VOLUME I

GEOLOGIC SUMMARY REPORT
OF THE
1984 EXPLORATION PROGRAM
SUNNYSIDE TAR SANDS PROJECT
CARBON COUNTY
UTAH

FOR

GENE E. TAMPA
DIRECTOR TAR SANDS AND SHALE PROJECTS
AMOCO CORPORATION
CHICAGO, ILLINOIS

BY

WM. S. CALKIN, D.SC.
CONSULTING GEOLOGIST
Golden, Colorado

June 28, 1985
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SUMMARY AND CONCLUSIONS</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>RECOMMENDATIONS</strong></td>
<td>A</td>
</tr>
<tr>
<td><strong>INTRODUCTION</strong></td>
<td>6</td>
</tr>
<tr>
<td><strong>GEOLOGIC SETTING</strong></td>
<td>6</td>
</tr>
<tr>
<td>Location</td>
<td>6</td>
</tr>
<tr>
<td>Access</td>
<td>6</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>7</td>
</tr>
<tr>
<td><strong>LAND STATUS</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>ENVIRONMENTAL CONSIDERATIONS</strong></td>
<td>9</td>
</tr>
<tr>
<td><strong>HISTORY AND PREVIOUS WORK</strong></td>
<td>10</td>
</tr>
<tr>
<td><strong>REGIONAL GEOLOGY</strong></td>
<td>15</td>
</tr>
<tr>
<td>San Rafael Swell</td>
<td>15</td>
</tr>
<tr>
<td>Uinta Basin</td>
<td>15</td>
</tr>
<tr>
<td>Eocene Lake Uinta</td>
<td>16</td>
</tr>
<tr>
<td>Piceance Creek Basin</td>
<td>18</td>
</tr>
<tr>
<td>Southeast Uinta Basin</td>
<td>18</td>
</tr>
<tr>
<td>Western Uinta Basin</td>
<td>19</td>
</tr>
<tr>
<td>Northeast Uinta Basin</td>
<td>19</td>
</tr>
<tr>
<td>Oil and Gas Fields</td>
<td>19</td>
</tr>
<tr>
<td>Sunnyside Area</td>
<td>20</td>
</tr>
<tr>
<td><strong>GEOLOGY OF THE PROJECT AREA</strong></td>
<td>22</td>
</tr>
<tr>
<td>Preview</td>
<td>22</td>
</tr>
<tr>
<td>Structure</td>
<td>22</td>
</tr>
<tr>
<td>Green River Formation</td>
<td>23</td>
</tr>
<tr>
<td>Parachute Creek Member</td>
<td>2A</td>
</tr>
<tr>
<td>Garden Gulch Member</td>
<td>2A</td>
</tr>
<tr>
<td>Douglas Creek Member</td>
<td>26</td>
</tr>
</tbody>
</table>
Table of Contents, Volume I  
(continued)  

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tar Sands</td>
<td>27</td>
</tr>
<tr>
<td>Overview</td>
<td>27</td>
</tr>
<tr>
<td>Depositional Environments</td>
<td>28</td>
</tr>
<tr>
<td>Tar Zones</td>
<td>29</td>
</tr>
<tr>
<td>Base of Tar Sands</td>
<td>30</td>
</tr>
<tr>
<td>Grain Size and Mineralogy</td>
<td>31</td>
</tr>
<tr>
<td>Porosity and Permeability</td>
<td>33</td>
</tr>
<tr>
<td>Shales</td>
<td>34</td>
</tr>
<tr>
<td>Limestones</td>
<td>36</td>
</tr>
<tr>
<td>Fossils and Paleoclimate</td>
<td>37</td>
</tr>
<tr>
<td>Rock Mechanics</td>
<td>41</td>
</tr>
<tr>
<td>DELTAIC ENVIRONMENTS</td>
<td>42</td>
</tr>
<tr>
<td>SUNNYSIDE DELTA COMPLEX</td>
<td>45</td>
</tr>
<tr>
<td>Bruin Point Subdelta</td>
<td>48</td>
</tr>
<tr>
<td>Dry Canyon Subdelta</td>
<td>49</td>
</tr>
<tr>
<td>Whitmore Canyon Subdelta</td>
<td>51</td>
</tr>
<tr>
<td>GEOPHYSICS</td>
<td>53</td>
</tr>
<tr>
<td>Gamma-Density-Caliper</td>
<td>53</td>
</tr>
<tr>
<td>Multi-Channel Sonic</td>
<td>54</td>
</tr>
<tr>
<td>Focused Electric</td>
<td>55</td>
</tr>
<tr>
<td>Neutron</td>
<td>55</td>
</tr>
<tr>
<td>Tar Sand Analysis</td>
<td>56</td>
</tr>
<tr>
<td>Electric Log Interpretation</td>
<td>57</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>61</td>
</tr>
<tr>
<td>APPENDIX</td>
<td></td>
</tr>
<tr>
<td>Photos No. 1 through No. 10</td>
<td></td>
</tr>
<tr>
<td>Figures No. 1 through No. 30</td>
<td></td>
</tr>
<tr>
<td>Tables No. 1 through No. 15</td>
<td></td>
</tr>
</tbody>
</table>
LIST OF PHOTOGRAPHS
(Appendix)

Photo 1  Looking northwest at the Sunnyside delta complex and Bruin Point
2  Looking southeast at the Sunnyside delta complex and Bruin Point
3  Looking northwest at thick tar zones in the proximal portion of the Sunnyside delta complex
4  Looking north at thin tar zones in the distal portion of the Sunnyside delta complex
5  Mini delta model in South Spring settling pond on Range Creek
6  Depositional surfaces and slopes within the mini delta model
7  Drill Core from Zone 35, Garden Gulch Member, Amoco No. 52
8  Drill Core from Zone 36, Garden Gulch Member, Amoco No. 53
9  Drill Core from Zone 37, Garden Gulch Member, Amoco No. 54
10 Drill Core from Zone 38, Garden Gulch Member, Amoco No. 52.
### LIST OF FIGURES
(Appendix)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General Location Map</td>
</tr>
<tr>
<td>2</td>
<td>Detailed Location Map</td>
</tr>
<tr>
<td>3</td>
<td>Tar and Coal Resources near Sunnyside Tar Sands</td>
</tr>
<tr>
<td>A</td>
<td>Land Status</td>
</tr>
<tr>
<td>5</td>
<td>Drill Hole Data of Thermal Tar Sand Tests by Shell Oil Company</td>
</tr>
<tr>
<td>6</td>
<td>Data from Signals Horizontal Wells Asphalt Mine</td>
</tr>
<tr>
<td>7</td>
<td>Structural Divisions of Utah</td>
</tr>
<tr>
<td>8</td>
<td>Geologic Section of San Rafael Swell</td>
</tr>
<tr>
<td>9</td>
<td>Geologic Section of Uinta Basin</td>
</tr>
<tr>
<td>10</td>
<td>Uinta Basin – Geologic Section and Oil and Gas Fields</td>
</tr>
<tr>
<td>11</td>
<td>Geologic Section of Price–Soldier Summit</td>
</tr>
<tr>
<td>12</td>
<td>Paleocene and Eocene Paleogeography of Northeastern Utah</td>
</tr>
<tr>
<td>13</td>
<td>Eocene Time Scale and Generalized Stratigraphic Column in the Uinta Basin</td>
</tr>
<tr>
<td>14</td>
<td>Relationship of bitumen content and compressive strength in sandstones, Sunnyside tar sands</td>
</tr>
<tr>
<td>15</td>
<td>Classification and characteristics of deltaic depositional systems</td>
</tr>
<tr>
<td>16</td>
<td>Conceptual models of environmental facies associated with prograding delta systems</td>
</tr>
<tr>
<td>17</td>
<td>Conceptual models of environmental facies associated with transgressive delta systems</td>
</tr>
<tr>
<td>18</td>
<td>Morphologic features of Mississippi River Subdeltas</td>
</tr>
<tr>
<td>19</td>
<td>Chronological and morphological development of Cubits Gap Subdelta, Mississippi River delta</td>
</tr>
<tr>
<td>20</td>
<td>Diagrams of a Delta Complex</td>
</tr>
<tr>
<td>21</td>
<td>Sections of distributary mouth bars, Mississippi River delta</td>
</tr>
<tr>
<td>22</td>
<td>Depositional model for reworked deltaic sands, Mississippi delta system</td>
</tr>
<tr>
<td>23</td>
<td>Idealized section of Bruin Point subdelta showing tar zones and depositional environments</td>
</tr>
<tr>
<td>24</td>
<td>Idealized section of Dry Canyon subdelta showing tar zones and depositional environments</td>
</tr>
<tr>
<td>25</td>
<td>Contour map of the base of the Sunnyside Tar Sands, Utah</td>
</tr>
</tbody>
</table>
List of Figures, Volume I
(continued)

Figure 26  Theoretical Sedimentation patterns recognized from SP curve shapes

27  Summary diagrams of meander point bar deposits and their major characteristics

28  Summary diagrams of distributary/channel mouth bar deposits and their major characteristics

29  Summary diagrams of bay-fill deposits and their major characteristics

30  Summary diagrams of lacustrine delta fill deposits and their major characteristics
## VOLUME I

### LIST OF TABLES
(Appendix)

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average Value from Deep Drill Holes, Sunnyside Tar Sands</td>
</tr>
<tr>
<td>2A</td>
<td>Total Depth and Member Data of 1980</td>
</tr>
<tr>
<td>2B</td>
<td>Total Depth and Member Data of 1981</td>
</tr>
<tr>
<td>2C</td>
<td>Total Depth and Member Data of 1982</td>
</tr>
<tr>
<td>2D</td>
<td>Total Depth and Member Data of 1984</td>
</tr>
<tr>
<td>3A</td>
<td>Tar Sand Data of 1980</td>
</tr>
<tr>
<td>3B</td>
<td>Tar Sand Data of 1981</td>
</tr>
<tr>
<td>3C</td>
<td>Tar Sand Data of 1982</td>
</tr>
<tr>
<td>3D</td>
<td>Tar Sand Data of 1984</td>
</tr>
<tr>
<td>4A</td>
<td>MSAT Thickness in Members, Data of 1980</td>
</tr>
<tr>
<td>4B</td>
<td>MSAT Thickness in Members, Data of 1981</td>
</tr>
<tr>
<td>4C</td>
<td>MSAT Thickness in Members, Data of 1982</td>
</tr>
<tr>
<td>4D</td>
<td>MSAT Thickness in Members, Data of 1984</td>
</tr>
<tr>
<td>5A</td>
<td>Status of Drill Holes - 1980 and 1981 Data Base</td>
</tr>
<tr>
<td>5B</td>
<td>Status of Drill Holes - 1982 Data Base</td>
</tr>
<tr>
<td>5C</td>
<td>Status of Drill Holes - 1984 Data Base</td>
</tr>
<tr>
<td>6</td>
<td>Direct and Indirect Methods of Tar Sand Analysis on Tar Zones in Amoco No. 17</td>
</tr>
<tr>
<td>7</td>
<td>Porosity and Fines of Tar Zones in Amoco No. 17</td>
</tr>
<tr>
<td>8</td>
<td>Analysis of Entrapped Gas from Amoco No. 9 and No. 11</td>
</tr>
<tr>
<td>9</td>
<td>Bruin Point Pilot Mine Outcrop AREA - Traverse Data</td>
</tr>
<tr>
<td>10</td>
<td>Correlations of Lithology and Typical Geophysical Responses, Sunnyside Tar Sands</td>
</tr>
<tr>
<td>11</td>
<td>General Rock Properties Associated with Environments of Deposition</td>
</tr>
<tr>
<td>12</td>
<td>Lithology Within the Sunnyside Delta Complex and Subdeltas</td>
</tr>
<tr>
<td>13</td>
<td>Idealized Tar Zone Data Sunnyside Tar Sands</td>
</tr>
<tr>
<td>14</td>
<td>Tar Zone Data in Bruin Point Subdelta Based on Lithology and Stratigraphy</td>
</tr>
<tr>
<td>15</td>
<td>Tar Zone Data in Dry Canyon Subdelta Based on Lithology and Stratigraphy</td>
</tr>
</tbody>
</table>
VOLUME II

LIST OF MAPS

Land Map (scale 1 in. = 2,000 ft.)
  Leasehold Ownership
  Surface Ownership
Tar Sand Isopach Map (scale 1 in. = 2,000 ft.)
Regional Map (scale 1 in. = 2,000 ft.)
Geologic Map North Half (scale 1 in. = 500 ft.)
Geologic Map South Half (scale 1 in. = 500 ft.)
Survey Control Map (scale 1 in. = 500 ft.)
Geologic Baseline Strike Sections (scale 1 in. = 500 ft.)
  10,000-20,000 NW
  20,000-29,000 NW
  29,000-36,000 NW

Geologic 4,000 NE Strike Sections (scale 1 in. = 500 ft.)
  20,000-29,000 NW
  29,000-36,000 NW

Geologic Dip Sections (scale 1 in. = 500 ft.)
  18,000 NW
  22,000 NW
  26,000 NW
  28,000 NW
  32,000 NW
### Measured Section

<table>
<thead>
<tr>
<th>No. 18</th>
<th>No. 19</th>
<th>No. 20</th>
<th>No. 21</th>
<th>No. 22</th>
<th>No. 23</th>
<th>No. 24</th>
<th>No. 25</th>
<th>No. 26</th>
</tr>
</thead>
</table>

### Amoco Drill Hole

| No. 49 | No. 50 | No. 51, gamma-density-caliper log, focused electric log | No. 52 | No. 53 | No. 54, gamma-density-caliper log, focused electric log | No. 55 | No. 56 | No. 57 | No. 58 | No. 59 | No. 60 | No. 61 | No. 62 | No. 63, gamma-density-caliper log, focused electric log |
SUMMARY AND CONCLUSIONS

The Sunnyside Tar Sands are located within the southwest portion of the Uinta Basin and are localized within a small delta complex that formed in Lake Uinta during Eocene time. The essence of the Sunnyside Tar Sands deposit is a stacked sequence of laterally continuous bituminous sandstone deposits alternating with red, green or gray shales. Amoco controls some seventy percent of the mineable tar sands within the entire Sunnyside deposit. Within the southern area the tar sands are mainly centered on the Amoco-Kaiser tract. Within the northern area the tar sands are largely localized within the Amoco hydrocarbon leases.

The Sunnyside Tar Sand deposit represents a wedge of bituminous sandstones that exist in an eight mile long and two-three mile wide area shown on the Tar Sand Isopach Map. The tar sands are localized within five to fifteen separate zones. The tar zones are thickest near the Roan Cliff face and thin downdip. These saturated zones are mainly sandstone deposits that range in thickness from 10-133 feet and contain bitumen that ranges from 5-13 weight percent or 12-32 gallons per ton. The general altitude of the sedimentary beds is N25-40 W with a dip of 5-7 NE. Examination of Photos 1 through 4 will help to comprehend the geology and the geometry of the Sunnyside Tar Sand deposit.

The lithology of the Sunnyside Tar Sand deposit consist of sandstones, siltstones, shales, limestones, and local thin conglomerates. The sandstones are well-saturated above the paleo oil-water interface. The fine grained to very fine grained sandstones are well-sorted with porosities of 25-30 percent. The sandstones formed in distributary channel, distributary mouth bar and beach to beach bar deposits. The siltstones commonly represent levee deposits and contain moderate to streaky saturation. Shales are nonsaturated except for fractures coated with bitumen in areas adjacent to tar zones. Red shales commonly formed in marsh environments, green shales commonly formed in shallow water depths of nearshore environments and gray shales commonly formed in moderate water depths of lacustrine environments. The limestones formed in shallow nearshore environments and contain irregular saturation with highly saturated algal and ostracodal zones. The local thin conglomerates contain nonsaturated siltstone or limestone pebbles in a saturated sandstone matrix. Various aspects of the lithology are summarized in Table 11. Drill core is shown in Photos 7 through 10.

The Sunnyside Tar Sand deposit exists within the Green River Formation. Three members of the Green River Formation are well-exposed along the Roan Cliffs and define the dominant environments of deposition associated with the Sunnyside delta complex. From oldest to youngest or bottom to top these are the Douglas Creek Member, Garden Gulch Member and Parachute Creek Member as seen in Figure 23.
The Douglas Creek Member represents the delta facies and within the southern (Amoco-Kaiser Tract) area contains the principal bituminous sandstones with intervening red shales. The Douglas Creek Member contains distributary channels and marshes of the delta plain and distributary mouth bars of the delta environments. Within the Bruin Point subdelta the Douglas Creek Member averages almost 500 feet thick to the base of the tar sands.

The Garden Gulch Member represents the shore facies and within the northern (Hydrocarbon Lease) area contains the principal bituminous sandstones with intervening green shales. The Garden Gulch Member contains distributary channels, distributary mouth bars and beach to nearshore bars of the delta and lacustrine environments. Tar sands, green shales and limestones characterize the Garden Gulch Member. Garpike fish scales, ostracods and algal limestones are common features. The average drilled thickness of the Garden Gulch Member is about 500 feet.

The Parachute Creek Member is the lake facies and contains limited tar sands, laminated gray shales and thin bedded deposits of the outer delta front and prodelta environments of deposition. The Parachute Creek Member has an average drilled thickness of 150 feet.

The Sunnyside delta complex has been defined on the basis of lithology and biota in the Douglas Creek, Garden Gulch and Parachute Creek Members. The Douglas Creek Member represents the delta facies. The Garden Gulch Member represents the shore facies. The Parachute Creek Member represents the lake facies. The Sunnyside delta complex contains fluvial, delta, beach and nearshore deposits that formed forty to fifty million years ago near the margin of ancient Lake Uinta. The major channels of the delta complex flowed toward N40-70 E. The Sunnyside delta complex is interpreted to be seventy-five percent fluvial dominated and twenty-five percent wave dominated. Based on the distribution of tar sands the Sunnyside delta complex has been divided into three separate areas that include the Bruin Point, Dry Canyon and Whitmore Canyon subdeltas as seen on the Tar Sand Isopach Map.

The Bruin Point subdelta contains about seventy percent of the mineable tar sands within fifteen numbered tar zones and is located in the southern (Amoco-Kaiser Tract) area. Within the Bruin Point subdelta the tar sands are mainly confined to the Douglas Creek Member or delta facies, have intervening red shales, and consist of distributary channels and distributary mouth bars. The Amoco data base within the Bruin Point subdelta contains 5551 feet of measured sections and 17,725 feet of core from deep vertical drill holes. Deep drill holes average 1086 feet.
The Dry Canyon subdelta contains about twenty-five percent of the mineable tar sands within eleven numbered tar zones and is located in the northern (Hydrocarbon Lease) area. Within the Dry Canyon subdelta the tar sands are mainly confined to the Garden Gulch Member or shore facies, have intervening green shales, and consist mainly of distributary mouth bars and beach bars. The Amoco data base in the Dry Canyon subdelta contains 15,966 feet of measured sections and 17,835 feet of core from deep vertical drill holes. Deep drill holes average 622 feet. The Dry Canyon subdelta has 8.5% more bituminous sandstone and 7.1% less shale than the Bruin Point subdelta.

The Whitmore Canyon subdelta contains about five percent of the mineable tar sands within four or five tar zones. Surface and subsurface data on the Whitmore Canyon subdelta is limited but suggests a transitional area of nearshore to lower delta plain.

6. Drill core and direct methods of tar sand analysis will always be necessary for reliable and definitive results of bitumen content within and peripheral to the Sunnyside Tar Sand deposit.
RECOMMENDATIONS

Control of all mineable tar sands within the Sunnyside Tar Sand deposit would be beneficial to project development. Amoco presently controls about seventy percent of the mineable tar sands. Other important areas of mineable tar sands exist in land controlled by GNC Energy Corporation, Mono Power and NOL. GNC controls important ground in the SE/4, section 29, T.13S., R.14E; the fee land of Crosby, St. Mary’s Parish; and a 5/6 interest in the Gibbs Heir Tract. Mono Power controls important ground in S/2, S/2 of Section 34, T.13S., R.14E. Additional important ground exists in the NOL area located in the SE/4, SE/4 of Section 33, T.13S., R.14E. Continued efforts should be made to acquire these mentioned areas.

Drilling programs, mining evaluations and geology studies should continue on a timely basis within and outside the mineable tar sands. Additional work inside the tar sand deposit will delineate the limits of the north area pilot mine and establish higher levels of confidence in the correlation and lateral continuity of the numbered tar zones. Work outside the mineable tar sands will establish grade and thickness of tar sands within the hydrocarbon leases, and this data can be utilized in condemnation procedures. In 1986 a two to three month exploration program should be completed. This program should include drilling of two 100 foot deep holes in the north area pilot mine and extensive field work in the peripheral areas. This geology field work will delineate the tar sands, establish drill hole locations and estimate drill hole depths for future drilling. Drill site inspection by the BLM and the archeologist can be completed during the 1986 field season in preparation for the necessary permits. An extensive drilling program in 1988 should complete all condemnation drilling in peripheral areas of hydrocarbon leases. In 1990 an extensive drilling program should be completed within the mineable tar sands to obtain all data necessary to finalize pilot mine and pre-mining programs.

Within the mineable tar sands additional work should be completed to determine the magnitude of any grade changes within numbered tar zones along depositional strike and depositional dip. A cut-off grade of 7-8 gallons per ton should be investigated as it represents a natural geological and visual limit. A cut-off grade of 7-8 gallons per ton would increase total reserves and include moderate grade bituminous sandstones and siltstones that exist in the upper and lower boundaries of numbered tar zones.

Direct tar sand analysis of drill core by Core Labs should continue as it gives the most reliable and consistent results of bitumen content. Indirect tar sand analysis by BPB Instruments is not a viable alternative because tar zones above the water level cannot be analyzed and the range of percent error is too large for reliable grade calculations. In 1984 ten deep drill holes had an average water level of minus 267 feet. The percent error between the direct and indirect methods ranges from +38.9% to -14.7% with a weighted average error of +1.2%. 
In future drilling only two geophysical logs should be utilized. The two most critical geophysical logs are the focused electric and gamma-density-caliper. These two logs should continue to be utilized on all drill holes within and outside the Sunnyside Tar Sand deposit. The two least beneficial geophysical logs are multi-channel sonic and neutron. Multi-channel sonic logs were run to obtain a data base for rock mechanics. The data base accumulated in 1981, 1982 and 1984 is considered to be adequate. The neutron log was run solely to evaluate the indirect method of tar sand analysis and is no longer necessary information.
INTRODUCTION

The 1984 Sunnyside exploration program consisted of: (1) diamond drilling of fifteen drill holes, (2) logging of all core and (3) additional geological mapping in the north area to better define the limits of the tar sands associated with the Sunnyside delta complex. Both regional and detailed geological studies were completed in order to comprehend the geometry of the Sunnyside Tar Sands deposit.

As in previous programs columnar sections or strip logs were compiled from the exploration results. The new twenty-four strip logs are included in Volume III and represent nine measured sections completed in the north area, ten deep drill holes completed in or near the north area and five shallow pilot mine drill holes completed near the Arco water tank. During the compilation of these twenty-four columnar sections detailed stratigraphic analysis established major and minor environments of deposition that defined various aspects of the Sunnyside delta complex. The numbered tar zones in all drill holes and measured sections were correlated throughout the delta complex. These numbered tar zones appear on the new strip logs as well as the updated geologic maps and cross sections. The use of these numbered tar zones (i.e. Zones 11, 21, 23, 25, 26, 31, 33, 35, 36, 99, 37, 38, 41, 42, 43, and 45) throughout the delta complex has led to a better comprehension of the Sunnyside Tar Sand deposit. The scope of this report represents a compilation of the geological studies of the delta complex at the Sunnyside Tar Sands Project completed during 1980-1984.

GEOGRAPHIC SETTING

LOCATION

As seen from Figure 1, the Sunnyside Tar Sands Project is located in north-eastern Utah about 120 airline miles southeast of Salt Lake City and 25 airline miles east of Price, Utah. Price is the nearest commercial center to the project and located about 35 road miles from the project area. As seen from Figure 2, the Sunnyside Tar Sands Project lies about 5 miles northeast of Sunnyside and is centered on section 2 and 3 (Amoco-Kaiser Tract), T.14S., R.14E., Salt Lake Meridian, Carbon County, Utah. The first set of sparsely vegetated cliffs near Sunnyside are known as the Book Cliffs, while the second set of moderately vegetated cliffs near Bruin Point are known as the Roan Cliffs. The Amoco-Kaiser Tract is located in the Roan Cliffs at the headwaters of Range Creek and at elevations between 9,000-10,000 feet. The Roan Plateau exists to the northeast of the project area.

ACCESS

General access to Price is via Salt Lake City, Utah or Grand Junction, Colorado. Access to the project from Price or Green River is via U.S. Route 6 to State Route 123 to East Carbon City and Sunnyside. As seen from Figure 2, final access from Sunnyside is over 5 miles of dirt road via Whitmore Canyon and Water Canyon to the Asphalt Mine. From the Asphalt Mine to Bruin Point a four-wheel-drive vehicle is usually required. The yearly rainfall is some 12-
15 inches at Sunnyside and approaches 30-40 inches at Bruin Point. Access during the spring is hampered by heavy snowfalls and during late summer by occasional rains. During the summer and early fall the road conditions on the property are generally good, but mobility on top is directly related to rainfall as the limey shales of the Parachute Creek Member that commonly exist on the top of the Roan Cliffs usually turn to slick mud after two days of wet weather. In 1980 the drilling was completed by mid-October without encountering any significant weather problems. In 1981 drilling was terminated in mid-October with two feet of snow on the ground. In 1982 the drilling was completed just before considerable rain and snow arrived in late September. In 1984 the drilling was completed by early September and encountered no significant weather problems.

**INFRASTRUCTURE**

The Sunnyside Tar Sands project is well-located to various facilities. Price is the local commercial center for the numerous coal mines and power plants in the Castle Valley. Salt Lake City is about 140 miles by road. Carbon County has a population of about 25,000. Price is the county seat and has a population of about 8000-10,000. Price has commercial railroad facilities with nearby Helper as a major depot on the line of the Denver and Rio Grande Railroad from Denver to Salt Lake City. A major spur of this railroad goes to Sunnyside to service the Sunnyside coal mines of Kaiser Steel Corporation. The Sunnyside coal mines produce 750,000 to 1,400,000 tons/yr of coking coal. Most of this labor force lives in East Carbon City which is located about 1 mile west of Sunnyside. Figure 3 shows the numerous coal mines in the Castle Valley. In the western and northern part of the Castle Valley power plants exist at Castlegate, Hiawatha, Huntington and Castle Dale. A methane recovery process is in progress at the Sunnyside coal mines. Local water supplies on the Amoco-Kaiser Tract produce the drill water necessary for the drilling rigs.

**LAND STATUS**

The land status of the area encompassing and surrounding the Sunnyside Tar Sands is shown on Figure 4. The heart of the Sunnyside Tar Sands deposit is within the Amoco-Kaiser Tract located in Sections 2 and 3 of T.14S., R.15E. as shown on Figure 4. This tract is sometimes referred to as the Kaiser Tract. The land within all of Section 2 and 75 percent of Section 3 (SW% excluded) of T.14S., R.14E. encompasses approximately 1,120 acres and was owned in fee by Kaiser Steel Corporation. Standard Oil Company (Indiana) completed purchase of this land from Kaiser Steel Corporation in 1979. Amoco Corporation now wholly owns the surface, water and mineral rights (except for coal) on this tract. Important additional tar sands exist to the west, north and south of the Amoco-Kaiser Tract.
Adjacent portions of tar sands exist to the west within parts of Section 4 near the Asphalt Mine. This land is owned in fee, by Crosby Corporation and by St. Mary's Parish Land Company. Crosby Corporation is a small group from Salt Lake City, while St. Mary's Parish Land Company is a Louisiana based firm with substantial oil and gas interests reportedly controlled by Congden and Carey of Denver, Colorado. The eastern 75 percent of Section 4 and the small unlabelled tract to the north in Section 33 have been leased by Crosby-St. Mary's to Great National Corporation, a Texas firm principally involved with coal mining in Oklahoma. In 1982 Standard Oil Company of California (Chevron) entered into a joint venture agreement with GNC Energy Corporation (formerly Great National Corporation) to develop the tar sands controlled by GNC. In 1983 Chevron dropped its joint venture agreement with GNC Energy Corporation.

Adjacent portions of tar sands exist to the north within parts of T.13S., R.14E., including Sections 20, 21, 28, 29, 32, 33 and 34. Amoco is the principal lessee of U.S.A. Oil and Gas property within Sections 20, 21, 28, NE/4 29, N 3/4 33, and NE/4 34. These oil and gas leases have now been converted into combined hydrocarbon leases.

Adjacent portions of tar sands exist to the south within parts of Sections 3, 10, and 11. The SW 1/4 of Section 3 and the area of interest in Section 10 are controlled by nine individual heirs of two parties known as Gibbs Heirs. Amoco Production controls a 16 2/3 percent interest within the Gibbs Heir Tract; GNC Energy controls a 60 percent interest; Sabine Corporation controls a 18 1/3 percent interest; and the remaining 5 percent is held by one of the heirs. The southeastern most portion of the Sunnyside Tar Sands lies beneath the Sunnyside Municipal Watershed in Sections 11, 12, 13 and W 1/2 of 10. This watershed was established by U.S. Public Law and is under the jurisdiction of the BLM office in Price. However, Mono Power has oil and gas leases within this watershed.

For clarity in the field the land status map of Figure 4 was enlarged to 1 inch equals 2,000 feet and is of the same scale as the Regional Map. The road from the Asphalt Mine to Bruin Point is an unmaintained county designated road with grades of 15-20 percent.
ENVIRONMENTAL CONSIDERATIONS

The Sunnyside Tar Sands project is located at elevations between 9,000 and 10,000 feet and at the headwaters of both Range Creek and Dry Creek. Range Creek is the home of local trout fisheries. Both Range Creek and Dry Creek flow to the Green River that is located nineteen miles due east of Bruin Point. This portion of the Green River exists within the proposed/designated Desolation Canyon Wilderness Area. A large area on the east side of the Green River contains the Uintah and Ouray Indian Reservation.

The project area is located immediately north of a large portion of the Sunnyside Municipal Watershed, and a small portion of this watershed is centrally located within the project area as seen on the Land Status Map (scale 1" = 2,000 feet). The Sunnyside Municipal Watershed was established by the U.S. Congress in 1920 or 1921 for the City of Sunnyside. The U.S. Steel and Kaiser Steel Companies with branch offices located in Sunnyside are currently endeavoring to transfer their 50-50 ownership rights on the Grassy Trail Reservoir located in Whitmore Canyon over to the City of Sunnyside.
HISTORY AND PREVIOUS WORK

1892
First small quarry operation mined 1,000 tons for street paving in Salt Lake City. Quarry located near 18,000 NW, 6,000 SW of baseline system on Geologic Map South Half, Scale 1" = 500 feet.

1902-1903
Another 1,000 tons of rock removed from small quarry.

1913
Utah Asphalt Company opens Asphalt Mine and shipped 2,000 tons between June-October. Asphalt Mine located near 17,500 NW, 2,500 SW of baseline system on Geologic Map South Half, Scale 1" = 500 feet.

1916 or 1917
Utah Asphalt Company closes operations having shipped 3,000 tons from quarry.

1925-1927
Utah Rock Asphalt Corporation builds aerial tramway operated by gravity and reopens Asphalt Mine in 1927. The aerial tramway was designed and made by American Steel and Wire Company of New York-Chicago-Boston.

1927-1931
Utah Rock Asphalt Corporation quarried 25,000-30,000 tons from the Asphalt Mine. The rock was transported to Whitmore Canyon by the three mile long aerial tramway system (still standing) and then by another tramway system (dismantled) to the processing site located near the terminus of the present railroad spur.

1931-1945
Rock Asphalt Company of Utah maintains yearly seasonal quarry work and removes 300,000 tons of rock used for paving within Utah and Colorado. The yearly output in 1945 was 20,000-30,000 tons.

1948
Rock Asphalt Company of Utah ceases mining operations.

1948
U.S. Geological Survey, Oil and Gas Map 86 states reserves total 1,600,000,000 cubic yards measured or indicated and 700,000,000 inferred.

1956
Gulf completes one cored drill hole to depth of 2,685 feet about 4 miles northeast of the Asphalt Mine.

1963 or 1964
Arco contracted Himes Drilling Company of Grand Junction, Colorado and completed five cored drill holes one to three miles north to northeast of the Asphalt Mine. The available data from these holes is very limited.

1964
Phillips Petroleum Company completed three drill holes. One hole is two miles northeast of the Asphalt Mine and the other two holes are four to five miles north of the Asphalt Mine. No drill data is available on these three holes.
1964-1966 Pan American completed regional work including four field measured sections and completed two cored drill holes two to four miles east and southeast of the Asphalt Mine (see Regional Map, Scale 1" = 2,000 feet).

1963-1966 Shell Oil Company completed six regional drill holes with two cored holes in Kaiser Steel's Tract. In-situ steam injection experiments were performed within Kaiser Steel's Tract. Three of the regional drill holes exist five to six miles southeast of the Asphalt Mine and one regional drill hole exists three miles north of the Asphalt Mine (see Regional Map, Scale 1" = 2,000 feet for specific location). Copies of drill logs and core analyses from these six holes are in the project files.

South of Bruin Point and about 800 feet east of the main communications building a steam flooding project was attempted by Shell Oil Company from a large open pad area.

The map in Figure 5 shows the location of six steam injection holes. One of these holes is Shell No. 2. The in-situ steam injection experiments consisted of steam soak and steam drive tests (Thurber and Welbourn, 1977). The tests were unsuccessful due to an extensive vertical fracture system and the inability to inject steam into the rock matrix.

The vertical fracture system has a fracture frequency of one fracture/four feet with a direction of EW to N70 W. The cross section in Figure 5 illustrates the geometry of the soak and drive intervals. As seen from the columnar section Shell drill hole No. 2 (Calkin, 1982), a major channel deposit exists from 725 to 945 feet and this channel deposit is also represented by the electric logs shown in Figure 5.

The steam soak tests were conducted during the first summer only. The tests consisted of eight day soak periods with eleven and eighteen day production cycles. The steam soak tests produced only trace amounts of viscous oil.

The steam drive tests were conducted during two summers and were designed to close vertical fractures and induce horizontal fractures. During the drive tests the drive interval in P-3 was the most sensitive to temperature and production but only produced 0.5 BOPD.

1965 Texaco completed three cored drill holes three to four miles north and northeast of the Asphalt Mine. Strip logs are available and within the project files.

1965 Mountain Fuels completed one drill hole five miles north of the Asphalt Mine. No lithologic data are available.
1965-1966

Signal Oil and Gas Company of Los Angeles, California drilled cored hole Sunnyside No. 1 (T.D. 1450') and performed in-situ steam injection experiments. Signal Sunnyside No. 1 was cored from 395-1450 feet. Geophysical logs on the hole consist of one induction electric log and two formation density logs.

Note: For the 1981 report the limited available lithologic and core analysis data was used to make a columnar section, and copies of the geophysical logs were not available.

The in-situ steam injection experiments were performed in the Asphalt Mine. Three parallel horizontal test wells oriented N32°W with T.D.'s of 366-390 feet exist in the north-west wall of the main pit. Some of the lithologic and saturation data from these wells is shown in Figure 6.

The purpose was to produce oil by application of steam. A five day huff and puff test on the center well (#101) injected 142,800 lbs. steam and produced no oil. From September 16 through November 1, 1966 the two outside wells (#102, #103) were used for steam injection with the center well (#101) used as a production well. Steam was injected at 510 psi and 470 F. A total of 4.84 million pounds steam (4,671 MM Btu) was injected. Total production from well #101 was 560 barrels of net crude and 10,000 barrels of water. The value BBL OIL divided by MM BTU injected is 0.12 (data from Glassett et al., 1978).

1977-1978

Amoco Production completed five cored drill holes in 1978 (No. 2, 3, 5, 6, 7) and started holes No. 1 and No. 4 within Sections 2 and 3. Amoco Production completed 6,304 feet of core drilling. This program was documented by a written report and maps by B.R. Wilson and G. Ziemba, March 1977, and memorandum FR-06-79 by T.L. Burgett with 5 maps by T.L. Burgett and D.A. Sawicki.

1979

Great National completed five cored holes that totalled 2894 feet. These holes were drilled along the Bruin Point road and within the Asphalt Mine. All holes are located within St. Mary's Parish-Crosby Corp. fee land. The location of these drill holes is shown on the Geologic Map South Half (scale 1" = 500'). Additional data from the drilling are shown on the Regional Map (scale 1" = 2000').

1979

Standard Oil Company (Indiana) completed purchase from Kaiser Steel for NE 1/4, SE 1/4 and NW 1/4 of Section 3 and all of Section 2, T.14S., R.14E.
1980 From mid-June to early October Amoco Minerals completed six cored drill holes (No. 1, 4, 8-11) within Sections 2 and 3. Amoco Minerals completed 6,733 feet of core drilling and utilized two Longyear 44 rigs. Geophysical logs were made by Century Geophysical Corporation on Amoco Nos. 4, 5, 8-11 and indicate significant correlation of lithology with saturated sands. Six measured sections were completed and totalled 6,437 feet. Additional data from the drilling is shown in Tables 2A, 3A, and 4A. The current status of the drill holes is shown in Table 5A.

1980 Great National completed eight cored drill holes that totalled 8922 feet. Six of the eight cored holes are located within the Bruin Point subdelta and two of the eight cored holes are located within the Whitmore Canyon subdelta. Five of the cored holes are near the Amoco-Kaiser Tract. One cored hole was drilled about three miles southeast of the Asphalt Mine within the Sunnyside Municipal Watershed and was drilled without obtaining permission from the BLM. The last two cored holes are located in the Whitmore Canyon subdelta three to five miles northwest of the Asphalt Mine. The location of all these drill holes is shown on the Regional Map (scale 1" = 2000') and most are also shown on the Geologic Map South Half (scale 1" = 500').

1981 From mid-June to mid-October Amoco Minerals completed fifteen cored drill holes (Amoco Nos. 12-26) for a total of 10,796 feet. Three Longyear 44 rigs were used. Five vertical shallow pilot mine holes totalled 1,003 feet. Amoco No. 16 was a 1,215 foot deep pilot mine hole. The proposed pilot mine area is located between Bruin Point and the Shell in-situ steam injection pad. Angle hole Amoco No. 25 was drilled 585 feet beneath Range Creek for geotechnical investigations. Geophysical logs were made by BPB Instruments and exhibit excellent correlation between lithology and tar sands. Golder Associates of Denver initiates geotechnical and hydrological studies and installs piezometer strings in Amoco Nos. 16, 21 and 26. Five measured sections were completed and totalled 4184 vertical feet. Additional data from the drilling is shown in Tables 2B, 3B and 4B. The current status of the drill holes is shown in Table 5A.

1982 From mid-June to mid-October Amoco Minerals completed twenty-two vertical cored drill holes (Amoco Nos. 27-48) for a total of 12,300 feet. Three Longyear 44 rigs were used. Seventeen drill holes were completed on the federal leases and totalled 10,471 feet. Four vertical shallow pilot mine holes were completed in the south area and totalled 580 feet. One project in-fill hole within the Amoco-Kaiser Tract totalled 1249 feet. Piezometer strings were installed in Amoco Nos. 4, 10 and 24. Geophysical logs were completed by BPB Instruments and exhibit excellent correlation between lithology and tar sands. Six measured sections were completed and totalled 3929 vertical feet. Additional data from the drilling is shown in Tables 2C, 3C and 4C. The current status of the drill holes is shown in Table 5B.
During late summer Mono Power in a joint venture with Phillips Petroleum drilled three to five holes in peripheral portions of the Sunnyside delta complex.

During the fall Chevron entered into a joint venture with GNC Energy and drilled 13 holes for a total of 11,390 feet in areas surrounding the old Asphalt Mine. Additional data and drill hole locations are shown on the Regional Map (scale 1" = 2000') and on the geologic Map South Half (scale 1" = 500').

1983

Chevron drops the joint venture agreement with GNC Energy.

Mono Power drills twenty-one vertical holes totalling 13,652 feet within peripheral areas of the Sunnyside Tar Sands deposit. Fifteen cored holes totalled 9797 feet with depths that range from 154-1404 feet. Six rotary holes totalled 3855 feet with depths that range from 393-1100 feet. Eighteen of these Mono Power holes were drilled within the Sunnyside Municipal Watershed outlined in Figure 2. These eighteen drill holes are located near the southern fringe of the Bruin Point subdelta as shown by the Tar Sand Isopach Map (scale 1" = 2000'). Hole BP-1A was drilled in the mid-portion of the Bruin Point, subdelta about one mile downdip from Bruin Point. Two holes (WCT-3 and WCT-4) were drilled in the Whitmore Canyon subdelta as shown by the Tar Sand Isopach Map. Hole locations and depths are shown on the Regional Map (scale 1" = 2000').

1984

From mid-June to early-September Amoco Minerals completed fifteen cored drill holes (Amoco Nos. 49-63) for a total of 7814 feet. These holes were all drilled on Federal leases and within the Dry Canyon subdelta or areas transitional to the Bruin Point subdelta. Two Longyear 44 rigs were used. Ten deep holes totalled 7364 feet and five shallow holes within the proposed north area pilot mine near the Area water tank totalled 450 feet. Geophysical logs were completed by BPB Instruments and exhibit excellent correlation between lithology and tar sands. Nine measured sections were completed within the Dry Canyon subdelta and totalled 6967 vertical feet. Additional data from the drilling is shown in Tables 2D, 3D, and 4D. The current status of the drill holes is shown in Table 5C.
REGIONAL GEOLOGY

The Sunnyside Tar Sands deposit is located near the northeast flank of the San Rafael Swell and within the southwestern edge of the Unita Basin as seen on Figure 7. Portions of both the San Rafael Swell and the Unita Basin can be seen from the vantage point near Bruin Point at the top of MS No. 4 and GN-8 shown on the Regional Map (scale 1" = 2000'). The San Rafael Swell influences an area almost 100 miles long by 50 miles wide. The Uinta Basin exists within an area some 150 miles in an east-west direction and up to 100 miles in a north-south direction. The Uinta Basin is bounded on the north by the Uinta Mountain Uplift, on the east by the Douglas Creek Arch, on the south by the Book Cliffs and on the west by the Wasatch Mountain Uplift. The Uinta Basin is an asymmetrical basin with the axial and deepest portion near and subparallel to the Uinta Mountains. The Green River separates the Uinta Basin into a western and eastern portion.

The complete uninterrupted regional stratigraphic section is well-exposed in a 100-mile long strip encompassing the San Rafael Swell and the Uinta Basin. The lower portion of the regional stratigraphic section from Permian through Cretaceous time is exposed within the region influenced by the San Rafael Swell. The upper portion of the regional stratigraphic section of Tertiary time is exposed within the Uinta Basin.

SAN RAFAEL SWELL

The San Rafael Swell is a north-northeast trending domal uplift with extensive exposures of sedimentary rocks of Permian, Triassic, Jurassic and Cretaceous age. A stratigraphic section of the San Rafael Swell is shown in Figure 8. The Permian rocks of the eroded core are predominantly sandstones and limestones of marine origin. The extensive exposures of Triassic and Jurassic rocks are predominantly sandstones and shales of continental origin. Cretaceous rocks exist on the gently dipping flanks with widespread exposures of the 5,000-foot thick Mancos Shale of marine origin. The Mancos Shale usually forms the base of the Book Cliffs. The Mesaverde Group is a regressive sequence with minor transgressive and regressive cycles. The Mesaverde Group consists of sandstones, siltstones and shales of nonmarine, transitional and marine origin that formed in floodplain, swamp, lagoon, beach and offbeach environments (McGookey, 1972). The Mesaverde Group forms the upper portion of the Book Cliffs and from oldest to youngest consists of the Star Point Sandstone (300 feet thick); Blackhawk Formation (700-1,000 feet thick); Castlegate Sandstones (0-200 feet thick) and Price River Formation (750 feet thick). Above thicknesses are from Hintze (1972). The Blackhawk Formation is the principal coal bearing unit of the Mesaverde Group. The Castlegate Sandstone is a fluvial-delta complex that forms a regressive sandstone tongue that wedges out seaward (east) near the Utah-Colorado stateline (Van de Graaf, 1972).

UINTA BASIN

The Uinta Basin contains extensive exposures of sedimentary rocks of Tertiary age. A stratigraphic section of the Uinta Basin is shown in Figure 9. In its simplest form the Tertiary stratigraphic nomenclature consists of the Wasatch Formation at the base and the Green River Formation at the top as shown in Figure 10. However, twelve miles northwest of the Sunnyside Tar Sands project in the upper Soldier Creek area a limestone tongue of Paleocene Lake Flagstaff...
intertongues with the Wasatch Formation and the stratigraphic terminology changes. The limestone tongue is known as the Flagstaff Member or Flagstaff Limestone with the underlying rocks named the North Horn Formation and the overlying rocks named the Colton Formation. The relationship of this stratigraphic nomenclature is seen in Figures 9 and 11. During Eocene time Lake Uinta encompassed much of northeastern Utah and northwestern Colorado. The area of Lake Uinta within Utah is largely confined to the Uinta Basin, while the area of Lake Uinta in Colorado is largely confined to the Piceance Creek Basin (McDonald, 1972).

As seen from the isopach maps in Figure 9, up to 18,000 feet of fluvial and lacustrine deposits accumulated in the Uinta Basin during early to middle Tertiary time (Osmond, 1965 and Hintze 1972). The principal Tertiary deposits from oldest to youngest are the Wasatch, Green River, Uinta, and Duchesne River Formations. The early classic work on the Green River Formation was done by Bradley (1931) in the Piceance Creek Basin. The Green River Formation (Tgr) was originally divided into three members that from oldest to youngest are the Douglas Creek Member (Tgd), Garden Gulch Member (Tgg) and Parachute Creek Member (Tgp).

**Eocene Lake Uinta**

Paleogeographic maps in chronological sequence illustrate the development of Lake Uinta and show the different source areas for sediments. These paleogeographic maps of northeastern Utah are shown in Figure 12 and show the paleogeographic setting for the development of the North Horn Formation in early Paleocene, the Green River Formation in middle Eocene and the Uinta Formation in late Eocene. The Sevier orogenic belt developed in the middle Cretaceous and represents the major source area for the Price River and North Horn Formations. Boulder-cobble-pebble conglomerates of the Price River Formation are well-exposed within a four-mile stretch along the highway slightly east of Thistle. As a result of the Laramide orogeny of Late Cretaceous age, the Uinta Mountains were uplifted, the San Rafael swell developed, and the ancestral Uncompahgre uplift of Pennsylvanian-Permian age was reactivated. All these uplifted areas created an internal basin in which Lake Uinta formed during the middle Eocene. Sediments were derived from the surrounding uplifted regions that include the Sevier orogenic belt, Uinta uplift, Uncompahgre uplift and San Rafael swell. Eroded sediments from these uplifted areas were deposited to form the Green River Formation. The composition of the sandstones from the Price River Formation of late Cretaceous age to the Green River Formation of Eocene age gradually changed from sublithic arenite to feldspathic arenite (Pitman, et. al., 1985). The sandstones at the Sunnyside Tar Sands deposit are feldspathic arenites (Remy, 1984).

Regional stratigraphic and geochronologic information are shown in Figure 13 for the sedimentary rocks of Eocene age in the Uinta Basin. The Eocene lasted 20 my (million years) from 58-38 Ma (millions of years before present) as defined by COSUNA (correlation of stratigraphic units of North America) of the American Association of Petroleum Geologists and reported by Salvador (1985). Tuffs near the Mahogany marker of the Green River Formation have K-Ar age dates of 45 Ma and sparse mammalian fossils define the Bridgerian-Uintan boundary at 44 Ma (Mauger, 1977). The age names of Wasatchian, Bridgerian, Uintan and Duchesnean are commonly used throughout the Uinta basin as listed.
in Figure 13 rather than those listed in the 1983 Geologic Time Scale of the Geological Society of America. As seen from Figure 13 the Green River Formation that encompasses the black shale facies through the SS-LS facies was deposited in the central portion of the Uinta Basin between 40-49 Ma. However, the Green River Formation that encompasses the Douglas Creek Member through the Evacuation Creek Member was deposited in marginal portions of the Uinta Basin during a 5 my (million year) span. From sediment accumulation rates Bradley (1929b) calculated that Lake Uinta existed for 6.5 my, and Picard (1963) estimated that Lake Uinta existed for 13.3 my.

The Sunnyside Tar Sands deposit exists within the upper portion of the Douglas Creek Member, throughout the Garden Gulch Member and in the lower portion of the Parachute Creek Member. The Mahagony marker (dated at 45 Ma by Mauger, 1977) is believed to exist within the lower portion of the Parachute Creek Member near Bruin Point. If the regional stratigraphy and geochronological information from the Uinta Basin is applied to the Sunnyside Tar Sands deposit, the data suggests that the Sunnyside delta complex formed in less than four million years.

Eocene Lake Uinta had dimensions approaching 150 miles long in an east-west direction by 40-100 miles wide in a north-south direction. Lake Uinta encompassed an area approaching 7,700 square miles with maximum depths of 200-600 feet. Lake Uinta has been described by Picard and High (1968) as the largest of several lakes that existed in Green River time. Lake Uinta can be compared in size and shape to Lake Ontario, Lake Erie or the southern half of Lake Michigan. Lake Ontario has an area of 7,540 square miles with a maximum depth of 210 feet. Lake Michigan has an area of 22,400 square miles with a maximum depth of 923 feet. Great Salt Lake is about 80 miles long by 35 miles wide and covers an area that ranges from 1,100-2,300 square miles with a depth that ranges from 13-34 feet.

Considerable controversy exists over whether Eocene Lake Uinta was a deep-water or shallow-water lake. The Green River Formation was deposited within Eocene Lake Uinta and has two interpretations for its environment of deposition (Buchheim and Surdam, 1977). The stratified-lake model is based on anerobic, H2S rich conditions within a relatively deep lake. The playa-lake model is based on aerobic conditions of a shallow lake with fringing mud flats. If Eocene Lake Uinta were a relatively deep water lake environmental conditions would have some of the characteristics of the Great Lakes. If Eocene Lake Uinta were a shallow lake environmental conditions would have some of the characteristics of Great Salt Lake. The controversy remains as different characteristics exist within different portions of Eocene Lake Uinta during different spans of time. Lake Uinta definitely became progressively more saline during Parachute Creek and Evacuation Creek time.

The significance of longshore currents and wave action within Lake Uinta are difficult to interpret. However, on the southern portion of Lake Michigan longshore currents with velocities up to 0.5 meters/sec and waves up to 1.8 meters high have been measured and are strong enough to modify the beach and nearshore bars (Fox and Davis, 1976). Eocene Lake Uinta was a sizeable lake and of sufficient size to develop wave energy that helped to disperse the deltaic sands into laterally continuous sheet-like patterns along the shoreline.
Piceance Creek Basin

A portion of Eocene Lake Uinta extended into an area of northwestern Colorado and is known as the Piceance Creek Basin. In 1931 Bradley completed the early classic work on the Piceance Creek Basin. The Douglas Creek Member was named by Bradley (1931) for exposures along Douglas Creek 20-30 miles south of Rangely, Colorado. There the member is 200 to 800 feet thick with large portions of sandstone, limestone, algae reefs and oolites. Ostracods, fish and turtle bones and gar-pike scales help to define the environment of deposition as near the lakeshore and often in shallow water. Bradley (1929) noted that the algae reefs are up to 18 feet thick and make up to 8 percent of the Douglas Creek Member. The algae reefs are irregularly distributed throughout the entire Green River Formation and represent shore deposits in water less than six feet deep (Bradley, 1929). The Garden Gulch Member was named by Bradley (1931) for exposures along Garden Gulch, a short tributary to Parachute Creek in the Piceance Creek Basin 20 miles west of Rifle, Colorado. In the Piceance Creek Basin the Garden Gulch Member is 200 to 700 feet thick and is characterized by paper shales. Fossils consist of ostracods, fish scales and plant fragments. The member represents nearshore lacustrine units (Bradley, 1931 and Cashion, 1967). The Parachute Creek Member was named by Bradley (1931) for exposures near Parachute Creek in the Piceance Creek Basin and ranges in thickness from 200 to 1,000 feet. Kerogen-rich oil shale beds distinguish this member that formed in shallow to deep lake environments. Within the Piceance Creek Basin the top of the Parachute Creek Member is from 300-500 feet above the Mahogany ledge (MacGinitie, 1969).

Southeast Uinta Basin

About twenty to fifty miles east of Bruin Point a large area within the southeast portion of the Uinta Basin was studied by Cashion (1967) to determine the fuel resources of the Green River Formation east of Green River. The Green River Formation was divided into the Douglas Creek, Garden Gulch and Parachute Creek Members by Cashion (1967). Here the Douglas Creek Member is 900 to 1,200 feet thick and contains six thin intertonguing nearshore-lacustrine units. The Garden Gulch Member is up to 230 feet thick and was deposited along a trough of Lake Uinta in less than 75 feet of water (Cashion, 1967). The Garden Gulch Member is characterized by thin even-bedded gray and brown shales that are locally paper thin. The Parachute Creek Member is a 400 to 700 foot thick sequence of marlstones, paper shales and siltstones with local tuffaceous beds.

The term Mahogany has been specifically applied to ledge, zone, bed and marker; all of which are associated with rich brown-colored oil shale units. The Mahogany ledge is a 2 to 60 feet thick outcrop sequence with a subsurface equivalent of the Mahogany zone. The Mahogany bed represents the thick oil shale bed containing the most kerogen and occurs near the top of the Mahogany ledge. The Mahogany bed is the most useful and widespread key bed in the Green River Formation. The Mahogany marker is a tuffaceous bed averaging 0.4 feet thick and is located 9 to 20 feet about the Mahogany bed. The Mahogany marker is a gray fine-grained unit that weathers to orange-brown rectangular blocks. Above data summarized from Cashion (1967).
Western Uinta Basin

The western Uinta Basin encompasses a large embayment-like area that is some twenty to seventy miles northwest of Bruin Point, west of Duchesne and north of Soldier Summit. In the western Uinta Basin the uppermost Cretaceous to lower Eocene strata have been divided into three major intertonguing lithofacies of open lacustrine, marginal lacustrine and alluvial by Fouch (1975) and Ryder, Fouch, and Elison (1976). The open lacustrine lithofacies is commonly 1,475 to 2,300 feet thick and is characterized by mud-supported carbonate and calcareous claystones. The marginal lacustrine lithofacies is commonly 985 to 1,150 feet thick and is characterized by gray-green calcareous claystone, mud- and grain-supported carbonates and sandstones of the lake margin carbonate flat, deltaic and interdeltaic depositional environments. The alluvial lithofacies is commonly 1,970 feet thick and is characterized by interbedded red claystone, siltstone and channel sandstone deposits of the high mudflat, lower deltaic plain and alluvial fan environments.

Northeastern Uinta Basin

About seventy-five miles northeast of Bruin Point excellent exposures of the Wasatch and Green River Formations exist along Raven Ridge updip from the Red Wash oil fields. Here the Green River Formation averages 3000 feet thick and consists of four facies as mapped by Koesoemadinata (1970). The first and lowermost facies is a variegated shale facies deposited in a fluvial environment assigned to the Wasatch Formation. The second facies is a sandstone facies deposited in a deltaic environment assigned to the Douglas Creek Member. The third facies is an ostracod and algal limestone facies deposited in a nearshore to offshore environment assigned to the Garden Gulch Member. The fourth facies is the black shale facies deposited in deep axial lacustrine environments assigned to the Parachute Creek Member. Two types of deltas exist within the Douglas Creek Member as suggested by Koesoemadinata (1970) and include a bar-finger or deep-water delta with relatively continuous sandstone bodies and a shoal-water delta with more discontinuous sandstone bodies. The only type of delta formed within the Garden Gulch Member is the shoal-water delta that has a cuspate shape.

Oil and Gas Fields

The Uinta Basin contains important oil and gas fields as shown in Figure 10. The principal producing horizons are localized within the lower portion of the Green River Formation and the upper portion of the Wasatch Formation (Ritzma, 1972). The four principal oil fields in the Uinta Basin are localized near the axial portion of the basin and located 25 miles south and west of Vernal, Uintah County, Utah. These four principal oil fields are the Greater Red Wash Field (1969 cumulative production 69,425,000 barrels with estimated reserves 65,425,000 barrels) and Ashley Valley, Bluebell and Roosevelt fields (combined 1969 cumulative production 20,829,000 barrels and with combined estimated reserves 15,921,000 barrels). The Bluebell field is in Duchesne County, while the other three fields are in Uintah County.
The Red Wash field is located in an anticlinal structure beginning some 4-8 miles down dip from exposures of the Green River Formation along Raven Ridge. The Red Wash field is within a lacustrine delta containing the Douglas Creek and Garden Gulch Members of the Green River Formation. The hydrocarbons are contained within a complex network of discrete sandstones largely confined to the Douglas Creek Member. The total effective oil producing section ranges from 60-210 feet with an average approaching 150 feet. Average porosities in the sandstones range from 13-15 percent and average permeabilities range from 75-125 milli-darcies. The Red Wash crude oil is a paraffin-base crude ranging from 22-30 API, while the Red Wash gas is over 95 percent methane. Above summarized from Chatfield (1972).

The Red Wash field contains high pour point crude oil in the Green River Formation at depths of 5500-5900 feet. Reservoir temperatures are from 125-135 F and the pour point is from 85-105 F. The multiple, isolated and separate sandstone stringers from three to thirty feet thick must be individually fractured to form production. Water as well as gas injection have been utilized to increase production. In order to maintain surface flow the crude must be kept above the pour point by heating tanks and flow lines. Above summarized from Bleakly (1963).

Sunnyside Area

At Kaiser Steel's Sunnyside coal mine the coal is localized within the Blackhawk Formation of the Mesa Verde Group. The relationships of the stratigraphic nomenclature are seen in Figure 11. Within the Sunnyside area the mesaverde Group overlies the marine Mancos Shale and contains the Blackhawk Formation, Castlegate Sandstone and Price River Formation (Osterwald, Maberry and Dunrud, 1981). The Blackhawk Formation contains important coal beds that formed in a delta plain environment associated with a system of late Cretaceous age. The Blackhawk Formation consists largely of wave-dominated deltaic deposits that have a broad lateral continuity and sheet-like geometry with sands separated in distributary channel, distributary mouth bar and shoreface environments (Balsley, 1982). The Blackhawk Formation forms the upper portion of the Book Cliffs and overlies the Mancos Shales. The Star Point Sandstone shown in Figure 11 is not present in the Sunnyside area. The Blackhawk Formation has been subdivided into five members, and the Sunnyside Member contains the principal coal bearing rocks (Balsley, 1982). The coal seams are 5 to 15 feet thick, contain medium volatile bituminous coal and form some of the most important deposits of coking coal in the western United States.

First magnitude faults within the Sunnyside mine generally strike N30 W and have common displacements of one to four feet with a maximum displacement of 33 feet. Twenty miles south on Kaiser Steel's South Lease, faults have common displacements of 10 to 100 feet with a maximum displacement of 150 feet (personal communication, Lynn Huntsman, Chief Engineer, Sunnyside Mine, 1980).

Within Water Canyon at the turn off to the Asphalt Mine sedimentary rocks of the North Horn, Wasatch and Green River Formations are well-exposed. On the north side of the canyon the Flagstaff Limestone was not found to exist between the North Horn Formation and the Wasatch Formation. However, Osterwald, Maberry and Dunrud (1981) show a thin 10-20 foot thickness of Flagstaff Limestone near the mouth of Water Canyon that thickens to 20-40 feet.
south of Sunnyside. Within Water Canyon as shown on the Regional Map (scale 1" = 2000') the North Horn Formation is about 300 feet thick, the Wasatch Formation is about 800 feet thick, and the Green River Formation is about 1500 feet thick. A gradational contact exists between the fluvial sediments of the Wasatch Formation and the lacustrine sediments of the Green River Formation. The base of the Green River Formation is below the lowermost ostracod beds and before the red colored sandstones that characterize the Wasatch Formation. Within the upper portion of Water Canyon the Green River Formation averages 1500 feet thick with a range from 1350-1700 feet. The Douglas Creek Member is 900-1000 feet thick. The lower half of the Douglas Creek Member contains nonbituminous sandstones and represents a fluvial environment of the upper delta plain. The upper half of the Douglas Creek Member contains bituminous sandstones and represents a fluvial-deltaic environment in the lower delta plain. These relationships are shown in Photo 2 of the Amoco Minerals 1980 Exploration Report (Calkin, 1981). The Garden Gulch Member is 300-500 feet thick, and the Parachute Creek Member is 150-200 feet thick. In the Sunnyside Tar Sands area the Mahogany marker has not been specifically identified. However, thin oil shale beds and bentonite zones exist in outcrop and have also been identified in the drill core.
GEOLGY OF THE PROJECT AREA

PREVIEW

Near Bruin Point flay lying sedimentary rocks of the Green River Formation are well-exposed along the Roan Cliffs and represent the only rocks encountered in the various drill holes. Exposures on the Roan Cliff faces provide an excellent cross section of the Green River Formation and the Sunnyside delta complex as seen in Photo Nos. 1 and 2. During 1980, 1981, 1982, and 1984 detailed lithologic and stratigraphic analysis was completed on twenty-six measured sections that totalled 21,517 vertical feet and fifty-three deep cored drill holes that totaled 35,560 feet. This information has been utilized to determine the geological relationships of major and minor environments of deposition that have defined various aspects of the Sunnyside delta complex located in the southwest portion of Eocene Lake Uinta.

On the basis of lithological and paleontological data the Green River Formation was separated in the field into the Parachute Creek Member, Garden Gulch Member and Douglas Creek Member as seen from Photo No. 1 and Figures 23 and 24. The Parachute Creek Member represents the lake facies. The Garden Gulch Member represents the shore facies and the Douglas Creek Member represents the delta facies. The three members of the Green River Formation each contain characteristic features that help to separate the members in the field.

The tar sands are localized within porous sandstones associated with channel deposits and sheet sands. These two general categories of tar sands can be divided into three specific types of deposits: distributary channel, distributary mouth bar and beach bar to beaches. The rocks in the project area consist of: thin to massive fine grained to very fine grained bituminous to nonbituminous sandstones; thin streaky saturated bituminous siltstones; nonbituminous red, green, and gray shales; thin bituminous to nonbituminous limestones; and occasional thin conglomerates associated with the channel deposits.

The Sunnyside delta complex is well-exposed along the Roan Cliffs for six to eight miles. The depositional strike is N45 E ±5° and the depositional dip is 4-7° NE ±1°. The principal orientation of the major channels is N40° -70° E. The principal direction of delta progradation is northeast. The Sunnyside delta complex as defined by the distribution of tar sands can be separated into three subdeltas as seen on the Tar Sand Isopach Map. The Bruin Point subdelta contains the main delta lobe, is centered on the Amoco-Kaiser Tract, is shown on the Regional Map and the Geologic Map South Half. The smaller Dry Canyon subdelta is centered on the hydrocarbon leases largely controlled by Amoco, is shown on the Regional Map and the Geologic Map North Half. The Whitmore Canyon subdelta contains minor tar sand units and can be seen on the Tar Sand Isopach Map and Regional Map. The major environments of deposition within the delta complex include lacustrine, delta and delta plain.

STRUCTURE

The Sunnyside Tar Sands area exists within a gently dipping homocline in the southwestern portion of the Uinta Basin and near the northeastern portion of the San Rafael Swell. The general attitude of the sedimentary beds is N45° W with relatively uniform dips of 4-7°NE. The beds have been tilted slightly from their original horizontal position. Structural deformation and faulting is minimal.
Faults are not common and where faults do exist they are of a very limited nature with minor displacements as indicated by both field and drill core evidence throughout the project area. Four examples illustrate this conclusion.

Example 1:
The most visible and obvious fault zone found in the project area is located about 1,000 feet south of the uppermost portion of measured section No. 6 as noted on the Regional Map, scale 1" = 2,000 feet. Here a limestone bed is displaced 6 feet by a N75 W, 86°SW trending reverse fault. The fault zone is 4 to 12 inches wide and is filled with distorted rich tar sand.

Example 2:
Exposures of a N55 W trending nearly vertical fault with a probable 3-5 foot displacement exist within an inaccessible wall of the small 1892 vintage quarry located near 18,000 NW 6,000 SW (see Geologic Map South Half, scale 1" = 500 feet).

Example 3:
Along Range Creek in the vicinity of Amoco No. 25 and No. 26 anomalous dips have a range of 10-30 NE. Drill hole evidence from angle hole Amoco No. 25 that passes beneath Range Creek indicates a subsurface monoclinal flexure with dips up to fifteen degrees. No fault gauge or slickensides have been noticed at the surface or in the drill core.

Example 4:
No field evidence for a major fault exists along the surface of Range Creek within the project area or for some six miles downstream to drill hole, Amoco Production, Kaiser Steel No. 1.

Other structural information exists from joints and fracture systems. The results of 1232 joint measurements by Golder Associates (1982) along the Bruin Point road, in the Asphalt Mine and adjacent portions of the Roan Cliffs indicates four major and five minor joint sets. The general attitudes of the four major joint sets are: N75°W, 88°SW; N40°W, 88 SW; N60°E, 88°NW; and N40 W, 10 NE. The general attitudes of the five minor joint sets are: N18°E, 50°NW; N26°SW, 52°SW; N75°W, 61°SW; N37°E, 52°SE; and N59°E, 40°SE. Thurber and Welbourn (1977) indicate that an extensive vertical fracture system has a fracture frequency of one fracture per four feet with a direction of EW to N70°E.

GREEN RIVER FORMATION

The Green River Formation has been separated into three members consisting from top to bottom of the Parachute Creek Member, Garden Gulch Member, and Douglas Creek Member. Specific field criteria have been developed to help separate these three members. Nevertheless, picking these conformable contacts is difficult and sometimes arbitrary due to the multiple transgressions and regressions that have occurred within the Sunnyside delta complex. However, after the Green River Formation was separated into these three members it was realized that the Parachute Creek Member represents the lake facies, the Garden Gulch Member represents the shore facies and the Douglas Creek Member represents the delta facies. Once these three dominant facies were recognized various aspects of the Sunnyside delta complex became more obvious.
Parachute Creek Member

The Parachute Creek Member represents the lake facies and is defined by prodelta and distal delta front environments of deposition. This member is characterized by laminated tan to buff shales and thin discontinuous bituminous sheet sands. Erosion has removed an unknown portion of this member in the north area, but its average thickness is one hundred eighty-three feet in the south area.

The Parachute Creek Member characteristically contains thinly laminated buff to gray shales; limited one to twelve inch thick zones of oil shale; limited one to twelve inch thick limestone zones; streaky saturated siltstone zones one to twelve inches thick; and thin sandstone zones that range from 1-15 feet thick but commonly are only 1-3 feet thick.

The laminations in the shales are commonly less than 0.25 mm thick and in the field weathering often creates a paper shale texture. The thin oil shale zones are most abundant within the Parachute Creek Member. Tuffaceous white to light orange bentonitic zones have been located in some drill holes. Tuffaceous zones have not been located in the outcrop except for a 6-10 inch green bentonitic zone near the North Spring.

The limestones are micritic to biomicritic with occasional zones of ostracod coquina. The ostracods are commonly about 0.5-1 mm in size and represent the microfossil fauna. "An ostracod is a tiny crustacean whose body is entirely enclosed in a dorsally hinged bivalve shell" (Grande, 1980, p. 236). In the Bruin Point pilot mine outcrop area a single fossil catfish about one foot long was found within a three inch thick talus slab of oil shale and represents the macrofossil fauna. The fossil catfish appears to be similar to the type (Astephus antiquus) pictured and described by Buchheim and Surdam (1977) and Grande (1980). The macrofossil flora are represented by algal-laminated sediments, stromatolites and debris of palm-like plant fragments.

The base of the Parachute Creek Member is determined by a combination of multiple criteria including: a local unconformity with fish scales in the underlying intraformational conglomerate (IFC); an algal laminated zone capping a micritic limestone; presence of oil shale and paper shales above but rarely below; a change from laminated buff or gray shales to poorly bedded gray-green shales that form small roughly cubic forms on weathered surfaces. On cliff faces the Parachute Creek Member is often characterized by relatively limited or sparse vegetation. In addition the Parachute Creek Member contains occasional minor bituminous sandstones associated with distal bar or beach bar deposits. These tar sands are commonly about five to fifteen feet thick and outcrop over relatively short lateral distances from five hundred to fifteen hundred feet.

Garden Gulch Member

The Garden Gulch Member represents the shore facies and is defined by nearshore, bay, beach and beach bar environments of deposition. This member is characterized by fossiliferous limestones and poorly bedded greenish gray shales.
The thickness of this member as based on measured section and drill hole data differs considerably depending upon its relative position in the delta complex. Within the proximal portions of the main delta lobe and thus nearest to the Roan Cliff the Garden Gulch Member averages almost three hundred feet thick. In the distal portion of the main delta lobe near Range Creek the Garden Gulch Member averages nearly five hundred-fifty feet thick. In the peripheral portions to the north and down Range Creek, the Garden Gulch Member is commonly six hundred to one thousand feet thick.

The Garden Gulch Member is characterized by numerous limestone beds with thin zones of ostracods, algal-laminated sediments, stromatolites and tufa; massive poorly bedded greenish gray shales; limited but diagnostic black shiny fish scales; turtle fragments; rare gar-pike fish fossils; bioturbated shales and siltstones; thin zones of streaky saturated to saturated siltstones; and some important bituminous channel and sheet sand deposits. The micritic to biomicritic limestone beds are from one to ten feet thick and when porous contain high degrees of saturation. The massive poorly bedded greenish gray shales are poorly exposed on the cliff face but small rock fragments roughly cubic in form are abundant in near-outcrop areas. Occasional thin zones of paper shales do exist within the upper part of the Garden Gulch Member.

The Garden Gulch Member contains a diagnostic and significant fossil assemblage that is helpful in establishing its nearshore relationship in the Sunny-side delta complex. Macrofossil fauna are represented by fish scales and one locality of numerous gar-pike fish fossils on measured section No. 3. Comparisons with data and photos in Grange (1980) suggest that the fish fossils found in measured section No. 3 are gar, Lepisosteus cuneatus. Grande (1980) describes gar scales as diamond-shaped ganoid scales with an enamel-like shiny polish.

The black fish scales in the Sunnyside area are commonly parallelograms with 0.1-0.2 inch dimensions. These gar-pike fish scales sometimes occur in the Parachute Creek and Douglas Creek Members but the vast majority are localized within the Garden Gulch Member. Microfossil fauna are represented by large quantities of ostracods. Macrofossil flora are represented by one to twelve inch thick zones of algal-laminated sediments, one to twenty inch high stromatolites and fragments of rounded masses of tufa deposits. These algal zones, algal heads and tufa were formed in nearshore to mud-flat environments associated with the lake shore. Various sized fragments of algal-laminated sediments, stromatolites and tufa are frequently found within some bituminous sandstones. This transported algal and tufa material is one of the multiple criteria used to distinguish distributary mouth bar deposits. Two large transported tufa balls exist near the upper portion of measured section No. 6.

The base of the Garden Gulch Member is determined by a combination of multiple criteria including the beginning of abundant red shales coupled with a flat topographic bench; general loss of fossiliferous limestones and greenish gray shales; and the beginning of abundant bituminous distributary channel deposits.
Douglas Creek Member

The Douglas Creek Member represents the delta facies and is defined by distributary channels, levee, and marsh environments of deposition. This member is characterized by red shales and thick massive bituminous sandstones.

As seen from Photo 1 the upper portion of the Douglas Creek Member is bituminous, while the lower portion is nonbituminous. In the vicinity of the main delta lobe in the Bruin Point subdelta the Douglas Creek Member averages 1,230 feet thick as determined from data associated with measured sections No. 1, 2, and 4. The bituminous upper portion averages 710 feet thick, while the nonbituminous lower portion averages 520 feet thick. The true thickness of the Douglas Creek Member within drilled areas cannot be determined as the drill holes commonly only extended a few tens of feet below the bituminous portion and are terminated just before or within the first clean sandstone.

Lithologically the upper portion of the Douglas Creek Member is characterized by thick massive fine grained to very fine grained bituminous sandstones; streaky saturated to saturated siltstones; red to maroon shales; occasional thin zones of coal and some thin but prominent limestones. Megascopically the bituminous sandstones are fine grained to very fine grained quartz arenite to quartzose sandstones with well-sorted subangular to subrounded quartz grains plus one to two percent fine grained to medium grained muscovite. The medium grained muscovite has a distinct crinkled texture.

Red shales are also characteristic of the Douglas Creek Member and coupled with carbonized and pyritized rootlets help define the marsh environment. Fragments of transported logs and coal exist within portions of measured section No. 1, A and 5 as well as within the north pit of the Asphalt Mine. The coal is spatially near transitions between marsh and channel environments of deposition. The limestones within the Douglas Creek Member consist of algal and ostracodal zones. The algal zones are thickest within the Douglas Creek Member and range from one to three feet thick with single algal heads one to two feet across. These thin but prominent algal stromatolite zones attest to minor lake transgressions within the Sunnyside delta complex. Zones of ostracodal limestones one to five feet thick exist within the middle and lower portions of the Douglas Creek Member. On the surface these ostracod zones sometimes have a whiteoolitic texture possibly caused by weathering. Swain (1964) noted that calcite overgrowths are present on some ostracod bivalves and form an oolitic texture. The lower ostracod zones help to establish topographic control on the lower limits of the Douglas Creek Member of the lacustrine Green River Formation versus the continental Wasatch Formation.
TAR SANDS

Overview

The tar, bitumen, asphalt, or oil impregnated zones in the Sunnyside area are localized within porous and permeable sandstones, siltstones and limestones of the Green River Formation. The vast majority of bituminous zones are localized within sandstone bodies located within the upper portion of the Douglas Creek Member and throughout the Garden Gulch Member.

The Sunnyside Tar Sands have a cumulative thickness of fifty to seven hundred feet. The tar sands are stacked and have a wedge shape with a long northwest axis and a short northeast axis. The tar sands are thickest near the Roan Cliff faces. Aspects of the tar sand stacking can be seen from Photos 1 through 4 and Figures 23 and 24. The distribution of the tar sands and the wedge shape which tapers to the north, east and south can be seen from the Tar Sand Isopach Map and Photos 1 through 4.

The Tar Sand Isopach Map illustrates four distinct factors about the Sunnyside Tar Sands. First, the thickest portion of the tar sands exist near Bruin Point. Second, the tar sands are concentrated within a northwest trending belt. Third, erosion has removed portions of the tar sands. Fourth, the Sunnyside Tar Sands formed within a delta complex that can be divided into three subdeltas. The tar sands of Sunnyside delta complex are concentrated along a northwest trending belt that is eight miles long and one to three miles wide. The long northwest trend represents depositional strike and the short northeast trend represents depositional dip. The northwest trending outcrops along the Roan Cliffs represent stacked deltaic and shoreline sequences.

Prior to the work by Amoco Minerals the stratigraphic position of the tar sands was usually placed within the Wasatch Formation. As a result of extensive field work and drilling programs the majority of the tar sands are located in the upper portion of the Douglas Creek Member and throughout the Garden Gulch Member. Holmes, Page and Averitt (1948) placed the major portion of the bituminous sands in the Wasatch Formation. Campbell (1975) noted that recent work by the Utah Geological and Mineral Survey placed the tar sands in the upper part of the delta facies (terminology of the western Uinta Basin) which roughly correlates with the Douglas Creek Member (terminology of the eastern Uinta Basin). Wilson and Ziemb (Amoco Production Report of March, 1977) indicate that the tar sands are localized within the Green River Formation.

The tar sands are thickest in the central and proximal portion of the delta complex and get progressively thinner and stratigraphically higher in all directions. Within the thick central and proximal portion located near the Asphalt Mine and the Amoco-Kaiser tract the tar sands are predominantly localized within the upper half of the Douglas Creek Member. The tar sands are associated with fifteen separate saturated zones within the main delta lobe of the Bruin Point subdelta. Within the Bruin Point subdelta the Douglas Creek Member contains about seventy-five percent of the tar sands, the Garden Gulch Member contains about twenty percent of the tar sands and the Parachute Creek Member contains about five percent of the tar sands. In the more distal
and thinner portions of the Sunnyside delta complex the tar sands are localized within the Garden Gulch Member. Within the Dry Canyon subdelta about ninety percent of the tar sands are located within the Garden Gulch Member and ten percent are located within the Douglas Creek Member. The tar sands are associated with three to eleven separate saturated zones within the Dry Canyon Subdelta located in the north area of hydrocarbon leases.

The fifteen numbered saturated zones in the Sunnyside delta complex range in thickness from ten to one hundred thirty-three feet and contain bitumen that ranges from five to thirteen weight percent bitumen or twelve to thirty-two gallons per ton. Tar films may exist in fractured shale adjacent to tar sands. The blackness of the fish scales appears to be related to the intensity of the nearby bitumen content.

Depositional Environments

The tar sands are largely confined to sandstone units, and these sandstones formed in specific depositional environments that are spatially and temporally associated with the delta complex. In general the tar sands are localized within channel deposits and sheet sands. In more detail the tar sands are associated with distributary channel deposits, distributary mouth bar deposits and beach bar to beach deposits. There are gradational aspects associated with these three specific types of sandstone deposits but multiple criteria can be used to distinguish or separate them. The distinguishing features are based on sedimentary structures, biota and lithology and were developed while logging core and measuring sections. Grain size is not a diagnostic feature as all the sandstones are megascopically similar. Thus the various tar sand deposits do not exhibit any obvious internal change in grain size. Distributary channel deposits and beach bar deposits can be considered the two end members of this series with distributary mouth bar deposits transitional to both.

Distributary channel deposits are distinguished by the following criteria: basal scours; channel lag deposits or IFC's (intraformational conglomerates) with nonbituminous siltstone intraclasts; trough cross bedding; one percent muscovite content; no or very limited bioturbation; tendency for "subangular" grains; and an association with red shales of adjacent marsh environments. Distributary channel deposits are shoestring-like with abrupt lateral changes and are often 30–250 feet thick. Distributary channel deposits are more prevalent in the basal portion of the tar sands.

Distributary mouth bar deposits are distinguished by the following criteria: IFC's with limestone intraclasts; planar cross bedding and planar bedding; climbing ripple laminations with high concentrations of muscovite (2–3 percent) and muscovite laminae; internal distorted bedding largely caused by gas heave structures or liquefaction; local rich bitumen content that is sap-like and often oozes, runs, and drips on the outcrops with southern exposures; nontransported internal limestone zones; broken and transported algal and tufa material; local fish scales; occasional zones a few inches thick with numerous ostracods in a sand matrix; bioturbation near the top; tendency for "subrounded" grains; and an association with greenish gray or mixed colored shales of adjacent nearshore to bay environments. Distribution mouth bars are lenticular to laterally gradational sandstone bodies that range in thickness from some 30–200 feet. Distributary mouth bar deposits are abundant in the middle portion of the tar sands.
Beach bar to beach deposits are distinguished by the following criteria: abundance of planar bedding; algal limestone zones below the base; thin internal biota trash zones; nearby mudcracks; and adjacent shaley environments of deposition including red shales of the marsh, mixed colored shales of the bay and greenish gray shales of the nearshore. Remy (1984) noted that beach deposits are slightly higher in muscovite and have a distinct biota content. Beach bar to beach deposits are sheetlike, laterally continuous and often 5-15 feet thick. The beach bar to beach deposits are interpreted to represent a continuum of the subaerial beach and subaqueous shoreface to nearshore sand deposits. In addition, these beach bar deposits may grade into shoaled areas that are laterally equivalent to the distributary mouth bar deposits. Evidence is often insufficient to distinguish or delineate the specific depositional environment associated with these sheet sands. Thus sheet sands may represent beach bar or beach deposits, thin distal shoaled areas of distributary mouth bars, and distal bar or delta-front sheet sand deposits. The lateral continuity of the sheet sands within peripheral portions of distributary mouth bar deposits is extensive. Beach and beach bar deposits are more prevalent in the upper and distal portions of the tar sands.

Tar Zones

Within the Sunnyside tar sand deposit almost forty separate tar sand units have been categorized into fifteen numbered tar zones. This was accomplished on the basis of downhole geophysics and assay data by John Rozelle of Pincock, Allen and Holt (formerly Golder Associates). The following criteria were utilized: frequency of intercepts in drill holes, minimum ten foot intercepts and minimum grade of ten gallons per ton. These numbered tar zones were correlated with lithology and depositional environments on a zone by zone and hole by hole basis. From this investigation fifteen tar zones were defined and represent major mineable tar zones. These numbered tar zones are a detailed representation of the MSAT values contained within Tables 1, 3, and 4. As seen from Table 13 these fifteen numbered tar zones are 11, 21, 23, 25, 26, 31, 33, 35, 36, 37, 38, 41, 42, 43 and 45. Zones 25 and 26 are bituminous limestones. These numbered tar zones have been identified on the strip logs of drill holes and measured sections in Volume III. For clarity and correlation these numbered tar zones also appear on the Geologic Map South Half and Geologic Map North Half (scale of 1" = 500') in Volume II. The thickness of numbered tar zones differ as do the interburden thicknesses as shown in Table 13. The distribution of these numbered tar zones is different within the Bruin Point and Dry Canyon subdeltas as shown in Table 13 and the two geologic maps (scale 1" = 500').

An idealized section of the numbered tar zones in the Bruin Point subdelta is shown in Figure 23. An idealized section of the numbered tar zones in the Dry Canyon subdelta is shown in Figure 24. Stratigraphic terminology and depositional environments are also shown in Figures 23 and 24. The stacked nature of these numbered tar zones is readily apparent from Figures 23 and 24. Detailed data on each of the numbered tar zones intersected by a drill hole in the Bruin Point subdelta is listed in Table 14 and for the Dry Canyon subdelta the data is listed in Table 15. The detailed data includes footage depths and elevations on the tops and bottoms of each numbered tar zones, thickness, average bitumen content, environment of deposition as well as footage depth.
and elevation at the base of the tar sands. These compilations were made for
tar zone correlations, for research reference to the data base and for
comparisons with the computerized data.

Initial analysis of the data in Tables 14 and 15 indicates the following:

1. Grade changes within a numbered tar zone show no consistent trend along
depositional strike or depositonal dip. Commonly the grades change by
one to four gallons per ton (gpt) from hole to hole within the same zone.

2. Grade changes across the base of the tar sands are abrupt. This is best
illustrated in Amoco No. 42 from Zone 42 (22.4 gpt) to Zone 43 (0.9 gpt).
Zones above the base of the tar sands may have decreasing values of
bitumen as in Amoco No. 17 from Zone 36 (20.2 gpt) to Zone 37 (16.3 gpt)
to Zone 38 (9.7 gpt) to Zone 41 (nonbituminous) or as in Amoco No. 10 from
Zone 36 (17.5 gpt) to Zone 37 (9.2 gpt) to Zone 38 (8.8 gpt) to Zone 41
(nonbituminous).

3. Nonbituminous sandstone zones exist below the base of the tar as shown in
Amoco No. 4 from Zone 41 (16.4 gpt) to Zone 42 (0.0 gpt) to Zone 43 (0.0
gpt) to Zone 45 (0.0 gpt). The deep drilling in Amoco No. 4 was extended
for 235 feet below the base of the tar sands to make sure there were no
additional tar zones.

4. Zone thickness is less in the Dry Canyon subdelta (range 10-83 feet) than
in the Bruin Point subdelta (range 10-133 feet).

Base of Tar Sands

Both Amoco drill hole and measured section data suggested that the base of the
tar sands was a relatively uniform surface that slopes gently down-dip and
represents an oil/water contact. In the field oil/water contacts are rarely
seen, but one was noticed in the extreme northwest portion of the Whitmore
Canyon subdelta as noted on the Regional Map (scale 1" = 500'). In Amoco drill
holes within the Bruin Point subdelta the bituminous zones abruptly terminate
at elevations between 8900-8600 feet. The elevation at the base of the tar
sands generally varies within limits of several hundred feet as seen in Tables
14 and 15 and from the geologic sections in Volume II. Detailed data on the
elevation and depth to the base of the tar sands is listed in Tables 14 and 15.
The drilled depths to the bottom of the tar sands (BSAT) are also listed in
Tables 1 and 3. The Regional Map lists BSAT depths and elevations for all
drill holes and measured sections in the area of the Sunnyside Tar Sands.

A subsurface contour map of the base of the tar sands is shown in Figure 25 and
was made from data in Tables 14 and 15. Figure 25 illustrates that the base of
the tar sands has a broad gently sloping to hollow-like depression within the
area of the Sunnyside Tar Sand deposit. The broadest and flatest area is
centrally located around Bruin Point. Looking northwest at Figure 25
gradients of this northeast sloping base of tar surface are normally about 600
ft/mi outside the tar sand deposit and about 100-300 ft/mi within the tar sand
deposit. Looking northeast at Figure 25 gradients of the base of tar surface from the Asphalt Mine to measured section No. 6 near the southeast limits of the Sunnyside Tar Sands rise at an average rate of 65' per 1000'. Looking northeast at Figure 25 gradients of the base of the tar surface from the Asphalt Mine to measured section No. 12 near the northwest limited of the Sunnyside Tar Sands rise at an average rate of 32' per 1000'. These gradients in the base of tar surface form a depression or bowl shape with the Asphalt Mine at the lowest portion and the outer limits on the rim.

Figure 23 indicates that the bituminous sandstones dip at an average rate of 100° per 1000' while the base of the tar falls downdip at an average rate of 30' per 1000'. In 5000 feet downdip the beds fall 500' while the base of the tar falls 150'. Thus the base of the tar is climbing relative to the numbered tar zones at a rate of 350' per 5000' and will cross different numbered tar zones in downsip directions. For example the base of the tar is at the bottom of Zone 45 in the Asphalt Mine but near Range Creek the base of the tar is commonly at the bottom of Zone 37.

In the vicinity of Range Creek a CO₂ gas zone exists at depth and slightly above the base of the tar sands. This gas zone is 50 feet wide by 6000 feet long and is outlined on the Geologic Map South Half (scale 1" = 500 feet). Based on seven drill holes that encountered C0₂ gas at depth (namely No. 9, 10, 14, 17, 21, 22, and 26), the gas zone averages 76 feet thick over a 93 foot interval and exists at average elevations between 8816 to 8723 feet. The gases are commonly entrapped in weak to poorly saturated sands near the base of the tar sands. These gases exist slightly above the barren sands that exist below the oil/water contact. The gases are often associated with sandstones that contain one to two percent disseminated pyrite. The gases consist predominately of CO₂ and CO with trace amounts of methane and other gases as noted in Table 8. The pyrite appears to be post-depositional and probably formed with the development of the bitumen.

**Grain Size and Mineralogy**

The grain size distribution within the tar sand zones differs within relatively small limits regardless of the environment of deposition. The tar sands are well-sorted and consist predominantly of fine to very fine sand. The sand grains consist largely of quartz and feldspar. Calcite and dolomite are the principal cementing agents.

After crushing and bitumen extraction, the grain size distribution of 109 samples (99 samples from channel deposits and 10 samples from sheet sands) was determined by sieve analysis on samples from the 1980 and 1981 exploration programs by Core Labs Inc. After crushing and bitumen extraction, the grain size data on samples from the 1982 exploration program proved to be totally unreliable due to incorrect laboratory procedures. After no crushing and bitumen extraction, grain size data from six samples was determined from an optical microscope at 400 magnification on core samples from the 1982 and 1984 exploration programs by Remy (1984). Average values from these sieve and microscope analyses are given below:
The above data indicates that 65-72 percent of the tar sand grains consist of fine to very fine sand. Coarse silt represents 2-10 percent of the tar sands. "Fines" or material that passes through a minus 325 mesh screen, (i.e. less than 44 millimicrons and consists of medium silt, fine silt and clay) represent 6-23 percent of the tar sands. This high percentage of difference in "fines" needs further explanation. In May, 1985 Core Labs reported sieve analysis data on "fines" from six entire (i.e. top to bottom) numbered tar zones in Amoco No. 17. The weighted average of "fines" within these six tar zones ranges from 4.69 to 10.09 percent as listed in Table 7. This recent data coupled with the microscope data suggests that the natural "fines" content ranges from 5-10 percent. Careful disaggregate and grinding procedures completed by Remy (1984) indicate that grinding can increase the "fines" content by 22-150 percent. This is largely caused by crushing of feldspar grains that make up almost 28 percent of the tar sands. The results of Remy (1984) are supported by results noted by Colville (1981). A laboratory report by Colville (1981) was brought to my attention by Jim Nalven in February, 1985. Colville did X-ray diffraction and microscopic examinations on the tar sands, presumably from the Asphalt Mine at Sunnyside. The X-ray diffraction work indicates feldspars make up about 30 percent of the sample, and Colville stated that "Crushing produced obvious grain breakage."

The general mineral composition of the tar sands is: quartz 55%; feldspar 30%; carbonates 8%; mica 1%; pyrite 0.5%; other 5.5%. Cements average 6% of the tar sands and consist of: dolomite 2.5%; calcite 1.5%; pyrite 0.5% and hematite 1.5%. These results are based on mineralogical analyses by three separate firms or individuals.

The detailed average composition of the tar sands based on thin section analysis of twenty samples by Remy (1984) is: pore space 22%; quartz 33%; feldspar 28%; carbonate fragments 3%; cements 5%; other 9%. Adjusting for the pore volume the detailed average mineral composition is quartz 42%, feldspar 36%, carbonate fragments 4%, cement 6%, other 12%. The crinkled muscovite, often noted in the core and used to distinguish distributary mouth bars, was
deformed by compaction as determined by Remy (1984). The detailed average mineral composition based on X-ray diffraction of twelve samples by Mineralogy Inc. of Tulsa, Oklahoma in 1981 is quartz 61%, feldspar 20%, carbonate 10%, clay 8.5% and pyrite 0.5%. The detailed average mineral composition based on X-ray diffraction of one sample by Colville (1981) is quartz >50%, feldspar 30%, mica 3%, carbonates 5% and other M2%.

Porosity and Permeability

Porosity values of selected tar sand samples commonly range from 22-29%. Entire tar zones have porosity values that commonly range from 15-18%. Permeability values of the selected tar sand samples commonly range from 400-800 md (milli-darcies).

During the 1984 exploration program efforts were made for the first time to obtain porosity and permeability data on the tar sands. Porosity values from selected footages in tar sands average 27% and have average permeability values of 812 md as based on eighteen samples analyzed by Core Labs, Inc. of Denver. A brief listing of the porosity and permeability values is given below:

<table>
<thead>
<tr>
<th>Type of Sample</th>
<th>Porosity</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous sandstone (18 samples)</td>
<td>23.8-29.1</td>
<td>37-3300</td>
</tr>
<tr>
<td>Nonbituminous sandstone (3 samples)</td>
<td>21.1-28.6</td>
<td>-</td>
</tr>
<tr>
<td>Bituminous siltstone (4 samples)</td>
<td>17.7-25.7</td>
<td>0.51-187</td>
</tr>
<tr>
<td>Bituminous limestone (5 samples)</td>
<td>14.8-24.5</td>
<td>0.14-1.4</td>
</tr>
</tbody>
</table>

Indirect porosity values were determined by BPB Instruments in Amoco No. 17. Tabulations of porosity values from eight numbered tar zones have averages that range from 9.8% to 18.5% as listed in Table 7.

Additional analytical data on the tar sands is limited and scattered. Eight analyses from tar sands within the Pan American-Preston Nutter CH-1 show the following: average porosity of 24.3 (range 24.0-26.9); average permeability of 398 md (range 173-491); average oil saturation of 42.8% (range 35.2-59.0); average water saturation of 16.9% (range 11.0-27.8). The Sunnyside Tar Sands have porosities of 25-30 percent and permeabilities of 154-677 md (Wells, 1958). The Sunnyside Crude has a viscosity of 60 cp at 340 F with no natural mobility at original reservoir conditions (Thurber and Welbourn, 1977). Amoco Production data from Amoco Nos. 2, 3, 5, 6, and 7 show the following: eleven analyses with average API gravity of 9.2 % (range 6.8-12.3); eight analyses with average C content of 85.3 (range 82.45-87.23); eight analyses with average H content of 10.4 (range 7.69-11.18); and based on one reported value an N content of 0.84 wt% and S content of 0.30 Wt%.
SHALES

In the vicinity of the Sunny side tar sands red, green and gray shales are abundant within the Green River and represent 44.6 percent of the investigated rocks in the Green River Formation as seen in Table 12. These different colored shales have been utilized in field mapping to help distinguish the three separate members of the Green River Formation. The red shales are a characteristic feature of the Douglas Creek Member or delta facies. The green shales are a characteristic feature of the Garden Gulch Member or shore facies. And the grey shales are a characteristic feature of the Parachute Creek Member or lake facies.

Potter, Maynard and Pryor (1980) have noted that the most obvious feature of a shale is its color; colors are the best guide for stratigraphic subdivision and correlation of shales; and color may have environmental significance. Shale color or pigmentation is controlled by two factors: (1) carbon content and (2) the oxidation state of iron. The color variation in shales develops the following two series as summarized from Potter, Maynard and Pryor (1980), Braunagel and Stanley (1977), and McBride (1974):

Series 1: RED grades to PURPLE grades to GREENISH GRAY
from left to right: decreasing Fe$^{2+}$ and increasing free iron
from left to right: increasing Fe$^{2+}$ and increasing carbon content

Series 2: GREENISH GRAY grades to GRAY grades to BLACK
from left to right: increasing carbon content

The greenish gray color is represented by the 5GY (hue) - 6/1 (chroma) color designation of the Geological Society of America rock color chart (Goddard et al, 1963).

Red shales commonly form in continental environments under oxidizing conditions. Delta plain deposits of late Cretaceous to Paleocene age near Monterrey and Saltillo, Mexico are characterized by an eighty percent abundance of red beds; green colored shales often underlie massive sandstone beds; groundwater seepage out of these overlying massive sandstone beds formed the green colored shales by reduction of the ferric iron content in red shales (McBride, 1974). This process may be the explanation for the small to moderate volumes of green colored shales that exist beneath the massive sandstone deposits of the Douglas Creek Member located in the north and south pits of the Asphalt Mine. Red to purple colors develop in delta plain facies and gray colors develop in prodelta and shelf facies; development of color within sediments is a post-depositional feature requiring hundreds to thousands of years (McBride, 1974).

"Red and purple rocks owe their color to pervasive hematite grain coatings and crystals intergrown with clay; brown rocks owe their color to faint or localized iron-oxide grain coatings; and gray rocks to organic matter and authigenic iron sulfide. Green rocks owe their color to chlorite and illite and to the absence of hematite, organic matter and sulfides. Olive and yellow claystone colors are imparted by color mixing of green clay and black organic matter." (McBride, 1974, p. 760). This information is helpful to a more comprehensive understanding of the colored shales associated with the Sunny side Tar Sands deposit.
Within the Sunnyside delta complex the greenish gray shales of 5GY to 5G color designation are one of the most characteristic features of the Garden Gulch Member and are considered to be deposited in nearshore environments associated with shallow to moderate water depths in the margins of Lake Uinta. The dominant color of the red shales of the Douglas Creek Member is grayish red (5R-4/2). These red shales are considered to be deposited in marsh environments of the delta plain. Mixed colored shales of different percentages of red, green, olive and purple (i.e. grayish red purple: 5RP-4/2) are considered to be deposited in interdistributary bay environments where alternate wetting and drying conditions may have prevailed. The gray colored shales of the Parachute Creek Member were deposited in moderate to deep water lake environments.

Corroborative evidence on the color of shales within a lacustrine delta complex exists in northeastern China as described by Shice and Hengjian (1981). Red shales developed mainly in the flood plain facies. Gray and green shales developed mainly in the deltaic distributary plain. Grayish black shales developed mainly in the delta front facies. And black shales developed mainly in the semi-deep to deep lake facies. This Heiyupao delta complex developed in the Songliao basin which was one of the largest lake basins that formed in the Asian continent during early to middle Cretaceous time. The Songliao basin covers an area of 260,000 sq km (Shice and Hengjian, 1981), while the modern Caspian Sea covers an area of 436,400 sq km (Picard and High, 1985).

Additional supporting evidence on the color of shales associated with specific environments exists in England and the Mississippi River delta. The greenish-gray (5GY-6/1) to olive gray (5Y-4/1) clays of the Cretaceous Weald Clay of southeastern England were deposited in shallow oxygenated brackish water marine environments; ostracods are commonly associated with the greenish gray (5GY-4/1) or light olive gray (5Y-6/1) clay as noted by MacDougall and Prentice (1964). Within the modern Mississippi River delta the color laminations found in muds deposited in brackish and saline marshes are considered to be the result of alternate wetting and drying of the sediments (Saxena, 1976).

Based on field relationships and information from the literature the red, green, mixed colored and gray shales within the Sunnyside delta complex are interpreted to represent distinct environmental conditions. The red shales are noncalcareous and were deposited in marsh environments under dominantly oxidizing conditions. Thin discontinuous pods/seams/seamlets of coal are localized within the red shales of the Douglas Creek Member and indicate local reducing conditions. Turtle fossils are found within the green shales of the Garden Gulch Member and indicate burial before the bone material was completely oxidized. The green shales of the Garden Gulch Member are calcareous and were deposited in shallow water environments under moderate oxygenated conditions. Transitional environments of the Garden Gulch Member contain variegated or mixed colored shales of olive, brown, purple, green and red colors. These variegated shales are calcareous and were deposited in interdistributary bays that experienced alternate wetting and drying that resulted in mixed reducing and oxidizing conditions. Within the Parachute Creek Member catfish-like and herring-like fish fossils have been found within thin oil shale beds. The gray shales of the Parachute Creek Member were deposited in moderate water depths under low oxygenated conditions.
Field relationships suggest that the red shales were formed within marsh environments associated with the lower delta plain deposits of the Douglas Creek Member. These red shales exist between the principal tar zones in the Bruin Point subdelta. The red shales appear to be more resistant to weathering than the green shales. The green shales were formed in nearshore environments of the Garden Gulch Member. The green shales exist between the principal tar zones in the Dry Canyon subdelta. The green shales readily crumble to cubic-like masses and are less resistant to weathering than the red shales. The gray shales were formed within the lacustrine environments associated with the lake deposits of the Parachute Creek Member. The gray shales exist at the surface within the Bruin Point subdelta but have been eroded off in the Dry Canyon subdelta. The gray shales become extremely slippery after significant wetting by precipitation or runoff and create mobility problems. The gray shales of the Parachute Creek Member commonly contain an extensive vertical fracture system that hinders core recovery and water return during drilling operations. Water associated with this vertical fracture system may cause local artesian flow at springs such as at the North Spring area or within drill holes such as at Amoco No. 2, Amoco No. 14 and Amoco No. 17.

LIMESTONES

Limestones represent a small but significant and repeated lithologic component of the Sunnyside delta complex. Almost seven percent of the rocks in the delta and subdeltas consist of limestones as seen from Table 12. Within the Bruin Point subdelta limestones average 1.5 percent of the Parachute Creek Member, 11.4 percent of the Garden Gulch Member and 1.5 percent of the Douglas Creek Member. Within the Dry Canyon subdelta limestones average 7.7 percent of the Garden Gulch Member and 3.3 percent of the Douglas Creek Member. Algal and ostracod zones exist within all three members of the Green River Formation but analysis within each subdelta clearly indicates that the limestones are concentrated within the Garden Gulch Member or shore facies. The limestones consist of one to five foot thick zones of micrites, biomicrites, algal mats, stromatolites and ostracod coquina.

Detailed petrographic work by Remy (1984) on the Sunnyside Tar Sands deposit indicates that carbonate cements are abundant in all tar sands but carbonate grains are localized only within beach to beach bar deposits. On the average tar sands formed in beach deposits contain 6.4 percent ostracods, 5.8 percent carbonate intraclasts and trace oolite. Carbonate grains are not common in tar sands formed in distributary channel and distributary mouth bar deposits. Authigenic carbonates are the most abundant cement in the tar sands and make up 3.3 percent of the rock. The carbonate cements consist of 1.3% calcite and 2.0% iron-rich dolomite. Calcite cement is more abundant in the beach to beach bar deposits. Iron-rich dolomite cement is more abundant in the distributary mouth bar and distributary channel deposits. Muller, et al (1977) state that within lake deposits calcite is a primary carbonate and dolomite is a secondary carbonate.
Within the Green River Formation four carbonate subenvironments of deposition were recognized by Williamson and Picard (1974) and consist of: shoreline (mudflat and beach-bar); lagoonal; shallow open nearshore (shoal transition); and offshore. Of these the lagoonal and nearshore environments are the most common and significant. The most abundant carbonate grains in the Green River Formation consist of fossils (calcareous algae, ostracods and gastropods) and coated grains (ooids and pisolites). The carbonate mineralogy consists of calcite and dolomite.

Within the Sunnyside Tar Sands deposit thin ostracod zones are associated with mixed color shales of the interdistributary bay environments. This is suggested to correspond to the lagoonal environments of Williamson and Picard (1974). The thickest and most prominent ostracod zones are interbedded with greenish gray shales, algal stromatolites and contain horizontal and cross stratification. These prominent and complex ostracod zones were commonly formed in nearshore environments. This conclusion agrees with Williamson and Picard (1974) who state that carbonate shoal deposits have the greatest lithologic, textural and stratification diversity of the four carbonate subenvironments of deposition.

Fossils within the limestones of the Sunnyside Tar Sands deposit include abundant ostracods, common calcareous algal mats, stromatolites, tufa and rare charophytes. Tufa deposits of calcium carbonate commonly form in seeps or springs near the shoreline of some fresh water lakes. Fresh water calcareous tufa and algal mats form by nonskeletal blue-green algae and stromatolites are commonly elongated parallel to sediment movement (Hoffman, 1973). Charophytes are small fresh water aquatic plants that have numerous branchlets or stems and consist of green algae. The single noted zone of charophytes is located in a two foot thick limestone bed located at the disconformity below Zone 36 at an elevation of 7980 or 323 vertical feet down from the top of measured section No. 19.

A significant aspect of the limestones in the Sunnyside delta complex is that the limestones commonly occur at the top of repeated major cycles of sandstone-shale-limestone deposition. These cyclic deposits are commonly tens to hundreds of feet thick and include sandstones conformably overlain by shales, that in turn are conformably overlain by limestones. The upper surface of the limestone is commonly eroded to form a local disconformity as seen at numerous locations in the measured sections and shown in Photo 6 of the 1980 Exploration Report. Measured sections were completed with a one hundred foot tape and an optical sight clinometer. No corrections were made for the low dips of 5-7. Outcrops were checked for one hundred feet on each side of the traverse line. There is no evidence of an angular unconformity between the limestone and sandstone units. After limestone deposition, erosion occurred. After a hiatus the next cycle of sandstone-shale-limestone deposition began. Each major cycle of sediment deposition represents a fining-upward sequence.

FOSSILS AND PALEOClimATE

Within the Sunnyside delta complex fossil flora and fauna are common, sparse or rare features in the stratified rocks as seen in Table 11. These fossils can be utilized to determine aspects of the paleo-environment and paleoclimate. An appreciation of the paleoclimate should lead to a more comprehensive understanding of the depositional environment of the Sunnyside Tar Sands deposit,
Ostracods and algal zones as well as gar-pike fish scales are common; turtle shell fragments and log fragments are sparse; gastropods, charophytes, leaf and fern fragments, and crocodile fragments are rare. Ostracods and algal rich zones are found within both the Douglas Creek and Garden Gulch Members. These ostracodal and algal zones are associated with shorelines and the limestone portion of cyclic deposition. The vast majority of the ostracodal limestones are in the Garden Gulch Member. Abundant ostracod zones are illustrated in Photo 7 of the 1982 Exploration Report. These fresh water ostracods have commonly been reworked by shallow water agitation and species identification would be very difficult; based on these fresh water ostracods the lake was usually alkaline and contained 10-20 parts per thousand dissolved salts of complex carbonates and bicarbonates (personal communication, R. Forrester, USGS, 1983).

During Garden Gulch time Eocene Lake Uinta was commonly alkaline to saline and contained some 10-20 parts per thousand dissolved salts. In contrast normal sea water has a salinity of 35-36 parts per thousand. Brackish water is "an indefinite term for water with a salinity intermediate between normal sea water and that of normal fresh water" (AGI Glossary of Geology, 1980, p. 79). Saline conditions are defined as greater than 3 parts per thousand and hypersaline conditions are greater than 40 parts per thousand. The salt content of Great Salt Lake is about 280 parts per thousand or eight times that of normal sea water.

Within the Sunnyside delta complex ostracods, algal mats and stromatolites, tufa zones, mudcracks and trace fossils are common features of the various shoreline environments. Trace fossils (tracks, trails, burrow and borings) can be seen within numerous portions of the Garden Gulch Member and can also be seen near the transition between the Garden Gulch and Parachute Creek Members. Tufas or calcium carbonate incrustations may form near calcareous springs or seeps and are often localized by wave splash along shorelines of lakes saturated with carbonates (Picard and High, 1979). The tufa deposits of Mono Lake, California are associated with the shoreline of an alkaline-carbonate lake; tufa often forms at orifices of sublacustrine springs; and these calcium carbonate deposits are the result of precipitation from mixing waters of different calcium and carbonate content (Dunn, 1953). Within the Sunnyside delta complex reworked tufa deposits originally associated with the limestone cycles occur in sandstone deposits near the middle and upper portions of the Garden Gulch Member. These reworked tufa deposits are commonly localized in basal IFC (intraformational conglomerate) zones of distributary mouth bar deposits.

The presence of both turtles and crocodiles within the Garden Gulch Member attest to a permanent water supply without a significant dry season as both these animals cannot exist without constant water (personal communication, J. Bown, USGS, 1983). Shell fragments of turtle carapaces and skulls are localized within the green shale facies and found more frequently within portions of the Dry Canyon subdelta. The fragments of turtle carapaces have been identified by reference to Ashley (1982) and Grande (1980) as well as examining turtle bones on modern beaches. Two rare vertebrate fossil
fragments have been identified as an upper leg bone and a sheath plate from a crocodile (personal communication, J. Bown, USGS, 1983). Thin coiled gastropods have been found in two localities within Measured Section No. 16.

Fossilized leaf fragments are very rare and the single specimen found in Amoco No. 39B at 555.5 feet represents a small-sized thick or heavy textured leaf from a member of the rose family; these heavy textured leaves are correlated with high temperature and low humidity conditions associated with a semi-arid, sub-tropical climate (personal communication, J. Wolfe, USGS, 1983. Other nondiagnostic flora include charophytes, fern fragments, palm-like fronds and log casts.

MacGinitie (1969) notes that the most prolific fossil plant horizons in the Green River Formation exist within the upper part of the Parachute Creek Member. The complex, varied and unique Green River flora have been extensively studied by MacGinitie (1969), and he concluded that the climate was subtropical, bordered on the subhumid and had an average rainfall of nearly twenty-eight inches per year. The closest modern analogs of the Green River flora environment are the savanna woodland floras that occur near the border of the dry tropics such as the region around Monterrey, Mexico and east of Mazatlan, Mexico (MacGinitie, 1969). The sparse coal deposits associated with the Sunnyside delta complex also suggests a general lack of humid conditions and are a possible indicator of a semi-arid environment.

During the formation of the Sunnyside delta complex the paleo-environment is interpreted to vary from subhumid to semi-arid and lie between a subtropical and tropical zone near the position of the Tropic of Cancer during Eocene time. Sandstones are considered to be deposited during subhumid conditions and limestones are considered to be deposited during semi-arid conditions. The numerous major cycles of sandstone-shale-limestone deposition discussed at the end of the limestone section must be considered in any paleoclimate evaluation. These major cycles of sandstone-shale-limestone deposition have been repeated at least eleven times and possibly twenty to thirty times during the deposition of the Sunnyside delta complex.

The cause of these major cycles of sandstone-shale-limestone deposition or fining-upward sequences is suggested to be the result of climatic and tectonic changes. Episodic uplift during the middle Tertiary is common within different portions of the Western United States. The climatic changes are suggested to be related to twenty thousand, forty thousand and one hundred thousand year climatic cycles that are emerging in the geological literature from studies completed by Vail, et al (1977).

Within Eocene Lake Gosuite the Green River Formation of Wyoming consists of three members that are from top to bottom the Laney Shale Member, Wilkins Peak Member and Tipton Shale Member. These three members formed in 4-5 my between 47.5-52.5 Ma (Grande, 1980). Sullivan (1985) has suggested that the Wilkins Peak Member of the Green River Formation in Wyoming was deposited during fluctuating climatic conditions. Perennial open stratified or meromictic lake conditions prevailed during humid subtropical times when the Laney Shale and Tipton Shale Members were deposited. Shallow saline-alkaline playa lakes conditions prevailed during more arid subtropical times when the Wilkins Peak Member was deposited.
Within the Piceance Creek Basin the Douglas Creek and Garden Gulch Members formed during dry subtropical climatic phases and the Parachute Creek Member formed during moist subtropical climatic phases. Based on palynomorph zones the duration of these climatic phases is around 0.7–1.0 my. The three members of the Green River Formation were deposited during 2.7 my between 48.3–51 Ma. Above information summarized from Newman (1980).
Compressive strength values are related to rock types and bitumen values. The tests were made on NQ core (1.87" diameter) from the 1980, 1981, 1982 and 1984 exploration programs by Core Labs, Inc. of Denver. The values associated with the four rock types are given below:

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Samples Tested</th>
<th>Compressive Strength in psi</th>
<th>Average Weight Percent Bitumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>sandstone</td>
<td>87</td>
<td>2,857-17,196</td>
<td>5,165</td>
</tr>
<tr>
<td>siltstone</td>
<td>35</td>
<td>4,918-22,482</td>
<td>9,642</td>
</tr>
<tr>
<td>limestone</td>
<td>47</td>
<td>3,334-26,002</td>
<td>8,795</td>
</tr>
<tr>
<td>shale</td>
<td>55</td>
<td>6,247-20,448</td>
<td>12,360</td>
</tr>
</tbody>
</table>

Based on these values three distinct categories exist: sandstones with an average value of 5,165 psi; siltstones-limestones with average values of 9,642 psi and 8,795 psi, respectively; and shales with an average value of 12,360 psi.

Within the sandstones bitumen content and compressive strength values are plotted in Figure 14. This plot indicates a linear relationship between bitumen content and compressive strength. Figure 14 illustrates increased bitumen content decreases the compressive strength.

Shales within the tar sand deposit can be separated into four different colors: gray, green, mixed and red. Each specific color has a definite association with a member of the Green River Formation. A detailed examination of the shales indicates that the gray, green, mixed and red shales have distinct average values as listed below:

<table>
<thead>
<tr>
<th>Shale</th>
<th>Member - Facies</th>
<th>Samples Tested</th>
<th>Compressive Strength in psi</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray</td>
<td>Parachute - Lake</td>
<td>6</td>
<td>12,592-20,448</td>
<td>15,511</td>
</tr>
<tr>
<td>Green</td>
<td>Garden Gulch - Shore</td>
<td>36</td>
<td>6,247-17,111</td>
<td>10,986</td>
</tr>
<tr>
<td>Mixed</td>
<td>Garden Gulch - Shore</td>
<td>5</td>
<td>7,824-17,096</td>
<td>12,601</td>
</tr>
<tr>
<td>Red</td>
<td>Douglas Creek - Delta</td>
<td>8</td>
<td>13,929-18,032</td>
<td>16,031</td>
</tr>
</tbody>
</table>

This data clearly defines two groups of shales with different compressive strength values. The gray and red shales can be grouped together with values of 15,511 psi and 16,031 psi, respectively. The green and mixed shales can be grouped together with values of 10,986 psi and 12,601 psi, respectively. The green and mixed shales of the Garden Gulch Member are definitely an order of magnitude lower in value than the gray shales of the Parachute Member and the red shales of the Douglas Creek Member. These different values suggest that important differences exist between the two shale groups and may be an important factor in mining the shale interburden. The north area is associated with the shale group with lower compressive strength values. The south area is associated with shales from both groups.
DELTAIC ENVIRONMENTS

An understanding of delta morphology is critical to a comprehension of the distribution of tar sands within the Sunnyside delta complex. A visual picture of delta morphology "is furnished by a pile of roughly superimposed leaves, in which the veins of the leaves represent natural levees and associated channel and crevasse deposits. Intervenin areas represent deposits of the marshes, lakes, and bays, whereas the outer margins of the leaves indicate beaches and bars" (Russell and Russell, 1955, p. 154).

There is an order to delta building with a constructional phase and a destructional phase. The constructional phase is associated with sediment influx and rapid deposition at distributary mouths under prograding conditions. The constructional phase is responsible for the major morphologic and lithologic characteristics of the delta sequence. The destructional phase is associated with reworking of the deltaic sands under transgressive conditions. The destructional phase is responsible for minor morphologic and lithologic characteristics of the delta sequence. Deltas build in one direction for a time, but then the river shifts location and the delta builds in another direction. This causes local constructional phases at distributary mouths and local destructional phases in areas of abandonment. Above summarized from Scruton (1960).

The significant association of hydrocarbon accumulations with delta systems has prompted extensive research on modern systems and a threefold classification of deltaic systems has become widely accepted. Galloway (1975) classified deltaic systems into fluvial dominated, wave dominated or tide dominated. Each type or combination of fluvial, wave, or tidal dominated system is characterized by a different delta morphology as shown in Figure 15. Different river names exist within the triangular classification diagram and help to show combinations of dominant factors. Some of the salient characteristics of this threefold classification are also listed in Figure 15. Fluvial dominated systems are characterized by elongated highly irregular protruding shorelines, low lateral continuity of sands, and sparsity of wave built features as shown by the Mississippi River delta in Figure 15. Wave dominated deltas are characterized by cuspy to straight shorelines, with high lateral continuity of sands, and well-developed barriers and beach ridges as shown by the Sao Francisco River delta in Figure 15. Tide dominated deltas tend to have discontinuous sand units that are perpendicular to the shoreline. The significance of fluvial, wave and tidal energy are shown on Figure 15. Climate is another important factor in the development of deltas as noted by Coleman (short course, March 13 and 14, 1985, Rocky Mountain Association of Geologists). A delta formed from a basin within a humid climate tends to have high sediment input that forms elongate laterally discontinuous sandstone bodies such as the Mississippi River delta. A delta that formed from a basin within an arid climate tends to have a more laterally continuous cuspate shaped delta such as the Burdekin delta in northeastern Australia shown within the wave dominated deltas of Figure 15.

Prograding conditions represent the seaward or lakeward movement of the shoreline and exist during times of fluvial dominance. A model for the development of facies with prograding delta systems is shown in Figure 16. Transgressive conditions represent the landward movement of the shoreline and exist during times of marine or lacustrine dominance. A model for the development of facies with transgressive delta systems is shown in Figure 17. Numerous
transgressions and regressions (i.e. prograding conditions) can be visualized as lateral changes or oscillations associated with a pendulum-like effect as noted by Daily (1975). The vertical stacking of these deltaic oscillations creates cycles of deposition. The three most important delta processes include (1) progradation or sediment influx, (2) lateral shift and (3) abandonment. These three processes are associated with the cyclic nature of deltaic systems and are related to a balance of sedimentation and subsidence (Saxena, 1976).

Knowledge of the geometry of the distributary mouth bar systems at the Sunnyside project would be helpful in the evaluation of the distribution of the tar sands. Literature research indicates that understanding river mouth processes and the formation of river mouth bars is the most fundamental and critical element in comprehending the cyclic evolution and vertical relationships of a deltaic sequence (Wright 1977, and Coleman and Prior, 1980). River mouth bars, bar finger sands, distributary mouth bars, and channel mouth bars are used synonymously. The geometry of distributary mouth bars reflect the effluent dispersion patterns at the river mouth. Wright (1977) has studied river-mouth processes and their resulting bar forms and placed them into three basic categories: (1) inertia dominated effluents, (2) friction dominated effluents, and (3) bouyant dominated effluents. (1) the inertia dominated effluents are normally associated with steep gradient streams entering deep fresh water lakes, have a low spreading angle and produce a narrow fan-like river mouth bar system. These inertia dominated effluents are relatively rare in the geologic record. (2) The friction dominated effluents are normally associated with rivers that prograde across flat shallow offshore slopes, have a wide spreading angle and produce shoaling and frequent channel bifurcations to form a wide river mouth bar system. The rivers have a high outflow velocity and a high bed load for at least part of the year. The shoaling and frequent channel bifurcations result in triangular "middle ground" shoals or multiple shallow internal bars. The crevasse-splay subdeltas of the Mississippi Delta are examples of friction dominated deposition in river-mouth environments. (3) The bouyant dominated effluents are normally associated with relatively deep river mouths joined by moderately deep salt water. This causes a salt water intrusion at the river mouth and results in a fresh water outflow that spreads as a bouyant plume above the salt water. The bouyant dominated effluents produce narrow elongated distributaries with parallel levees and few bifurcations. The South Pass and Southwest Pass distributaries of the Mississippi Delta system represent examples of the bouyant dominated effluents. The above information was summarized from Wright (1977). The Sunnyside delta complex contains combinations of friction and bouyant dominated systems. Based on the arcuate main delta lobe near Bruin Point friction dominated systems prevailed in the Bruin Point subdelta. Based on the elongated Dry Canyon ridge that extends northeastward from the Arco water tank, bouyant dominated systems prevailed within the Dry Canyon subdelta.

The principal of lateral accumulation or migration is one of the single most important concepts associated with deltaic sandstone deposition; and accumulation is usually in the direction of transport (Weimer, 1976). The numerous shifting subdeltaic patterns of the modern Mississippi River are illustrated in Figures 18 and 19. The sequential development of the West Bay complex, or subdelta C, at The Jump is illustrated in Figure 18. The sequential development of the Cubits Gap complex, or subdelta D, is well-
illustrated in Figure 19. Depth contours are shown in Figure 19 and clearly illustrate the chronological and morphological development of distributary channels and distributary mouth bar systems. "Water depths over most distributary mouth bars rarely exceed three meters (Coleman and Prior, 1982, p. 155).

During progradation in humid climates distributary mouth bars form half conical or lens-shaped sand deposits at the mouth of distributary channels as seen in plan and cross section views on Figures 20 and 21. At a later time when the water transgresses back across these deltaic sands, they are reworked to form tabular or sheet-like sand deposits as seen in plan and cross section views on Figure 22. The distributary mouth bars of the Mississippi River delta are migrating at rates of 5-6 km per 100 years as illustrated in Figure 21. The shorelines of the Danube River delta in the Black Sea are migrating at rates of about 6 km per 100 years (Almazov, 1963). The processes that rework deltaic sands occurred within the Sunnyside delta complex and are well-illustrated by Photos 8 and 9 of the 1982 Exploration Report.

The Mississippi River delta system consists of a cyclic or orderly repetition of depositional events. Cyclic deposition of detrital and nondetrital deposits is a major characteristic of the Mississippi River delta system and accounts for the vertical and lateral distribution of lithologic units. The detrital deposits are characterized by relatively high percentages of elastics (sands and silts), abrupt lithologic changes and rapid rates of deposition. The nondetrital deposits are characterized by nonclastics (shales and limestones), organic-rich components, considerable lateral continuity and slow rates of deposition. The nondetrital deposits represent bounding sediments or surfaces that are extremely important for correlation. Above summarized from Coleman and Gagliano (1964).
SUNNYSIDE DELTA COMPLEX

As exposed along the Roan Cliffs, the essence of the Sunnyside delta complex is a sequence of laterally continuous stacked bituminous sandstone deposits alternating with red, green or gray shales. The Sunnyside delta complex contains fluvial and deltaic deposits with associated beach and nearshore deposits that formed near the margin of ancient Lake Uinta.

The fifteen hundred foot high and six to eight mile long exposures of the Sunnyside delta complex along the Roan Cliffs are considered to be unique and offer an excellent opportunity to examine a lacustrine delta complex. The Sunnyside delta complex represents a small scale version of classic delta models. The Sunnyside delta complex is considered to be fifty to one hundred times smaller than the Mississippi River delta complex.

The numerous bituminous sandstone deposits represent distributary channel, distributary mouth bar and beach deposits that form relatively continuous sheets of bituminous sandstones. The lateral continuity of these sandstone deposits is caused by a combination of factors that include: (1) bifurcating distributary channel deposits with high volumes of fine to very fine grained sandstone, (2) shoaled distributary mouth bars and (3) reworking of the distributary mouth bars by waves and longshore currents to form beach and nearshore sandstone deposits. At the Sunnyside delta complex waves and longshore currents were associated with Lake Uinta. In nontidal Lake Michigan spring tides reach 0.25 feet; average breaker height in the summer is 0.8 feet with a period of 3.2 seconds; and longshore drift or longshore currents caused by wave swash close outlet channels in ridge and runnel systems (Davis, Jr. et al, 1972). Similar waves and longshore currents existed within Eocene Lake Uinta and are considered an important factor in the dispersal and lateral distribution of the sandstone deposits in the Sunnyside delta complex. Anastomosing distributary channels are also considered an important factor in explaining these laterally continuous sheets.

The Sunnyside delta complex has been defined on the basis of the distribution of tar sands with greater than fifty feet of cumulative thickness. The various field investigations have been largely restricted to areas containing these bitumen pay zones. As seen on the Tar Sand Isopach Map, the Sunnyside delta complex has been divided into three separate areas that include the Bruin Point, Dry Canyon and Whitmore Canyon subdeltas. The Sunnyside delta complex has been separated into these three subdeltas on the basis of field expression, lithology, tar sand distribution and interpreted environments of deposition. An understanding of this delta complex and its subdeltas helps to comprehend the distribution of the tar sands.

The Sunnyside delta complex was formed in river-delta-beach-nearshore environments associated with the margins of Lake Uinta during Eocene time some 45-50 Ma. As shown on the Tar Sand Isopach Map, the shoreline or depositional strike is parallel to the Roan Cliffs and oriented N40-50 W. The tar sands are distributed parallel to the ancient shoreline over a strike distance of six to eight miles. The tar sands are distributed along depositional dip or downslope from the ancient shoreline for a distance of two to three miles. The tar sands are distributed over a vertical range of 200 to 1200 feet.
During its development the Sunnyside delta complex experienced a major prograding phase in Douglas Creek time within the Bruin Point subdelta and a major prograding phase in Garden Gulch time within the Dry Canyon subdelta. The major transgressive phase occurred in Parachute Creek time. In addition numerous minor transgressions and regressions occurred during the complete development of the Sunnyside delta complex. Three of these minor transgressive-regressive cycles are well-exposed in the Bruin Point Pilot Mine Outcrop Area as seen on Photos No. 3 and No. 9 of the 1982 Exploration Report. This area was examined in detail; the traverse data appears in Table 9; and the traverse stations are located on the Geologic Map South Half (scale 1" = 500 feet). The multiple transgressions and regressions have caused cyclic changes in the relative position of tar sand units and environments of deposition.

The Sunnyside delta complex is characterized by cyclic deposition of sandstones, shales and limestones associated with an oscillating continuum of shorelines that are multi-stacked in the vicinity of the Roan Cliffs. These eleven to fifteen cycles or repeated intervals of detrital and nondetrital deposits range from fifty to one hundred-fifty feet thick. Then formed by climatic cycles that caused multiple transgressions and regressions of ancient Lake Uinta.

The major environments of deposition associated with the Sunnyside delta complex are lacustrine, delta and delta plain. The minor lacustrine environments of deposition are prodelta, delta front, nearshore, bay and beach bar. The minor delta environments of deposition include distributary mouth bar, levee, nearshore, bay and beach bar. The minor delta plain environments of deposition include distributary channel, levee, and marsh. The common characteristic features of rocks associated with these different environments of deposition are detailed in Table 11.

Field interpretations suggest that the Bruin Point subdelta is the oldest and the Whitmore Canyon subdelta is the youngest. Within the Bruin Point subdelta the tar sands are largely confined to the Douglas Creek Member. Within the Dry Canyon subdelta the tar sands are largely confined to the Garden Gulch Member. From the Tar Sand Isopach Map it is apparent that the migration of these three subdeltas is largely toward the northwest. The cause of this phenomena is coreolis force, which in the northern hemisphere causes a counterclockwise flow direction as well-illustrated by cyclonic weather patterns. Coreolis force results in the formation of larger levees on the down-flow or down-current side with a resulting migration of channels to the up-current side since these smaller levees are easier to breach (personal communication, H.H. Reading, 1983). Observations in the literature on the Danube River delta in the Black Sea and on the Rhone delta in the Mediterranean Sea west of Marseilles, France indicate that the coreolis force has caused similar deflections. As seen in Figure 15, the Danube River has three main channels: a lower, middle and upper. In the Black Sea there is a strong drift or longshore current from the north toward the south. Through time these three Danube River channels have drifted northward at spacings of about thirty kilometers with the upper or Kiliya channel as the youngest.
The Rhone delta is older on the west and younger on the east (Zenkovich, 1967). This coreolis force may seem minor, but it does influence the migration pattern of deltas and adds to a greater understanding of the migrating subdeltas within the Sunnyside delta complex.

Within the Sunnyside Tar Sands deposit the bitumen pay zones are almost exclusively confined to the porous and permeable sandstones deposits. These bituminous sandstones have a dominant sheet-like distribution that thickens in areas of major channel and distributary mouth bar deposits. Sheet sands are ubiquitous throughout the Sunnyside delta complex and formed under different conditions. Thin sheet sands are commonly 10-20 feet thick and represent beach and nearshore bar deposits. Thick sheet sands are commonly 30-60 feet thick and represent dispersed distributary channel and distributary mouth bar deposits. Massive bituminous sandstone deposits often 100-250 feet thick represent localized major channel and/or distributary mouth bar deposits. These massive bituminous sandstone deposits appear as major clots on the Roan Cliffs (see Geologic Maps - North Half and South Half) and are associated with a major prograding phase. Beach and nearshore bar deposits are more commonly associated with sandstone dispersal within a minor transgressive phase. The sandstone units are thick in the proximal portion of the delta as seen in Photo 3 and thin in the distal portion of the delta as seen in Photo 4.

The Sunnyside delta complex is suggested to be about fifty to seventy-five percent fluvial dominated and twenty-five to fifty percent wave dominated. This interpretation is based on the distribution of the tar sands shown on the Tar Sand Isopach Map, the distribution of sheet sands and channel deposits as well as the distribution of adjacent environments of deposition. Bitumen saturation in the Athabasca Oil Sands is controlled by lithology and "achieving an understanding of the depositional environments is the single most important step in seeking to map and project the zones of high grade bitumen pay" (Mossop, 1980, p. 609).

Deltaic systems associated with major lakes, either modern or ancient, are rarely described in the geological literature. Axelsson (1967) describes the Laitaure delta that formed at one end of Lake Laitaure in northern Sweden. The multichannel delta has five coalescing distributary mouth bars. The delta covers about two square miles and is about two thousand meters wide along depositional strike and three thousand meters long down depositional dip. The delta formed at one end of a long narrow lake that is about two miles wide and eight miles long. The Laitaure delta represents a large scale version of the four thousand square foot mini delta shown in Photos 5 and 6. Other data noted by Axelsson (1967) indicates that the Rhone delta progrades into the Mediterranean Sea at rates between 15-30 meters per year; the northern subdelta of the Danube River progrades into the Black Sea at rates of 27 meters per year; while the Volga and Terek deltas prograde into the Caspian Sea at rates of 100 meters per year. The Sunnyside delta complex as defined by the tar sands covers an area between 15-20 square miles. Many aspects of the Sunnyside delta complex can be comprehended by visual comparisons with modern deltaic systems regardless of their size. A specific modern analogue for the Sunnyside delta complex has not yet been determined.
BRUIN POINT SUBDELTA

The thickest tar sand accumulations exist near Bruin Point and are within the Bruin Point subdelta as seen on the Tar Sand Isopach Map. The Bruin Point subdelta represents the main deposition center of the Sunnyside delta complex and contains portions of the Parachute Creek, Garden Gulch and Douglas Creek Members as seen in Photo 1 and Figure 23. The Bruin Point area contains eight to fifteen numbered tar zones. Large areas of cumulative MSAT's (main saturated zones) up to 300-700 feet thick are localized in the area of Bruin Point and upper Range Creek as seen on the Tar Sand Isopach Map. The Bruin Point subdelta was the area of principal investigation in 1978, 1980, and 1981. The largest volume of tar sands are localized within the upper portion of the Douglas Creek Member and contained within a nine hundred foot thick zone on the Roan Cliff face that thins over a distance of two miles to a two hundred foot thick zone in the vicinity of Range Creek.

The Bruin Point subdelta has a large arcuate or lobate shape as seen on the Tar Sand Isopach Map. The cause of this lobate shape is suggested to be from extensive sediment influx and partial modification by waves in the shore margin of Lake Uinta. The major locations of linear symetrical ripples occur peripheral to the Bruin Point subdelta and are parallel to its general lobate shape as seen on the Geologic Map South Half. These linear ripples are interpreted to be deposited in shallow water near the lake margin adjacent to the delta complex. Lobate type deltas are characterized by slow progradation as there is a significant downslope loss of sediments on a moderate to deep platform or shelf; open basin energy conditions exist; and the system is fluvial dominated but wave influenced (Galloway, 1975). The Bruin Point subdelta is considered to be fifty to seventy-five percent fluvial dominated and twenty-five to fifty percent wave influenced. The fluvial influence was dominant during the prograding phases, while the wave influence was more important during transgressive phases.

Within the Bruin Point subdelta as seen in Table 13 the Parachute Creek Member or lake facies has an average thickness of 150 feet based on deep drill hole information. The Garden Gulch Member or shore facies has an average thickness of 484 feet based on all deep drill hole data. But more detailed examination indicates that the Garden Gulch Member thickens lakeward. The Douglas Creek Member or delta facies has an average drilled thickness of 452 feet to the first nonbituminous sands. Within the Bruin Point subdelta the principal of lateral accumulation is helpful to explain the sheet-like distribution of the Sunnyside tar sands that are well-exposed above the Asphalt Mine and seen in Photo 1 and Figure 23. These stacked accumulations of bituminous sandstones are associated with multiple transgressions and regressions near the margin of Lake Uinta.

Deep drilling within the Bruin Point subdelta totals 17,725 feet as seen in Table 12. All drill holes were logged in detail on a foot by foot basis and recorded at a scale of 1" =10'. The lithology of the Bruin Point subdelta based on these 17,725 feet of core is: 31.9% sandstone; 12.3% siltstone, 47.6% shale; 6.6% limestone and 1.6% conglomerate. The siltstones and conglomerates are commonly associated with the sandstones. If the lithology is tabulated by
the Parachute Creek, Garden Gulch and Douglas Creek Members, significant changes of lithology exist within the Bruin Point subdelta as seen in Table 12. The changes in the percent sandstone, shale, and limestone are dramatic and reflect the lake, shore and delta environments of deposition as seen below:

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Delta</th>
<th>Shore</th>
<th>Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>%SS</td>
<td>53.4</td>
<td>22.3</td>
<td>4.9</td>
</tr>
<tr>
<td>%SH</td>
<td>28.5</td>
<td>53.5</td>
<td>86.1</td>
</tr>
<tr>
<td>%LS</td>
<td>1.5</td>
<td>11.4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

The Bruin Point subdelta represents the primary area of bituminous sandstones within the Sunnyside delta complex and contains about seventy percent of the total mineable tar sands within the entire Sunnyside delta complex. As seen in Figure 23 and Photo 1 the major portion of these tar sands are contained within the Douglas Creek Member (delta facies). Minor portions of the tar sands are associated with the Garden Gulch Member from tar zones 21 through 33. Limited tar sands are contained within the Parachute Creek Member in tar zone 11.

Specific sandstone units and intervening shale horizons within the Bruin Point subdelta are characterized by specific geophysical signatures that enabled Golder Associates during 1981 to separate the bituminous sandstones into numbered tar zones. Idealized data from these numbered tar zones is contained within Table 13. The Bruin Point subdelta is characterized by bituminous sandstones and intervening red shales, while the Dry Canyon subdelta is characterized by bituminous sandstones and intervening green shales. Initial difficulty in correlating numbered tar zones between these two subdeltas. Ultimately three separate beach to nearshore bar deposits associated with the green shales of the Dry Canyon subdelta provided the framework that established lateral continuity and correlations of numbered tar zones from one subdelta to the other.

**DRY CANYON SUBDELTA**

The Dry Canyon subdelta represents an important secondary deposition center of the Sunnyside delta complex and contains portions of the Garden Gulch and Douglas Creek Members as seen in Photo 2 and Figure 24. The Dry Canyon subdelta is the second most important area of bituminous sandstones as seen on the Tar Sand Isopach Map and contains cumulative MSAT's up to 200-400 feet thick. The Dry Canyon subdelta was the principal area of investigation in 1982 and 1984. The major tar sands are within the Garden Gulch Member and localized within a four hundred foot thick zone on the Roan Cliff face that thins downdip over a distance of one mile to a two hundred foot thick zone beneath the Dry Canyon ridge road. This subdelta contains about twenty percent of the total mineable tar sands.
within the entire Sunnyside delta complex. As seen in Figure 24 and Photo 2 the major portion of these tar sands are contained with the Garden Gulch Member or shore facies from tar zone 31 through 37. Minor portions of the tar sands are associated with the Douglas Creek Member or delta facies from tar zones 38 through 45. The tar sands are primarily contained within distributary mouth bar and beach bar deposits as seen in the idealized section of the Dry Canyon subdelta in Figure 24.

The Dry Canyon subdelta is considered to be a fluvial-dominated elongated delta system as interpreted by the two mile long ridge that extends northeast from the Arco water tank. This elongated ridge system is actually some three miles long as it exists between 24,000 NW and 28,000 NW and is defined by Measured Section No. 9, Amoco No. 48, Arco water tank, Amoco No. 31, Amoco No. 43, Amoco No. 38 and Texaco Government Wolf B-2 as shown on the Regional Map. The elongated type of delta system is characterized by fluvial dominance and weak wave energy associated with rapid progradation into a shallow platform or shelf (Galloway, 1975). Within the well-dissected Dry Canyon subdelta much of the present topographic expression including the elongated Dry Canyon distributary-like ridge and minor ridges off this main ridge are believed to be an expression of paleo-geomorphology. Present topographic ridges and bulges are underlain by tar sands as determined by field work and drill hole information.

As seen on the Tar Sand Isopach Map the Dry Canyon and Bruin Point subdeltas are adjacent to each other and interfinger near their transitional boundary. Some numbered tar zones are often continuous with minor thinning from one subdelta to another. However, some numbered tar zones of the Bruin Point subdelta pinch out near the transitional boundary as determined by John Rozelle. The bituminous sandstones within the Dry Canyon subdelta are associated with two to eleven numbered tar zones. The thickness and number of tar zones gradually decreases to the northwest over a distance of three miles from the southeastern edge of the Dry Canyon subdelta near 20,000 NW to the northwestern limits of the Dry Canyon subdelta near 36,000 NW as seen on the Regional Map and Tar Sand Isopach Map.

Near the transitional boundary of the Bruin Point and Dry Canyon subdeltas at 20,000 NW to 22,000 NW there is an abrupt four hundred foot change in elevation. The Parachute Creek Member has been eroded away within the Dry Canyon subdelta. The Garden Gulch Member has an average thickness of 522 feet as seen in Table 13. Within the Dry Canyon subdelta the Garden Gulch Member thicken gradually but dramatically from five hundred feet near the Roan Cliff face to almost one thousand feet in two miles down depositional dip. The drilled thickness of the Douglas Creek Member averages 100 feet as seen in Table 13.

Deep drilling within the Dry Canyon subdelta totals 17,835 feet as seen in Table 12. The lithology of the Dry Canyon subdelta based on these 17,835 feet of core is: 40.4% sandstone; 10.3% siltstone; 40.5% shale; 7.1% limestone and 1.7% conglomerate. Lithologic differences between the Dry Canyon and Bruin Point subdeltas are significant with changes in percent sandstone and shale the most pronounced as seen in Table 12 and listed below:
The Dry Canyon subdelta has 8.5 percent more bituminous sandstone and 7.1 percent less shale than the Bruin Point subdelta. Changes in the percent of limestone, siltstone and conglomerate are minor as seen in Table 12.

There are significant changes in the lithology of the Garden Gulch Member between the Dry Canyon and the Bruin Point subdeltas. Changes in percent sandstone and shale are the most pronounced as seen in Table 12 and listed below:

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Dry Canyon Subdelta</th>
<th>Bruin Point Subdelta</th>
</tr>
</thead>
<tbody>
<tr>
<td>% SS</td>
<td>40.4</td>
<td>31.9</td>
</tr>
<tr>
<td>% SH</td>
<td>40.5</td>
<td>47.6</td>
</tr>
</tbody>
</table>

Within the Dry Canyon subdelta the Garden Gulch Member has an 84.3 percent increase in sandstone content and a 25.4 percent decrease in shale content. This indicates that the amount of sandstone deposition increases during Garden Gulch time in the vicinity of the Dry Canyon subdelta. It also suggests that lateral accumulation occurred in a northwest direction from the Bruin Point subdelta to the Dry Canyon subdelta and that the Dry Canyon subdelta is younger than the Bruin Point subdelta.

WHITMORE CANYON SUBDELTA

The Whitmore Canyon subdelta is the least significant area of bituminous sandstones within the Sunnyside delta complex and contains one to five separate bituminous sandstone zones. The principal portion of these tar sands are localized in the Garden Gulch Member and associated with minor distributary mouth bar and beach-bar deposits. The Whitmore Canyon subdelta has received limited field investigation, and limited drilling information from four holes is available. As seen from the Tar Sand Isopach Map the area contains a tar sand strip about two miles long by one thousand feet wide. This single elongated strip contains cumulative MSAT's up to 100-200 feet thick. This subdelta is suggested to contain some five percent of the total mineable tar sands within the entire Sunnyside delta complex.

The Whitmore Canyon subdelta was partially examined in the northern half of Section 23 and the southern portion of Section 14, T13S, R13E in early October, 1982 with variable snow cover. The initial interpretation of the Whitmore Canyon subdelta suggests a lower delta plain to delta fringe sequence of distributary channels and thin distributary mouth bar deposits. The tar sands are predominantly associated with green shales and nonbituminous algal-
ostracodal limestone zones in the nearshore environment. The area also contains some red shales of the lower delta plain environments near the oil/water contact. The Whitmore Canyon subdelta represents the waning stages of deltaic deposition within the Sunnyside delta complex.

In the examined area the Whitmore Canyon subdelta contains MSAT's that range from 10-150 feet thick with an MSAT (main saturated zones) average approaching 60-75 feet. These MSAT's do not have a consistent thickness and the overall grade is suggested to be slightly less than the grade in the Dry Canyon subdelta. The outcrops examined are interpreted to be in the 6-8 weight percent bitumen range or 14-19 gallons per ton. No tar seeps in the 10 weight percent bitumen range or 20-24 gallons per ton were noticed.

The drill hole data is from GN-13 and GN-15. GN-13 is located in SWk, Section 13, T.13S., R.13E and GN-15 is located in the NEfc, Section 30, T.13S., R.14E. as indicated on the Regional Map. limited information on the GN drill holes is available from a May, 1982 open report submitted to the U.S. Synthetic Fuels Corporation and data supplied by Chevron Resources to Golder Associates in the summer of 1983. GN-15 contains five bituminous zones 21-77 feet thick with bitumen averages that range from 7.8 to 10.2 weight percent. These five zones total 245 feet. Four of these zones have a weighted average of 8.6 weight percent bitumen or approximately 20 gallons per ton. GN-13 contains five bituminous zones 19-84 feet thick that total 210 feet. Three of these zones have bitumen averages that range from 6.1 to 6.9 weight percent. These three zones total 170 feet with a weighted average of 6.5 weight percent bitumen or approximately 15.5 gallons per ton.

During the summer of 1982 Mono Power-Phillips located seven potential drill sites within the Whitmore Canyon subdelta. Two of these sites were drilled in 1983 but no geological data is available. The location and depths of these two holes were determined in the summer of 1984 and are shown on the Regional Map.

The dissected topography surrounding the Whitmore Canyon subdelta would create a separate mining area as seen from the Tar Sand Isopach Map. Based on this physical isolation, a relatively thin distribution of bituminous sandstones of possible lower grade and a westward climbing paleo oil/water interface between 9,200-9,400 feet, the Whitmore Canyon subdelta is considered the least favorable mineable resource area within the Sunnyside delta complex.
GEOPHYSICS

Geophysical logs were run on each drill hole to obtain geological and geophysical information that could be utilized for rock correlation and evaluation of the bitumen content. The four logs include gamma-density-caliper; multi-channel sonic; focused electric; and neutron-neutron. Attempts to complete the four logs were dependent on downhole conditions. The neutron logs were only run during the 1984 exploration program.

During the 1980 exploration program the geophysical logging was completed by Century Geophysical of Grand Junction, Colorado. These logs are of moderate quality and have one single print-out sheet for all logs. These single sheets are difficult to use and have not been utilized by Golder Associates or myself for any significant geological or geophysical correlation. During the 1981, 1982, and 1984 exploration programs the geophysical logging was completed by BPB Instruments, Inc. of Grand Junction, Colorado. These logs are of excellent quality, have single print-out sheets for each log and have been used extensively for geological and geophysical correlation. The BPB logs were initially run at a scale of 1" = 10' to correspond to the scale of the detailed lithology logs completed on each drill hole. The geophysical logs were also reduced to a scale of 1" = 50' for additional correlation purposes. These reduced geophysical logs correspond to the scale of the lithology strip logs of each drill hole and the measured sections included in this report. The gamma, density and focused electric logs have proved to be the most beneficial logs for geological investigations within the Sunnyside Tar Sands deposit.

GAMMA-DENSITY-CALIPER

The gamma-density-caliper log is obtained from one tool and was utilized to test natural radioactivity levels, determine differences in rock density and check the uniformity in hole size. This tool operates effectively in cased or uncased holes and in dry or fluid conditions.

The natural radioactivity within rock units tends to be low in sandstones and higher in shales, limestones and coals. Natural radioactivity is related to the uranium-radium series, thorium series and potassium $^{40}$. Within the Sunnyside delta complex the gamma responses in API units exist largely between 100-200 with local kicks commonly in the range of 400-800 and rarely up to 1,000. Detailed correlations of high gamma responses with the detailed lithology logs at a scale of 1" = 10' indicates that the high responses are commonly related to biota concentrations associated with limestones. The biota concentrations are black fish scales, bone fragments and/or ostracod zones. The gamma responses related to biota concentrations may be related to either the K40 isotopes or minor uranium concentrations. No uranium minerals have been recognized on the property. Local coal seamlets or pods up to a few inches thick are rare within the Sunnyside delta complex but usually cause high gamma responses. The coal seamlets commonly have responses in API units that range from 150-300 and are rarely in the range of 600-800. These gamma responses from coal may be related to minor uranium concentrations.
The gamma log has often been used as a shale indicator or shale log in the evaluation of shaly units, and this shale indicator is based largely on differences in potassium content. The average shale contains some two percent potassium, 6 ppm uranium and 12 ppm thorium (Merkel, 1979). Gamma responses within the shales of the Sunnyside delta complex range from 80-180 API units with slight differences in the range of 20 API units from hole to hole. Detailed correlation of the different colored shales with gamma responses indicates subtle differences exist between the red, green, variegated shales and gray shales as seen in Table 10. Each colored shale type has a range in API units of about 40 within the overall range of 80-180. For example within one hole responses in API units for red shales might range from 80-120, green shales from 120-160, variegated or mixed colored shales from 140-180, and gray shales from 140-180. Although slight background differences in the range of 20 API units exist from hole to hole, within any one hole red shales have a background value of X, green shales at X + 20 with variegated and/or gray shales at X + 40. The different shales do have a subtle but distinctly different gamma responses, and these can be utilized for lithologic interpretation.

The density log is a reflection of the electron density of the rock material. Density values can be read directly from the log. Porosity values can be determined indirectly from log interpretation charts. Typical density and porosity values are given in Table 10. When density logs are used in combination with the sonic log, the elastic moduli can be determined for engineering purposes.

The caliper log indicates the size of the drill hole. In 1980 and 1981 oversized bits, 3.032 inches in diameter were used by Longyear with average daily drilled footage approaching 60 feet per ten hour shift. In 1982 and 1984 regular bits, 2.980 inches in diameter, were used by Longyear with the average daily drilled footage approaching 100 feet per ten hour shift. Apparently the regular bit allows better water circulation at the bottom of the hole and drilling proceeds at a higher rate. With few exceptions the three inch diameter hole shows no variation in size. The exceptions are caused by minor caving that is commonly associated with the Parachute Creek Member. The rock units within the Garden Gulch and Douglas Creek members exhibit very limited caving within the drill holes.

MULTI-CHANNEL SONIC

The sonic log represents a recording of the time required for a sound/acoustic wave to travel through typically two foot of rock formation. This internal transit time is given in microseconds per foot. The transit time is a function of the lithology, porosity and type of fluid in the pore space; if the lithology is known, good porosity values can be obtained by utilizing the sonic log (Schlumberger, 1972).

Within the Sunnyside delta complex the interval transit time has a range from 60 to 120 microseconds per foot. As seen in Table 10 sandstones commonly have a range of 80 to 95; siltstones commonly have a range from 70 to 85; limestones commonly have a range of 60 to 70; and shales commonly have a range of 65 to 90. The sonic log has been utilized to obtain primary porosity values and coupled with the density log could be utilized to determine compressive strength index.
Primary porosity values of bituminous sandstones and limestones were determined by (1) obtaining the interval transit time in microseconds per foot from the sonic log, (2) determining the lithology from the drill hole core logs and (3) utilizing the log interpretation charts from Schlumberger. These determined porosity values are noted in Table 10. Porosity values determined from sonic logs are considered by the geophysical industry to be better and more specific than porosity values determined from density logs. The bituminous sandstones have a porosity range between 20-34% with 25-27% porosity as the most prevalent. The higher porosity values appear near the top of distributary mouth bar deposits, while some of the lower porosity values are associated with beach to nearshore bar deposits. The bituminous limestones have porosities that range from 15-26% as seen in Table 10. Porosities of 20-26% are commonly associated with ostracodal limestones, coquinas or biomicrites. Porosities of 15-20% are commonly associated with the more dense limestones or micrites.

**FOCUSED ELECTRIC**

Resistivity logs are obtained by passing a current through the rocks, measuring the voltages and determining the resistivity values. Conventional electric logs are greatly affected by conditions in the borehole and adjacent formations. These variable conditions can be minimized by the use of focusing currents to control the path taken by the measured current (Schlumberger, 1972). The focused-electric logs must be completed with fluid in the hole and represent a calibrated resistivity of the rock units. Impermeable beds such as a shale are electrically conductive due to the presence of ion-bearing water and have low resistivity values; permeable beds are less electrically conductive and have higher resistivity values (Merkel, 1979). Within the Sunnyside Tar Sands project shales tend to have low resistivity values that range from 40-600 ohm/meters as seen in Table 10. The presence of hydrocarbons causes higher resistivity values as hydrocarbons are normally insulators (Schlumberger, 1972). Within the Sunnyside Tar Sands project bituminous zones cause resistivity values to increase dramatically with values up to 5,000 ohm/meters for bituminous sandstones and values up to 10,000 ohm/meters for bituminous limestones as seen in Table 10.

**NEUTRON**

The neutron log is obtained from one tool that bombards the rock formation with neutrons. The drill hole must contain fluid for the sonde to function. The bombarding neutrons are slowed down most effectively by hydrogen ions as both the neutrons and hydrogen ions have the same atomic mass. The log measures this slowing down reaction of the neutrons that is proportional to the amount of hydrogen in the formation. In effect the neutron log measures the hydrogen ion content in the formation. Crude oil and water have essentially the same hydrogen density; dry gas (i.e. no dissolved liquid hydrocarbons) has a lower hydrogen content; and clean reservoir rocks contain little or no hydrogen. The neutron log measures the rate of decrease of neutron density and converts this to a calibrated porosity value for oil and water saturated rocks. Thus the neutron log can record porosity. The above data was summarized from Schlumberger (1972), Merkel (1979) and Dresser Atlas (1982).
In 1984 neutron logs were completed on drill holes Amoco Nos. 49-53, Amoco Nos. 60-63 and Amoco No. 17. Porosity values of the bituminous sandstones from the neutron-neutron logs range from 24-38 percent. These porosity values are 20-40 percent higher than helium porosities obtained by Core Labs Inc. of Denver. The neutron log is a necessary component of the three logs needed by BPB Instruments to complete an indirect tar sand analysis.

TAR SAND ANALYSIS

Determination of the bitumen content of tar sands can be done by direct and indirect methods. Direct analysis of core provides the best measurement of bitumen content and to date is the only method utilized on the tar sands. Geophysical well-logging techniques coupled with computer programs can provide indirect measurement of bitumen content. A method that utilizes the focused-electric, neutron and density logs has been used by BPB Instruments, Inc. to determine the grade of bitumen associated with the Athabasca Tar Sands; but no specific information is available from BPB to compare the percent error between bitumen content based on direct core analysis versus indirect well log analysis. The computer tar sand analysis by BPB requires input from a density, neutron and focused electric log; results are shown graphically in strip log form at 1" = 10' and in a computer printout list at six-inch and two-foot intervals. The format includes volume percentages of porosity, matrix and shale; percentages of silt and clay; water and tar porosity, and water and tar weight percent.

In 1984 BPB Instruments completed a demonstration of indirect tar sand analysis on Amoco No. 17. The results of the indirect method are compared in Table 6 with the results of the direct method by numbered tar zones. The percent error between the direct and indirect methods ranges from +38.9% to -14.7% with an average error of -0.05% and a weighted average error of +1.2%. Values for the indirect method are based on the six-inch interval printout lists. The two-foot interval printout lists were found to be totally inadequate as the abrupt lithologic and bitumen boundaries could not be sufficiently isolated. All parameters within the data base of the BPB indirect tar sand analysis were examined to find and evaluate additional applications. No parameter can be correlated with the "fines" content of the tar zones in Amoco No. 17. The "fines" content of each tar zone was tabulated from data of Core Labs and is listed in Table 7. Within Amoco No. 17 porosity values shown in Table 7 were determined from the BPB printout list. No porosity values were determined by Core Labs in Amoco No. 17, so comparisons of porosity values from direct and indirect methods cannot be made.

The indirect method of tar sand analysis by BPB Instruments can be used to determine bitumen content but some definite analytical and physical limitations do exist. The analytical limitations are shown in Table 6 and indicate a range of percent error that exceeds a reliable five to ten percent level. The physical limitations are twofold. The hole must remain open and fluid conditions must exist in the entire hole as both the neutron-neutron and focused electric logs require fluid to function properly. Amoco No. 17 was selected as the research hole because it maintains full water levels. But in 1984 the geophysical tools ( sondes) were stopped at a depth of 928 feet. The hole was completed in 1981 to a drilled depth of 1015 feet. Drill holes within the Sunnyside Tar Sands deposit are rarely full of water immediately after the drilling is terminated. Therefore, tar zones that exist above the water level cannot be analyzed by the indirect method.
The abrupt topographic changes within the Sunnyside Tar Sands deposit and peripheral areas cause irregular and unreliable water level conditions in drill holes. Drill core and direct core analysis will always be necessary for reliable and definitive results of bitumen content. The indirect well log analysis is not considered to be a viable alternative to the direct core analysis. As the project continues dewatering of the deposit will escalate, and the indirect method of tar sand analysis will become more problematic.

ELECTRIC LOG INTERPRETATION

Electric logs can be used as lithology logs and aid in the interpretation of sedimentary environments of deposition. The electric logs that best reflect lithology are the (1) spontaneous potential log that measures different natural responses of electric current in millivolts and (2) the resistivity log that measures different responses of resistivity in ohm/meters. Fluid must be in the hole to obtain an SP (spontaneous potential) or R (resistivity) log. The SP log has been recognized as a sedimentation curve and used extensively to interpret various aspects of lithology. Some of the initial work was published by Fisher (1969), Visher (1969) and Pirson (1970) as summarized in Figure 26. Diagrams of SP log responses associated with deltaic environments are shown by Coleman and Prior (1982) and reproduced in Figures 27 through 30.

The overall shape and detailed patterns of the curves in electric logs are a reflection or signature of lithology. By convention the spontaneous potential log is indicated on the left side of the hole and the resistivity log is indicated on the right side. The SP and R logs in Figures 26-30 illustrate mirror-like responses. On both the SP and R logs the so-called shale line is nearest the hole, while the so-called sand line is further away from the hole. Thus portions of the curve nearest the hole represent a high shale content and portions of the curve away from the hole represent a high sandstone content. Deflections in the curve represent changes in energy conditions and grain size. Abrupt or large deflections in the curve indicate rapid changes in energy levels during deposition that result in rapid grain size changes. Small deflections indicate small changes in the energy conditions that result in gradual changes in grain size. Serrated patterns indicate fluctuating energy levels. Smooth patterns indicate relatively constant energy levels and limited changes in grain size. Changes in the shape and pattern of the curves reflect changes in energy conditions as well as changes in grain size and can be used to interpret lithology and sedimentary environments of deposition.

Pirson (1970) and Merkel (1979) indicate the SP log curves are controlled by grain size distribution and strongly reflect sedimentation patterns. Pirson (1970) has divided the SP log curves into three fundamental shapes: bell-shaped; barrel-shaped; and funnel-shaped. Each shape characteristically develops in a different portion of a deltaic system as shown in Figures 26 through 30.
The bell-shaped curve commonly exists within channel sands as seen in Figure 27, electric log response no. 2 and 6. The SP response or deflection continues to decrease upward and inward toward the shale line and indicates a continuing decrease in energy conditions with a continuing decrease in grain size. This fining upward sequence is characterized by a bell-shaped curve and is a signature for fluvial/river environments. Bell-shaped curves are indicative of meander-belt channel sands within the fluvial system and are located within or above the upper delta plain. Bell-shaped curves are not common within the Sunnyside delta complex but exist in modified forms near the base of the tar sands along the Roan Cliff face.

The barrel-shaped curve commonly exists within the lower delta plain as seen in Figure 26, Number A; Figure 28, electric log responses No. 5 and 8; Figure 29, electric log response No. 6; and Figure 30, electric log responses No. 3, 6, and 8. The SP response or deflection is abrupt and extended at both the bottom and top; this indicates rapidly changing energy conditions at both the bottom and top. These energy conditions are indicative of sedimentation related to both fluvial and prograding processes (Merkel, 1979) and are characteristically associated with distributary channels of delta complexes. Barrel-shaped curves are a common feature within both the Bruin Point subdelta and the Dry Canyon subdelta.

The funnel-shaped curve commonly exists within the delta fringe as seen in Figure 26, number B; Figure 28, electric log responses No. 3 and 7; Figure 29, electric log responses No. 3, 4, and 8; and Figure 30, electric log response No. 2. The SP response or deflection gradually increases upward and outward toward the sand line and indicates a continuing increase in energy conditions with a continuing increase in grain size. This coarsening upward sequence is characterized by a funnel-shaped curve and is a signature of distributary mouth bar deposition in the delta fringe. Funnel-shaped curves are a common feature in portions of both the Bruin Point subdelta and Dry Canyon subdelta.

Within the Sunnyside Tar Sand deposit the focused electric type of resistivity log has been used to more clearly define the bitumen content of the tar sands. The FE log has repeatedly demonstrated high accuracy as a lithology log. It shows direct correlations with lithologic differences when superimposed over the drill hole logs at a scale of 1" = 10*. The detailed accuracy of the FE log is such that one to three inch shale, limestone and conglomerate partings within the bituminous sandstones have direct obvious responses. Thin sandstone and siltstone zones within the shales also have direct obvious responses. The shape and patterns of the focused electric (FE) log serve as guides in evaluation of sedimentary environments of deposition. In 1984 core recovery from ten deep drill holes averaged ninety-nine percent. Sedimentary environments of deposition were initially established while logging the core, but the FE logs offer additional patterns and trends of sedimentation.
within the Sunnyside delta complex lithology, sedimentary structure, and biota were primarily utilized to determine the various environments of depositions. Other influencing factors include Walther's Law of Facies and the shape of focused electric curves. As stated by Visher (1965) Walther's Law of Facies indicates that sediments which are areally adjacent must succeed each other vertically. As stated by Reineck & Singh (1980) Walther's Law of Facies indicates that environments that are laterally associated with each other geographically may become associated in a vertical sequence. The shapes of the focused electric curves have been utilized to delineate sedimentation patterns and define environments of deposition. Bell-shaped curves indicate meander-belt channel sands within the fluvial systems that extend into the upper delta plain. Barrel-shaped curves indicate distributary channels within the lower delta plain. Funnel-shaped curves indicate distributary mouth bar deposits in the delta fringe. Within the Sunnyside delta complex bell-shaped curves exist near the base of the tar sands, barrel-shaped curves commonly exist near the middle portion of the tar sands and funnel-shaped curves are present in the distal portions of the tar sand deposit. Serrated barrel-shaped curves are the most prevalent within the main portion of the Sunnyside Tar Sand deposit. Beach and nearshore bar deposits tend to have a serrated barrel-shaped or a weakly defined funnel-shaped curve. High gamma responses exist at the base of numbered tar zones with a ninety percent frequency of occurrence (John Rozelle, personal communication, 1985). These high gamma responses commonly reflect limestone units.

Electric log interpretations on Amoco drill holes support the idealized geology sections shown in Figures 23 and 24. In Volume III some geophysical logs have been included with the lithology logs for Amoco Nos. 51, 54, and 63. Direct comparisons of the geophysics and geology can be made by superimposing the lithology, gamma-density-caliper and focused electric logs. All logs are at a scale of 1" = 50'.

Drill hole No. 51 is near the transitional area between the Bruin Point and Dry Canyon subdeltas. Amoco No. 51 is in the proximal portion of the Dry Canyon subdelta. Serrated barrel-shaped curves are commonly associated with the tar sands and suggest stacked deltaic deposits. High gamma responses occur at the base of some tar zones. The bulk density differences between sandstone and shale are readily apparent.

Drill hole No. 54 is in the proximal portion of the Dry Canyon subdelta and located between the north area pilot mine and the Arco water tank. Within Amoco No. 54 Zone 41 has an overall barrel-shaped curve but consists of two stacked bell-shaped curves. Zone 37 has a serrated barrel-shaped curve. These curves suggest that distributary channels exist near the base of the tar sand deposit and are transitional to overlying distributary mouth bar deposits. This relationship is shown in the idealized geology section of Figure 24. The periodic gamma kicks in Amoco No. 54 are largely associated with limestone and IFC zones. These periodic gamma kicks indicate a cyclic nature within the Sunnyside delta complex.
Drill hole No. 63 is near the northeastern distal portion of the Bruin Point subdelta. The serrated barrel-shaped curves associated with tar zones suggest distributary mouth bar deposits. From the base of one tar sand deposit across lithologic boundaries to the base of the next tar sand deposit the FE curves are bell-shaped and show fining upward sequences. Zone 36 is associated with a funnel-shaped curve and suggests a distributary mouth bar near the delta fringe. Gamma kicks are associated with oil shale and limestone. The lithology strip log of Amoco No. 63 shows the common occurrence of limestones below tar sands in Zones 21, 35, 36, and 37. These subsurface limestone zones offer additional evidence for the cycles of sandstone-shale-limestone deposition or repeated fining upward sequences within the Sunnyside Tar Sands deposit.
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Photo 2. Looking southeast at the Sunnyside delta complex and Bruin Point, located just below the upper yellow dot. The northern portion of the Sunnyside delta complex is well-exposed along the Roan Cliffs and the Right Fork of Whitmore Canyon occupies the main drainage in the foreground. The left skyline is 2.3 miles away, Bruin Point is 3.5 miles away and the right skyline is 5.5 miles away. The upper portion of the fifteen to twenty percent grade road to Bruin Point is along the ridge line between the two yellow dots. The left blue dot locates the proposed north area pilot mine. The right blue dot is near drill hole Amoco No. 47 and 22,000 NW. The radio tower to the left of the upper yellow dot and above the right blue dot is near 20,000 NW. This area between 20,000 NW to 22,000 NW represents the transitional area between the Bruin Point subdelta to the right and the Dry Canyon subdelta to the left. Tar sands in Zones 33, 35, and 36 are visible below the right blue dot. The distinct near-horizontal band just above the right yellow dot and extending to the left marks bituminous Zone 37. The ridge line between the left blue dot and the right green dot locates measured section No. 9. Zones 41 and 42 are located on either side of the large aspen-covered saddle in the middle portion of measured section No. 9 and below the right blue dot. The right green dot locates the bottom of bituminous Zone 45 and the base of the tar sands at an elevation of 9000 feet. The left green dot is located on measured section No. 5 near the base of bituminous Zone 42 at an elevation of 9100 feet. Immediately below this left green dot is nonbituminous Zone 43 near 28,000 NW. The base of the tar sands gradually rises to the left and is near an elevation of 9300 feet at the baseline intersection with 36,000 NW in the northern portion of the Dry Canyon subdelta. The prominent cliff between the left yellow dot and the right green dot is the main subject of Photo 3.
Photo 1. Looking northwest at the Sunnyside delta complex and Bruin Point, located just below the right yellow dot. The southern portion of the Sunnyside delta complex is well-exposed on the Roan Cliffs and the continuity of the gray-colored zones of tar sands is apparent. Bear Canyon is in the lower left. The view is almost two miles wide and taken from three miles southeast of Bruin Point as shown on the Tar Sand Isopach Map. The upper portion of the fifteen to twenty percent grade road to Bruin Point is along the ridge line between the two yellow dots. The Asphalt Mine is located behind the left green dot. Both green dots are near the base of the tar sands. This view shows the Roan Cliff portion of the Bruin Point subdelta that is within the Green River Formation of Eocene age. The sedimentary beds strike northwest and dip five to seven degrees northeast. The Parachute Creek Member on lake facies lies above the blue dot, is about one hundred fifty feet thick and is well-exposed on the light gray nonvegetated slopes. The Garden Gulch Member or shore facies lies between the blue and red dots, is about three hundred and twenty feet thick and is characterized by greenish gray shales and thin limestones. The Douglas Creek Member or delta facies exists below the red dot and contains the largest volume of tar sands with intervening reddish brown shales. The upper portion of the Douglas Creek Member between the red and right green dots is about three hundred feet thick and contains sheet-like gray-colored bituminous sandstones. The four prominent tar zones at and below the red dot represent Zone 35, Zone 36, Zone 37, and Zone 41 at the right green dot. Measured section No. 3 exists along the ridge line between the blue and left green dots. Below the plane of the two green dots and left yellow dot white to red-stained sandstones of the Douglas Creek Member are nonbituminous. At the viewpoint cumulative thickness of the tar sands is less than fifty feet with the base of the tar sands near an elevation of 9600 feet. Above the Asphalt Mine the cumulative thickness of the tar sands is five hundred feet with the base of the tar sands near an elevation of 8800 feet.
Photo 3. Looking northwest at thick tar zones in the proximal portion of the Sunnyside delta complex. The foreground and right portion of the photo encompass eight hundred vertical feet between the trees at the top right near an elevation of 9700 feet to the base of the photo near an elevation of 8900 feet below the lowermost green dot. The photo was taken on the Bruin Point road near drill site CR-12. The red dot is fifteen hundred feet away and locates drill site CR-25 with a vertical depth of 874 feet. In CR-25 from 0-832 feet tar sands occupy 710 feet or eighty-five percent of the footage. The base of the tar is at a depth of 832 feet and an elevation of 8798 feet. The numerous green dots mark nine gray-colored tar zones. Starting above CR-25 from top to bottom the nine green dots mark Zones 33, 35, 36, 37 (light green dot), 38, 41, 42, 43 and 45. The left light green dot is twenty-four hundred feet away and shows the position of Zone 37 on measured section No. 4. The two light green dots are both on Zone 37 and help to illustrate the lateral continuity of this bituminous sandstone unit. Zone 37 is the most voluminous and single most important sandstone unit in the entire Sunnyside Tar Sands deposit. Zone 37 contains 21.52 percent of the geologic reserves (Pincock Allen and Holt; April, 1985; Figure 6-3). The right blue dot is sixty-five hundred feet away and is near drill site Amoco No. 48 and the proposed north area pilot mine. Amoco No. 48 begins in Zone 31, but the tree cover obscures the outcrops of Zone 31. The left blue dot is near the top of measured section No. 9. From Amoco No. 48 tar Zone 31 does not continue laterally into measured section No. 9. The main subject of Photo 4 is about two miles downdip from Photo 3.
Photo 4. Looking north at thin tar sands in the distal portion of the Sunnyside delta complex that is located in the southwest portion of the Uinta Basin. At the center skyline the snow-capped peaks of the Uinta Mountains are eighty miles away and near the north side of the Uinta Basin. The photo is taken from the lower portion of measured section No. 18 as shown on the Tar Sand Isopach Map. The lower foreground is about one thousand feet away and the upper right portion is about three thousand feet away. The ridge line extending from the lower left corner to the upper right corner locates measured section No. 15 and encompasses almost twelve hundred vertical feet from an elevation near seventy-eight hundred feet in the lower left to almost nine thousand feet in the upper right. The upper green dot represents the "base of the brown" or bottom of the Parachute Creek Member or lake facies. The Garden Gulch Member or shore facies is seven hundred thirty feet thick and exists between the upper green dot and the upper yellow dot. This shore facies with its characteristic greenish gray shales is almost twice as thick in the distal portion as in the proximal portion of the Sunnyside delta complex. Between the two yellow dots the reddish brown shales of the Douglas Creek Member or delta facies are visible. From top to bottom the green dots represent bituminous Zones 11, 31, 33, 36, 99, and 37. These six zones contain visual estimates of weak (1-3 wt%) to moderate (3-6 wt %) bitumen with Zones 36 and 99 containing the highest bitumen concentrations. Photo 7 of the 1982 exploration report illustrates Zones 36 and 99 with intervening beds of ostracodal limestones and greenish gray shales. The two yellow dots represent nonbituminous Zones 41 and 42. This photo is about two miles downdip from the previous photo. Comparisons of Photo 3 and Photo 4 illustrate the distinct thinning of the tar sand units from the proximal to the distal portion of the Sunnyside delta complex.
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\[ m \]

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\[ f \land 7 \]

\[ \forall \xi \]

\[ \mathfrak{i}^* \]

\[ \nu \mathfrak{C} \mathfrak{f}? \]
Mini delta model in South Spring settling pond on Range Creek. View looks north up Range Creek and shows a small delta system that has developed in the pond during the four year period from June, 1980 to June, 1984. This mini delta model helps to visualize concepts and terminology used at the Sunnyside delta complex. Upstream from the yellow dot the fluvial system has meandering channels. Downstream from the yellow dot the channels or distributaries are relatively straight. Field work throughout the Sunnyside delta complex suggests that channels or distributaries are relatively straight. The distributary channels near the right blue dot and between the two red dots form distributary mouth bars at the pond interface. The area between the yellow and two red dots represents the proximal portion of this mini delta model. Field work and logging of core both indicate thickening of many sandstone units near the cliff face. The Asphalt Mine below Bruin Point is suggested to have formed in the proximal portion of a deltaic environment. The distance between the two blue dots is forty-three feet. Near the right blue dot the east distributary is three feet wide and near the right red dot the west distributary is five feet wide. Below the left blue dot miniature beaches exist and are transitional to beach bar deposits that in turn are transitional to distributary mouth bar deposits. The two red dots and the right blue dot in this photo are located in the same positions in Photo 6.
Photo 6. Depositional surfaces and slopes within the mini delta model. The view is looking east across the delta mouth and shows the prograding depositional slopes at the pond interface. The view also helps to visualize the dispersal patterns of sediments at a delta mouth and the lateral continuity associated with migrating distributary mouth bars and adjacent transitional beach bar deposits. All sediments near the delta mouth are soft and measurements on the subaqueous depositional slopes were taken with a flat board and dipmeter. The distributary mouth bar to the right of and below the blue dot has subaqueous slopes of twenty-six degrees. The mouth bar of the main distributary between the two red dots has subaqueous slopes of twenty-nine degrees on the east or far side and thirty-six degrees on the west or near side. Subaqueous slopes in the foreground are thirty-one degrees. The Sunnyside delta complex is about six hundred times larger than this mini delta model. But the distribution of sediments, processes of development and concepts that explain Photos 5 and 6 can be applied to the Sunnyside delta complex.
Photo 7. Drill Core from Zone 35, Garden Gulch Member, Amoco No. 52 between 429-486 feet.

<table>
<thead>
<tr>
<th>Environment of Deposition</th>
<th>Tar Zone</th>
<th>Vertical Depth in feet</th>
<th>Description</th>
<th>Bitumen Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearshore</td>
<td>429-441</td>
<td>nonbituminous greenish gray (5GY 6/1 to 5G 6/1) to medium bluish gray (5B 5/1) shale; massive to thinly bedded with tar films on fractures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distributary Mouth Bar</td>
<td>441-443.5</td>
<td>bituminous limestone IFC with ostracodal and algal clasts</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>443.5-466.8</td>
<td>bituminous fine grained to very fine grained quartz sandstone with 1-2% fine grained muscovite; some laminae solely crinkled muscovite; rich tar obscures bedding features</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>466.8-467.1</td>
<td>three inch bituminous siltstone IFC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>467.1-477.9</td>
<td>bituminous fine grained to very fine grained quartz sandstone; rich tar in sealed vertical fracture from 470-474</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levee</td>
<td>477.9-481</td>
<td>nonbituminous gray shale</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>481-486</td>
<td>bituminous siltstone with bedding planes at 5-10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Footage</th>
<th>Wt %</th>
<th>Gal/Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>431-441</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>441-451</td>
<td>9.7</td>
<td>23.3</td>
</tr>
<tr>
<td>451-461</td>
<td>10.5</td>
<td>25.2</td>
</tr>
<tr>
<td>461-471</td>
<td>10.9</td>
<td>16.0</td>
</tr>
<tr>
<td>471-477.9</td>
<td>10.4</td>
<td>25.0</td>
</tr>
<tr>
<td>477.9-481</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>481-486</td>
<td>8.2</td>
<td>19.7</td>
</tr>
</tbody>
</table>
HI

—:"A

\textsuperscript{7}P_1
Photo 8. Drill Core from Zone 36, Garden Gulch Member, Amoco No. 53 between 431-489 feet.

<table>
<thead>
<tr>
<th>Environment of Tar Deposition</th>
<th>Vertical Depth in feet</th>
<th>Description</th>
<th>Bitumen Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributary Mouth Bar</td>
<td>431-453.5</td>
<td>bituminous fine grained to very fine grained quartz sandstone; 1% fine grained muscovite; six inch siltstone IFC near 448</td>
<td>431-441 9.8 23.6</td>
</tr>
<tr>
<td>Nearshore</td>
<td>453.3-455.8</td>
<td>2.5 foot thick bituminous biomicrite to ostracod coquina</td>
<td>453.3-455.8 8.7 20.8</td>
</tr>
<tr>
<td></td>
<td>455.8-460.8</td>
<td>strong bioturbation in nonbituminous greenish gray shale</td>
<td>455.8-460.8 1.1 2.7</td>
</tr>
<tr>
<td></td>
<td>460.8-470.3</td>
<td>interbedded bituminous siltstone and nonbituminous greenish gray shale</td>
<td>460.8-470.3 2.4 5.7</td>
</tr>
<tr>
<td></td>
<td>470.3-480.4</td>
<td>interbedded bituminous quartz sandstone and greenish gray shale</td>
<td>470.3-480.4 1.0 2.4</td>
</tr>
<tr>
<td>Beach</td>
<td>480.4-486.9</td>
<td>bituminous fine grained to very fine grained quartz sandstone with current ripple laminations to small-scale, medium-angle trough crossbedding</td>
<td>480.4-486.9 3.3 7.9</td>
</tr>
<tr>
<td>Nearshore</td>
<td>486.9-489</td>
<td>nonbituminous light gray shale</td>
<td>486.9-492 0.5 1.3</td>
</tr>
</tbody>
</table>
Photo 9. Drill Core from Zone 37, Garden Gulch Member, Amoco No. 54 between 419-477 feet.

<table>
<thead>
<tr>
<th>Environment of Deposition</th>
<th>Tar Zone</th>
<th>Vertical Depth in feet</th>
<th>Description</th>
<th>Bitumen Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributary Mouth Bar</td>
<td>419-421</td>
<td>bituminous fine grained to very fine grained quartz sandstone with 3&quot; and 5&quot; siltstone IFC's</td>
<td>418-428 6.5</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>421-439.5</td>
<td>bituminous fine grained to very fine grained quartz sandstone with drill scars</td>
<td>428-440 9.2</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td>439.5-444.4</td>
<td>shale-siltstone IFC</td>
<td>440-450 6.9</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>444.4-445.3</td>
<td>nonbituminous light to medium gray shale</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>445.4-450.4</td>
<td>bituminous fine grained to very fine grained quartz sandstone with two 5&quot; shale IFC's</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>450.4-454.3</td>
<td>nonbituminous light gray shale (i.e. internal waste)</td>
<td>450-454.3 2.3</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>454.3-473.3</td>
<td>bituminous fine grained to very fine grained quartz sandstone with planar bedding at 10°</td>
<td>454.3-464.3 9.7</td>
<td>23.2</td>
</tr>
<tr>
<td>Nearshore</td>
<td>473.3-476.5</td>
<td>weakly bituminous IFC of greenish gray shale</td>
<td>473.3-483.3 0.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>476.5-477</td>
<td>nonbituminous greenish gray (5GY 6/1 to 5G 6/1) shale</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Photo 10. Drill Core from Zone 38, Garden Gulch Member, Amoco No. 52 between 778-836 feet.

<table>
<thead>
<tr>
<th>Environment of Deposition</th>
<th>Tar Zone</th>
<th>Vertical Depth in feet</th>
<th>Description</th>
<th>Bitumen Analysis Footage Wt % Gal/Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributary Mouth Bar</td>
<td>778-780.6</td>
<td>bituminous fine grained to very fine grained sandstone with 19&quot; siltstone IFC</td>
<td>772.6-782.6</td>
<td>8.6  20.5</td>
</tr>
<tr>
<td></td>
<td>780.6-796.7</td>
<td>bituminous fine grained to very fine grained quartz sandstone with 1% fine grained muscovite; local siltstone IFC's and 2.7 feet of streaky saturated siltstone</td>
<td>782.6-792.6</td>
<td>10.1  24.3</td>
</tr>
<tr>
<td></td>
<td>796.7-813.1</td>
<td>bituminous fine grained to very fine grained quartz sandstone with planar crossbedding at dips of 25-30 near base</td>
<td>802.6-813.1</td>
<td>8.2  19.8</td>
</tr>
<tr>
<td>Inter- distributary bay</td>
<td>813.1-815</td>
<td>bituminous ostracodal micrite and non-bituminous light gray shale with limited ostracods</td>
<td>813.1-823.1</td>
<td>0.1  0.2</td>
</tr>
<tr>
<td></td>
<td>815-825</td>
<td>nonbituminous mixed colored shale: gray 35%, green 25%, purple 5%, olive 5%, red 30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>825-827</td>
<td>ostracodal micrite to ostracodal coquina</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>827-830</td>
<td>nonbituminous mixed colored shale</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>830-831</td>
<td>transitional contact of Garden Gulch Member and Douglas Creek Member</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marsh</td>
<td>831-836</td>
<td>pale red (5R 4/2) to grayish red (5R 6/2) shale; possible rootlets</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DETAILED LOCATION MAP
SUNNYSIDE TAR SANDS
UTAH

SCALE: 1" = 1 MI.
EXPLANATION

Outcrop of oil-impregnated rock.
Underlain by oil-impregnated rock.
Underlain by scattered, lean oil-impregnated rock.

Cretaceous outcrop with coal seams thicker than 4 feet.
Cretaceous outcrop with thin coal seams.

Deeply buried Cretaceous strata.

K
Coal mine.

Tar and Coal Resources Near Sunnyside Tar Sands
from Energy Resources Map of Utah,
Map 44.

005?2
Both a steam drive and steam soak pilot test were conducted.

A cross-section across the pilot area shows the zones used for drive and soak operations.

Thurber and Weibourn, 1977

Figure 5

Drill Hole Data of Thermal Tar Sand Tests by Shell Oil Company
Note: All three of these holes are oriented N32°W and are, therefore, nearly at right angles to the principal channel trends of N40° to 70°E. The data demonstrates that abrupt lateral changes exist in directions perpendicular to the channel trends.

Figure 6

Data from Signal's Horizontal Wells, Main Pit, Asphalt Mine
Structural Divisions of Utah

Figure 7
Figure 8  Geologic Section of San Rafael Swell.
Figure 9  Geologic Section of Uinta Basin.

Hintze, 1972
Figure 10 Uinta Basin - Geologic Section and Oil and Gas Fields.
Figure 11 Geologic Section of Price-Soldier Summit.

Hintze, 1972
Middle Eocene paleogeography, Upper Parachute Creek Member, Green River Formation, northeastern Utah.

Late Eocene paleogeography, saline facies, Uinta Formation, northeastern Utah.

Early Paleocene paleogeography, North Horn Formation, northeastern Utah.

Picard, 1985

Figure 12

Paleocene and Eocene Paleogeography of Northeastern Utah
### CENOZOIC

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>EPOCH</th>
<th>AGE</th>
<th>nCKa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary</td>
<td>PLEISTOCENE</td>
<td>Quaternary</td>
<td>0.01</td>
</tr>
<tr>
<td>Oligocene</td>
<td>PICAZIAN</td>
<td>ZANCLEAN</td>
<td>MESSINIAN</td>
</tr>
<tr>
<td>Eocene</td>
<td>OLIGOCENE</td>
<td>LUTETIAN</td>
<td>53 Ma</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>CENOZOIC</td>
<td>58 Ma</td>
<td></td>
</tr>
</tbody>
</table>

**Figur 13**

Eocene Time Scale and Generalized Stratigraphic Column in the Uinta Basin

---

**GENERALIZED STRATIGRAPHIC COLUMN OF EOCENE NON-MARINE SEDIMENTARY UNITS OF THE UINTA BASIN.**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uinta FM.</td>
<td>Halfway</td>
<td>Fluvial sandstones, conglomerates</td>
</tr>
<tr>
<td>Uinta FM.</td>
<td>Randlett</td>
<td>Fluvial sandstones, conglomerates</td>
</tr>
<tr>
<td>Uinta FM.</td>
<td>Myton</td>
<td>Fluvial sandstones, conglomerates</td>
</tr>
<tr>
<td>Uinta FM.</td>
<td>Wagonhound</td>
<td>Fluvial sandstones, conglomerates</td>
</tr>
</tbody>
</table>

---

1. Salvador, 1985
2. Mauger, 1977

---

**REFERENCES:**

1. Salvador, 1985
2. Mauger, 1977
Figure 14; Relationship of Bitumen Content and Compressive Strength in Sandstones, Sunnyside Tar Sands
FLUVIAL FACES (DOMINANTLY SAND)

DELTA MARGIN SAND FACES

Sediment input

Marsh/swamp and muddy overbank
sediment veneer

Schematic diagram depicting the threefold division of sedimentary systems into fluvial-dominated, wave-dominated, and tide-dominated types. The relative importance of sediment input, wave energy flux, and tidal energy flux determine the morphology and internal stratigraphy of the delta. (After Galloway 1975)

REINECK & SINGH, 1980

TABLE 2. CHARACTERISTICS OF DELTAIC DEPOSITIONAL SYSTEMS

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Wave-Dominated</th>
<th>Tide-Dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel type</td>
<td>Elongate to lobate</td>
<td>Arcuate</td>
</tr>
<tr>
<td>Bulk composition</td>
<td>Muddy to mixed</td>
<td>Estuarine to irregular</td>
</tr>
<tr>
<td>Framework facies</td>
<td>Distributary mouth bar and channel fill sands</td>
<td>Coastal barrier and beach ridge sands</td>
</tr>
<tr>
<td>Framework orientation</td>
<td>Parallels depositional slope</td>
<td>Parallels depositional strike</td>
</tr>
</tbody>
</table>

GALLOWAY, 1975

Classification and Characteristics of Deltaic Depositional Systems.
MISSISSIPPI DELTA SYSTEM (MODERN), LOUISIANA

ROCKDALE DELTA SYSTEM, LOWER WILCOX GROUP (EOCENE), TEXAS

Fig. 16 CONCEPTUAL MODELS OF ENVIRONMENTAL FACIES ASSOCIATED WITH PROGRADING DELTA SYSTEMS
NVERTED MISSISSIPPI DELTA SYSTEM (MODERN), LOUISIANA

DISTAL DISTRIBUTARY BAR MOUTH DEPOSITS

PRODELTA FACIES

MARSH DISTRIBUTARY CHANNEL DEPOSITS

DISTRIBUTARY MOUTH BAR DEPOSITS

DISTAL BAR DEPOSITS

FLUVIAL FACIES

100 - 500

- 200

- 100

0 - 0

FLUVIAL DELTA MARINE

EXPLANATION
Lignite or Peat

Modified After Fisher, 1969

SUNNYSIDE DELTA SYSTEM, GREEN RIVER FORMATION (EOCENE), UTAH

ASPHALT MINE

BRUIN POINT

DEPOSITS

MARSH DISTRIBUTARY CHANNEL DEPOSITS

DISTRIBUTARY MOUTH BAR DEPOSITS

BEACH BAR DEPOSITS

PRODELTA FACIES

10,000

L. 9,000

FLUVIAL DELTA LAKE

EXPLANATION
COAL

\^\^\^ LAKE, DELTA TRANSGRESSIVE DEPOSITS

Fig. 17 CONCEPTUAL MODELS OF ENVIRONMENTAL FACIES ASSOCIATED WITH TRANSGRESSIVE DELTA SYSTEMS
Intenlellaic basin between two Mississippi River delta systems.

Modern Mississippi River Suulistritija
A: Dry Cypress Bayou Complex
B: Grand Liard Complex
C: West Bay Complex
D: Cubits Gap Complex
E: Baptiste Collette Complex
F: Garden Island Bay Complex

After Coleman & Gagliano, 1964

Figure 18 Morphologic features of Mississippi River Subdeltas

Morgan, 1967
Chronological development of Cubits Gap splay of the modern birdfoot delta of the Mississippi. (A) Map of area in 1838 prior to opening of crevasse; (B) Area about 1870, ten years after opening of Cubits Gap; (C) Cubits Gap area in 1877, 17 years after initiation of crevasse. Note extensive sub-aerial marsh deposits and multiplicity of distributary channels; (D) Cubits Gap splay in 1903 showing extensive progradation of splay; (E) Cubits Gap in 1953, showing selection and maintenance of relatively few distributaries and subsidence along seaward margin of the splay; and (F) isopach map of sediments in Cubits Gap splay. Map constructed from contouring interval between pre-crevasse bathymetric charts and present-day elevations. All figures from Welder (1959).

Fisher, Brown, Scott and McGowen, 1969

Figure 19 Chronological and morphological development of Cubits Gap Subdelta, Mississippi River Delta
Figure 20

Diagrams of a delta complex illustrating relationships of distributary mouth bars (bar finger sands) and associated sheet sands.
Cross section showing the thickness and the underlying lithologic sequence of distributary mouth bars for the four major passes of the Mississippi delta (after Fisk). Map shows the location.

Saxena, 1976

Seaward migration of distributary-mouth bar at Southwest Pass during the period 1764–1959 (modified from Gould, 1970).

Coleman & Prior, 1980

Figure 21 Sections of distributary mouth bars, Mississippi River Delta
Fig. 22 DEPOSITIONAL MODEL FOR REWORKED DELTAIC SANDS, MISSISSIPPI DELTA SYSTEM

After Saxena, 1976
FIGURE 23 = IDEALIZED SECTION OF BRUIN POINT SUBDELTA SHOWING TAR ZONES AND DEPOSITIONAL ENVIRONMENTS
FIGURE 24 = IDEALIZED SECTION OF DRY CANYON SUBDELTA SHOWING TAR ZONES AND DEPOSITIONAL ENVIRONMENTS
FIGURE 25  SUBSURFACE MAP OF THE BASE OF THE SUNNYSIDE TAR SANDS, UTAH

EXPLANATION

Data Point From Deep Core Hole Or Measured Section.

--- 8900 Solid Contour Line Supported By Numerous Data Points.
--- 9200 Dashed Contour Line Supported By Limited Data Points.

20,000 NW Transitional Area Between Bruin Point Subdelta To Southeast And Dry Canyon Subdelta To Northwest.
Delta System — Destruction*! Facies

- Inland marsh and tnetosis
- Abandoned former distributary channels (flooded with marsh deposits)
- Bay sound muds (local oyster reefs)
- Reworked delta margin sands
- DeatruCional bay (muds)
- Distal bar sand
- Prodeita muds

Delta system: Constructional Facies

Distributary channel sands
Bar crest sand
Bar slope sand
Distal bar sand
Prodeita shale & clay

Bar flank sand

Calcaceous

Barrel shape SP curve
Upward increase in sand content
SP and resistivity curves have symmetrical deflections
No sand
Regressive sands

Pirson, 1970

Figure 26 Theoretical sedimentation patterns recognizable from SP curve shapes
Summary diagram illustrating the major characteristics of meandering point-bar deposits.

Figure 27 Summary Diagrams of Meander Point Bar Deposits and their Major Characteristics.
Summary diagram illustrating the major characteristics of the distributary-mouth bar deposits in the subaqueous deltaplain.

Figure 28 Summary Diagrams of Distributary-mouth Bar Deposits and their Major Characteristics. coleen aprior, 1982
Summary diagram illustrating the major characteristics of the bay-fill deposits in the lower delta plain.

Figure 29 Summary Diagrams of Bay-fill Deposits and their Major Characteristics.
SCHEMATIC

LACUSTRINE DELTA FILL

VERTICAL SEQUENCE

Lithology, Grain Size, Lokeward, Dip, Porosity

DESCRIPTION

FeCO₃, Pyrite
Burrowed, FeCO₃
Ripple drill, Pyrite

If}, x-b-d., lcour,lill

Sm. x-bed.
Ripple drill, lenticular

Parallel bed., Pyrite
Burrowed, x-h., Pyrite

SAND ISOPACH & LOG LOCATIONS

Summary diagram illustrating the major characteristics of lacustrine delta-fill deposits in the upper delta plain.

Figure 30 Summary Diagrams of Lacustrine Delta-fill Deposits and their Major Characteristics.
## Table 1

**Average Values From Deep Drill Holes**

Sunnyside Tar Sands - Carbon County, Utah

<table>
<thead>
<tr>
<th>DRY CANYON SUBDELTA</th>
<th>BRUIN POINT SUBDELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22 Holes</td>
</tr>
<tr>
<td></td>
<td>1 Hole</td>
</tr>
<tr>
<td></td>
<td>7 Holes in 1984</td>
</tr>
<tr>
<td></td>
<td>17 Holes in 1982</td>
</tr>
<tr>
<td>Average Values of</td>
<td></td>
</tr>
<tr>
<td>TD</td>
<td>636'</td>
</tr>
<tr>
<td>TSAT</td>
<td>311*</td>
</tr>
<tr>
<td>MSAT</td>
<td>262'</td>
</tr>
<tr>
<td>DSAT</td>
<td>91'</td>
</tr>
<tr>
<td>BSAT</td>
<td>593'</td>
</tr>
<tr>
<td>M ZONE</td>
<td>502'</td>
</tr>
<tr>
<td>% MSAT in Tgp</td>
<td>0</td>
</tr>
<tr>
<td>% MSAT in Tgg</td>
<td>100%</td>
</tr>
<tr>
<td>% MSAT in Tgd</td>
<td>0</td>
</tr>
<tr>
<td>thickness Tgp</td>
<td>0</td>
</tr>
<tr>
<td>thickness Tgg</td>
<td>619'</td>
</tr>
<tr>
<td>thickness Tgd</td>
<td>16'</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>TD = Total depth</td>
<td></td>
</tr>
<tr>
<td>TSAT = Total footage: all saturated sediments</td>
<td></td>
</tr>
<tr>
<td>MSAT = Total footages main saturated zones, minimum 10 feet thick and minimum 10 gals/ton</td>
<td></td>
</tr>
<tr>
<td>DSAT = Depth to top of principal tar sands (overburden)</td>
<td></td>
</tr>
<tr>
<td>BSAT = Depth to bottom of tar sands</td>
<td></td>
</tr>
<tr>
<td>M ZONE = Thickness of Main Zone (BSAT minus DSAT)</td>
<td></td>
</tr>
<tr>
<td>Tgp = Parachute Creek Member</td>
<td></td>
</tr>
<tr>
<td>Tgg = Garden Gulch Member</td>
<td></td>
</tr>
<tr>
<td>Tgd = Douglas Creek Member</td>
<td></td>
</tr>
<tr>
<td>** = Deen cirill heiles penetrate all tar sands to th12 top of the first nonbituminous sandstones.</td>
<td></td>
</tr>
</tbody>
</table>

This apparent reversal of percentages is caused by the fact that drill holes Amoco No. 60 and No. 63 are located in distal portions of the Bruin Point subdelta and Amoco No. 52 is located in the transitional area between the Bruin Point and Dry Canyon subdeltas.
Table 2A
Total Depth and Member Data of 1980
From Deep Drill Holes and Measured Sections
(all data in feet)

<table>
<thead>
<tr>
<th>Drill Hole and Measured Section</th>
<th>Encountered Thickness Tgp</th>
<th>Depth to Member Contact</th>
<th>Total Thickness Tgg</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness Tgd</th>
<th>Total Depth TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoco No. 1*</td>
<td>212</td>
<td>212</td>
<td>317</td>
<td>529</td>
<td>696</td>
<td>1225</td>
</tr>
<tr>
<td></td>
<td>2**</td>
<td>155</td>
<td>234</td>
<td>389</td>
<td>585</td>
<td>974</td>
</tr>
<tr>
<td></td>
<td>3**</td>
<td>182</td>
<td>342</td>
<td>524</td>
<td>736</td>
<td>1260</td>
</tr>
<tr>
<td></td>
<td>4*</td>
<td>137</td>
<td>360</td>
<td>497</td>
<td>896</td>
<td>1393</td>
</tr>
<tr>
<td></td>
<td>5**</td>
<td>105</td>
<td>361</td>
<td>466</td>
<td>374</td>
<td>840</td>
</tr>
<tr>
<td></td>
<td>6**</td>
<td>378</td>
<td>342</td>
<td>720</td>
<td>472</td>
<td>1192</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>149</td>
<td>348</td>
<td>497</td>
<td>618</td>
<td>1115</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>240</td>
<td>325</td>
<td>565</td>
<td>720</td>
<td>1285</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>112</td>
<td>243</td>
<td>355</td>
<td>559</td>
<td>914</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>246</td>
<td>356</td>
<td>602</td>
<td>734</td>
<td>1336</td>
</tr>
</tbody>
</table>

1980 actual cored footage total = 6733

<table>
<thead>
<tr>
<th>Measured Section</th>
<th>Encountered Thickness</th>
<th>Depth to Member Contact</th>
<th>Total Thickness</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness</th>
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<td>185</td>
<td>185</td>
<td>305</td>
<td>490</td>
<td>960</td>
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1980 vertical height total = 6437

Tgp Parachute Creek Member
Tgg Garden Gulch Member
Tgd Douglas Creek Member
TD Total Depth
VH Vertical Height
* partly drilled by Amoco Production in 1978 (No. 1 to TD 334' and No. 4 to TD 201')
** completely drilled by Amoco Production in 1978
Table 2B

Total Depth and Member Data of 1981
From Deep Drill Holes and Measured Sections
(all data in feet)

<table>
<thead>
<tr>
<th>Drill Hole and Measured Section</th>
<th>Encountered Thickness Tgp</th>
<th>Depth to Member Contact</th>
<th>Total Thickness Tgg</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness T*d</th>
</tr>
</thead>
<tbody>
<tr>
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<td>612</td>
</tr>
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<td>0</td>
<td>296</td>
<td>296</td>
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<td>608</td>
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<td>148</td>
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<td>546</td>
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<td>71</td>
<td>550</td>
<td>621</td>
<td>194</td>
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</table>

1981 deep hole footage total = 9208

| Shell No. 1 Pan               |                           |                         |                     |                         |                          |                  |
| American No. 1                | 139                       | 139                     | 775                 | 914                     | 1286                     | 2200                |

1981 vertical height total = 4184

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<td>454</td>
<td>71</td>
<td>525</td>
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</tr>
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</table>

MS Dry Canyon 222 222 850 1072 328 1400

Tgp = Parachute Creek Member
Tgg = Garden Gulch Member
Tgd = Douglas Creek Member
TD = Total depth
VH = Vertical height

Note: Shallow south area pilot mine holes include:
Amoco No. 15 TD 160'
No. 18 TD 282'
No. 19 TD 160'
No. 20 TD 265'
No. 23 TD 136'
No. 25 (geotechnical hole) TD 585'

00552
Table 2C

Total Depth and Member Data of 1982
From Deep Drill Holes and Measured Sections
(all data in feet)

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>Encountered Thickness Tgp</th>
<th>Depth to Member Contact</th>
<th>Total Thickness Tgg</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness Tgd</th>
<th>TD</th>
</tr>
</thead>
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<td>-</td>
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<td>-</td>
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<td>23</td>
<td>465</td>
</tr>
<tr>
<td>34</td>
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<td>-</td>
<td>473</td>
<td>341&amp;550*</td>
<td>102</td>
<td>575</td>
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<td>35</td>
<td>0</td>
<td>-</td>
<td>373</td>
<td>250&amp;444*</td>
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<td>385</td>
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<td>652</td>
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<td>417</td>
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<td>250&amp;450*</td>
<td>195</td>
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<td>522</td>
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</tbody>
</table>

1982 deep hole footage total = 11720

<table>
<thead>
<tr>
<th>MS No.</th>
<th>Encountered Thickness</th>
<th>Depth to Member Contact</th>
<th>Total Thickness</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness</th>
<th>TD</th>
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<tbody>
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1982 vertical height total = 3929

* multiple interfingering contacts

Tgp Parachute Creek Member
Tgg Garden Gulch Member
Tgd Douglas Creek Member
TD Total Depth
VH Vertical Height

Note: shallow south area pilot mine holes include: Amoco No. 27 TD 174'
      No. 28 TD 141'
      No. 29 TD 95'
      No. 30 TD 170'

00553
Table 2D

Total Depth and Member Data of 1984
From Deep Drill Holes and Measured Sections
(all data in feet)

<table>
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<tr>
<th>Drill Hole and Measured Section</th>
<th>Encountered Thickness Tgp</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness Tgg</th>
<th>Depth to Member Contact</th>
<th>Encountered Thickness Tgd</th>
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<td></td>
<td>750</td>
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<td>-</td>
<td>750</td>
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<td>660</td>
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<td>-</td>
<td>-</td>
<td>660</td>
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<td>620</td>
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<td>550</td>
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1984 deep hole footage total = 7364

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<td>555</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>405</td>
<td>181</td>
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</tr>
</tbody>
</table>

1984 vertical height total = 6967

Note: Drill Holes Amoco No. 55-59 are shallow north area pilot mine holes:
Amoco No. 55 TD 80; No. 56 TD 90; No. 57 TD 90; No. 58 TD 90; No. 59 TD 100.

* = multiple interfingering contacts
Tgp = Parachute Creek Member
Tgg = Garden Gulch Member
Tgd = Douglas Creek Member
TD = Total depth
VH = Vertical height

00554
Table 3A
Tar Sand Data of 1980 From Deep Drill Holes and Measured Sections
(all data in feet)

<table>
<thead>
<tr>
<th>Drill Hole and Measured Section</th>
<th>CE</th>
<th>TD</th>
<th>TSAT</th>
<th>MSAT</th>
<th>BSAT</th>
<th>DSAT</th>
<th>M Zone</th>
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</thead>
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</table>

<table>
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<th>VH</th>
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</thead>
<tbody>
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</table>

TSAT = total footage all saturated sediments
MSAT = total footage main saturated zones, minimum 10 ft thick and minimum 10 gals/ton
BSAT = depth to bottom of tar sands
DSAT = depth to top of principal tar sands (maximum overburden)
M Zone = thickness of main zone (BSAT minus DSAT)
CE = collar elevation
TD = total depth
TE = top elevation
VH = vertical height
## Table 3B

Tar Sand Data of 1981 From Deep Drill Holes and Measured Sections
(all data in feet)

<table>
<thead>
<tr>
<th>Drill Hole and Measured Section</th>
<th>CE</th>
<th>TD</th>
<th>TSAT</th>
<th>MSAT</th>
<th>BSAT</th>
<th>DSAT</th>
<th>M Zone</th>
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| Pan                            |     |     |      |      |      |      |        |
| American No. 1                 | 9300 | 2200 | 80   | 47   | 939  | 455  | 484    |
|                               | TE  |     |      |      |      |      |        |
|                               | VH  |     |      |      |      |      |        |
| MS No 7                       | 9585 | 618  | 197  | 147  | 535  | 135  | 400    |
| 8                             | 9845 | 1075 | 185  | 125  | 780  | 333  | 447    |
| 9                             | 9815 | 1052 | 557  | 470  | 838  | 170  | 668    |
| 10                            | 9607 | 914  | 156  | 93   | 690  | 0    | 690    |
| 11                            | 9280 | 525  | 76   | 56   | 363  | 323  | 40     |
| MS Dr>7 Canyon                | 8820 | 1400 | 124  | 79   | 850  | 435  | 415    |

- **TSAT** = total footage all saturated sediments
- **MSAT** = total footage main saturated zones, minimum 10 ft thick and minimum 10 gals/ton.
- **BSAT** = depth to bottom of tar sands
- **DSAT** = depth to top of principal tar sands (maximum overburden)
- **M Zone** = thickness of main zone (BSAT minus DSAT)
- **CE** = collar elevation
- **TD** = total depth
- **TE** = top elevation
- **VH** = vertical height
### Table 3C

**Tar Sand Data of 1982 From Deep Drill Holes and Measured Sections**
*(all data in feet)*

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<th>MSAT</th>
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- **TSAT** = total footage all saturated sediments
- **MSAT** = total footage main saturated zones, minimum 10 ft thick and minimum 10 gals/ton
- **BSAT** = depth to bottom of tar sands
- **DSAT** = depth to top of principal tar sands (maximum overburden)
- **M Zone** = thickness of main zone (BSAT minus DSAT)
- **CE** = collar elevation
- **TD** = total depth
- **TE** = top elevation
- **VH** = vertical height
Table 3D

Tar Sand Data of 1984 From Deep Drill Holes and Measured Sections
(all data in feet)

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TSAT = total footage all saturated sediments
MSAT = total footage main saturated zones, minimum 10 ft thick and minimum 10 gals/ton
BSAT = depth to bottom of tar sands
DSAT = depth to top of principal tar sands (maximum overburden)
M Zone = thickness of main zone (BSAT minus DSAT)
CE = collar elevation
TD = total depth
TE = top elevation
VH = vertical height
Table 4A

MSAT Thickness in Members of Green River Formation
(all data in feet)
(1980 data, a base)

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MSAT = tar zones that are a minimum of 10 feet thick with a minimum of 10 gals/ton
Table 4B

MSAT Thickness in Members of Green River Formation
(all data in feet)
(1981 data base)

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MSAT = tar zones that are a minimum of 10 feet thick with a minimum of 10 gals/ton
Table 4C

MSAT Thickness in Members of Green River Formation
(all data in feet)
(1982 data base)

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<td>0</td>
<td>183</td>
<td>0</td>
<td>183</td>
</tr>
<tr>
<td>46</td>
<td>0</td>
<td>222</td>
<td>0</td>
<td>222</td>
</tr>
<tr>
<td>47</td>
<td>0</td>
<td>286</td>
<td>128</td>
<td>414</td>
</tr>
<tr>
<td>48</td>
<td>0</td>
<td>271</td>
<td>34</td>
<td>305</td>
</tr>
</tbody>
</table>

| MS No. 12                            | 0   | 48  | 0   | 48   |
| 13                                   | 0   | 214 | 15  | 229  |
| 14                                   | 0   | 128 | 0   | 128  |
| 15                                   | 15  | 77  | 0   | 92   |
| 16                                   | 0   | 46  | 0   | 46   |
| 17                                   | 0   | 63  | 0   | 63   |

MSAT = tar zones that are a minimum of 10 feet thick with a minimum of 10 gals/ton
Table 4D

MSAT Thickness in Members of Green River Formation
all data in feet
(1984 data base)

<table>
<thead>
<tr>
<th>Deep Drill Hole and Measured Section</th>
<th>TgP</th>
<th>Tgg</th>
<th>Tgd</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoco No. 49</td>
<td>0</td>
<td>205</td>
<td>0</td>
<td>205</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
<td>439</td>
<td>0</td>
<td>439</td>
</tr>
<tr>
<td>51</td>
<td>0</td>
<td>392</td>
<td>0</td>
<td>392</td>
</tr>
<tr>
<td>52</td>
<td>0</td>
<td>448</td>
<td>0</td>
<td>448</td>
</tr>
<tr>
<td>53</td>
<td>0</td>
<td>104</td>
<td>0</td>
<td>104</td>
</tr>
<tr>
<td>54</td>
<td>0</td>
<td>340</td>
<td>0</td>
<td>340</td>
</tr>
<tr>
<td>60</td>
<td>0</td>
<td>133</td>
<td>0</td>
<td>133</td>
</tr>
<tr>
<td>61</td>
<td>0</td>
<td>152</td>
<td>0</td>
<td>152</td>
</tr>
<tr>
<td>62</td>
<td>0</td>
<td>201</td>
<td>0</td>
<td>201</td>
</tr>
<tr>
<td>63</td>
<td>0</td>
<td>159</td>
<td>0</td>
<td>159</td>
</tr>
<tr>
<td>MS No. 18</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>19</td>
<td>0</td>
<td>55</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>72</td>
<td>0</td>
<td>72</td>
</tr>
<tr>
<td>21</td>
<td>0</td>
<td>115</td>
<td>0</td>
<td>115</td>
</tr>
<tr>
<td>22</td>
<td>0</td>
<td>355</td>
<td>192</td>
<td>547</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
<td>105</td>
<td>0</td>
<td>105</td>
</tr>
<tr>
<td>24</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>233</td>
<td>0</td>
<td>233</td>
</tr>
<tr>
<td>26</td>
<td>0</td>
<td>262</td>
<td>0</td>
<td>262</td>
</tr>
</tbody>
</table>

MSAT = tar zones that are a minimum of 10 feet thick with a minimum 10 gals/ton
**Table 5A**

Status of Drill Holes
1980 and 1981 Data Base

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>Surface</th>
<th>Down Hole</th>
<th>TD (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoco No. 1</td>
<td>open with 20' casing</td>
<td>stoppage at 346'</td>
<td>1225</td>
</tr>
<tr>
<td>2</td>
<td>cement plug in casing</td>
<td>fully cemented</td>
<td>974</td>
</tr>
<tr>
<td>3</td>
<td>cement plug unlocated</td>
<td>(?)</td>
<td>1260</td>
</tr>
<tr>
<td>4*</td>
<td>locked cap on piezometers</td>
<td>instruments</td>
<td>1393</td>
</tr>
<tr>
<td>5</td>
<td>two foot cement plug on top of cloth rags in 20' casing</td>
<td>open (?)</td>
<td>840</td>
</tr>
<tr>
<td>6</td>
<td>cement plug located</td>
<td>(?)</td>
<td>1192</td>
</tr>
<tr>
<td>7</td>
<td>cement plug unlocated</td>
<td>(?)</td>
<td>1232</td>
</tr>
<tr>
<td>8*</td>
<td>locked cap on 10' casing</td>
<td>open (?)</td>
<td>1115</td>
</tr>
<tr>
<td>9</td>
<td>threaded plug on 10' casing</td>
<td>(?)</td>
<td>1285</td>
</tr>
<tr>
<td>10*</td>
<td>locked cap on piezometers</td>
<td>instruments</td>
<td>914</td>
</tr>
<tr>
<td>11</td>
<td>broken plug on 10' casing</td>
<td>(?)</td>
<td>1336</td>
</tr>
<tr>
<td>12</td>
<td>screw cap on 10' casing</td>
<td>stoppage at 450'</td>
<td>1268</td>
</tr>
<tr>
<td>13</td>
<td>screw cap on 20' casing</td>
<td>open</td>
<td>609</td>
</tr>
<tr>
<td>14</td>
<td>screw cap on 30' casing</td>
<td>open with bit and 30' casing in bottom of hole</td>
<td>1025</td>
</tr>
<tr>
<td>15**</td>
<td>screw cap on 20' casing</td>
<td>open</td>
<td>160</td>
</tr>
<tr>
<td>16*</td>
<td>locked cap on piezometers</td>
<td>instruments</td>
<td>1215</td>
</tr>
<tr>
<td>17</td>
<td>screw cap on 20' casing</td>
<td>open to 928' (7-JL9-84)</td>
<td>1015</td>
</tr>
<tr>
<td>18**</td>
<td>screw cap on 10' casing</td>
<td>open</td>
<td>282</td>
</tr>
<tr>
<td>19**</td>
<td>screw cap on 20' casing</td>
<td>open</td>
<td>160</td>
</tr>
<tr>
<td>20**</td>
<td>screw cap on 20' casing</td>
<td>open</td>
<td>265</td>
</tr>
<tr>
<td>21*</td>
<td>locked cap on piezometers</td>
<td>instruments</td>
<td>1200</td>
</tr>
<tr>
<td>22</td>
<td>screw cap on 20' casing</td>
<td>open with ground-up bit in bottom of hole</td>
<td>899</td>
</tr>
<tr>
<td>23**</td>
<td>screw cap on 20' casing</td>
<td>open</td>
<td>136</td>
</tr>
<tr>
<td>24*</td>
<td>locked cap on piezometers</td>
<td>instruments</td>
<td>1110</td>
</tr>
<tr>
<td>25</td>
<td>screw cap on 350' casing</td>
<td>open, 45 angle</td>
<td>585</td>
</tr>
<tr>
<td>26*</td>
<td>locked cap on piezometers</td>
<td>instruments</td>
<td>815</td>
</tr>
<tr>
<td>Shell No. 1</td>
<td>covered, no casing visible</td>
<td>(?)</td>
<td>806</td>
</tr>
<tr>
<td>2</td>
<td>covered, no casing visible</td>
<td>(?)</td>
<td>1399</td>
</tr>
<tr>
<td>3</td>
<td>covered, no casing visible</td>
<td>(?)</td>
<td>1189</td>
</tr>
<tr>
<td>Signal No. 1</td>
<td>bull plug and 8' casing</td>
<td>(?)</td>
<td>1450</td>
</tr>
</tbody>
</table>

**Note:**
*All locks are same with common key, Special No. 1 Master Lock Key 2405. Screw caps need 2-3 foot pipe wrench for removal.*

**Shallow pilot mine hole in Bruin Point area.*
Table 5B
Status of Drill Holes
(1982 data base)

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>Surface</th>
<th>Down Hole</th>
<th>TD (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27**</td>
<td>screw cap on 10' casing</td>
<td>open</td>
<td>17A</td>
</tr>
<tr>
<td>28**</td>
<td>screw cup on 10' casing</td>
<td>open</td>
<td>1A1</td>
</tr>
<tr>
<td>29**</td>
<td>screw cap on 10' casing</td>
<td>open</td>
<td>95</td>
</tr>
<tr>
<td>30**</td>
<td>screw cap on 30' casing</td>
<td>open</td>
<td>170</td>
</tr>
<tr>
<td>31</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>62A</td>
</tr>
<tr>
<td>32</td>
<td>road cover on 10' casing</td>
<td>fully cemented</td>
<td>8A0</td>
</tr>
<tr>
<td>33a</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>383</td>
</tr>
<tr>
<td>33b</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>2AA</td>
</tr>
<tr>
<td>33c</td>
<td>soil cover on 30' casing</td>
<td>fully cemented</td>
<td>A65</td>
</tr>
<tr>
<td>3A</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>575</td>
</tr>
<tr>
<td>35</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>560</td>
</tr>
<tr>
<td>36</td>
<td>road cover on 10' casing</td>
<td>fully cemented</td>
<td>700</td>
</tr>
<tr>
<td>37</td>
<td>rock cover on 10' casing</td>
<td>fully cemented</td>
<td>57A</td>
</tr>
<tr>
<td>38</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>A16</td>
</tr>
<tr>
<td>39a</td>
<td>road cover on 10' casing</td>
<td>fully cemented</td>
<td>590</td>
</tr>
<tr>
<td>39b</td>
<td>road cover on 10' casing</td>
<td>fully cemented</td>
<td>753</td>
</tr>
<tr>
<td>40</td>
<td>road cover on 20' casing</td>
<td>fully cemented</td>
<td>690</td>
</tr>
<tr>
<td>A1</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>57A</td>
</tr>
<tr>
<td>A2</td>
<td>screw cap on 20' casing</td>
<td>stoppage at 380'</td>
<td>12A9</td>
</tr>
<tr>
<td>A3</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>A3A</td>
</tr>
<tr>
<td>AA</td>
<td>road cover on 10' casing</td>
<td>fully cemented</td>
<td>500</td>
</tr>
<tr>
<td>A5a</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>190</td>
</tr>
<tr>
<td>A5b</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>626</td>
</tr>
<tr>
<td>A6</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>530</td>
</tr>
<tr>
<td>47</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>900</td>
</tr>
<tr>
<td>A8</td>
<td>soil cover on 10' casing</td>
<td>fully cemented</td>
<td>710</td>
</tr>
</tbody>
</table>

** Shallow pilot mine hole in Bruin Point area.
Table 5C
Status of Drill Holes
(1984 data base)

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>Surface</th>
<th>Down Hole</th>
<th>TD (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>soil cover on 20' casing</td>
<td>*</td>
<td>600</td>
</tr>
<tr>
<td>50</td>
<td>road cover on 20' casing</td>
<td>*</td>
<td>750</td>
</tr>
<tr>
<td>51</td>
<td>road cover on 40' casing</td>
<td>*</td>
<td>660</td>
</tr>
<tr>
<td>52</td>
<td>rock cover on 20' casing</td>
<td>*</td>
<td>1011</td>
</tr>
<tr>
<td>53</td>
<td>soil cover on 20' casing</td>
<td>*</td>
<td>620</td>
</tr>
<tr>
<td>54</td>
<td>soil cover on 20' casing</td>
<td>*</td>
<td>726</td>
</tr>
<tr>
<td>55**</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>80</td>
</tr>
<tr>
<td>56**</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>90</td>
</tr>
<tr>
<td>57**</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>90</td>
</tr>
<tr>
<td>58**</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>90</td>
</tr>
<tr>
<td>59**</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>100</td>
</tr>
<tr>
<td>60</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>834</td>
</tr>
<tr>
<td>61</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>544</td>
</tr>
<tr>
<td>62</td>
<td>road cover on 10' casing</td>
<td>*</td>
<td>550</td>
</tr>
<tr>
<td>63</td>
<td>soil cover on 10' casing</td>
<td>*</td>
<td>1069</td>
</tr>
</tbody>
</table>

** shallow pilot mine hole in Dry Canyon area

* all holes are fully plugged with Shur-gel from bottom to near the top of the surface casing and also include a three to five foot cement plug at top of casing, a labelled cap screwed into the top of the surface casing and a foot of cover
<table>
<thead>
<tr>
<th>Zone</th>
<th>Thickness</th>
<th>Core Labs²</th>
<th>BPB Instruments</th>
<th>Percent Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>7</td>
<td>not analyzed</td>
<td>3.82</td>
<td>?</td>
</tr>
<tr>
<td>21</td>
<td>29</td>
<td>5.85</td>
<td>4.99</td>
<td>-14.70</td>
</tr>
<tr>
<td>23</td>
<td>14</td>
<td>6.35</td>
<td>5.48</td>
<td>-13.70</td>
</tr>
<tr>
<td>31</td>
<td>21</td>
<td>6.38</td>
<td>6.74</td>
<td>+5.64</td>
</tr>
<tr>
<td>35</td>
<td>21</td>
<td>6.70</td>
<td>6.50</td>
<td>-2.98</td>
</tr>
<tr>
<td>36</td>
<td>29</td>
<td>8.56</td>
<td>7.85</td>
<td>-8.29</td>
</tr>
<tr>
<td>37</td>
<td>145</td>
<td>6.90</td>
<td>6.54</td>
<td>-5.22</td>
</tr>
<tr>
<td>38</td>
<td>50¹</td>
<td>4.81</td>
<td>6.68</td>
<td>+38.88</td>
</tr>
</tbody>
</table>

average % error = -0.05

weighted average % error = +1.24

Footnotes:

¹ Only the upper fifty feet of eighty-two foot thick Zone 38 was used as sonde stopped at 928 feet. Total depth drilled was 1015 feet.

² Direct analysis by soxhlet extraction on composites of core intervals two to ten feet thick in 1981.

³ Indirect analysis by computer program at six inch intervals in 1984.

Table 6. Direct and Indirect Methods of Tar Sand Analysis on Tar Zones in Amoco No. 17, Sunnyside Tar Sands.
<table>
<thead>
<tr>
<th>Zone</th>
<th>Thickness</th>
<th>Porosity</th>
<th>Environment</th>
<th>Fines&lt;sup&gt;2&lt;/sup&gt; (-325 mesh)</th>
<th>Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>7</td>
<td>2.70-19.41</td>
<td>9.83</td>
<td>DF&lt;sup&gt;3&lt;/sup&gt;</td>
<td>not analyzed</td>
</tr>
<tr>
<td>21</td>
<td>32</td>
<td>3.14-20.16</td>
<td>12.48</td>
<td>DMB</td>
<td>6.46-7.58</td>
</tr>
<tr>
<td>23</td>
<td>14</td>
<td>4.09-19.58</td>
<td>13.22</td>
<td>BB</td>
<td>4.69</td>
</tr>
<tr>
<td>31</td>
<td>21</td>
<td>6.65-23.73</td>
<td>16.01</td>
<td>DMB</td>
<td>7.96-8.45</td>
</tr>
<tr>
<td>35</td>
<td>26</td>
<td>0.00-21.80</td>
<td>15.29</td>
<td>DMB</td>
<td>6.35-6.79</td>
</tr>
<tr>
<td>36</td>
<td>29</td>
<td>11.49-23.28</td>
<td>18.09</td>
<td>DC</td>
<td>5.95-6.71</td>
</tr>
<tr>
<td>37</td>
<td>146</td>
<td>0.00-34.08</td>
<td>16.70</td>
<td>DC</td>
<td>6.03-10.94</td>
</tr>
<tr>
<td>38</td>
<td>50&lt;sup&gt;^2&lt;/sup&gt;</td>
<td>3.00-26.30</td>
<td>18.46</td>
<td>DC</td>
<td>4.83-14.54</td>
</tr>
</tbody>
</table>

Footnotes:

1. **Indirect analysis by BPB Instruments at six inch intervals.**

2. Only the upper fifty feet of eighty-two foot thick Zone 38 was used as sonde stopped at 928 feet. Total depth drilled was 1015 feet.

Two to ten feet thick completed in 1985.

DF = delta front sheet sand
DMB = distributary mouth bar
BB = beach bar
DC = distributary channel

Table 7. Porosity and Fines of Tar Zones in Amoco No. 17, Sunnyside Tar Sands.
Table 8

Analysis of Entrapped Gas from Amoco No. 9 and No. 11

<table>
<thead>
<tr>
<th>Specie</th>
<th>Amoco No. 9 1251 ft</th>
<th>Amoco No. 11 1334 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>1.75</td>
<td>2.48</td>
</tr>
<tr>
<td>Ethane</td>
<td>0.43</td>
<td>0.44</td>
</tr>
<tr>
<td>Propane</td>
<td>1.58</td>
<td>0.32</td>
</tr>
<tr>
<td>Isobutane</td>
<td>0.61</td>
<td>–</td>
</tr>
<tr>
<td>n-Butane</td>
<td>2.25</td>
<td>–</td>
</tr>
<tr>
<td>Isopentane</td>
<td>0.76</td>
<td>–</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>1.01</td>
<td>–</td>
</tr>
<tr>
<td>CO₂</td>
<td>3120.00</td>
<td>9577.00</td>
</tr>
<tr>
<td>CO</td>
<td>74.80</td>
<td>43.40</td>
</tr>
</tbody>
</table>

NOTE: No detectable H₂S or SO₂.

Table 9

Bruin Point Pilot Mine Outcrop Area
Traverse Data

**UPPER TAR SAND**

<table>
<thead>
<tr>
<th>Station</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>med angle med scale sweeping XB; bit (5-6%) FG-VFG SS; 1% muse; 6 ft thick SE edge fades to zero in 20 ft</td>
</tr>
<tr>
<td>2</td>
<td>7-8 ft exposed thickness; med angle med scale sweeping XB; bit (5-6%) FG-VFG qtz SS</td>
</tr>
<tr>
<td>3</td>
<td>planar bedded SS about 13 ft thick; overlies 2-3 in. stromatolite zone w/ very ltd disturbance; planar bedding (90%) small scale low-med angle planar XB (10%); local IFC (3-15 in. thick) Is clasts w/ ltd transport; EOD = BAR.</td>
</tr>
<tr>
<td>4</td>
<td>10 ft thick FG-VFG bit (5-6%) qtz SS; overlies local stromatolite Is zone 1-2 ft exposure; planar bedding (70%) low-med angle planar XB (30%); channel direction N30-40E.</td>
</tr>
<tr>
<td>5</td>
<td>11 ft thick FG-VFG bit (5-6%) qtz SS; overlies local bit stromatolitic Is zone 1-2 ft thick; planar bedding (90%) low angle med scale planar XB (10%).</td>
</tr>
<tr>
<td>6</td>
<td>7 ft thick FG-VFG bit (5-6%) qtz SS; overlies inplace stromatolitic zone 1-2 ft exposed; planar bedding (90%) low-med angle med scale planar XB (10%).</td>
</tr>
<tr>
<td>7</td>
<td>7 ft thick FG-VFG bit (5-6%) qtz SS, overlies 3-4&quot; algal stromatolitic Is zone; planar bedding and low angle planar sweeping XB.</td>
</tr>
<tr>
<td>8</td>
<td>9 ft thick FG-VFG bit (5-6%) qtz SS; planar bedding (90%) low angle med scale planar XB (10%); overlies Is zone-stromatolitic to biota trash; 28 vert ft to middle ss unit.</td>
</tr>
<tr>
<td>9</td>
<td>8 ft thick FG-VFG bit (5-6%) qtz SS; overlies 2-3 ft exposures of Is; algal stromatolite (20%) biota trash (10%) micrite (70%); planar bedding (100%).</td>
</tr>
<tr>
<td>10</td>
<td>8 ft thick FG-VFG bit (5-6%) qtz SS; overlies in place biotnicrite (bit) zone 2-3 ft thick; 6&quot; IFC with Is and sh clasts; Is zone is discontinuous; Rob found catfish fossil in wk oil shale talus slab.</td>
</tr>
<tr>
<td>11</td>
<td>3 ft thick FG-VFG bit (5-6%) qtz SS; shale slope area; MSAT stops at 40'; distant mapping of major tar sands for Geologic Maps (1&quot; = 500 ft) within 95% confidence limits.</td>
</tr>
<tr>
<td>12</td>
<td>7 ft thick FG-VFG bit (5-6%) qtz SS; 6&quot; micrite to biomicrite w/ biota trash; planar bedding and low angle sweeping planar XB.</td>
</tr>
</tbody>
</table>
Table 9 (continued)

Station 13 6 ft thick FG-VFG bit (5-6%) qtz SS; 6" micrite to biomicrite w/ biota trash; planar bedding (70%) low med angle sweeping planar XB (30%).

14 4 ft thick FG-VFG bit (5-6%) qtz SS; 10 ft beyond is a 2 ft thick bit micrite zone with 6.5 ft thick tar sand on top.

15 7 ft thick, FG-VFG bit (5-6%) qtz SS; 3-4 ft thick bit micrite-biomicrite zone below; planar bedding (80%) low-med angle med scale planar XB (20%); middle tar sand unit 27 ft vertically below.

Note: lateral 500-1000' and vertical 100-200' continuity on 1000 ft grid for ore reserves probably has correlation and reliability with 80-85% confidence limits; thus 200 ft horizontal slices and 1000 ft vertical sections in good shape.

MIDDLE TAR SAND

16 11-12 ft thick FG-VFG bit (5-6%) qtz SS; base poorly exposed.

LOWER TAR SAND

17 56 feet from base of middle tar sand to top of lower tar sand.

18 tar sand 50 ft thick; prominent and strong distorted bedding in lower portion = mouth bar; VFG-FG bit qtz SS; planar bedding on top; deposition in mouth bar episodal.

19 poorly exposed; 15 ft thick; largely covered by talus in small gully.

20 approx. 50 ft thick mouth bar; VFG-FG bit SS (6-7 wt% bit); preferred direction of paleocurrent by Rob's direction = N40E; highly distorted bedding (50%) med angle med scale planar cross sets (50%).

21 approx. 50 ft thick mouth bar; VFG-FG bit SS (6-7 wt% bit); basal 30-35 ft distorted portion; upper 15-20 ft med angle med scale planar XB sets.

22 40-50 ft exposures; top: 15-20 ft thick w/ planar cross sets; lower portion: distorted bedding and local limited Is IFC's (1-6" thick); Is clasts as bones, algal stromatolites and micrite.

23 approx. 50 ft thick mouth bar; poorly exposed in talus shoot; with this type of continuity 200 ft slices and 1000 ft sections = no problems in correlation.
Table 9 (continued)

<table>
<thead>
<tr>
<th>Station</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>46 ft thick mouth bar; exposures to SE are spruce covered but laterally continuous; bit content 6-7 wt%; top 15 ft planar sets; lower 31 ft distorted bedding; FG-VFG bit Qtz SS; probable coalescing mouth bars, thus sheet sand (bar) and mouth bar combinations are transitional to each other; this is probably continuous in subsurface to 1980 favorite outcrop (1980 Photo No. 6); possibly this mouth bar is also a regressive-transgressive beach bar system; top of lower tar sand to bottom of middle tar sand = 52 vert feet.</td>
</tr>
<tr>
<td>25</td>
<td>15 ft exposed thickness, probably 20 ft thick; planar bedding; bit SS = bar; FG-VFG bit Qtz SS (6 wt% bitumen); at base of middle tar sand unit.</td>
</tr>
<tr>
<td>26</td>
<td>27 vertical feet from top of middle tar sand to base of upper tar sand; approx. by station no. 8; good traverse; 200 ft slices and 1000 ft XS are OK, 90-95 confidence limits; 1500 ft XS = 75-80% confidence.</td>
</tr>
</tbody>
</table>

Note: 1) 100 foot distance between traverse stations measured by tape.

2) 100 foot distance between traverse stations measured by tape.

3) completed 9/14/81 W. Calkin and R. Roy
<table>
<thead>
<tr>
<th>LITHOLOGY</th>
<th>TYPICAL</th>
<th>GEOPHYSICAL</th>
<th>MULTICHANNEL SONIC CHANNEL ONE</th>
<th>RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gamma (api)</td>
<td>Density (g/cc)</td>
<td>Focused Electric ohm/meters</td>
<td>Multichannel Sonic Channel One microsec/ft</td>
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<tr>
<td>Shale (nonbituminous) and all colors</td>
<td></td>
<td>80-180</td>
<td>2.35-2.50</td>
<td>40-600</td>
</tr>
<tr>
<td>Red</td>
<td>80-120</td>
<td>2.40-2.50</td>
<td>40-200</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>120-160</td>
<td>2.35-2.45</td>
<td>100-600</td>
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<tr>
<td>Variegated</td>
<td>140-180</td>
<td>2.40-2.45</td>
<td>40-150</td>
<td></td>
</tr>
<tr>
<td>Gray</td>
<td>140-180</td>
<td>2.40-2.45</td>
<td>200-600</td>
<td></td>
</tr>
<tr>
<td>Siltstone (bituminous)</td>
<td>100-140</td>
<td>2.30-2.40</td>
<td>100-500</td>
<td></td>
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<tr>
<td>Sandstone (bituminous)</td>
<td>100-140</td>
<td>2.15-2.25</td>
<td>1000-5,000</td>
<td>80-95</td>
</tr>
<tr>
<td>Sandstone (nonbituminous)</td>
<td>80-120</td>
<td>2.20-2.25</td>
<td>100-1000</td>
<td></td>
</tr>
<tr>
<td>Limestone (nonbituminous to bituminous)</td>
<td>100-800</td>
<td>2.35-2.40</td>
<td>100-10,000</td>
<td>60-70</td>
</tr>
<tr>
<td>Oil shale</td>
<td>60-80</td>
<td>2.1 -2.2</td>
<td>20-100</td>
<td></td>
</tr>
</tbody>
</table>

Table 10. Correlations of Lithology and Typical Geophysical Responses, Sunnyside Tar Sands
### Table 11
General Rock Properties Associated with Environments of Deposition

<table>
<thead>
<tr>
<th>Environment of Deposition</th>
<th>Abbreviation</th>
<th>Principal Rock Types</th>
<th>Common Color</th>
<th>Fossils</th>
<th>Distinguishing Characteristics</th>
<th>Bitumen Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prodelta</td>
<td>PD</td>
<td>shale and marlstone</td>
<td>tan to It gray</td>
<td>limited; ostracods, plant debris, small fish, thin algal zone</td>
<td>thinly laminated gray shales</td>
<td>negligible: In thin sandstones &amp; some fractures</td>
</tr>
<tr>
<td>Delta Front</td>
<td>DF</td>
<td>shale and siltstone</td>
<td>tan to It gray</td>
<td>gray shales laminated to thinly bedded with paper shales and oil shale</td>
<td>negligible: In thin siltstones, sandstone &amp; some fractures</td>
<td></td>
</tr>
<tr>
<td>Nearshore</td>
<td>RS</td>
<td>limestone and shale</td>
<td>greenish gray</td>
<td>important: ostracods, thick algal zones, fish scales, turtles</td>
<td>thin white limestones, thick green shales fossil zones, strong bloturbation</td>
<td>negligible to moderate low to high In limestones and thin sandstone</td>
</tr>
<tr>
<td>Interdelta-bay</td>
<td>ID</td>
<td>shale and limestone</td>
<td>olive drab, brown, purple, green</td>
<td>moderate: algal zones, ostracods</td>
<td>mixed colored laminated shales, moderate bloturbation</td>
<td>negligible: on some fractures near tar</td>
</tr>
<tr>
<td>Marsh</td>
<td></td>
<td>shale</td>
<td>red and brown</td>
<td>limited: rootlets and plant debris</td>
<td>red shales, rootlets, weak bloturbation</td>
<td>negligible: on some fractures near tar zones</td>
</tr>
<tr>
<td>Levee</td>
<td></td>
<td>siltstone</td>
<td>tan to brown</td>
<td></td>
<td>micro-trough cross bedding, moderate bloturbation, 1-2Z muscovite</td>
<td>moderate: low to moderate, streaky</td>
</tr>
<tr>
<td>Beach or Beach Bar</td>
<td>B or BB</td>
<td>fine grained to very fine grained sandstone</td>
<td>dark gray to black</td>
<td>limited: ostracods, biota trash, fish scales</td>
<td>planar bedding, basal limestone common</td>
<td>significant: moderate to high</td>
</tr>
<tr>
<td>Distributary Mouth Bar</td>
<td>DMB</td>
<td>fine grained to very fine grained sandstone</td>
<td>dark gray to black</td>
<td>very limited: ostracods, algal debris</td>
<td>planar cross bedding, current ripple laminations with muscovite laminae, IFC’s with limestone clasts, distorted bedding, 2-3% muscovite</td>
<td>significant: moderate to high</td>
</tr>
<tr>
<td>Distributary Channel</td>
<td>DC</td>
<td>fine grained to very fine grained sandstone</td>
<td>dark gray to black</td>
<td>very limited: garpike fish and logs</td>
<td>trough cross bedding, channel scour, IFC’s with siltstone clasts, 1-2Z muscovite</td>
<td>significant: moderate to high</td>
</tr>
</tbody>
</table>

IFC intraformation conglomerate
Bloturbation fossil burrows of small organisms

W. Calkin 5-22-85
<table>
<thead>
<tr>
<th>DRILLED FOOTAGE IN DATA BASE</th>
<th>DELTA OR SUBDELTA Member and (Facies)</th>
<th>LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% SS</td>
</tr>
<tr>
<td>35,560'</td>
<td>SUNNYSIDE DELTA COMPLEX</td>
<td>35.50</td>
</tr>
<tr>
<td>17,725'</td>
<td>BRUIN POINT SUBDELTA</td>
<td>31.93</td>
</tr>
<tr>
<td>17,835'</td>
<td>DRY CANYON SUBDELTA</td>
<td>40.38</td>
</tr>
</tbody>
</table>

| AVERAGE DRILLED THICKNESS     | BRUIN POINT SUBDELTA                  | data base: 19 deep holes |
|                               |                                       | % SS  | % SL  | % SH | % LS | % CG |
| 150'                          | Parachute Creek (Lake)                | 4.92  | 7.15  | 86.10 | 1.52 | 0.31 |
| 484'                          | Garden Gulch (Shore)                  | 22.30 | 11.67 | 53.48 | 11.36 | 1.19 |
| 452'                          | Douglas Creek (Delta)                 | 53.37 | 14.19 | 28.50 | 1.45 | 2.49 |

1,086' Average TD

| AVERAGE DRILLED THICKNESS     | DRY CANYON SUBDELTA                  | data base: 24 deep holes |
|                               |                                       | % SS  | % SL  | % SH | % LS | % CG |
| -0-                           | Parachute (Lake)                     |       |       |      |      |      |
| 522'                          | Garden Gulch (Shore)                 | 41.05 | 9.60  | 39.88 | 7.71 | 1.76 |
| 100'                          | Douglas Creek (Delta)                | 36.05 | 14.86 | 44.23 | 3.30 | 1.56 |

622' Average TD

EXPLANATION

SS = sandstone
SL = siltstone
SH = shale
LS = limestone
CG = conglomerate

Note: Data based on deep drill holes during 1980, 1981, 1982, and 1984 exploration programs but includes 1978 initial drilling on Amoco No. 1 and No. 4,

Table 12. Lithology Within the Sunnyside Delta Complex and Subdeltas
SUNNYSIDE DELTA COMPLEX

DRY CANYON SUBDELTA

UJ > $ 2

£ 2 <

UJ £

u. o

z o

tvj o

^ M

UJ 00

Q

UJ m

Q m

u. m

z

9600-

9400-

9200-

9000-

8800-

AVERAGE COLLAR ELEV.

9531'

116.5

37'

29'

9600

86

38'

22'

42'

37'

19'

35'

22'

36'

130;

53'

36'

72'

1:33;

53'

-9600

-9000

-9400

-8800

-8600

36

22

40

37

19

28

17

38

51

19

42

15

AVERAGE TD 622'

86'

42

-8600

55'

All TAR zones are bituminous sandstones except zones 25 & 26 which are bituminous limestones.

Note: 1. Idealized zone data is cumulative, based on all drill holes in computerized model and does not correlate with elevations.

2. Average drill hole data is based on deep AMOCO holes drilled in 1980-1984 and correlates with elevations.

Table 13 Idealized TAR Zone Data
SUNNYSIDE TAR SANDS, UTAH
Based on Lithology and Stratigraphy
Bruno Point Subdelta
Sunsetsive: Tar Sands

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>Elevation</th>
<th>Depth</th>
<th>Thickness</th>
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</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>9916-999</td>
<td>8970-983</td>
<td>9706-9773</td>
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<td>9706-9678</td>
<td>9706-9678</td>
<td>9706-9678</td>
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<td>9506-9501</td>
<td>9471-9454</td>
<td>120-125</td>
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</table>
### Table 14 (continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Elevation</th>
<th>Depth (ft)</th>
<th>Thickness</th>
<th>X BIT</th>
<th>EOD</th>
<th>Base of Tar</th>
<th>Zone*</th>
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<tbody>
<tr>
<td>12</td>
<td>9946-9945</td>
<td>245</td>
<td>11.0</td>
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<td>13</td>
<td>9900-9898</td>
<td>261.25</td>
<td>11.5</td>
<td>7.8/15.4</td>
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<td>10.0/19.5</td>
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<tr>
<td>14</td>
<td>9841-9833</td>
<td>235.25</td>
<td>11.1</td>
<td>8.2/15.7</td>
<td>SB</td>
<td>10.0/19.5</td>
<td>SHALLOW PILOT MINING HOE</td>
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<tr>
<td>15</td>
<td>9749-9726</td>
<td>217</td>
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<td>9.5/18.4</td>
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<td>16</td>
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<td>10.6/20.4</td>
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<tr>
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<td>12.0</td>
<td>9.5/18.4</td>
<td>SA</td>
<td>10.6/20.4</td>
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<tr>
<td>18</td>
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<td>205</td>
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<td>9.5/18.4</td>
<td>SA</td>
<td>10.6/20.4</td>
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</tr>
<tr>
<td>19</td>
<td>9505-9493</td>
<td>205</td>
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<td>9.5/18.4</td>
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<td>SHALLOW PILOT MINING HOE</td>
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<tr>
<td>20</td>
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<td>9.5/18.4</td>
<td>SA</td>
<td>10.6/20.4</td>
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</tr>
<tr>
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<td>12.0</td>
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*Note: EOD = End of Depth; X BIT = X-Bit Thickness; Base of Tar = Base of Tar Thickness; Zone* = Zone of Mining Operation.*
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<th>Bit</th>
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**Table 14 (continued)**

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**Explanation**

- **collar elevation**
- **total depth**
- **designated tar zone, top and bottom**
- **top picked by geophysics**
- **no core**
- **not drilled as below base of tar**
- **not a designated major tar zone, separate zone, and not used in zine model**
- **less than 5 feet thick**
- **no analyses**
- **nonbituminous**
- **weak bitumen content**
- **moderate bitumen content**
- **weighted average bitumen in wt% per ton**
- **based on sandstone only except zone 25 & 24**
- **114 feet thick of multiple tar sands**
- **environment of deposition**
- **delta front**
- **distal bar**
- **beach**
- **beach-bar**
- **nearshore**
- **interdistributary bay**
- **lagoon**
- **distributary mouth bar**
- **distributary channel**
**Table 15**

**TAR ZONE DATA**

Based on Lithology and Stratigraphy

Dry Canyon Subdelta

Sunnyside Tar Sands

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**Notes:**
- Thickness values may vary slightly due to natural variations in the data.
- Base values are rounded for readability.
- All measurements are in meters (m) unless specified otherwise.

---

**Legend:**
- **Base:** Depth of base of the TAR Zone
- **Thick:** Thickness of the TAR Zone
- **Top:** Top of the TAR Zone
- **Shell:** Shell thickness
- **S:** Sulfur content
- **X:** X-ray absorption
- **H:** Hydrocarbons
- **K:** Kerogen type
- **L:** Limestone
- **M:** Mudstone
- **E:** Erosion
- **D:** Deposition
- **S:** Sandstone
- **X:** Xerophytic vegetation
- **F:** Fluvial deposits
- **B:** Bioturbation

---

**Table 15 Continued...**

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**Sunnyside Tar Sands:**
- **Depth:** Values range from 9551 to 9206 meters, indicating the TAR Zone's depth.
- **Thickness:** Varies from 2.3 to 10.4 meters, showing the thickness of the TAR Zone across different sections.
- **Erosion:** Occurs in various sections, suggesting different levels of erosion affecting the TAR Zone.

---

**Base Data:**
- **9551-9532:** Base of the TAR Zone at 9551 meters.
- **9470-9452:** Base of the TAR Zone at 9470 meters.
- **9409-9359:** Base of the TAR Zone at 9409 meters.
- **9345-9293:** Base of the TAR Zone at 9345 meters.
- **9265-9225:** Base of the TAR Zone at 9265 meters.
- **9195-9119:** Base of the TAR Zone at 9195 meters.
- **9208-8959:** Base of the TAR Zone at 9208 meters.
- **8989:** Base of the TAR Zone at 8989 meters.
- **611:** Base of the TAR Zone at 611 meters.
- **8904-8701:** Base of the TAR Zone at 8904 meters.
- **7510-8401:** Base of the TAR Zone at 7510 meters.
- **6408-6107:** Base of the TAR Zone at 6408 meters.
- **5506-5205:** Base of the TAR Zone at 5506 meters.
- **4504-4203:** Base of the TAR Zone at 4504 meters.
- **3502-3201:** Base of the TAR Zone at 3502 meters.
- **2500-2200:** Base of the TAR Zone at 2500 meters.
- **1508-1207:** Base of the TAR Zone at 1508 meters.
- **1006-8805:** Base of the TAR Zone at 1006 meters.
- **8004-7703:** Base of the TAR Zone at 8004 meters.
- **7002-6601:** Base of the TAR Zone at 7002 meters.
- **6000-5809:** Base of the TAR Zone at 6000 meters.

---

**Ko. 34 Elevation:**
- **Eroded:** Indicates the TAR Zone is eroded in this section.
- **Drill Hole:** Locations where data is collected.
- **Values:** Range from 53.7 to 57.8, indicating the TAR Zone's depth across various sections.

---

**Ko. 35 Elevation:**
- **Eroded:** Indicates the TAR Zone is eroded in this section.
- **Drill Hole:** Locations where data is collected.
- **Values:** Range from 54.3 to 57.6, indicating the TAR Zone's depth across various sections.

---

**Ko. 36 Elevation:**
- **Eroded:** Indicates the TAR Zone is eroded in this section.
- **Drill Hole:** Locations where data is collected.
- **Values:** Range from 57.3 to 59.3, indicating the TAR Zone's depth across various sections.

---

**Ko. 37 Elevation:**
- **Eroded:** Indicates the TAR Zone is eroded in this section.
- **Drill Hole:** Locations where data is collected.
- **Values:** Range from 59.2 to 62.5, indicating the TAR Zone's depth across various sections.

---

**Ko. 38 Elevation:**
- **Eroded:** Indicates the TAR Zone is eroded in this section.
- **Drill Hole:** Locations where data is collected.
- **Values:** Range from 62.3 to 65.6, indicating the TAR Zone's depth across various sections.
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<thead>
<tr>
<th>Hole</th>
<th>No. 41</th>
<th>Elevation</th>
<th>Depth</th>
<th>Thickness</th>
<th>X BIT</th>
<th>EOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9176-9187</td>
<td>129-141</td>
<td>165-197</td>
<td>291-301</td>
<td>324-360</td>
<td>372-411</td>
</tr>
<tr>
<td></td>
<td>9145-9111</td>
<td>12</td>
<td>32</td>
<td>10</td>
<td>5</td>
<td>3.125</td>
</tr>
<tr>
<td>So. 43</td>
<td>Eroded</td>
<td>9437-9218</td>
<td>9159-9137</td>
<td>9118-9055</td>
<td>9862-9826</td>
<td>999-435</td>
</tr>
<tr>
<td></td>
<td>907-9007</td>
<td>36</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>5.8/13.9</td>
</tr>
<tr>
<td>No. 46</td>
<td>Eroded</td>
<td>9387-9351</td>
<td>9336-9323</td>
<td>9233-9257</td>
<td>9861-9771</td>
<td>976-128</td>
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<td></td>
<td>9894-9849</td>
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<td>12</td>
<td>9</td>
<td>5</td>
<td>5.8/13.9</td>
</tr>
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<td>9118-9055</td>
<td>9862-9826</td>
<td>999-435</td>
</tr>
<tr>
<td></td>
<td>907-9007</td>
<td>36</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>5.8/13.9</td>
</tr>
<tr>
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<td>9159-9137</td>
<td>9118-9055</td>
<td>9862-9826</td>
<td>999-435</td>
</tr>
<tr>
<td></td>
<td>907-9007</td>
<td>36</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>5.8/13.9</td>
</tr>
<tr>
<td>No. 49</td>
<td>Eroded</td>
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<td>999-435</td>
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<tr>
<td></td>
<td>907-9007</td>
<td>36</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>5.8/13.9</td>
</tr>
<tr>
<td>Drill Hole</td>
<td>Zone*</td>
<td>Data No.</td>
<td>23T</td>
<td>23B</td>
<td>25T</td>
<td>25B</td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>----------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>No. 53 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 54 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 55 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 56 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 57 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 58 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 59 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 61 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
</tr>
<tr>
<td>±</td>
<td>No. 62 Elevation</td>
<td>Depth</td>
<td>Thickness</td>
<td>Eroded</td>
<td>Eroded</td>
<td>Eroded</td>
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</table>
### Table 15 (continued)

#### EXPLANATION

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>CE</td>
<td>collar elevation</td>
</tr>
<tr>
<td>TD</td>
<td>total depth</td>
</tr>
<tr>
<td>21T-21B</td>
<td>designated tar zone, top and bottom</td>
</tr>
<tr>
<td>GP-17</td>
<td>top picked by geophysics</td>
</tr>
<tr>
<td>NC</td>
<td>no core</td>
</tr>
<tr>
<td>ND</td>
<td>not drilled</td>
</tr>
<tr>
<td>*</td>
<td>not a designated major tar zone, separate zone, and not used in mine model</td>
</tr>
<tr>
<td>THIN</td>
<td>less than 5 feet thick</td>
</tr>
<tr>
<td>NA</td>
<td>no analyses</td>
</tr>
<tr>
<td>NONBIT</td>
<td>nonbituminous</td>
</tr>
<tr>
<td>WK</td>
<td>weak bitumen content</td>
</tr>
<tr>
<td>MOD</td>
<td>moderate bitumen content</td>
</tr>
<tr>
<td>X BIT 5.6/13.4</td>
<td>weighted average bitumen in vtZ/gals per ton</td>
</tr>
<tr>
<td></td>
<td>(based on sandstone only except zone 25 &amp; 26)</td>
</tr>
<tr>
<td>114M</td>
<td>114 feet thick of multiple tar sands</td>
</tr>
<tr>
<td>EOD</td>
<td>environment of deposition</td>
</tr>
<tr>
<td>DF '</td>
<td>delta front</td>
</tr>
<tr>
<td>DB</td>
<td>distal bar</td>
</tr>
<tr>
<td>B</td>
<td>beach</td>
</tr>
<tr>
<td>BB</td>
<td>beach-bar</td>
</tr>
<tr>
<td>KS</td>
<td>nearshore</td>
</tr>
<tr>
<td>BAY</td>
<td>interdistributary bay</td>
</tr>
<tr>
<td>L</td>
<td>levee</td>
</tr>
<tr>
<td>DMB</td>
<td>distributary mouth bar</td>
</tr>
<tr>
<td>DC</td>
<td>distributary channel</td>
</tr>
</tbody>
</table>
June 30, 1985

Mr. Gene E. Tampa
Director Tar Sands and Shale Projects
Amoco Corporation, MC 2903
200 East Randolph Drive
Post Office Box 5910-A
Chicago, Illinois 60680

Dear Mr. Tampa:

This three volume report on the Sunnyside Tar Sands project is a summary of the geological field and office work completed during the 1984 exploration program. The written report represents a compilation of data from the 1980, 1981, 1982 and 1984 exploration programs. Each year additional data and research has continued to refine the geological interpretations associated with the Sunnyside delta complex.

The summary and conclusions as well as recommendations occur at the beginning of the report. The detailed geological aspects occur near the end of the written report. All photographs, figures and tables are in numerical order in the Appendix at the end of the written report. The various maps are in the pockets of Volume II. The strip logs of drill holes and measured sections completed during the 1984 exploration program are in the pockets of Volume III. Some typical geophysical logs accompany specific strip logs.

The support and cooperation of Amoco Minerals during both the field and research phases of this tar sand project is gratefully acknowledged. This report is the result of four years of exploration programs. It is the result of combined efforts by numerous people of Amoco's staff. I especially wish to thank Jim Nalven for his coordinating efforts and Stan Leland for his work in completing all the drafting.

Ten copies of this report have been made and eight copies have been sent to your office. One copy has been sent to the Golden, Colorado office of Pincock, Allen and Holt, Inc. One copy has been retained by me.

If there are any questions regarding the geological aspects of the Sunnyside Tar Sands project that need clarification, please contact me.

Sincerely,

Wm S. Calkin
GEOLOGIC SUMMARY REPORT
OF THE
1984 EXPLORATION PROGRAM
SUNNYSIDE TAR SANDS PROJECT
CARBON COUNTY, UTAH

Volume I

004J2