DEPOSITIONAL ENVIRONMENT OF THE SLIVERVILLE SANDSTONE (UPPER DEVONIAN), LAFAYETTE TOWNSHIP, MCKEAN COUNTY, PENNSYLVANIA

by

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Abstract: The Music Mountain oil field produced 6,222,640 barrels of oil over a period of twenty one (21) years. Total oil remaining in place may exceed 97 million barrels. Yet previous attempts at secondary recovery have been unsuccessful due to a lack of understanding of the internal stratigraphy of the producing formation, the Sliverville sandstone. Based on the analysis of two cores, thin-sections from the cores, a gross sand isolith, and stratigraphic cross-sections it appears that the Sliverville sandstone was deposited in a riverine estuary environment. This environment is composed of a barrier island complex that can be traced in a landward direction to a riverine source. While the oil field has an obvious northeast-southwest orientation the major depositional mechanism is a result of tidal channel(s) migration that actually transect the field in a northwest-southeast direction. Therefore, sand units will show better continuity perpendicular to the overall strike of the field. If secondary recovery is to be economically feasible, a more efficient system design can be generated from the above knowledge.

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INTRODUCTION

The Music Mountain oil field is located nine (9) miles south of Bradford, Pennsylvania in Lafayette Township, Mckean County, Pennsylvania. The field varies in width from 800 to 2,600 feet and is approximately four (4) miles long, striking northeast-southwest. Figure 1 shows the general location of the Music Mountain oil pool and its relationship to other Mckean County oil fields.

The discovery well, the Sliverville #110, was drilled in 1937 by Niagara Oil Corporation. Initial production was 44 barrels of oil per hour from a sandstone located at a depth of 1,639 feet. This interval was later to become known as the "Sliverville" sand (Stearns et al., 1971). It is commonly believed that the field was named "Music Mountain" for the sound that filled the air when Niagara Oil workers "blew down" the gas from the well in order to allow the oil to flow.

Approximately 400 wells were drilled in the Music Mountain field during its primary productive life. As a result of this activity 6,222,640 barrel of oil were produced. Given estimates of initial oil saturation as high as eighty per cent (Finalle, 1985) and knowing the reservoir

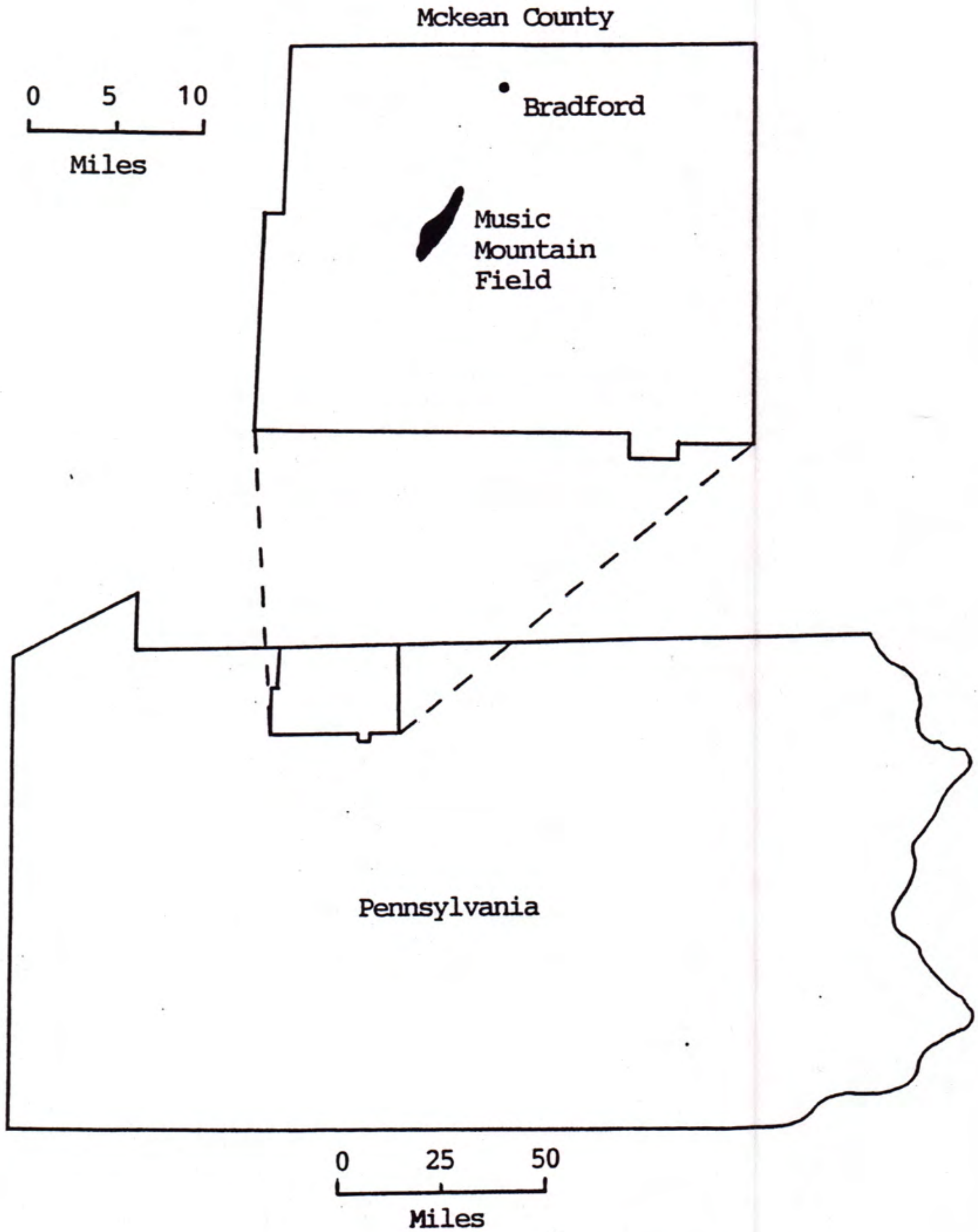


Figure 1 General location of Music Mountain Field

drive depleting practices that took place during the production of the field, the Sliverville sand is a prime candidate for waterflooding (secondary recovery).

In order to examine the feasibility of a waterflood operation one would like to know as precisely as possible the reservoir characteristics of the producing formation. This includes, but is not limited to, determination of porosity, permeability, thickness, and areal extent. By determining the depositional environment and lithologic characteristics of the producing formation one not only has a deeper understanding of these factors and how they were determined, but may also enable one to recognize trends of permeability barriers that can not be recognized solely by empirical analysis. For this reason this study was initiated.

Chapter 1

Geologic Setting

1.1 Regional Setting

Paleogeographical reconstruction of Late Devonian time based on paleomagnetic data places the Appalachian Basin in the southern tropics, approximately between 5-20 degrees latitude (Dott and Batten, 1971; Woodrow et al., 1973; and Scotese et al, 1979). Based on facies distribution and paleobiogeography Boucot and Gray (1983) approximate a more southerly location (30 degrees or more south latitude). Nevertheless, assuming ancient atmospheric conditions and circulation patterns were similar to today's, the climate would have been much warmer and more humid in Late Devonian than the study area is subject to today. Figure 1-1 depicts the approximate location of the Appalachian Basin in Late Devonian time based on paleomagnetic data.

The study area was located at or very near the shoreline of a shallow epieric sea (the Catskill Sea) in Late Devonian time. From the east streams travelled over the Catskill Alluvial Plain carrying sediment to the Catskill Sea located to the west. Waves, currents, tides, seafloor configuration, as well as other local factors

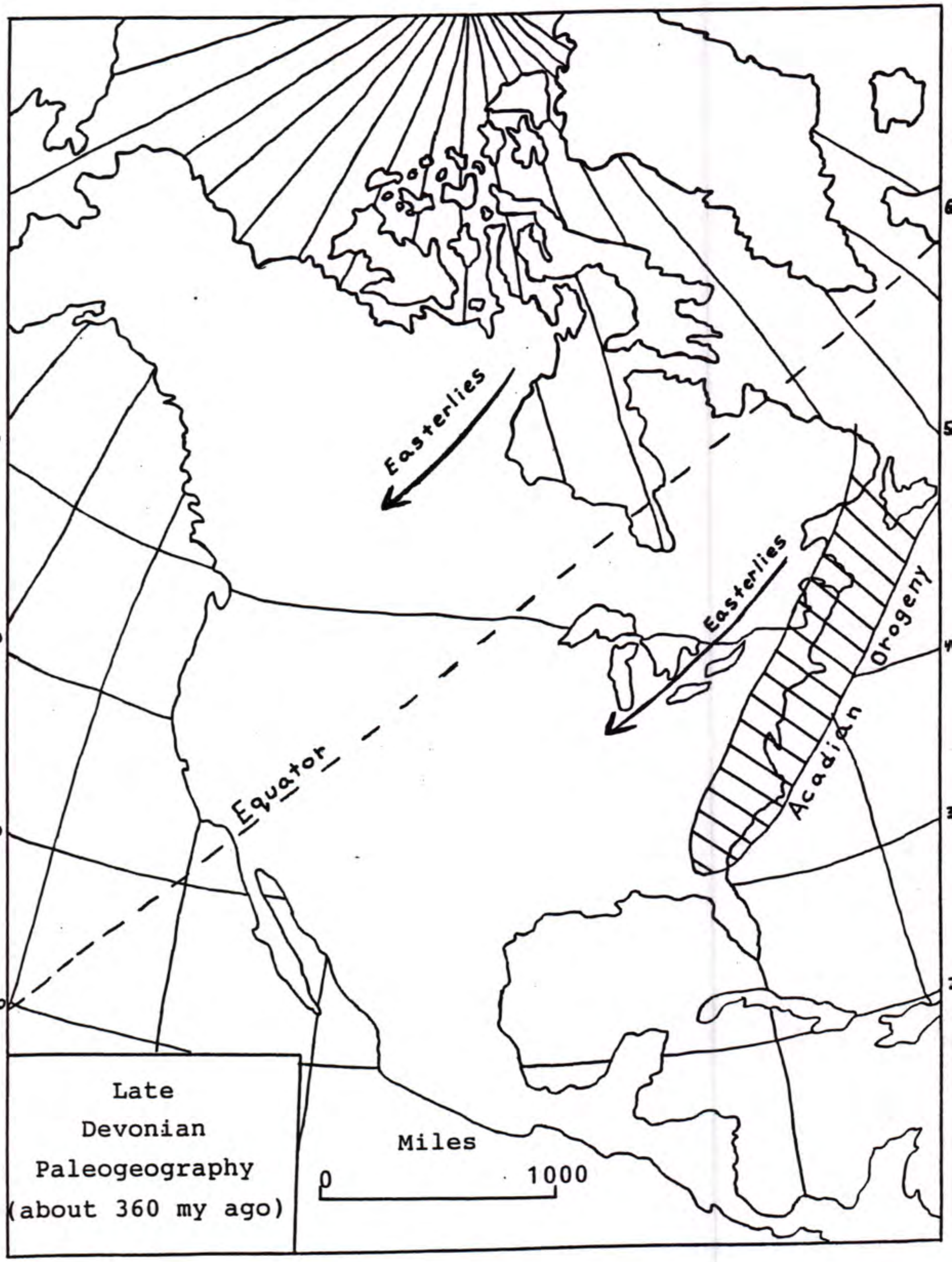


Figure 1-1 Location of Appalachian Basin in Devonian time

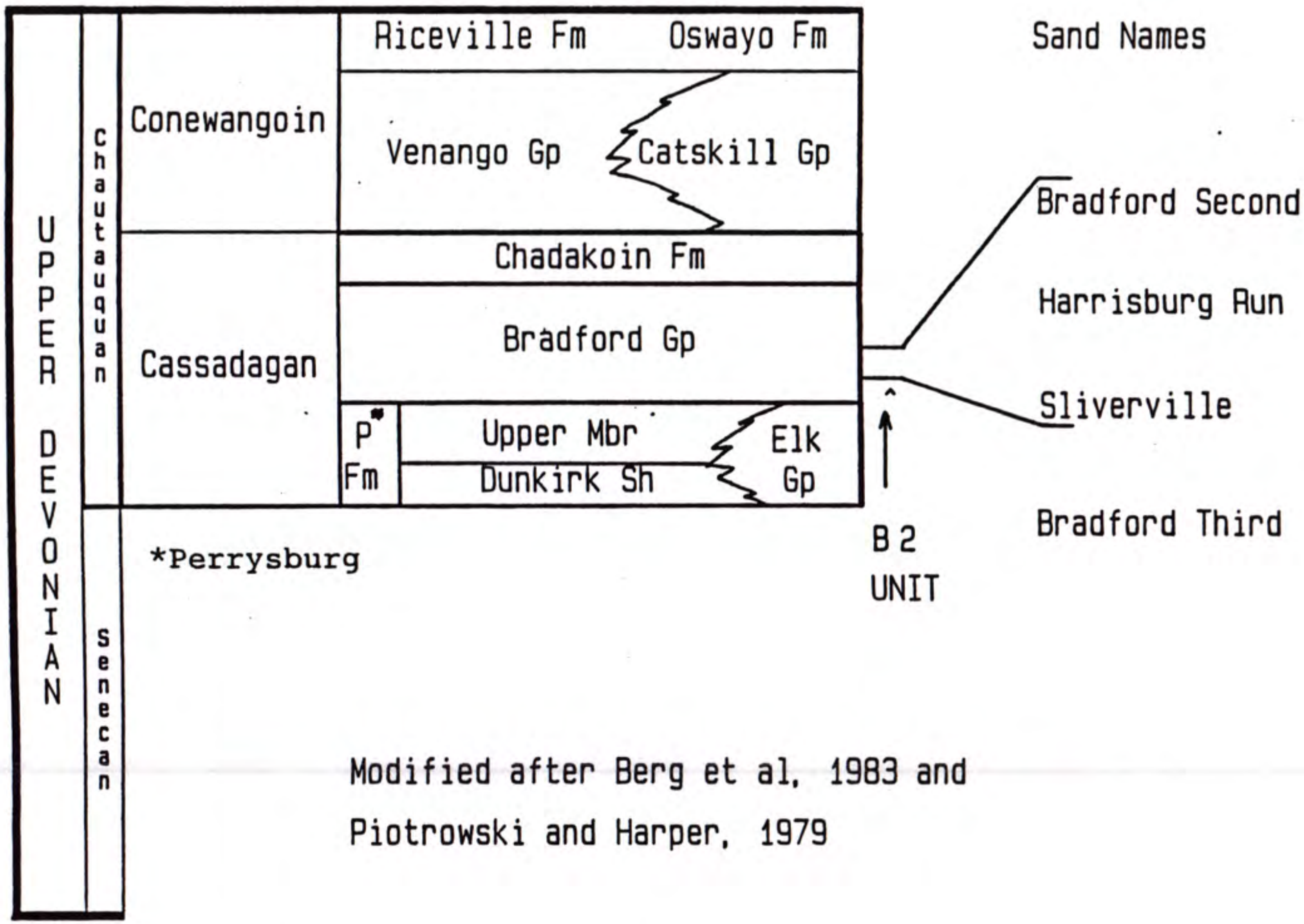
contributed to the determination of sediment size, lithology, and sorting of the material which was deposited in and at the margin of the sea.

1.2 Local Subsurface Stratigraphy

The Sliverville sandstone is one of several isolated sandstone bodies within the Bradford Group which occur only in its type locality. Figure 1-2 depicts the subsurface stratigraphy in the study area. Below the group level all terms are informal and predominantly derived from driller's terms.

The Bradford Third sandstone is a grayish-brown to chocolate-brown, fine to very fine-grained sandstone. Quartz grains are predominantly angular, in part due to secondary quartz overgrowth (Fettke, 1938,1941). Small well-rounded, transparent to milky-white quartz pebbles may rarely be seen. The pebbles sometimes reach three (3) millimeters in diameter. The quartz pebbles are found mostly in the upper units of the sandstone. In thin-section grains form an interlocking mosaic of angular quartz. Sparse grains of muscovite, biotite, and plagioclase are seen in most all of the thin-sections examined by Fettke (1938).

Fettke (1938) states that the Bradford Third sandstone is obviously marine, based on the marine fossils distributed throughout the entire sand body. However, fragmented



Modified after Berg et al, 1983 and Piotrowski and Harper, 1979

Figure 1-2 Subsurface stratigraphy in study area carbonized plant remains are also present and must have been transported by streams, currents, and waves. Among the fossils identified in core samples by previous workers are: Productella lachrymosa, Camarotoechia contracta, Spirifer mesacostalis, Edmondia obliqua, Schuchertella chemungenus, and Leiorhynchus mesicostale.

The Sliverville sandstone lies atop the Bradford Third sandstone. The Sliverville is a light-gray to brown, and on occasion chocolate brown, coarse to very coarse sandstone. Quartz pebbles may be found among the very coarsest sand units. Miospores (Traverse, 1988) and large fragmented lignitic plant remains can be found in some of the shale units. The shales range in color from green to black and red.

The Harrisburg Run lies atop the Sliverville sandstone. This sandstone is characterized as a thin, fine-grained, grayish-brown to chocolate brown sandstone. The basal section of the Harrisburg Run was penetrated by one of two cores (which will be discussed in greater detail in later sections) examined in this study. Additionally, abundant brachiopod fragments were present in the basal section of the Harrisburg Run sandstone.

The Harrisburgh Run sandstone and Sliverville sandstone are sometimes referred to as "sub-members" of the Bradford Second sandstone (Klingensmith, 1984). However, examinations of well cuttings by Fettke (1938) reveal that all three sandstones may be seen existing as separate sandstones in many wells. The Bradford Second sandstone averages approximately 325 feet in thickness and occupies the second largest areal extent of the Upper Devonian sandstones in the study area; the Bradford Third sandstone covering the largest area. The Bradford Second sandstone is grayish-brown, fine to very fine-grained with appreciable amounts of interbedded shales.

1.3 Local Structure

As shown in Figure 1-3, the most prominent local structural features in the study area are the northeast-southwest trending folds of the Bradford Anticline. Of less significance are the gently folded Big Shanty Syncline and Simpson Anticline. Structure mapped on the erosional surface at the base of the Olean conglomerate (characterized as the lowermost Pennsylvanian strata, Fettke, 1939, 1941) and the top of the Bradford Third sandstone are parallel, suggesting deformation responsible for the present structure of the Bradford Third sandstone was post-Pennsylvanian (Fettke, 1941).

Structure contours on top
of Bradford Third Sand
contour interval 20 feet

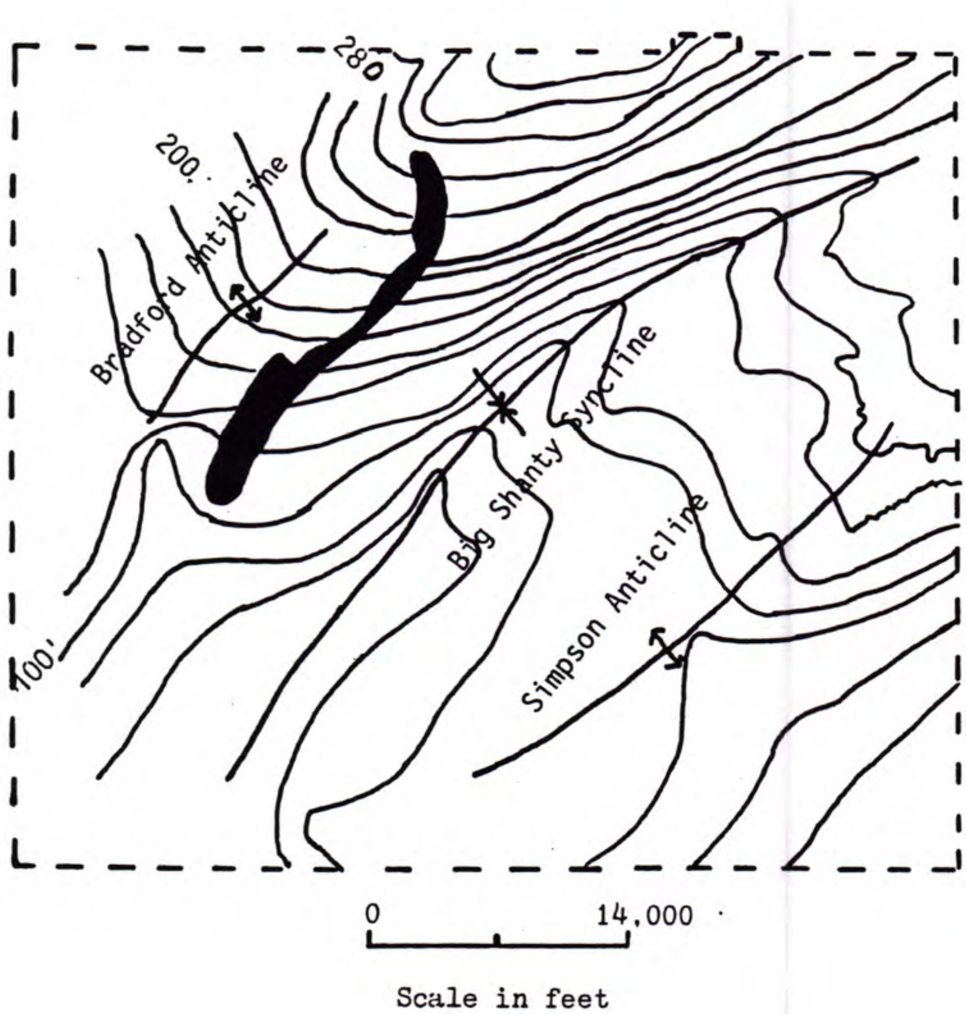


Figure 1-3 Relationship of Music Mountain Field to local structure

Chapter 2

History of Previous Work

Fettke's 1941 publication of Music Mountain oil pool and other oil pools in Lafayette Township contains the most information about the Sliverville sandstone with regard to geological characteristics. All other publications that deal with the Sliverville sandstone or Music Mountain oil field (directly) are geared toward the reservoir characteristics of the sand body. Consequently, any statements relative to possible depositional environment scenarios or geologic characteristics are references to Fettke's work.

Fettke (1941) discusses the surface and subsurface stratigraphy of Lafayette Township. The youngest outcrops are of Pennsylvanian age and the oldest are Late Devonian in age. In the subsurface he describes the Conneat and Canadaway Groups. Fettke states that the Canadaway Group (Upper Devonian) contains all the producing formations (sandstones) which constitute the Bradford Fields. He also states that all of the Canadaway Group was deposited under marine conditions.

A core sample which penetrated one fourth of the Canadaway Group was described. In the core description the Sliverville sandstone was encountered at a depth between 1810 and 1820 feet. The northeast-southwest trending folds of the Bradford Anticline is characterized as the most prominent structural feature, plunging steeply to the southwest. The Big Shanty Syncline and Simpson Anticline appear as more gentle and broader folds. Comparison of structure mapped on the top of the Bradford Third sandstone and on the erosional surface of the Olean conglomerate suggested to Fettke that at least part of the Bradford Third's structure was developed later than the Pottsville Series of strata (youngest of the Pennsylvanian outcrops).

Deposition of the oil and gas sands is described as discontinuous, yielding lenticular sand bodies as opposed to blanket sands. Depositional dynamics of the Late Devonian Period are related to the Acadian Orogeny. The study area was covered by a shallow sea with the shoreline located not far to the east-southeast. Streams rising out of Appalachia travelled over the Catskill Alluvial Plain toward the sea to the west. Waves, tidal currents, longshore currents, and sea floor configuration all played important roles in determination of sediment size, sorting, and sand body thickness and distribution. Fettke states that some sand bodies represent ancient offshore bars and others resemble barchane or dune-like sand bodies in outline, similar to those found on the floor of the North Sea.

Cross-sections parallel and perpendicular to basinal strike were constructed from information contained in 138 well records. Correlation of sand bodies was attempted. Additionally, sieve analysis from ten fragments of the Sliverville was presented. Based on this analysis the Sliverville is described as a medium to coarse grained sandstone, sub-angular to angular with evidence of silica overgrowths. Small amounts of calcite cement are cited as well as occasional greenish grey clay seams and clay pellets (Fettke, 1941).

In conclusion, permeability and porosity characteristics of the individual sands are reviewed as well as individual field production histories. Fettke states that it is his belief that the Sliverville sandstone is more akin to the Venango sandstones of southwestern Pennsylvania than to the Bradford Third sandstone.

Elicker (1954) submitted an internal engineering and geological report to South Penn Oil Company. The focus of the study was to attempt to establish the internal stratigraphy of the Sliverville sandstone and to review the previous production and operational practices conducted in the three leases that South Penn had purchased in March of 1952. The purpose of the study was to conclude if correlation of specific sand units within the Sliverville was possible and couple the data with the review of previous ventures to suggest methods to increase production.

Elicker concluded that attempts at sand unit correlation were unsuccessful and attributed this to his belief that the sand units occurred as separate and irregularly distributed lenses. Based on past operational practices, Elicker entertained three alternative avenues of operation: conversion of the reservoir to a gas storage field, waterflooding the field, or restructuring the present gas-recycling program. The volumes of injection gas required, the cost associated with well conditioning and different well equipment, the need for additional lease acquisition, and an unfavorable market indicated that gas storage would not be cost-effective. High sand unit permeabilities, wax precipitation due to temperature losses associated with relatively cooler flood waters, and the results of previous attempts suggested that the effects of waterflooding would be uncertain. Reconstruction of the present gas-recycling system provided the most promising possibilities. Included in the report were: an isopach map of net sand (however, "net sand" was not defined nor any methodology offered), a base map showing well locations and the location of gathering lines, and two cross-sections.

Stearns et al. (1971) in an internal proposal for Pennzoil Producing Company, outlined the economic justification and design for a waterflood operation of Music Mountain field. Included in this proposal were: an index map showing the location of the field, a structure map of the top of the Sliverville with a line indicating a gas/oil contact, an isopach of gross sand, an isopach of net sand (thickness of sand deemed to be oil productive), dip and strike structural and lithologic cross sections, and a schematic of the proposed waterflood design. A good deal of text was devoted to previous secondary recovery attempts. From January, 1940 until October, 1942 outside gas and produced gas was recycled into the reservoir in an attempt to maintain reservoir pressure. Stearns et al. attribute poor results to insufficient injection volumes and poor design. The first waterflood operation commenced in March, 1942 and continued until August, 1943, at which time injection ceased in all but five wells. The results of this waterflood are not known. Pennzoil Project #4 was a steam-injection system which operated from February 2, 1966 until January, 1967. It was concluded by Stearns et al that this project was unsuccessful because at this point in the life of the field the original gas cap had been so depleted that injected steam was breaking through the oil and occupying the old gas cap.

The ultimate proposal was to water flood the southern section of the field because of thicker sand occurrences and higher oil saturations in that area. Because the limits of the field (sand body) are well defined, feathering out to shales at the edges, and because the original gas cap had been extensively depleted the suggestion was to inject water onto the oil from an up-dip direction and force the oil into the lower units of the Sliverville which had proven, by means of core and log analyses, to possess higher permeability.

This report was geared toward economics and contained little in the way of analysis of depositional environments, yet the authors state that the Sliverville seems to have been deposited as a "barrier-bar beach complex". From a review of previous work it is strongly suspected that this was a conclusion based not on the results of this proposal but an unreferenced allusion to Fettke (1941).

Klingensmith (1983), conducted another Pennzoil in-house evaluation of the Music Mountain field. As part of the evaluation the work of Fettke (1941), Elicker (1954), and Stearns et al. (1971) was reviewed as well as well drilling reports, well logs, core reports, and plugging reports of some wells abandoned by South Penn Oil Company (now Pennzoil).

This internal report included a map of the areal extent of the field's gas cap, a structure map of "good sand" from Stearn et al's report, and a map showing Pennzoil's acreage in the field. Major conclusions drawn from this study were as follows: The producing formation exhibits high permeabilities, averaging 1.5 to 2 Darcies with streaks exceeding 5 Darcies. The sand body is approximately four miles long, one quarter of a mile wide, and trends in a northeast-southwest direction. The sand body is lenticular in cross section. The field is overlain by a gas cap. Because the northeast end of the field is structurally highest, gas saturations, as observed in production and by examination of cores, are substantially higher in that area. Therefore, this area is less favorable for waterflooding. The southwest portion of the field, an area of 80 to 100 acres, appears to be suitable for water flooding (in the lower sand units of the Sliverville). Net productive sand thickness in this area averages 20 to 25 feet with an average porosity of 10 per cent and an average water saturation of 22 per cent.

By far the most important economic factor revealed in this study was the consequence of past plugging and abandonment procedures of old wells. The practice was to place a plug over the Harrisburg Run sand, which lies atop the Sliverville. Thus, fluids are free to migrate and communicate throughout the entire interval of the Sliverville via the uncemented well bore. A successful waterflood requires isolation of the injection zone. Isolation is important because the injection zone should be the only avenue of permeability between the injection well(s) and the production well(s). If this is not the case then injected fluids will find alternative paths of permeability and the remaining oil in place will not be effectively flushed and swept toward the production well(s). Before any waterflood can be attempted Klingensmith suggests that all abandoned wells be re-entered and plugged in a manner that will allow for zone isolation. He further suggests that given the economics at the time it is not feasible to initiate a waterflood.

Chapter 3

Data

With the exception of the 1941 publication by Fettke, any detailed treatment of the Sliverville sandstone or the Music Mountain field has been initiated by the oil industry and is geared toward ascertaining the reservoir properties of the sandstone. Pennzoil controls 57 per cent of the field acreage at the present time. Their acreage is predominantly in the southern portion of the field. Pennzoil has granted access to all data within their possession. These data consist of well logs, three waterflood studies of the field, two well cores and other miscellaneous reports.

Correspondence with the Pennsylvania Geologic Survey, the Pennsylvania Oil and Gas Administration, and leaseholders in the field has yielded no additional data within the limits of the field or outside of the field. Figure 3-1 shows the portion of Music Mountain field for which well logs are available and the location of the well cores.

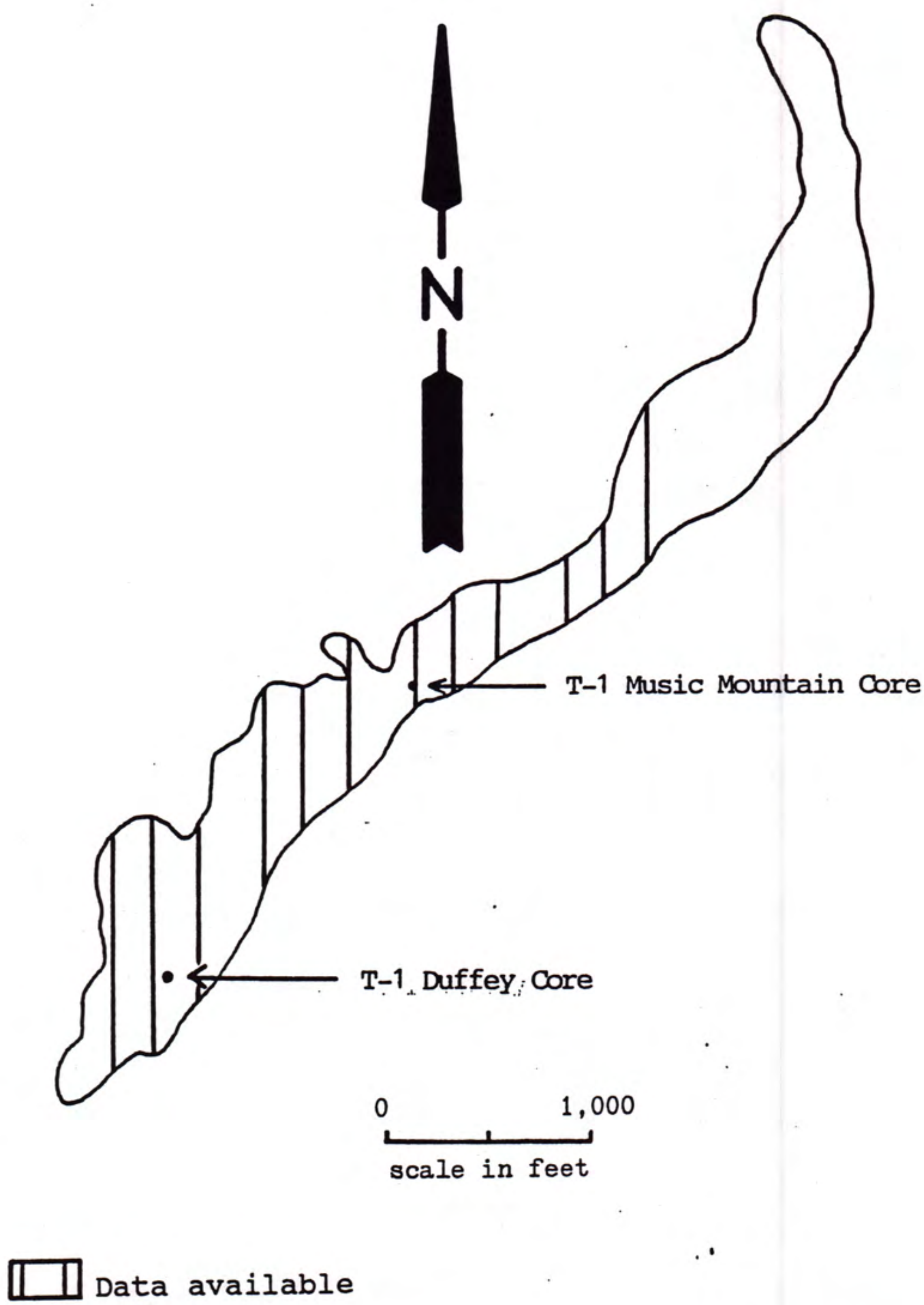


Figure 3-1 Portion of Music Mountain Field for which data are available

3.1 Geophysical Logs

Of the approximately 100 well logs obtained from Pennzoil, 70 were used in this study. The logs range in age from the 1930's to the 1950's and consequently lack the quality of today's logs. Additionally, some of the logs are difficult to read. Approximately 3/4 of the logs are gamma ray logs and the other 1/4 are spontaneous potential curves. A resistivity tool was coupled with each of these.

Both the spontaneous potential curve and the gamma ray log record naturally occurring physical phenomena of the strata versus depth. The spontaneous potential curve registers currents produced by predominantly electrochemical interactions between the formation water (connate water) and conductive drilling fluids (mud filtrate). The standard gamma ray log measures total natural radioactivity of a formation due to the presence of potassium, thorium, and uranium (Schlumberger, 1987). One major difference between the spontaneous potential tool and the gamma ray tool is that the spontaneous potential tool must be run in a conductive drilling fluid (specifically, a liquid) while a gamma ray tool may be run in wells drilled with air. Additionally, the spontaneous potential tool must be run before casing is run in a well. The gamma ray log may be run in an open hole or cased hole.

3.1.a Gamma Ray Logs

The gamma ray log records naturally occurring gamma radiation in formations. Units are in API units and, as is the case of the spontaneous potential curve, the gamma ray log is typically recorded in the first track of a well log with units increasing to the right. When a gamma ray log is run the logging engineer will calibrate the tool in the field to a standard of known API units. Prior to the establishment of API gamma ray units, micrograms of radium-equivalents per ton of formation (ugm Ra-eq/ton) were used (Schlumberger, 1987). Shales typically contain more radioactive material than sandstones (for example) and respond with a high API gamma ray response (Seismograph Service Corporation, Birdwell Division, date unknown). Therefore, the gamma ray log is useful for differentiation between shales and other (more permeable) formations and for correlation with formations in other wells with similar gamma ray signatures (Action Systems, Inc., 1982). Figure 3-2a shows a typical gamma ray log.

3.1.a Spontaneous Potential Curves

The spontaneous potential curve responds to electrical currents set up as a result of ion flow between formation waters and drilling mud filtrate. Spontaneous potential is measured in millivolts (mV) and is typically recorded in the first track of well logs. Figure 3-2a shows a typical spontaneous potential curve. Curve deflection may

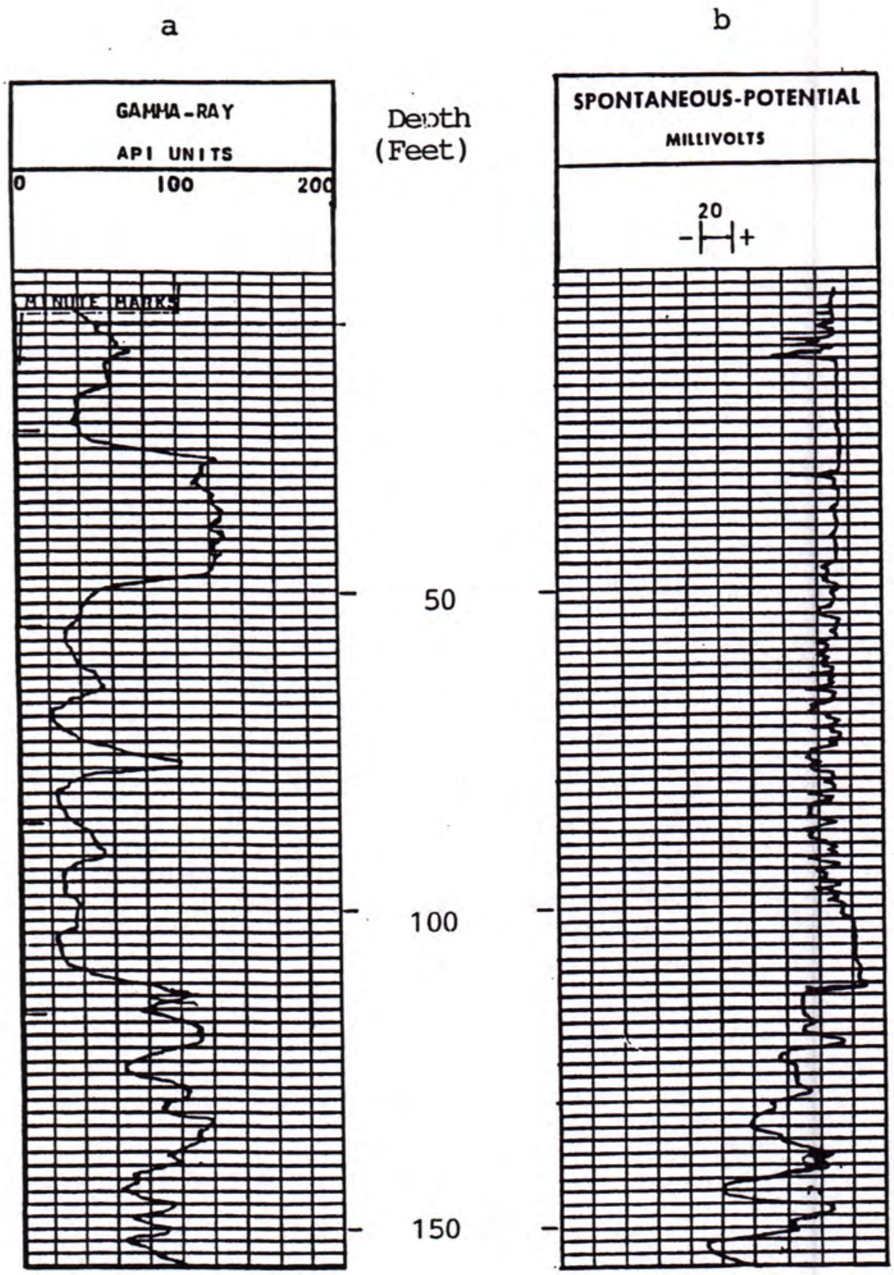


Figure 3-2 a) Gamma ray log b) Spontaneous Potential Curve be either positive (to the right of track one) or negative (to the left of track one). If the formation water is more saline than the drilling mud filtrate the deflection will be to the left. Conversely, if the mud filtrate is more saline curve deflection will be to the right, in a positive direction. The intensity of the curve is a maximum opposite permeable formations (Schlumberger, 1987; Gearhart Industries, Inc., date unknown; Seismograph Service Corporation, Birdwell Division, date unknown).

A great deal of discussion could be devoted to how the spontaneous potential curve responds to different lithologies, bed thicknesses, and different salinity relationships between drilling mud filtrate and connate water. However, as it relates to this study, the scope of interpretation and use of the spontaneous potential curve may be narrowed significantly. In all the wells that ran the spontaneous potential curve the drilling fluid was of a lesser salinity than formation waters. Additionally, from knowledge drawn from analysis of the core it is clear that the lithologies dealt with in this study are sandstones and shales. Therefore, the spontaneous potential curve will be used to distinguish between shales and sandstones and to correlate units of similar curve deflection in wells (Schlumberger, 1987).

3.2 Core Data

A core is a physical sample of a formation. Cores may be extracted as a cylinder of rock over a continuous interval or at precise locations on the sides of a pre-drilled borehole. Conventional, diamond core, and rubber-sleeve and plastic-sleeve diamond cores retrieve a continuous cylinder of rock. Sidewall cores allow the operator to take distinct samples at zones whose location can be picked from a geophysical log which has been run in that well. The continuous coring methods previously mentioned is part of the drilling stage of the well and thus the operator must rely on other forms of data to determine at what point to start coring operations (Dickey, 1986).

The only satisfactory means by which an oil company may determine the lithology and reservoir characteristics ofa formation that only occurs in the subsurface is by means of a core. Coring is the single best means of acquiring insight to sedimentary structures and textures of a subsurface formation, both of which may provide important information as to the depositional environment of the formation (Dickey, 1986).

In addition to the aforementioned observations that may be gleaned from a core, fossil evidence may also be preserved in cores. For many years paleontologists and micropaleontologists have realized the value of coring. Microfossils such as foraminifera and radiolaria are often extremely well preserved in cores. Often, larger fossils such as brachiopods may also be preserved in cores without any destruction. These faunal data can be used to pinpoint depositional environments or subenvironments. Core data are used in this study and considering the relative lack of log data, the availability of core data is significant.

Eleven wells were cored within the study area. Nine wells were Baker (or "chip") cored and two were diamond bit cored. A conventional diamond bit core yields a continuous cylinder of rock, while a Baker breaks the strata into chips, less useful for interpretation of depositional environments because no structure and fabric may be destroyed. Of the two diamond cored wells (the T-1 Music Mountain and the T-1 Duffey) only the T-1 Duffey was available in its' entirety. The majority of the T-1 Music Mountain core was retrieved from storage in Pennsylvania and Texas, but the location of perhaps as many as six (6) core boxes is unknown. The location of the samples from the baker-cored wells is also unknown and are presumed destroyed or lost over the years as acreage and data has changed hands (Klingensmith, personal communication, 1983).

3.2.1 T-1 Duffey Core

The formations in the T-1 Duffey were cored with a 3 1/2" diamond core barrel from depths of 1,706.5' to 1,783.3'. Due to coring difficulty, the interval from 1,783.3' to 1,788.6' was drilled with a conventional bit.

The interval between 1,788.6' to 1,802.5' was Baker cored. The top of the Sliverville sand was estimated to be at 1,730' and the bottom at 1,789.1'. Depths of the aforementioned cored intervals were based on ("corrected to") gamma ray log depths by Depetro, 1971a). Consequently, approximately 75' of strata was diamond cored and of this approximately 50' of the Sliverville sandstone was diamond cored.

3.2.2 T-1 Music Mountain Core

In the same year that the T-1 Duffey was cored the T-1 Music Mountain was cored and analyzed by Depetro (1971b). The interval from 1724.0' to 1840.3' was cored with a 3 1/2" core barrel. The top of the Sliverville was placed at 1706.5'. From the core 109.1' of "net sand" was tested for porosity, permeability and oil saturation by Depetro. Figure 3-3 shows the interval for which core data are available as plotted against the gamma ray logs curves of the T-1 Duffey and T-1 Music Mountain wells.

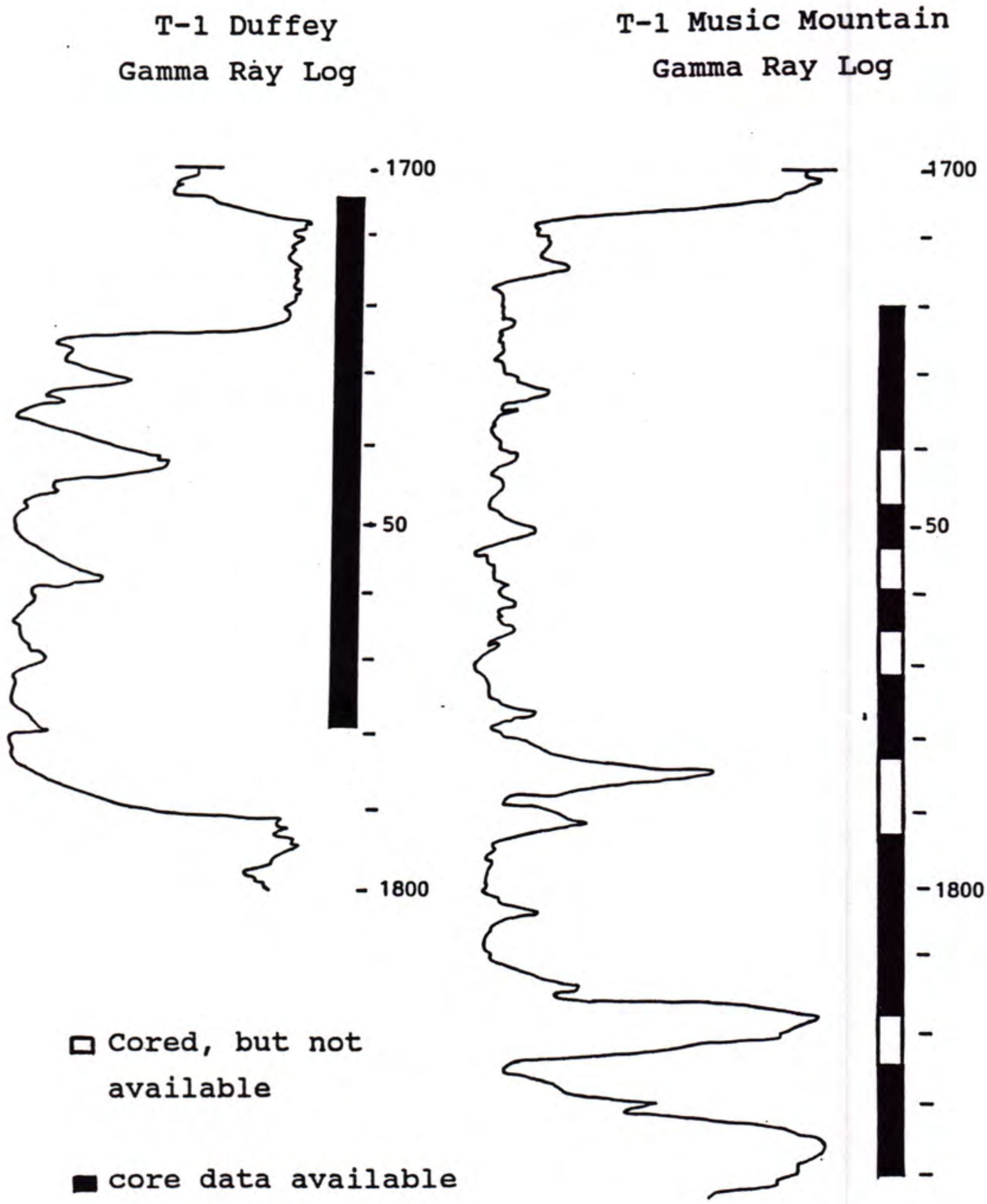


Figure 3-3 Interval for which core data is available. Depths measured from ground surface

Chapter 4

Methodology

The most obvious, yet important, generality to remember when trying to reconstruct the depositional environment of a formation is that there are a number of characteristics that distinguish one sedimentary environment or subenvironment from another. This is apparent from examination of environments operating today. Once these characteristics have been identified, either a firm conclusion or reasonably intelligent hypothesis as to the particular depositional environment may be made. The distinction between hypothesis and conclusion will differ according to the amount of data available.

Some of the more important characteristics that can aid in the determination of depositional environments are: macrogeometry or areal distribution of sediments, sediment composition, sediment size, sorting, color, stratification, sedimentary structure, and floral and faunal elements (guide fossils). Other properties such as porosity and permeability which are affected by the presence of cement or matrix are of great interest to petroleum geologists for interpretation of reservoir characteristics of a formation. The particular methods used in this study for identification of the aforementioned characteristics follow.

4.1 Macrogeometry and Areal Distribution

Determination of macrogeometry of the Sliverville sand body was achieved by construction of an isolith map which was based on sand thickness as suggested by well logs. Examination of two wells in which both a gamma ray (GR) log and a spontaneous potential (SP) log were run revealed that both log types yield comparable values of formation thickness. Therefore, both log types were used for construction of the isolith map.

On each log a theoretical 100% shale line and 100% sand line was drawn. On the gamma ray log the shale line would be a line which marked the highest readings of gamma radiation. The gamma ray portion of a log is shown in the first (extreme left) track of a log where more than one logging tool is run. Units increase toward the right. Therefore, the theoretical 100% shale line in a gamma ray log would be on the right of track one at the highest gamma radiation levels registered. Conversely, the 100% sand line on a gamma ray log runs along the left side of track one bounding the lowest readings of gamma radiation.

Typically, either a gamma ray tool or a spontaneous potential tool is run in a well (along with other logging tools), but not both. As in the case of the gamma ray tool, the spontaneous potential tool appears at the left side of a log where more than one logging tool was run. Spontaneous potential increases toward the left. Therefore, the 100% shale line would bound the lowest readings of spontaneous potential and, as is the case with the gamma ray log, would be at the right of grid one. Conversely, the 100% sand line would bound the highest readings of spontaneous potential and would therefore be on the left side of track one.

After the 100% shale line and 100% sand line was constructed, a line was constructed on each log 7/10 of the way from the shale line to the sand line. The total number of feet of formation which registered spontaneous potential or gamma radiation at levels that reached or surpassed this line was deemed "gross sand". Because the shale line and sand line boundaries can move somewhat as series of strata with differing ranges of spontaneous potential or gamma radiation are encountered, the logging engineer will typically run the tool to the bottom of the interval to be logged and calibrate the tool to the extremes readings as the tool is raised up the well. However, the extremes can surpass the range of the track measurements and the logging engineer often trades off a little accuracy in order to keep the readings in the range of the track. Given this predicament and examination of the Sliverville's variations in signature in the well logs used for the isolith, it was determined that 7/10 (70%) of the deflection toward the 100% sand line would significantly negate tracking variations and adequately distinguish sand units within the formation.

The total number of feet of gross sand was recorded for each well and is documented in Appendix A. These values were spotted over the well locations and contoured at an interval of 20 feet.

In order to show how sand thickness varies along strike and dip directions cross sections B-B' and A-A' (Figures 5-3 and 5-4, respectively) were constructed. All logs chosen for the cross-sections are gamma ray logs. The particular logs used for the strike cross-section were chosen because they were close enough to the axis of strike and at regular enough intervals along strike as to give adequate control over the length of the overall formation. The logs used for the dip cross-section were chosen because they are as close as possible to being parallel to dip while being of the same type of log (gamma ray).

4.2 Structural Analysis

Although Fettke (1938, 1941), Elicker (1954), Stearns et al. (1971), and Klingensmith (1984) do not attribute the favorable reservoir characteristics of the Sliverville sandstone to structure, internal differentiation among the Slivervilles' productive sand units may be seen by use of a structure map modified after Stearns et al. (1971).

4.3 Internal Stratigraphy and Sedimentary Features

In an attempt to establish internal stratigraphy and identify sedimentary features the T-1 Duffey and T-1 Music Mountain cores were examined and described. Photographs of the available portions of the cores were taken and lithologic charts were constructed. The cores were moistened with water to enhance detail in the photographs. Detailed core descriptions of the T-1 Duffey and T-1 Music Mountain cores appear in Appendix B and C, respectively. The cores were examined with a hand lens of 10X magnification. Additionally, a comparison slide with sieved sediments of fine silt, silt, coarse silt, fine sand, sand, coarse sand, and very coarse sand were used for quantification of sediment size.

4.4 Sediment Characteristics

Twenty seven thin-sections were made from pieces of core taken from the T-1 Duffey core and eleven thin-sections were constructed from pieces of the T-1 Music Mountain core. Both cores were cut longitudinally shortly after they were extracted from the wells. The shale between the Harrisburgh Run and the Sliverville was not cut and the shale at the base of the Sliverville was already disaggregated. All thin-sections were taken from one side of the pre-cut semi-cylinder of core so as to keep one semi-cylinder totally intact for future inspection.

Thin-sectioned intervals were selected based on visual grain size change, sedimentary structure change, or other facies change that might help identify a potential characteristic sub-environment. Appendix D lists the thin-section designations and the depth at which they were taken. The thin-sections were oriented on slides with the long axis of the slide oriented perpendicular to the long axis of the cores. This orientation is arbitrary, but consistent. The thin-sections were prepared at a laboratory and stained with alizarin red to identify feldspars. For size analysis the thin-sections were placed under a plane light microscope with a mechanical stage. The short axes of three hundred grains were measured for each thin-section. Initially, a point-count of five hundred grains was attempted, but due to the relatively large size of the grains, the slide had to be remounted in the mechanical stage and examined two to three times in it's entirety to measure five hundred grains. The average grain size of each thin-section was calculated and is tabulated in Appendix E.

Each thin-section was also examined using a petrographic microscope with a mechanical stage. Under plane light a visual comparator was utilized to identify degree of sorting (Longiaru, 1986). Roundness was also noted under plane light. The same grain would then be examined under polarized light and categorized as either quartz, feldspar or rock fragments (McBride, 1963). As was the case for the size classification point-count three hundred grains were examined for each thin-section in order to determine composition. Not all thin-sections were examined for lithologic purposes. Lithologic thin-sections were chosen based on visual lithologic changes as seen in the cores. Thin-sections used for mineralogic characterization were plotted according to their relative percentages of quartz, feldspar, and rock fragments.

4.5 Flora and Fauna

In an attempt to identify macrofossils, each shale unit within the T-1 Duffey and T-1 Music Mountain core was partially disaggregated. The procedure used (Rollins, 1983) calls for 1000 grams of crushed rock to be placed in a bucket containing 4-5 liters of sodium hypochloride (NaOCl); household bleach. Next, it stated that NaO beads may be added to enhance the reaction; however, this step was omitted. Although it was not always possible to secure 1000 grams of crushed shale from each shale unit (for fear of destroying the future interpretive integrity of the cores) the ratio of rock to sodium hypochloride was maintained. The mixture was allowed to soak for two weeks.

After two weeks of disaggregation the mixture was wet-sieved through #20-#60-#100-#220 nested Tyler sieves. The sub-samples were allowed to dry and then were examined with a binocular microscope to determine the presence of macrofossils.

Chapter 5

Results and Observations

5.1 Gross Sand Isolith

The wells used for calculation of gross sand are shown in Figure 5-1. Figure 5-2 is an isolith of gross sand contoured at a twenty (20) foot interval. The first observation noted is a distinct Northeast-Southwest orientation of the sand body. Gross sand varies from zero (0) feet to in excess of 105' in well #17, Lot #8. This well is located near the approximate center of the field with respect to strike and dip. In the northeast corner of Lot #8, and less pronounced in the Gorton and Duffey leases, contour lines diplay orientations more closely paralleling dip direction. However, the majority of contours indicates that depositional strike is Northeast-Southwest.

5.2 Cross-sections

Figures 5-3 and 5-4 are cross-sections taken parallel to strike and dip of the gross sand isolith, respectively. In Figure 5-3 six gamma ray logs were used to construct a cross-section of sand thickness parallel to the strike of the sand body. The purpose of this cross-section is to

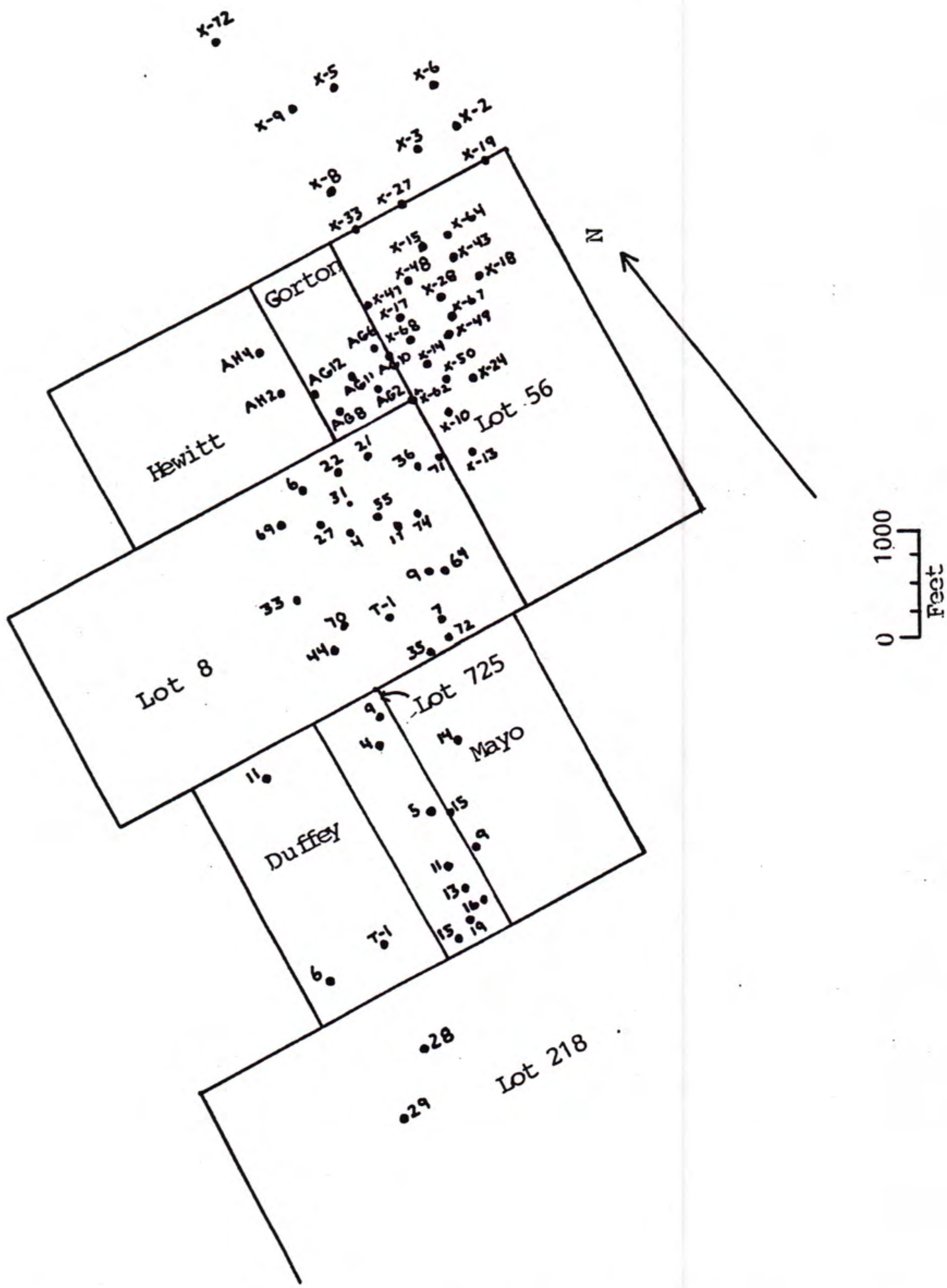


Figure 5-1 Wells used in calculation of gross sand

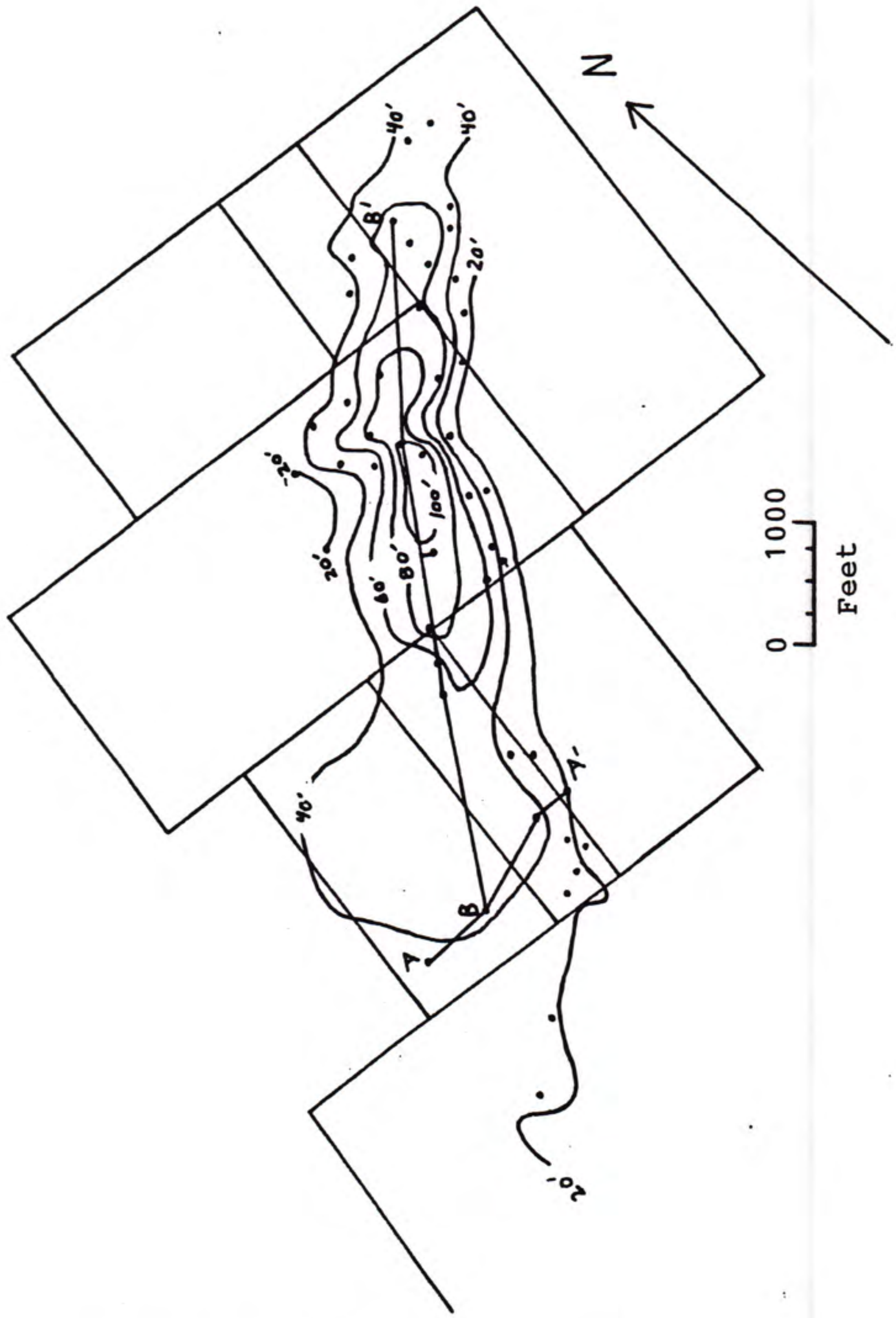
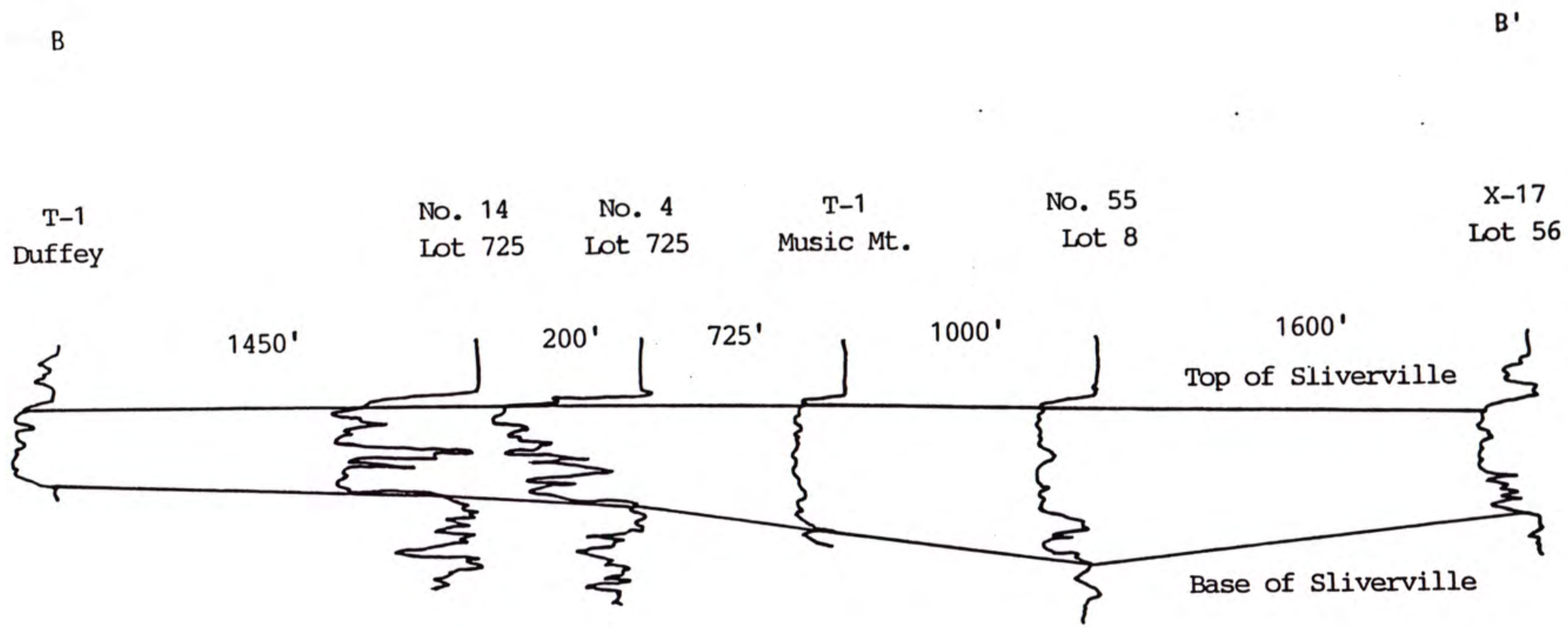


Figure 5-2 Isolith of gross sand



Verticle Scale 1"=150'

Horizontal Scale 1"=1500'

all logs are gamma ray

Figure 5-3 Cross-section B-B' taken parallel to strike determine how sand thickness and gamma ray log signatures vary along strike.

Moving in a northeasterly direction from the T-1 Duffey well to #14, Lot 725, gross sand gradually increases from 48' to 58' over a horizontal distance of approximately 1450'. Continuing northeasterly 200' to #4, Lot 725 gross sand decreases only one foot. At the T-1 Music Mountain gross sand has increased to 96' and in the next well of the strike cross-section, #55, Lot #8, the second highest thickness of gross sand is encountered, 101'. Well X-17, Lot #56 is the most northeasterly well in the strike cross-section and registers a value of 66' of gross sand.

The T-1 Duffey, #14, Lot 725, #4, Lot 725, and X-17, Lot 56 all seem to be somewhat consistent in gross sand values. A marked increase in gross sand in a strike direction can be seen to take place between #4, Lot 725 and the T-1 Music Mountain and #55, both located in Lot #8. Additionally, this is the same area of the gross sand isolith which is offset in a dip direction.

Of importance are the various gamma ray log signatures along the strike of the gross sand isolith. Wells #14 and #4 of Lot 725, and to a less extent X-17, Lot 56, are registering more shales than the other logs. The gamma ray log signatures of the other wells are more rounded.

Figure 5-4 is a cross-section taken parallel to the dip direction of the gross sand isolith. The most westerly well in the cross-section is the Duffey #6, which registers 37' of gross sand. Moving 885' in an easterly direction to the T-1 Duffey, gross sand increases to 48'. Gross sand gradually decreases to 43' in #11, Lot #725, 740' further east, and decreases rapidly to 16' in the Mayo #9 which is only 245' east of #11, Lot #725.

Although a log in line with the dip cross-section, but further west is not available for inspection the gross sand isolith does show a picture of a lenticular dip cross-section. Gamma ray log signatures in an easterly direction along strike indicate rapid thinning of gross sand. Thinning in a westerly direction is more gradual, but referring to the boundary shown in the gross sand isolith and based on a review of the previous work of Fettke, 1941 and Stearns et al. 1971, (all whom had access to more of the original well logs) it is indicated that the Sliverville pinches out totally a short distance to the west of the Duffey #6.

As was the case with cross-section B-B', all logs in this cross-section are gamma ray. There is less variability in log signature than was seen in the strike cross-section, but the T-1 Duffey seems to indicate the presence of fewer shale units than the other wells in the cross-section. Overall, prevalence of shale breaks is consistently higher

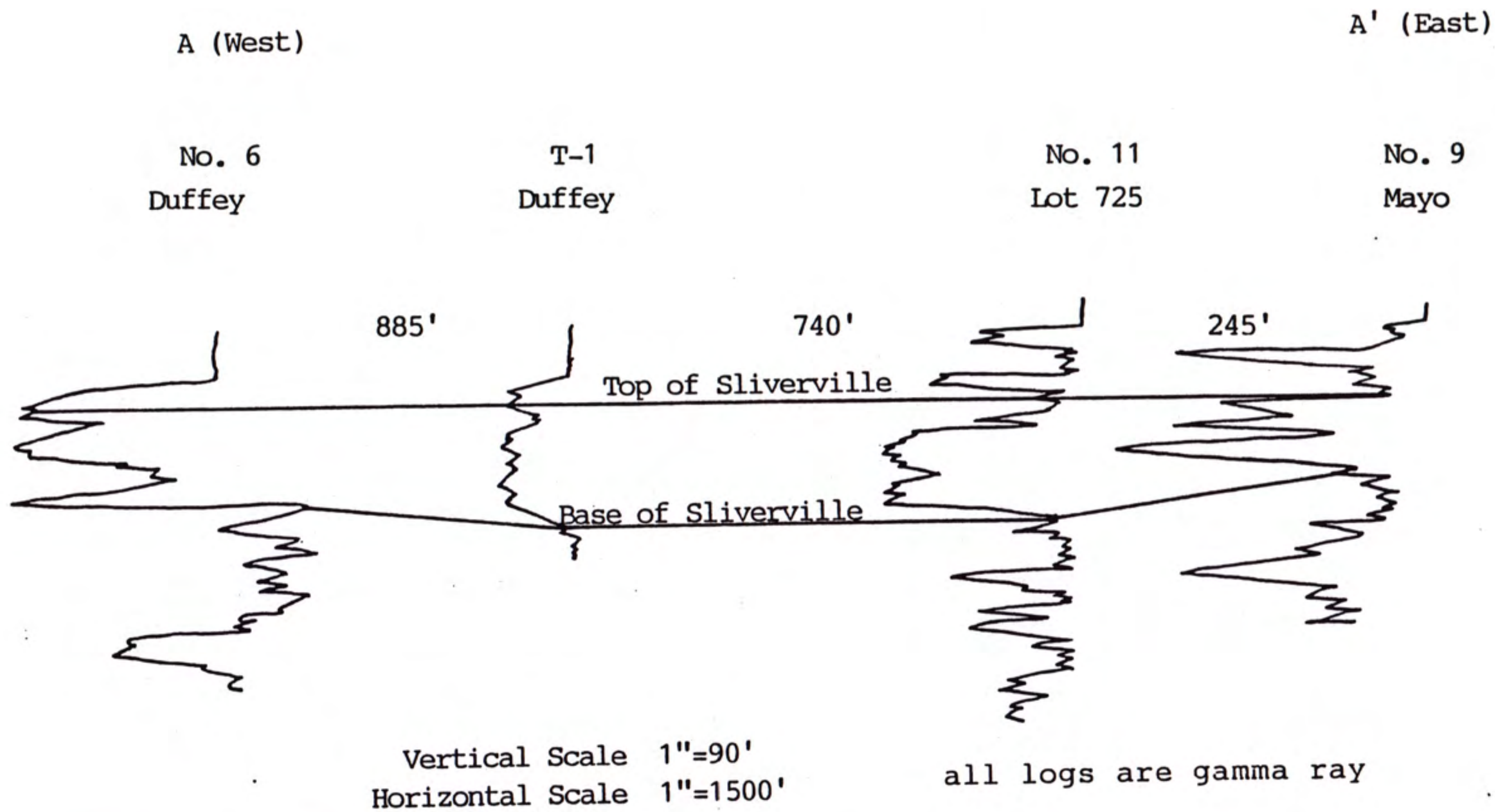


Figure 5-4 Cross-section A-A' taken parallel to dip

than was indicated in Lot #8 of the strike cross-section by the T-1 Music Mountain and well #55.

5.3 Structure Map

Figure 5-5 is a structure map of the top of the Sliverville, contoured on a 20' interval, modified from Stearns et al (1971). Generally, structure echoes what the gross sand isolith is showing with respect to macrogeometry and areal distribution. The Sliverville is oriented Northeast-Southwest and is lenticular in a dip direction. Based on Figure 5-5, which was based on the top of the Sliverville, the Sliverville is a positive feature, higher in the middle than on the sides. Coupled with the gross sand isolith, which also thickens in the middle and feathers out at the edges, it is inferred that the "anticlinal" (positive) profile of the Sliverville is due to sediment accumulation as opposed to structural deformation.

5.4 Core Descriptions

Detailed core descriptions of the T-1 Duffey and T-1 Music Mountain appear in Appendices C and D, respectively. Figures 5-6, 5-7, and 5-8a-8e are photographs of the cores. As mentioned in Chapter 3, not all of the cored interval of the T-1 Music Mountain was found, so although Figure 5-7 is presented as a continuous sequence of photographs, missing core data is present.

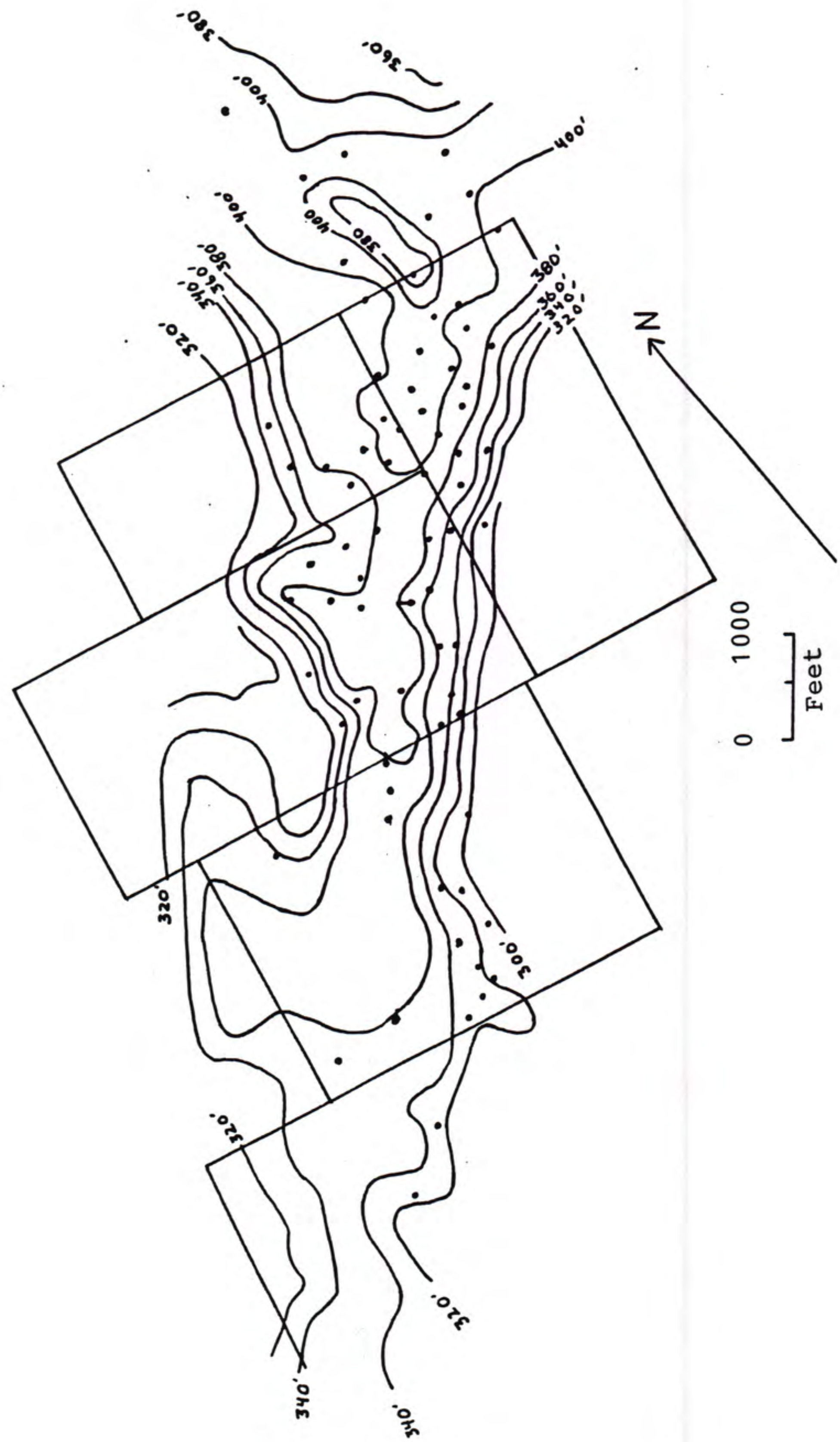


Figure 5-5 Structure mapped on the top of the Sliverville

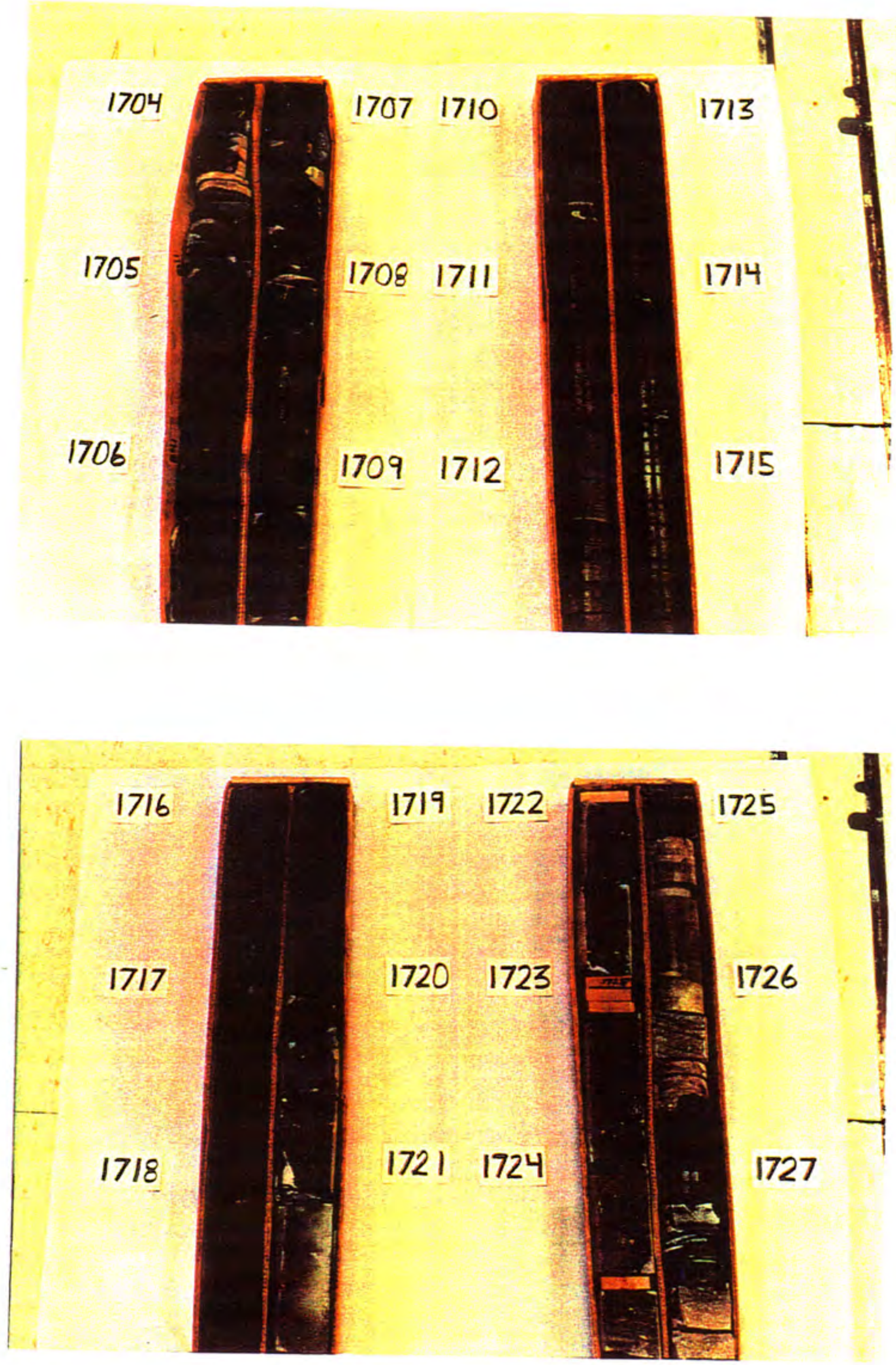
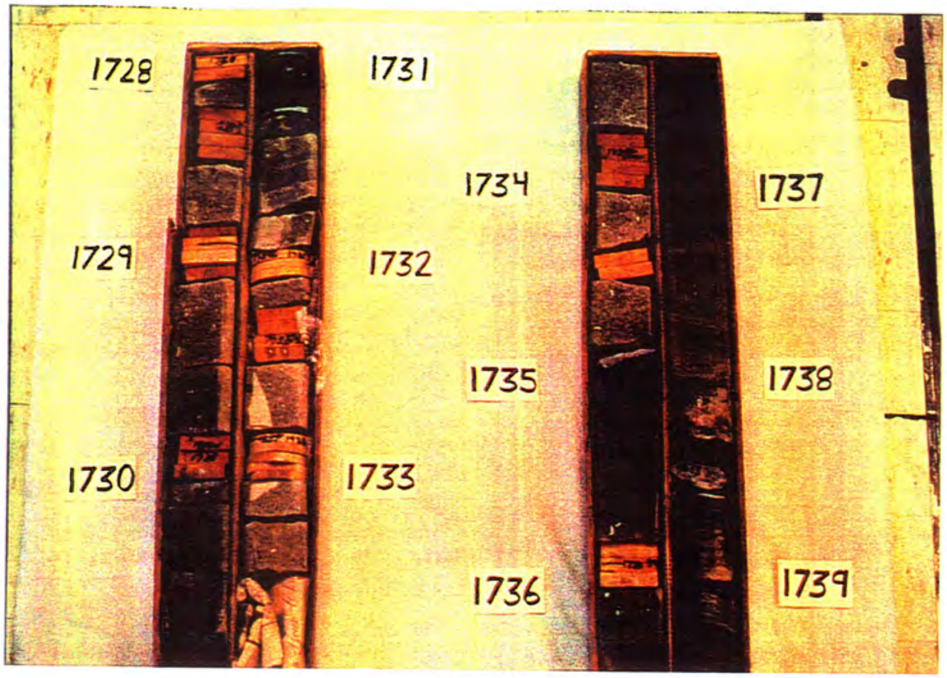


Figure 5-6 T-1 Duffey core



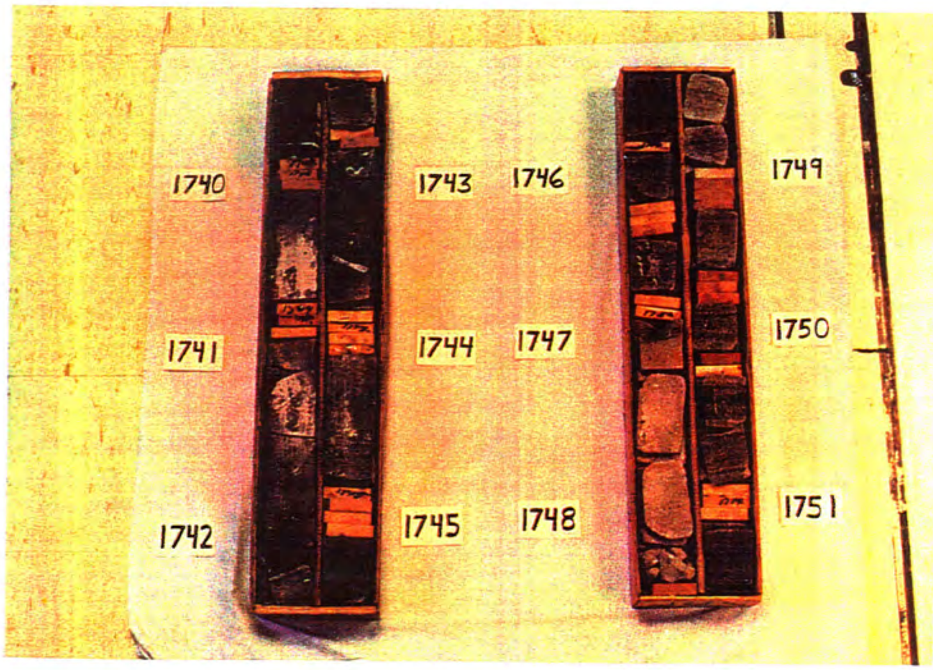
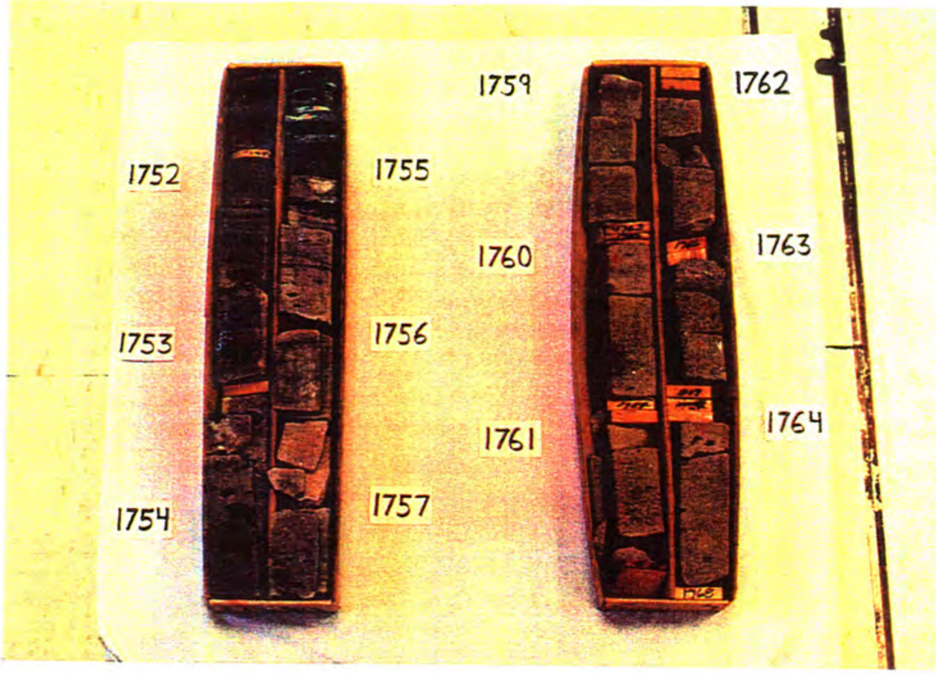


Figure 5-6 (continued) T-1 Duffey core



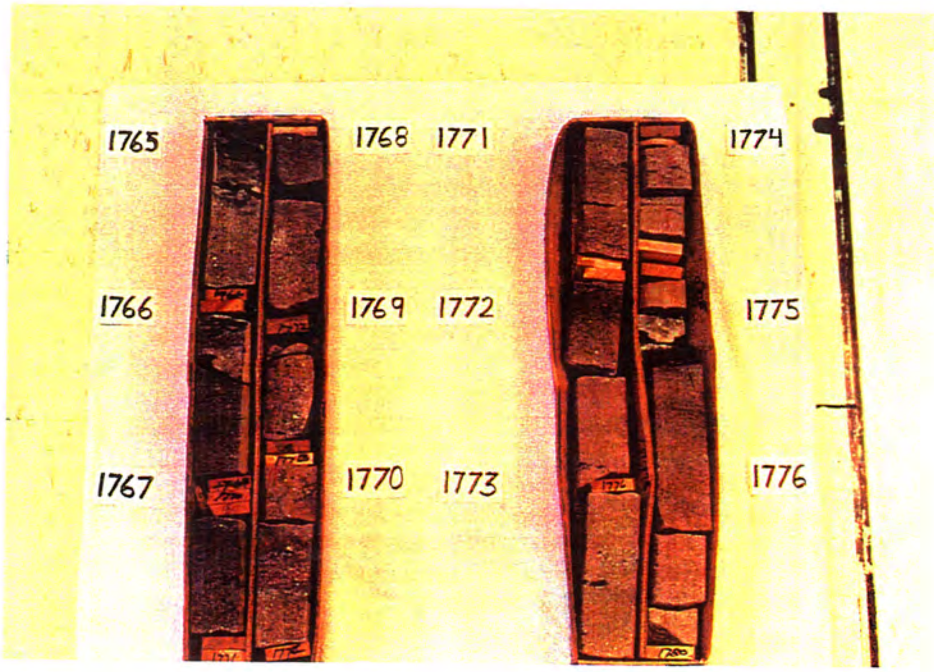
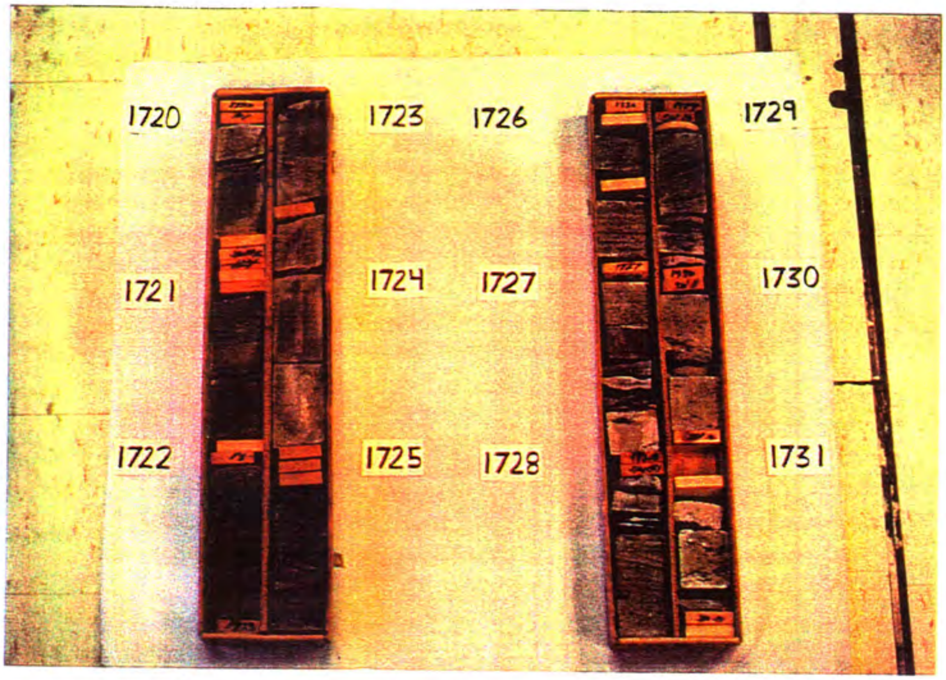


Figure 5-6 (continued) T-1 Duffey core



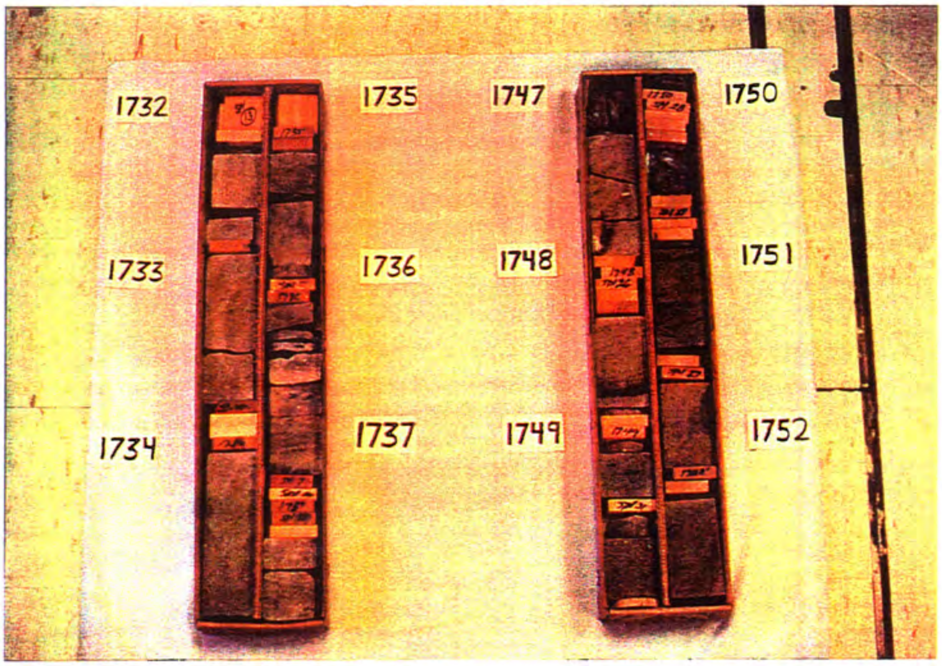
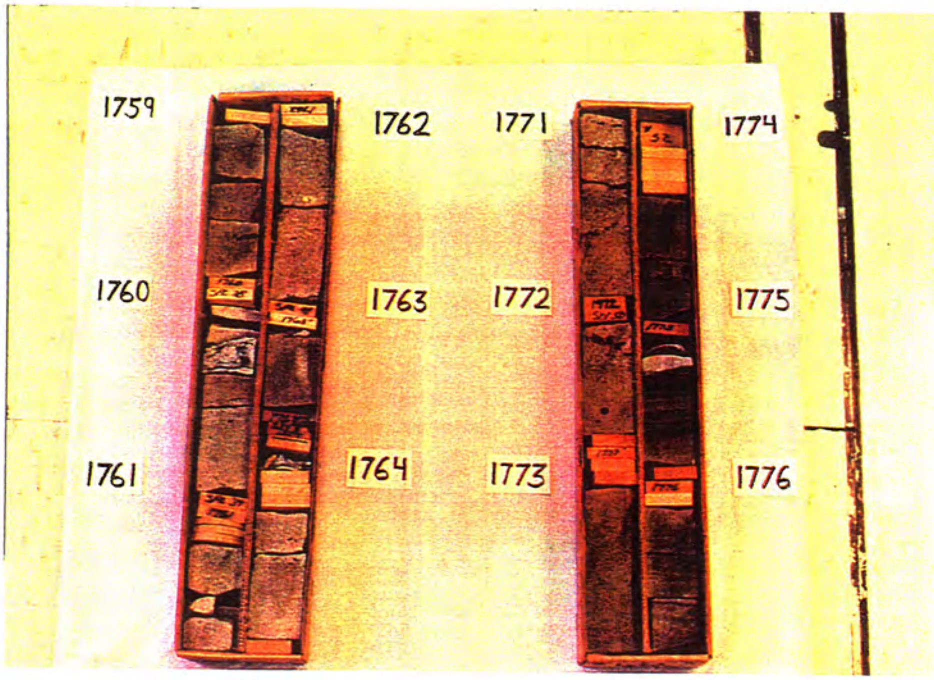


Figure 5-7 T-1 Music Mountain core



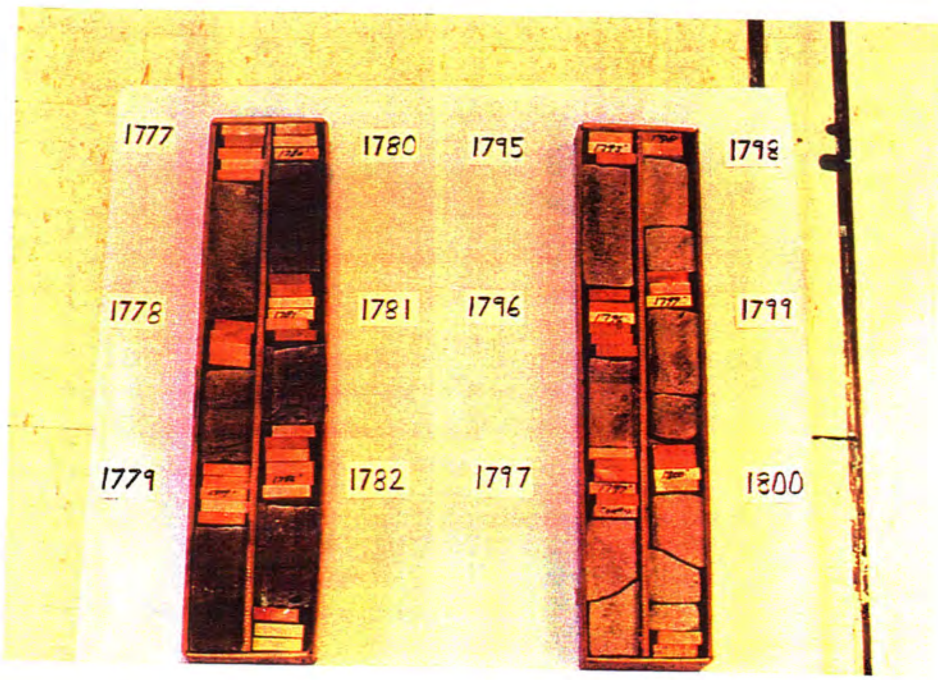
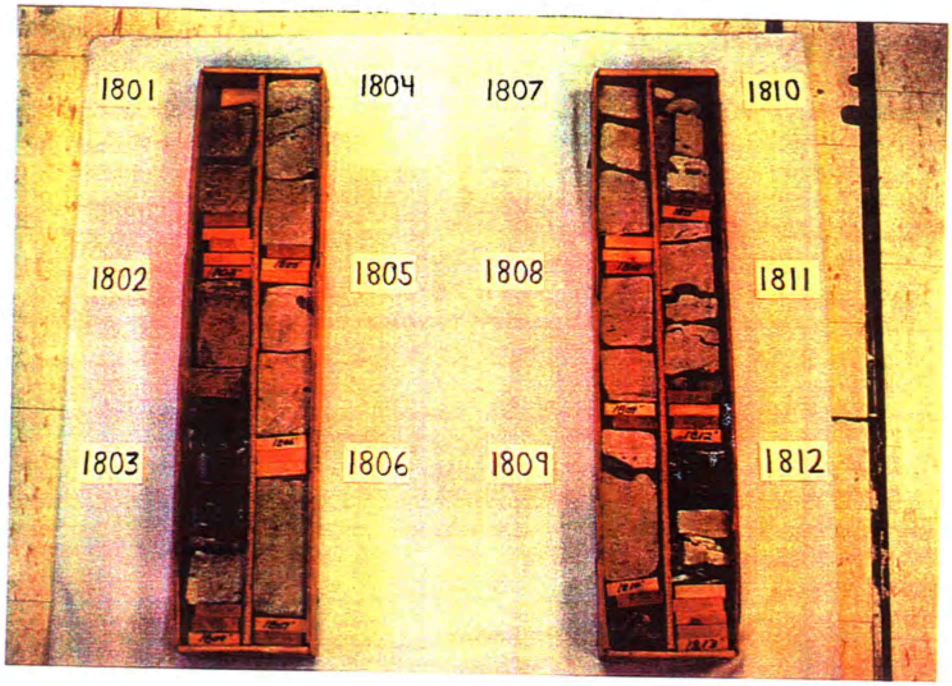


Figure 5-7 (continued) T-1 Music Mountain core



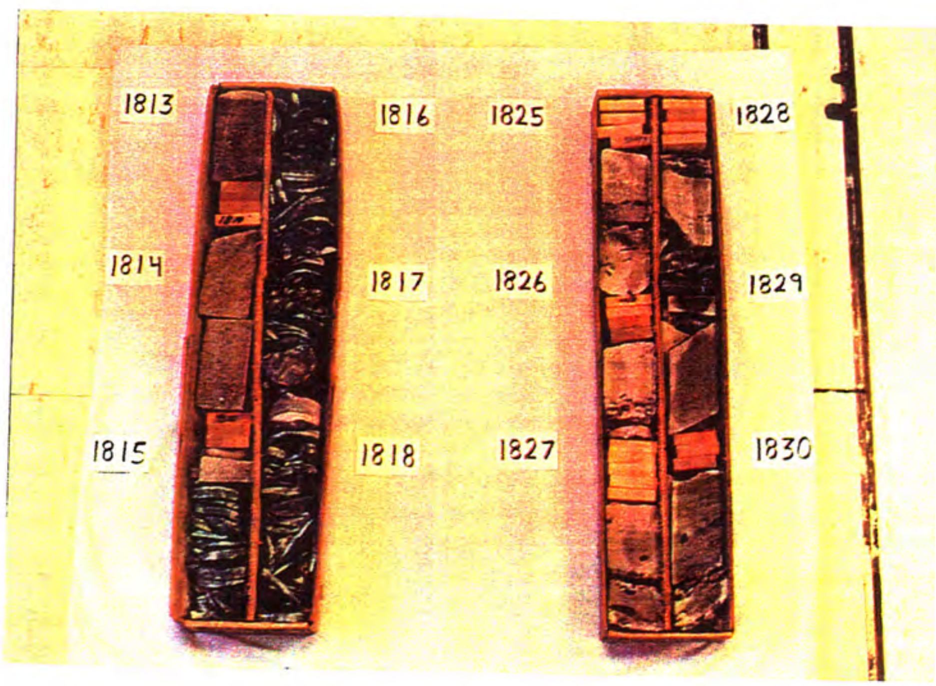


Figure 5-7 (continued) T-1 Music Mountain core

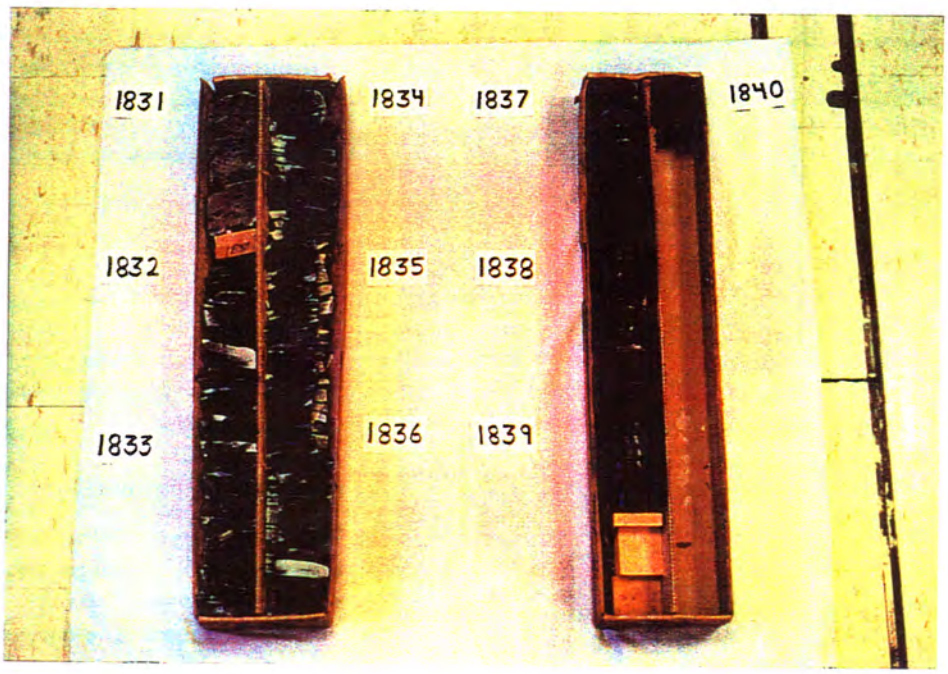


Figure 5-7 (continued) T-1 Music Mountain core

Figure 5-8a Cross-bedding, T-1 Music Mountain

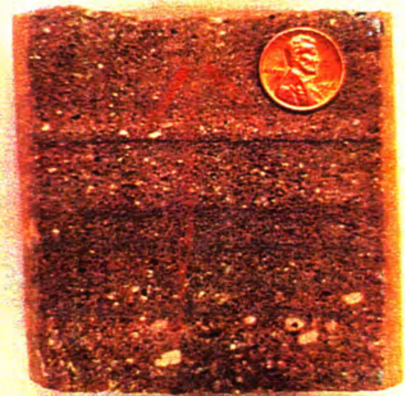


Figure 5-8b Planar laminations, T-1 Music Mountain

Figure 5-8c Horizontal burrow filled with coarse sand, T-1 Music Mountain

Figure 5-8d Erosional contact, T-1 Duffey

Figure 5-8e Chocolate-brown rip-up clasts from dessication-cracked mud, T-1 Music Mountain

Figures 5-9 and 5-10 are charts that illustrate overall lithology and prominent sedimentary features of the cores. The most prevalent lithology is coarse to very coarse quartz sand. Sand color varies from light gray to off-white. The sediment can be massive, cross-bedded, or planar laminated. Cross-bed sets are tangential, and may be bi-directional, however it can not be ruled out that adjacent uni-directional ripples are merely being eroded by later ripples. Figure 5-8a shows a zone of cross-bedding seen in the T-1 Music Mountain core at a depth of 1725.5-1726'. Likely, the massive sands are part of a bed structure of some sort, that can not be determined within a core. Figure 5-8b is a photograph of planar laminations seen in the T-1 Music Mountain at the depth of 1775.5-1775.9'. Planar laminations can be achieved under either weak or strong "shear forces" (functional definition being similar to water velocity). The intensity of the shear force can be determined by examination of the grain size of the sediments (Harms et al, 1982).

Shales are the other major observable units comprising both cores. The shale unit near the base of the Harrisburgh Run in the T-1 Duffey core and at the base of the Sliverville in the T-1 Music Mountain core contain red coloration. In the T-1 Duffey the shale is greenish gray with some red intervals. In the basal shale of the T-1 Music Mountain the shale is black and red. More red coloration is seen in the T-1 Music Mountain basal shale. Figure 5-8c is a photograph of a horizontal burrow through

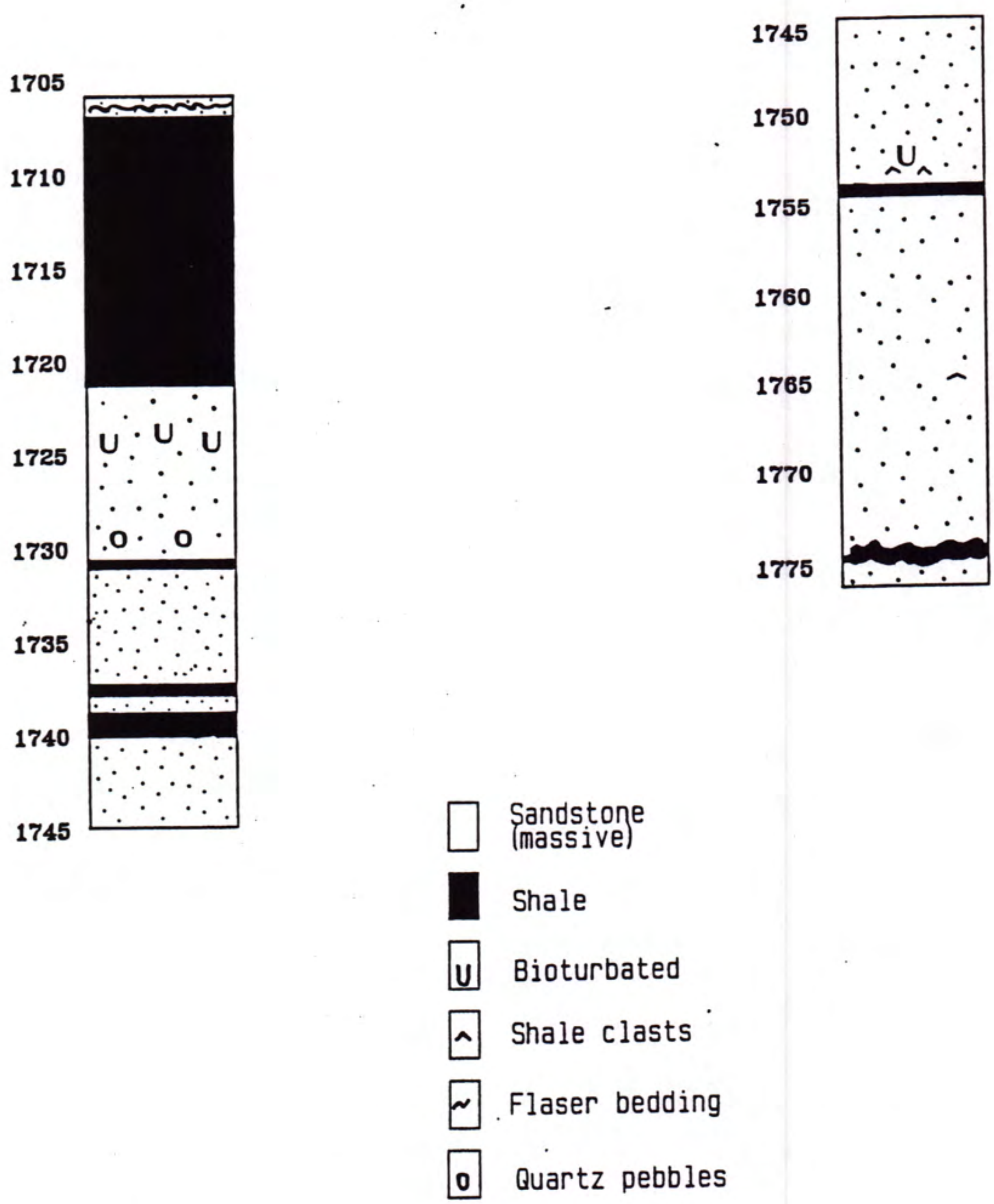


Figure 5-9 Lithologic chart of T-1 Duffey Core

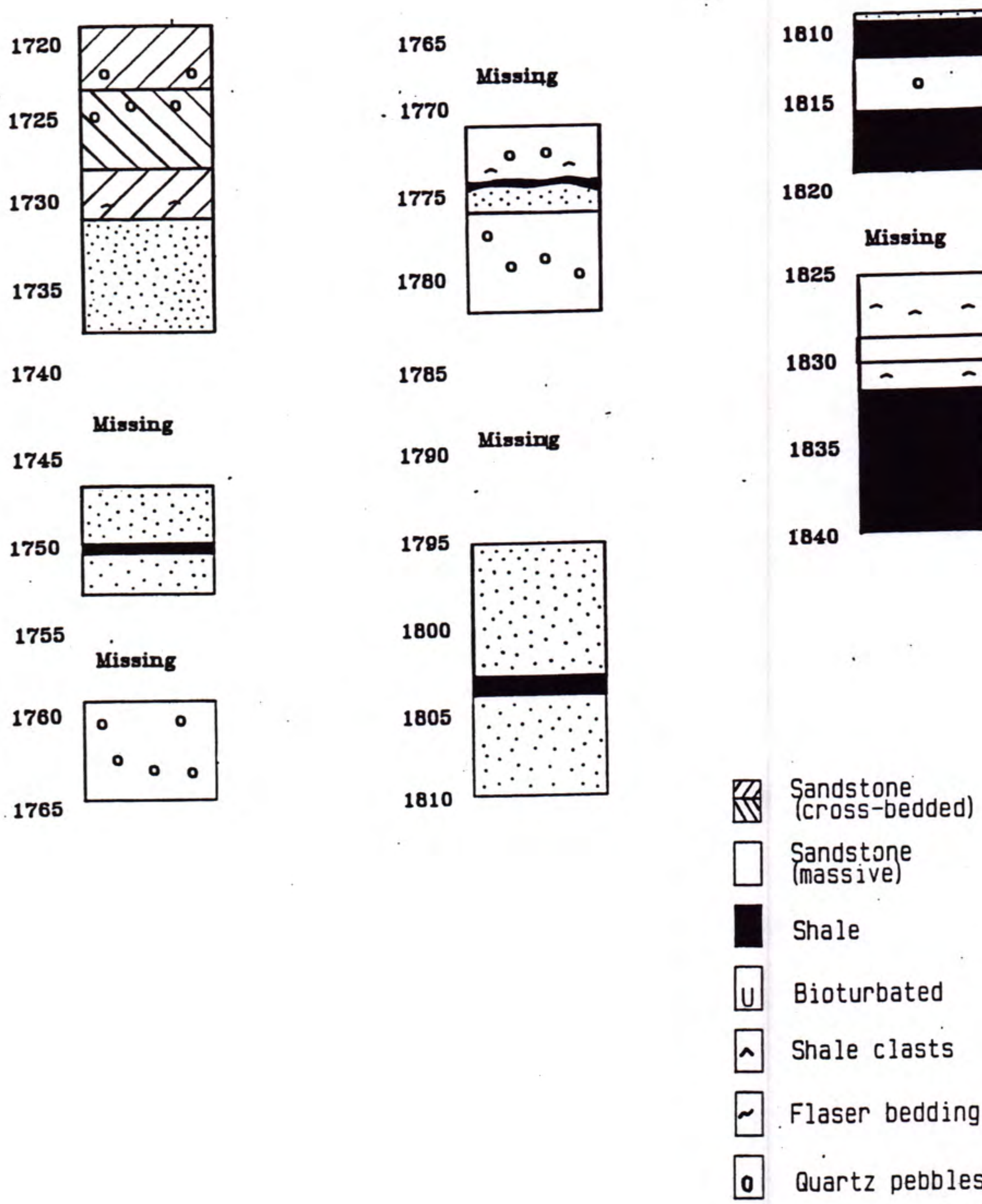


Figure 5-10 Lithologic chart of T-1 Music Mountain core

the the basal shale of the Sliverville in the T-1 Music Mountain core. The burrow was filled with coarser sand and subsequently maintained the integrity of the burrow as other finer sediment deformed around the burrow (Crimes, 1985). The other shale units found in both cores are predominantly greenish-gray.

Except for the erosional contact at 1726.5-1726.75' most contacts between sandstone units and shales are manifested as flaser bedding. In Figure 5-8d the eroding unit is coarse to very coarse-grained sand and shell lag. This is clearly a unit of the Sliverville sandstone. The overlying Harrisburgh Run sandstone is a very fine to fine-grained brown sandstone. Therefore, the top of the Sliverville in the T-1 Duffey should be placed at 1724-1726.75' where a transition is seen from fine brown sand to coarse white sand. This differs slightly from Depetro's (1971a) pick of the top of the Sliverville. In the basal shale of the T-1 Music Mountain one can see shale surrounding sand laminae that may be as little as a few grains in thickness. In the same core one may see shale inclusions defining a bedding plane, wavy and undulating bedding where sand is the prominent sediment, wavy and undulating bedding where shale sized material is the prominent sediment, or wispy and flaky chocolate-brown shale inclusions as seen in Figure 5-8e. It is proposed that these flaky and wispy shale inclusions are likely desiccation-cracked mud that was washed into the surrounding sediment (Hopkins, 1990; Cloyd, 1990).

5.5 Sediment Characteristics

Detailed thin-section descriptions of the T-1 Duffey and T-1 Music Mountain appear in Appendices F and G. The average of mean grain size as measured by the short axes of grains in thin-section is .424 millimeters in the T-1 Duffey core and .494 millimeters in the T-1 Music Mountain. These values approach the lower limit of coarse sand (Friedman and Sanders (1978). Appendix E is a tabulation of mean grain size measurements.

Disagreement concerning the relation of point-counted grain size to sieved sediment has been identified long before this point. Some of the arguments and shortfalls of relating the two sets of data may be seen in Friedman, 1958, 1965a, 1965b, 1971; Packham, 1955; and Sahu, 1964. In sieved samples the axis exerting the most influence on size determination is the intermediate axis. This is because non-spherical grains will orient themselves so that the long axis is perpendicular to the mesh, especially when vertical agitation is applied. If a grain is spherical one can think in terms of the long and short axes approaching the same length as the intermediate axes. Therefore, the axiom of maximum influence being due to the intermediate axis still holds true. Further, in a cylindrical grain the short axis is the same length as the intermediate.

Given the above argument, in thin-section the ideal situation would be to measure the "true" intermediate axis of a number of grains. However, in a thin-section one sees the intersection of one of an infinite number of planes that arbitrarily intersects different sections of different grains. The two-dimensional section of a grain may be parallel to any one of the axes or, more likely, at some angle other than parallel to any axis. Furthermore, even if the thin-section has cut exactly parallel to a known axis of a grain it may have cut through the tip of the grain, that is showing a dimension in cross-section which is less than the actual diameter (or length of the grain).

In this study the short axes of grains were measured. This choice of axis is arbitrary, but was consistent for all the measurements. The determination that the Sliverville is within the sand size and rather coarse at that is substantiated by Fettke (1941) who did attempt sieve analysis of large fragments of rock that were retrieved from a well that was "shot" with nitroglycerine to enhance permeability. The percentage of grains retained on the .295 millimeters screen was 69.8 per cent of the total by weight. Those grains which were retained on the .417 millimeter opening screen composed 50.4 per cent of the total sample by weight. Fettke's analysis coupled with a visual comparison of the cores with sieved and mounted sediments of known size, led to the author's belief that thin-section-generated data is comparable to sieved analysis in this case.

As Pettijohn (1957) illustrated in table form; there are many classification schemes for sandstones. As stated in Chapter 3, quartz, feldspar, and rock fragments were chosen as end-members in this study (McBride, 1963). Also discussed by Pettijohn (1963) are the diversity of terms used to refer to the resultant combination of the end-members. All thin-sections examined for minerology contained 96% or more detrital quartz. The term chosen for this mixture is "orthoquartzite", which has taken on the generic connotation over the years of meaning any sandstone which contains at least 95% detrital quartz grains (Pettijohn, 1957). Figures 5-11 and 5-12 are plots of percentage quartz, feldspar, and rock fragments for the T-1 Duffey and T-1 Music Mountain, respectively. In thin-section silica, calcite, and (rarely) hematite are seen as a cementing agent. Quartz grains are both monocrystalline and polycrystalline. Secondary quartz overgrowths may be identified by the presence of dust rims and have been documented by Fettke (1941). Under cross-nicols vermicular kaolinite may be seen on some of the grains. Figures 5-13a-d are photomicrographs depicting some of the common characteristics of the Sliverville. Based on thin-section identification and reference to a visual comparator (Longiaru, 1986) and visual inspection of the core with comparison to sieved and slide-mounted sediment classes the Sliverville is moderate to well-sorted and sub- to well-rounded.

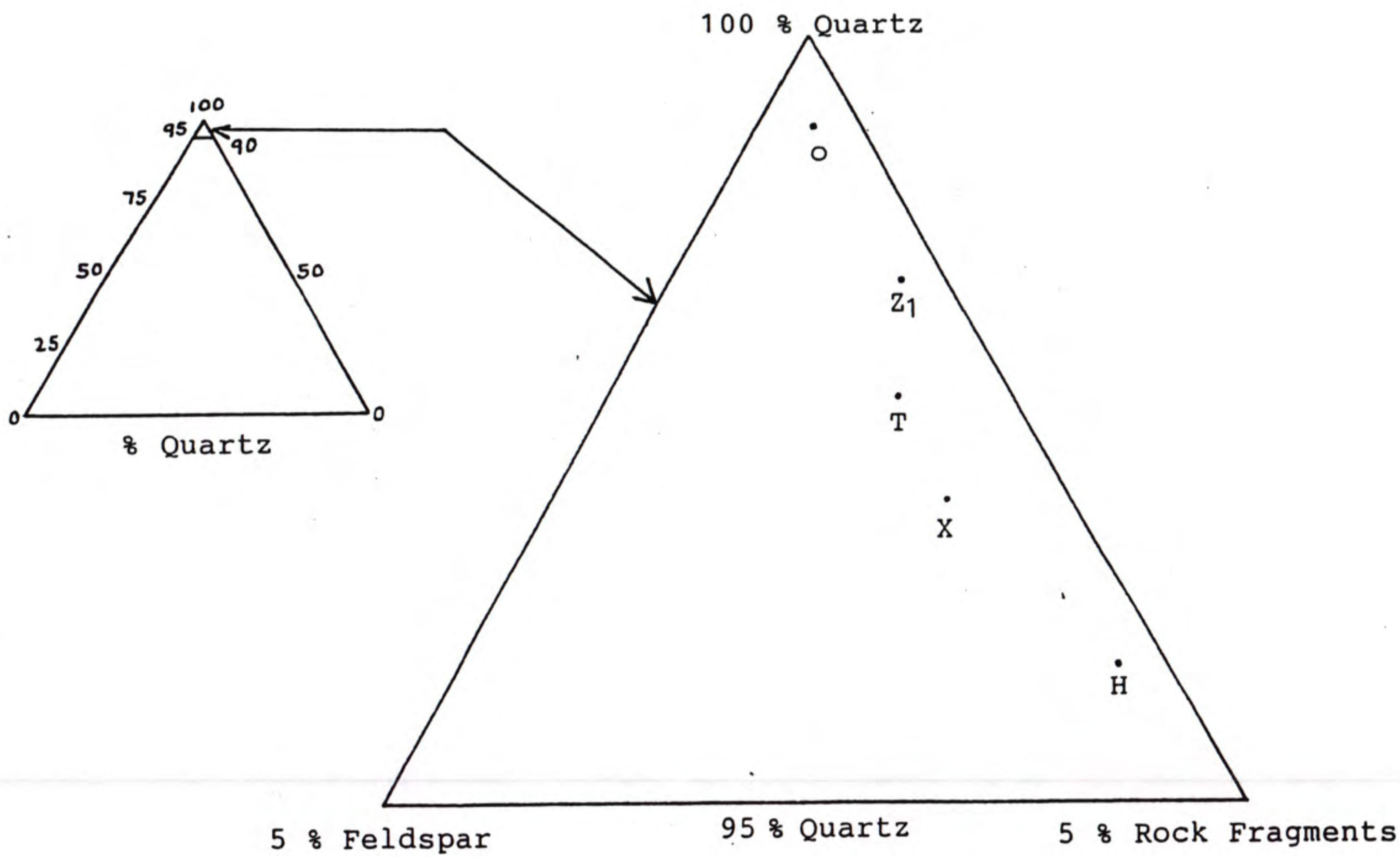


Figure 5-11 Sandstone classification based on T-1 Duffey thin-section data (after McBride, 1963)

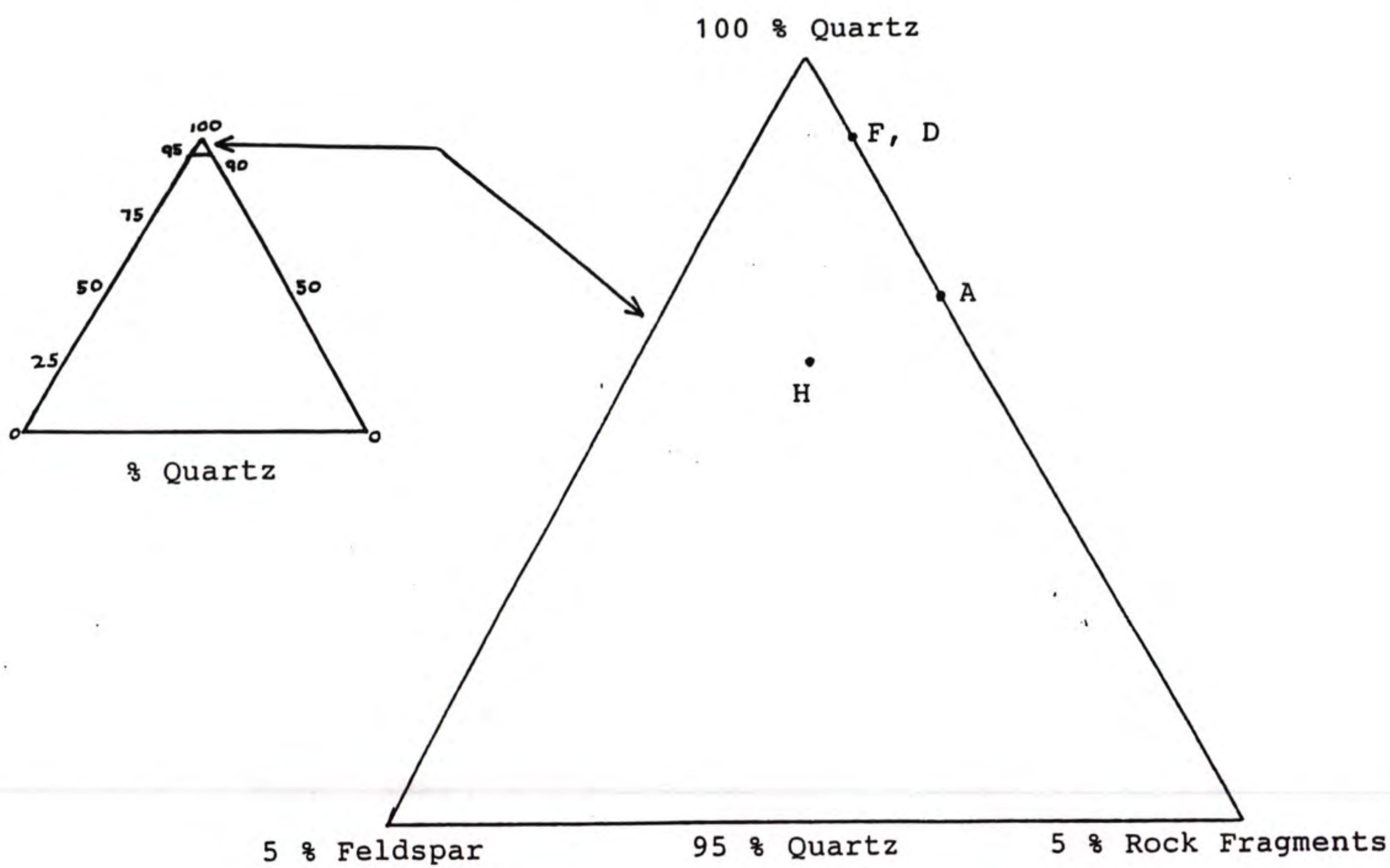


Figure 5-12 Sandstone classification based on T-1 Music Mountain thin-section data (after McBride, 1963)

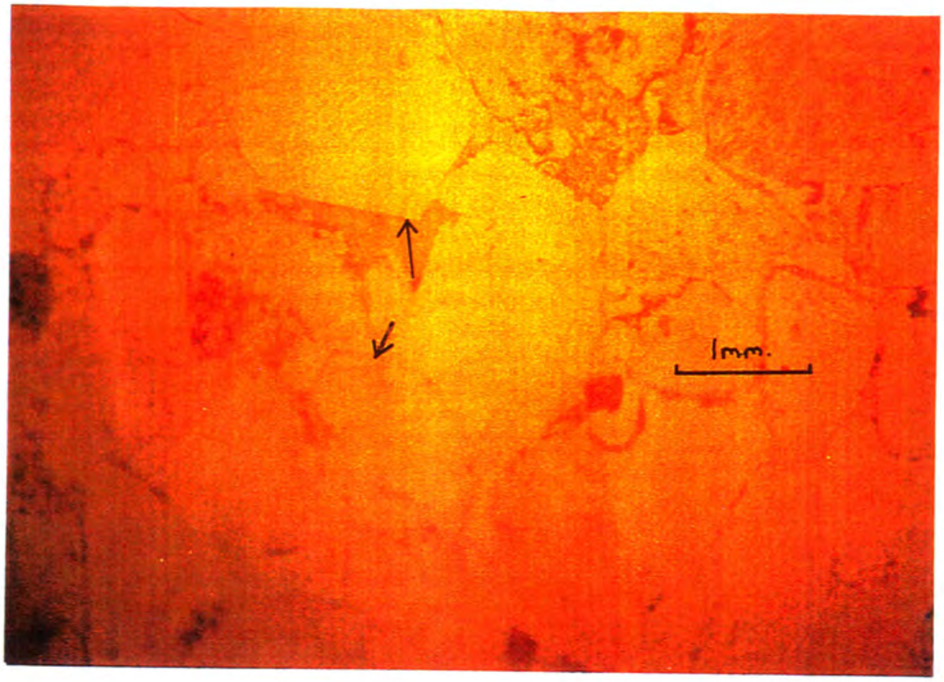


Figure 5-13a Quartz overgrowth under plane-polarized light

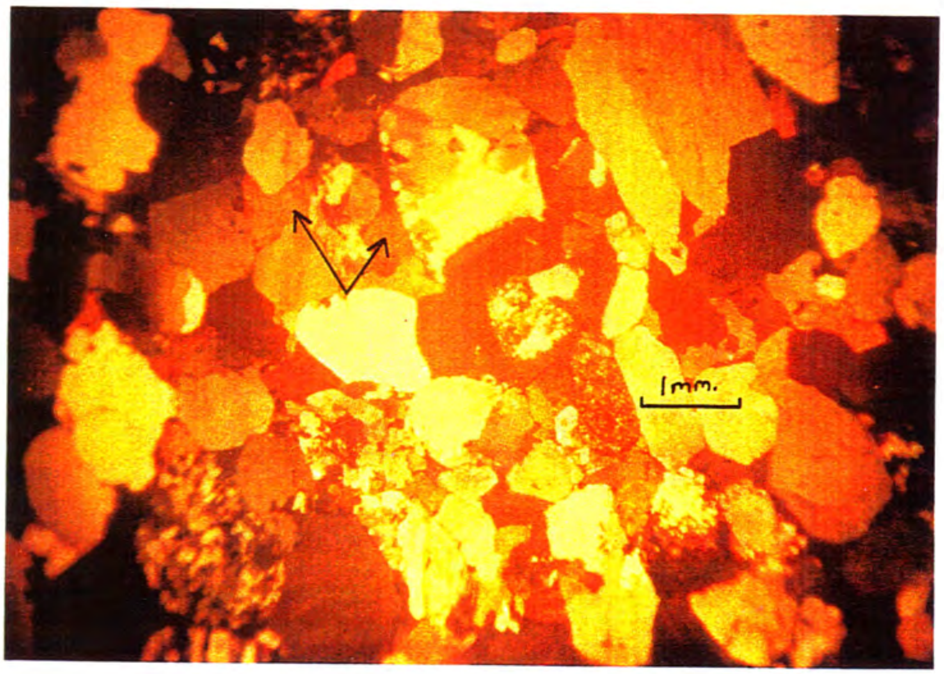


Figure 5-13b Calcite cement under cross-nicols

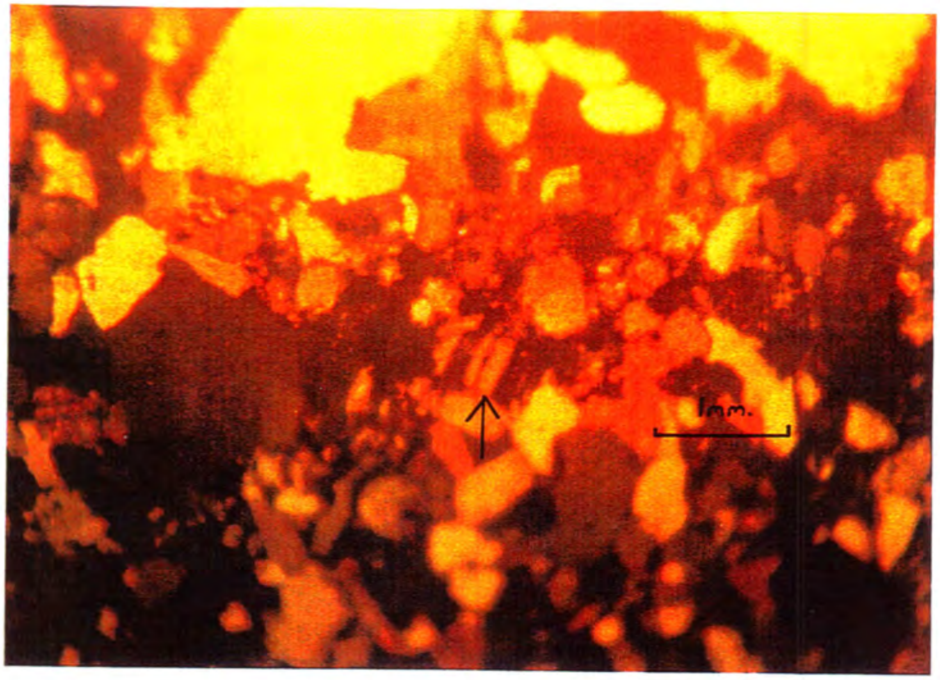


Figure 5-13c Feldspar grain under cross-nicols

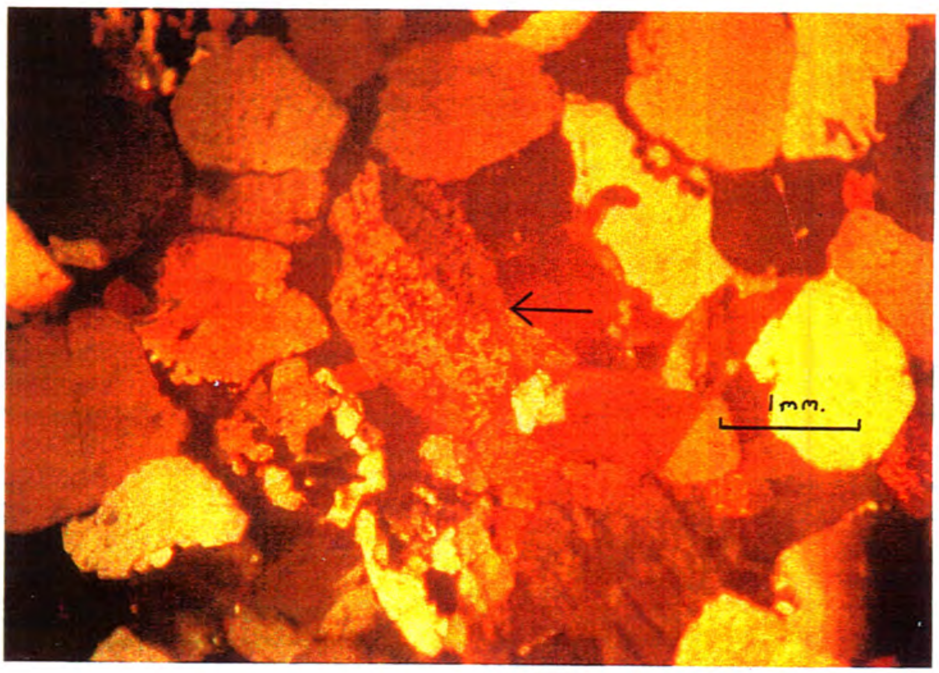


Figure 5-13d Authigenic vermicular kaolinite under cross-nicols

5.6 Flora and Fauna

Every shale unit contained a moderate amount of the Miospore Tasmanites, believed to be the resting cysts of (fossil) unicellular alga (Brooks et al., 1971; Taylor, 1981; Rollins, 1985; Traverse, 1988). Tasmanites were abundant from the Silurian to the Cretaceous and are of marine and/or brackish origin. Although originally bean-shaped to spheroidal, they are often found to be disc-shaped in sediment as a result of compaction (Brooks et al., 1971). Lignitic plant fragments were found in the T-1 Duffey at a depth of 1,738' and in the T-1 Music Mountain core in the basal shale unit which extends from 1832-1840.5'. One plant fragment found in the basal shale unit of the T-1 Music Mountain core was one (1) inch long and 3/4" wide. As Fettke (1941) pointed out, the angularity of these plant fragments suggest that their source was relatively near. As with the algal resting cysts of Tasmanites, a nearshore source is suggested.

Additionally, many burrows, predominantly horizontal in orientation, were seen in the basal shale unit of the T-1 Music Mountain core. The prevalence of horizontal traces suggest a quiet setting where organic particulates, on which the animals fed, settle out and form a source of food on the mud (Howard, 1975; Gall, 1983). As discussed in Chapter 2 the overlying Harrisburgh Run is rich in brachiopods and these have been previously identified by others. With the exception of shell lag encountered at the base of the erosional contact in the T-1 Duffey core fossil evidence within the coarse sand units of the Sliverville is absent. Although organisms can survive in the high energy environments (which are suggested by the sediment sizes and sedimentary features seen in the sand units of the Sliverville) it is certainly not conducive. Therefore, the absence of macrofossils is considered typical and probably caused by high energy.

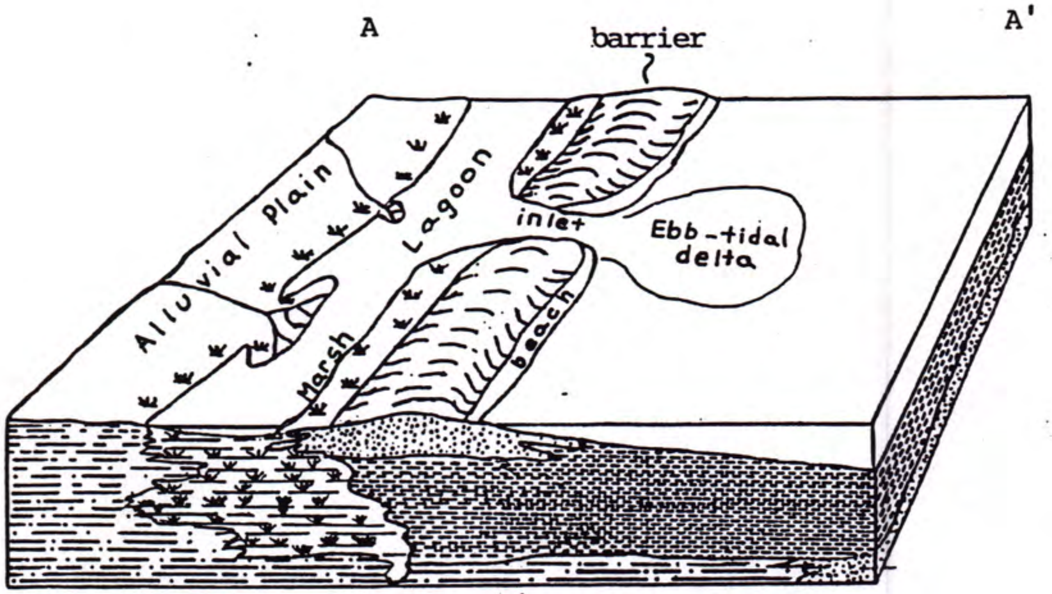
Chapter 6

Proposed Depositional Environment

6.1 Depositional Model

Fettke used the term "barrier-bar complex" to define the depositional environment that he believed was suggested by the geometry and areal distribution of the Sliverville. The term "barrier island complex" is more commonly used in literature. Friedman and Sanders, (1978) define a barrier island complex as "all the depositional environments and sediments associated with barrier islands or spits. These environments and sediments being elongate islands composed mainly of unconsolidated sediment and separated from the mainland by a lagoon or bay". The "back-barrier" refers to the sub-environments associated with the interval between the mainland and the barrier island(s). Figure 6-1 (modified after Friedman and Sanders, 1978 and Donselaar, 1989) shows some of the major subenvironments of a barrier island complex.

The terminology and associated deposits and depositional mechanisms of barrier island complexes have been well documented in Holocene and ancient sequences. Among these studies of barrier islands and barrier island complexes are: MacNeil (1950), Price (1951), Rusnak (1957), Sabins (1963), Davies (1964),Thomas and Mann (1966), Hoyt



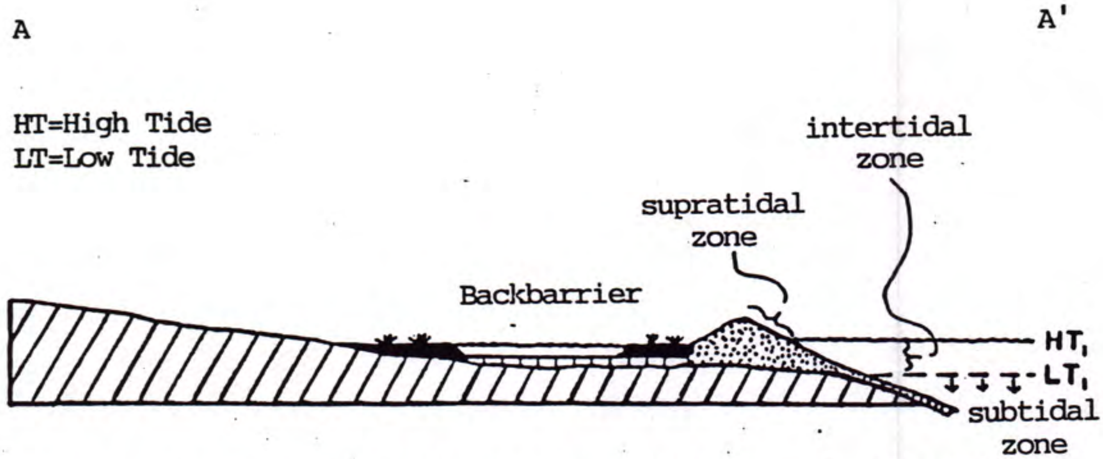


Figure 6-1 Associated sub-environments of a barrier island complex

(1967), Weidie (1968), Davies et al (1971), Leblanc (1971, 1972), Blatt et al (1972), Heckel (1972), Harms et al (1975), Baker (1979), Potter (1979), Reading (1979), Weimer (1979), Hayes (1980), Selley (1980)McCubbin (1982), Laughrey (1985), Imperato et al (1988), Penland et al (1988), and Donselaar (1989). Some of the terms used to refer to the sub-environments of deposition within a barrier island complex are: barrier islands, tidal inlet and tidal channel, sub-, inter-, and supra-tidal zones, lagoon, and marsh. Some of the associated depositional sequences are : back-barrier, inlet-fill, and flood and ebb-tidal deltas.

The terminology adopted, with regard to classification under a depositional model, is that of Reading's (1979), furthered by Frey and Howard (1986). Both Reading and Frey and Howard use the term "estuary". More specifically, Frey and Howard's "riverine estuary" is the term that is perceived to be the best explanation of the environmental setting associated with the Sliverville. Their estuarine model encompasses not only the associated barrier island complex subenvironments, but considers that the upper reaches of a barrier island complex may grade into a fluvatile environment. Therefore, the upper reaches of a riverine estuary may exhibit more fluvatile features inherent in a predominantly uni-directional flow environment and change (transitionally) to a well sorted linear sand sequence, which in the lower reaches is affected by the action of waves, tides, and longshore drift. The prevalence of fluvatile or wave and tide dominated sequences will vary greatly depending upon how far away one is from the lower reaches of the associated river. Frey and Howard propose that an estuary should be elevated to the same hierarchical rank as a delta. The reason being; the estuary is composed of several subenvironments (many of which have been mentioned), but is in its entirety a distinctly recognizable entity.

6.2 Conclusion

The Sliverville Sandstone was deposited in a riverine estuarine environment. The tidal range manifested in the lower reaches of the depositional system was meso-tidal (between 2-4 meters) (Davies, 1964). The deposits are dominated by tidal channel (through inlets) sequences which probably migrated laterally quite a bit. Parts of the depositional system were subaerial while most were in shallow water. The source of sediment was close, supplying coarse-grained sediments and washing plant material and carbon-rich mud from the intervening lagoon into units further offshore. The action of waves, tides, and longshore drift provided the needed mechanisms to winnow fine material and result in a deposit that is predominantly composed of coarse to very coarse-grained sand. The entire Sliverville sequence was then transgressed by the overlying Harrisburgh Run due to a relative rise in sea level.

6.3 Evidence Cited

Certainly no single characteristic or even handful of characteristics can be cited as unequivocally pointing to a riverine estuarine environment. However, assuming that what is seen in the cores and thin-sections are more typical than atypical of the Sliverville's deposits this environment of deposition is preferred. It seems fitting (at this point) to reveal the author's thoughts regarding the documentation of catastrophic storm events in the rock record. Based on the paleogeographical reconstruction of the general study area in Late Devonian time Appalachia and the Catskill shoreline would be located very near the equator. Based on the number of hurricanes and tropical storms that occur in the tropics today (in any given year) and coupled with the fact that the amount of time represented by either of the cores is measured in at least tens of years, if not hundreds, or thousands of years, it seems quite normal that storm-induced floods would manifest themselves during the interval of deposition.

The Sliverville Sandstone is a lenticular sand body oriented Northeast-Southwest as evidenced by a gross sand isolith and cross-sections of the gross sand isolith parallel to strike and dip. Fettke (1941) stated that the strike of the Sliverville parallels the Catskill Sea shoreline. That barrier islands parallel the shoreline has been documented by each author listed under paragraph two of section 6.1.

The dominant sediments seen in both cores are coarse to very coarse, moderately to well-sorted sand-sized quartz with very little feldspar or rock fragments. The lack of feldspar in fluvatile and fluvatile-influenced depositional environments can be an indication of the proximity to the source of sediment. However, in this study it is believed that based on the large size of the quartz sediment seen, the lack of feldspars is likely to be caused by chemical weathering. The study area was located near the equator when deposition took place which imparted a warm and humid climate. This type of climate is conducive to chemical weathering (Grim, 1968) (Gall, 1983). Prevalence of coarse sand and the associated winnowing effects of waves in a barrier island complex is cited by: Reading, 1979; Selley, 1980; Gall, 1983; and Frey and Howard, 1986.

The majority of the sediments are likely tidal channel deposits (with fluvial influence when traced to the upper reaches). The dominance of tidal channel deposits in barrier island complexes due to lateral migration has been documented by: Reading, 1979; Penland et al, 1988; and Donselaar, 1989. Tidal channel identification is characterized by an erosive base (Reading, 1979; Gall, 1983; Penland, 1988; and Donselaar, 1989) which is seen in both cores. Shell and shale-ball lag may also be observed at the base of tidal channel sequences in both cores and has been documented as being indicative of tidal channel basal sequences by: Hayes, 1980; Frey and Howard, 1986; and Donselaar, 1989. Also, what appears to be bidirectional cross-bedding is seen in the T-1 Music Mountain overlaying the more massive units of coarse to very coarse sand. Bi-directional cross-bedding is thought to be characteristic of tidal channel deposits (Reading, 1979), (Hayes, 1980), (Gall, 1983), (Donselaar, 1989) although Penland et al (1988) indicate that due to time-velocity asymmetry, inherent in the tidal cycle, bedding features remain uni-directional, but may be flat-topped due to subordinate current flow.

Furthermore, tidal channel migration imparts a characteristic sequence as the main stream is abandoned and in-filled. A composite of this sequence described by Penland, et al, 1988 is seen by examination of the T-1 Duffey and T-1 Music Mountain cores. This sequence is characterized by (1) shell or shale-ball lag at the base of the erosive channel. Above this sequence are (2) the coarsest sediments deposited in the deepest parts of the channel. This is typically seen as massive quartz. As the channel is abandoned the massive sediments are topped by (3) cross-bedded sand and then by (4) planar bedding as water depth decreases in the area of the old abandoned and in-filling channel.

Flaser bedding is abundant in both cores. Reading, 1979; Gall, 1983; Frey and Howard, 1986; and Penland, 1988 state that an abundance of flaser bedding is indicative of estuarine environments. Flaser bedding is perceived to indicate varying energy levels. Originally, it was thought that any occurrence of flaser bedding was significant;

however, the school of thought has changed to the belief that flaser bedding must comprise an appreciable percentage of the deposits to be indicative of overall energy variability (Frey and Howard, 1986).

Further evidence of a barrier island complex (riverine estuarine environment) is the presence of the lagoonal sequence at the base of the T-1 Music Mountain core. Characteristics of lagoonal sequences in humid climates are documented by: Reading, 1979; Gall, 1983; Frey and Howard, 1986; and Donselaar, 1989. Seen in the T-1 Music Mountain core are black and red shales with occasional interbedded coarse sand (at times only a few grains thick). The muds are bioturbated with a prominence of horizontal to near horizontal orientations. The horizontal nature of the burrows is due to deposit-feeders that seek the organic matter that settles out of the water onto the floor of the lagoon (Gall, 1983). Deposition of fine organic material can only take place in quiet water, which would be the case in a lagoonal setting (Howard, 1975; Gall, 1983). Furthermore, with few exceptions, endofauna needs aerated water and sediments to flourish (Gall, 1983). Therefore, this supports the likelihood that the red coloration is due to oxidizing conditions.

Additional evidence that the basal unit of the T-1 Music Mountain is of lagoonal origin is the lignitic plant fragments (Reading, 1979) (Donselaar, 1989). The material was probably washed in from the upper reaches of the depositional system which would be dominantly fluvatile in nature (Reading, 1979). The statement that part of the depositional sequence was subaerial is based on the close proximity of a supra-tidal environment, inferred by the presence of ripped up mud-cracked material. The supra-tidal zone is that zone of the coast which is only inundated by water during the highest of tides. Except during the period of highest tides the fine material (predominantly mud) is exposed to the atmosphere and desiccation cracks form (Gall, 1983). A storm-induced flood could be the mechanism for inundation of the supra-tidal zone.

Finally, the statement that the tidal range was "meso" is based on the relative size of the overall sand body and the evidence of a high degree of tidal channel migration. Above 4 meters tidal range (macrotidal) barrier islands will not form (Davies, 1964). On the other end of the spectrum of tidal range is "microtidal" which is characterized by a tidal range of zero to 2 meters. The Galveston barrier island is a classic example of a microtidal environment (Leblanc, 1972). The microtidal environment is conducive to very long, narrow barrier islands up to tens or hundreds of kilometers long with usually few tidal inlets. Furthermore, if a tidal channel does exist it remains relatively stable with little lateral migration (Reading, 1979). The evidence seen in this study does not suggest a microtidal environment.

The Sliverville was most likely deposited in a mesotidal environment which is more conducive to a greater number of tidal inlets and shorter sand bodies. The tidal channels are more subject to switching and migrating as a result of the increased tidal affect. The Sliverville is approximately 6.5 kilometers. However, the Sliverville may have been of greater areal extent, but was eroded during transgression.

In a prograding barrier island complex dunes will commonly form on the top of the islands, landward from the beach. However, when a transgressive episode occurs those sections of the barrier island complex which were topographically higher, such as the dunes, are eroded. What is preserved are those areas that are topographically lower, at or below sea-level. These areas would be the back-barrier environments (lagoon, and lower shoreface) and tidal channel deposits. Therefore, in a transgression it is common to see lagoonal sequences topped directly by tidal channel sequences and then by lower shoreface and nearshore marine deposits(Donselaar, 1989). This is what is evidenced by analysis of the cores.

Chapter 7

Estimated Original Oil in Place

Before any secondary recovery efforts may be undertaken, an estimate of original oil in place (OOIP) must be calculated. One way of estimating OOIP requires knowledge of the reservoir drive mechanism. This is not always known, but when it is one can base the estimate of reserves on the volume of oil produced during the field's primary production life. There is enough empirical data from other fields to predict what percentage of original oil in place is routinely produced in primary production. The drive mechanism that is suspected for the Music Mountain field is solution/gas, but this is difficult to verify (Finalle, 1985). In a solution/gas drive reservoir the majority of natural gas is entrenched in the oil; as the fluids are produced the gas expands and imparts this energy to production in the form of pressure. Cumulative primary production from a reservoir such as this ranges from 6-26% of the OOIP.

If one examines the cumulative production of the Music Mountain field tabulated in Appendix H one will find a total of 6,222,640 barrels of oils. If one applies the aforementioned range of primary production: 6,222,640 is 6% of 97,488,026 and 26% of 17,710,590. Therefore, the OOIP may have been between 17,710,590 to 97,488,026 barrels of oil. However, as mentioned, it is not certain that the reservoir is driven by solution/gas. In this case the method to be employed must be the material balance equation (Craft and Hawkins, 1959)(Slider, 1976)(Dake, 1980). The material balance equation is as follows:

7758(O)(1-Sw-Sg)(h)(A)/Bo

where:

7758=Constant=the number of barrels(42 gallons) that could be contained in one acre of space with one foot thickness.

O=Porosity of the reservoir material=percentage of reservoir that is void space.

(1-Sw-Sg)=Oil saturation=Given a total volume of void space being 1, subtract that percentage of void space occupied by water (Sw) and gas (Sg)

Sw=Percentage of pore space occupied by water

Sg=Percentage of pore space occupied by gas

h=Height of the reservoir (thickness) measured in feet

A=Area of reservoir measured in square feet

Bo=Reservoir volume factor=ratio of a given mass of oil at the pressure and temperatures that exist under reservoir conditions to the same mass of oil at standard temperature and pressure (unitless)

To determine original oil in place the values supplied to the material balance equation must represent initial conditions; before production has started. From analysis of the T-1 Duffey and T-1 Music Mountain core an average porosity of 12.6% was calculated. This is expressed in the equation as .126. Stearns et al (1971) calculated an area of 800 acres of the field to possess sufficient porosities, sand thicknesses, and oil saturations to be deemed productive. This figure will be used for area. The average reservoir thickness as determined by Stearns et al (1971) will also be used for this calculation; this number is 25 feet. According to Bradford District personnel, the proper reservoir volume factor for the Music Mountain field is 1.1.(Richmond, 1984). All that is lacking is the value of (1-Sw-Sg), which is the initial oil saturation. However, this can only be estimated because the best method of determining this parameter is by core analysis. The T-1 Duffey and T-1 Music Mountain cores were not taken until 1971, fourteen years after the primary life of the field. Discussions with Pennzoil's Bradford District engineer revealed that original oil saturation is estimated as being between 60 and 80 percent (Finalle, 1984). Therefore, one can substitute the aforementioned values into the material balance equation and then express the equation as a function of oil saturation.

(7758 barrels/acre foot)(.126)(So)(25 ft.)(800 acres)/Bo rewritten as a function of oil saturation:

$$OOIP=17,772(So)$$

Figure 7-1 shows how the original oil in place varies according to initial oil saturation.

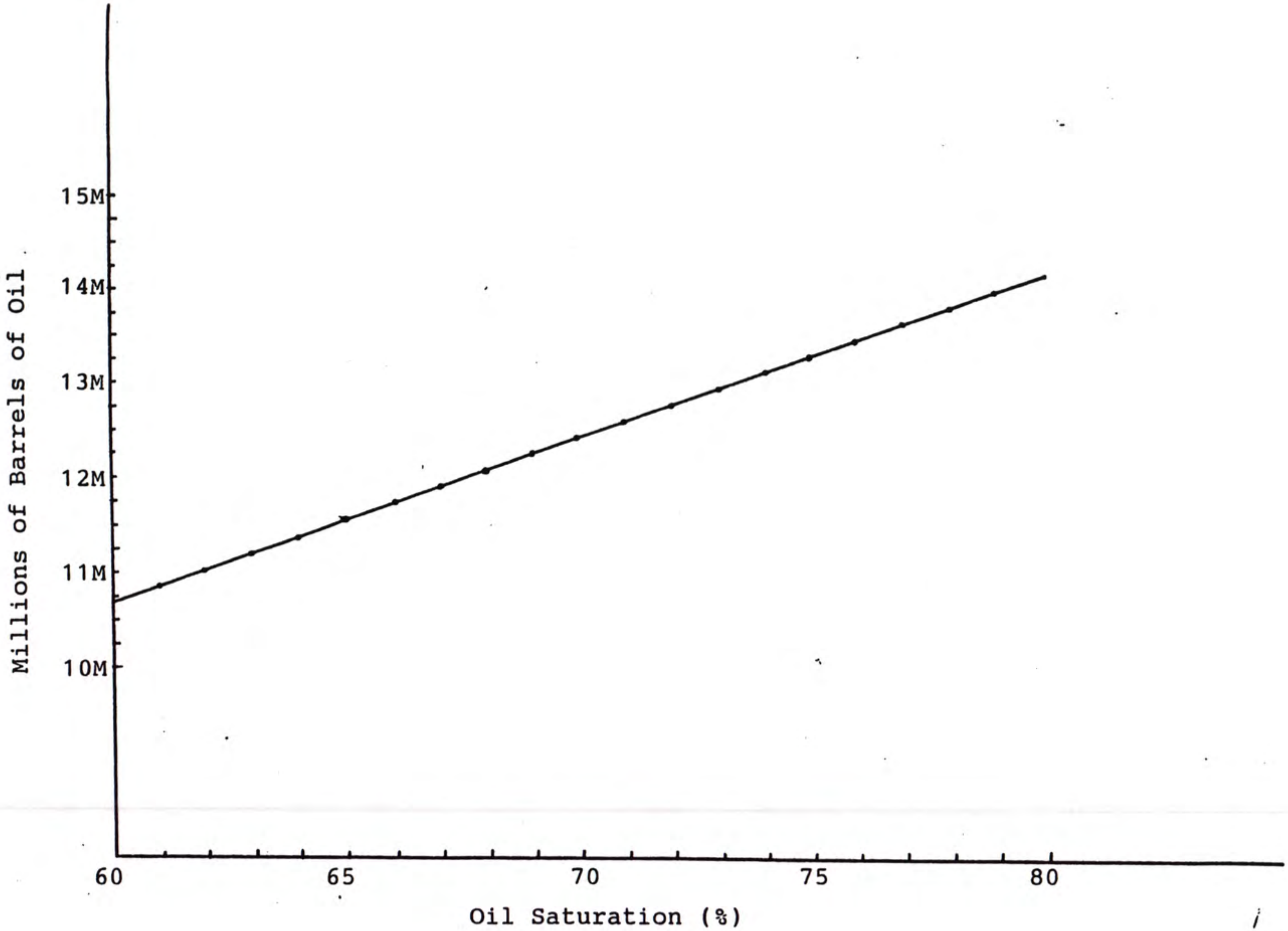


Figure 7-1 Original Oil in Place as a function of oil saturation

Chapter 8

Implications With Regard to Waterflooding

8.1 Economics

The most important consideration with regard to the economic feasibility of waterflooding the Music Mountain Field is the cost associated with re-abandonment of old wells. The other major factor with regard to cost-effectiveness of a waterflood is the market price of oil. At this writing the world market price of oil has oscillated between thirty to forty dollars a barrel for the last two to three months, based on tension mounting in the Middle-East. The price of Pennsylvania crude oil lags somewhat behind the world market level, but only by a few dollars. Given the present value of oil and the fact that the majority of expenses associated with a waterflood operation are incurred at start-up, a new cost-benefit analysis should be completed.

8.2 Design Considerations

Based on the conclusions of this study, it is still not clear where permeability barriers will occur. Permeability barriers that have been identified are shales, silica, and calcite cement. Fortunately, based on thin-section analysis, silica and calcite cement do not constitute a major percentage of intergranular space.

Furthermore, dilute hydrochloric acid would dissolve any calcite. Identification of shales is part of the overall problem as stated by Elicker (1954) of correlation of specific units within the Sliverville. Although it is agreed that field-wide correlation of sand units will be difficult, if not impossible, (knowing the dynamic nature of deposition), correlation over a relatively short distance might greatly be enhanced by running dip-meter logs in wells that would be directly involved in the waterflood system. The dip-meter log will show the dip of the subsurface units and can substantiate or cast doubt on correlation of units based purely on gamma ray or spontaneous potential curve signatures.

A powerful tool has been fashioned by this investigation, the identification of the mechanisms of deposition of the Music Mountain Field. The majority of deposits are coarse to very coarse-grained sand and were likely the result of tidal channel(s) deposition. The tidal channel(s) transported and deposited sediment perpendicular to the strike of the entire field and migrated laterally during time. Therefore, the coarsest sand may be better recognized as sand bodies that trend east-west. The more the tidal channel migrates laterally (north-south) the greater the areal extent of coarse permeable sand. It it quite possible that there is more than one of these isolated sand bodies that represents a tidal channel sequence. This may be what is being seen as thicker zones of gross sand which have a definite dip orientation. It is the author's belief that if analysis indicate waterflooding to be economically viable that the new-found knowledge of depositional dynamics coupled with dip-meter log technology will provide for the best possible waterflood design.

APPENDIX A

Tabulation of Gross Sand

Lot Number or Property	Well	Gross Sand
Mayo	9	16'
	14	31'
	15	31'
	16	0'
Duffey	6	37'
	11	34'
	T-1	96'
Gorton	AG6	45'
	AG8	26'
	AG10	58'
	AG11	35'
	AG12	23'
Hewitt	AH2	6'
	AH4	12'
Lot 44	X-2	17'
	X-3	24'
	X-5	17'
	X-8	28'
	X-9	19'
	X-27	18'
	X-45	23'
	X-72	12'
Lot 56	X-10	24'
	X-13	8'
	X-14	67'
	X-15	48'

	X-16	2'
	X-17	66'
	X-18	19'
	X-24	4'
	X-28	74'
	X-33	30'
	X-47	28'
	X-48	18'
	X-62	61'
	X-64	61'
	X-67	53'
	X-68	62'
	X-69	58'
Lot 2	25	18'
	34	12'
	35	30'
	36	35'
	37	21'
	38	20'
	39	32'
Lot 3	24	36'
Lot 8	4	45'
	6	43'
	7	50'
	9	55'
	17	106'
	21	84'
	22	47'
	27	53'
	31	86'
	33	21'
	35	67'
	36	72'

	44	18'
	55	101'
	64	25'
	69	21'
	70	72'
	71	25'
	72	27'
	73	28'
Lot 218	28	30'
	29	34'
Lot 725	4	57'
	5	33'
	9	82'
	11	43'
	13	33'
	14	58'
	15	29'
	16	11'
	19	26'

APPENDIX B

T-1 Duffey Core Description

1704-1704.5':	Wavy interbedded very fine to fine-graine brown sand and dark gray shale. Shell fragments and signs of bioturbation.
1704.5-1720.5':	Greenish gray and red clay. Some bioturbation, slightly micaceous.
1720.5-1724':	Very fine to fine-grained brown sand, abundant shell fragments, highly bioturbated.
1724-1726.75':	Transition from very fine to fine-grainec brown sand to coarse to very coarse-grained white sand. Approximatel 1/2" cycles of alternating coarse to ver coarse white sand and very fine to fine brown sand.
1726.75':	Erosional contact between overlying sandstone and underlying flaser-bedded unit.
1726.75-1727.75':	Flaser-bedded dark gray shale and coarse white sand.

1727.75-1730.8': Very coarse to conglomeritic white sand. Some quartz pebbles 1/8-1/4" long. Massive.

1730.8-1731': Gray shale.

1731-1735': Coarse to very coarse grained, white sand. Almost no quartz pebbles seen.

1735-1736.5': Fine to medium grained, brown sand with with thin black laminae.

1736.5-1737.25': Gray shale with interbeds of coarse brown sand and some carbonaceous material.

1737.25-1738.25': Medium to coarse-grained brown sand, massive.

1738.25-1740': Gray shale and wavy interbeds of coarse-grained brown sand.

1740-1742': Fine to medium-grained, brown sand.

1740.25-1741': Interbeds of thin black laminae.

1741-1742': No laminae interbeds.

1742.25-1742.35': Dark gray shale.

1742.35-1754.5': Coarse to very coarse-grained, oil-stained sand.

1742.35-1749.75': Massive.

1749.75-1752.5': Cycles (1/2-1") of alternating coarse and very coarse-grained, white sand.

1752.5-1754.5': Coarse to very coarse-grained, massive white sand with gray shale inclusions.

1754.5-1755': Dark shale with some burrows filled with fine-grained, brown sand.

1755-1775': Coarse to very coarse-grained sand.

1755-1765': Massive light gray to brown (probably oil-stained) sand.

1765-1765.25': White sand with wavy and wispy dark gray shale clasts.

1765.25-1766': Massive light gray to brown (probably due to oil stain) sand.

1766-1766.25': White sand with wavy dark gray shale clasts.

1766.25-1775': Light gray to brownish (probably due to oil stain) massive sand.

1775-1775.25': Dark gray shale with interbeds of coarse white sand.

1775.25-1777': Gray to light brown (probably due to oil stain) massive sand.

APPENDIX C

Music Mountain Core Description

1720-1731.5': Planar cross-bedded, light gray to off-white quartz. Cross-bed sets are approximately 1/2-1" thick and are graded. From 1720-1723.5'cross-bed sets grade between medium and coarse-grained sand.

1723.5-1725': Bedding not apparent.

1725-1727.5': Cross-bed sets grade between coarse and very coarse to conglomeritic. Quartz is light gray to off-white.

1725.5': 1/4" dark gray shale.

1727.5-1731.5: 1/2" planar cross-bed sets. Sets grade between coarse to very coarse sand.

1728.2': 1/2" dark gray shale.

1731.5-1738': Coarse to very coarse, massive, light gray to off-white quartz.

1731.5-1732': Wavy green-gray shale inclusions in very coarse white sand. Some quartz pebbles 1/4" long.

1732-1738': Light gray to off-white, coarse to very coarse, massive quartz.

1736.5': 1/2" thick dark gray shale.

1731-1747': Missing.

1747-1753': Coarse to very coarse sand. Light gray to off-white, massive quartz. Stained with oil and/or drilling mud.

1747-1747.3': Dark gray shale.

1748.8': Wavy discolored feature approximately 1/2" thick.

1750.5-1750.75': Dark gray shale.

1751-1751.5': Black wavy, possibly carbonaceous streaks approximately 1/4" thick.

1753-1759': Missing.

1759-1765': Coarse to very coarse (conglomeritic is places), sand. Light gray to off-white quartz.

1760.4-1760.5': Wavy interbedded coarse white sand and dark greenish-gray shale.

1762.6': 1" long milky white quartz pebble.

1763.1-1763.3': Wavy interbedded white, coarse sand and dark greenish-gray shale.

1764-1764.1': Wavy interbedded white, coarse sand and dark greenish gray shale.

1765-1775': Missing.

1771-1775': Coarse to very coarse sand (conglomeritic in places). Massive, light gray to off-white quartz.

1772.3-1773': 1/2" zone of dark brown to black elongated shale inclusions which seem to define a bedding plane at approximately 20-25 degrees to the axis of the core.

1773-1775': Wavy interbedded white, coarse sand and greenish-gray shale.

1775-1776': Parallel-bedded fine and medium sand. Light brown to greenish black in color.

1776-1779': Coarse to very coarse sand, light gray to off-white quartz. One or two sets of bidirectional cross-beds. Each set is graded between medium and coarse sand.

1779-1779.75': Coarse to very coarse sand, massive. Light brown.

1779.75-1783': Light brown medium sand with some quartz pebbles up to 1/8" long.

1781.75': Greenish-gray shale inclusions.

1783-1795': Missing.

1795-1803': Coarse to very coarse sand. Massive, light gray to off-white in color. Some quartz pebbles up to 1/8" thick.

1803-1804': Shale. Color predominantly greenish-gray with 1/32" intervals of black (possibly carbonaceous) material.

1804-1814': Coarse sand to conglomeritic quartz. Massive, light gray to off-white in color.

1804.1': Wavy black clay inclusions which seem to define a bedding plane approximately 35 degrees with the axis of the core. One 1" wide chocolate brown and black shale inclusion.

1810-1812': Wavy chocolate brown and black shale inclusions, lignitic, plant fragments, and sulfur-like residue.

1812-1812.3': Shale. Greenish-gray with 1/8" interbeds of medium sand-sized quartz.

1814-1815.5': Coarse to very coarse, gray to light brown sand. Massive quartz with some quartz pebbles 1/8" long.

1815.5-1819': Shale. Greenish-gray and red. Occasional intervals of coarse white sand with calcite cement.

1819-1825': Missing.

1825-1827.5': Coarse to very coarse, off-white sand with chocolate brown and black shale inclusions.

1827.5-1828.2': Light gray, coarse to very coarse sand with chocolate brown and black shale inclusions.

1828.2-1828.5': Wavy interbedded chocolate brown and black shale and coarse white sand.

1828.5-1830': Brown, medium sand, burrowed.

1830-1832': White coarse sand with black and chocolate brown, wavy and wispy shale inclusions and flakes. Flakes resemble edges of desiccation cracks.

1832-1840.5': Shale. Red and black, burrowed. Burrows sometimes filled with medium to coarse white sand. Also some very thin laminae of medium to coarse white sand interrupts the

shale.

APPENDIX D

Thin-sectioned Intervals

T-1 Duffey Core

Thin-section Designation	Depth
A	1723.0'
B	1724.9'
C	1725.1'
D	1725.7'
E	1726.6'
F	1728.2'
G	1730.2'
H	1732.3'
I	1734.2'
J	1736.1'
K	1738.1'
L	1739.7'
M	1741.0'
N	1743.4'
O	1747.3'
P	1751.5'
Q	1753.6'
R	1756.0'
S	1759.4'
T	1761.1'
U	1765.1'
V	1765.6'
W	1768.5'
X	1770.5'
Y	1773.5'
Z	1774.5'
Z1	1776.8'

T-1 Music Mountain Core

Thin-section Designation	Depth
A	1720.2'
B	1726.3'
C	1736.3'
D	1747.0'
E	1759.6'
F	1773.4'
G	1779.4'
H	1797.7'
I	1825.4'
J	1831.2'
K	1775.6'

APPENDIX E

Mean Grain Size

T-1 Duffey

Thin-section	Millimeters
A	.145
B	.365
C	.170
D	.095
E	.480
F	.525
G	.570
H	.555
I	.550
J	.275
K	.250
L	.245
M	.180
N	.505
O	.515
P	.400
Q	.410
R	.400
S	.495
T	.500
U	.550
V	.525
W	.550
X	.615
Y	.590
Z	.465
Z1	.520

T-1 Music Mountain

Thin-section	Millimeters
A	.556
B	.580
C	.560
D	.445
E	.443
F	.438
G	.185
H	.556
I	.902
J	.273
K	*

* K Not intended to be included in size point-count

APPENDIX F

Thin-section Descriptions

T-1 Duffey

A: Well-sorted, sub-angular to sub-rounded, fine-grained sand quartz. Dominantly quartz grains with rare mica between quartz boundaries. Moderate amount of recrystallized brachiopod shell fragments.

B: Poorly sorted. Sub-rounded to well-rounded, very coarse sand. Very coarse sand as matrix with medium to coarse sand as matrix. Some chert and mica present. Abundant poly-crystalline quartz.

C: Poorly sorted, sub-rounded to well-rounded. Mono-crystalline and poly-crystalline quartz. Dominantly coarse to very coarse sand as framework with medium to coarse sand as matrix, but some calcite cement, also trace chert present.

D: Well-sorted, very fine to fine-grained sand, sub-rounded quartz. Traces of chert, mica, and calcite (as individual grains).

E: Moderately to well-sorted, sub- to well-rounded, coarse to very coarse sand. Matrix and some calcite cement present.

F: Coarse sand to conglomeritic. Moderately to well-sorted. Sub-rounded quartz with some chert and calcite as grains.
Intergranular porosity seen as black under cross-nichols.

G: Poorly to moderately sorted, sub-angular to sub rounded quartz. Medium-grained sand. Fair amount of porosity noted under cross-nichols.

H: Coarse to very coarse grained sand. Poor to moderately sorted, sub-angular to sub-rounded. Dominantly matrix with traces of calcite and silica cement.

I: Coarse to very coarse sand. Moderately sorted, sub-angular to sub-rounded quartz. Trace amounts of calcite and chert grains. Quartz grains are oil-strained. Large amount of inter-granular porosity with small amounts of calcite cement.

J: Well-sorted, sub-rounded quartz. Fine sand-sized, little porosity.

K: Poorly to fairly well sorted, quartz. Sub-rounded oil-stained quartz grains.

L: Poorly sorted, sub-angular to sub-rounded quartz. Abundant calcite cement in a dominantly matrix configuration.

M: Poorly sorted, sub-angular to sub-rounded quartz. predominantly matrix with a trace of calcite cement. Quartz grains are oil-stained.

N: Poorly sorted, sub-angular to sub-rounded quartz. predominantly matrix.

O: Moderately sorted, sub-angular to sub-rounded quartz. High amount of intergranular porosity present.

P: Poorly sorted, sub-angular quartz. Dominantly matrix with a trace of calcite cement.

Q: Poorly sorted, sub-angular quartz. Matrix.

R: Well sorted, sub-rounded to well-rounded quartz. Calcite and silica cement present.

S: Moderately to well sorted, sub-rounded to well-rounded quartz. High degree of intergranular porosity.

T: Moderately sorted, sub-angular to sub-rounded quartz. High degree of intergranular porosity.

U: Moderately sorted, sub-angular to sub-rounded quartz. Some matrix and traces of silica cement present, but primarily intergranular porosity maintained.

V: Moderately to well sorted, sub-rounded quartz. Calcite present as grains and cement.

W: Moderately sorted, sub-rounded quartz. Matrix, calcite cement, and intergranular porosity present in approximately equal amounts.

X: Poorly sorted, sub-rounded quartz. Calcite cement present as well as silica over-growth rings on some quartz grains.

Y: Moderately sorted, sub-rounded quartz. Traces of calcite cement present. High degree of intergranular porosity.

Z: Moderately sorted, sub-rounded quartz. Some silica overgrowth rings present. High degree of intergranular porosity.

Z1: Moderately to fairly well sorted, sub-rounded quartz. High degree of intergranular porosity.

APPENDIX G

Thin-section Descriptions

T-1 Music Mountain

A: Moderately sorted, sub-angular quartz. Trace amounts of calcite grains and calcite cement. Little intergranular porosity seen.

B: Moderately to well-sorted, sub-angular to sub-rounded quartz. Trace calcite as grains and cementing agent.

C: Moderately to well-sorted, sub-angular to sub-rounded quartz. Trace calcite cement. Fair amount of intergranular porosity seen. Vermicular kaolinite abundant on few grains.

D: Moderately to well-sorted, sub-angular to sub-rounded quartz. Little intergranular porosity present.

E: Well-sorted, sub-angular to sub-rounded quartz. Trace amounts of calcite as grains and cementing agent.

F: Moderately to well-sorted, sub-angular to sub-rounded quartz. Trace calcite grains and as as cementing agent. Little intergranular porosity seen.

G: Poorly to moderately-sorted, sub-angular to sub-rounded quartz. Abundant calcite, seen primarily as matrix. Consequently, little intergranular porosity present.

H: Well-sorted, sub-rounded quartz. Good percentage of intergranular porosity. Rare calcite grains, trace silica cement.

I: Moderately-sorted, sub-angular to sub-rounded quartz. Calcite cement abundant. Consequently, little intergranular porosity seen.

J: Poorly-sorted, sub-angular to sub-rounded quartz. Abundant calcite, as grains and primarily as cementing agent. Chocolate-brown mud flakes seen, up to 18 millimeters long and 4 millimeters wide. Little porosity.

K: Distinct laminae of very well-sorted material, primarily quartz, but also laminae composed primarily of mica. Quartz is sub-angular to sub-rounded. Abundant calcite cement. Very little porosity.

APPENDIX H

Production History of Music Mountain Field
(Barrels)

Year	Total	Cumulative
1937	15,477	15,477
1938	40,682	56,159
1939	734,845	791,004
1940	1,308,460	2,099,464
1941	1,047,825	3,147,289
1942	496,574	3,643,863
1943	394,660	4,038,523
1944	322,266	4,360,789
1945	231,749	4,592,538
1946	256,515	4,849,053
1947	294,885	5,143,938
1948	224,015	5,367,953
1949	209,799	5,577,752
1950	161,430	5,739,182
1951	119,871	5,859,053
1952	95,896	5,954,949
1953	83,440	6,038,389
1954	83,579	6,121,968
1955	48,688	6,170,636
1956	28,699	6,199,335
1957	11,213	6,210,548
1958	12,092	6,222,640

Total
6,222,640

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