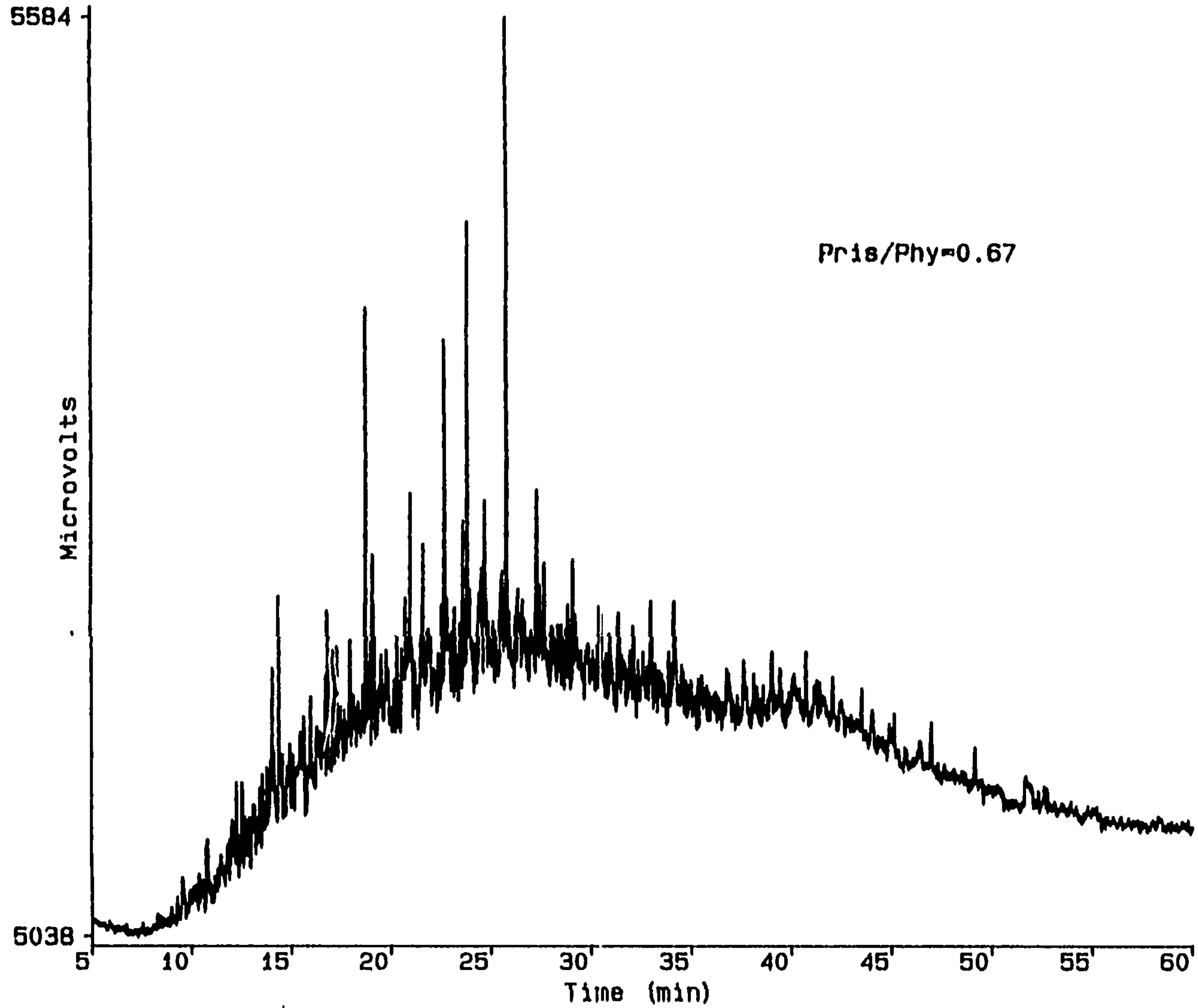
#2146 MANYBERRIES 16-16-5-4W4 1166-1167.5 m

Data file: /VARIAN/OILALTA862
Report: 18051
Acquired: Tue Feb 18, 1997 7: 43: 59 am
Time range: 5.00-60.00

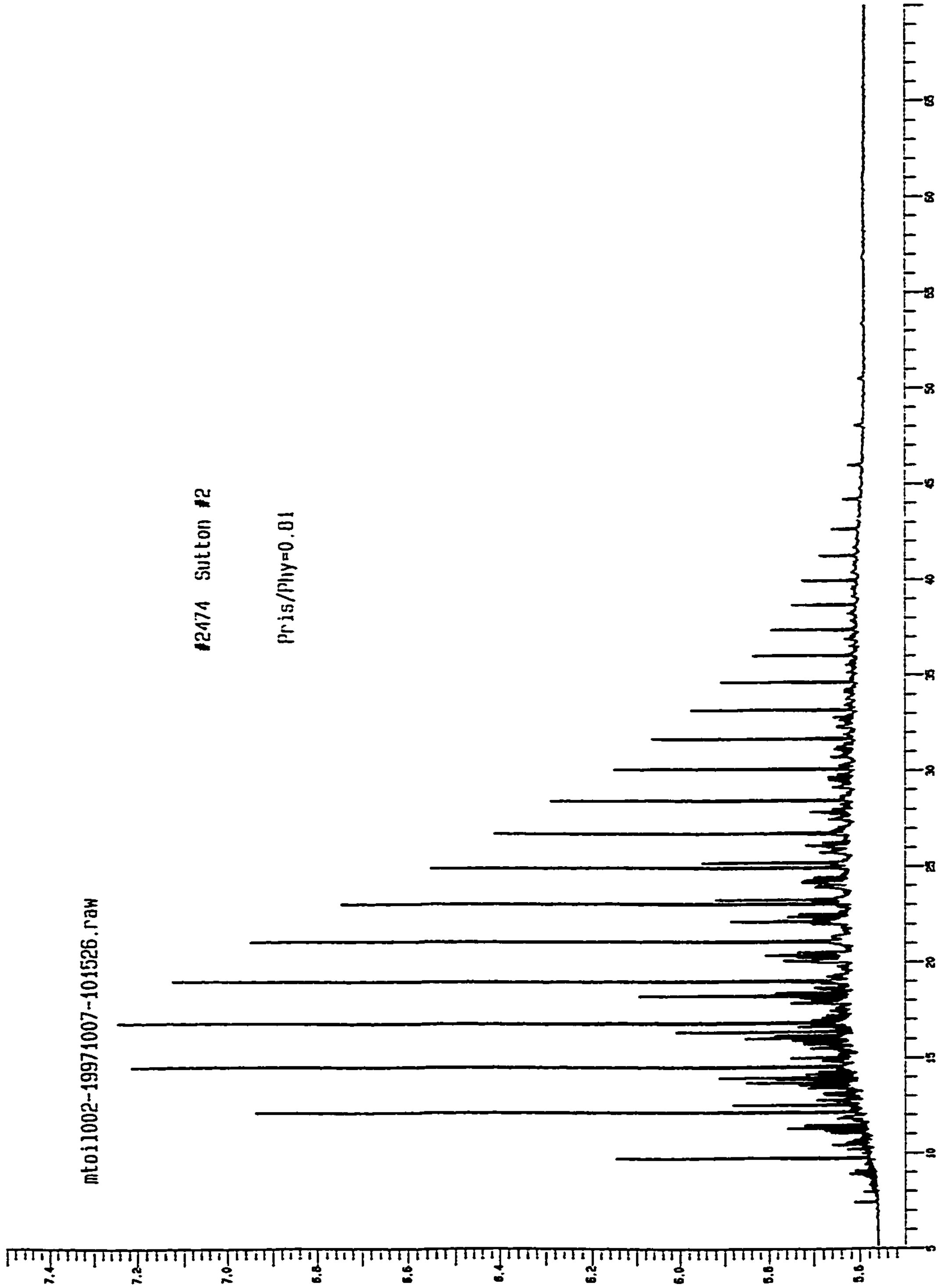


#2365 BLACK BUTTE 9-20-1-8W4 936.5-940.0 m

Data file: /VARIAN/OILALTA863
Report: 18054
Acquired: Tue Feb 18, 1997 9:11:36 am
Time range: 5.00-60.00



#2366 BLACK BUTTE 16-20-1-8W4 936-941 m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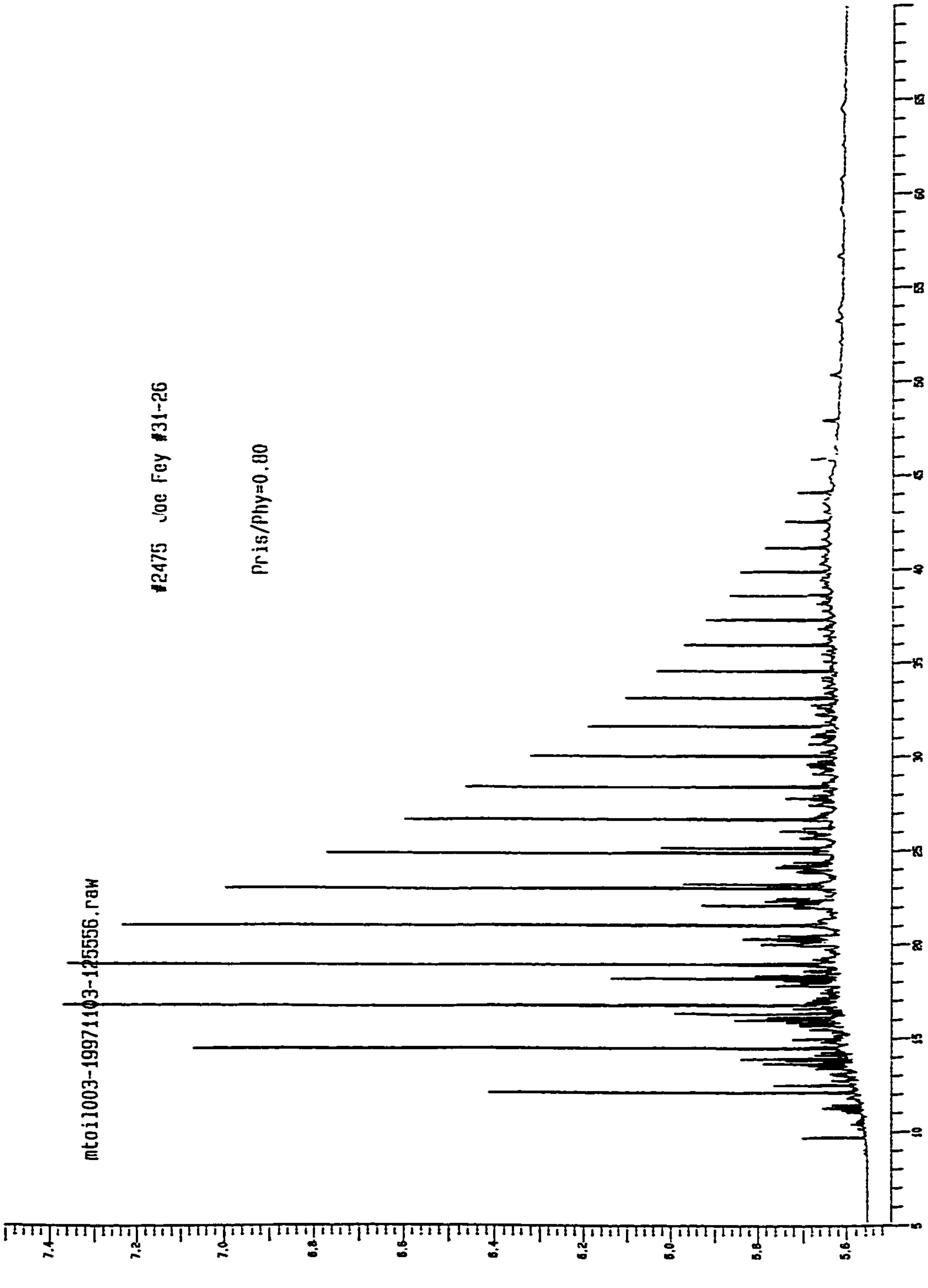
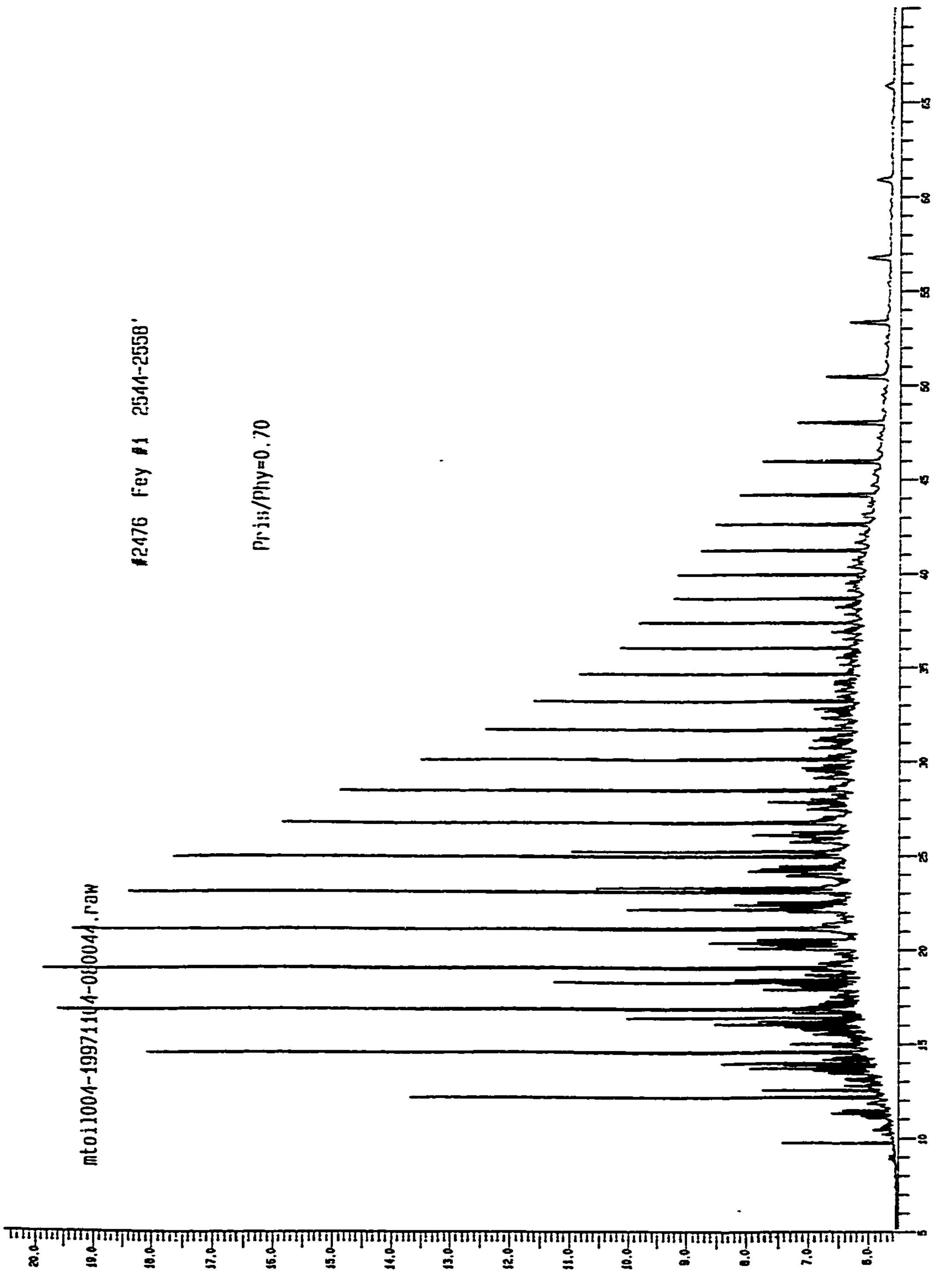
#2474 Sutton #2
Pris/Phy=0.01


mtoil003-19971103-125556.raw
#2475 Joe Fey #31-26
Pris/Phy=0.80


mtoil004-19971104-080044.raw
#2476 Fey #1 2544-2558'
Pris/Phy=0.70

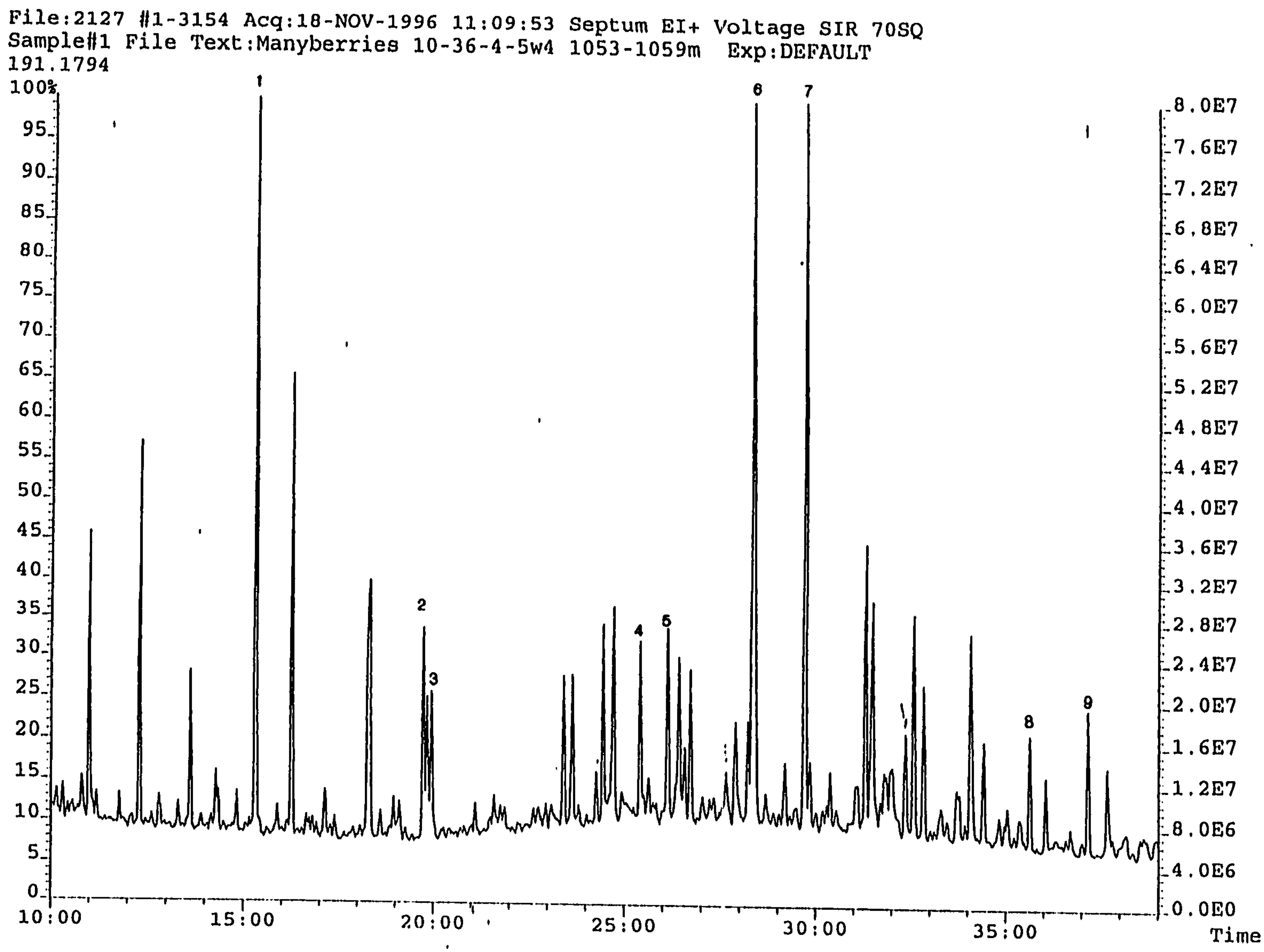
APPENDIX 6: GAS CROMATOGRAPHY/MASS SPECTROMETERY (GCMS) DATA FOR FAMILY M OILS

A m/z 191

1	C_{23} tricyclic diterpane
2	C_{24} tetracyclic terpane
3	C_{26} tricyclic terpane
4	18α(H)-trisnorhopane (C_{27})
5	17α(H)-trisnorhopane (C_{27})
6	17 α(H)21β(H) norhopane (C_{29})
7	17 α(H)21β(H) hopane (C_{30})
8	17 α(H)21β(H) tetrahomohopane (C_{34})
9	17 α(H)21β(H) pentahomohopane (C_{35})

B m/z 217 and m/z 218

A	C_{21} 5α(H),14β(H),17β(H)-pregnane
B	C_{27} 13β(H)17α(H)20S diasterane
C	C_{27} 5α(H)14α(H)17α(H)20R sterane
D	C_{29} 5α(H)14α(H)17α(H)20S sterane
E	C_{29} 5α(H)14α(H)17α(H)20R sterane
F	C27 5α(H)14β(H)17β(H)20R sterane
G	C27 5α(H)14β(H)17β(H)20S sterane
H	C28 5α(H)14β(H)17β(H)20R sterane
I	C28 5α(H)14β(H)17β(H)20S sterane
J	C29 5α(H)14β(H)17β(H)20R sterane
K	C29 5α(H)14β(H)17β(H)20S sterane


File:2127 #1-3154 Acq:18-NOV-1996 11:09:53 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 10-36-4-5w4 1053-1059m Exp:DEFAULT
191.1794
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
8.0E7
7.6E7
7.2E7
6.8E7
6.4E7
6.0E7
5.6E7
5.2E7
4.8E7
4.4E7
4.0E7
3.6E7
3.2E7
2.8E7
2.4E7
2.0E7
1.6E7
1.2E7
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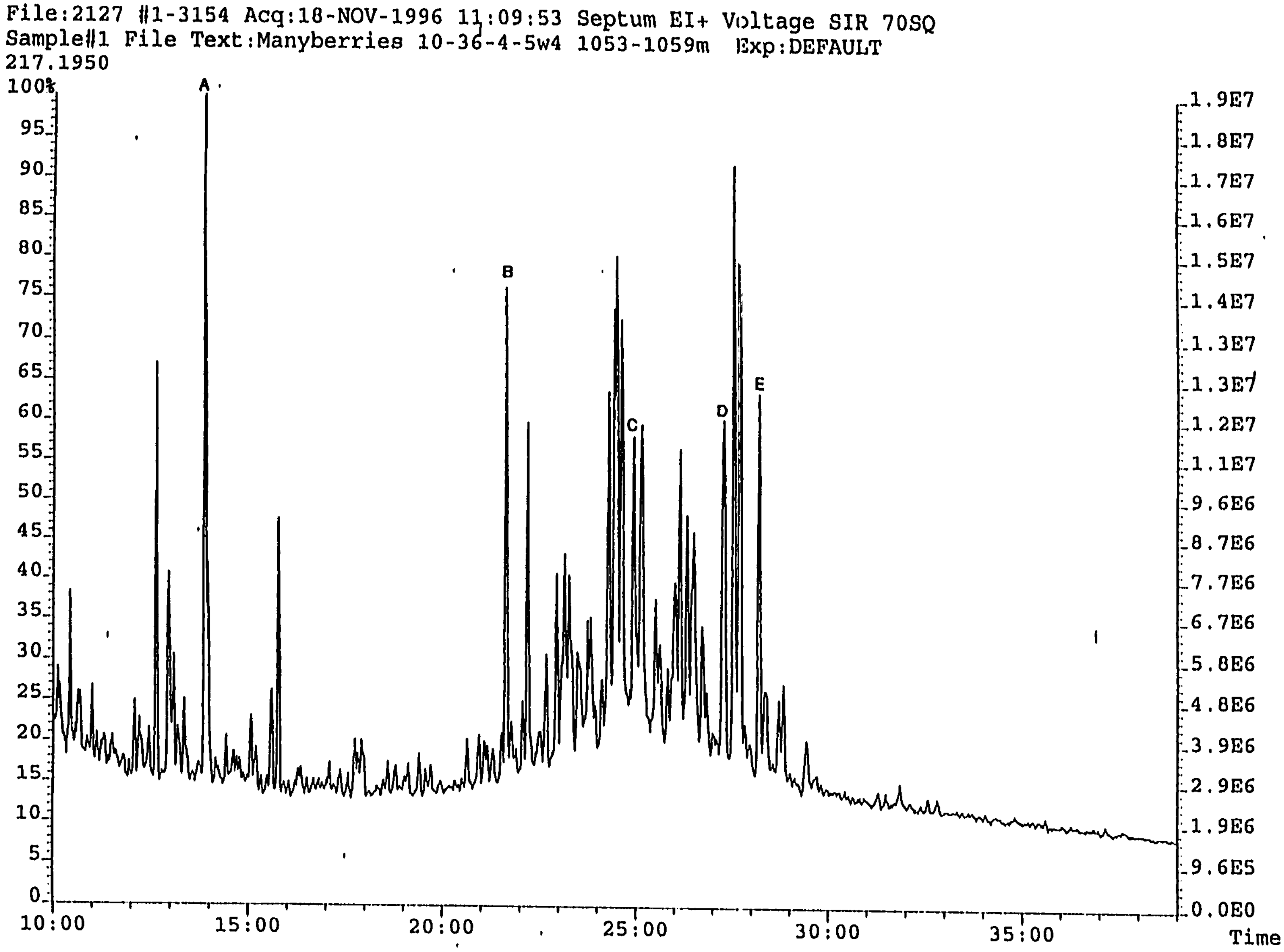
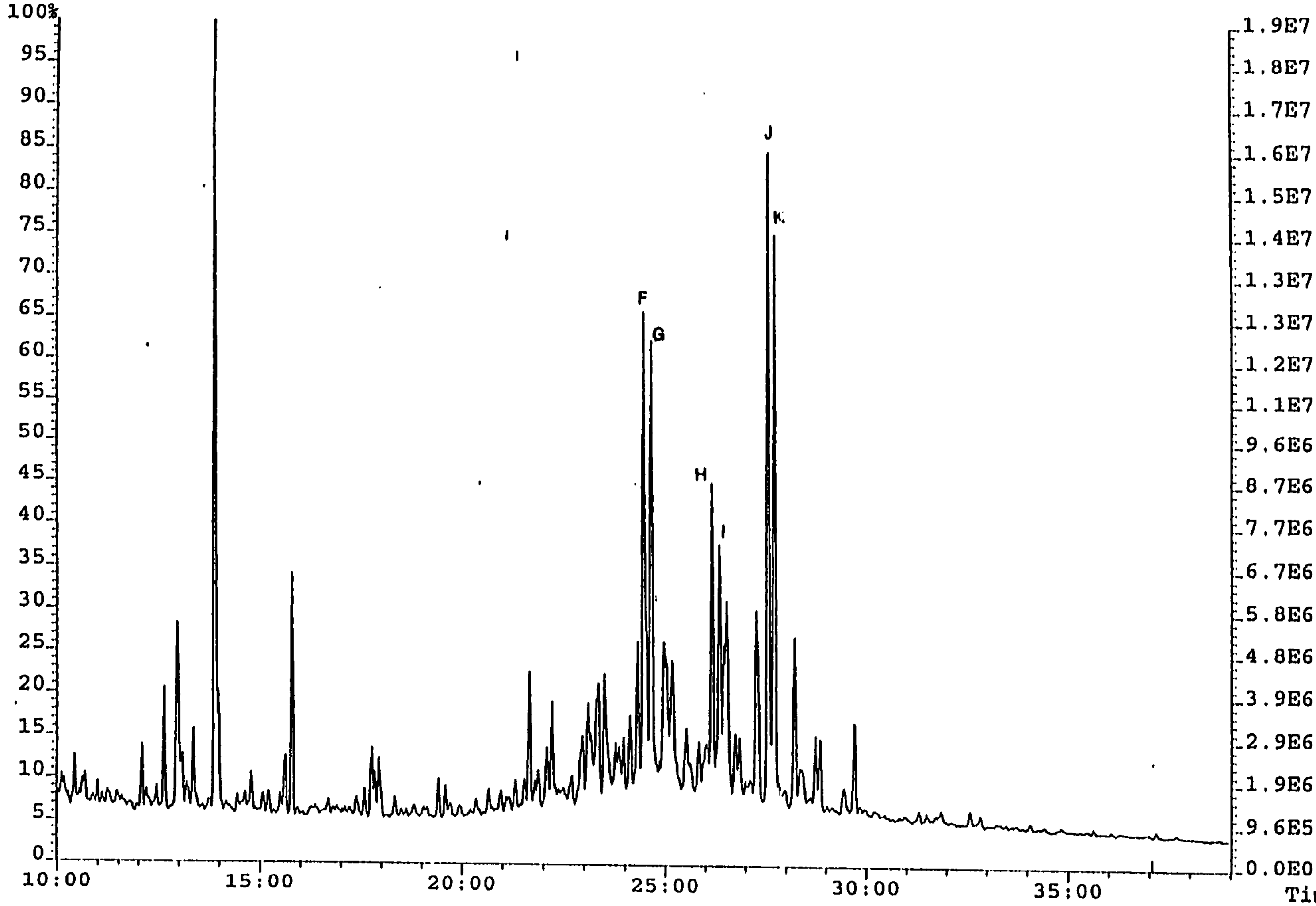
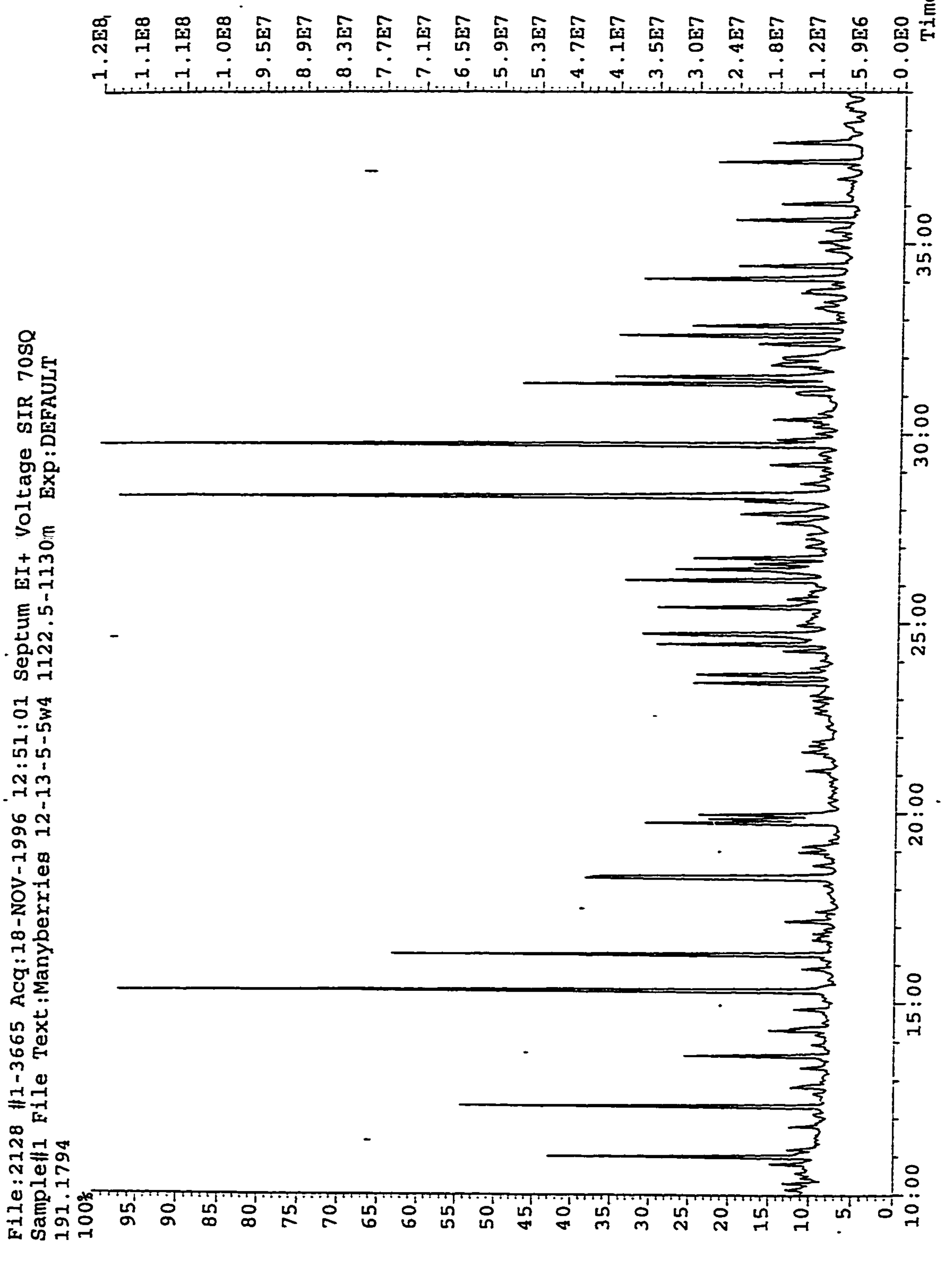
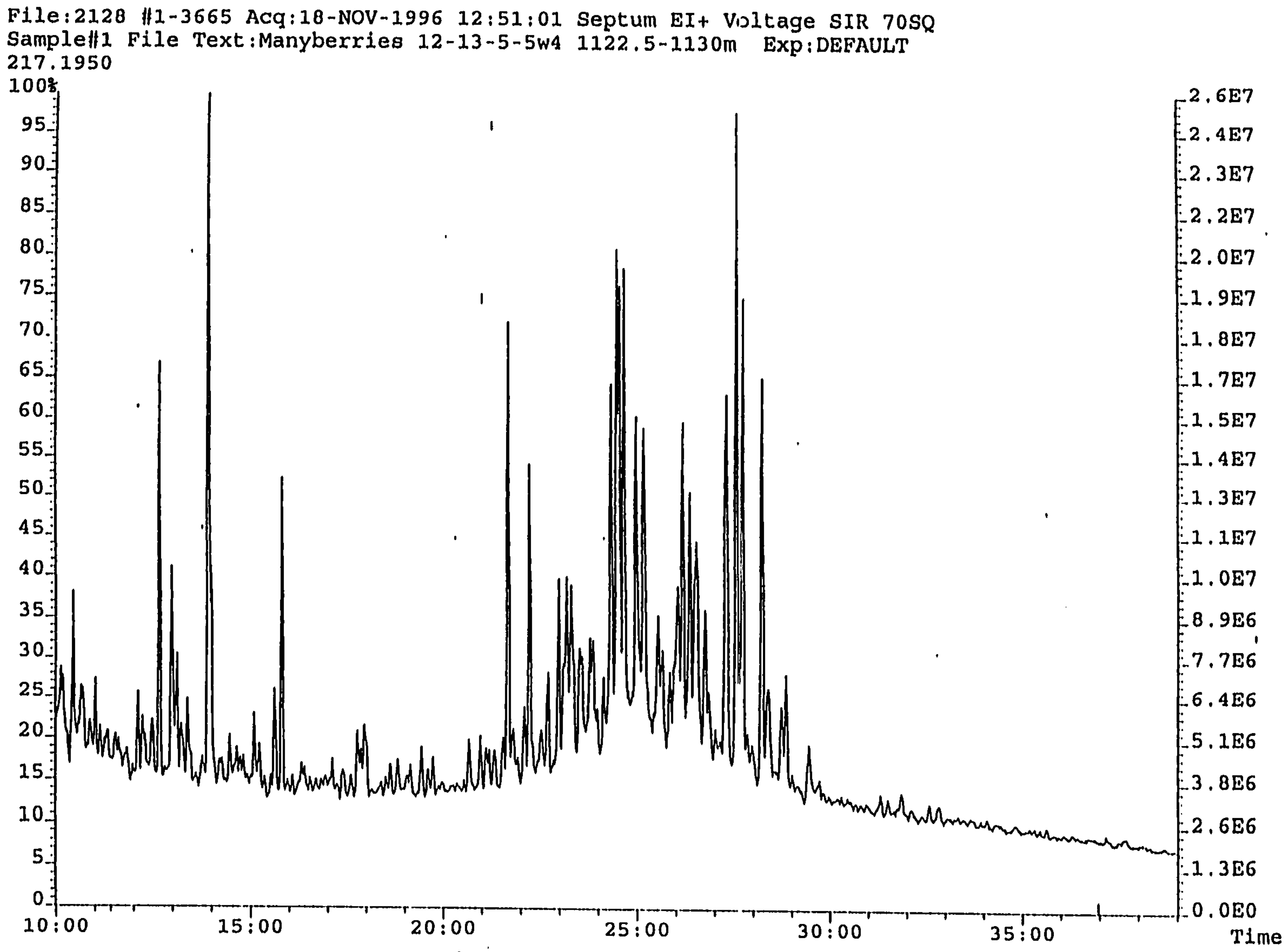
1
2
3
4
5
6
7
8
9


File:2127 #1-3154 Acq:18-NOV-1996 11:09:53 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 10-36-4-5w4 1053-1059m Exp:DEFAULT
217.1950
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
A
B
C
D
E
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.9E7
1.8E7
1.7E7
1.6E7
1.5E7
1.4E7
1.3E7
1.3E7
1.2E7
1.1E7
9.6E6
8.7E6
7.7E6
6.7E6
5.8E6
4.8E6
3.9E6
2.9E6
1.9E6
9.6E5
0.0E0

File:2127 #1-3154 Acq:18-NOV-1996 11:09:53 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 10-36-4-5w4 1053-1059m Exp:DEFAULT
218.2028




File:2128 #1-3665 Acq:18-NOV-1996 12:51:01 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-13-5-5w4 1122.5-1130m Exp:DEFAULT
191.1794
100%
Time
15:00
20:00
25:00
30:00
35:00
1.2E8
0.0E0


File:2128 #1-3665 Acq:18-NOV-1996 12:51:01 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-13-5-5w4 1122.5-1130m Exp:DEFAULT
217.1950
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
2.6E7
2.4E7
2.3E7
2.2E7
2.0E7
1.9E7
1.8E7
1.7E7
1.5E7
1.4E7
1.3E7
1.1E7
1.0E7
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7.7E6
6.4E6
5.1E6
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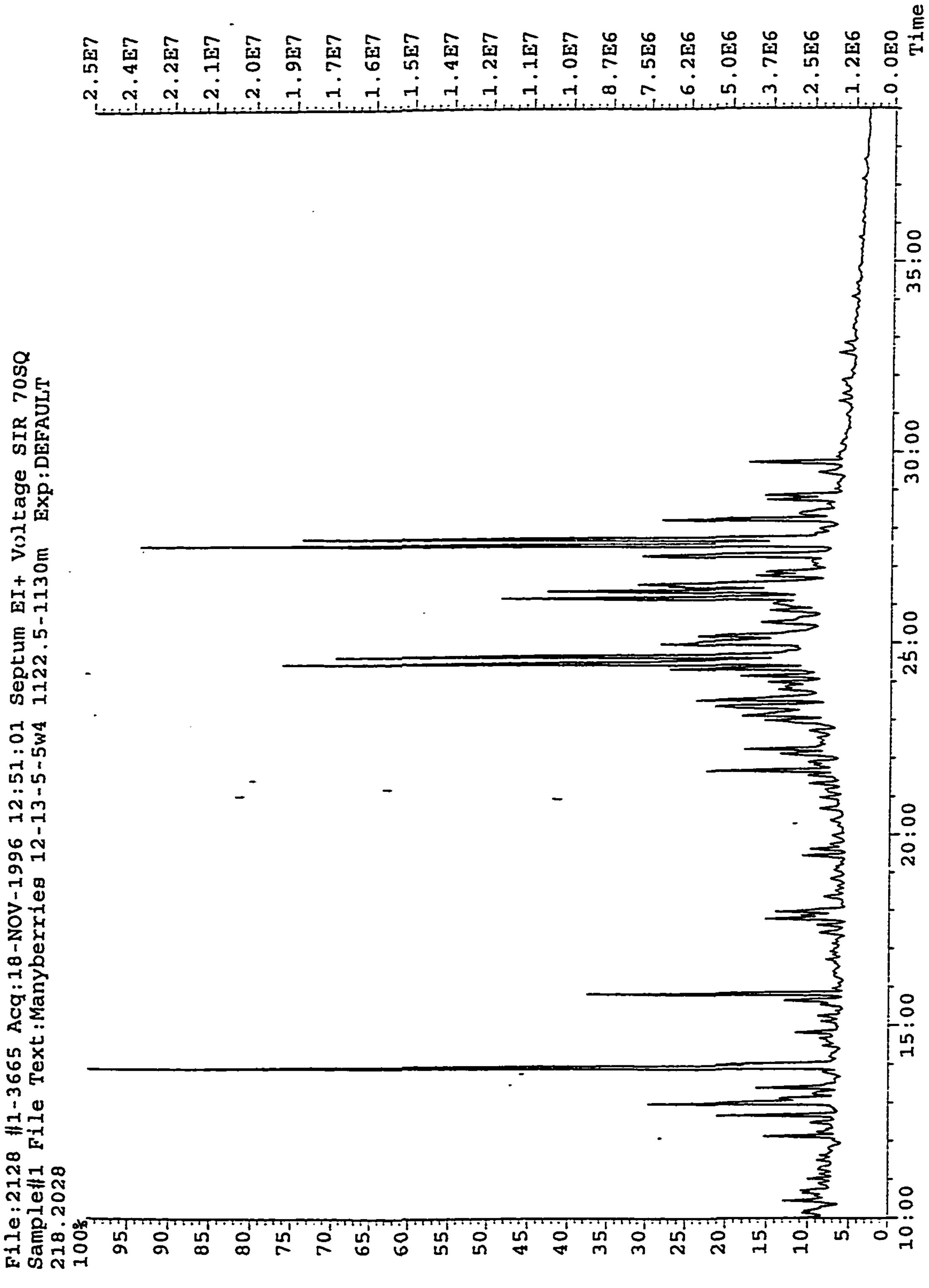
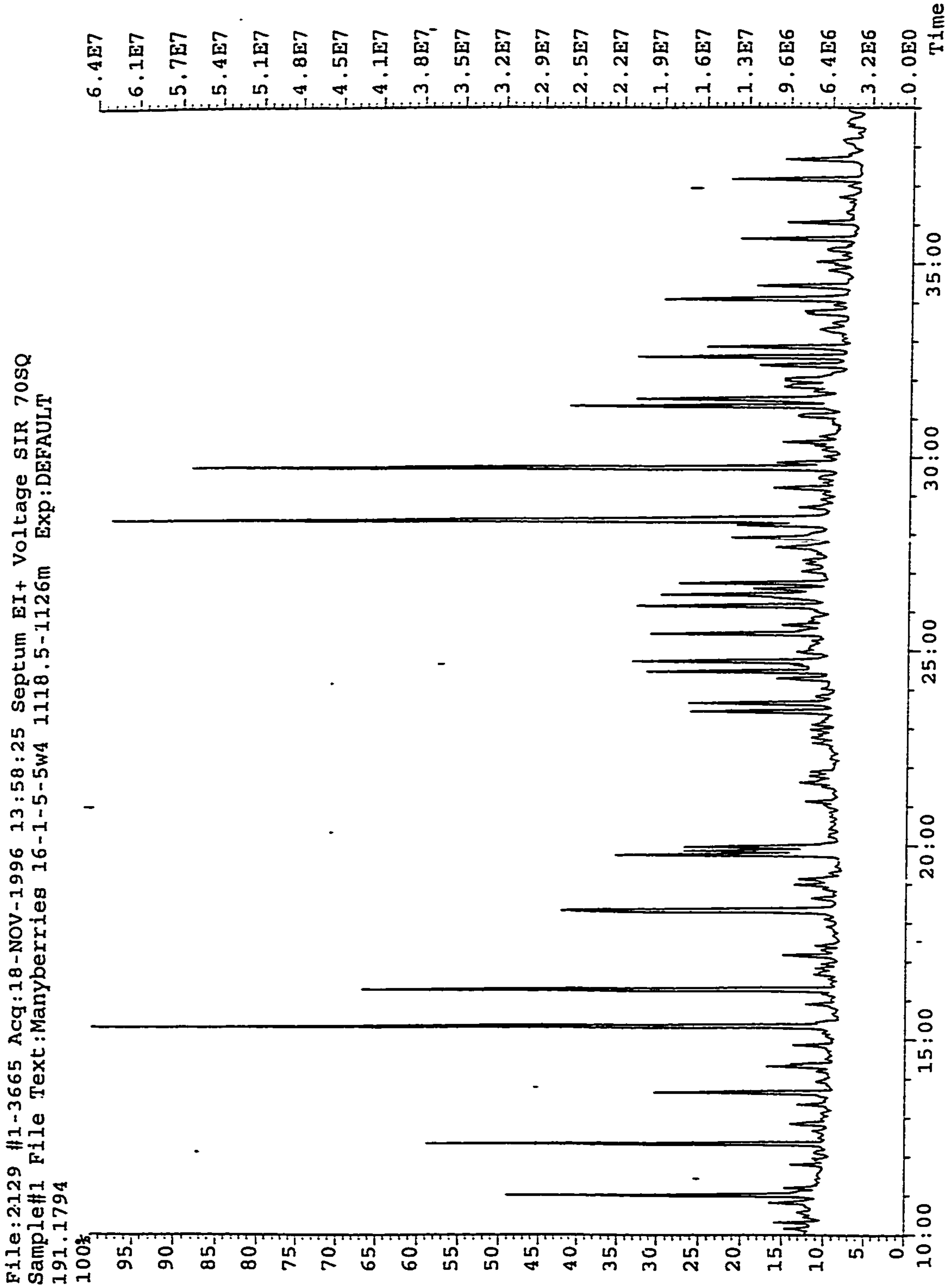
0.0E0


File:2128 #1-3665 Acq:18-NOV-1996 12:51:01 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-13-5-5w4 1122.5-1130m Exp:DEFAULT
218.2028
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
2.5E7
2.4E7
2.2E7
2.1E7
2.0E7
1.9E7
1.7E7
1.6E7
1.5E7
1.4E7
1.2E7
1.1E7
1.0E7
8.7E6
7.5E6
6.2E6
5.0E6
3.7E6
2.5E6
1.2E6
0.0E0


File:2129 #1-3665 Acq:18-NOV-1996 13:58:25 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-1-5-5w4 1118.5-1126m Exp:DEFAULT
191.1794
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
6.4E7
6.1E7
5.7E7
5.4E7
5.1E7
4.8E7
4.5E7
4.1E7
3.8E7
3.5E7
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2.5E7
2.2E7
1.9E7
1.6E7
1.3E7
9.6E6
6.4E6
3.2E6
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10:00
15:00
20:00
25:00
30:00
35:00
Time

File:2129 #1-3665 Acq:18-NOV-1996 13:58:25 Septum EI+ Voltage SIR 70SQ
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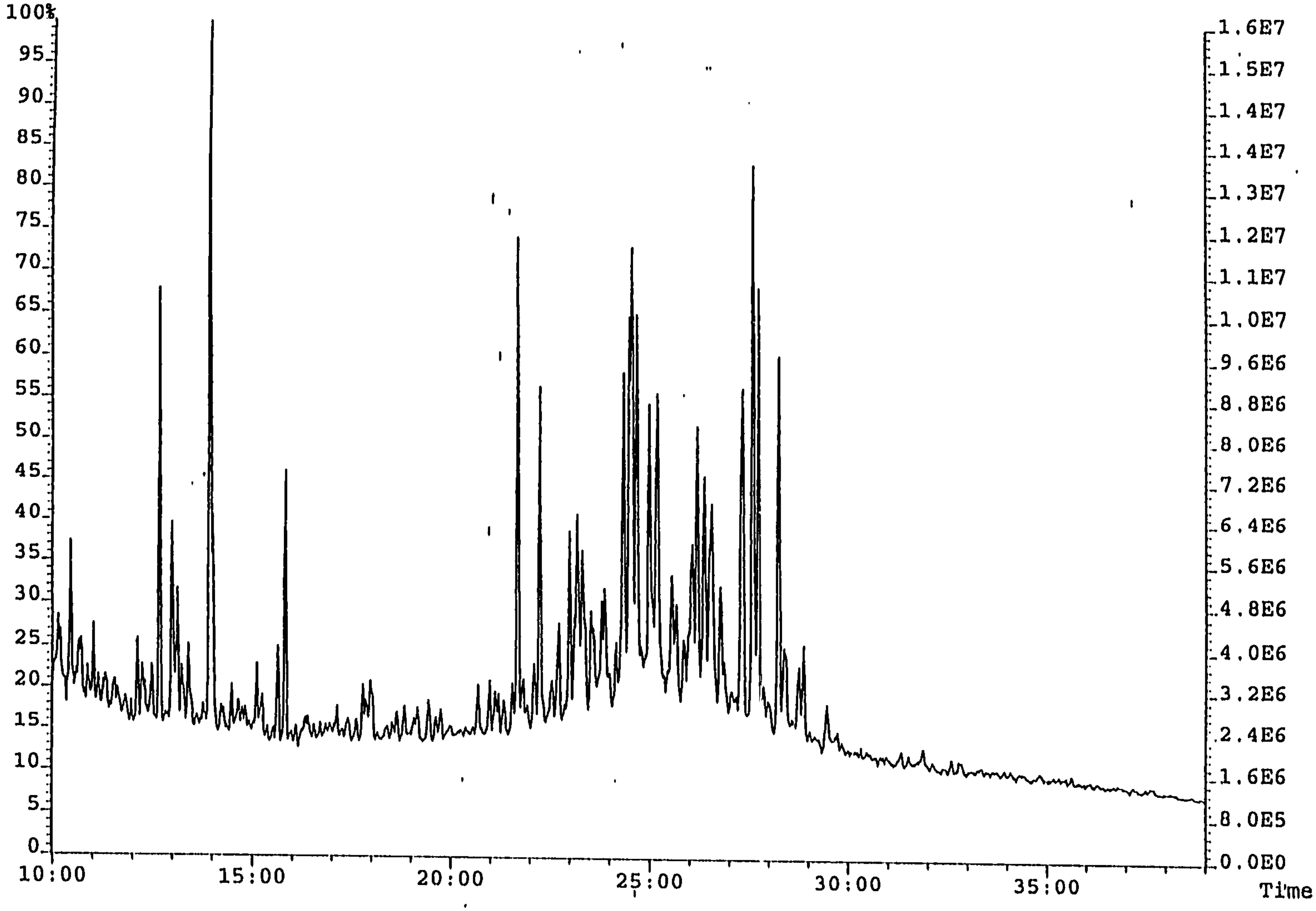
217.1950



File:2129 #1-3665 Acq:18-NOV-1996 13:58:25 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-1-5-5w4 1118.5-1126m Exp:DEFAULT
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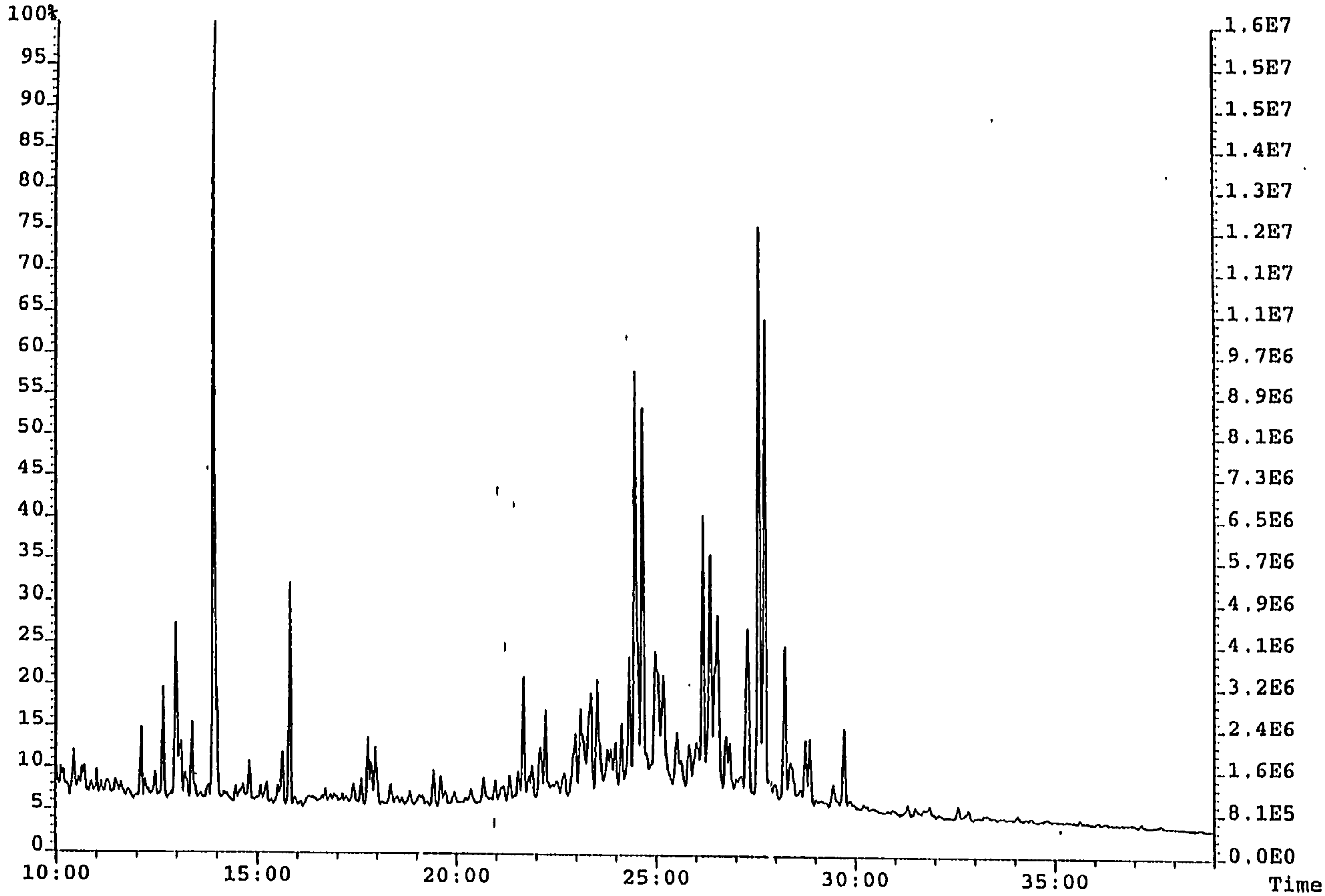

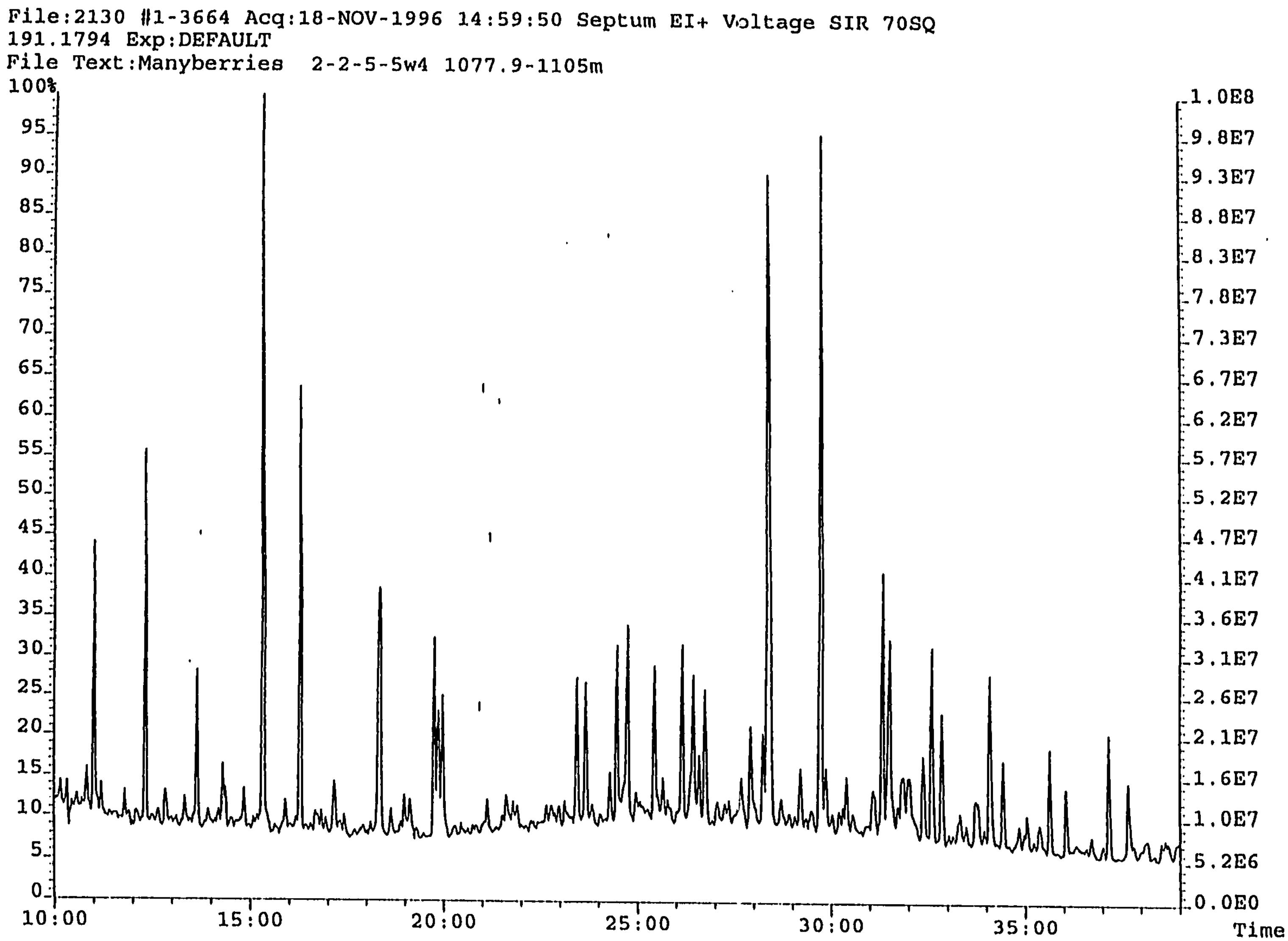
File:2130 #1-3664 Acq:18-NOV-1996 14:59:50 Septum EI+ Voltage SIR 70SQ
191.1794 Exp:DEFAULT
File Text:Manyberries 2-2-5-5w4 1077.9-1105m
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
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15:00
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Time
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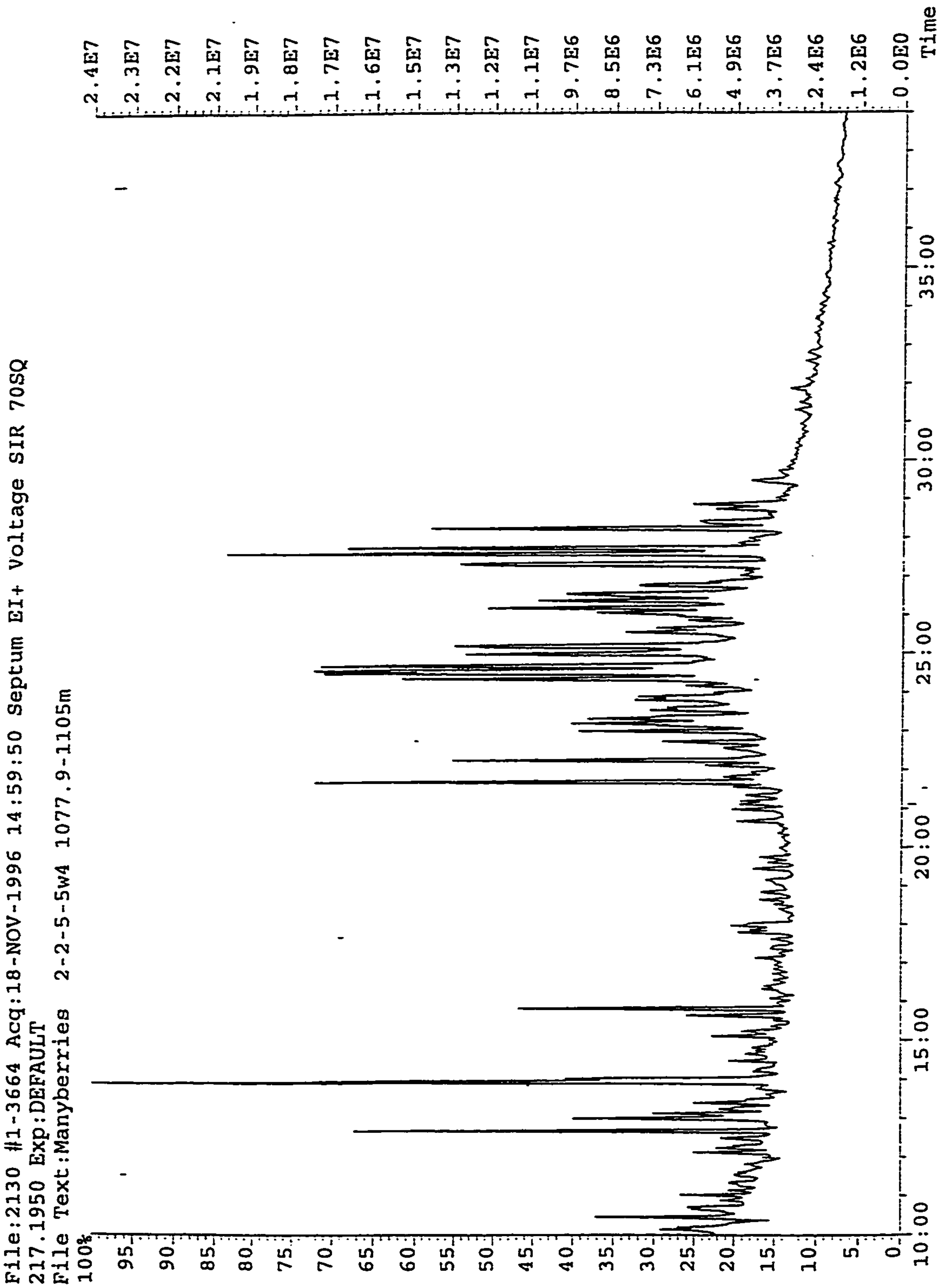
File:2130 #1-3664 Acq:18-NOV-1996 14:59:50 Septum EI+ Voltage SIR 70SQ
217.1950 Exp:DEFAULT
File Text:Manyberries 2-2-5-5w4 1077.9-1105m
100%
95
90
85
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75
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60
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50
45
40
35
30
25
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15:00
20:00
25:00
30:00
35:00
Time
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2.2E7
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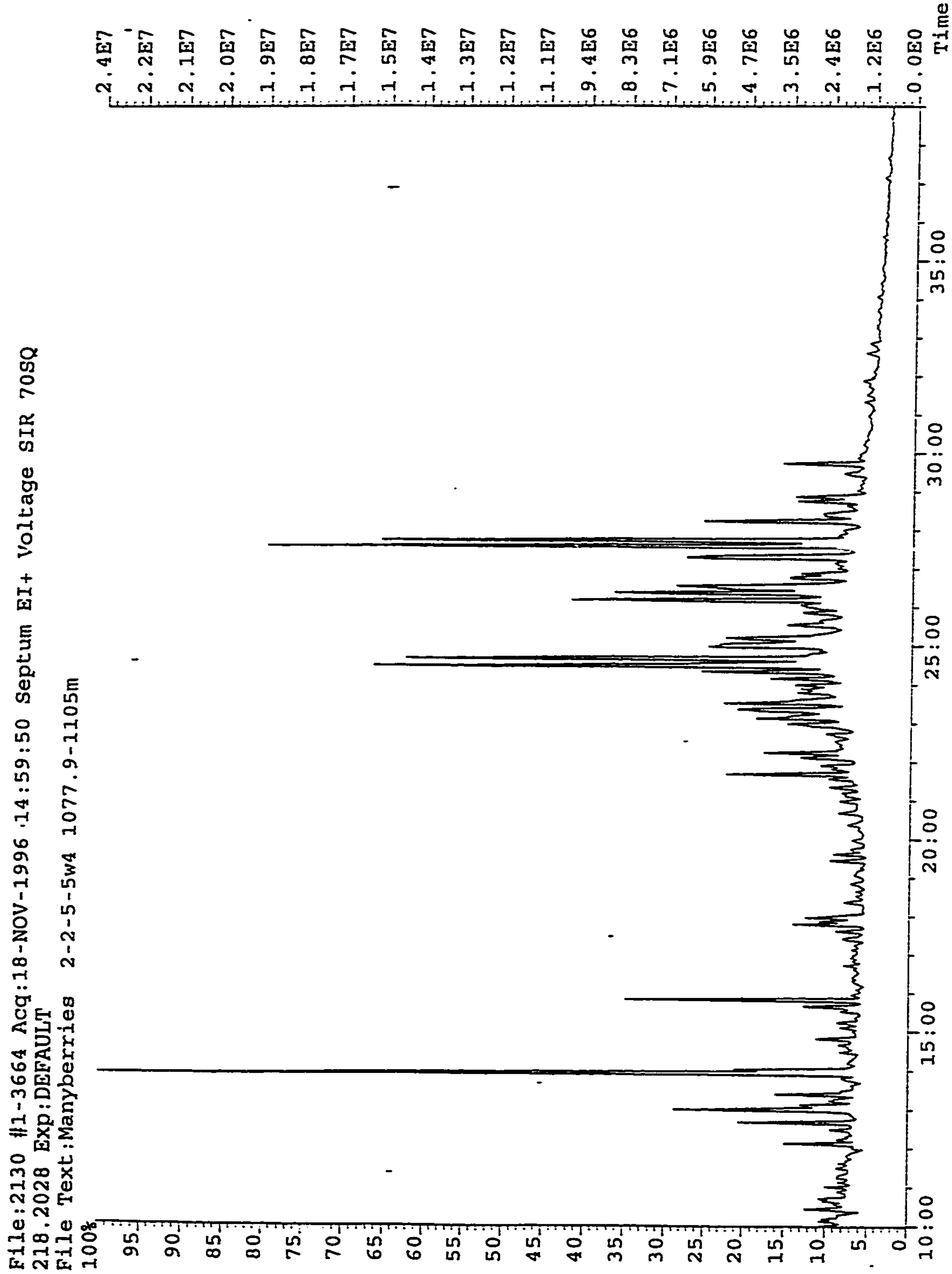
File:2130 #1-3664 Acq:18-NOV-1996 14:59:50 Septum EI+ Voltage SIR 70SQ
218.2028 Exp:DEFAULT
File Text:Manyberries 2-2-5-5w4 1077.9-1105m
100%
95
90
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15
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5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
2.4E7
2.2E7
2.1E7
2.0E7
1.9E7
1.8E7
1.7E7
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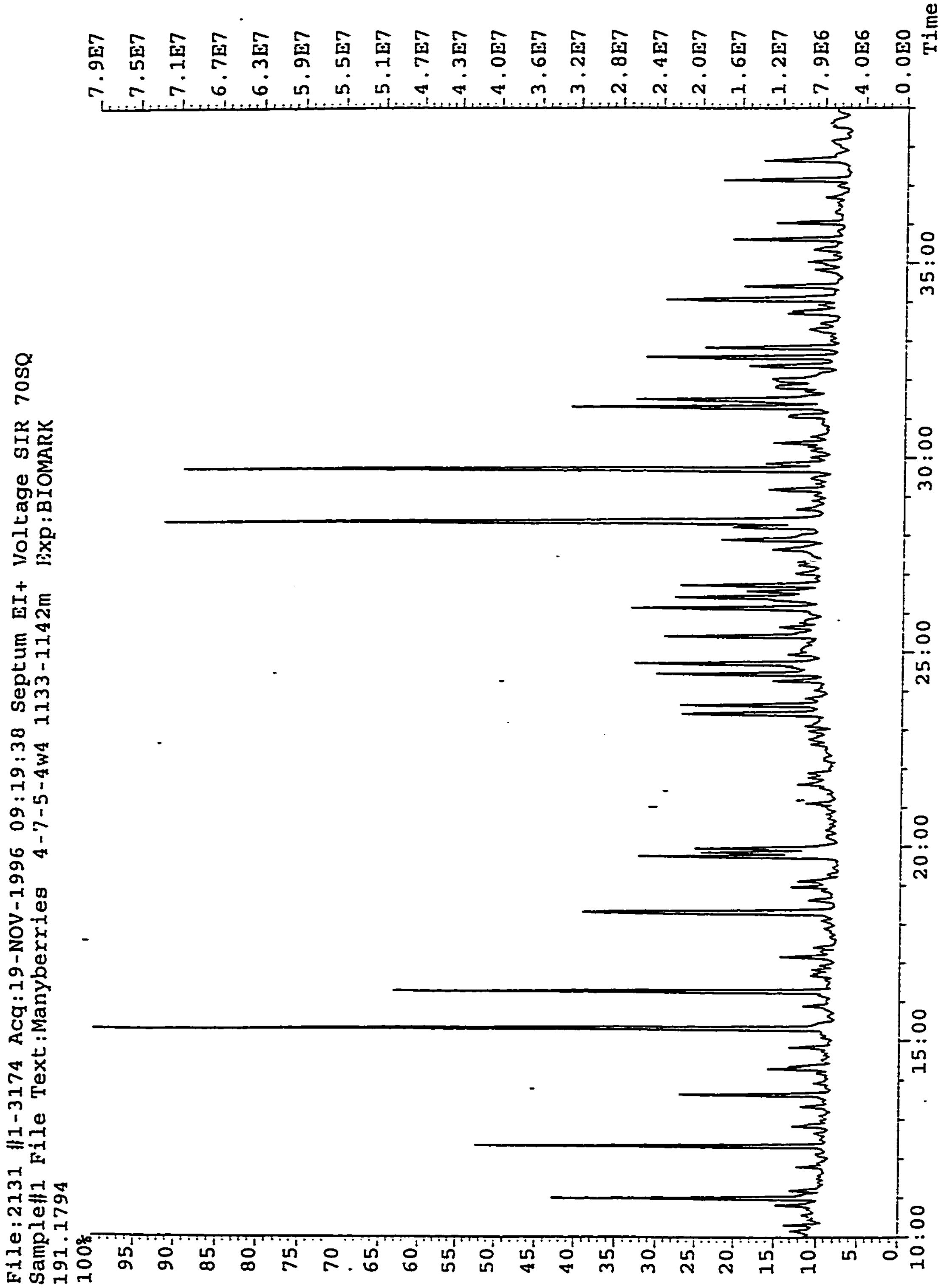
File:2131 #1-3174 Acq:19-NOV-1996 09:19:38 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 4-7-5-4w4 1133-1142m Exp:BIOMARK
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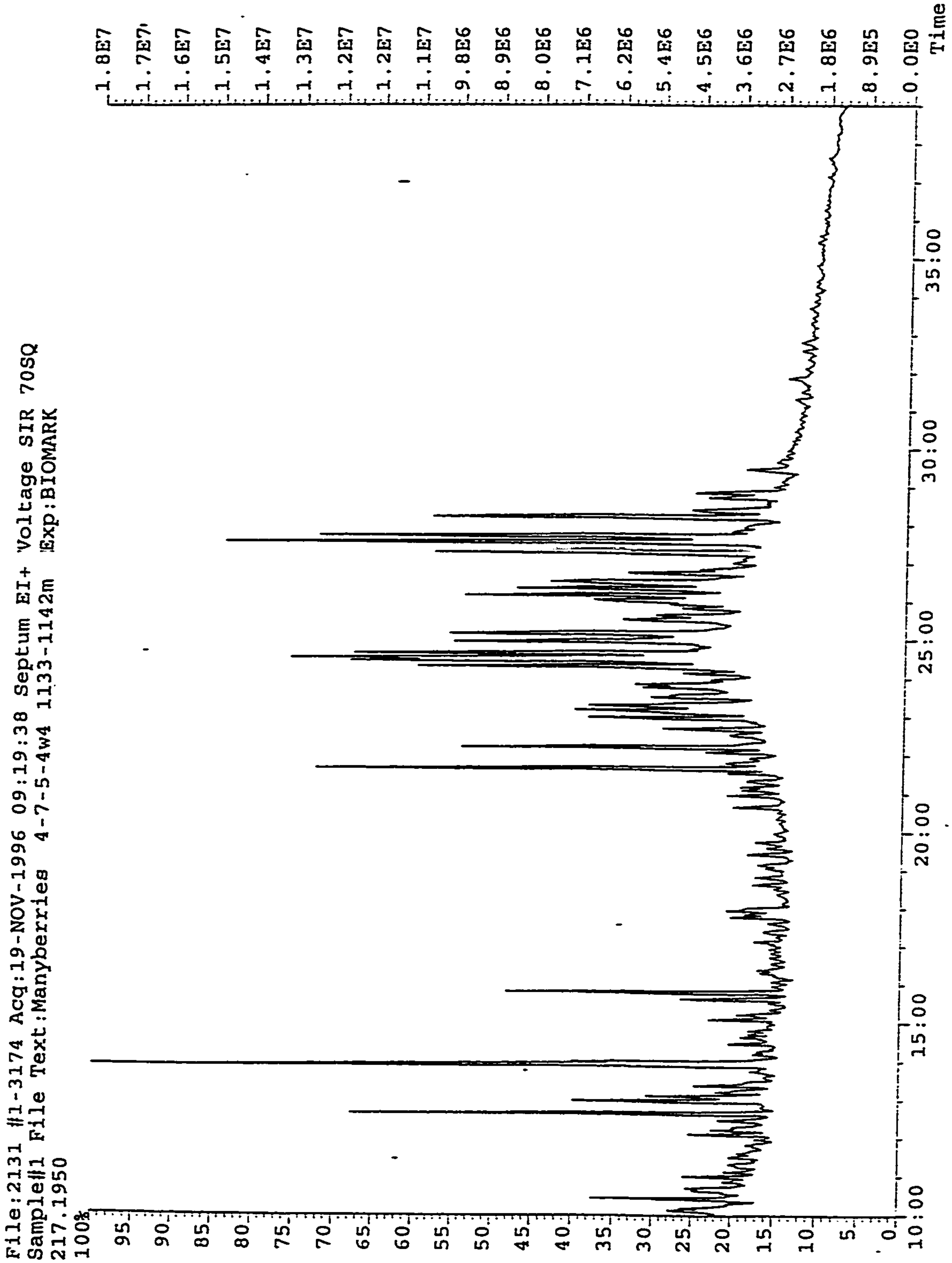
100%
7.9E7
0.0E0
Time
10:00
15:00
20:00
25:00
30:00
35:00


File:2131 #1-3174 Acq:19-NOV-1996 09:19:38 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 4-7-5-4w4 1133-1142m Exp:BIOMARK
217.1950
100%
1.8E7
1.7E7
1.6E7
1.5E7
1.4E7
1.3E7
1.2E7
1.2E7
1.1E7
9.8E6
8.9E6
8.0E6
7.1E6
6.2E6
5.4E6
4.5E6
3.6E6
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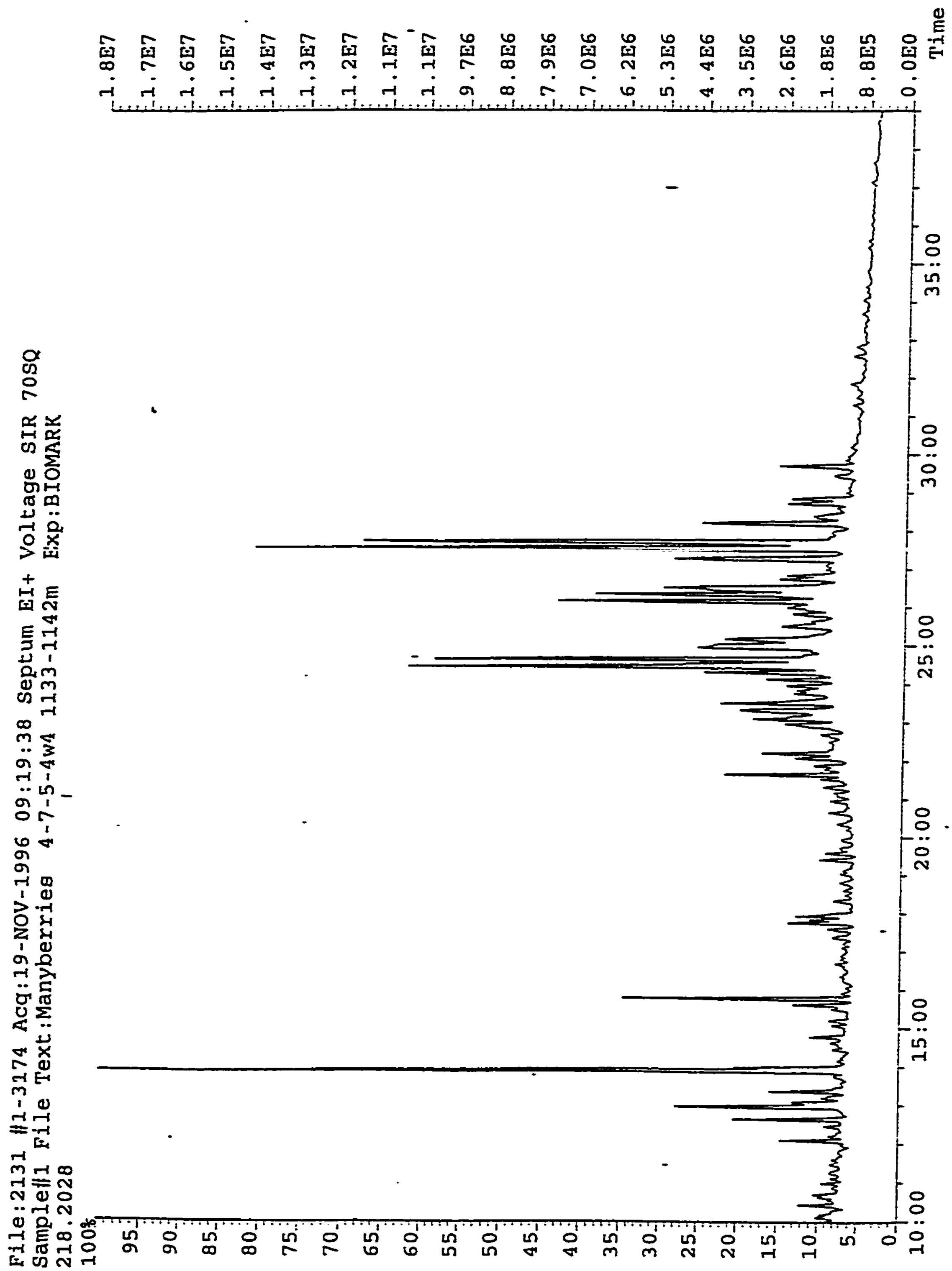
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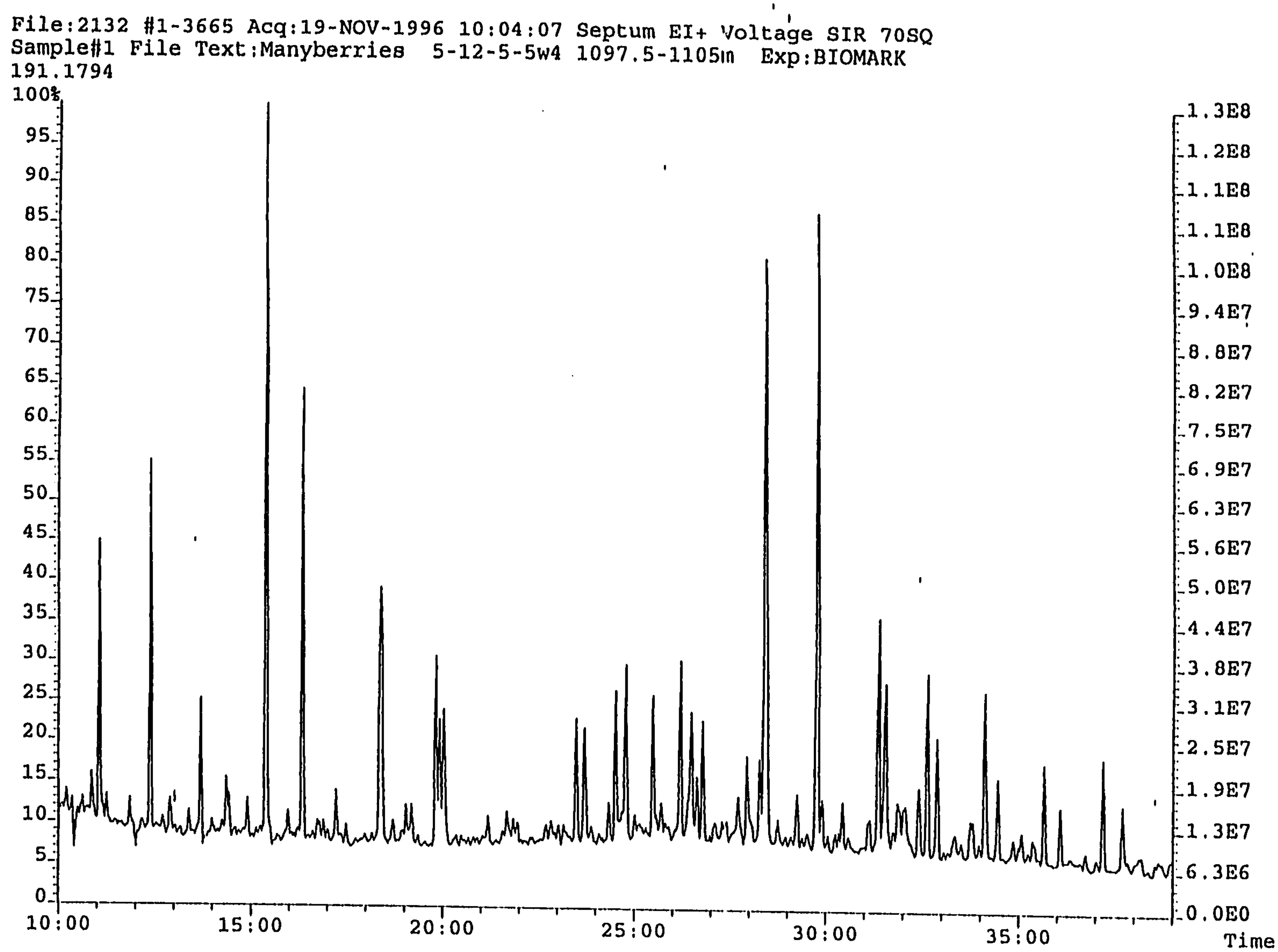
218.2028
Time


File:2132 #1-3665 Acq:19-NOV-1996 10:04:07 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 5-12-5-5w4 1097.5-1105m Exp:BIOMARK
191.1794
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1.3E8
1.2E8
1.1E8
1.1E8
1.0E8
9.4E7
8.8E7
8.2E7
7.5E7
6.9E7
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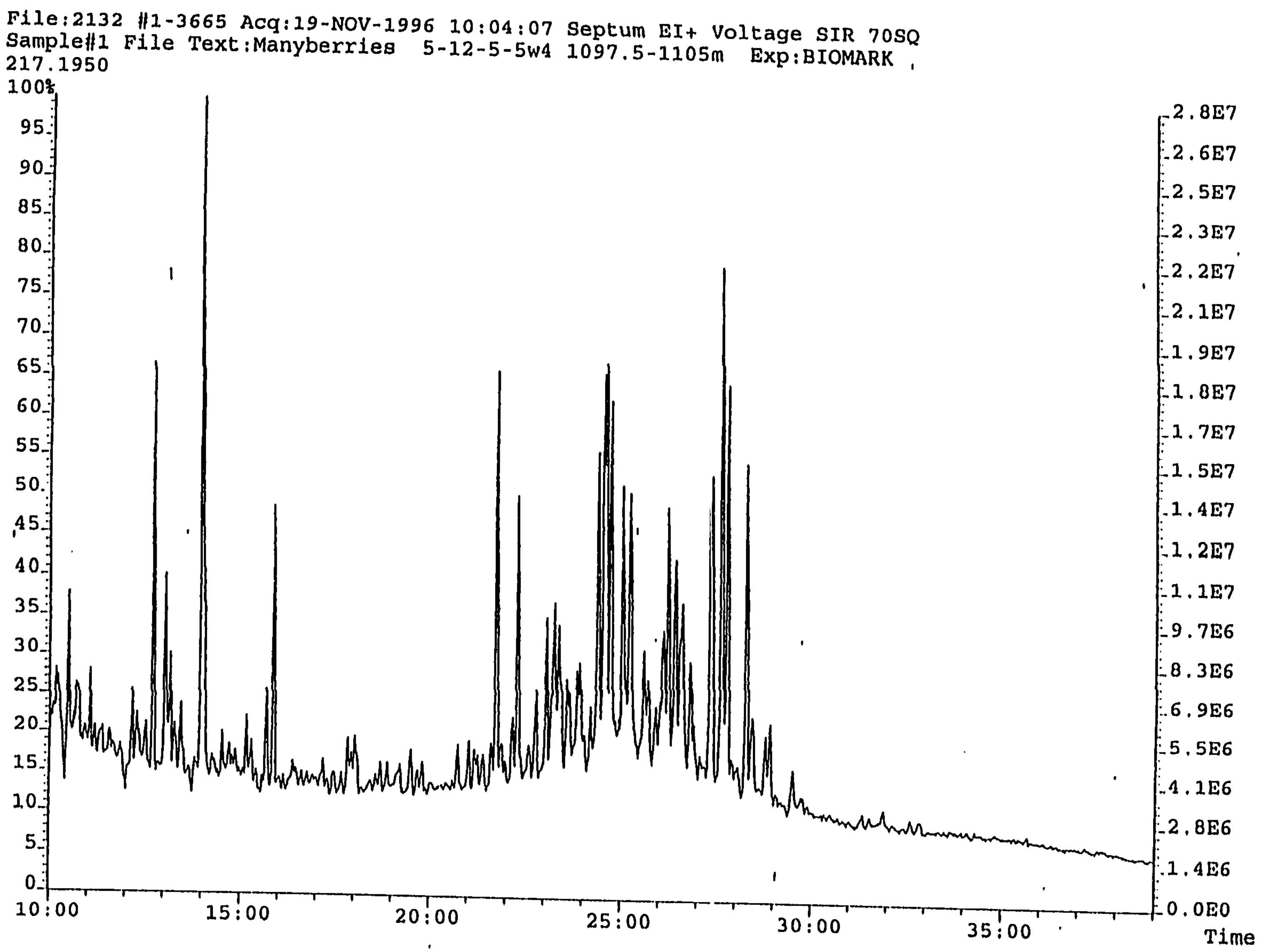
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217.1950
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2.8E7
2.6E7
2.5E7
2.3E7
2.2E7
2.1E7
1.9E7
1.8E7
1.7E7
1.5E7
1.4E7
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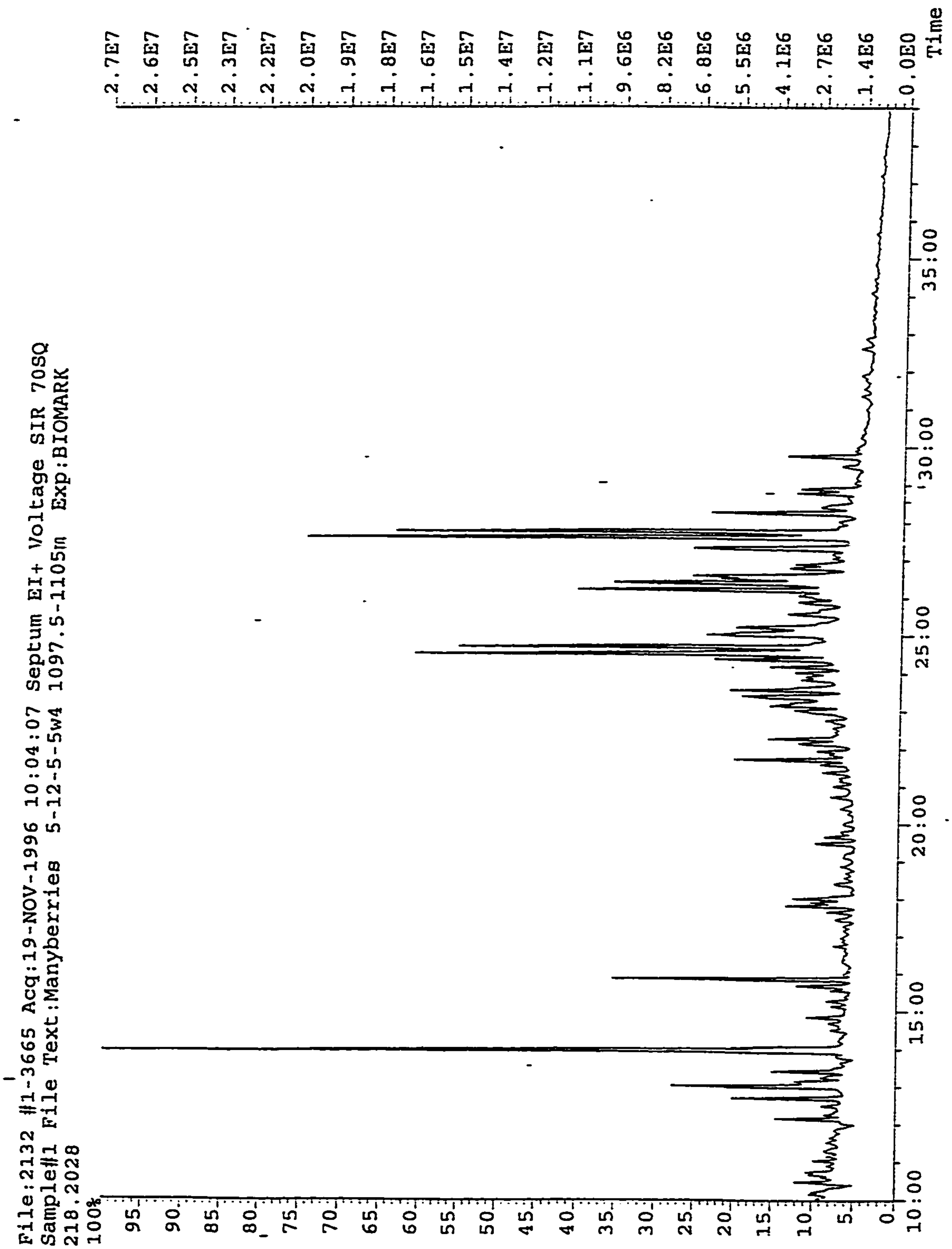
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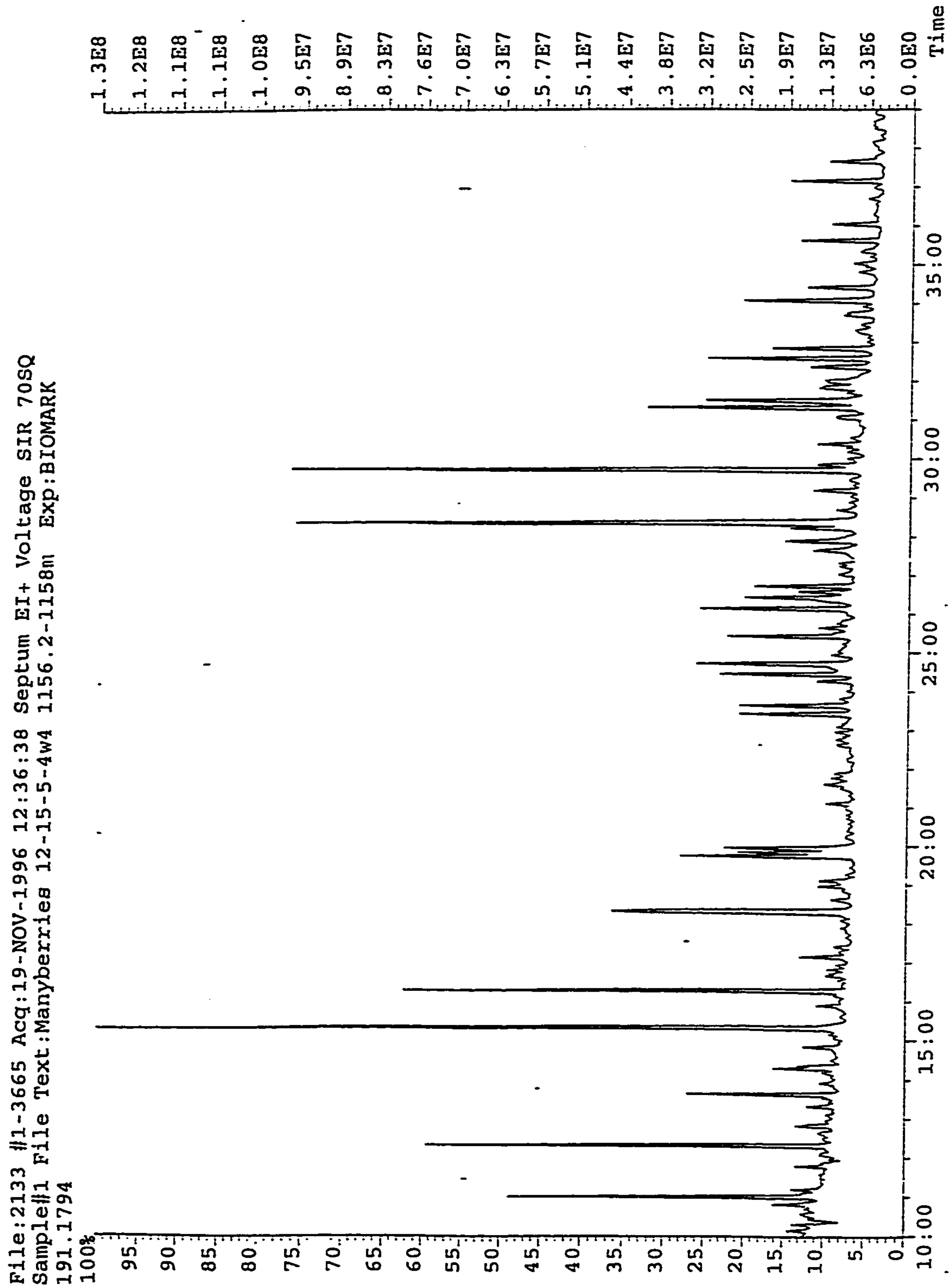
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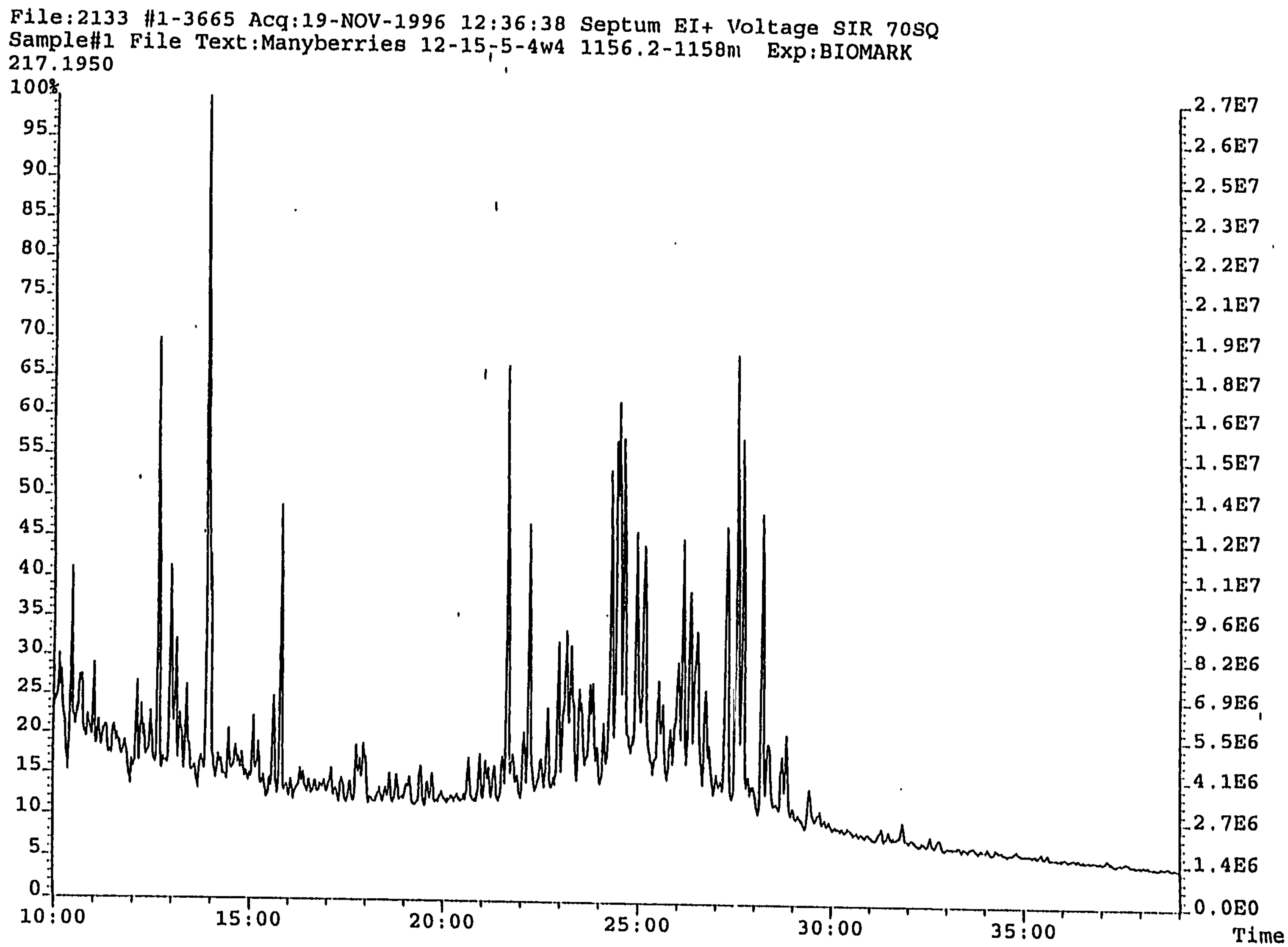
Time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1.9E7
1.8E7
1.6E7
1.5E7
1.4E7
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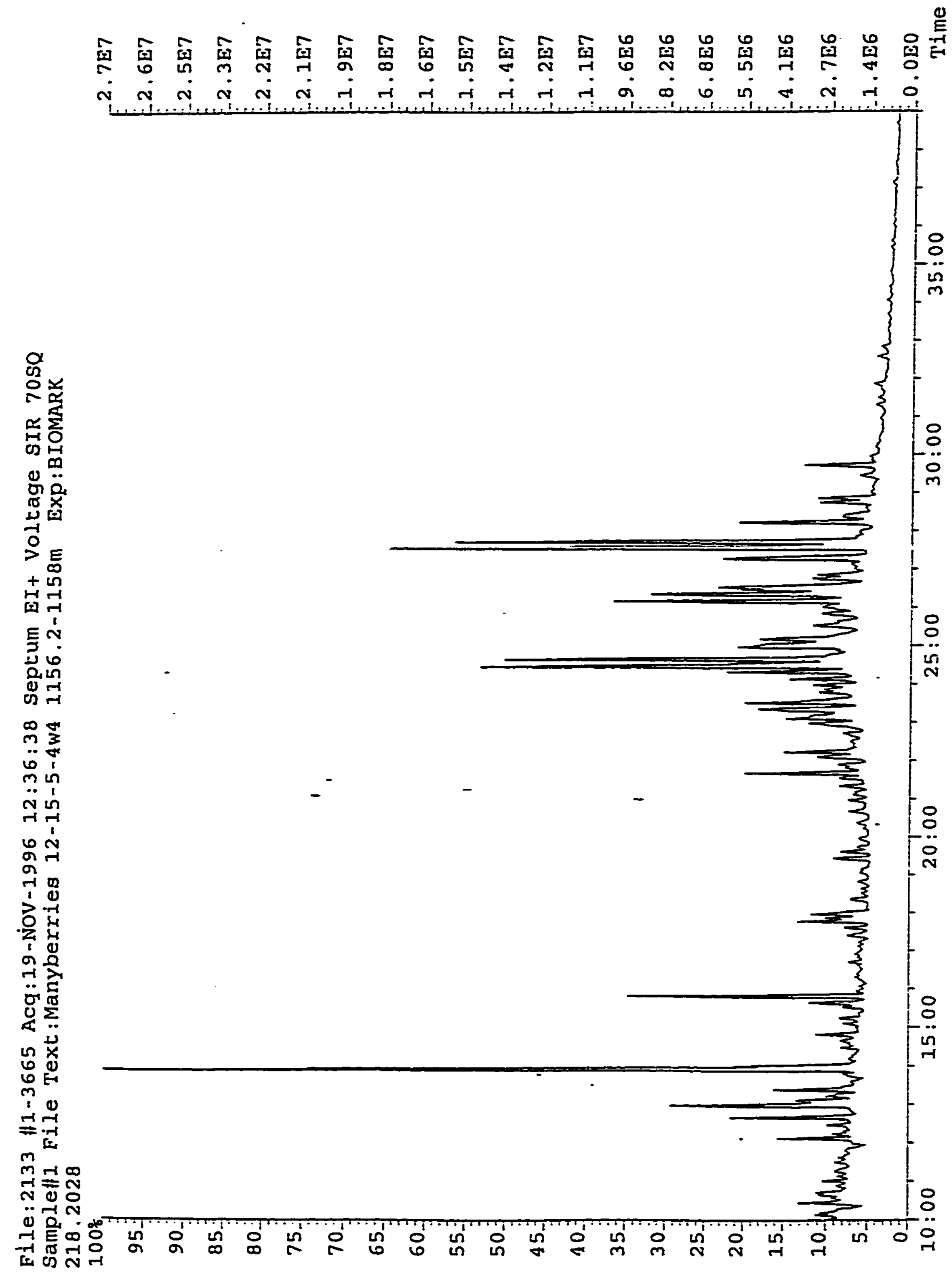

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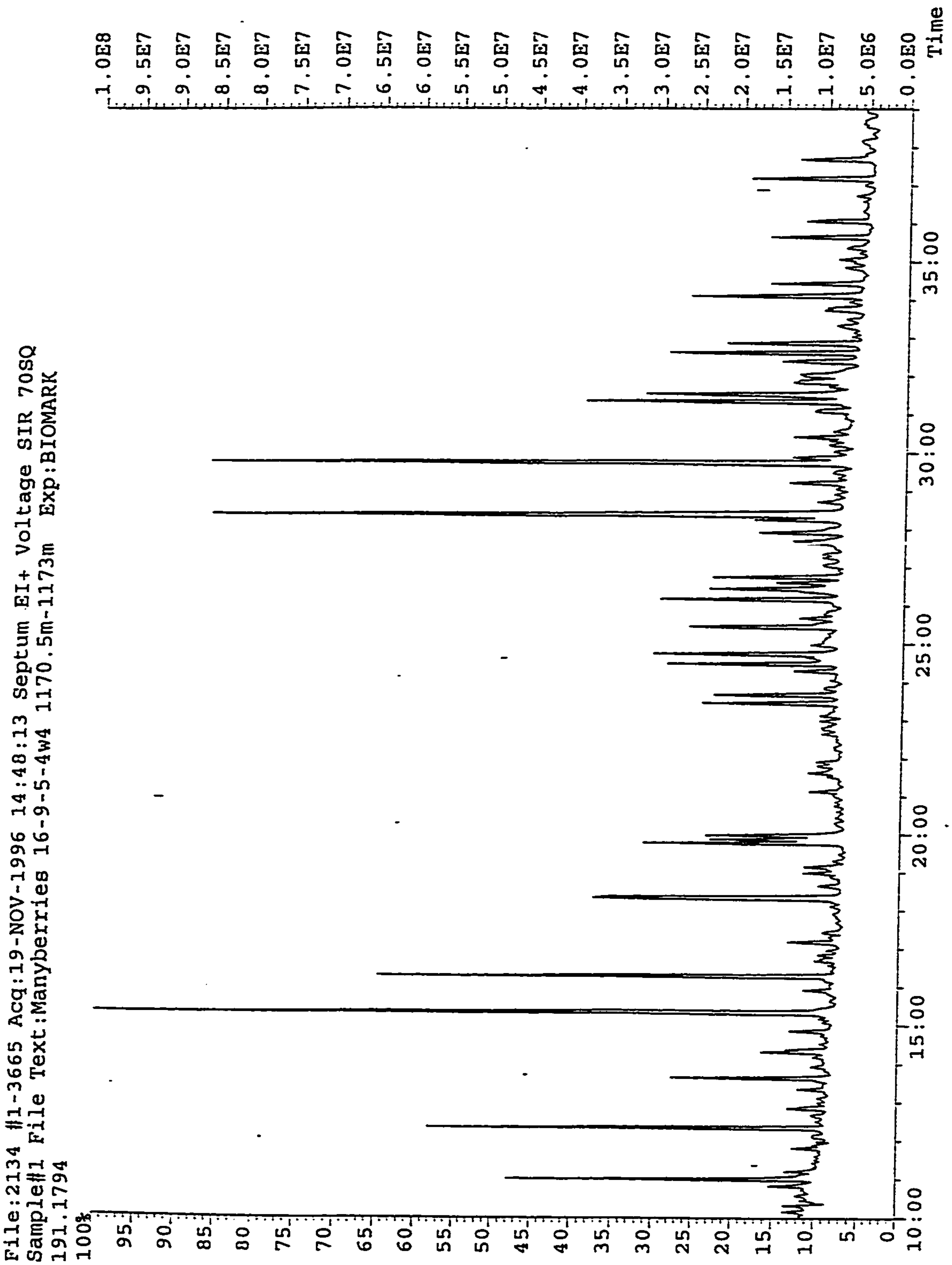
File:2134 #1-3665 Acq:19-NOV-1996 14:48:13 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-9-5-4w4 1170.5m-1173m Exp:BIOMARK
191.1794
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7.5E7
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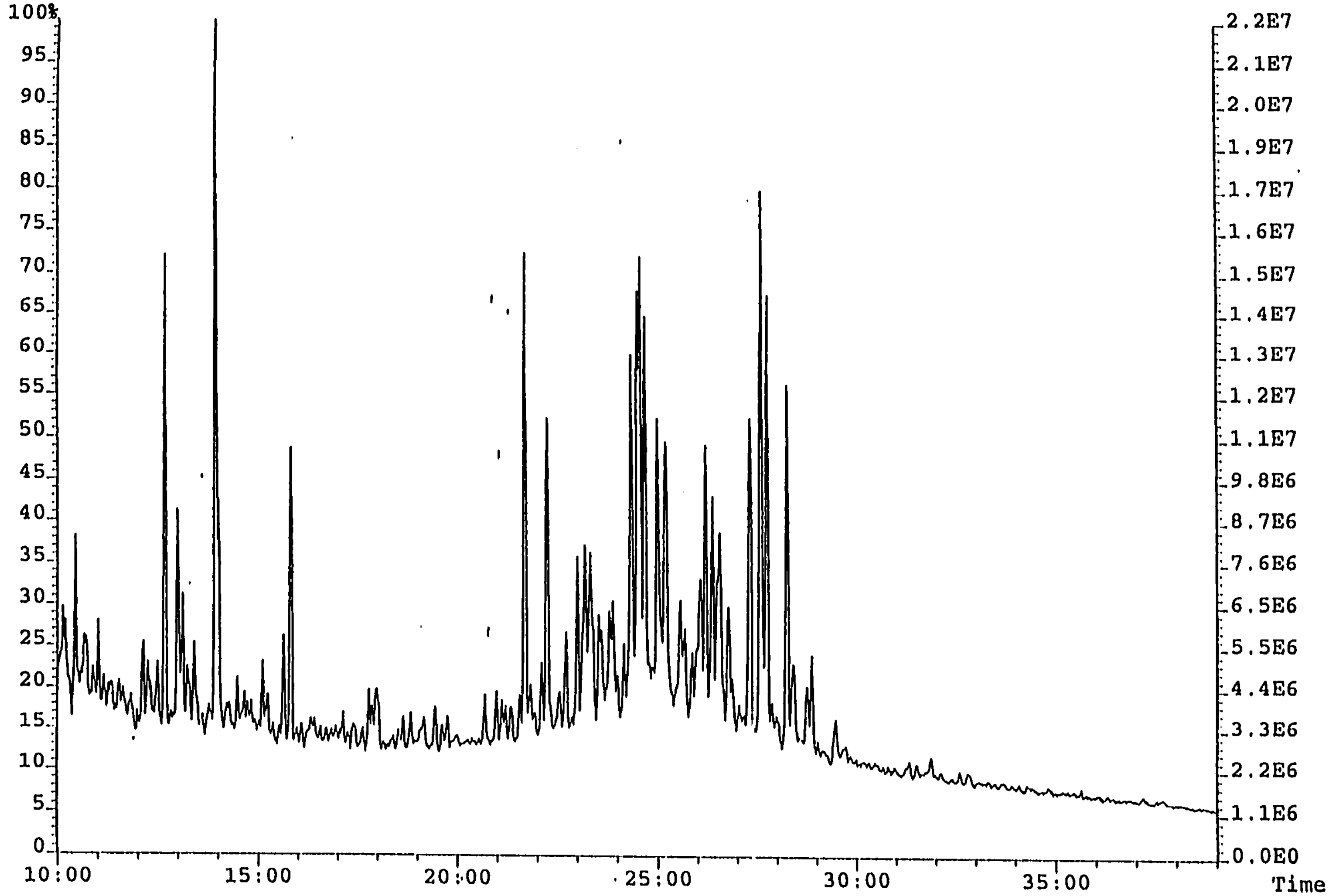
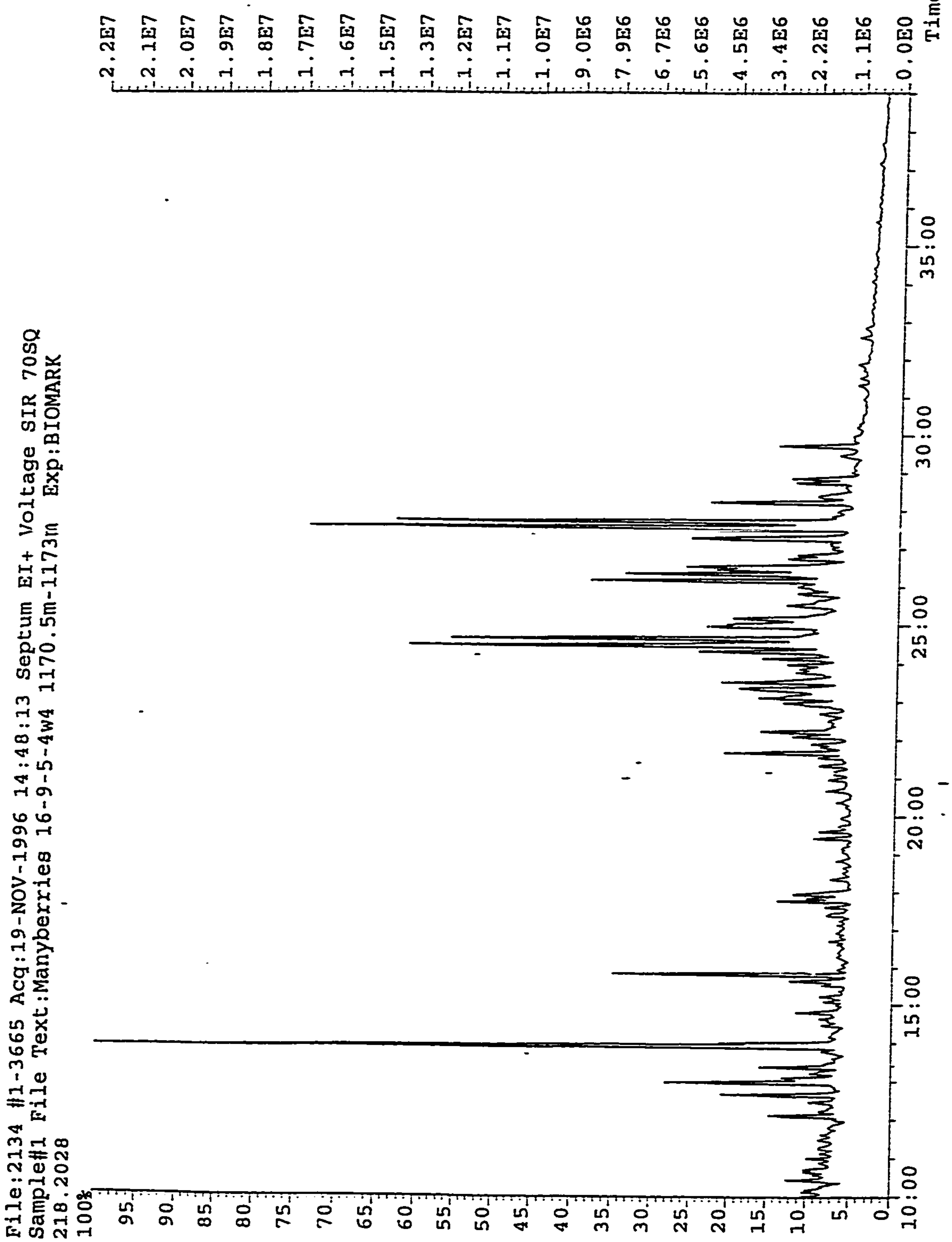
File:2134 #1-3665 Acq:19-NOV-1996 14:48:13 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-9-5-4w4 1170.5m-1173m Exp:BIOMARK
217.1950




File:2134 #1-3665 Acq:19-NOV-1996 14:48:13 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-9-5-4w4 1170.5m-1173m Exp:BIOMARK
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1.1E7
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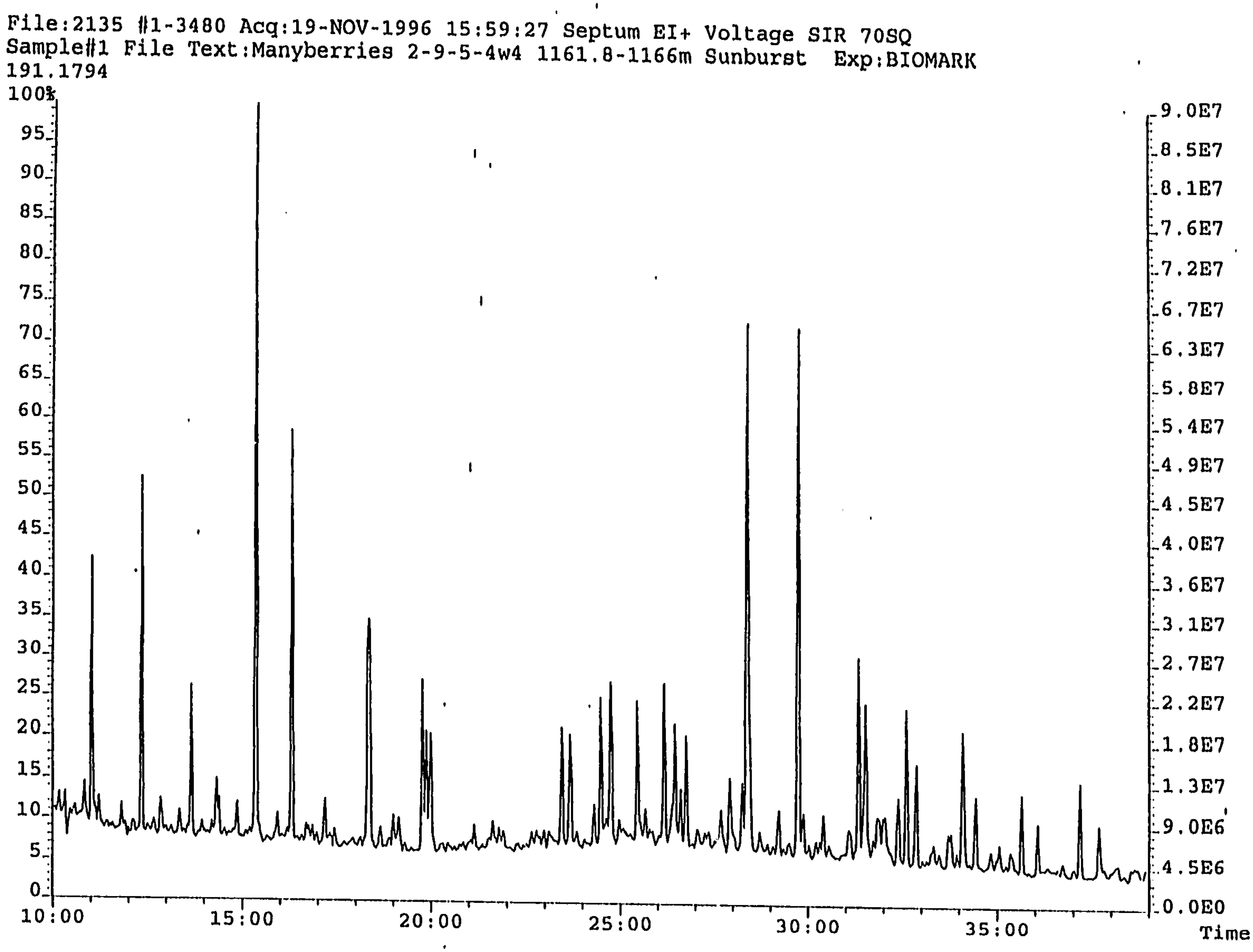
File:2135 #1-3480 Acq:19-NOV-1996 15:59:27 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 2-9-5-4w4 1161.8-1166m Sunburst Exp:BIOMARK
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6.7E7
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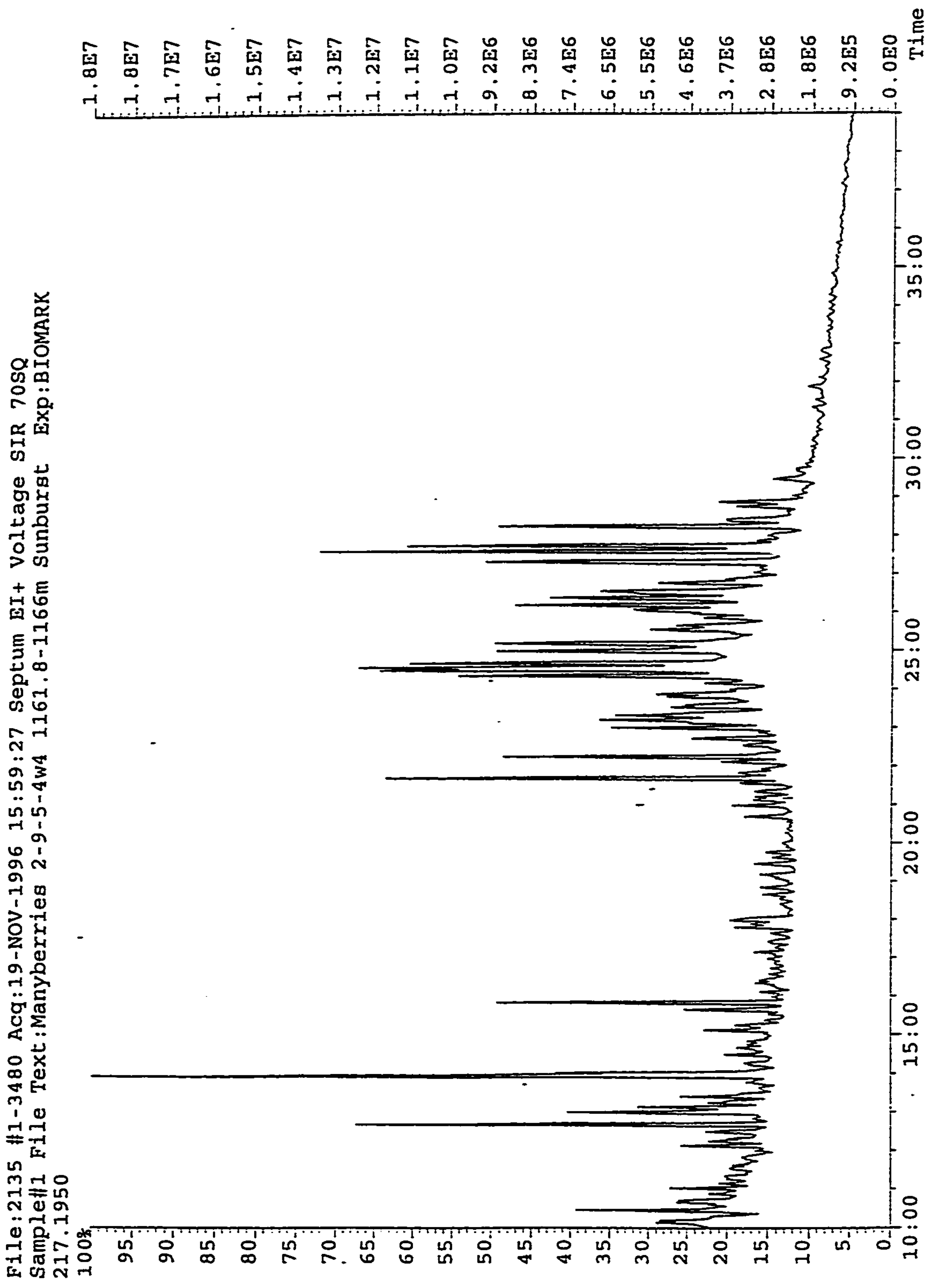
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Sample#1 File Text:Manyberries 2-9-5-4w4 1161.8-1166m Sunburst Exp:BIOMARK
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1.1E7
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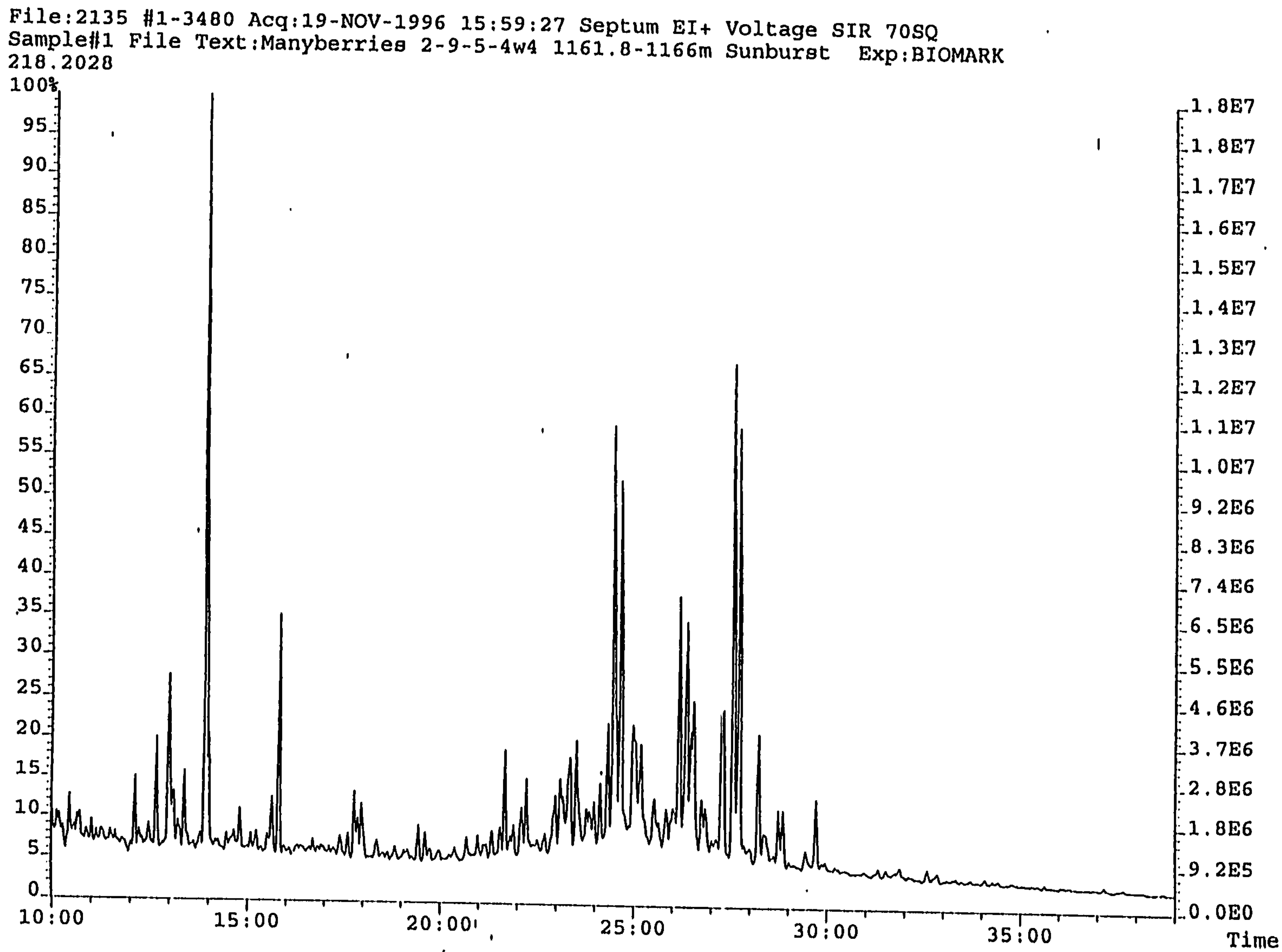
File:2135 #1-3480 Acq:19-NOV-1996 15:59:27 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 2-9-5-4w4 1161.8-1166m Sunburst Exp:BIOMARK
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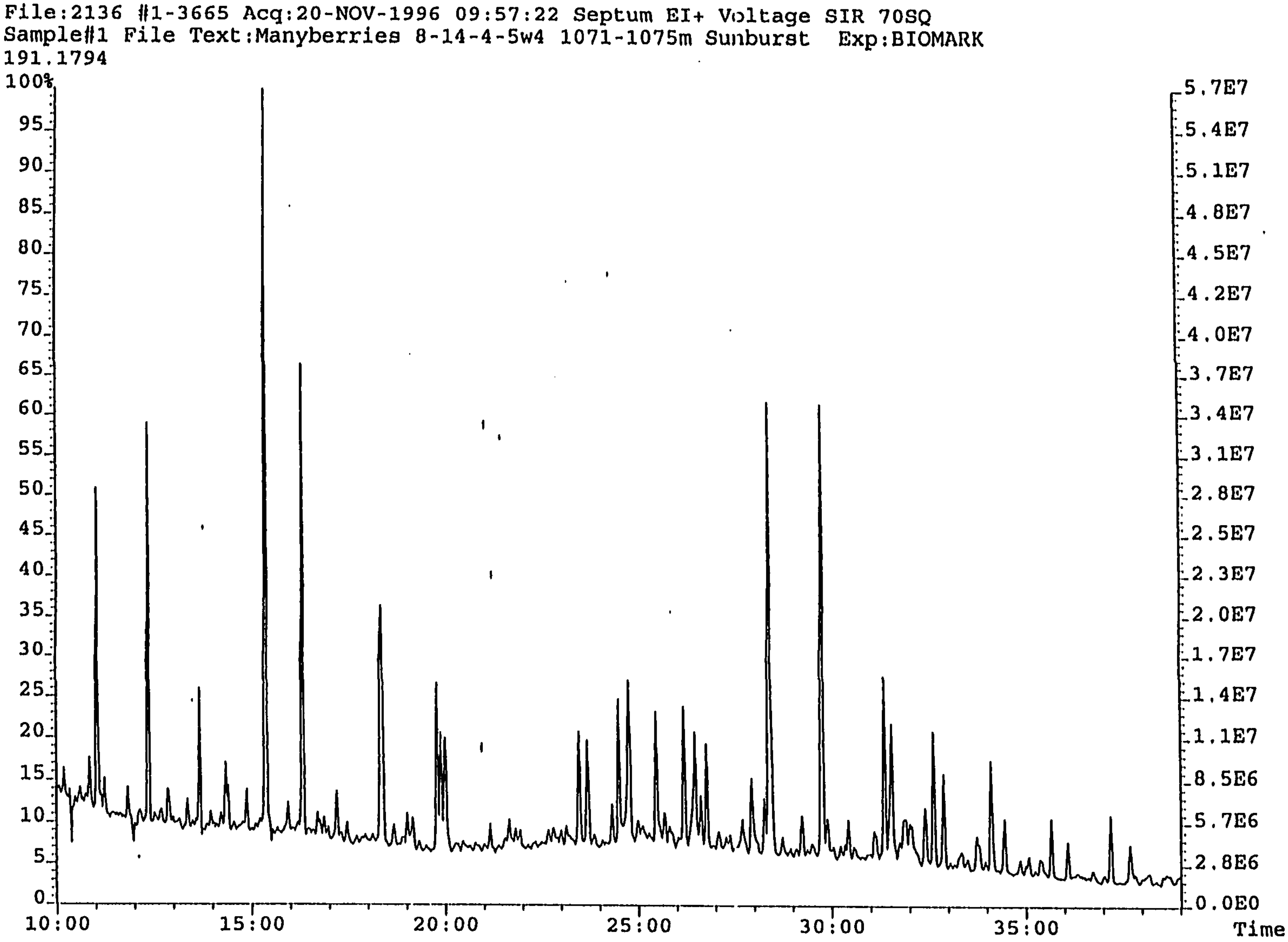
File:2136 #1-3665 Acq:20-NOV-1996 09:57:22 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 8-14-4-5w4 1071-1075m Sunburst Exp:BIOMARK
191.1794
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4.5E7
4.2E7
4.0E7
3.7E7
3.4E7
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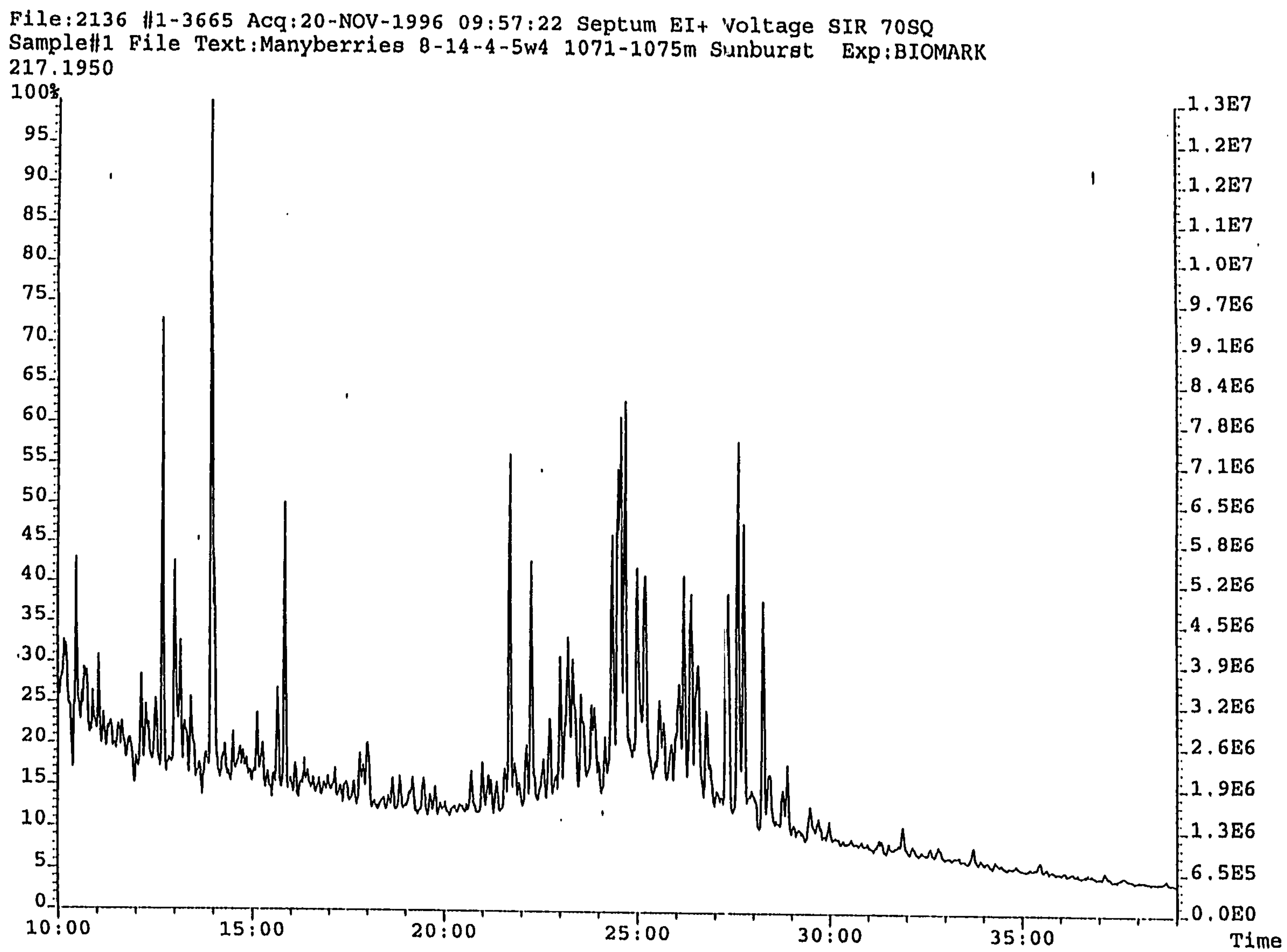
File:2136 #1-3665 Acq:20-NOV-1996 09:57:22 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 8-14-4-5w4 1071-1075m Sunburst Exp:BIOMARK
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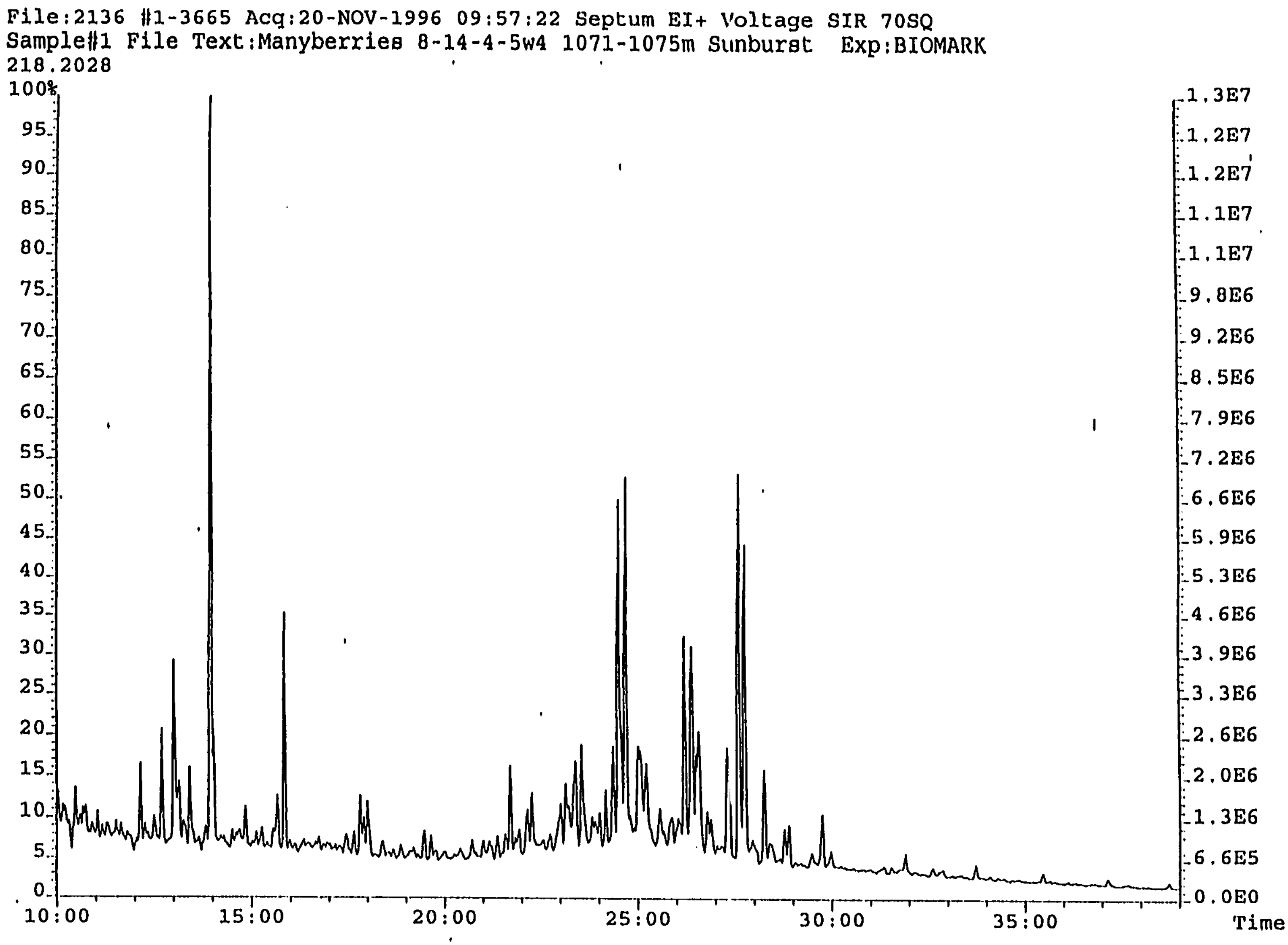
Time


File:2136 #1-3665 Acq:20-NOV-1996 09:57:22 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 8-14-4-5w4 1071-1075m Sunburst Exp:BIOMARK
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7.2E6
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4.6E6
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3.3E6
2.6E6
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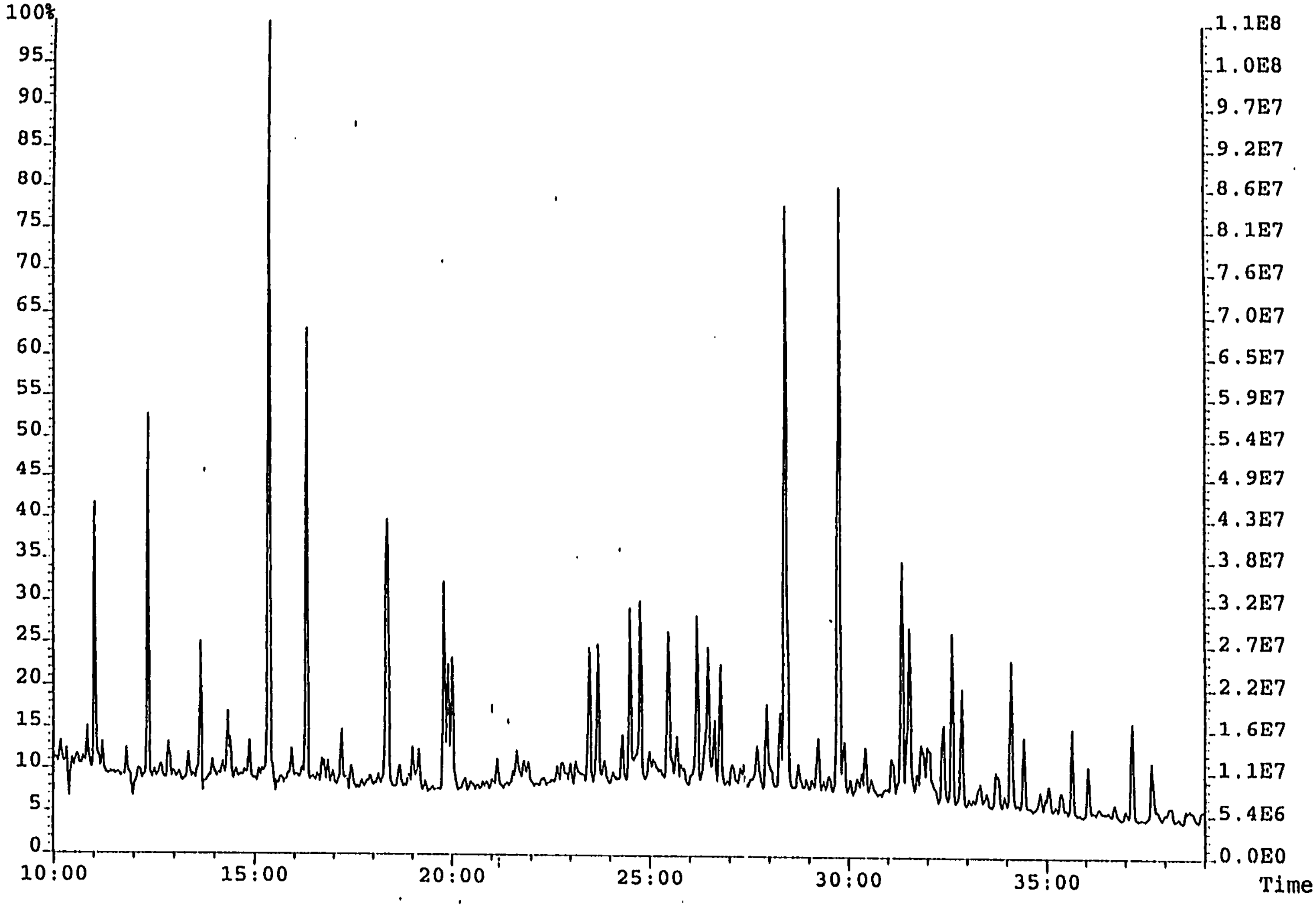
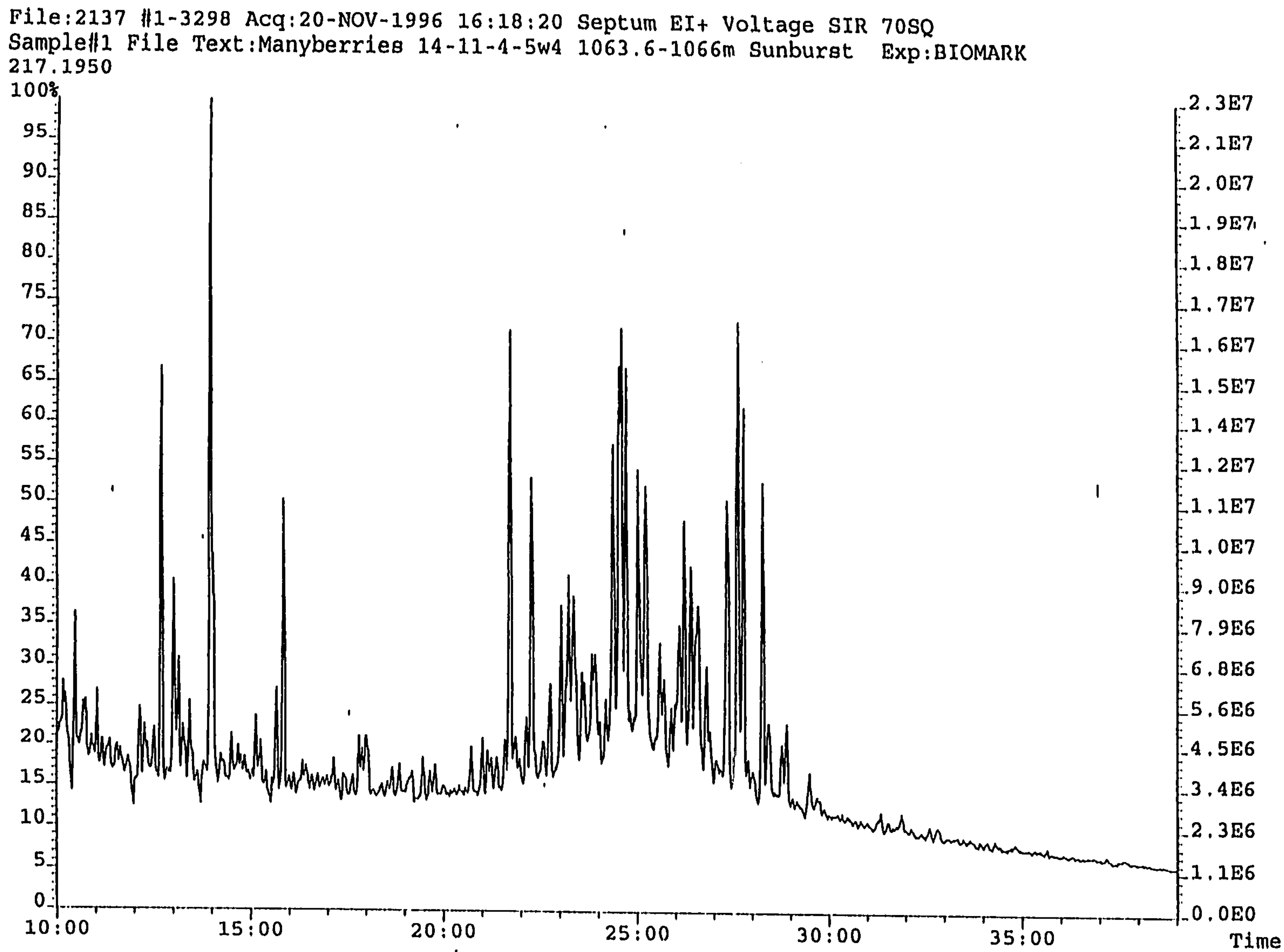
Time

File:2137 #1-3298 Acq:20-NOV-1996 16:18:20 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 14-11-4-5w4 1063.6-1066m Sunburst Exp:BIOMARK
191.1794




File:2137 #1-3298 Acq:20-NOV-1996 16:18:20 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 14-11-4-5w4 1063.6-1066m Sunburst Exp:BIOMARK
217.1950
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1.6E7
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1.1E7
1.0E7
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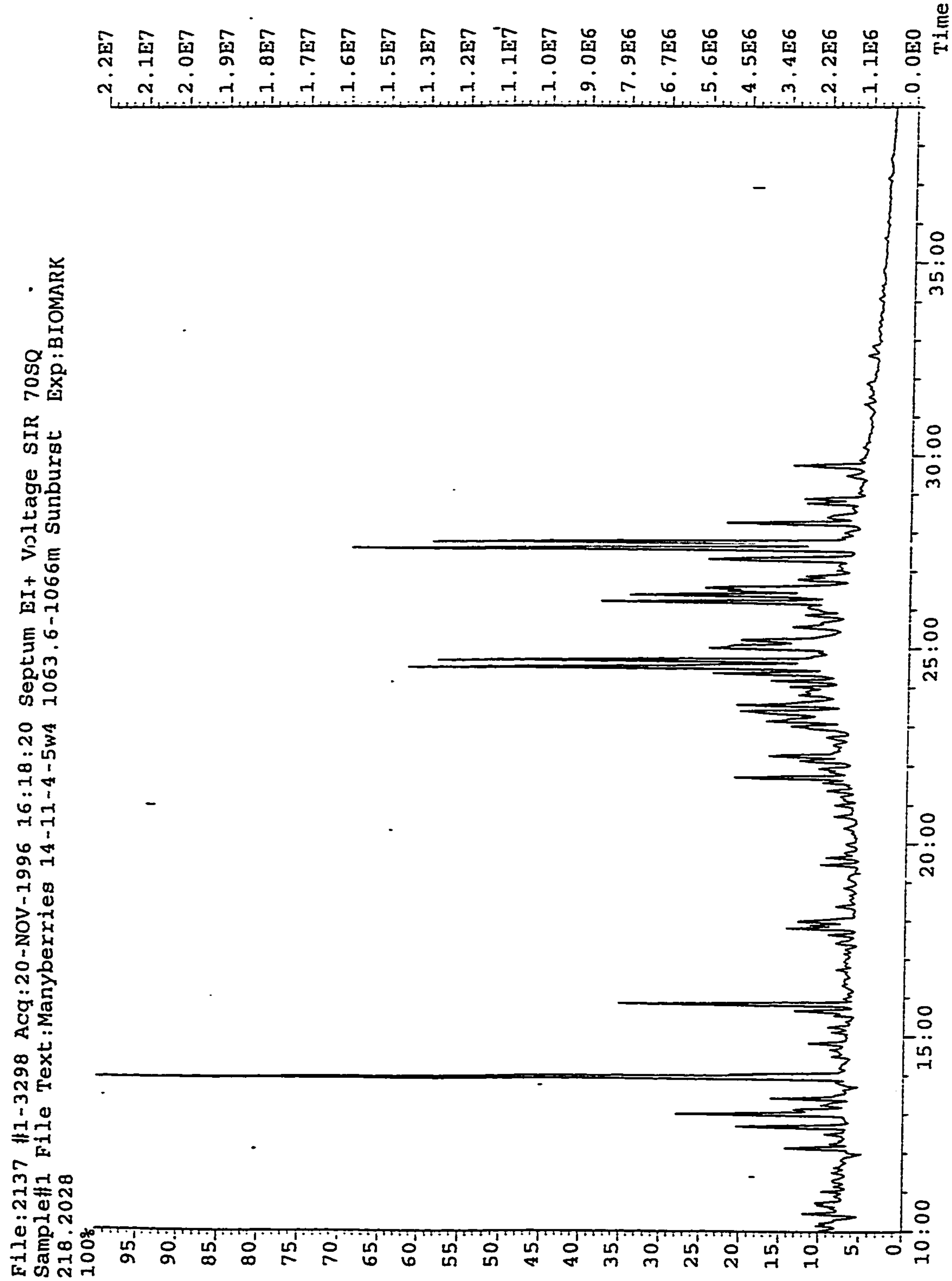
File:2137 #1-3298 Acq:20-NOV-1996 16:18:20 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 14-11-4-5w4 1063.6-1066m Sunburst Exp:BIOMARK
218.2028
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1.8E7
1.7E7
1.6E7
1.5E7
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1.2E7
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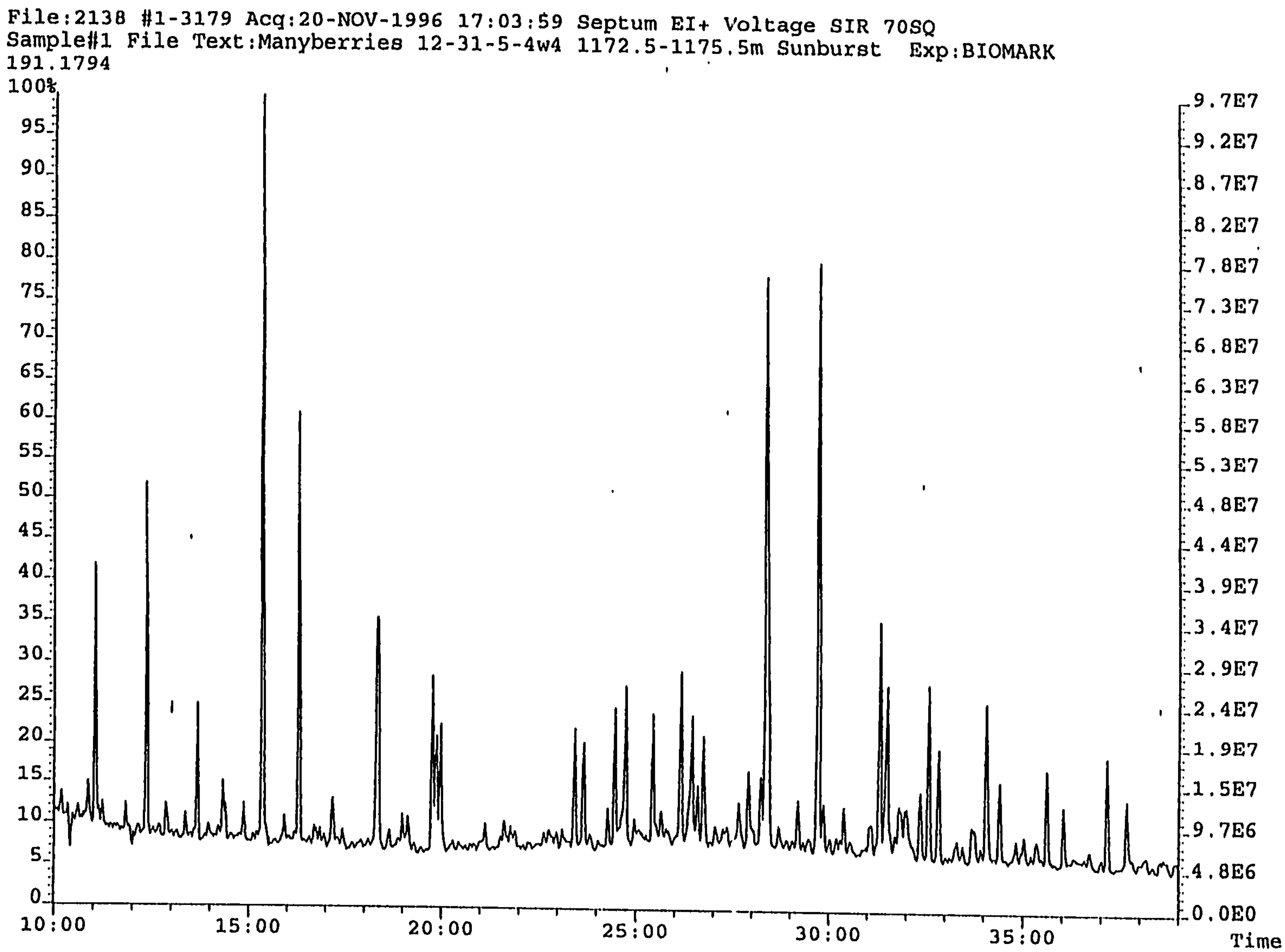
File:2138 #1-3179 Acq:20-NOV-1996 17:03:59 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-31-5-4w4 1172.5-1175.5m Sunburst Exp:BIOMARK
191.1794
100%
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4.8E7
4.4E7
3.9E7
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2.4E7
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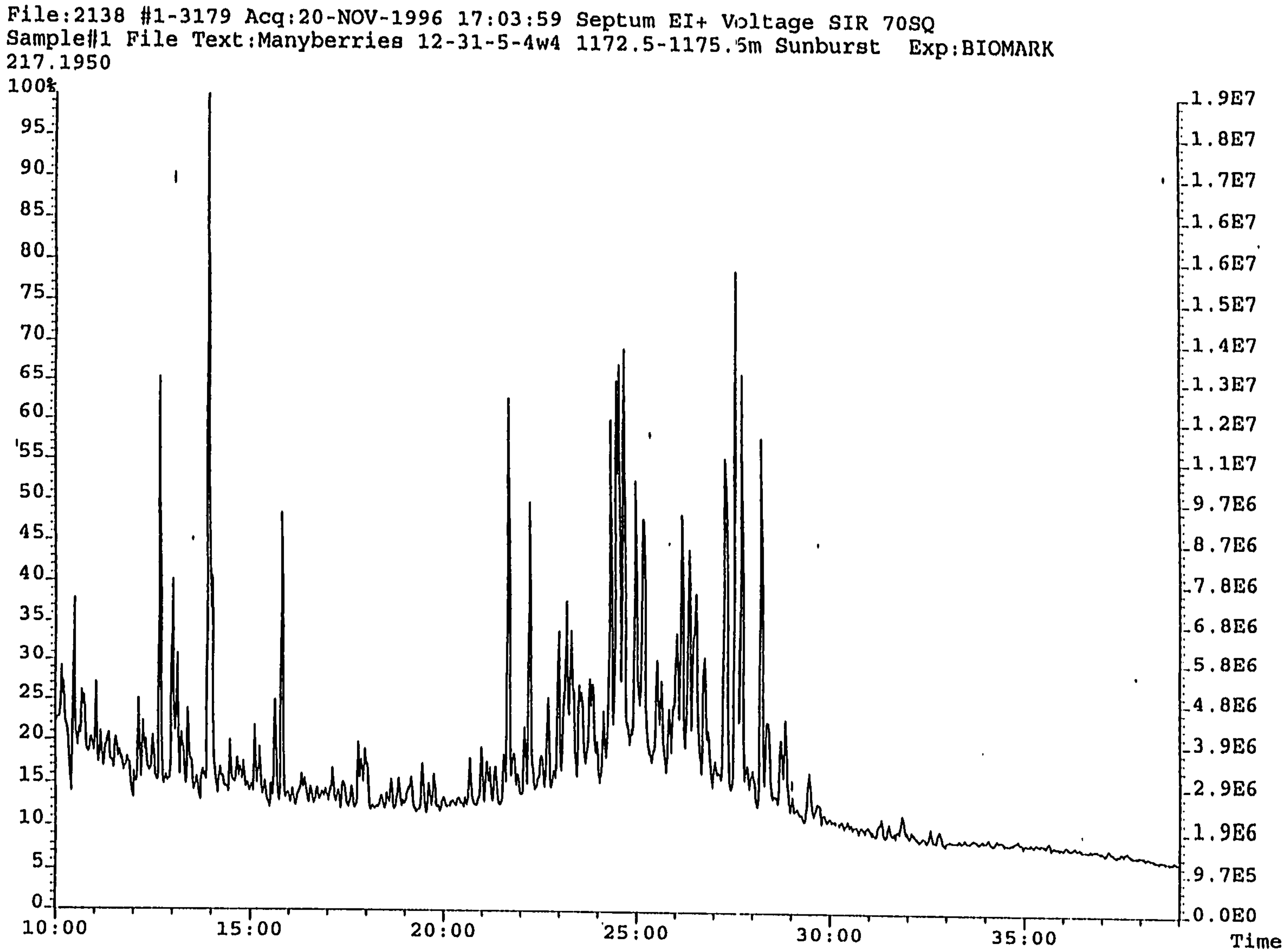
File:2138 #1-3179 Acq:20-NOV-1996 17:03:59 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-31-5-4w4 1172.5-1175.5m Sunburst Exp:BIOMARK
217.1950
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7.8E6
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5.8E6
4.8E6
3.9E6
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1.9E6
9.7E5
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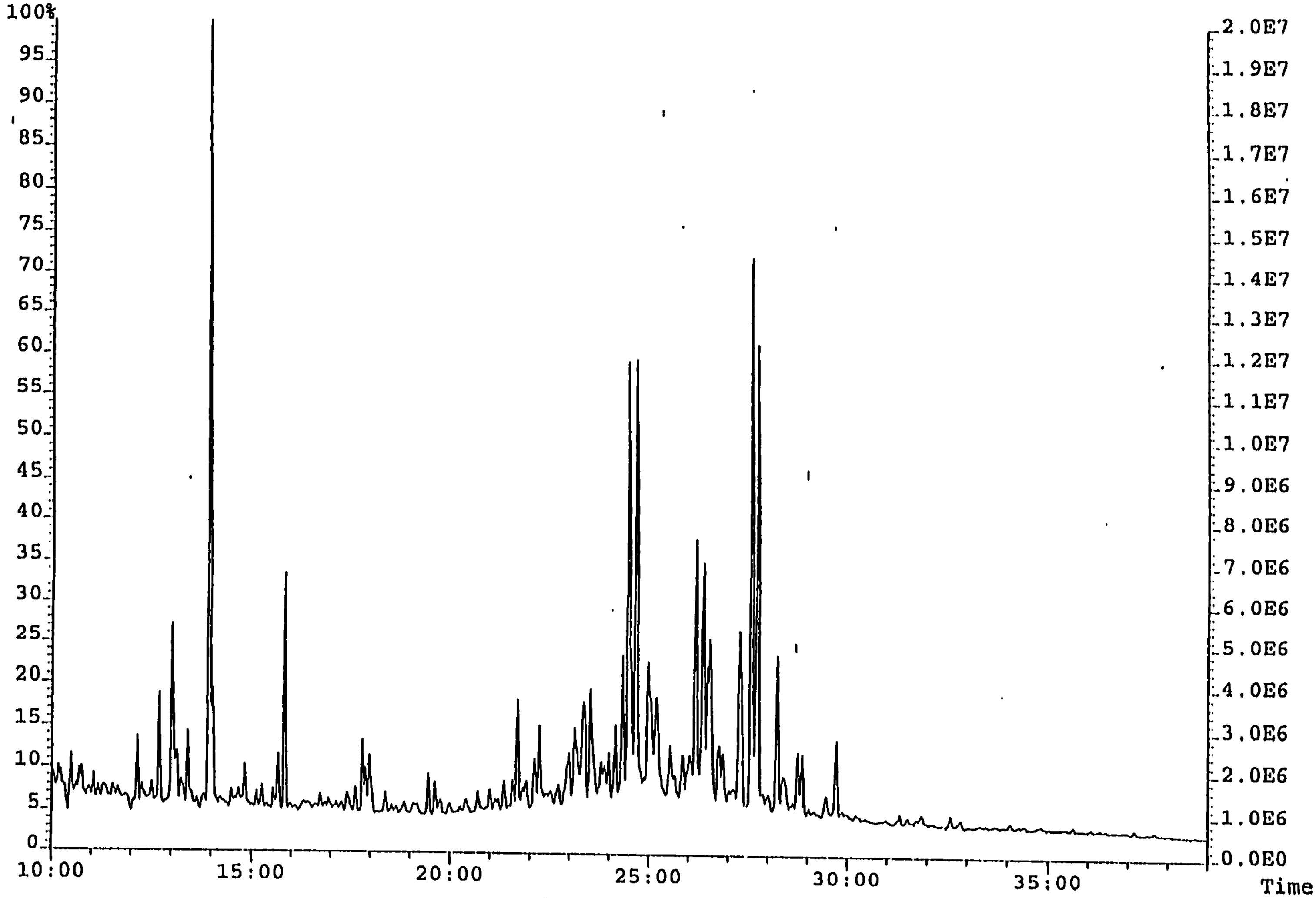
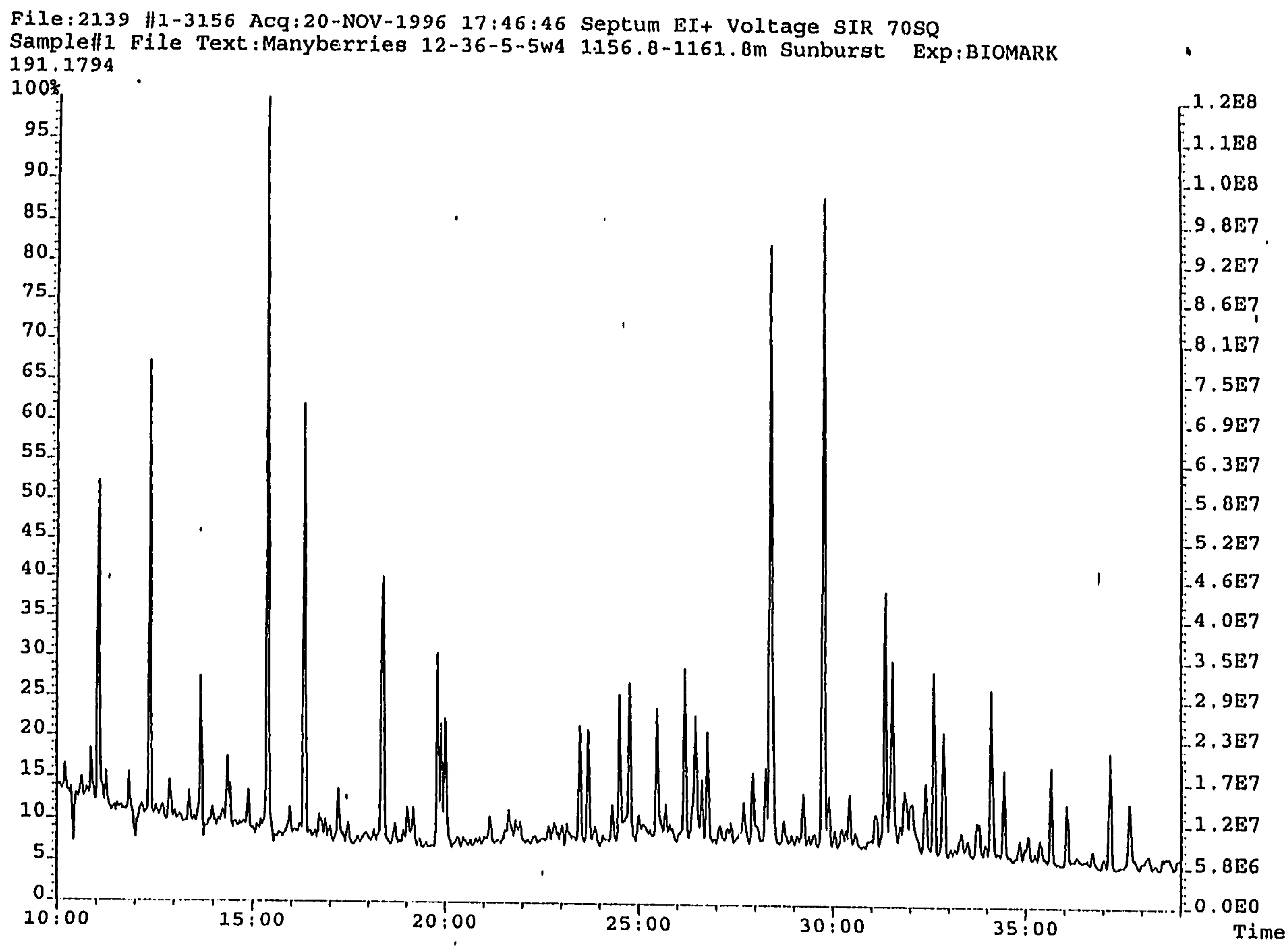
File:2138 #1-3179 Acq:20-NOV-1996 17:03:59 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-31-5-4w4 1172.5-1175.5m Sunburst Exp:BIOMARK
218.2028




File:2139 #1-3156 Acq:20-NOV-1996 17:46:46 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-36-5-5w4 1156.8-1161.8m Sunburst Exp:BIOMARK
191.1794
100%
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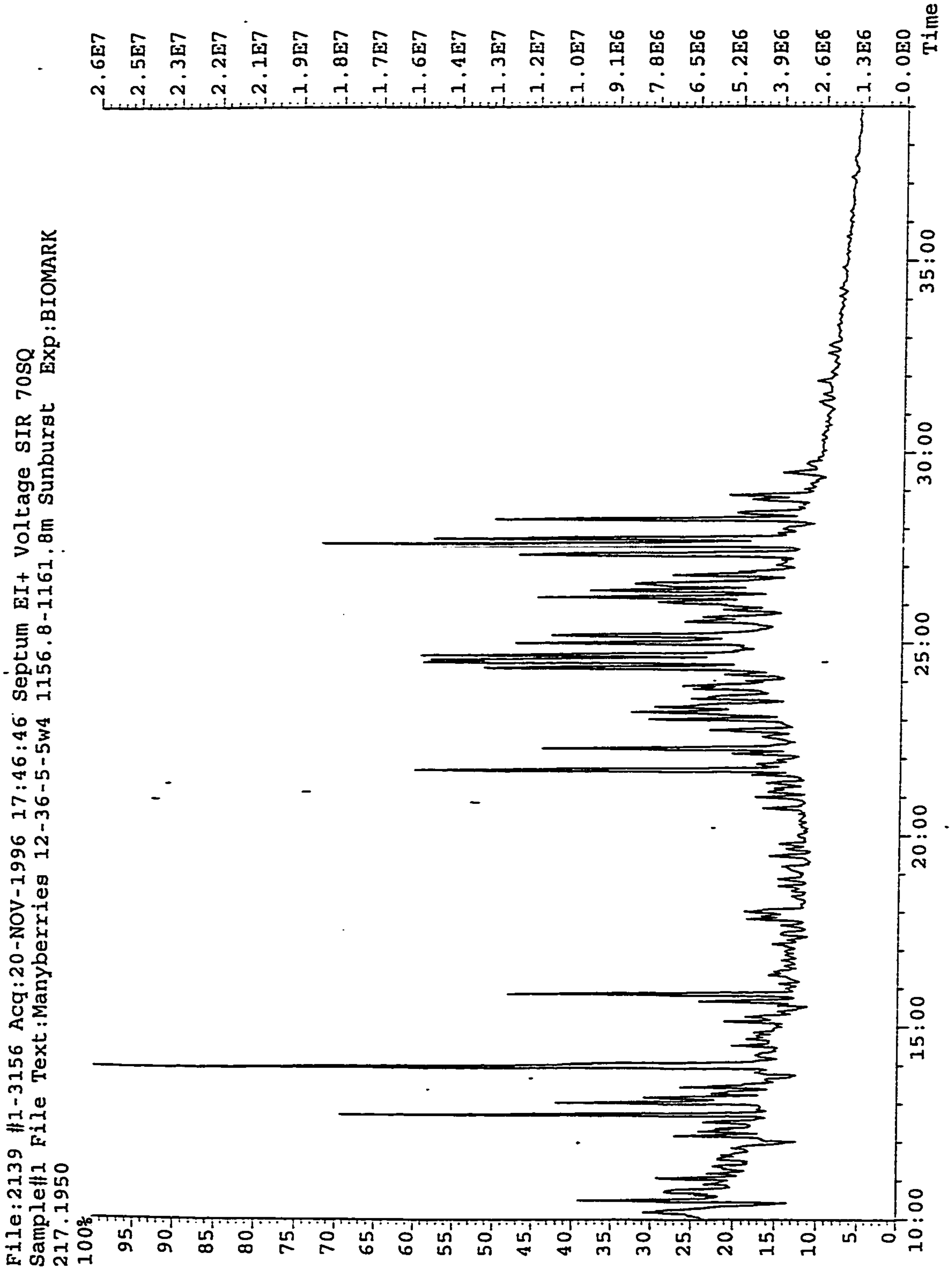
35
30
25
20
15
10
5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.2E8
1.1E8
1.0E8
9.8E7
9.2E7
8.6E7
8.1E7
7.5E7
6.9E7
6.3E7
5.8E7
5.2E7
4.6E7
4.0E7
3.5E7
2.9E7
2.3E7
1.7E7
1.2E7
5.8E6
0.0E0


File:2139 #1-3156 Acq:20-NOV-1996 17:46:46 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-36-5-5w4 1156.8-1161.8m Sunburst Exp:BIOMARK
217.1950
100%
95
90
85
80
75
70
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60
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20
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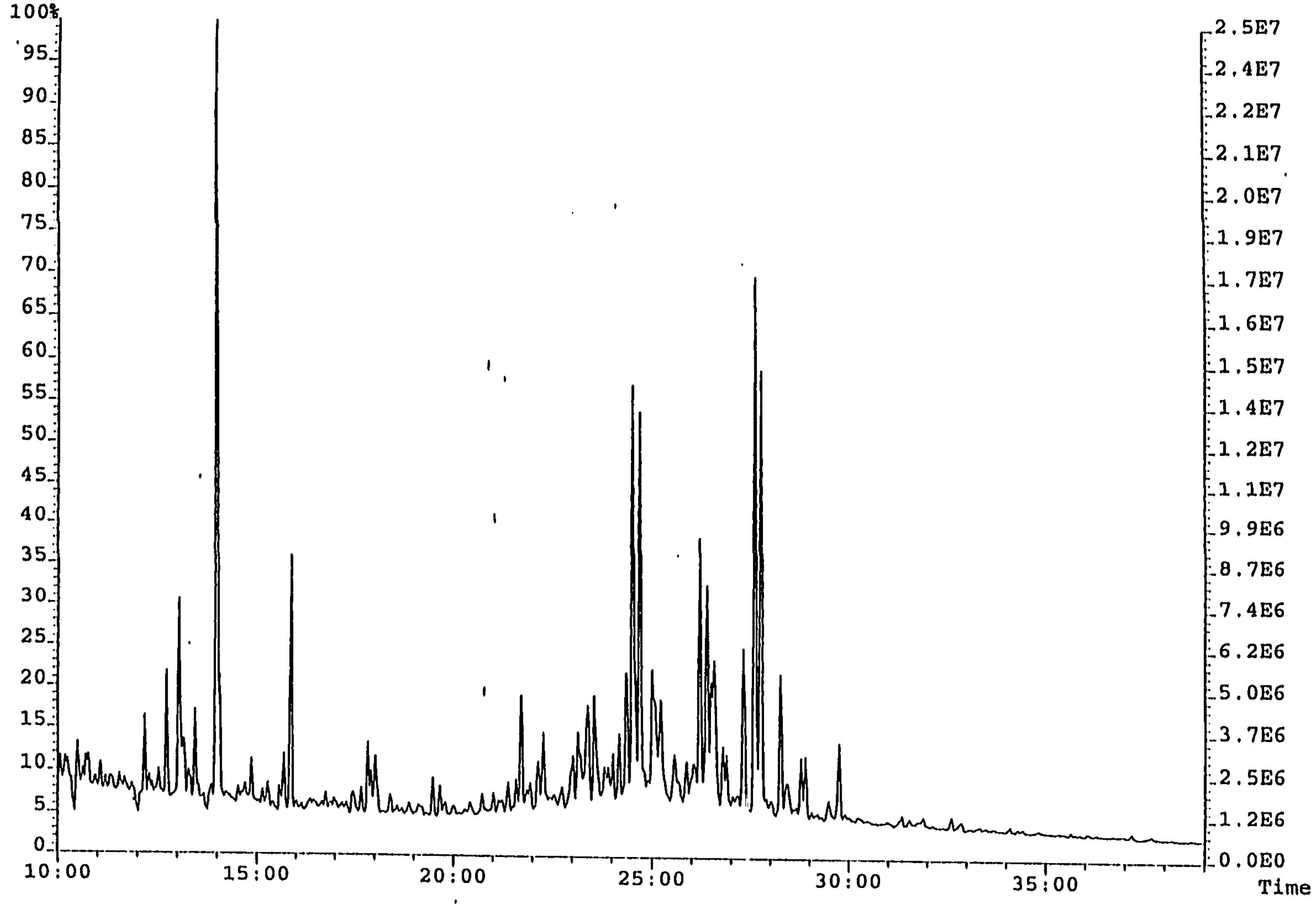
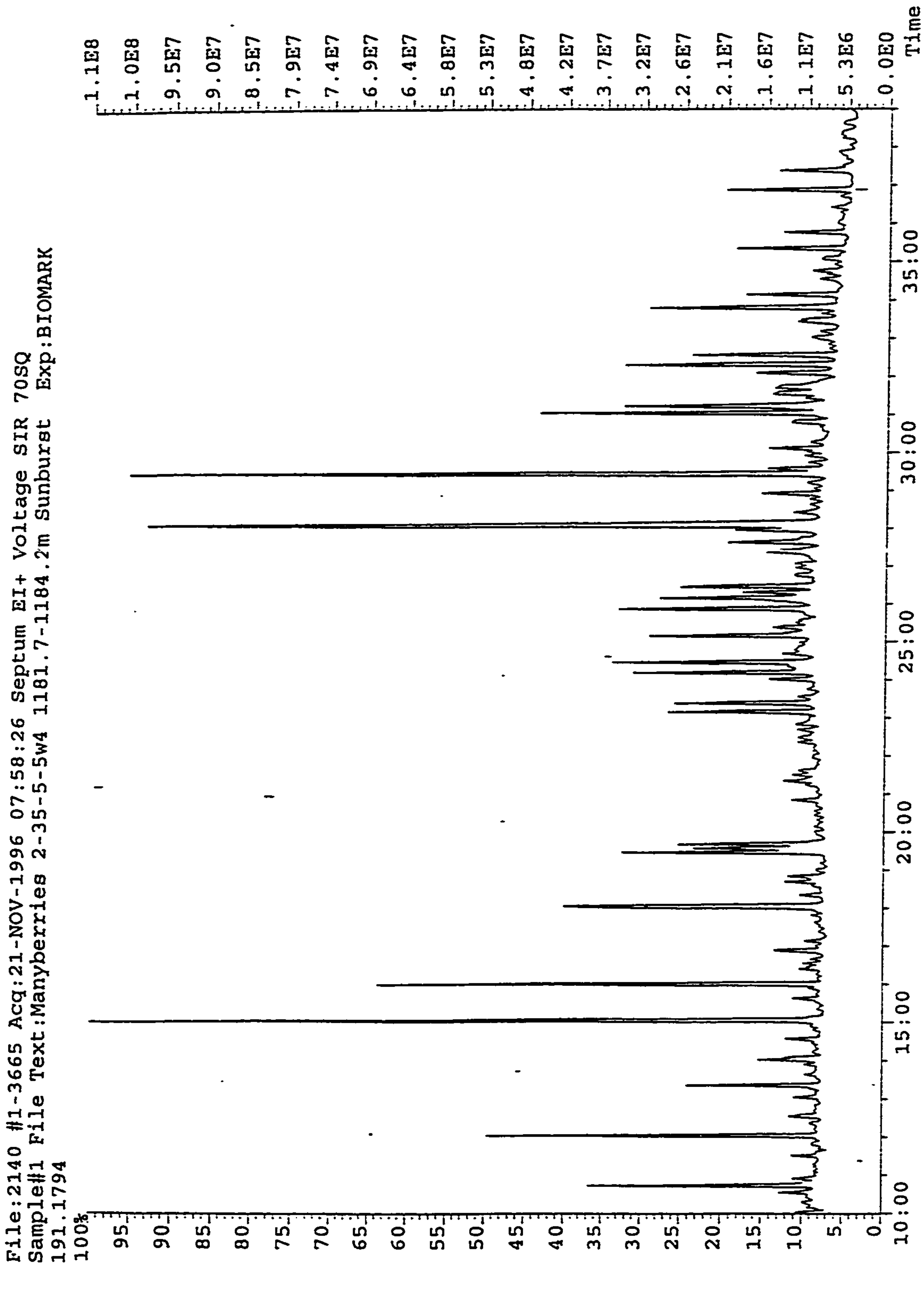
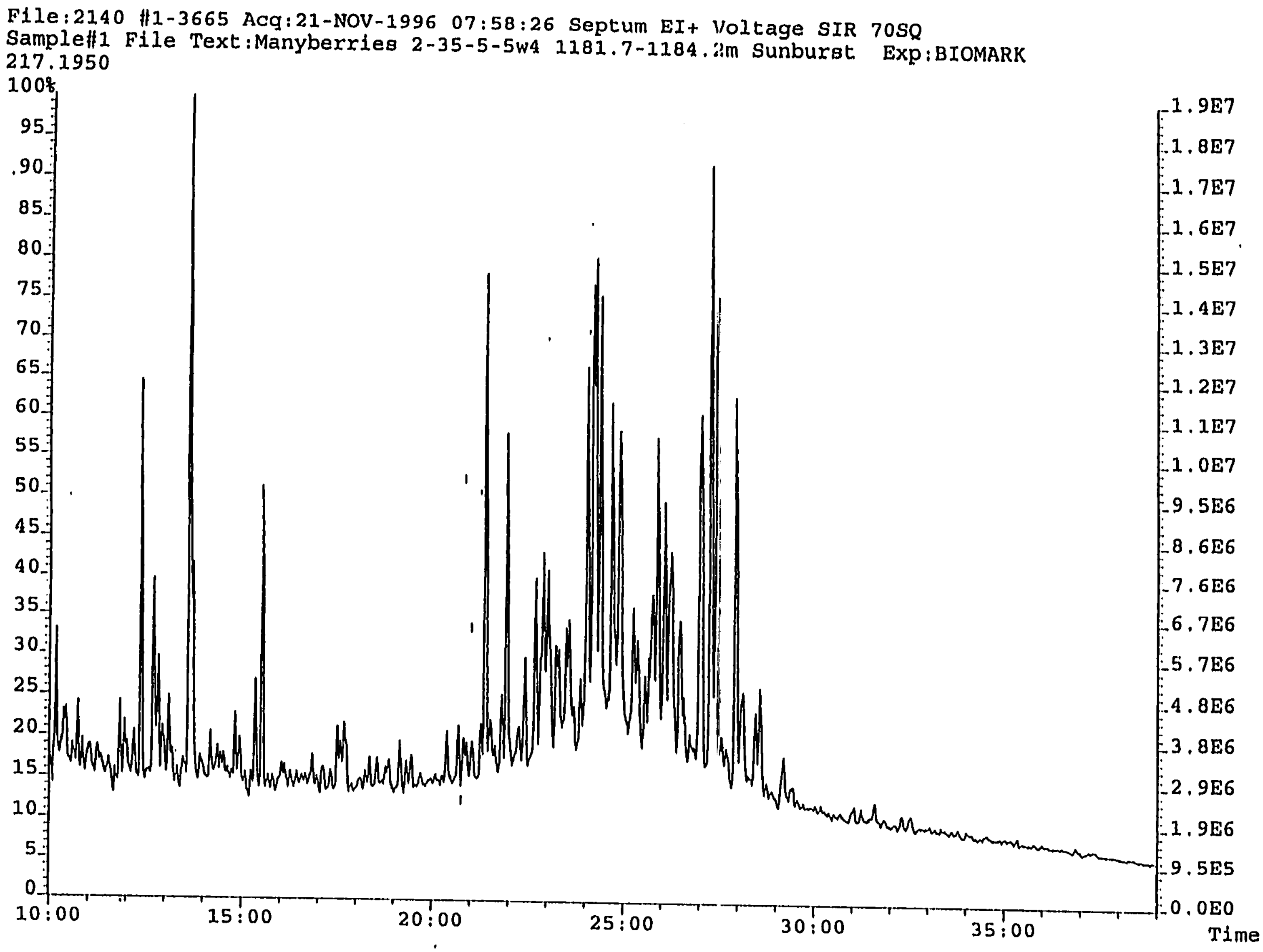
10:00
15:00
20:00
25:00
30:00
35:00
Time
2.6E7
2.5E7
2.3E7
2.2E7
2.1E7
1.9E7
1.8E7
1.7E7
1.6E7
1.4E7
1.3E7
1.2E7
1.0E7
9.1E6
7.8E6
6.5E6
5.2E6
3.9E6
2.6E6
1.3E6
0.0E0

File:2139 #1-3156 Acq:20-NOV-1996 17:46:46 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 12-36-5-5w4 1156.8-1161.8m Sunburst Exp:BIOMARK
218.2028




File:2140 #1-3665 Acq:21-NOV-1996 07:58:26 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 2-35-5-5w4 1181.7-1184.2m Sunburst Exp:BIOMARK
191.1794
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.1E8
1.0E8
9.5E7
9.0E7
8.5E7
7.9E7
7.4E7
6.9E7
6.4E7
5.8E7
5.3E7
4.8E7
4.2E7
3.7E7
3.2E7
2.6E7
2.1E7
1.6E7
1.1E7
5.3E6
0.0E0


File:2140 #1-3665 Acq:21-NOV-1996 07:58:26 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 2-35-5-5w4 1181.7-1184.2m Sunburst Exp:BIOMARK
217.1950
100%
95
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80
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70
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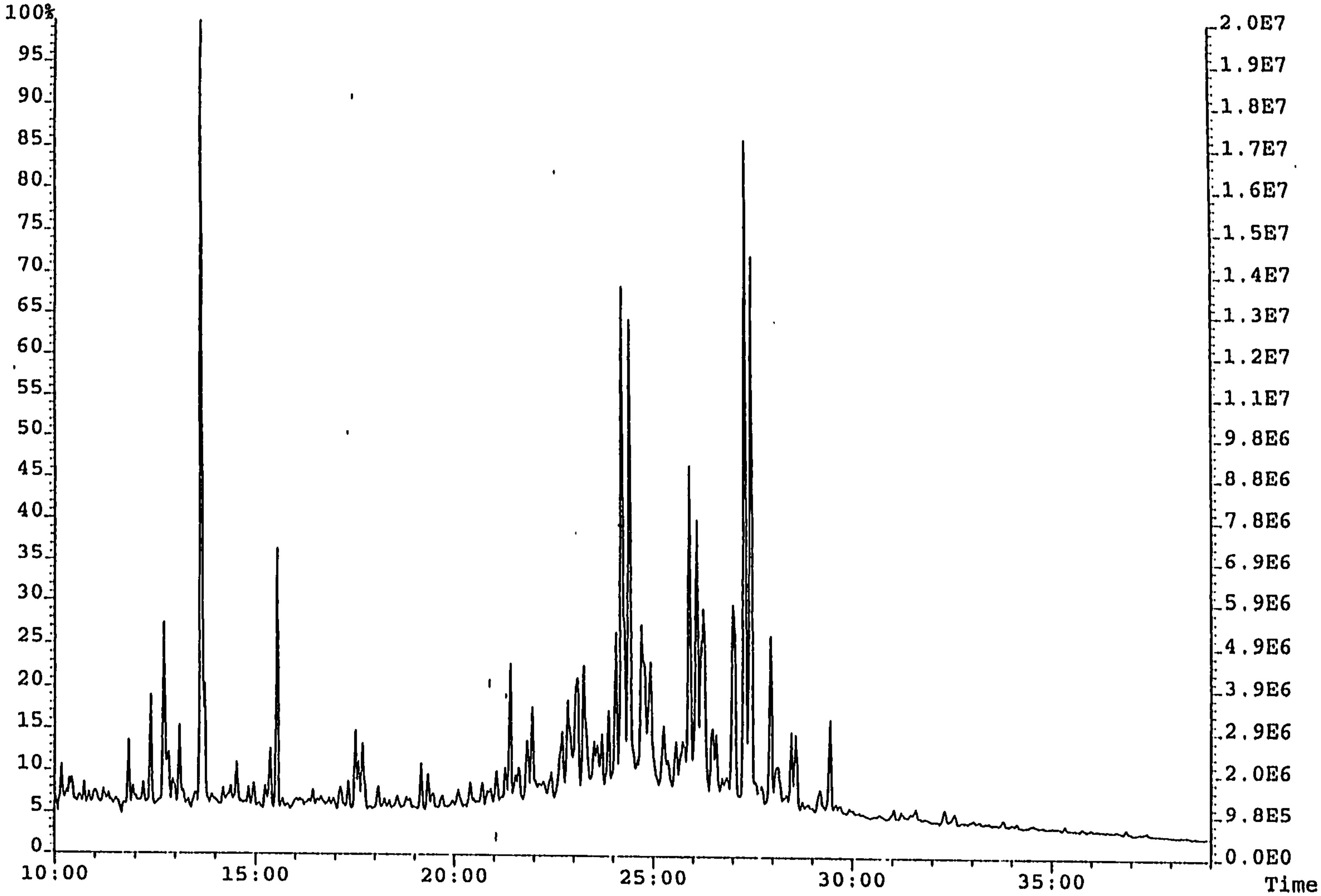
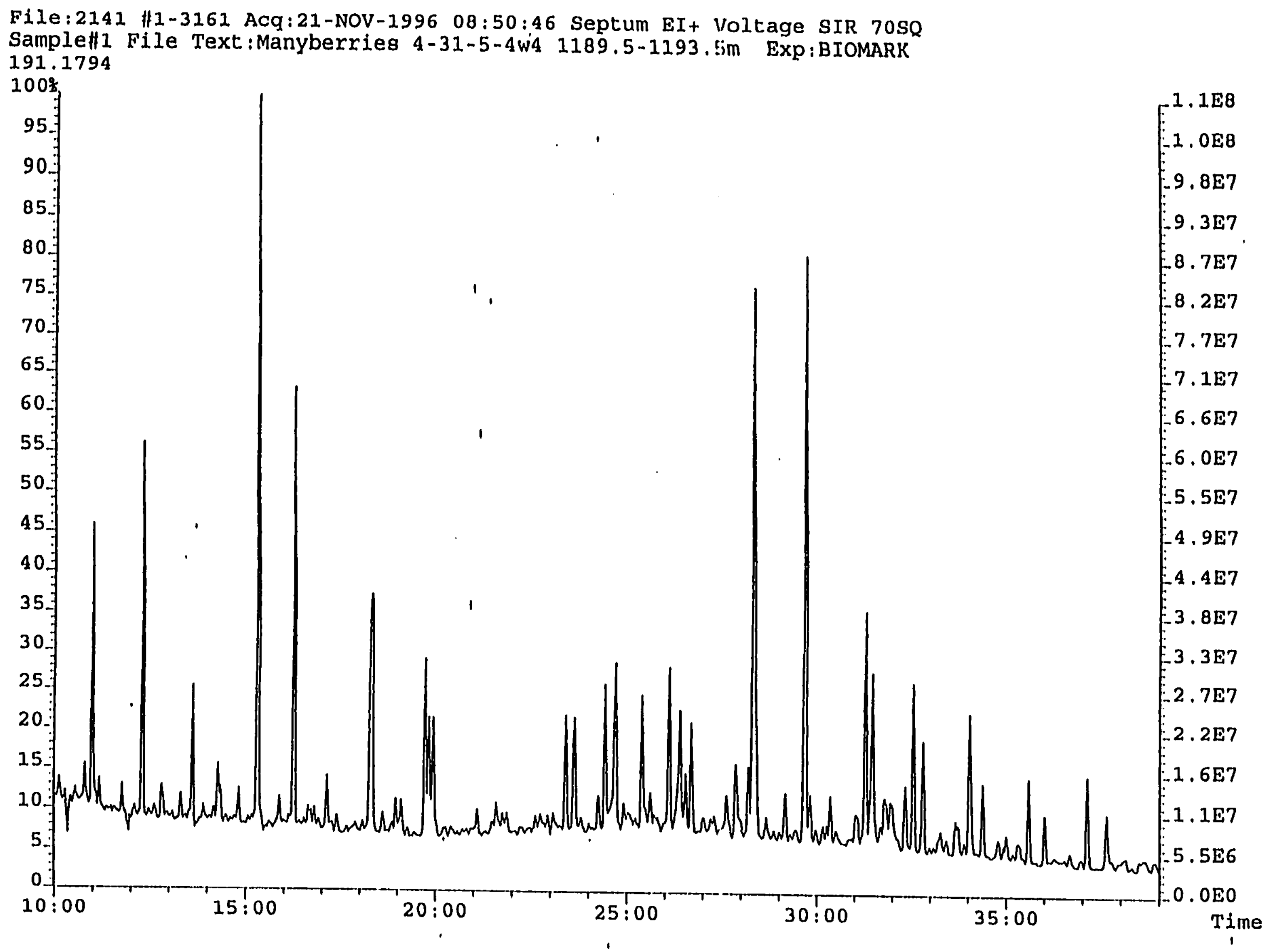
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.9E7
1.8E7
1.7E7
1.6E7
1.5E7
1.4E7
1.3E7
1.2E7
1.1E7
1.0E7
9.5E6
8.6E6
7.6E6
6.7E6
5.7E6
4.8E6
3.8E6
2.9E6
1.9E6
9.5E5
0.0E0

File:2140 #1-3665 Acq:21-NOV-1996 07:58:26 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 2-35-5-5w4 1181.7-1184.2m Sunburst Exp:BIOMARK
218.2028




File:2141 #1-3161 Acq:21-NOV-1996 08:50:46 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 4-31-5-4w4 1189.5-1193.5m Exp:BIOMARK
191.1794
100%
95
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80
75
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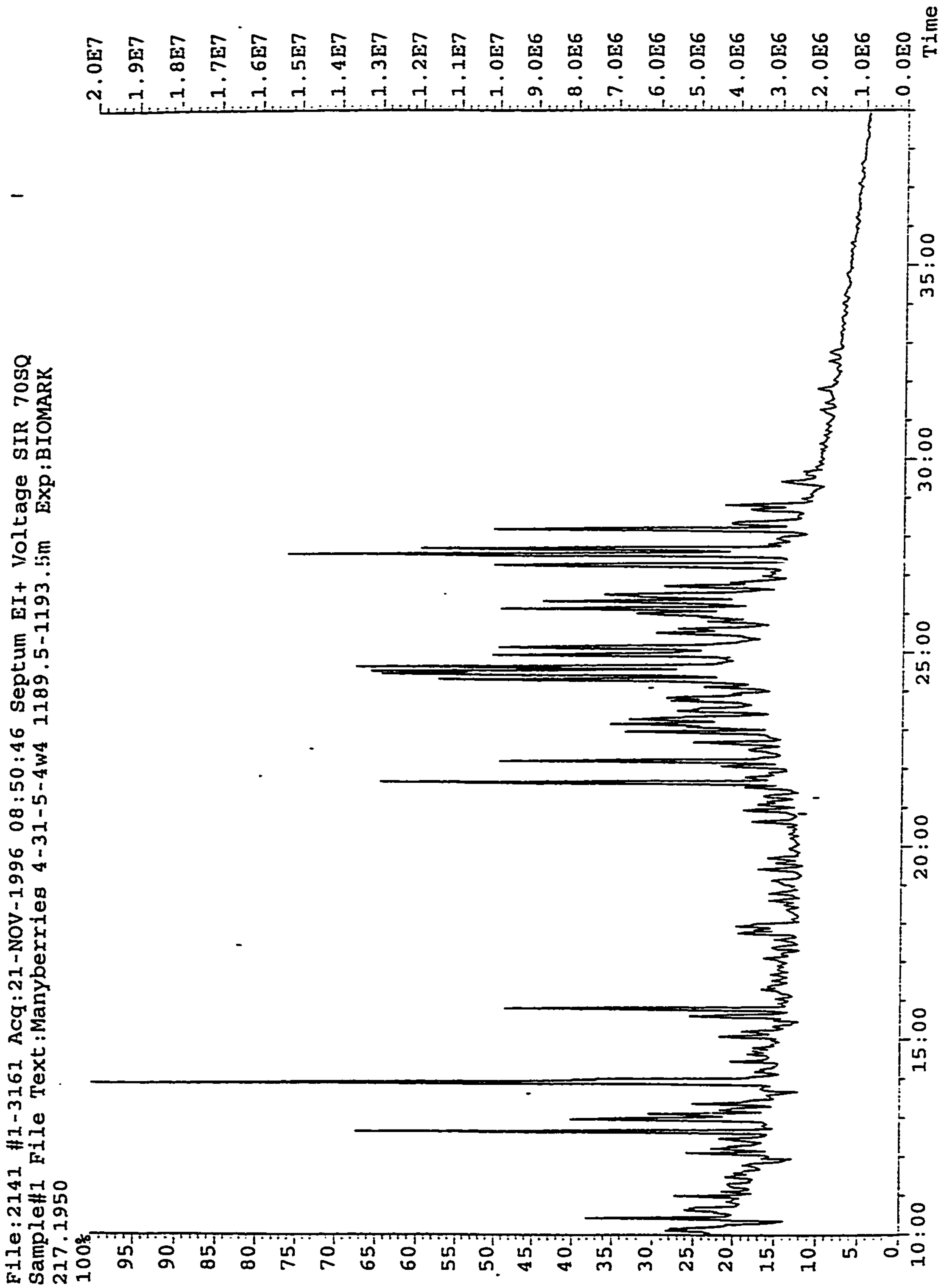
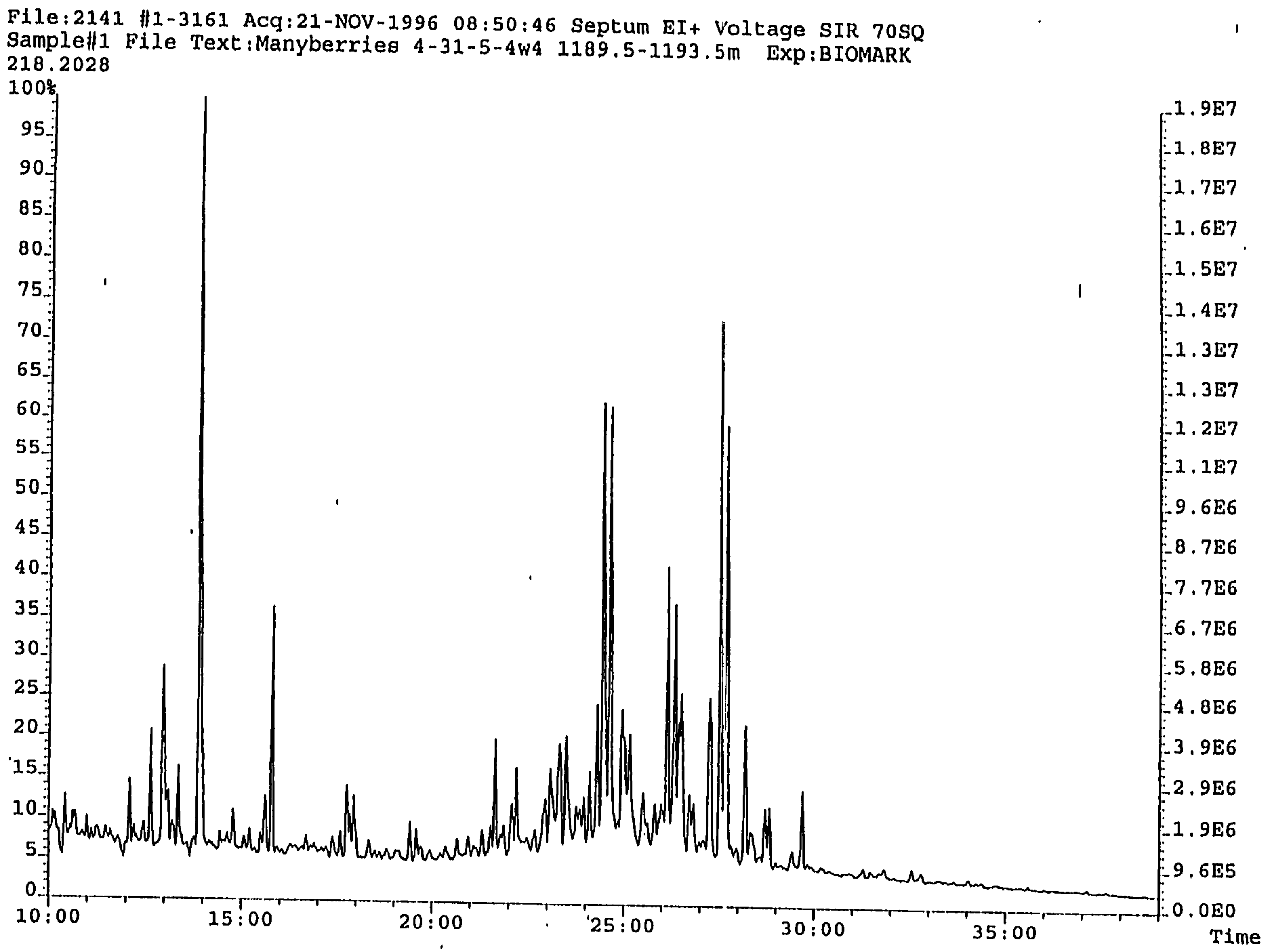
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.1E8
1.0E8
9.8E7
9.3E7
8.7E7
8.2E7
7.7E7
7.1E7
6.6E7
6.0E7
5.5E7
4.9E7
4.4E7
3.8E7
3.3E7
2.7E7
2.2E7
1.6E7
1.1E7
5.5E6
0.0E0


File:2141 #1-3161 Acq:21-NOV-1996 08:50:46 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 4-31-5-4w4 1189.5-1193.5m Exp:BIOMARK
217.1950
100%
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
2.0E7 1.9E7 1.8E7 1.7E7 1.6E7 1.5E7 1.4E7 1.3E7 1.2E7 1.1E7 1.0E7 9.0E6 8.0E6 7.0E6 6.0E6 5.0E6 4.0E6 3.0E6 2.0E6 1.0E6 0.0E0
10:00 15:00 20:00 25:00 30:00 35:00
Time


File:2141 #1-3161 Acq:21-NOV-1996 08:50:46 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 4-31-5-4w4 1189.5-1193.5m Exp:BIOMARK
218.2028
100%
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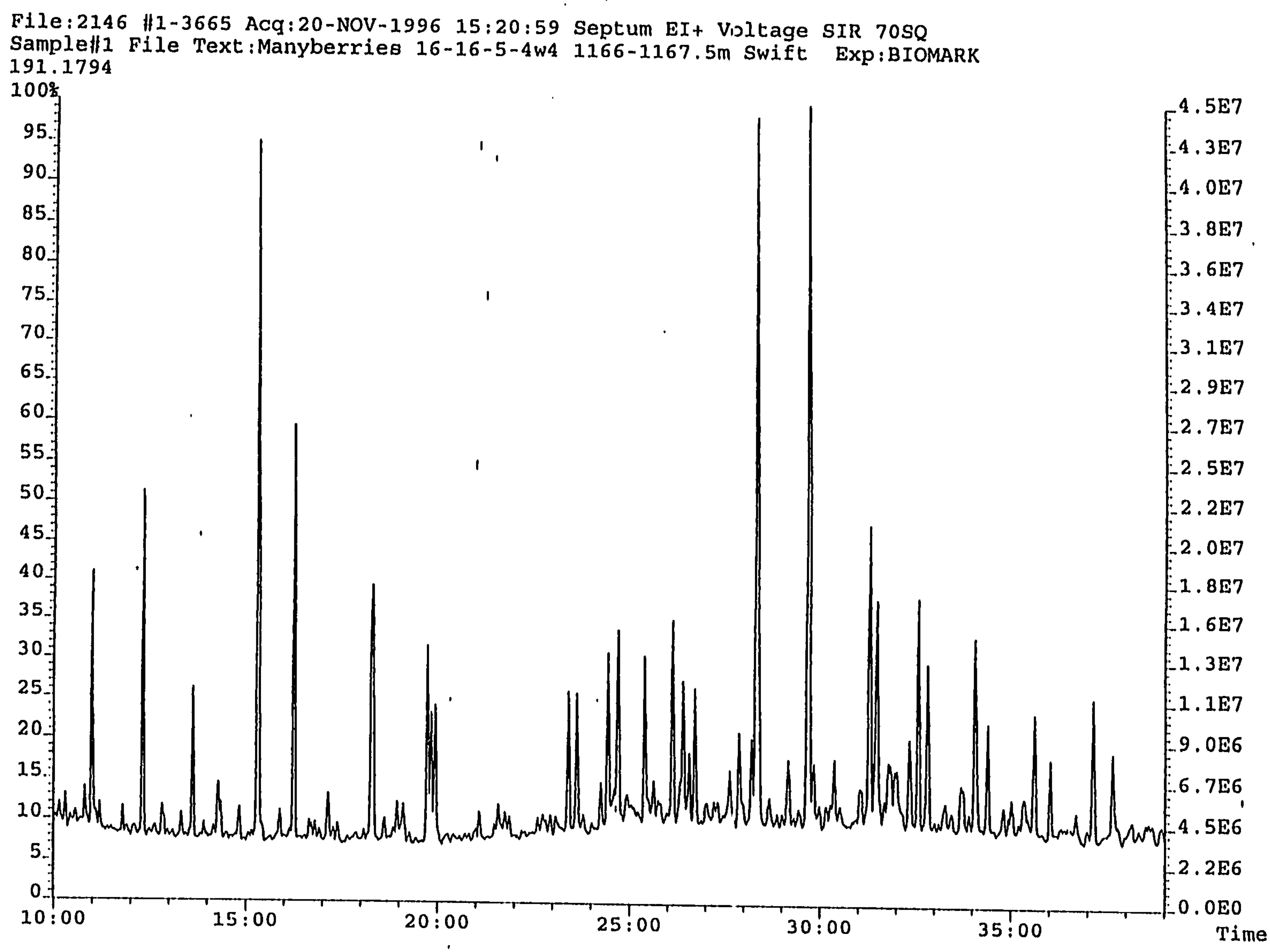
25:00
30:00
35:00
Time
1.9E7
1.8E7
1.7E7
1.6E7
1.5E7
1.4E7
1.3E7
1.3E7
1.2E7
1.1E7
9.6E6
8.7E6
7.7E6
6.7E6
5.8E6
4.8E6
3.9E6
2.9E6
1.9E6
9.6E5
0.0E0


File:2146 #1-3665 Acq:20-NOV-1996 15:20:59 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-16-5-4w4 1166-1167.5m Swift Exp:BIOMARK
191.1794
100%
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10:00
15:00
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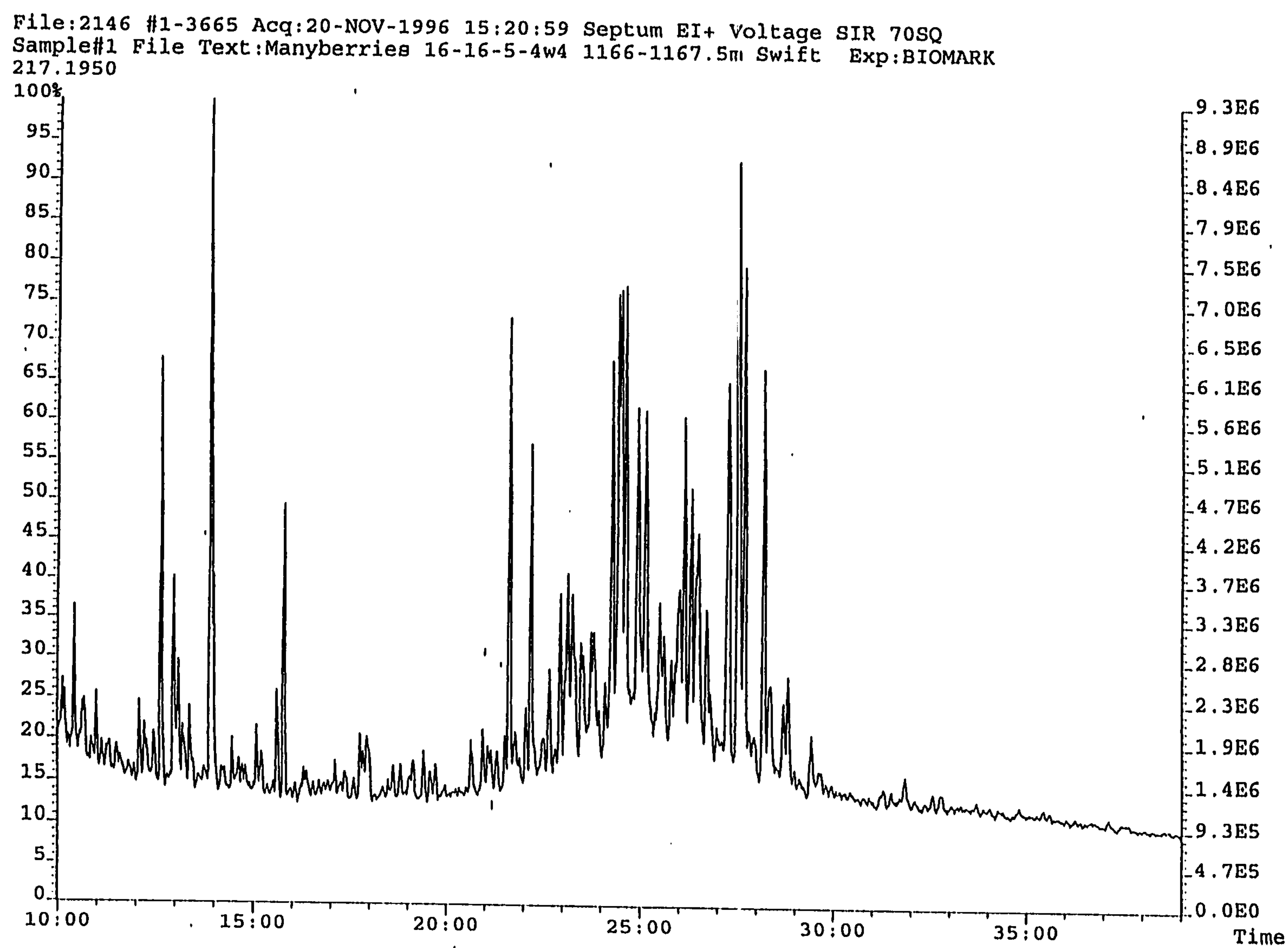
25:00
30:00
35:00
Time
4.5E7
4.3E7
4.0E7
3.8E7
3.6E7
3.4E7
3.1E7
2.9E7
2.7E7
2.5E7
2.2E7
2.0E7
1.8E7
1.6E7
1.3E7
1.1E7
9.0E6
6.7E6
4.5E6
2.2E6
0.0E0


File:2146 #1-3665 Acq:20-NOV-1996 15:20:59 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-16-5-4w4 1166-1167.5m Swift Exp:BIOMARK
217.1950
100%
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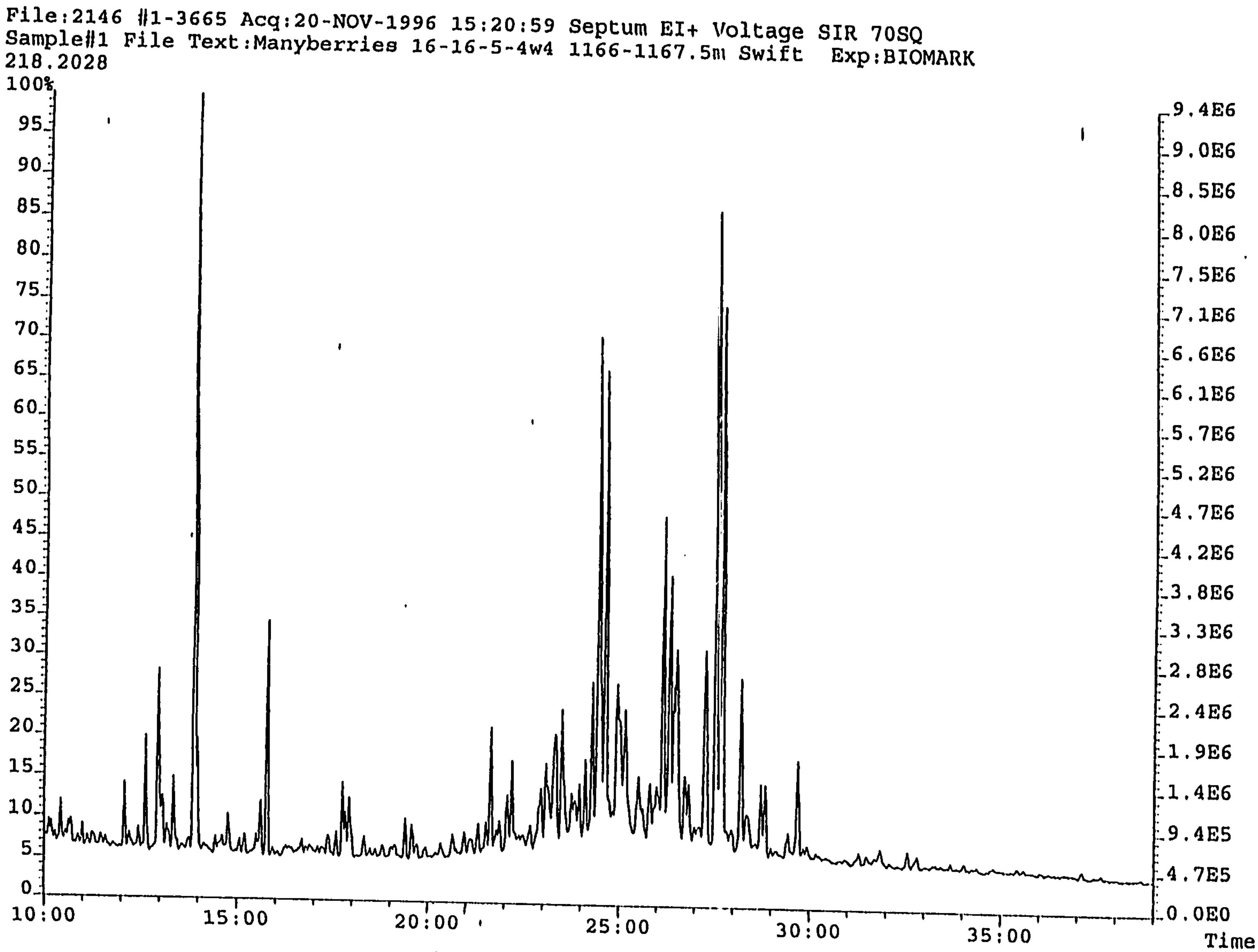
10:00
15:00
20:00
25:00
30:00
35:00
Time
9.3E6
8.9E6
8.4E6
7.9E6
7.5E6
7.0E6
6.5E6
6.1E6
5.6E6
5.1E6
4.7E6
4.2E6
3.7E6
3.3E6
2.8E6
2.3E6
1.9E6
1.4E6
9.3E5
4.7E5
0.0E0


File:2146 #1-3665 Acq:20-NOV-1996 15:20:59 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Manyberries 16-16-5-4w4 1166-1167.5m Swift Exp:BIOMARK
218.2028
100%
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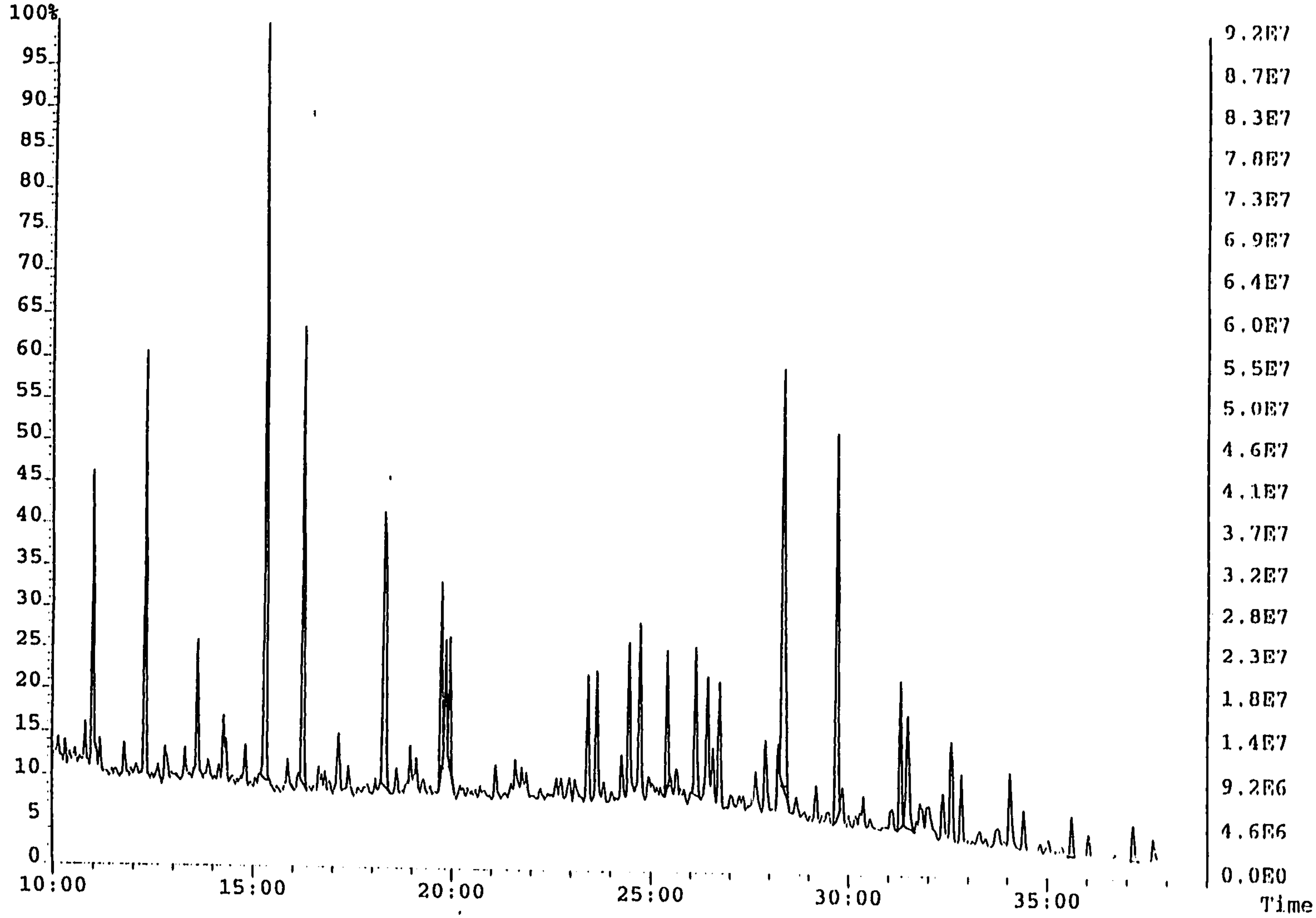
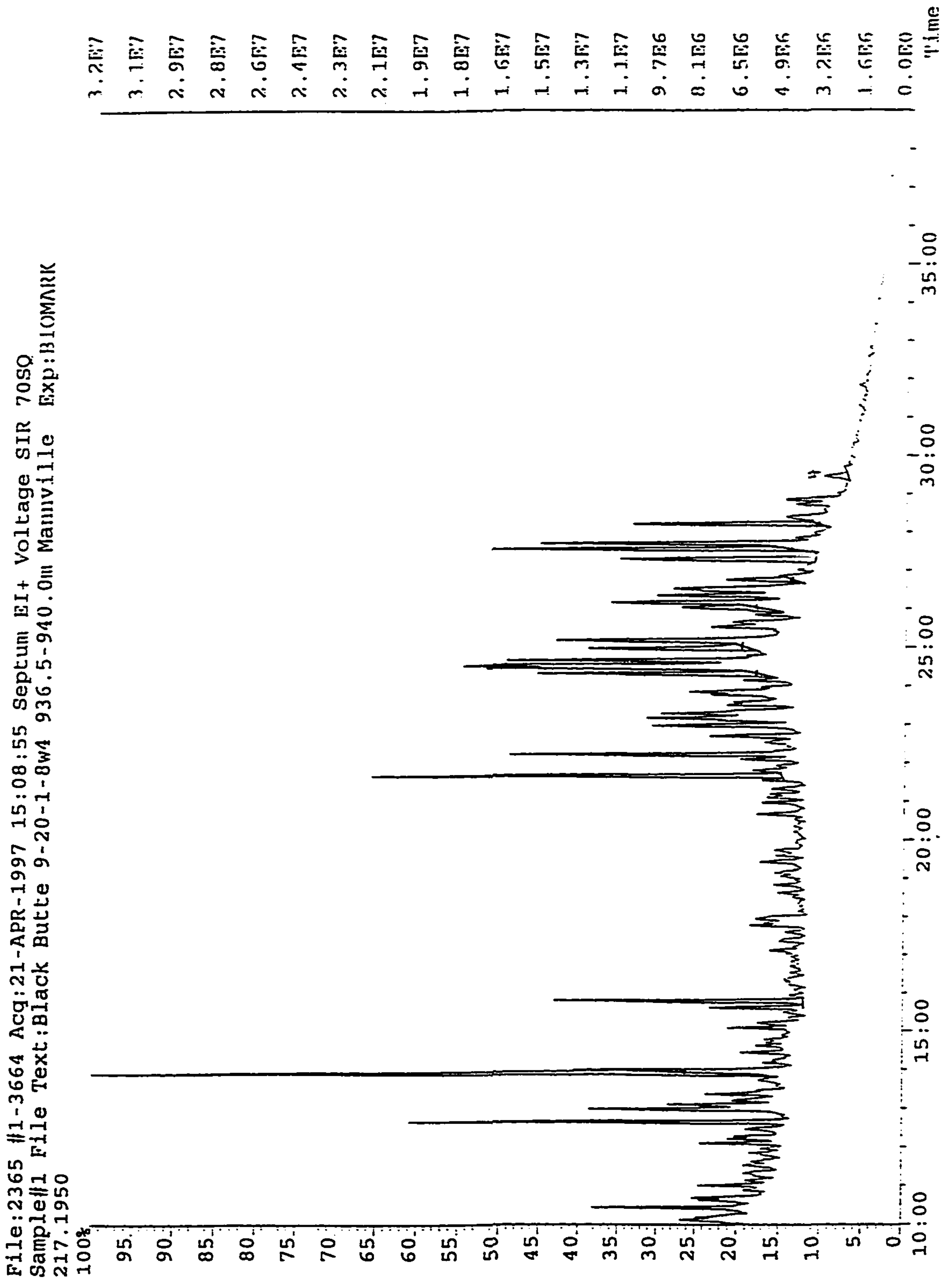
15:00
20:00
25:00
30:00
35:00
Time
9.4E6
9.0E6
8.5E6
8.0E6
7.5E6
7.1E6
6.6E6
6.1E6
5.7E6
5.2E6
4.7E6
4.2E6
3.8E6
3.3E6
2.8E6
2.4E6
1.9E6
1.4E6
9.4E5
4.7E5
0.0E0

File:2365 #1-3664 Acq:21-APR-1997 15:08:55 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Black Butte 9-20-1-8w4 936.5-940.0m Mannville Exp:BIOMARK
191.1794




File:2365 #1-3664 Acq:21-APR-1997 15:08:55 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Black Butte 9-20-1-8w4 936.5-940.0m Mannville Exp:BIOMARK
217.1950
100%
95
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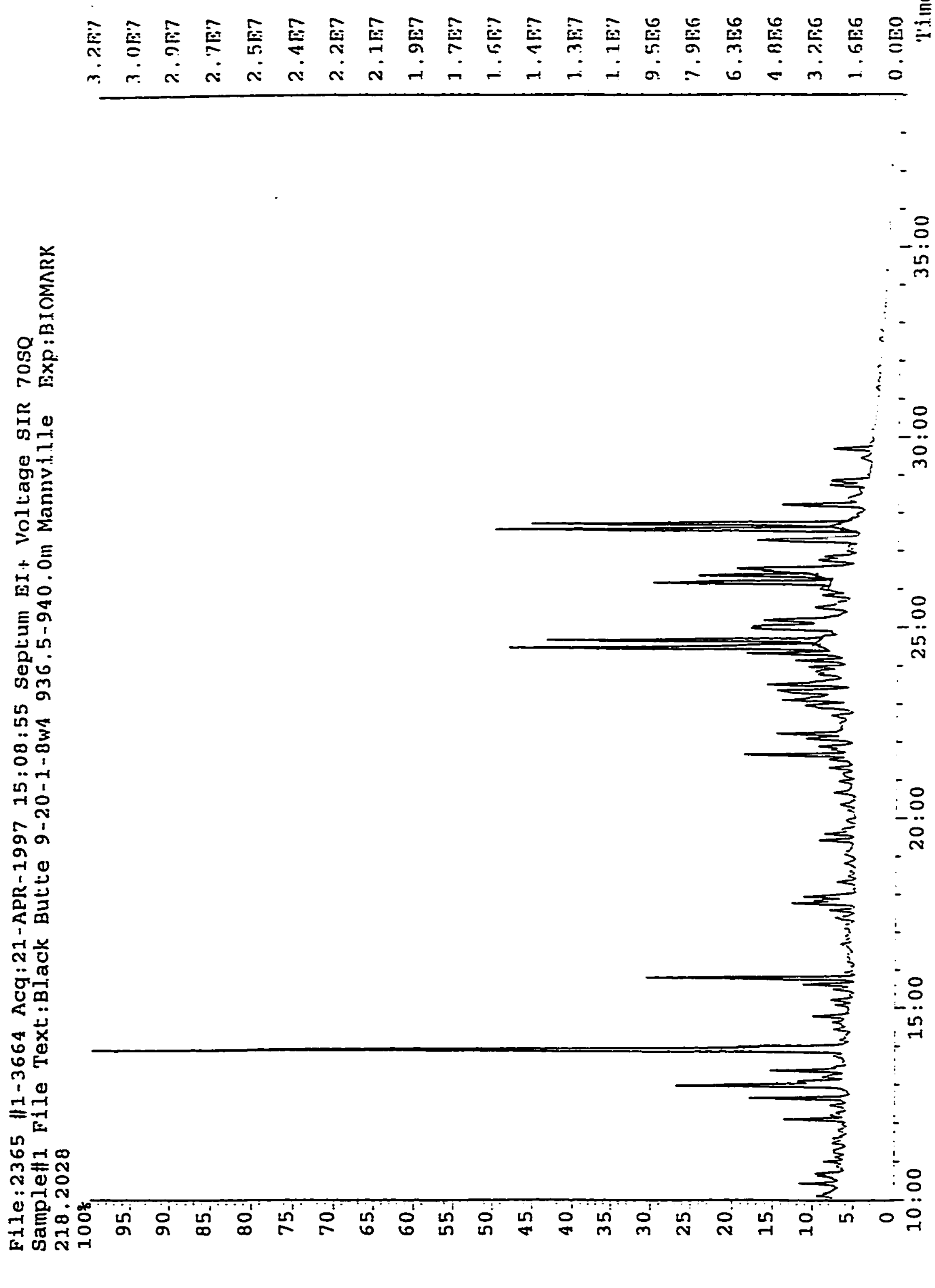
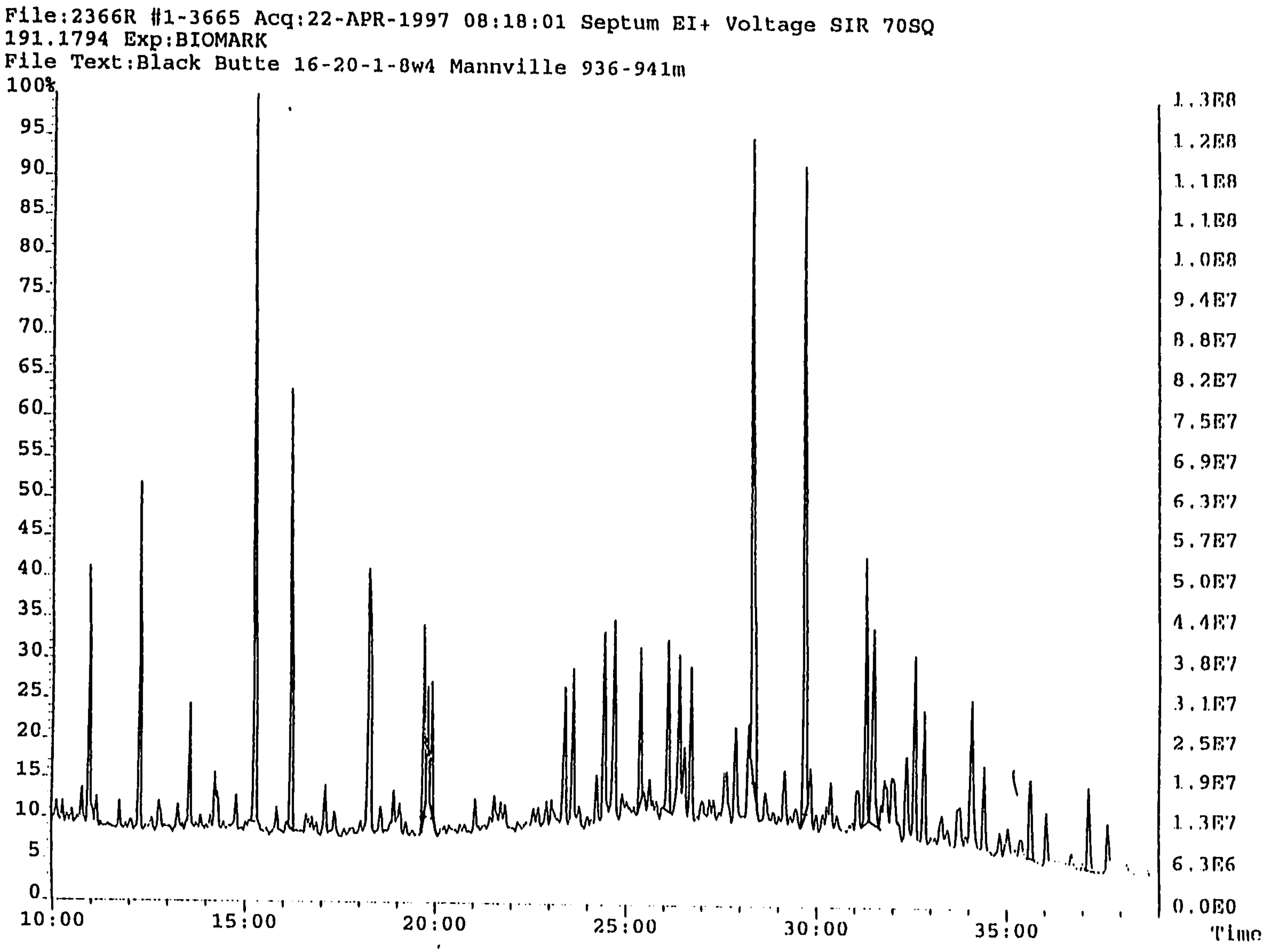
10:00
15:00
20:00
25:00
30:00
35:00
Time
3.2E7
3.1E7
2.9E7
2.8E7
2.6E7
2.4E7
2.3E7
2.1E7
1.9E7
1.8E7
1.6E7
1.5E7
1.3E7
1.1E7
9.7E6
8.1E6
6.5E6
4.9E6
3.2E6
1.6E6
0.0E0


File:2365 #1-3664 Acq:21-APR-1997 15:08:55 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Black Butte 9-20-1-8W4 936.5-940.0m Mannville Exp:BIOMARK
218.2028
100%
10:00
15:00
20:00
25:00
30:00
35:00
Time
3.2E7
0.0E0


File:2366R #1-3665 Acq:22-APR-1997 08:18:01 Septum EI+ Voltage SIR 70SQ
191.1794 Exp:BIOMARK
File Text:Black Butte 16-20-1-8w4 Mannville 936-941m
100%
95
90
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20
15
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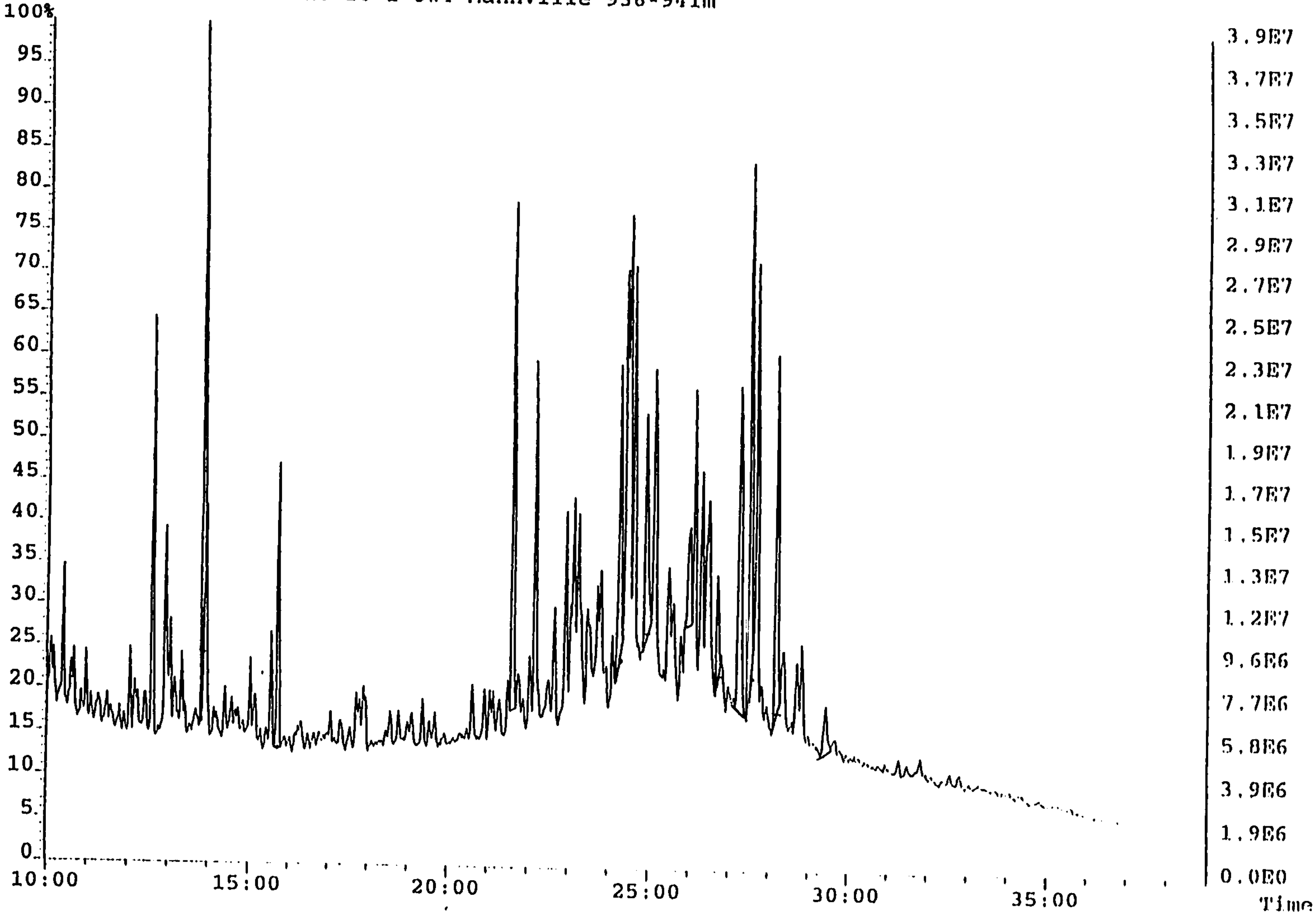
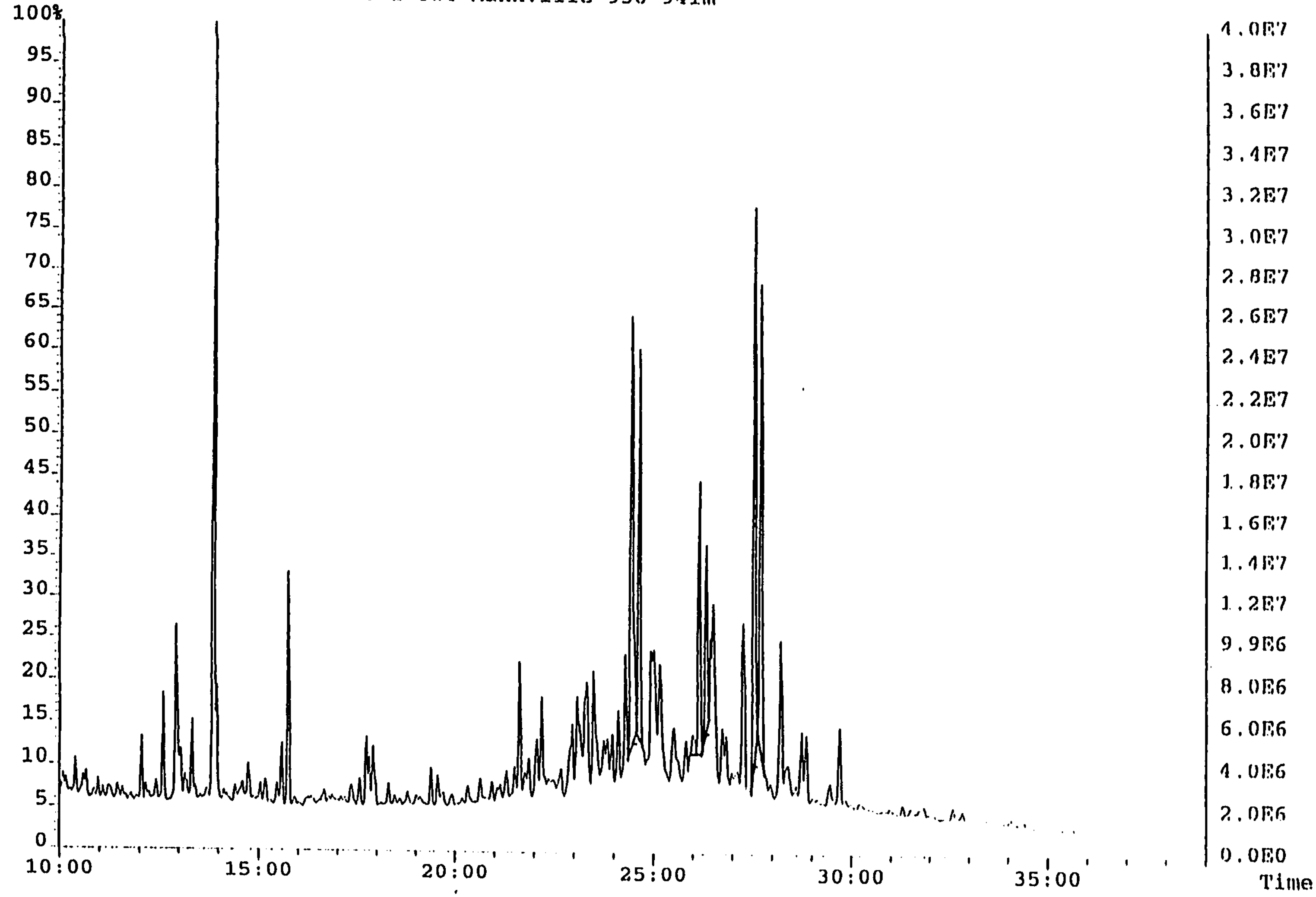
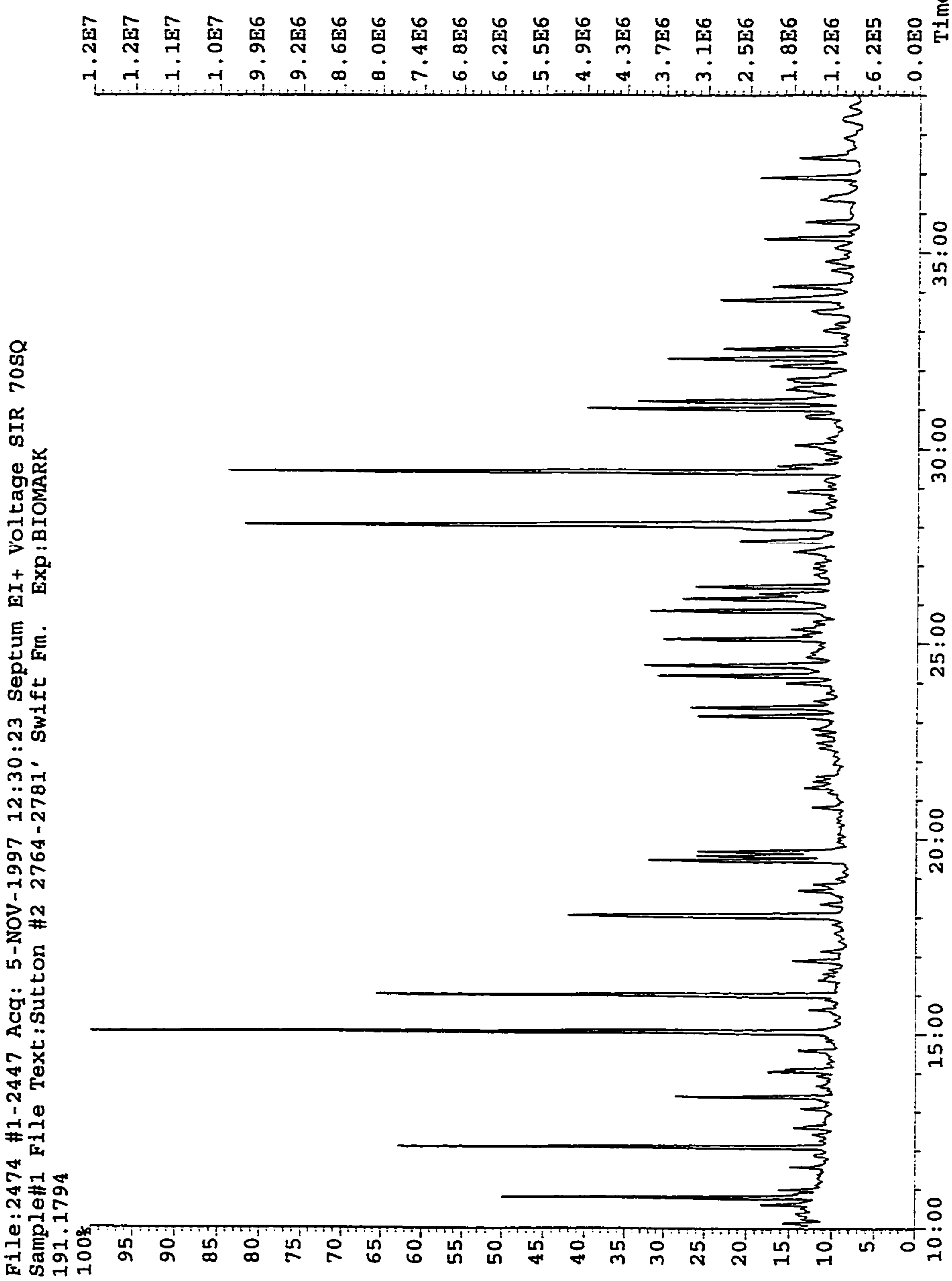
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.3E8
1.2E8
1.1E8
1.1E8
1.0E8
9.4E7
8.8E7
8.2E7
7.5E7
6.9E7
6.3E7
5.7E7
5.0E7
4.4E7
3.8E7
3.1E7
2.5E7
1.9E7
1.3E7
6.3E6
0.0E0

File:2366R #1-3665 Acq:22-APR-1997 08:18:01 Septum EI+ Voltage SIR 70SQ
217.1950 Exp:BIOMARK
File Text:Black Butte 16-20-1-8w4 Mannville 936-941m



File:2366R #1-3665 Acq:22-APR-1997 08:18:01 Septum EI+ Voltage SIR 70SQ
218.2028 Exp:BIOMARK
File Text:Black Butte 16-20-1-8w4 Mannville 936-941m




File:2474 #1-2447 Acq: 5-NOV-1997 12:30:23 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Sutton #2 2764-2781' Swift Fm. Exp:BIOMARK
191.1794
100%
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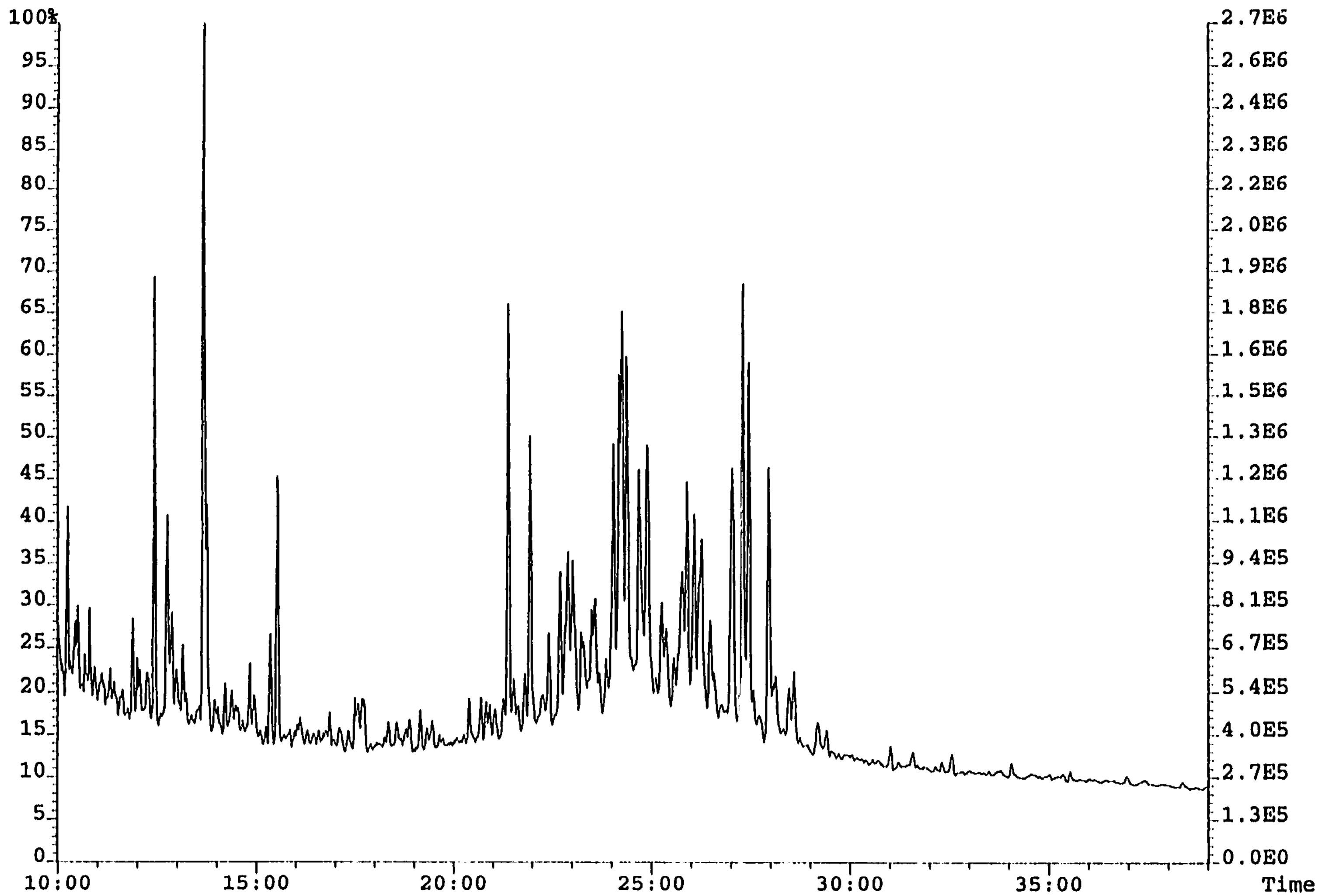
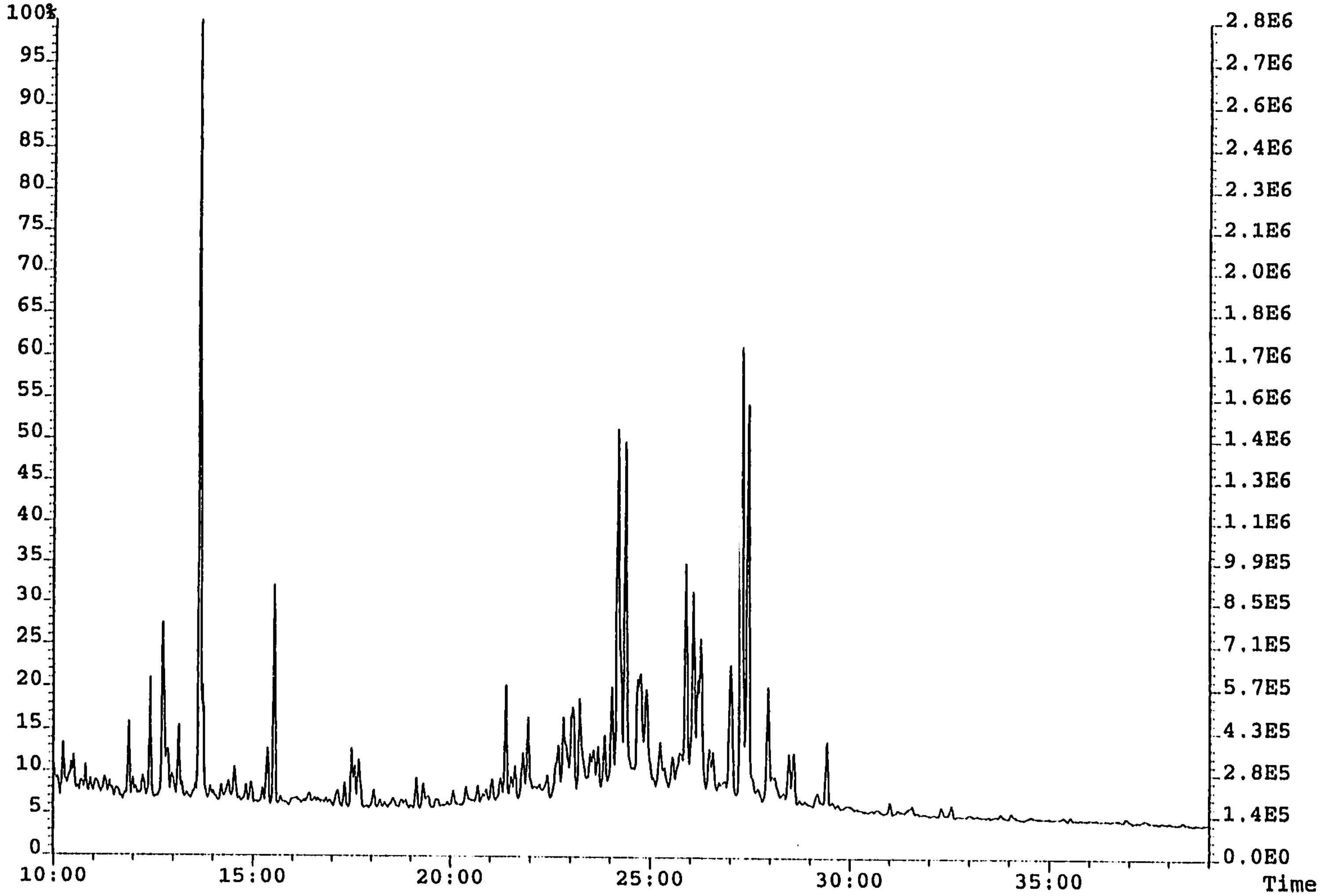
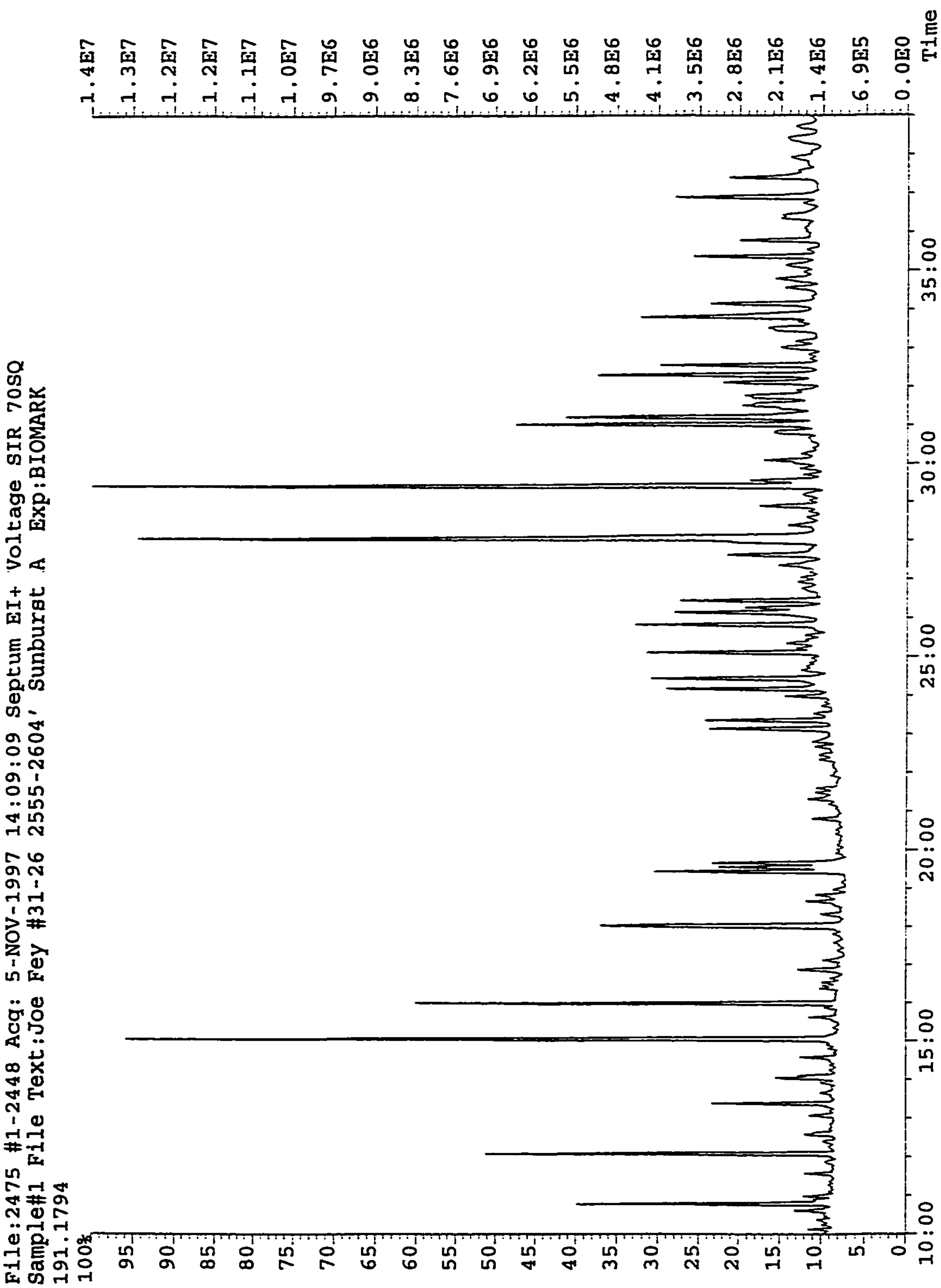
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.2E7
1.2E7
1.1E7
1.0E7
9.9E6
9.2E6
8.6E6
8.0E6
7.4E6
6.8E6
6.2E6
5.5E6
4.9E6
4.3E6
3.7E6
3.1E6
2.5E6
1.8E6
1.2E6
6.2E5
0.0E0

File:2474 #1-2447 Acq: 5-NOV-1997 12:30:23 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Sutton #2 2764-2781' Swift Fm. Exp:BIOMARK
217.1950



File:2474 #1-2447 Acq: 5-NOV-1997 12:30:23 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Sutton #2 2764-2781' Swift Fm. Exp:BIOMARK
218.2028




File:2475 #1-2448 Acq: 5-NOV-1997 14:09:09 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Joe Fey #31-26 2555-2604' Sunburst A Exp:BIOMARK
191.1794
100%
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15
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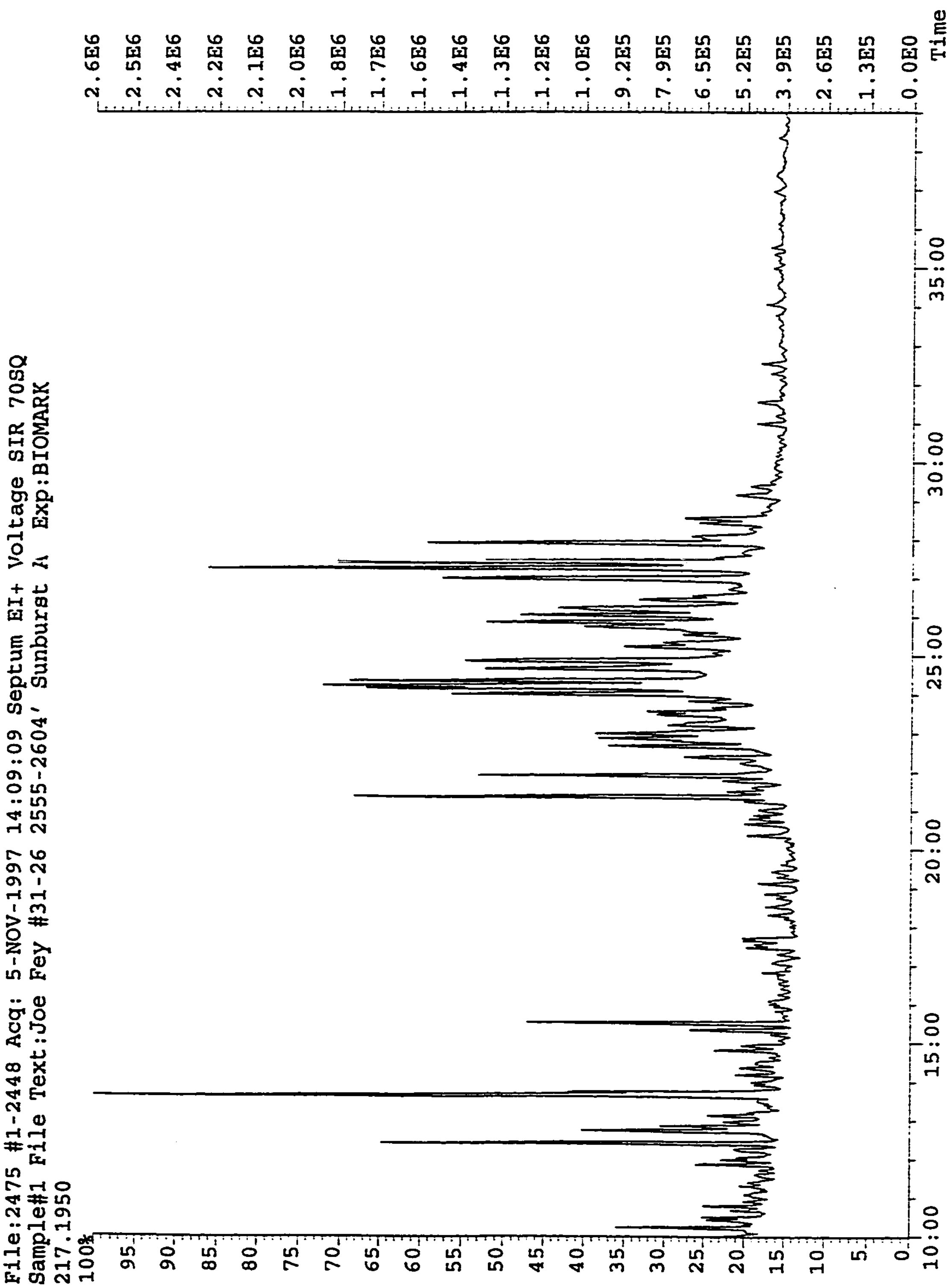
10:00
15:00
20:00
25:00
30:00
35:00
Time
1.4E7
1.3E7
1.2E7
1.2E7
1.1E7
1.0E7
9.7E6
9.0E6
8.3E6
7.6E6
6.9E6
6.2E6
5.5E6
4.8E6
4.1E6
3.5E6
2.8E6
2.1E6
1.4E6
6.9E5
0.0E0


File:2475 #1-2448 Acq: 5-NOV-1997 14:09:09 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Joe Fey #31-26 2555-2604' Sunburst A Exp:BIOMARK
217.1950
100%
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10:00
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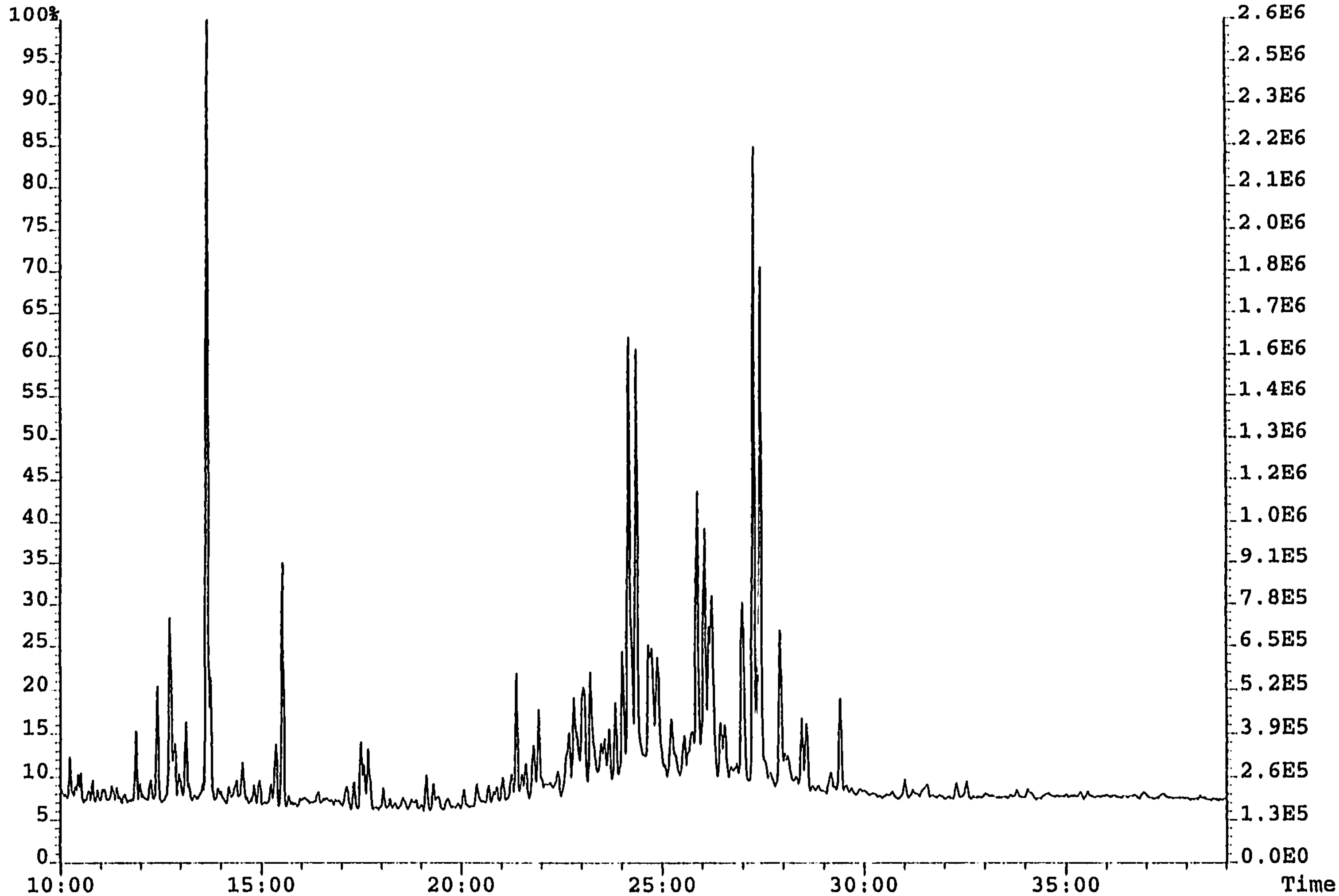
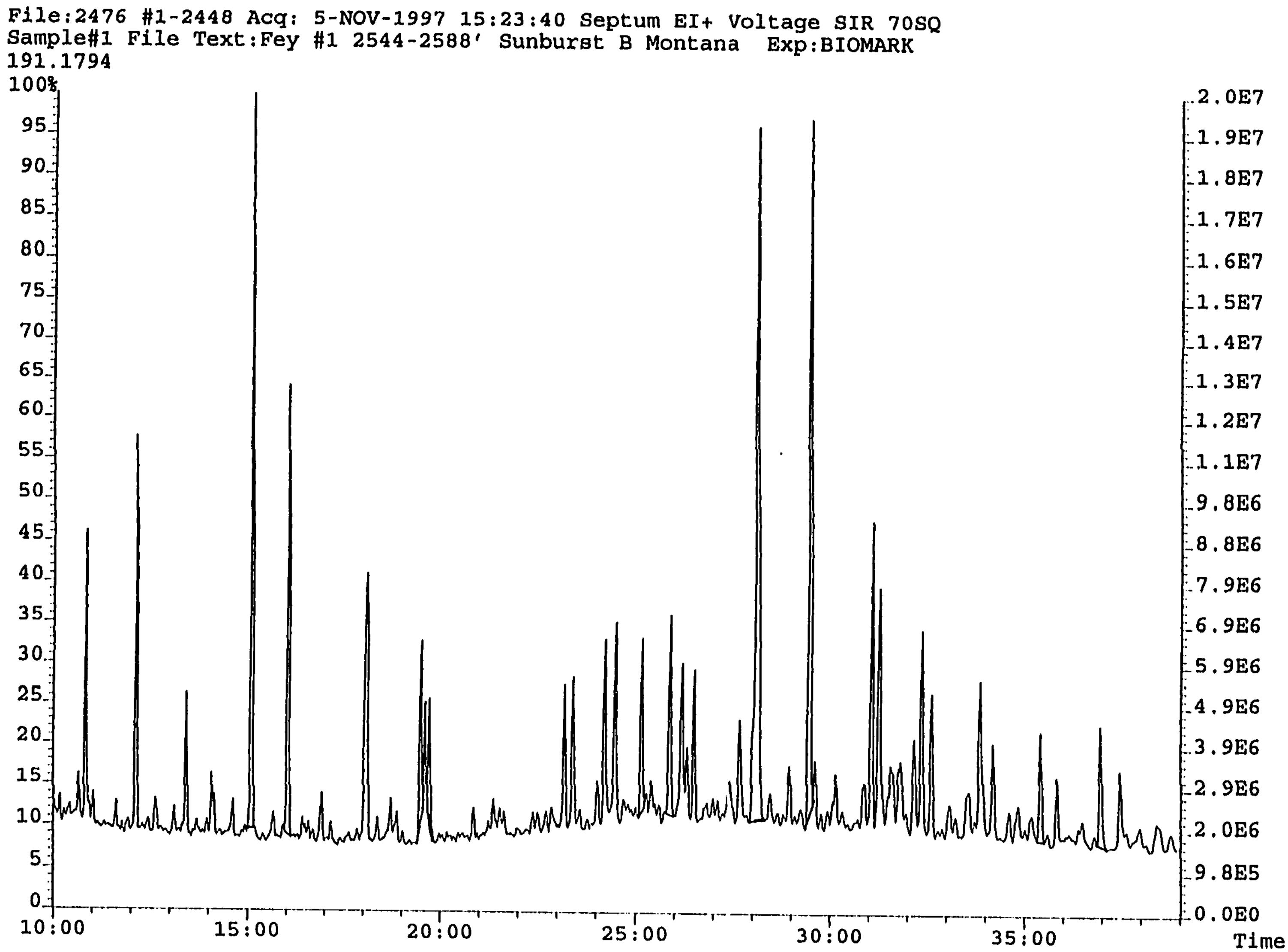
20:00
25:00
30:00
35:00
Time
2.6E6
2.5E6
2.4E6
2.2E6
2.1E6
2.0E6
1.8E6
1.7E6
1.6E6
1.4E6
1.3E6
1.2E6
1.0E6
9.2E5
7.9E5
6.5E5
5.2E5
3.9E5
2.6E5
1.3E5
0.0E0

File:2475 #1-2448 Acq: 5-NOV-1997 14:09:09 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Joe Fey #31-26 2555-2604' Sunburst A Exp:BIOMARK
218.2028




File:2476 #1-2448 Acq: 5-NOV-1997 15:23:40 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Fey #1 2544-2588' Sunburst B Montana Exp:BIOMARK
191.1794
100%
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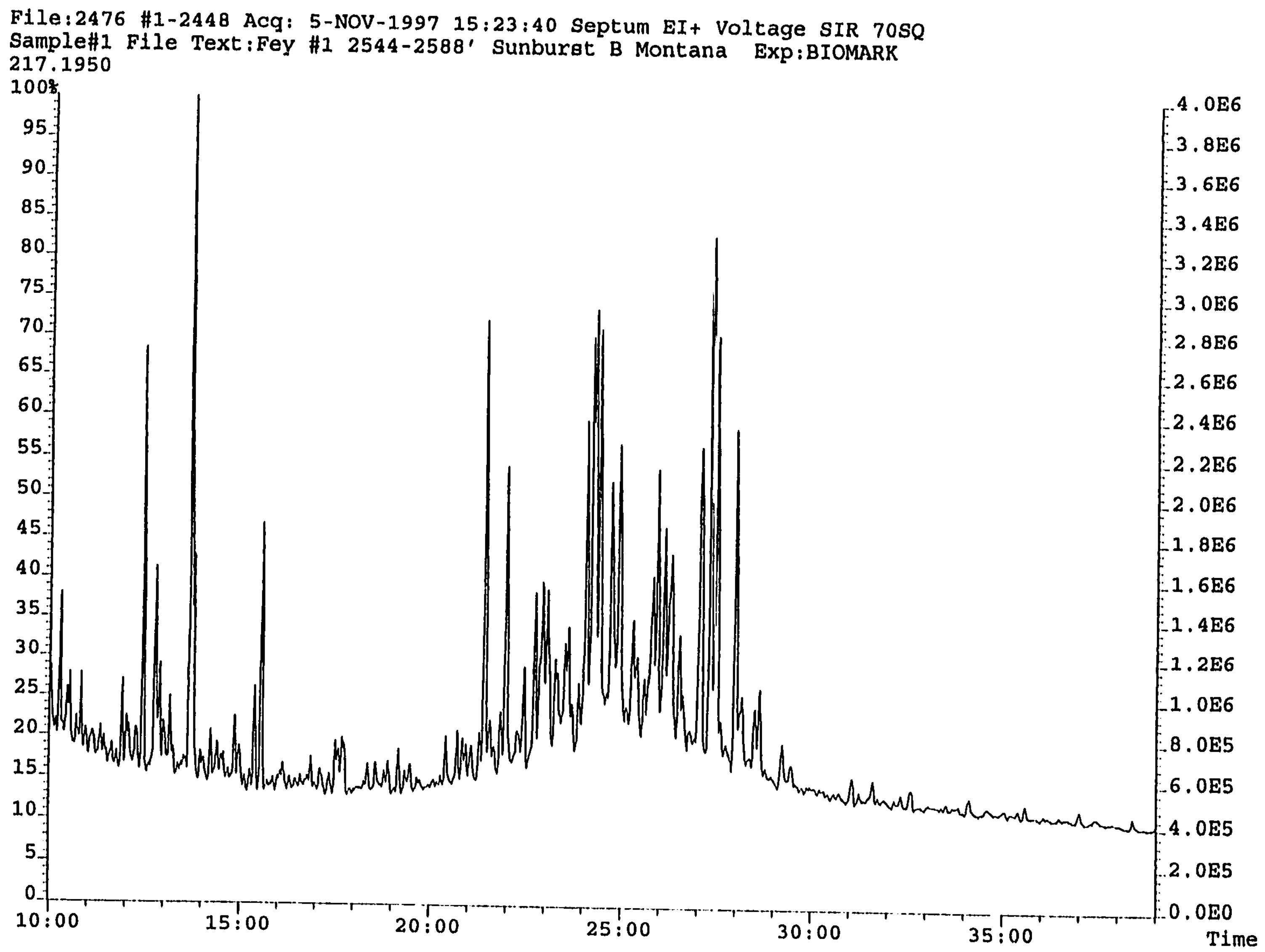
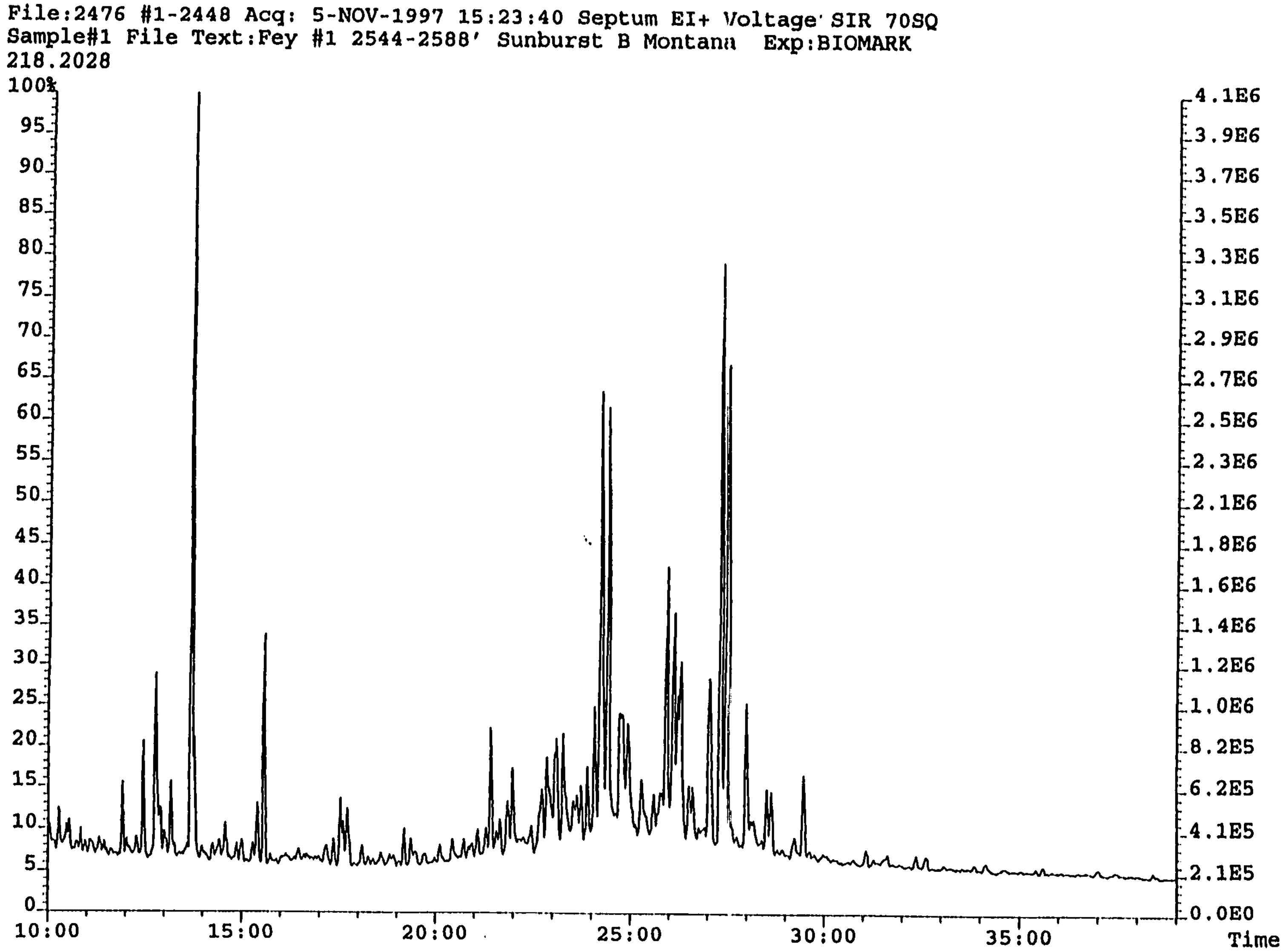
10:00
15:00
20:00
25:00
30:00
35:00
Time
2.0E7
1.9E7
1.8E7
1.7E7
1.6E7
1.5E7
1.4E7
1.3E7
1.2E7
1.1E7
9.8E6
8.8E6
7.9E6
6.9E6
5.9E6
4.9E6
3.9E6
2.9E6
2.0E6
9.8E5
0.0E0


File:2476 #1-2448 Acq: 5-NOV-1997 15:23:40 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Fey #1 2544-2588' Sunburst B Montana Exp:BIOMARK
217.1950
100%
Time
10:00
15:00
20:00
25:00
30:00
35:00


File:2476 #1-2448 Acq: 5-NOV-1997 15:23:40 Septum EI+ Voltage SIR 70SQ
Sample#1 File Text:Fey #1 2544-2588' Sunburst B Montana Exp:BIOMARK
218.2028
100%
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10:00
15:00
20:00
25:00
30:00
35:00
Time
4.1E6
3.9E6
3.7E6
3.5E6
3.3E6
3.1E6
2.9E6
2.7E6
2.5E6
2.3E6
2.1E6
1.8E6
1.6E6
1.4E6
1.2E6
1.0E6
8.2E5
6.2E5
4.1E5
2.1E5
0.0E0