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Rio Blanco Oil Shale Project

PROGRESS REPORT 5

GEOTECHNICAL DATA GATHERING PROJECT

GEOLOGIC PROGRAM
SECTION 1.1
TRACT C-a GEOLOGIC REPORT

To Area Oil Shale Supervisor
United States Geological Survey

orporation
an
Stan Oil Company (Indiana)

PROGRESS REPORT 5

GEOTECHNICAL DATA GATHERING PROJECT

GEOLOGIC PROGRAM

SECTION 1.1

TO

AREA OIL SHALE SUPERVISOR
UNITED STATES GEOLOGICAL SURVEY

By

RIO BLANCO OIL SHALE PROJECT
Gulf Oil Corporation
and
Standard Oil Company (Indiana)

January 30, 1976

TABLE OF CONTENTS

SECTION 1.1.4

SECTION 1.1

SECTION 1.1.1

TABLE OF CONTENTS

ADDITIONAL ENCLOSURE:
Tract C-a Geologic Report

SECTION 1.1.3

SECTION 1.1.4

SECTION 1.1

SECTION 1.1.1

1.1 Geologic Program

The nine major tasks which make up the geologic program are as follows: Corehole Program, Laboratory Analyses, Stratigraphic Compilation, Aerial Photography, Compilation of Topographic Maps, Photogeologic Mapping, Surface Geologic Mapping, Seismic Program, and Structural Compilation. Most of these tasks had been completed prior to this reporting period and reported in previous Progress Reports. During this reporting period the reclamation of drill pads, was finished with the fall seeding, reassays of some of the core intervals were being conducted. Areal photography of 84 Mesa was completed, as was preliminary topographic mapping of 84 Mesa. A detailed Geologic Report of Tract C-a is being submitted as part of Progress Report 5 - Interpretive Text. The results of the rock mechanics program is submittal to the Area Oil Shale Supervisor in the RBOSP Progress Report 5 - Confidential Volume.

SECTION 1.1.3

SECTION 1.1.4

SECTION 1.1.5

SECTION 1.1.1

1.1.1 Corehole Program

A description of the corehole program was presented in RBOSP Progress Report 2 - Summary. Figure 1.1-1 is a map of Tract C-a showing the pre-lease corehole as well as the location of Gulf-Standard (Indiana) coreholes drilled during the summer and fall of 1974. Work conducted in conjunction with the corehole program during the quarterly reporting period (September, October, and November) consisted of drill site reclamation as described in the following paragraphs.

Some drill site reclamation was completed in October of 1974, in areas where drilling and associated activities were basically completed. Results of this effort were inspected in April 1975, and work required by the AOSS to complete reclamation was set forth.

In summary, some eighteen new drill sites were created for the RBOSP 1974-75 geotechnical drilling program; three pre-lease drill sites were disturbed anew for additional RBOSP holes. This resulted in twenty one drill sites for which reclamation was specified and completed generally as follows:

1. Drill and coreholes were marked. Waste from the drilling operation was removed. The disturbed area was then reshaped to a contour commensurate with the surrounding topography; a flat area was left around holes in which further completion work will be done.

2. Prior to seeding the area was prepared by ripping.

3. Seeding was accomplished mainly by a tractor-drawn seed drill; seeding was done by hand in a few small areas to complete seeding or in areas not reached by the drill. One of three different seed mixtures was used.

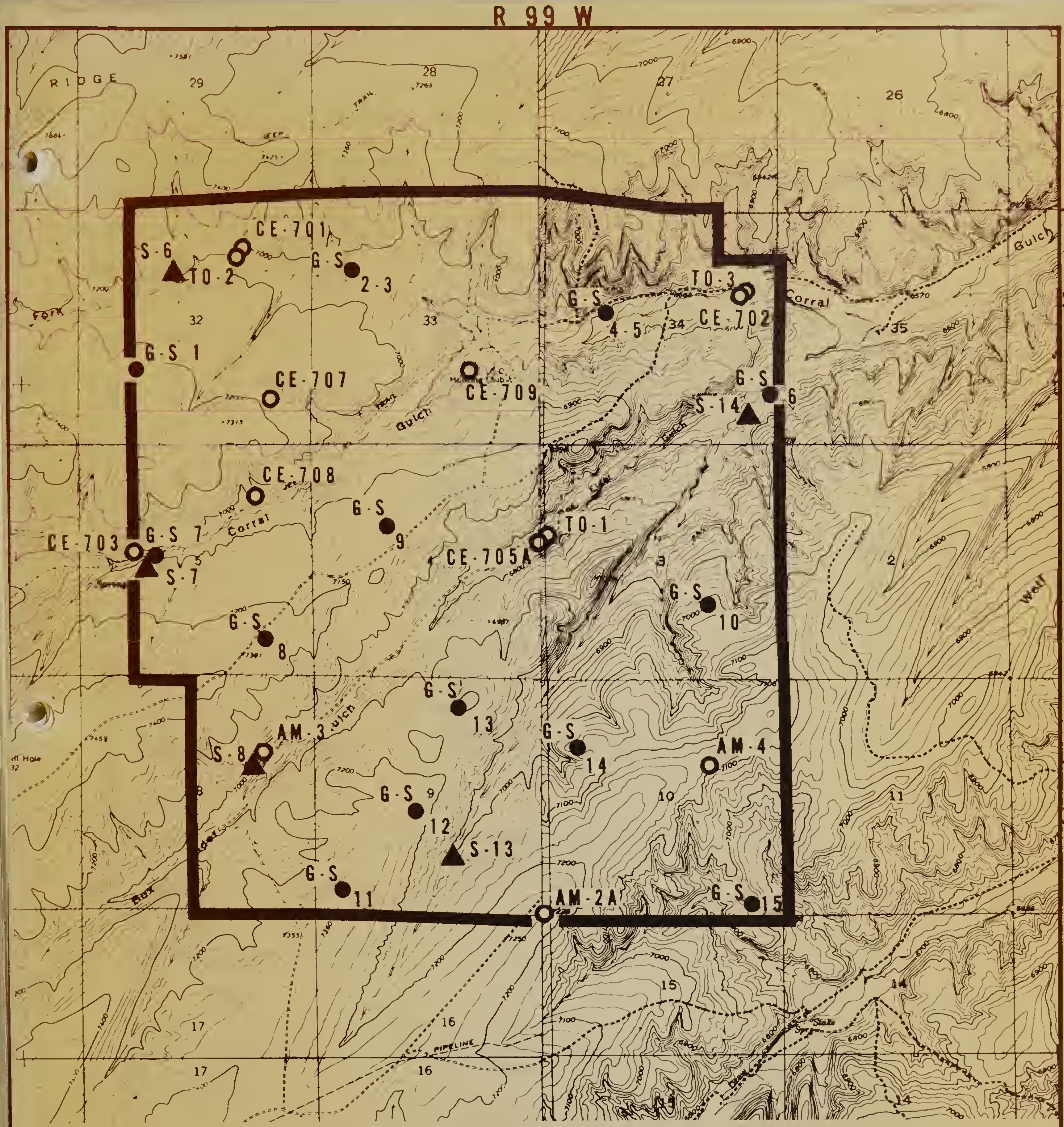
4. The seeded area was drug lightly with chains after seeding. No fertilizer or watering was used.

5. Fencing of thirteen of the new RBOSP drill pads was completed as required by the AOSS. Standard three-strand barbwire range fence was used.

Further details of the present status of the subject drill sites is reported in Table 1.1-1.

It is believed that the subject drill pads have been reasonably reclaimed at this point. An inspection will be made around May or June 1976, to determine the viability of the seeding.

Required reclamation of drill sites at G-S-6, G-S D18, and the access road to G-S 14 will be completed either in 1976 or when they are no longer in use. Drill site reclamation at G-S M5 will be completed during 1976.



PRE-SALE CORE HOLES

○ CAMERON

TO ○ TOSCO

AM ○ AMOCO

POST SALE CORE HOLES

G-S ● GULF - STANDARD

S-6 ▲ ALLUVIAL AQUIFER TEST WELL

GULF - STANDARD (INDIANA)

RIO BLANCO OIL SHALE PROJECT

TRACT C-a

COREHOLE PROGRAM

FIGURE 1.1-1

Table 1.1-1

STATUS OF DRILL SITE RECLAMATION

Drill Site-Hole Numbers	RBOSP (RB) or Pre-lease(PL)	Seed Mixture* Used	Fencing	Other Reclamation
G-S 1	RB	SM-1**	Yes	
G-S 2-3	RB	SM-2**	Yes	
G-S 4-5	RB	SM-2; Reseed SM-3	Yes	
G-S 6	RB	Not seeded yet; storage supply area	Yes	
G-S 7	RB	SM-2	Yes	Some sagebrush slash covering
G-S 8	RB	SM-1; reseeded SM-3	Yes	
G-S 9	RB	SM-1**	Not required	
G-S 10	RB	SH-1; Reseed SM-3	Not required	
G-S 11	RB	SM-3	Yes	
G-S 12; G-S D-16	RB	SM-3	Yes	
G-S 13	RB	SM-1	Not required	Slash covering
G-S 14	RB	SM-1	Yes	
G-S 15	RB	Not required. Too rocky.	Not required	Slash covering
G-S M-1	RB	SM-3	Yes	Slash covering
G-S M-2	RB	SM-3	Yes	
G-S M-3	RB	SM-3**	Yes	
G-S M-4	RB	SM-3***	Yes	Slash covering
G-S M-5	RB	Not seeded yet	Not fenced	
G-S D-17	PL	SM-3	Prev. fenced	
G-S D-18	PL	Not seeded yet; headquarters site	Not fenced	
G-S D-19	PL	SM-3	Prev. fenced	

*Seed Mixtures (SM) Used:

SM-1	SM-2	SM-3	lbs/acre
40% Western Wheatgrass	90% Western Wheatgrass	Winterfat	1.5
5% Annual Rye	10% Annual Rye	Lewis Flax	1.0
15% Big Sage		Luna Pubesent Wheat Grass	2.5
10% Bitterbrush		Oahe Intermediate Wheat Grass	2.5
20% Beardless Wheatgrass		Forwing Saltbush	0.5
10% Needle & Threadgrass		Sand Dropseed	1.0
100%	100%		
8 lbs/acre	8 lbs/acre		9.0

**Small areas 50' x 100' around hole seeded subsequently with SM-3.
***Missing Lewis flax seed from mixture; ran short of supply.

SECTION 1.1.3

SECTION 1.1.4

SECTION 1.1.5

SECTION 1.1.6

SECTION 1.1.2

1.1.2 Laboratory Analyses

The general objectives of these programs were summarized in Section 1.1.2 of Progress Report 4 - Summary. During this reporting period oil shale core intervals from G-S 4-5 and G-S 6 were being reassayed. Also, assaying of intervals of core withheld from assay for rock mechanics testing was begun. A final report on the rock mechanics test was completed.

1.1.2.1 Oil Shale Assays

Re-assay of core intervals in the lower portions of G-S 4-5 and G-S 6 not yet completed. Anticipate results will be available for Report 6. Assaying of some core intervals previously withheld for rock mechanics testing has begun. This new data will be submitted to AOSS as available in subsequent progress reports. The entire core from G-S 13 is still withheld from assaying in the event that additional rock mechanics testing requiring complete core is necessary.

1.1.2.2 Nahcolite Analysis

The results of the nahcolite analyses were submitted to the AOSS as described in Section 1.1.2.2 of RBOSP Progress Report 2 - Summary.

1.1.2.3 Extractable Alumina

The results of the extractable alumina analyses on processed shale was submitted to AOSS in Section 1.1.2.3 of Progress Report 2 - Interpretive Text. The concentration of extractable alumina in processed shale was found to vary considerably with stratigraphy. RBOSP is continuing to study the commercial potential of alumina extraction consistent with the development of Tract C-a.

1.1.2.4 Trace Elements

The analyses of seven trace elements in fresh and processed oil shale samples were reported in Section 1.1.2.4 of RBOSP Progress Report 2 - Summary. The mineral identification and occurrence of the same seven trace elements were reported in RBOSP Progress Report 3 - Summary.

1.1.2.5 Gas Samples

The gas sampling program has been completed and was reported in Section 1.1.2.5 of RBOSP Progress Report 2 - Summary.

1.1.2.6 Rock Mechanics

An extensive rock mechanics program was initiated during the exploration phase of this project to determine the rock mechanics parameters essential for mine design. Rock mechanics parameters for mine design were determined primarily by laboratory tests of core from G-S core holes 2-3, 4-5, 6, 11 and 15. A report by RE/SPEC Inc., "Final Summarization and Analysis of Laboratory Rock Mechanics Test Data For Core Samples From Oil Shale Lease Tract C-a" contains the results of the rock mechanics program. This report is submitted to the Area Oil Shale Supervisor in Section 1.1.2.6 of the Confidential Volume of Progress Report 5.

The following rock properties, considered important for mine design, were obtained from testing of cores and geophysical logging.

- Uniaxial compressive strength
- Modulus of elasticity
- Tensile strength
- Angle of internal friction
- Cohesion
- Rock density
- Shear strength
- Modulus of rupture
- Poission's ratio
- Dynamic Elastic Properties

Laboratory test results for uniaxial compressive strength, tensile strength, modulus of elasticity, modulus of rupture and angle of internal friction were correlated with ore grade, irrespective of zone. In addition to these analyses, the test results from core from only the Mahogany zone were correlated with ore grade.

Information regarding the in situ rock characteristics was obtained from surface geologic mapping, seisviewer logs and core logs from which the nature, number and orientation of major joints were determined to the extent possible with the available data. The in situ rock stresses were utilized from published information on hydrofracture tests made by the U.S. Geological Survey in drill holes CE 702 and CE 703.

Following is a discussion of the various individual rock strength parameters utilized during the Phase I mine studies.

1.1.2.6.1 Uniaxial Compressive Strength

The uniaxial compressive strength of oil shale has been shown in the past to be directly related to oil shale grade. Compressive strength decreases with an increase in oil shale grade. It is noted that compressive strength, irrespective of zone on Tract C-a, appears to be generally lower than the compressive strength of the Mahogany zone at Anvil Points and Colony Mines. Also, the Mahogany zone compressive strength appears to be higher than in the case where all zones are considered. In all cases, compressive strength appears to become constant in the range of 34 to 40 GPT.

The reason for the apparent difference between rock strength and ore grade by zone and irrespective of zone is not known. The difference may be related to the detailed mineralogy of the various mining horizons which contain varying minor amounts of nahcolite and dawsonite as well as various clay minerals.

1.1.2.6.2 Modulus of Elasticity

The modulus of elasticity also decreases with increasing oil shale grade between 0 and 45 GPT. The modulus of elasticity values for Tract C-a were plotted irrespective of zone. Sufficient data were not available for determination of the ore grade-modulus relationship by zone except for the Mahogany zone, where the modulus of elasticity tends to be higher than in the case where all zones are considered.

It is to be noted that the modulus of elasticity for all zones within Tract C-a is significantly lower in the low oil content range than in the Mahogany zone at Anvil Points. The reason for this apparent differences is not known, but as in the case of the compressive strength, the difference is possibly related to mineralogy.

1.1.2.6.3 Tensil Strength

Tensil strength was determined by Brazil splitting tests of core samples. Tensile strength appears to increase with oil content between 0 and 28 GPT. At approximately 28 GPT, tensil strength values become almost constant.

1.1.2.6.4 Angle of Internal Friction - Intact Rock

Sufficient data are available to correlate oil content with the angle of internal friction for intact rock in the range between 10 and 45 GPT. This angle ranges from near 43¼ at 10 GPT to 25¼ at 45 GPT.

1.1.2.6.5 Angle of Internal Friction - Rock Joints

Tests on rock samples containing planes of weakness are limited. The results of the tests indicate that the strength of jointed rock is

quite high, possibly in the general range of intact or unjointed rock. The average coefficient of sliding friction, as determined from test results, is about 0.7 or an angle of internal friction of 35°, for both open and sealed joints.

1.1.2.6.6 Cohesion

The limited testing of Tract C-a rock samples containing sealed joints indicates cohesion may average about 250 psi.

1.1.2.6.7 Density

The relation between oil content and grain density has been well established by investigators in the Piceance Creek basin. The best known curve for oil content-density is the John Ward Smith curve (described in "Specific Gravity - Oil Yield Relationships of Two Colorado Oil Shale Cores", Industrial and Engineering Chemistry, Vol. 48, No. 3, pp. 441-444) developed by the U.S. Bureau of Mines. From density determinations of Tract C-a core, it was found that a modification of the John Ward Smith relationship gave a better data fit to Tract C-a conditions.

1.1.2.6.8 Shear Strength

No definite relationship has been established between oil shale grade and shear strength of Tract C-a oil shale. Laboratory test values from triaxial tests were found to range from 2505 to 3950 psi. The average value from direct shear tests for the peak shear strength of intact samples is as high as 2350 psi. The shear strength parallel to the stratification in oil shale appears to be higher than the post mining lateral stresses present. The average residual shear strength from direct shear tests on intact samples is 825 psi.

1.1.2.6.9 Modulus of Rupture

This rock strength parameter was also determined, although it was not used directly for any design analysis of open pit mine slopes. A conservative value for the modulus of rupture of two times the tensile strength parallel to the oil shale bedding has been used for design. However, on Tract C-a the modulus of rupture has proved to be 3 to 4 times the tensile strength.

1.1.2.6.10 Poisson's Ratio

Testing has shown Poisson's ratio to be independent of oil shale grade and highly dependent on stress levels during testing. Poisson's ratios were also determined for discrete zones within the mining sequence for use in finite element analysis of pit slopes.

1.1.2.6.11 Dynamic Elastic Properties

The above properties which have been established for oil shale are all static properties. In order to determine in situ elastic

properties utilizing Birdwell borehole velocity logs, a number of dynamic tests were performed on core samples to establish a ratio between the static and dynamic elastic properties. The ratio of static to dynamic modulus of elasticity generally increases with depth. As expected, the dynamic elastic constants are greater than the static elastic constants. If no in situ measurements are available, the in situ static modulus of elasticity and Poisson's ratio will be taken as 0.43×10^6 psi and 0.37 respectively, for the Mahogany zone.

SECTION 1.1.3
SECTION 1.1.4
SECTION 1.1.5
SECTION 1.1.6
SECTION 1.1.7

1.1.3 Stratigraphic Compilation

The stratigraphic compilation has been completed and was reported in Section 1.1.3 of RBOSP Progress Reports 3 and 4 - Summaries. In addition, six oil shale assay histogram cross sections and six density log cross sections are included in Section 1.1.3 of the Confidential Volume of Progress Report 5.

1.1.4 Aerial Photography

Aerial photography of an additional 8,200 acres covering the 84 Mesa area north of Tract C-a has been completed. These photographs have been used in the detailed topographic mapping of the 84 Mesa area.

SECTION 1.1.5

SECTION 1.1.6

SECTION 1.1.7

1.1.5 Compilation of Topographic Maps

Preliminary mapping using the photographs mentioned in Section 1.1.4 has been completed and is presently being checked for accuracy. These will be submitted to the AOSS when finalized.

SECTION 1.1.9

SECTION 1.1.6

SECTION 1.1.7

1.1.6 Photogeologic Mapping

Photogeologic mapping has been completed as reported in Section 1.1.6 of RBOSP Progress Report 2 - Summary.

SECTION 1.1.9

SECTION 1.1.7

1.1.7 Surface Geologic Mapping

The surface geologic mapping of about ten square miles has been completed as was reported in Section 1.1.7 of Progress Report 2 - Summary.

1.1.8 Seismic Program

The seismic program was discontinued as reported in Section 1.1.8 of RBOSP Progress Report 2 - Summary.

SECTION 1.1.9

1.1.9 Structural Compilation

A revised Middle A-groove structure map (Revision 1) is enclosed in Section 1.1.9 of the Confidential Volume of Progress Report 5. Two additional faults recently located in the northwest corner of Tract C-a have beed added to this map. Revisions also include minor changes to interpretations of several other faults.

RIO BLANCO OIL SHALE PROJECT

PROGRESS REPORT 5

GEOTECHNICAL DATA GATHERING PROJECT

GEOLOGIC PROGRAM

SECTION 1.1

TRACT C-a GEOLOGIC REPORT

To Area Oil Shale Supervisor
United States Geological Survey

Gulf Oil Corporation
and
Standard Oil Company (Indiana)

TABLE OF CONTENTS

Note: Numbering format corresponds to that used in the DDP; Section 3 - Baseline Conditions, Chapter 3 - Geology.

LIST OF TABLES

LIST OF FIGURES

LIST OF ENCLOSURES AND BACK-UP EXHIBITS
(Submitted to AOSS Under Separate Cover 12/16/75)

Enclosure Number

1-A: Tract C-a Correlation Network; Gamma Ray-Density Log Cross Sections (Set of 6).

1-B: Tract C-a Correlation Network; GPT Histogram Log Cross Sections (Set of 6). CONFIDENTIAL

2: Tract C-a Zonal Isograde-Isopach Maps (Set of 20) CONFIDENTIAL: Delivered Rolled.

3: Amuedo & Ivey Tract C-a Middle A-Groove Structure Map.

4: Tract C-a Overburden Map, Surface to Middle A-Groove.

Back-up Exhibits

Full scale Figure 3-3-4: SW-NE 3-Core Hole Histogram Cross Section, Tract C-a.

Full scale Figure 3-3-5: RBOSP Tract C-a Middle A-Groove Structure Map, Geologic Revision 1.

TRACT C-a GEOLOGIC REPORT

In May, 1974, Gulf-Standard (Indiana) submitted to the Area Oil Shale Supervisor their Tract C-a Exploratory Plan which specified the various data gathering programs and engineering studies considered necessary to formulate the Detailed Development Plan. Section 5 of the G-S Exploratory Plan presented a summary report of the tract's geology as then known or interpreted and listed additional geologic investigations designed to more fully evaluate its structure, stratigraphy and mineral resources.

On June 27, 1974, the AOSS conditionally approved both the G-S Exploratory Plan's Geologic Exploration Plan and Subsurface Hydrology Plan. Attached was a list of 14 conditions which Gulf-Standard accepted. On August 27, 1974, the AOSS amended three of the previous conditions of approval, which pertained to analysis for trace elements, radioactivity and chemical constituents in ground water, oil shale and overburden. These revisions were also accepted by Gulf-Standard.

The purpose of this geologic report as part of RBOSP Progress Report 5, Interpretive Text, is to:

- Review the data gathering programs related to the additional geologic investigations as outlined in the G-S Exploratory Plan. The AOSS has been kept formally advised periodically as to the status of these activities in RBOSP Progress Reports 1 thru 4 which cover activities in each seasonal quarter from 3/1/74 to 8/31/75. These reports also list data compiled by these activities which have been transmitted to the office of the AOSS.
- Incorporate the results of the additional programs into previously existing control and present a detailed updated version of Tract C-a geology as now known or interpreted. Pertinent information from published sources is also included.
- Provide the detailed report on which the geologic portion of the DDP will be based (Section 3, Chapter 3).

All additional geologic investigations as outlined in the G-S Exploratory Plan are now complete with the exception of:

- A limited amount of surface geologic mapping: All field work was terminated on December 11, 1974, when heavy snow fall in the area forced its suspension for the season. At that stage, the mapping within Tract C-a was about 70-80% completed. Rio Blanco planned to complete the surface geologic mapping program during the first half of 1975. However, in March, 1975, Rio Blanco elected to defer completion of the program until priorities were defined as to where and what type of additional surface geologic control was yet needed based on mining and engineering studies then in progress. After evaluating all available photogeologic, surface geologic and subsurface geologic data, Rio Blanco decided sufficient control was already compiled to define the tract's major geologic characteristics and formulate the DDP. The unfinished surface mapping program was therefore cancelled to be replaced by field-checking of the unfinished areas as required (see Surface Geologic Mapping, item 3.1.C).
- Incorporation of Fischer assays of core held for rock mechanics tests in 8 G-S core holes and check re-assays in two G-S core holes: Of the approximately 2150' of core involved in the above programs, assays are now complete on about 1450' of core. This new assay data will be incorporated into tract control with appropriate revised maps and cross sections submitted to the AOSS (see Laboratory Analyses, item 3.1.F).
- A detailed review of the questionable structural data resulting from the seismic program: At present, this data is in "hold status" because the subsurface structure shown by the seismic program significantly conflicts with known structure clearly defined at the surface. Extensive seismic record processing required to separate surface noise from reflected energy may have resulted in erroneous portrayal of subsurface structure. Considerable detailed evaluation of the basic

field records will be necessary to determine its usefulness and reliability (see Seismic Exploration Program, item 3.1.G).

Data yet forthcoming as listed above may result in some minor revision of the Tract C-a geology as currently defined. However, the tract geology presented in this report is considered representative of its major structural, stratigraphic and mineral resource characteristics.

It should be recognized, however, that future supplemental geologic programs, particularly those furnishing more subsurface structural control, may result in significant revisions of structure in local portions of the tract. These revisions can be expected to be most pronounced where additional structural control is obtained in the vicinity of fault zones. Further, tract development will expose to view even more structural data in open pit walls and/or underground mines.

Whatever the source, new data will be evaluated and incorporated into present geologic control as it is obtained. Revisions in the tract's geologic framework will be made periodically as required with copies furnished to the office of the AOSS.

3.1 REVIEW OF DATA GATHERING PROGRAM

A. Aerial Photography - Approximately 392 square miles of color and color-infrared aerial photography was completed in September, 1974, by Bovay Engineers, Inc.-IntraSearch, Inc. The area overflown is shown in Figure 3-3-1 and encompasses the originally planned 380 square miles plus an additional 12 square miles on its northwest border in the vicinity of the Spring Creek headwaters immediately downslope from Cathedral Bluffs. This additional area was overflown to provide new photo coverage over a potential area of interest for waste disposal.

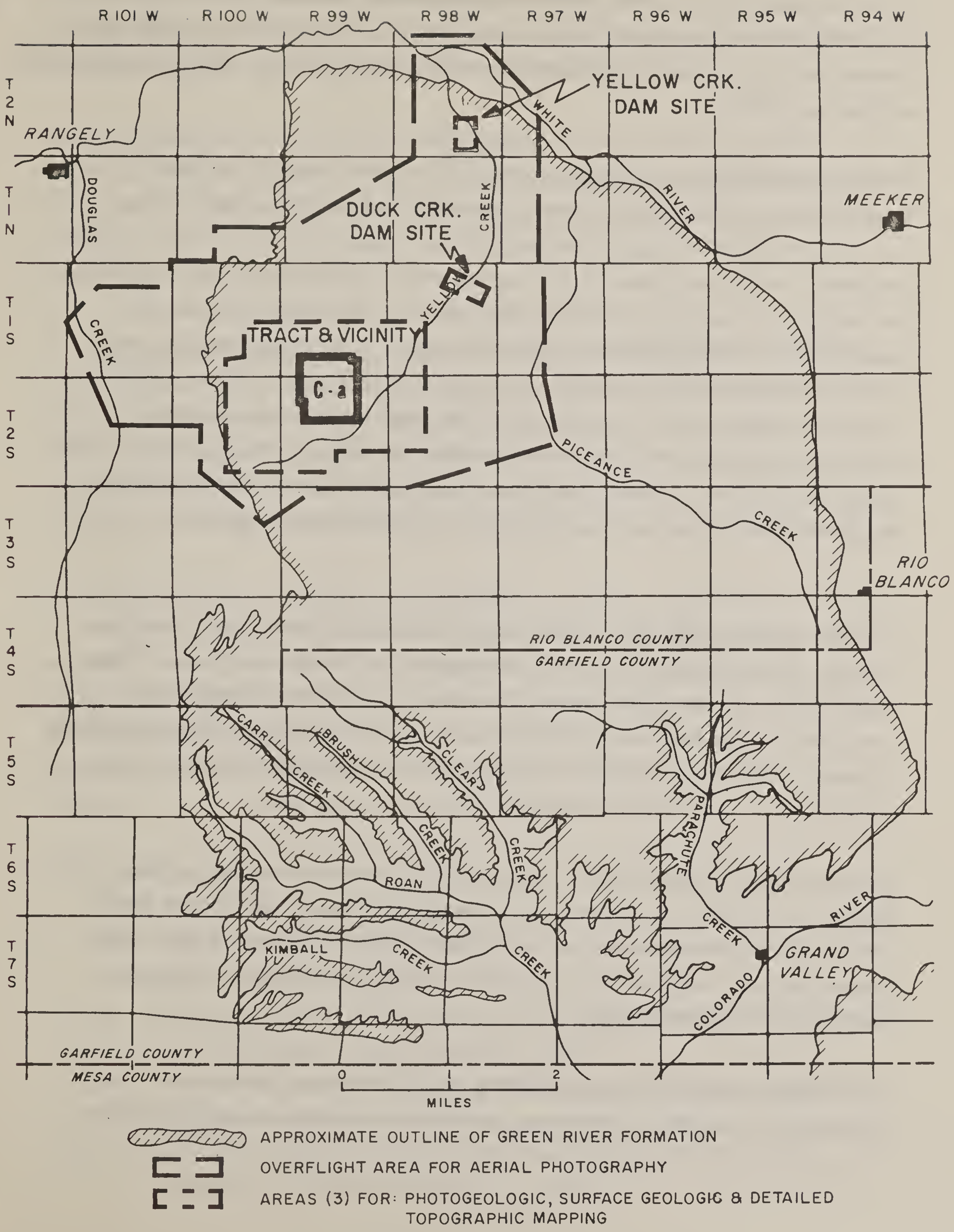


Figure 3-3-1
REGIONAL MAP, PICEANCE CREEK BASIN

Prior to overflight, survey parties established necessary ground control including the location and appropriate paneling of existing section and quarter-section corners (monuments) so that they would be readily identifiable on the new photos.

Color photography was obtained at both 1" to 3000' and 1" to 1000' scale. Color-infrared photography was obtained at 1" to 1000' scale.

The total overflight area of 392 square miles far exceeds that required for detailed topographic mapping and geologic evaluation of the 85 square miles covering Tract C-a and Vicinity, Duck Creek Dam Site and Yellow Creek Dam Site as outlined in the G-S Exploratory Plan. This relatively large overflight area was designed to provide new photo coverage as base control for other studies including off-tract facilities, corridor location, surface hydrologic and environmental investigations. The photographs obtained are on file at the Rio Blanco office.

B. <u>Photogeologic Mapping</u> - Trollinger Geological Associates used the new aerial photography for their photogeologic interpretations. Three areas totalling about 85 square miles were critically examined with particular emphasis on the definition of surface fault and joint-fracture systems. These three areas are identified as Tract and Vicinity, Duck Creek Dam Site and Yellow Creek Dam Site on Figure 3-3-1 .

Because Bovay Engineers, Inc., was at this time only in the initial stages of contructing new detailed topographic maps, TGA posted their photogeologic interpretations on 1"-1000' scale topographic base maps composited and expanded from existing 1"-2000' scale USGS 7.5 minute quadrangle topographic maps.

Rio Blanco furnished TGA with middle A-groove datums in on-tract core holes and in available off-tract core holes and conventionally drilled wells. TGA incorporated this subsurface control into their photogeolgic interpretation of the Tract and Vicinity area by form-line contouring their photogeologic control at this structural horizon.

TGA completed their preliminary photogeologic map of the Tract and Vicinity area in October, 1974. Their final report including maps of all three areas was completed in November, 1974. These data provided the base control for subsequent surface geologic mapping by Amuedo and Ivey.

C. Surface Geologic Mapping - Amuedo and Ivey commenced their surface geologic mapping program immediately upon receiving TGA photogeologic data and aerial photos. A&I overlaid with clear film all photos on which TGA photogeologic data was posted to prevent TGA's work from destruction or alteration with field use. In this way, TGA and A&I interpretations were kept separate for subsequent review by Rio Blanco.

All field work was terminated on December 11, 1974, when heavy snow fall in the area forced its suspension for the season. At that stage, surface geologic mapping within Tract C-a was about 70-80% completed (A&I, 1975-B) and the mapping of Yellow Creek Dam Site was completed (A&I, 1975-A). Because geologic conditions were found very favorable at the Yellow Creek Site, surface mapping of the Duck Creek Site was postponed indefinitely.

A&I's geologic mapping of Tract C-a involved the following tasks:

- Field-check all TGA photo-defined or suspected fault and joint-fracture systems.
- Determine the orientation of faults and the amount and direction of displacement associated with them.
- Map surface structure with plane-table and alidade methods utilizing laterally persistent key beds. Lower the defined surface structure to the middle A-groove horizon by means of key bed(s) to middle A-groove isopachs.

- Obtain surface joint orientation data.
- Measure several stratigraphic sections to define the general lithology of the tract's surface rocks.

A&I originally posted all their Tract C-a field data on an expanded 1"-500' scale topographic base map constructed by Rio Blanco from existing 1"-2000' scale USGS 7.5 minute quadrangle maps. In February of 1975, the new 1"-500' scale Bovay topographic base map of the tract was completed. At Rio Blanco's direction, A&I transferred the TGA photogeology, the subsurface middle A-groove datums and the A&I surface geologic mapping to this new base map.

Rio Blanco planned to have A&I complete their surface geologic mapping program in the Tract C-a and Vicinity area during the first half of 1975. However, in March, 1975, Rio Blanco deferred all further surface geologic mapping until priorities were defined as to where and what kind of additional surface geologic control is yet needed, if any, based on mining and engineering studies. After evaluating all available photogeologic, surface geologic and subsurface geologic data, Rio Blanco decided sufficient control was already compiled to define the tract's major geologic characteristics and formulate the DDP. Additional surface geologic mapping would not result in a major revision of the tract's structure as currently known but only further refine it. A&I were instructed to finalize all data that had been compiled to that point and submit them to Rio Blanco. The last of their work, including written reports with conclusions and recommendations, was received in March for the Yellow Creek Dam Site and in April for Tract C-a and Vicinity.

D. Topographic Mapping - Bovay Engineers, Inc., completed detailed topographic map construction in February, 1975. These maps were compiled by photogrammetric methods from the newly flown 1" to 1000' scale aerial photography. Map horizontal control surveys are referred to the Colorado State Plane Coordinate System, North Zone, modified to a 7200' datum. Lambert Conformal Conic Projection vertical control surveys are related to mean sea level.

The three areas, Tract C-a and Vicinity, Duck Creek Dam Site and Yellow Creek Dam Site, shown on Figure 3-3-1, encompassing a total of about 85 square miles, were mapped on 89 map sheets at a horizontal scale of 1" to 200' and a contour interval of 5'. The 84 map sheets comprising the Tract C-a and Vicinity area, about 81 square miles, were photographically reduced to a horizontal scale of 1" to 500' and composited into a set of 9 map sheets with Tract C-a located in the center sheet of a three by three map sheet pattern.

E. Core Hole Program - The core hole program in the G-S Exploratory Plan originally proposed the drilling of 15 new core holes on Tract C-a supplementing the 12 pre-sale tract core holes (6 Cameron, 3 Amoco and 3 TOSCO). However, two of the proposed core hole locations were found topographically unfavorable by representatives of BLM, Meeker, when jointly field-checked by BLM and G-S personnel. These two core holes (original locations G-S 3 and 4) were subsequently eliminated from the program. Two other proposed core holes (original locations G-S 2 and 5) were moved to compensate for the loss of the two core holes and still maintain a good core hole "spread" across the tract. The new core hole locations were designated G-S 2-3 and 4-5 with a revised program of 13 new core holes rather than the originally proposed 15. AOSS approval of the revised core hole program was received on June 27, 1974. Figure 3-3-2 shows the location of all core holes on Tract C-a.

The core hole program was commenced on July 3, 1974 and completed on October 27, 1974. Late in the program, Rio Blanco requested AOSS approval to reduce overburden coring in core holes G-S 10, 11, 13 and 14, a total of about 2100'. Overburden data obtained up to that point was considered representative of the tract and additional coring would only be redundant. In addition, the reduced overburden coring lowered the cost of the program and expedited its completion prior to the forthcoming winter season. This approval was obtained on September 11, 1974.

Numerous contractors were involved in the program. Limnetics, Inc., and Denver University provided biological and archeological clearance,

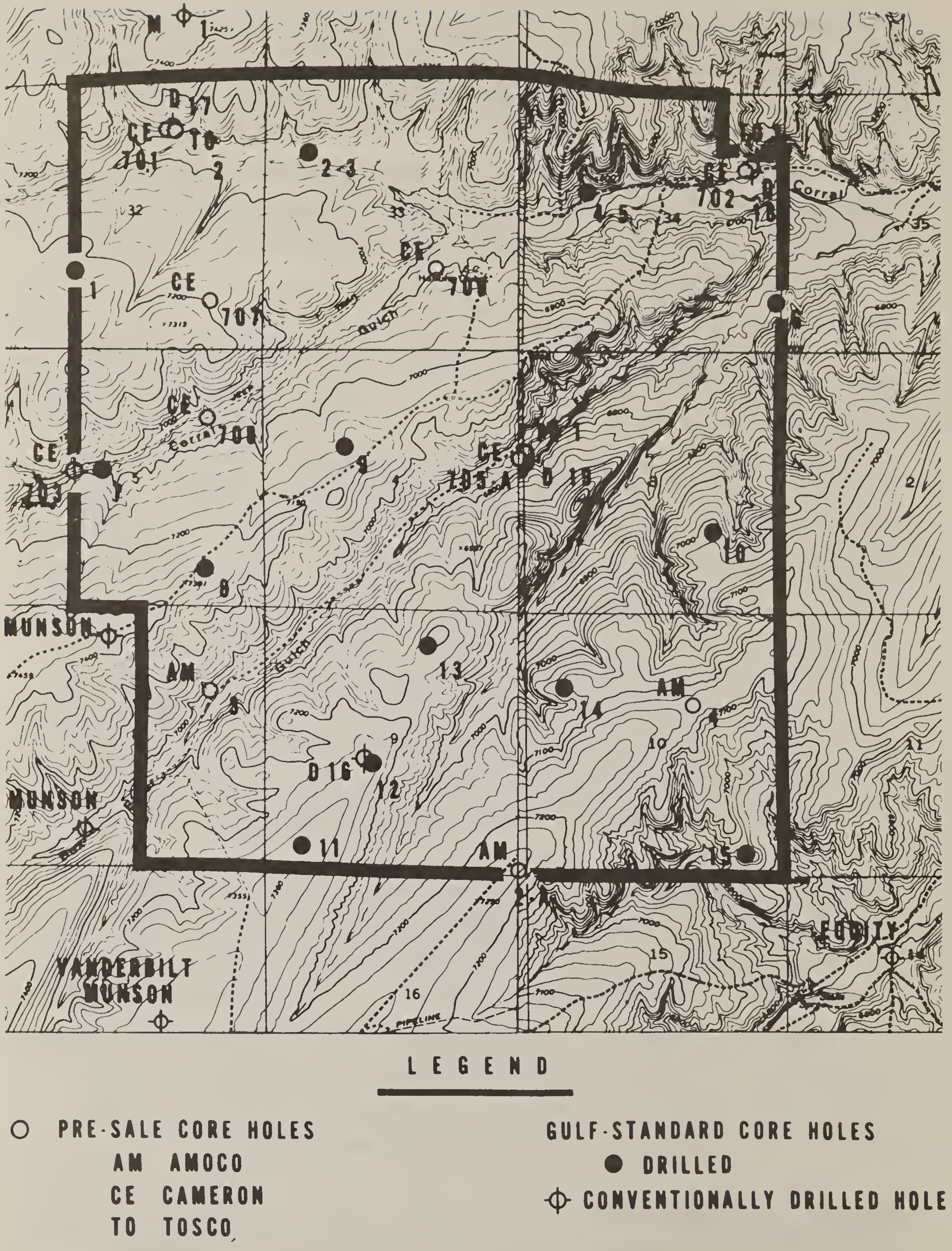


Figure 3-3-2

CORE HOLE LOCATIONS, TRACT C-a

respectively, for the core hole sites and their access roads prior to any earth moving. Amoco Production Company furnished considerable logistical support throughout the program. The drilling contractors were Carmack Drilling Company and Dreiling Drilling, Inc., each furnishing one rig. McDowell-Smith Associates surveyed the core hole locations and established their ground elevations. Amuedo and Ivey furnished on-site geological personnel to photograph the core, describe and log its lithologic and structural characteristics, and appropriately mark and box it for shipment off tract. A&I also collected gas samples for analysis generally at the A-groove, B-groove and total depth. Hydrologic data was collected by Wright Water Engineers during the drilling program. Schlumberger Well Services and Birdwell Division of Seismograph Service Corporation were contracted for geophysical (mechanical) logging. Core Laboratories, Inc., transported core to Rifle for Fischer assay, preparation of samples for other analyses and storage. They also analyzed the gas samples collected. Late in the program, Core Lab installed H_2S gas detectors at coreholes G-S 11, 14 and 15 and the 4 D-holes drilled for hydrologic testing to obtain data on its concentrations.

Core cut in all G-S core holes was 3.5" in diameter. Drilling fluid was air-mist rather than mud to minimize formation damage and provide optimum hydrologic test conditions.

All efforts were made to obtain maximum core recovery. Table 3-3-1 summarizes the program's core recovery on a hole by hole basis. The two core holes with the lowest percent core recovery are G-S 9 and 12, both of which were intentionally located within fault zones where highly fractured shale resulted in lower core recovery.

Continuous borehole directional surveys run in core hole G-S 8 and in G-S 15 were computer-analyzed by Amoco Production Company, Denver. Borehole positions, relative to hole point of origin (surface location), were computed at stations every 50' from base surface casing to total depth. Table 3-3-2 is a brief summary of the analysis results.

Table 3-3-1

SUMMARY OF CORE RECOVERY; G-S CORE HOLE PROGRAM TRACT C-a

G-S CH No.	TD	Core Cut	Core Rec.	Core Lost	% Core Recovery
1	1,404	1,360.7	1,317.1	43.6	96.8
2-3	1,424	1,352.5	1,240.1	112.5	91.7
4-5	1,663	1,615.5	1,486.2	129.3	92.0
6	1,781	1,624.5	1,565.0	59.5	96.3
7	1,200	1,159.7	1,148.2	11.5	98.9
8	1,616	1,548.2	1,458.6	89.6	94.2
9	1,600	1,556.4	1,357.5	198.9	87.2
10	1,902	1,550.3	1,455.5	94.8	93.9
11	1,886	1,495.4	1,404.9	90.9	93.9
12	1,800	1,759.0	1,588.6	170.4	90.3
13	1,751	1,481.0	1,387.2	93.8	93.7
14	1,794	1,546.6	1,421.1	125.5	91.9
15	1,835	1,794.4	1,690.9	103.5	94.2
Totals	21,656'	19,844.6	18,520.8	1,323.8	93.3 (Avg.)

Table 3-3-2

HOLE DEVIATION SUMMARY

	G-S 8	G-S 15
Max. hole drift from vertical (degrees):	3.6	2.2
Hole displacement at TD from surface location (feet, direction from true north):	50.1 W 5.1 S	45.0 W 11.0 N
Net Horizontal Displacement:		
Distance (feet):	50.4	46.3
Bearing:	S84°W	N76°W
Total depth, driller (feet):	1616.0	1835.0
Deepest station analyzed (feet):		
Log measured:	1600.0	1816.0
Corrected vertical:	1598.8	1815.3
Difference:	1.2	0.7

Both core holes drifted predominately westward with a lesser north-south component and reflects their tendency to "climb" subsurface structure. This is characteristic of most, if not all holes, whether conventionally drilled or cored. It is assumed that all other core holes on Tract C-a deviated in a similar manner. For interpretive purposes, the holes are assumed vertical and representative of the thickness of the stratigraphic section each penetrated, requiring no correction.

F. Laboratory Analyses

1. Fischer Assays - Core Laboratories, Inc., ran Fischer assays of approximately 2' core increments concurrently with the core hole drilling program and completed assays of all "released" core (defined below) on December 31, 1974. These assays were performed at temporary lab facilities established in Rifle specifically for the G-S core hole program to minimize core transport distance and expedite the total assay program. Core Lab also maintained storage facilities for Rio Blanco in Rifle where core, crushed core surplus to that required for assay retort feed, and spent shale derived from the assays are retained.

Shale oil generated from the individual assays was saved and composited into rich and lean zonal samples. Intervals for these zones were designated by Rio Blanco based on gamma ray-density logs (hereafter called density logs) and furnished to Core Lab prior to assaying. The composite shale oil samples were shipped to Gulf Research and Development Company for analysis to determine if shale oil characteristics vary from zone to zone.

"Released" core is that which Rio Blanco directed Core Lab to assay as received for resource information. "Unreleased" core is that which Rio Blanco directed Core Lab to segregate from their normal assay stream and retain for rock mechanics tests. This testing program requires full unslabbed core for various tests. Selected intervals in seven core holes, G-S 1, 2-3, 4-5, 6, 8, 11 and 15, together with all core in G-S 13 were reserved for this testing program.

Oil shale grades estimated from density logs by Amuedo and Ivey are currently being used for resource data within the selected intervals for which assay data is not available in the seven G-S core holes listed above and G-S 13 is essentially being treated as a "non-existent" core hole for resource calculations. As the rock mechanics testing is completed in each core hole, this core is released for resource data assaying. Grades now estimated by A&I from density logs will be replaced by lab-assays and G-S 13 will be incorporated into tract resource control.

Rio Blanco's construction of isograde-isopach contour maps of 19 discrete oil shale zones and the main oil shale interval (middle A-groove to Blue marker) located certain intervals in two core holes, G-S 4-5 and 6, which were suspected of questionable GPT grade data. Closely spaced grade contours required to honor all available control strongly suggested anomalous grade data. Core Lab has run re-assays in these intervals and confirmed the presence of erroneous original assay data.

Preliminary review of some of the re-assays in these two core holes indicates some are higher and others are lower than the original assays. Adjustment of the tract's oil shale resources in the vicinity of these two core holes will be required. The adjustment may result in appreciable average grade changes in some oil shale zones, but it should not result in a major revision of the tract's oil shale resources as presented in this report. However, the re-assay data will be incorporated into the tract resource control (computer mineral inventory) and appropriate revisions made to the tract resource estimates. Revised resource estimates, including new zonal isograde-isopach maps will be furnished to the AOSS as this work is completed.

2. Acid Extractable Alumina - In eight core holes spaced across Tract C-a (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15), Rio Blanco selected

intervals for quantitative analysis of acid extractable alumina in spent shale. These intervals were selected prior to Fischer assaying based mainly on rich and lean oil shale zonation as evidenced on density logs and modified by significant lithologic changes on A&I core description logs. No analysis interval was allowed to exceed 100' in thickness. Interval boundaries were furnished to Core Lab, Rifle, who composited representative samples of spent shale for each interval as the Fischer assays were run. These samples were forwarded to Core Lab, Casper, where the extractable alumina analyses were performed using the techniques outlined in USBM Report of Investigations No. 7286 (1969). All analyses in the eight G-S core holes were completed on January 17, 1975.

3. Nahcolite - Minor amounts of nahcolite were located in all G-S core holes except G-S 2-3 in which it is totally absent. Where nahcolite was identified on Amuedo and Ivey core description logs, Core Lab, Rifle, prepared samples for nahcolite quantitative analysis from surplus crushed fresh core, excess to that required for their Fischer assay feed. These samples were forwarded to Core Lab, Casper, where the analyses were performed using the techniques outlined in USGS Professional Paper No. 750B (1971). All analyses were completed on January 30, 1975.

One thin nahcolite-bearing shale interval in core hole G-S 13 has not yet been analyzed. As stated above (item 3.1.F.1) all core in this core hole is retained for rock mechanics tests which require full unslabbed core.

4. Trace Elements - At Rio Blanco's request and well in advance of any actual lab work, Core Lab contacted the U. S. Environmental Protection Agency, Denver, to determine what quantitative analysis techniques would be appropriate for the trace elements listed in Table 3-3-3 in both fresh and spent oil shale. Core Lab used the techniques listed as recommended by the EPA by letter dated July 23, 1974. Specific references describing these techniques are cited in Rio Blanco Oil Shale Project Progress Report No. 2 (Feb., 1975).

In the same eight core holes spaced across the tract which were analyzed for extractable alumina (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15), Rio Blanco selected intervals for trace element quantitative analysis of both fresh and spent shale. To minimize sample handling and preparation, the intervals selected in each of the eight core holes were the same as those selected for extractable alumina analysis of spent shale. In addition, intervals were selected in overburden rocks containing no oil shale for trace element analysis in fresh rock samples only.

Table 3-3-3

TRACE ELEMENT AND ANALYSIS TECHNIQUE

Element	Analysis Technique
Antimony	Atomic absorption spectrophotometry
Arsenic	Atomic absorption spectrophotometry
Boron	Visible spectrophotometry
Cadmium	Atomic absorption spectrophotometry
Fluoride	Specific ion electrode
Mercury	Flameless atomic absorption spectrophotometry
Selenium	Fluorometry

Interval boundaries were furnished to Core Lab, Rifle, who composited representative samples of fresh crushed shale, spent shale and fresh overburden intervals as the Fischer assays were run. These samples were forwarded to Core Lab, Casper, where the trace element analyses were performed. All analyses in the eight G-S core holes were completed by January 17, 1975.

Colorado School of Mines Research Institute was subcontracted by Core Lab to identify the trace element-bearing minerals. Preliminary identification of these minerals in both fresh and spent shale samples from core holes G-S 2-3 and 7 was completed on February 28, 1975, using X-ray diffraction and element partitioning techniques.

G. Seismic Exploration Program - About 10 miles of shallow high resolution seismic line was planned within Tract C-a as outlined in the G-S Exploratory

Plan. Petroleum Geophysical Company, the seismic contractor, commenced experimental shooting in early December, 1974. After two unsuccessful attempts to obtain reliable data, the program was terminated by Rio Blanco on January 31, 1975.

The first experimental shooting attempt consisted of two days of spot shooting with 200% coverage and failed to define reliable mappable reflections within the shallow target oil shale interval. The second involved 1.5 miles of continuous 600% coverage line along Corral Gulch crossing a well-defined surface fault system (graben). Considerable seismic record processing with various filters was required in an effort to separate surface noise from reflected energy and optimize the shallow reflections. This processing may have resulted in an erroneous portrayal of subsurface structure because the seismic profile obtained does not agree with well defined structure as observed at the surface. This problem has been discussed with Gulf and Standard (Amoco) geophysicists. The concensus is that the seismic data requires additional interpretation and is of little value in its present form because of the low confidence level currently attributed to it. Considerable detailed evaluation of the basic field records will be necessary to determine the usefulness of the seismic data. Until this evaluation is made, the data will remain in "hold status" and will not be incorporated into tract structural control.

PGC prepared a brief written report describing the techniques used in their experimental shooting. This report was received on February 26, 1975.

H. Geologic Evaluation (Data Compilation) - As new stratigraphic, structural and resource information was obtained from the various phases of the G-S Exploratory Plan's geologic portion (Sec. 5), it was continuously incorporated into existing geologic control on a rough draft basis to monitor both the progress and results of the various data gathering activities. The one exception to this data incorporation is the results of the seismic program which remain in "hold status" for reasons previously cited.

Two key maps, middle A-groove structure and main oil shale interval isopach (middle A-groove to Blue marker) were maintained throughout the course of the G-S core hole program to monitor the newly acquired subsurface stratigraphic and structural data and readily define any major variations from that anticipated based on available pre-existing on-tract and off-tract control. The only major "surprises" occurred in core holes G-S 9 and 12 which were both intentionally drilled in down-thrown blocks of fault zones (graben). Both core holes encountered the middle A-groove horizon at a structural datum considerably higher than anticipated. The data from these core holes will be discussed more fully under Structure (item 3.3.B).

1. Stratigraphic - Rio Blanco initiated the detailed stratigraphic data compilation within Tract C-a in November, 1974, with the construction of 6 subsurface stratigraphic cross sections (4 east-west and 2 north-south ties) consisting of density logs of all 25 tract core holes. Standard scale logs of 1"-20' (vertical) were photographically reduced to a more convenient 1"-50' scale for these sections.

Amoco EDP (Electronic Data Processing) generated new histogram logs for all 12 pre-sale tract core holes plotting shale GPT grade versus depth at a log vertical scale of 1"-20'. These logs portray grades based on both lab-assay data of recovered core and density log estimates of missing core intervals. As G-S core hole Fischer assays were received from Core Lab, Rio Blanco manually constructed similar scale histogram logs for these new holes. After additional information was posted to these logs by Amuedo and Ivey (discussed below), they were photographically reduced to the more convenient 1"-50' vertical scale and a second set of 6 subsurface stratigraphic cross sections constructed, identical in lay-out and vertical scale to the previously constructed 6 density log sections.

These two sets of cross sections, designed to complement each other, provided the base control necessary to develop a detailed subsurface correlation network across Tract C-a. In addition, they provided a convenient means to visually display the stratigraphic positions of other significant data as discussed below.

Amuedo and Ivey were assigned the task of developing the Tract C-a subsurface correlation network following guidelines established by Rio Blanco. Rio Blanco's files containing data previously compiled on the 12 pre-sale core holes together with all new data in the 13 G-S core holes were furnished to A&I who:

- Established over 120 correlative log "picks" on the density log cross sections which are stratigraphically persistent throughout the tract's 25 core holes in the oil shale-bearing interval defined at its base by the Orange marker and extending upward to about 150' above the A-groove. Average correlation frequency within this 1200-1300' thick interval is about one every 10' of logged hole. Both gamma ray and density log responses were used to establish the correlations (A&I, 1975-C, p. 4). The gamma ray response reflects variations in the rock's natural radioactivity. The density response reflects variations in its oil content but must be used with caution since it is highly sensitive to hole gauge and rock vugularity.
- Correlated the 120+ log "picks" established on the density log cross sections to their stratigraphic equivalents on the histogram cross sections by matching density log responses to corresponding histogram log peaks and troughs (discrete assay increments of high and low grades). Slight adjustments were made as required uphole or downhole to compensate for suspected out-of-place core. However, stratigraphic continuity was maintained with no correlations allowed to cross bedding planes.
- Established a rich-lean oil shale zonation based on the density and histogram log cross sections placing as much 17+ GPT shale as possible into the rich zones and still maintain stratigraphic continuity. Zones were designated (named) using established USGS nomenclature (Cashion and Donnell, 1972) and

expanded stratigraphically above and below the oil shale interval discussed in that reference. A total of 19 zones, 9 rich and 10 lean, together with over 100 "subzones" were defined in the tract's 1200-1300' thick oil shale-bearing interval discussed above.

- Posted the established tract correlation network on the two sets of tract stratigraphic cross sections showing:
  - Zonal correlations on the grade histogram log sections.
  - Both zonal and "subzonal" correlations on the density log sections.
- Prepared for computer input purposes a data sheet for each tract core hole listing all zonal and "subzonal" correlations established together with their respective density and histogram log depths.

A&I were assigned additional tasks to be performed concurrent with the development of the Tract C-a subsurface correlation network. These tasks involved the compilation of significant subsurface data and the posting of this data to appropriate core hole logs. At this point in time, the correlation network's set of 6 reduced 1"-50' vertical scale density log cross sections was already constructed. However, the grade histogram logs of the tract core holes were still at the standard vertical scale of 1"-20' with Core Lab Fischer assays in a few of the G-S core holes yet forthcoming. After all assays were received and the histograms plotted, A&I posted additional data to these larger scale histogram logs which were subsequently reduced to the more convenient 1"-50' vertical scale for construction of the correlation network's second set of 6 cross sections. At Rio Blanco's direction, A&I:

- Estimated GPT oil grades from density logs of all missing (lost) and "unreleased" core intervals, the latter retained for rock mechanics tests. Grade estimates were made in all G-S core holes except G-S 13 whose entire core is held for rock mechanics tests. Estimates were listed numerically on Core Lab assay sheets for Amoco EDP computer input and posted on appropriate 1"-20' vertical scale core hole histogram logs (later reduced for cross section construction).

- Reviewed lithologic core descriptions in all 25 tract core holes to:
    - Locate evidence of suspected faulting in the subsurface.
    - Define the base of the leached zone.
    - Identify the mode of nahcolite occurrence (beds, stringers, nodules, etc.)
- Posted to the correlation network's 1"-50' vertical scale density log cross sections:
    - Evidence of suspected faulting in the subsurface, all tract core holes.
    - Base of the leached zone, all tract core holes.
- Posted to individual 1"-20' vertical scale grade histogram logs (later reduced for cross section construction):
    - Mode of nahcolite occurrence, all tract core holes.
    - Core Lab quantitative analyses of acid extractable alumina in spent shale, 8 G-S core holes.
    - Core Lab quantitative analyses of nahcolite, all G-S core holes where present (except G-S 13).
    - USBM X-ray diffraction analyses of dawsonite and nahcolite, 2 Cameron core holes, Nos. 702 and 707.

As A&I's work progressed both on the tract's subsurface stratigraphic correlation network together with the compilation and posting of additional data to appropriate core hole logs, results were periodically reviewed with Rio Blanco to resolve any problem areas. The network and both its cross sectional displays (6 density log sections and 6 grade histogram log sections) were finalized and approved by Rio Blanco on March 5, 1975. A brief report summarizing A&I's work was completed on April 21, 1975.

Rio Blanco constructed trace element histogram logs of the 8 G-S core holes which were analyzed by Core Laboratories, Inc., for concentrations of antimony, arsenic, boron, cadmium, fluoride, mercury and selenium in fresh shale, spent shale and fresh overburden rocks. Each log portrays in bar graph and numeric form the stratigraphic position of each interval analyzed and the analysis results in parts per million for each of the 8 core holes (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15). The data were first posted to standard 1"-20' vertical scale logs and later reduced to the more convenient 1"-50' scale matching the log scale of the tract correlation network's cross sections. Amuedo and Ivey finalized each reduced log with the posting of the network's 19 rich-lean zonal boundaries in March, 1975.

2. Resource - Preliminary Tract C-a resource compilation of oil shale, nahcolite and extractable alumina in spent shale progressed as various data were received. Early in the G-S core hole program, it became apparent that nahcolite is not a significant tract resource because of its relatively limited occurrence.

Detailed tract oil shale and extractable alumina resource compilation was initiated in early March, 1975. By necessity, this detailed compilation was preceded by the completion of:

- All Fischer assaying of "released" core and extractable alumina analyses of composite spent shale samples by Core Laboratories, Inc.
- All grade estimates from density logs of missing and "unreleased" core intervals in 12 of 13 G-S core holes by Amuedo and Ivey (core hole G-S 13 retained in its entirely for rock mechanics tests).
- The tract correlation network by A&I and its approval by Rio Blanco.
- Input and edit-check of all oil shale grade data, both lab-assays and density log estimates of 12 of 13 G-S core holes by Amoco EDP.

Amoco EDP data banks previously contained oil shale grade data, both lab-assays and density log estimates of missing core, in the 12 pre-sale tract core holes (3 Amoco, 6 Cameron and 3 TOSCO). With the addition of equivalent information in 12 of 13 G-S core holes, their data banks contained oil shale resource data in 24 of 25 Tract C-a core holes.

Amoco EDP generated a computer tape duplicating the above shale resource data in the 24 tract core holes. This tape and all other geologic data compiled by Rio Blanco were forwarded to Morrison-Knudsen Company, Inc., the major mining contractor, for use in their various investigations. M-K's computer application of the data included the construction of:

- The "prime mineral inventory" which defines the tract's oil shale resource adjusted to its present-day structural configuration. Computer input included core hole GPT grade data, the A&I stratigraphic correlation network and the RBOSP middle A-groove structure map.
- The "working mineral model" which provides output from the "prime mineral inventory" in a form suitable for open pit and underground mining evaluations. In open pit evaluations, selected horizontal "slices" 30, 40 and 50' thick can be made to define the resource in 100' by 100' squares throughout the tract. In underground mine evaluations, selected intervals between any two stratigraphic markers and 30, 60 and 80' thick intervals controlled at their tops by a stratigraphic marker can be made to define the resource in 100' by 100' squares throughout the tract.

Amoco EDP computed average GPT oil grades and thicknesses in each of the 24 assayed tract core holes for all 19 oil shale zones defined by the Tract C-a correlation network. Equivalent computer output from M-K was checked against Amoco's and found to be in perfect agreement. Amoco EDP also computed average grades and thicknesses for each tract core hole's main oil shale interval (middle A-groove to Blue marker) for tie to off-tract regional control. Rio Blanco then constructed hand-contoured isograde-isopach maps of the tract's 19 zones and main oil shale interval using reduced 1"-1000' horizontal scale Bovay topographic base maps.

All 20 isograde-isopach maps were completed by the middle of June, 1975. These maps portray in-place oil shale resource characteristics across the tract.

As stated previously (item 3.1.F.2) the intervals in 8 G-S core holes selected by Rio Blanco for acid extractable alumina quantitative analysis of composite spent shale samples were based mainly on rich and lean oil shale zonation as evidenced by density log response. These composite samples were prepared by Core Lab, Rifle, concurrent with their Fischer assay program and analyzed by Core Lab, Casper, well in advance of the tract correlation network's completion. Rio Blanco adjusted the analysis data to each of the network's 19 oil shale zones by standard weighting methods (multiplying each analysis increment thickness within a zone by its weight percent alumina, summing the products and dividing the sum by the zonal thickness to obtain the zone's average weight percent alumina). Total tonnage of extractable alumina in spent shale was then calculated for each of the 19 zones. Compilation of data in table form was completed in July, 1975.

3. Structural - Rio Blanco initiated the detailed structural compilation within Trace C-a and the immediate surrounding area with the selection of the middle A-groove horizon as the key structural marker for the tract. This electric log marker is regionally persistent throughout the Piceance Creek basin, easily identifiable without the benefit of Fischer assays and stratigraphically located near the top of the Mahogany zone, the uppermost rich zone within the Parachute Creek Member's main oil shale interval. Selection of this electric log marker was made at the very beginning of the G-S core hole program to monitor tract subsurface structure as evidenced by the new G-S core holes. The structure map maintained during the course of the drilling program was considered the "preliminary" tract structure map.

The structural compilation proceeded in a sequential manner incorporating additional control as it was obtained. Rio Blanco furnished Trollinger Geological Associates, Inc., with middle A-groove datums in on-tract core holes and in available off-tract core holes and conventionally drilled wells. TGA incorporated this subsurface structural control into their photogeologic interpretation of the tract and its immediate vicinity by form-line contouring structure at this horizon. TGA's final map therefore composited both subsurface and photogeologic control. At this point, the TGA map was considered the "second phase" tract structure map.

Amuedo and Ivey's surface geologic mapping followed using the TGA map for base control. A&I's surface mapping was added and the data lowered to the middle A-groove horizon by means of isopachs. Their final map, therefore, composited subsurface, photogeologic and surface geologic mapping control. At this point, the A&I map was considered the "third phase" tract structure map.

In the course of their respective structural investigations, both TGA and A&I were encouraged to make their own evaluations of the available data and present the structural interpretations each considered to be most likely. As is commonly the case in most structural evaluations, multiple interpretations of the same data were possible in certain parts of Tract C-a, particularly where associated with faulting. Rio Blanco reviewed all structural data compiled and where multiple interpretations were found possible, selected the one believed most probable. Considering the vast amount of structural data compiled on Tract C-a, most interpretations made by TGA, A&I and Rio Blanco are either in full or very close agreement. Significant variations in interpretation are relatively limited. Rio Blanco's middle A-groove structure map, submitted in this report, is the "fourth phase" tract structure map. It portrays Rio Blanco's interpretations in those areas where the previously discussed multiple interpretations were found possible.

As stated previously, most if not all the tract's <u>major</u> structural characteristics have been defined by compositing photogeologic, surface geologic and subsurface geologic mapping within the tract compiled to this data. Additional surface geologic mapping within the tract should not result in a major revision of its middle A-groove structure as currently known, but only further refine it. However, this does not preclude the need for periodic update of the tract's structure as additional subsurface control is obtained by supplemental core drilling, detailed review of the PGC seismic, or tract development (open pit and/or underground mining).

It should be pointed out that the Rio Blanco middle A-groove structure map for Tract C-a is identified as "Geologic Revision 1". It includes additional data obtained and evaluated subsequent to the structure map forwarded to the AOSS in RBOSP Progress Report No. 2 (Feb., 1975). Further revisions will be made as required if additional structural control is obtained which significantly changes the structure portrayed.

Finally, Amuedo and Ivey compiled joint-fracture orientation data from Birdwell seisviewer logs run in 8 G-S core holes (G-S 2-3, 7, 9, 10, 11, 12, 14 and 15) and 4 deep conventionally drilled holes used for hydrologic testing (D-16, 17, 18 and 19). The 4 D-holes twin core holes G-S 12, CE 701, CE 702 and CE 705-A, respectively. These logs provide a continuous acoustic picture of the borehole wall oriented to magnetic north. A&I completed their investigations in April, 1975, and this data was forwarded to Morrison-Knudsen for use in their mining studies.

3.2 STRATIGRAPHY

A. General Information - Tertiary sedimentation in the tri-state area of SW Wyoming, NE Utah and NW Colorado was controlled by the geomorphic features produced by the Laramide orogeny. This series of major tectonic events occurred during late Cretaceous-early Tertiary time and formed large highland source areas from which Tertiary sediments were derived and subsequently deposited in the adjacent intermountain basins.

Tertiary environments of deposition varied considerably from basin peripheries toward their depositional centers resulting in the highly diversified rock types and facies changes so characteristic of continental sedimentation. Sediments deposited along basin edges nearest their source areas were characteristically more clastic than their more basinward stratigraphic equivalents. Pulsating uplift of the surrounding highlands (and/or corresponding subsidence of the basins), cyclic abundance of plant and animal life available to contribute organic material to the sediments, fluctuating lake shorelines, water depth and water chemistry (fresh, brackish, saline) were all important contributing factors in the type of sediments deposited. Roehler (1974, p. 57-64) identified ten environments of deposition in the Eocene rocks of the tri-state area ranging from mountain front or pediment to lacustrine evaporite. Geochemical conditions necessary for oil shale deposition were first postulated by Bradley (1929) and more recently by Smith (1969, p. 185-190; 1974, p. 71-79).

The oil shale-bearing Tertiary Green River Formation was deposited in two large Eocene lakes occupying two vast intermountain basins, one centered in SW Wyoming and the other in NE Utah and NW Colorado. Lake Gosiute occupied the greater Green River basin of SW Wyoming, a portion of which extended southeastward into the Sand Wash basin of NW Colorado. Lake Uinta occupied the Uinta basin of NE Utah and the Piceance Creek basin of NW Colorado (Bradley, 1929, p. 88). The intervening present-day Douglas Creek arch was innundated by Lake Uinta (Donnell, 1961, p. 862) and was probably a gentle low relief sub-lake high. This probability is supported by thinning of Eocene sediments over the arch (Cashion and Donnell, 1972; Newman, 1974, p. 47-55).

Oil shale has been defined by various authors in different ways. The term is actually a lithologic misnomer because the rock is not shale nor does it contain oil in the conventional sense. Most oil shale is dolomitic marlstone (argillaceous limestone) containing variable amounts of organic matter derived chiefly from algae, aquatic organisms, waxy spores and pollen grains. This organic matter is only slightly soluble in ordinary petroleum solvents, but a large part can be converted to synthetic oil by destructive distillation. Standards have not been set for the minimum amount of extractable oil necessary to qualify the rock as oil shale. Therefore, the term is used more qualitatively than quantitatively (Brobst and Tucker, 1973, p. 3&4).

B. Regional - This discussion will be confined to the stratigraphy of the Piceance Creek basin in which Tract C-a is located and deal only with those intervals pertinent to the tract's development, namely, the oil shale-bearing Green River Formation and the overlying Uinta Formation.

Figure 3-3-3 is an updated generalized stratigraphic column of Eocene rocks in the Piceance Creek basin. No attempt is made to maintain vertical scale representative of individual unit thicknesses. It is designed to portray the relative stratigraphic positions of the major Eocene units discussed below. Also shown are the stratigraphic positions of the main oil shale interval of the lower Parachute Creek Member, the oil shale interval within Tract C-a and several key stratigraphic markers (both lithologic and geophysical log) which will be discussed in detail in the next item of this report.

There is a great amount of literature on the Tertiary stratigraphy of the Piceance Creek basin beginning principally with the classic work of Bradley (1929, 1931) and continuing to the present time. Bradley divided the Green River Formation into four members, named in ascending order, the Douglas Creek, Garden Gulch, Parachute Creek and Evacuation Creek Members, with the youngest member forming most of the surface bedrock over the basin. Donnell (1961, p. 851) added a fifth member, the Anvil Points, along the eastern margin of the basin. It is a near-shore clastic facies laterally equivalent to the more basinward Douglas Creek, Garden Gulch and lower part of the Parachute Creek Members.

Bradley's nomenclature remained unchanged for over 40 years until the Evacuation Creek Member was determined to be stratigraphically equivalent to the lower part of the Uinta Formation in the Uinta basin of Utah (Cashion and Donnell, 1974). With the revised correlation, the Green River Formation is now composed of three main members (and Donnell's Anvil Points Member) and the overlying Uinta Formation comprises most of the surface bedrock of the Piceance Creek basin.

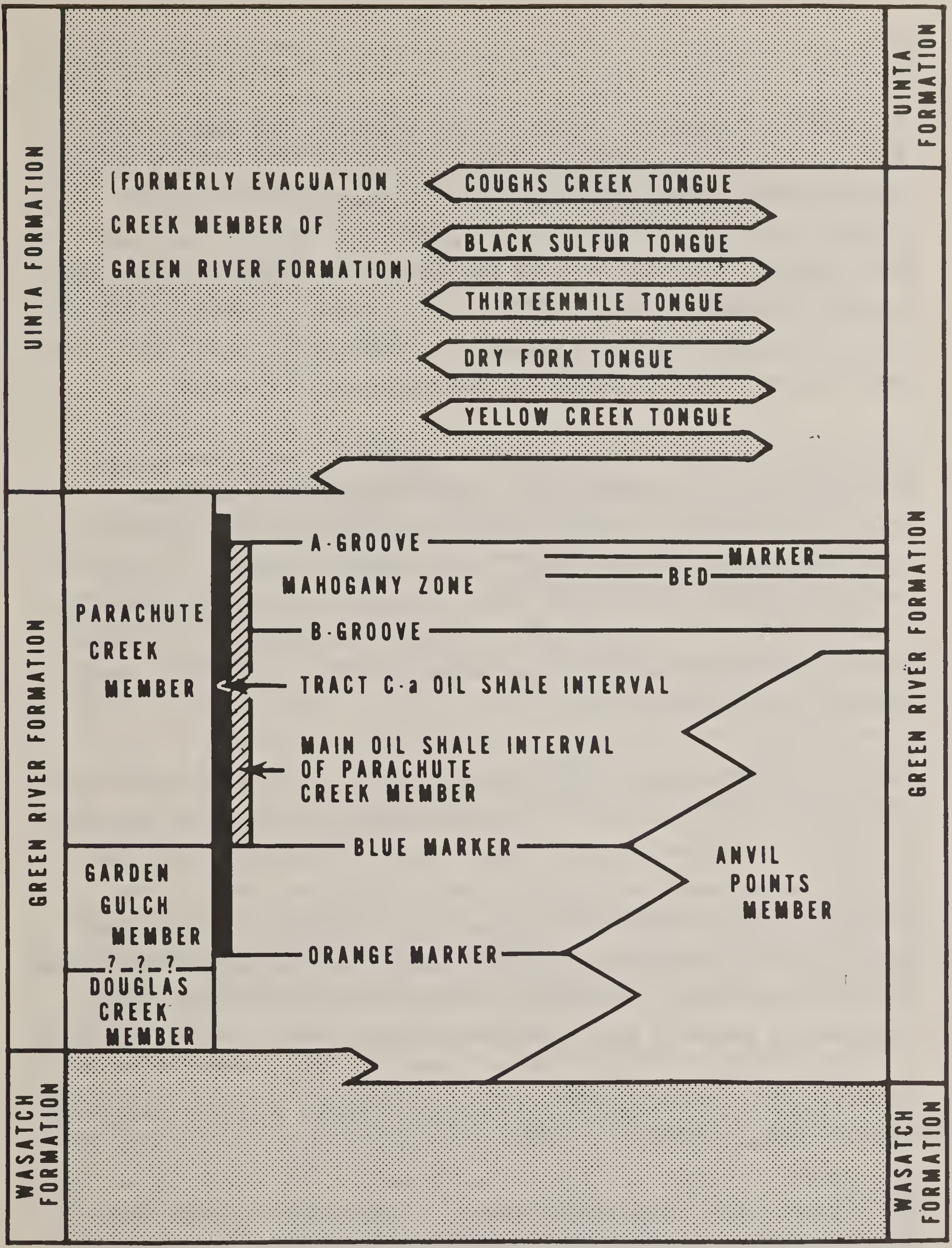


Figure 3-3-3

GENERALIZED STRATIGRAPHIC COLUMN OF TERTIARY EOCENE SERIES,
PICEANCE CREEK BASIN

The lower two members of the Green River Formation, the Douglas Creek and overlying Garden Gulch, are undifferentiated in this report because there is some disagreement as to where the boundary of the two is located in the basin's subsurface. Operators of the Rio Blanco Gas Unit, southeast of Tract C-a, use the base of the Orange marker as the boundary (Chancellor, et al, 1974, p. 227). However, Roehler (1974, p. 60) states none of the rocks mapped as Garden Gulch in most parts of the basin are equivalent to Bradley's type section on the outcrop.

The lacustrine Douglas Creek-Garden Gulch Members (undifferentiated) consist mainly of interbedded gray shale, mudstone and sandstone in its lower part and gray to black oil shale in its upper part. The unit intertongues with the underlying fluvial Wasatch Formation. This intertonguing represents the initial phases of Lake Uinta and the transition from a fluvial to a lacustrine environment of deposition. Its contact with the overlying Parachute Creek Member is placed at the Blue marker in the basin's subsurface.

The lacustrine Parachute Creek Member contains the major portion of the basin's oil shale resources. It consists mainly of tan, brown and black oil shale interbedded with thin tuffs (volcanic ash beds) in its lower part and barren marlstone and siltstone in its upper part. Saline minerals are also present in its lower part (nahcolite, dawsonite and halite) whose concentrations increase towards the geochemical depositional center of the basin. The member's contact with the overlying Uinta Formation is generally both gradational (transitional) and intertonguing.

The Uinta Formation was deposited during the waning phases of Lake Uinta and its sediments reflect a transition from a lacustrine to a fluvial environment of deposition (Cashion and Donnell, 1974, p. G3, Duncan, et al., 1974, p. F3). It consists mainly of light brown to brown lenticular sandstone and siltstone. Several of the sandstones are thick, massive and medium to coarse-grained (Donnell, 1961, p. 857). Evidence of local channeling of these sandstones into underlying sediments has recently been defined (O'Sullivan, 1975, p. G4). Interbedded with these dominantly clastic sediments are lesser amounts of lacustrine light-gray marlstone. Five of these marlstone units have been recently mapped within the Uinta Formation which exhibit considerable areal persistence and merge laterally with the underlying Parachute Creek Member of the Green River Formation. These units have been designated tongues of the Green River Formation. In ascending order, they are named, Yellow Creek, Dry Fork, Thirteenmile, Black Sulfur and Coughs Creek Tongues (Duncan, et al, 1974; O'Sullivan, 1975).

C. Tract C-a

1. Key Stratigraphic Markers - Figure 3-3-4 is a 3-core hole SW-NE cross section across Tract C-a oriented normal to isopach or depositional strike of the Parachute Creek Member's main oil shale interval (defined below). It is designed to conveniently portray the tract's major stratigraphic characteristics. The section shows the stratigraphic positions of four key electric log markers and two key lithologic markers which are persistent throughout most of the Piceance Creek basin and are extremely useful in subsurface correlations, both locally and regionally. The electric log markers are particularly useful in that they are easily recognizable without the benefit of Fischer assay data or lithologic descriptions.

The four electric log markers are, in stratigraphically ascending order, the Orange marker, Blue marker, B-groove and A-groove. All are associated with low resistivity intervals which reflect low grade oil shale zones.

The Orange marker forms the base of a low resistivity interval and defines the lower stratigraphic limit of the richer oil shale zones in the upper part of the Douglas Creek-Garden Gulch Members (undifferentiated).

The Blue marker forms the top of a low resistivity interval and defines the contact of the Douglas Creek-Garden Gulch Members with the overlying Parachute Creek Member.

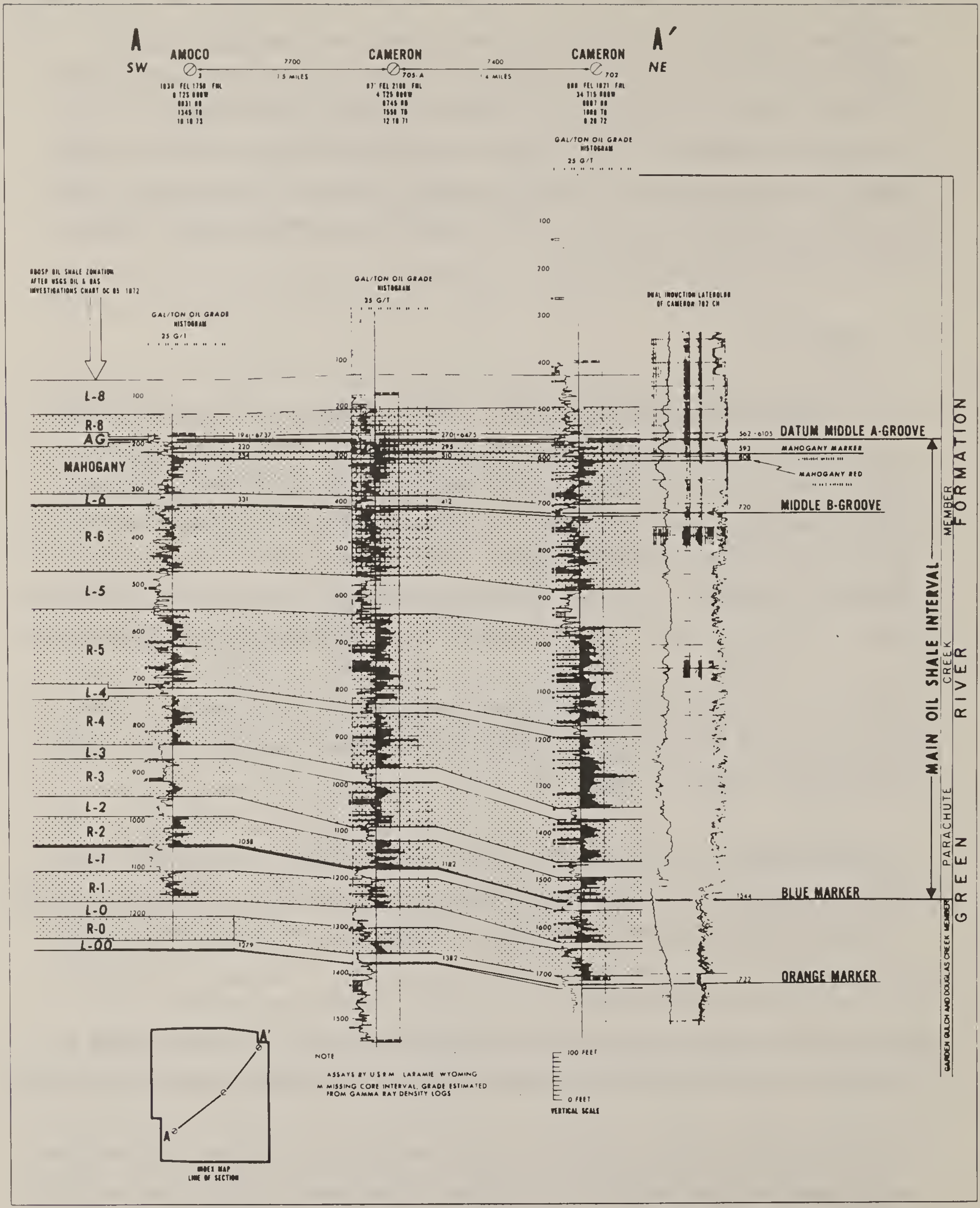


Figure 3-3-4

SW-NE 3-CORE HOLE HISTOGRAM CROSS SECTION, TRACT C-a

The A and B-grooves are two low resistivity units which define the top and bottom of the Mahogany zone, respectively. The tops or bases of these grooves have commonly been used in subsurface mapping throughout the basin. However, their deepest inflections on resistivity logs (middle A-groove, middle B-groove) are more consistent regional "log picks", particularly where the resistivity log deflections are gradational and not sharply defined.

The A-groove and Blue marker are very important key markers because they define the top and bottom, respectively, of the main oil shale interval of the lower Parachute Creek Member. Although some rich oil shales occur immediately above and below this interval, the thickest and richest oil shale zones are within the stratigraphic section defined by these two key markers.

Within the Mahogany zone are two important lithologic markers in its upper part. The Mahogany marker is an analcimized tuff or volcanic ash bed generally 2 to 6" thick about 25 to 30' below the middle of the A-groove. About 15' below the Mahogany marker is a 2 to 4' thick interval of very high grade dark brown to black oil shale called the Mahogany bed. It stands out distinctly on oil shale grade histogram logs.

2. Lithology - Several of the key stratigraphic markers described in the previous item provide convenient boundaries which segregate major lithologic units within Tract C-a. The following is a brief description of these units as summarized from core description logs and surface stratigraphic data compiled by A&I (1975-B).

The uppermost part of the Douglas Creek-Garden Gulch Members of Figure 3-3-3 and Figure 3-3-4 (Orange marker to Blue marker) consists mainly of light gray to brownish gray oil shale with lesser amounts of gray shaley siltstone. Illite clay is reported to comprise the major portion, 60-70%, of the shale's mineral constituents (Robb and Smith, 1974, p. 94). As such, the interval may be more aptly described as organic-rich clay shale rather than oil shale defined as organic-rich dolomitic marlstone.

The interval ranges in thickness from about 180 to 240' increasing across the tract generally to the southwest. This thickening towards the Douglas Creek arch, the basin's margin, reflects the inclusion of additional clastics (Trudell, et al., 1974, p. 68) from a probable source area in that direction.

The overlying main oil shale interval (Blue marker to A-groove) of the lower Parachute Creek Member consists mainly of dolomitic marlstone with variable amounts of organic matter (oil shale). Numerous thin tuff beds are interbedded with the oil shale. Illite is reported to comprise less than 20% of the oil shale's mineral constituents (Trudell, et al., 1974, p. 68). Higher grade shales are generally brown, dark brown or black. Lower grade shales tend to be lighter in color, commonly gray, tan or light brown. The interval ranges in thickness from about 860 to 980' increasing across the tract basinward to the northeast. Dawsonite and minor amounts of nahcolite are present in this interval, both of which will be discussed in a later item of this report. Vugs resulting from the dissolution of nahcolite are scattered throughout the interval and are particularly concentrated in one zone where the term "Swiss cheese" is most descriptive.

The overlying upper part of the Parachute Creek Member ranges in thickness from about 360 to 580' increasing basinward across the tract to the northeast. Its lowermost 110 to 140' is mainly light gray to medium brown marlstone (oil shale) grading upward into light gray barren marlstone interbedded with gray siltstone and fine-grained sandstone. Outcrops of this unit's uppermost beds form the light gray canyon walls in the tract's major drainages.

The overlying Uinta Formation covers most of the tract's surface. It consists mainly of brown to light brown fine-grained massive sandstones with lesser amounts of siltstone. The formation's contact with the underlying Parachute Creek Member is transitional and is placed at the major color change between dominantly light gray sediments below and dominantly brown sediments above. Its thickness ranges over the tract from 0 to 350'.

3. Correlation Network - The subsurface stratigraphic correlation network established within Tract C-a is portrayed on Enclosure 1-A, a set of 6 cross sections across the tract (4 east-west and 2 north-south ties) consisting of gamma ray-density logs of all 25 tract core holes. Key starting points for the network's construction were the four key regionally persistent electric log markers discussed previously, namely, the A and B-grooves and the Blue and Orange markers. The mechanics of the network's development were discussed under Geologic Evaluation, Stratigraphic.

Logs on each cross section are horizontally aligned ("hung") on the middle A-groove datum and are of the same vertical scale, 1"-50'. An index map on each cross section shows its geographic position within the tract. Each density log cross section shows all 124 correlations established in the 1200 to 1300' thick interval defined at its base by the Orange marker and extending upward to about 150' above the A-groove. Correlation frequency averages about one every 10' of logged hole (A&I, 1975-C, p. 4). Both density log correlations and their equivalent grade histogram correlations are portrayed.

4. Oil Shale Zonation - The oil shale zonation established within Tract C-a is shown on Figure 3-3-4, the 3-core hole cross section across the tract and on Enclosure 1-A, the correlation network's set of 6 density log cross sections. The zonation is based on that established by Cashion and Donnell (1972), discussed below, which zoned the main oil shale interval of the Parachute Creek Member bounded at its top by the A-groove and at its base by the Blue marker. Rio Blanco's zonation expands their zonation above and below the main oil shale interval resulting in 19 zones, 9 rich and 10 lean. These zones are designated L-00 through L-8 in stratigraphically ascending order. The Mahogany and A-groove (AG) zonal nomenclature is retained because of their well established usage. They would be equivalent to an R-7 and L-7 zone, respectively, if the letter-number designations were used since they lie stratigraphically between the underlying R-6 and L-6 zones and the overlying R-8 and L-8 zones.

Two basic parameters control the zonation established within Tract C-a. First, as much 17+ GPT shale as possible was placed into the richer zones. Second, stratigraphic continuity was maintained based on equivalent correlations on both the density log and histogram cross section sets of the tract correlation network.

Alternating rich and relatively lean oil shale zones in the Green River Formation are not unique to Tract C-a. They reflect widespread cyclic changes in lacustrine environments of deposition whose regional persistence has long been recognized. Bradley (1931) mapped the Mahogany ledge (zone in subsurface) and his "upper and lower oil shale groups" throughout parts of the outcrop area in both the Piceance Creek and Uinta basins. Trudell, Beard and Smith (1970) constructed a series of cross sections throughout the Piceance Creek basin relating the stratigraphic positions of both lithologic and geophysical log markers to rich and lean oil shale zones. Cashion and Donnell (1972) published a Utah to Colorado correlation chart which divided the main oil shale interval of the Parachute Creek Member into several rich shale zones separated by lean zones and designated the rich zones R-2 through R-6 and Mahogany in ascending stratigraphic order. Brobst and Tucker (1973, p. 7) later applied the Cashion and Donnell zonation to the "pipeline section" outcrop on Cathedral Bluffs about five miles southwest of Tract C-a and added letter "L" designations to the lean shale zones.

Any attempt to explain the alternating rich and lean oil shale zones, either within Tract C-a or regionally, first requires a brief review of rich versus lean oil shale production. In its most basic terms, rich oil shale production required two essential conditions:

- An abundant supply of organic matter derived from the remains of plentiful aquatic and near-shore terrestrial plant and animal life, particularly aquatic plant life.
- An environment of deposition conducive to the preservation of that organic matter.

When both conditions were optimum, rich oil shale was produced. When either one or both conditions were of lesser quality, relatively leaner oil shale was produced.

Bradley (1929, p. 101) first recognized the first condition on a seasonal organic growth basis and termed the results "varves" which are cyclic pairs of minute laminations, one darker and richer than the other due to the inclusion of relatively more organic matter. Both Bradley (1929, p. 103) and more recently Smith (1969, p. 187; 1974, p. 74) proposed the existence of a thermally and chemically stratified Lake Uinta consisting of two non-mixing layers to explain the second condition. The upper layer was an oxidizing environment, warm and fresh enough to support prolific aquatic life. The lower layer was a cooler, fairly stagnant reducing environment favorable to the preservation of organic remains settling to the lake floor.

The concept of a stratified lake consisting of two non-mixing layers requires a relatively deep water-low energy environment. Waves and currents in the upper layer were moderate while currents in the lower layer below wave base were relatively slow. Bradley (1929, p. 103) proposed a water depth of 75 to 100' to provide the quiescent waters needed for a stratified Lake Uinta but also cited the present-day formation and preservation of varved sediments in McKay Lake, Ottawa, at depths of only 32'. Later, Bradley (1966, p. 1333-1338) discovered organic remains similar to those of the Green River Formation being deposited at the bottoms of four present-day lakes, two in Florida and two in East Africa, at depths of only 2 to 30'. In addition, the organic material did not decay in these four lakes even in an oxidizing environment. These findings may cause some argument as to the need for lake stratification with a lower reducing layer required to preserve organic matter for oil shale production. However, the formation of oil shale's characteristic long-range correlative varves and their subsequent preservation strongly support a persistent and quiescent lake bottom, below wave base and with slow lake bottom currents, precluding depths of just a few feet. With depths of just a few feet, periodic storm-induced wave and current action would tend to destroy the fragile varved sediments. Bradley's originally proposed depth of 75 to 100' for Lake Uinta still appears valid although a depth as shallow as about 30' is not unreasonable as evidenced by the present-day varved sediments at Lake McKay, Ottawa.

In summary of the above review of rich versus lean oil shale production:

- Rich shale was produced when both essential conditions were optimum; an abundant supply of organic matter coupled with an environment of deposition conducive for its preservation.
- Lean shale was produced when either one or both essential conditions were less than optimum.
- Lake depths in the 75 to 100' range, but possibly as shallow as only about 30', were sufficient to provide the quiescent water needed for lake stratification into two non-mixing layers. The upper layer was a moderate energy environment, oxidizing, and capable of supporting prolific aquatic life. The bottom layer was a low energy environment, reducing, and favorable for the preservation of organic matter. More shallow lake depths resulted in a bottom layer of relatively higher energy environment, less reducing, and therefore less favorable for the preservation of organic matter.
- Alternating rich and lean oil shale zones are analogous to Bradley's "varves". Both reflect basinwide cyclic production of rich and lean shale. While "varves" were seasonal in duration of deposition (annual), the thicker alternating rich and lean zones may be termed "mega-varves" representing deposition over considerably longer time-spans.

One important factor remains to be considered which significantly influenced oil shale deposition and the resultant alternating rich and lean zones within Tract C-a. That factor is the geographic location of the tract within the Piceance Creek basin.

Tract C-a is located on the west flank of the Piceance Creek basin about 15 miles east of the crest of the northerly trending Douglas Creek arch. During Lake Uinta time, the arch was a gentle low-relief sub-lake high, a "shoaling area", perhaps even slightly emergent at times, with lake waters more shallow on or near its crest than basinward down its flanks. Cyclic changes in lake level of just a few feet may have shifted favorable oil shale depositional conditions related to lake depth several miles depending on lake bottom slope. A lowering of the level, a lake regressive stage, shifted favorable depth conditions basinward to the northeast (tract lean zone deposition). A rise in the level, a lake transgressive stage, shifted favorable depth conditions outward to the southwest covering a more extensive area (tract rich zone deposition). Cyclic periods of abundant and less abundant aquatic life growth may have also contributed to the deposition of alternating rich and lean zones within the tract as well as regionally. The 3-core hole cross section of Figure 3-3-4 shows additional influence of the Douglas Creek arch on Tract C-a oil shale deposition. Zones L-0 through L-2 generally thicken southwestward across the tract towards the arch reflecting the inclusion of additional clastics derived from a source area in that direction. The overlying R-3 through L-8 zones generally thicken northeastward across the tract towards the basin's depocenter.

Finally, as shown in Figure 3-3-4 the main oil shale interval of the Parachute Creek Member contains most of the rich oil shale zones and stratigraphic sections above and below the main oil shale interval contain relatively lower grade oil shale zones. This "sandwich" relationship reflects cyclic gradational changes in environments of deposition associated with Lake Uinta, proceeding from relatively lean to relatively rich and back to relatively lean oil shale generation.

5. Accessory Minerals

a. Acid Extractable Alumina - Quantitative analyses of composite interval spent shale samples in eight G-S coreholes spaced across Tract C-a (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15) indicate extractable alumina (Al_2O_3) is present in all 19 rich and lean zones as well as in the relatively low grade to barren oil shales overlying them. Two important questions need to be answered; first, what minerals are contributing to the extractable alumina; and second, what is the stratigraphic distribution of these minerals?

The main minerals contributing extractable alumina are dawsonite [$NaAl(OH)_2CO_3$], analcite ($NaAlSi_2O_6 \cdot H_2O$) or analcime ($NaAlSi_2O_3 \cdot H_2O$), and a third mineral initially termed gibbsite [$Al(OH)_3$] to account for "excess alumina" (Smith and Young, 1969, p. 2). This third mineral was later tentatively identified as nordstrandite (Smith, 1974, p. 74) with the same aluminum trihydroxide formula as gibbsite. Dawsonite and the "excess alumina" mineral nordstrandite always occur with each other (Smith, 1974, p. 74) and are most heavily concentrated in the lower part of the main oil shale interval of the Parachute Creek Member.

"Excess alumina" was also recognized by Desborough and Pitman (1974, p. 85) based on bulk chemical analyses of eight very rich oil shale samples from four Piceance Creek basin core holes. Four samples from the Mahogany bed and four samples from a rich bed in the R-4 zone were tested. After allocation of the Al_2O_3 obtained to K_2O required for K-feldspar ($KAlSi_3O_8$), and to Na_2O_3 required for albite ($NaAlSi_3O_8$), analcime and dawsonite, excess Al_2O_3 remained. The presence of an aluminum-rich compound containing no sodium or silicon was also verified by microprobe analysis of one shale sample which contained 5 weight percent of surplus alumina.

Dawsonite occurs as microscopic crystals finely disseminated throughout the oil shale and as thin laminations along bedding planes (Hite and Dyni, 1967, p. 29). Analcime commonly occurs as an alteration product in volcanic ash beds (tuffs) but also occurs disseminated in oil shale (Desborough and Pitman, 1974, p. 85). The "excess alumina" mineral nordstrandite probably occurs in a manner similar to dawsonite.

As was the case in oil shale deposition and zonation discussed previously, the geographic position of Tract C-a within the Piceance Creek basin is again a significant factor influencing the stratigraphic distribution of extractable alumina minerals within it. Stratigraphic occurrences of these minerals outside the tract must be brought into proper prospective with similar information compiled within the tract.

Within Tract C-a, USBM X-ray diffraction analyses in core holes CE 702 and CE 707 (Smith, 1974, unpublished) show dawsonite and therefore nordstrandite (after Smith, 1974, p. 74) occur in an interval from the upper part of the R-2 zone through the lower part of the R-5 zone. A minor amount is also present in the L-1 zone of core hole CE 707. In the more basinward core hole CE 702, located in the northeast corner of the tract, analcime occurs commingled with dawsonite in only one of 219 dawsonite-bearing samples (0.5%). In the more westward core hole CE 707, nearer the basin margin, analcime is commingled with dawsonite in 25 of 174 dawsonite-bearing samples (14%). The concentration of dawsonite is highly variable ranging from a few to as high as 15 weight percent in individual beds. Analcime occurs stratigraphically above and below the dawsonite-bearing interval, generally in higher concentrations.

At the "pipeline outcrop section" on Cathedral Bluffs in Sec. 34, T. 2 S., R. 100 W. about 5 miles southwest of Tract C-a, Brobst and Tucker (1973) described and sampled a 909' thick interval from the base of the Parachute Creek Member to about 310' above the Mahogany ledge. This interval is stratigraphically equivalent to the tract's R-2 through L-8 zones and above. X-ray diffraction analysis of 70 samples from the outcrop section indicates only analcime-bearing oil shale is present. Dawsonite-bearing shales are completely absent.

At the other extreme, about 12 miles northeast and basinward of Tract C-a, Robb and Smith (1974, p. 91-100) present a core hole X-ray diffraction mineral profile showing very high dawsonite concentrations occurring in oil shales of the lower part of the Parachute Creek Member. The core hole is the USBM-AEC Colorado No. 1 located in Sec. 13, T. 1 N, R. 98 W. The profile covers a stratigraphic interval 2,060' thick from the upper part of the Garden Gulch-Douglas Creek Members to the top of the Mahogany zone, equivalent to the tract's L-00 through Mahogany zones. In the very rich dawsonite-bearing shales of the 853' thick unleached saline section, analcime is completely absent except in only 6 samples analyzed. In the overlying 480' thick leached saline section immediately below the Mahogany, lesser amounts of dawsonite occur together with analcime but their concentrations are generally in inverse proportions. In other words, the two minerals do not favor each other in common occurrence. Analcime occurs both stratigraphically above and below the dawsonite-bearing shale interval.

Brobst and Tucker (1973, p. 40-42) located dawsonite and analcime occurring together in scattered oil shales below the Mahogany ledge in R-5 and R-6 zone outcrops along the extreme northern margin of the basin. The outcrops are located along lower Piceance Creek road in Sec. 11, 14 and 15, T. 1 N., R 97 W. In a 45' thick section in the R-5 zone, X-ray diffraction analysis of 54 samples showed that dawsonite content varies inversely with analcime content. Later, Desborough and Pitman (1974, p. 84) extended dawsonite's occurrence stratigraphically even higher when its presence was defined in the Mahogany zone's richest oil shale unit, the Mahogany bed, in four widely spaced core holes in the Piceance Creek basin. Analcime was found in common occurrence with dawsonite in two of the four core holes (Desborough, Pitman and Huffman, 1974, p. 5). In comparison, dawsonite's highest stratigraphic occurrence within Tract C-a is in the R-5 zone.

Stratigraphic distribution of acid extractable alumina minerals within Tract C-a is a compromise between Brobst and Tucker's outcrop section on Cathedral Bluffs southwest of the tract and Robb and Smith's mineral profile in the USBM-AEC core hole northeast of the tract. The former consists of analcime-bearing oil shale with no dawsonite. The latter consists of a prolific dawsonite-rich shale interval in the lower part of the Parachute Creek Member with strong dawsonite-analcime mineral segregation sandwiched between two analcime-bearing shale intervals. The highest stratigraphic occurrence of dawsonite within the tract is in the R-5 zone while the USBM-AEC core hole it is in the R-6 zone.

In summary, the main minerals contributing to acid extractable alumina within Tract C-a in zones R-2 through R-5 are dawsonite and the "excess alumina" mineral tentatively identified as nordstrandite. In zones stratigraphically above and below these zones, analcime is the main contributor. The thickest and richest dawsonite-nordstrandite deposits occur in the lower part of the Parachute Creek Member basinward to the northeast of Tract C-a. Dawsonite-nordstrandite content decreases to zero at the basin's west margin with analcime peripheral to dawsonite-nordstrandite in stratigraphically equivalent sections on the outcrop. Although dawsonite-nordstrandite and analcime do not generally favor each other in common occurrence, some stratigraphic intermixing is present increasing westward across the tract as evidenced in the CE 707 core hole. The intermixing, or stratigraphic overlap, was probably caused by periodic lake level fluctuations and lateral variations in the lake's geochemistry. Beard, Tait and Smith (1974, p. 103) report the same mineral relationship on a basinwide basis for the lower part of the Parachute Creek Member. Results of extractable alumina analyses are presented in the confidential volume.

b. Nahcolite - Only minor amounts of nahcolite ($NaHCO_3$) were encountered in the G-S core hole program on Tract C-a. In core hole G-S 2-3, it was found to be totally absent. Where nahcolite was defined in the core, quantitative analyses were performed. These analyses are complete except in core hole G-S 13 whose entire recovered core is retained intact for rock mechanics tests. The lack of nahcolite analysis data in this core hols is insignificant because it penetrated only one occurrence of nahcolite, a 3 to 4" bed in the R-4 zone.

Posted on the gamma ray-density log cross sections of Enclosure 1-A is the base of the leached zone. It is defined as the stratigraphically lowermost evidence in each core hole of nahcolite post-depositional removal by ground water. It is usually placed immediately below the lowermost occcurrence of vugs or solution cavities. The base of the leached zone is equivalent to the "dissolution surface" of Hite and Dyni (1967, p. 27) and Dyni (1974, p. 117).

Within Tract C-a, very limited amounts of nahcolite occur as thin beds, stringers, nodules and coatings or small crystal growths on both vug walls and shale partings. The few scattered beds that are present are usually less than 1' thick with a maximum thickness of 2' occurring in the L-2 zone of core hole CE 702, the most basinward core hole located in the northeast corner of the tract. Its relative abundance increases northeastward across the tract.

Stratigraphically, nahcolite occurs within the tract as high as the R-8 zone in core hole G-S 9 to as low as the R-2 zone in core hole G-S 8. However, most occurrences are in the lowermost part of the main oil shale interval's R-3 through R-4 zones.

The present-day occurrence of nahcolite within the tract is controlled by twc factors; first, its primary deposition; and second, the subsequent removal of this water-soluble mineral by ground water. As was the case in previous discussions on both oil shale zonation and extractable alumina within Tract C-a, the tract's geographic position within the Piceance Creek basin exerted a significant influence on nahcolite's primary deposition within it.

Tract C-a is located about 7 miles southwest and peripheral to the geochemical depocenter of nahcolite and associated halite (NaCl). In the vicinity of the eastern part of T. 1 S., R. 98 W., deposition of these two minerals was most extensive in the lower part of the Parachute Creek Member. At this locality, nahcolite beds up to 30' thick and halite interstratified with nahcolite and oil shale in zones up to 65' thick were deposited. One core hole penetrated about 910' of oil shale which averaged 28.4 weight percent nahcolite (Dyni, 1974, p. 111-122). Away from this saline depocenter, both minerals decrease in concentration and thickness toward the basin margins. Primary deposition of nahcolite within Tract C-a was limited to nodules and a few relatively thin beds and stringers. Halite never was deposited within the tract.

Subsequent removal of the water-soluble nahcolite by ground water leaching has reduced its original concentrations within the tract considerably. The base of the leached zone, portrayed on the cross sections of Enclosure 1-A, is consistently in the lower part of the R-3 zone in all tract core holes with the exception of G-S 7 where it is stratigraphically higher in the lower part of the R-4 zone. Its position need not follow stratigraphic boundaries because it is a post-depositional event controlled by ground water action. Below this "dissolution surface" (Dyni, 1974, p. 117), nahcolite originally deposited is still present. Above it, much of the originally deposited nahcolite has been removed, some of which was redeposited on vug walls and shale partings. The base of the leached zone is not sharply defined in that empty vugs or solution cavities and collapse breccia are present stratigraphically below unleached nahcolite occurrences (Trudell, et. al., 1974, p. 69). Evidence of nahcolite's removal by dissolution is scattered throughout the leached zone in all core holes within Tract C-a but is most striking in the R-3 zone. This zone is extremely vugular throughout most of the tract and the term "Swiss cheese" has been appropriately used in describing its core. In the equivalent unleached R-3 zone of core hole G-S 7, the core contains many nahcolite nodules and stringers.

6. <u>Trace Elements</u> - In the same eight G-S core holes spaced across Tract C-a selected for extractable alumina analyses (G-S 1, 2-3, 4-5, 7, 9, 10, 11, and 15), quantitative trace element analyses were performed on both fresh and processed shale. In addition, analyses were performed on fresh overburden rocks containing little to no oil shale. The seven trace elements tested for are antimony, arsenic, boron, cadmium, fluoride, mercury and selenium.

To minimize sample handling and preparation, the composite intervals selected in each core hole for trace element analyses were the same as those selected for extractable alumina in processed shale. Since interval selection preceded the establishment of the final oil shale zonation within the tract, interval boundaries are generally close but not necessarily coincident with the zonal boundaries.

Table 3-3-4 summarizes the fresh shale, processed shale and overburden analyses compiled in the eight G-S core holes listing the ranges and arithmetic average concentrations of each trace element. Arithmetic averages were compared to averages weighted to composite interval analysis thicknesses in two G-S core holes and found to be virtually identical.

Also shown in Table 3-3-4 for direct comparison are similar data on fresh shale recently reported by Desborough, Pitman and Huffman of the USGS (1974, p. 9). Their data are based on analyses of ten oil shale samples. Six samples are from the Mahogany bed, the richest oil shale unit in the Mahogany zone, four from core holes in Colorado and two from core holes in Utah. Their other four samples are from a rich bed in the R-4 zone, all from core holes in Colorado.

Desborough, et al., also cite the following additional trace element analyses in their report (1974, p. 11-13):

- Antimony - Concentrations ranging from 1 to 6 ppm in fresh shale as determined in their work are 2 to 15 times higher than those of Cook (1973), who reported 0.39 ppm in processed shale from the Mahogany zone. This difference may indicate that antimony was volatilized during retorting of Cook's sample.
- Arsenic - Concentrations ranging from 25 to 75 ppm in fresh shale as determined in their work are 3 to 10 times higher than that reported by Cook (1973) in processed shale from the Mahogany zone. This difference suggests that arsenic resides principally in the volatile organic-rich fraction and is therefore mobilized during retorting. However, additional studies of raw and processed shale show that this is not the case as evidenced by analyses of TOSCO composite core samples.

Table 3-3-4

TRACE ELEMENT SUMMARY; FRESH & PROCESSED SHALE, OVERBURDEN

(Concentrations in parts per million)

Trace	USGS Report		8 G-S Core Holes					
Element	Fresh Shale		Fresh Shale		Processed Shale		Overburden	
	Range	Avg.(a)	Range	Avg.(b)	Range	Avg.(c)	Range	Avg.(d)
Antimony	1-6	2.4	0.2-1.7	0.6	0.1-1.2	0.4	0.2-0.8	0.4
Arsenic	25-75	39.5	0.9-15.7	7.1	1.0-12.4	5.2	3.8-12.6	8.1
Boron	30-300	95	14-516	150	0.5-278	108	19-226	113
Cadmium	0.6-1.2	0.8	1.4-4.0	2.6	1.3-3.9	2.6	0.8-2.9	1.5
Fluoride	700-2100	1290	75-1488	622	64-1217	475	131-1134	485
Mercury	0.07-2.9	0.48	0.13-3.6	0.76	0.01-3.04	0.47	0.06-1.91	0.50
Selenium	0.1-3.0	1.7	0.1-1.3	0.4	0.1-1.1	0.5	0.1-0.7	0.2

Arthmetic Averages
(a) Avg. of 8-10 samples
(b) Avg. of 209-210 samples
(c) Avg. of 209 samples
(d) Avg. of 21 samples

A composite sample representing about 50' of the Mahogany zone was provided by TOSCO. One fraction was retorted by conventional Fischer assay methods. The processed shale represented 83.7 weight percent of the fresh shale. Ten separate portions of both fresh and processed shale, each weighing 0.5 to 0.75 grams, were analyzed for arsenic by a commercial laboratory. The results of 10 analyses (ppm) for both fresh and processed shale is shown below.

	Fresh shale	Processed shale
Mean	62.5	64.5
Standard deviation	7.5	4.4
Range	55-75	60-70

The above results indicate that about 85% of the arsenic remains in the processed shale and about 15% is apparently volatilized during retorting, when the processed shale concentration is converted to raw shale concentration using the ash value of 83.7 weight percent. However, the actual amount volatilized during retorting is uncertain due to limited analytical precision.

- Mercury: Concentrations ranging from 0.07 to 2.9 ppm in fresh shale are reported by Desborough, et al., in their work. J. R. Donnell and V. E. Shaw of the USGS reported a range of 0.1 to 1.0 ppm for 183 analyses of a continuous sequence of oil shale from 30' above the top of the Mahogany zone to 60' below the base of the Mahogany zone. Cadigan (1970) reported a median (half higher, half lower) of 0.1 ppm for 260 samples from the Uinta and Green River Formations.
- Selenium: Concentrations ranging from less than 0.1 to 3 ppm in fresh shale as determined in their work are 10 to 20 times greater than the value of 0.08 ppm in processed shale reported

by Cook (1973). The selenium in Cook's sample is suspected of being lost during retorting.

At this point, it is unknown why some of the USGS and Rio Blanco trace element concentrations shown in Table 3-3-4 are not in better agreement. Analytical methods, laboratory procedures and sample intervals (composite versus specific core increments) and sample contamination are some of the factors considered. We have discussed this question with Core Laboratories, Inc., who performed the trace element analyses on the G-S core hole samples. They have reviewed their work and believe their data are reliable. Further, we have discussed this question with J. R. Donnell and V. E. Shaw of the USGS and are cooperating with them to resolve it by furnishing G-S core samples for USGS analysis.

Desborough, Pitman and Huffman (1974, p. 8-13) report some of the mineralogical residences of these seven trace elements as follows:

Trace Element	Mineral Residence
Antimony	(Unknown)
Arsenic	Pyrite
Boron	K-feldspar
Cadmium	Sphalerite or Wurtzite
Fluoride	Fluorite and Cryolite
Mercury	(Unknown)
Selenium	Sulfide minerals or iron selenide

Colorado School of Mines Research Institute (1975) conducted mineral residence analyses for these seven trace elements in fresh and processed shale composite samples from core holes G-S 2-3 and 7. Their work, utilizing X-ray diffraction and element partitioning techniques, indicates that with the exception of cadmium not occurring in quartz, each of the seven trace elements probably occurs by ionic substitution in eight of the common minerals comprising oil shale; namely, quartz, dolomite, calcite, analcime, andesine, illite, dawsonite and pyrite. In addition, comparison of analysis results between equivalent samples of fresh and processed shale indicates that only two of the trace elements, arsenic and selenium, are present in possibly significant quantities in kerogen, the organic fraction in oil shale. The other five are associated primarily with the mineral fraction and are retained in the shale after retorting.

7. Measurements of Methane and Hydrogen Sulfide Gas - Methane (CH_4) is the simplest and most common hydrocarbon compound generated by the decomposition of organic matter in the absence of oxygen. If the organic matter is sulfur-bearing, which it commonly is, hydrogen sulfide (H_2S) is also formed. In the case of oil shale, as well as coal and marine shales, both gases are commonly generated in the subsurface as a direct result of the sediment's partial distillation.

Both methane and hydrogen sulfide have been detected in the oil shale section within Tract C-a. The gases probably occur trapped in vugs and fractures as well as dissolved in the ground water. Hydrogen sulfide is very soluble in water while methane is slightly soluble.

- Methane - In all 13 G-S core holes, gas samples for methane quantitative analysis were collected generally when the A-groove, B-groove and total depth were reached. The three samples collected in core hole G-S 8 were lost, possibly during transit off tract; therefore, no analyses are available in this core hole.

  In the G-S core hole program, a total of 49 gas samples were analyzed, 36 of which either contained no methane or methane in quantities too small to measure (reported as "nil"). The remaining 13 samples contained methane ranging from less than 0.01 to 3.21 vol. % and averages 0.91 vol. %. Methane concentrations were consistently highest in samples collected at or near total depth when the entire oil shale section was exposed to the bore hole. These highest concentrations at total depth suggest a combination of several uphole shale intervals simultaneously contributing methane to the bore hole.

  Table 3-3-5 summarizes the 13 analyses of methane where this gas was present in measurable quantities. Also shown are the two analyses of ethane where this gas was detected.

Table 3-3-5

SUMMARY OF METHANE MEASUREMENTS, G-S CORE HOLE PROGRAM

Core Hole	Location of Measurements Depth	Zone	Mole %[a] Methane (CH_4)	Mole % Ethane (C_2H_6)
G-S 1	1404 TD	-L-00	0.19	0.02
G-S 4-5	1663 TD	-L-00	1.39	N
G-S 6	636	MZ	0.03	N
	647	MZ	0.05	N
G-S 7	1200 TD	-L-00	0.23	N
G-S 9	955	R-5	$<$ 0.01	N
G-S 10	1129	R-5	0.19	N
	1903 TD	-L-00	1.90	N
G-S 11	1886 TD	-L-00	0.32	N
G-S 12	1800 TD	-L-00	1.96	N
G-S 13	1746	-L-00	3.21	$<$ 0.01
G-S 14	1794 TD	-L-00	1.21	N
G-S 15	1833 TD	-L-00	1.16	N

Note: -L-00 = below L-00 zone
N = None
(a) Equivalent to volumetric percent for an ideal gas. The difference between the two for methane at standard conditions is negligible.

There is some question as to the reliability of the methane quantitative analysis results because of the sample-catching procedure used. Samples were collected in evacuated steel cylinders by tapping into the "blooey line", the pipe discharging the return air-mist drilling fluid. Any methane present was already diluted by the air-mist fluid. The 3.21 vol. % analyzed in the sample obtained at 1746' near total depth in core hole G-S 13 suggests a higher methane concentration may have been present in this hole which was diluted by the air-mist drilling fluid prior to sample capture.

Another factor which may result in questionable quantitative methane data is the so-called "flash effect" which may be applicable to certain oil shale intervals. In the D-J basin of eastern Colorado, the Cretaceous Niobrara Formation contains marine shales which release significant quantities of methane to the drilling fluid (mud) due essentially to the rotary cutting and grinding action of the drill bit. Mud-logging units commonly record high methane readings in the drilling mud while this formation is being penetrated. However, when these "gas shows" are drill-stem tested, usually little to no gas is recovered. Once the well has drilled through the Niobrara Formation toward deeper objective horizons, methane readings in the mud-logging units normally decrease rapidly and stabilize after the gas has left the mud stream while circulating through the mud pits.

- Hydrogen Sulfide - The distinct odor of hydrogen sulfide was noted in all but 4 of the 13 G-S core holes, namely, G-S 1, 7, 8 and 12. It is noteworthy that these four core holes are all located in the western half of the tract suggesting a general westward decrease in the presence of this gas. It was also reported in several of the pre-sale core holes as well. Its stratigraphic occurrence is erratic, ranging from as high as above the L-8 zone in core holes G-S 6 and 13 to as low as below the L-00 zone in G-S 14 and 15. Its noted presence at any given depth in a core hole does not necessarily mean its source is the shale interval at or near the depth at which it is reported. It may have entered the bore hole from any interval(s) above that depth.

Late in the G-S drilling program, it was noted that the analyses of gas samples collected in cylinders off the "blooey lines" failed to disclose the presence of measurable quantities of hydrogen sulfide. Yet, its odor at times suggested concentrations may have been present in measurable quantities. The cylinders were examined for evidence of H_2S reaction with their inner metallic walls but none was found. Hydrogen sulfide monitors were installed on core holes G-S 11, 14 and 15 and on the four D-holes (deep hydrologic tests) twinning core holes G-S 12, CE 701, 702 and 705-A. Unfortunately, these monitors were prone to frequent breakdown. However, when operative, most hydrogen sulfide concentrations observed were less than 1 ppm (parts per million). The maximum concentration recorded was 2.8 ppm at depth 958' in the R-4 zone in D-19 which twinned the CE 705-A core hole.

3.3 STRUCTURE

A. Regional - The Piceance Creek basin is a broad northwest-trending structural trough about 130 miles long and 60 miles wide (Murray and Haun, 1974, p. 36). These dimensions far exceed that part of the basin presently underlain by the Green River Formation which is an area approximately 60 by 40 miles. Considerable Green River sediments around the basin's periphery have subsequently been removed by erosion.

The basin is bounded on the north by the Axial Basin uplift (Axial Fold and Fault belt, an eastward extension of the Uinta Mountain uplift); on the east by the White River uplift whose west flank is the Grand Hogback monocline; on the southeast and south by the Elk and West Elk Mountains and Gunnison uplift; on the southwest by the Uncompahgre uplift; and on the west by the Douglas Creek arch which separates the Piceance Creek basin from the Uinta basin of Utah (Murray and Haun, p. 33).

The basin is asymetric with very gently dipping flanks on the south and west and more steeply dipping flanks on the north and east. Pre-Green River formations along the Grand Hogback on the basin's east side are locally vertical or even overturned. The structural axis of the basin is within 20 miles of its north and east margins (Donnell, 1961, p. 859).

Numerous gentle subparallel northwest-trending folds are present in the basin. The most prominent of these folds is Piceance Creek dome with structural closure of over 200' mapped at the surface (Donnell, 1961, p. 859). Faults are also present which generally trend in the same direction as the folds. Several pairs of these faults define graben (Donnell, 1961, Austin, 1971, Murray and Haun, 1974, p. 35). A graben is a crustal block between two faults, generally elogate compared to its width, that has been lowered or downthrown relative to blocks on either side. The graben-bounding faults are generally steep, and in most cases, if not all, are either normal faults (gravity or tension) or are essentially vertical. In some cases, these faults have been described as steep reverse faults but the validity of these observations is questionable (Billings, 1942, p. 201). The graben-bounding faults commonly converge with depth because, by definition, their hanging walls are lowered relative to their footwalls.

B. <u>Tract C-a</u> - Tract structure as interpreted by RBOSP from photogeologic (TGA, 1974), surface geologic (A&I, 1975-B) and subsurface core hole and off-tract well control is shown on Figure 3-3-5. The datum mapped is the middle of the A-groove, the top of the Parachute Creek Member's main oil shale interval as portrayed on the cross section of Figure 3-3-4.

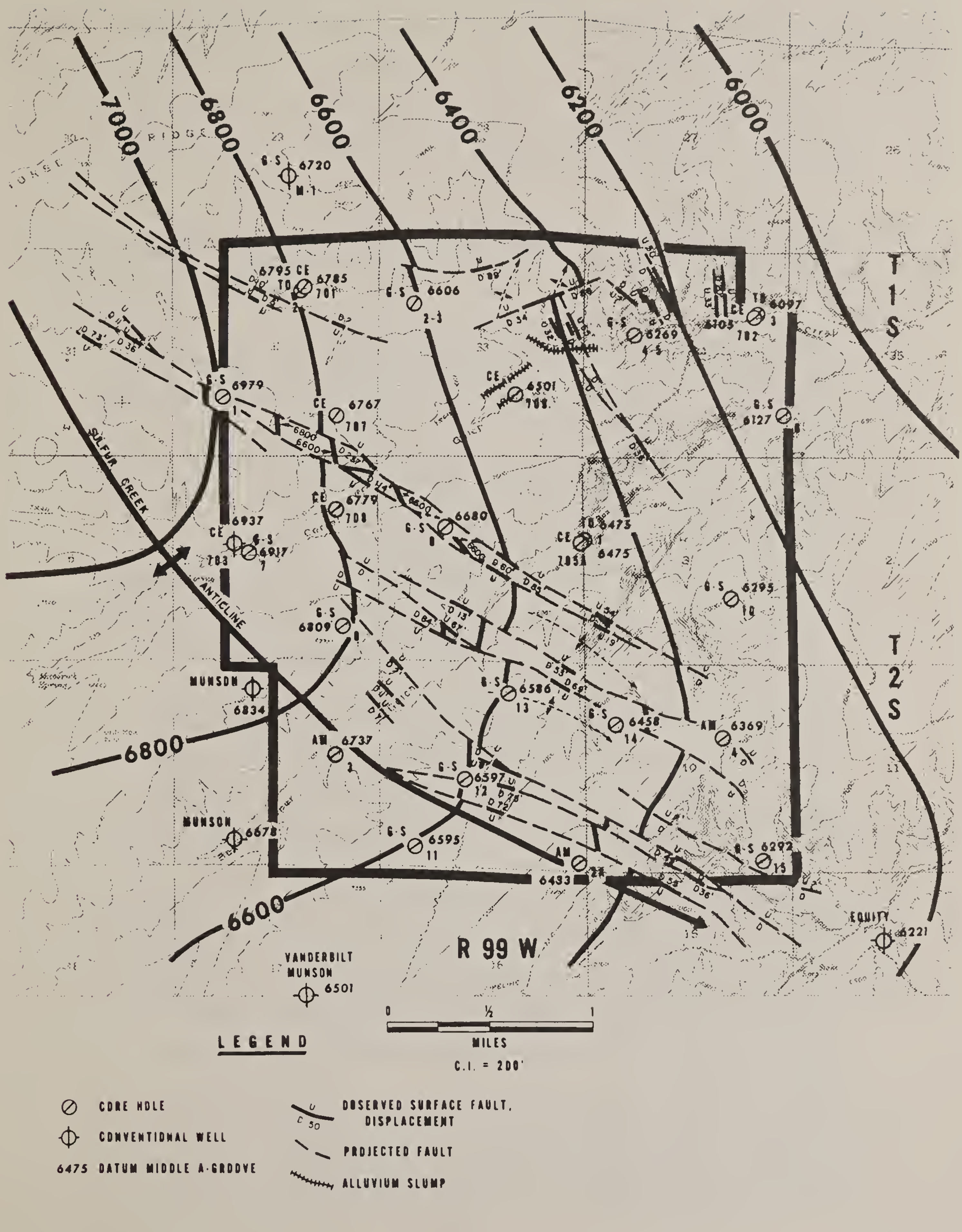


Figure 3-3-5

RBOSP TRACT C-a MIDDLE A-GROOVE STRUCTURE MAP
(Geologic Revision 1)

Enclosure 3 is Amuedo and Ivey's middle A-groove structure map of the tract which honors all their surface structural control obtained by plane-table mapping of key surface beds. Structure defined at the surface is projected to the middle A-groove horizon by means of isopachs. Also shown is the TGA photogeology which provided the base control for A&I's surface geologic mapping program.

The RBOSP map of Figure 3-3-5 and the A&I map of Enclosure 3 differ in the following aspects:

- The alignment of the graben faults in the vicinity of core hole G-S 9; a difference of interpretation as to the positions of the fault traces.
- Fault planes on the A&I map are projected into nearby core holes in which evidence of faulting is interpreted. This was done at RBOSP's direction to explore this definite possibility. Fault planes on the RBOSP map are assumed vertical with evidence of faulting in nearby core holes interpreted as either paralleling subsidiary or cross faults between the major graben-bounding faults.
- Magnitude of fault displacement measured at the surface is projected to the A-groove horizon on the A&I map. On the RBOSP map, they are shown with lesser displacement at the A-groove horizon in some cases where displacement diminishing with depth is interpreted.
- Middle A-groove contouring on the A&I map honors all surface plane table mapping control lowered by isopachs. On the RBOSP map, the contours are smoothed out considering the possibility of local thinning and thickening of the sections isopached between the key surface beds mapped and the subsurface A-groove horizon.
- Two step faults in the tract's northwest corner are shown on the RBOSP map which are absent on the A&I map. These faults were located subsequent to the A&I surface mapping program.

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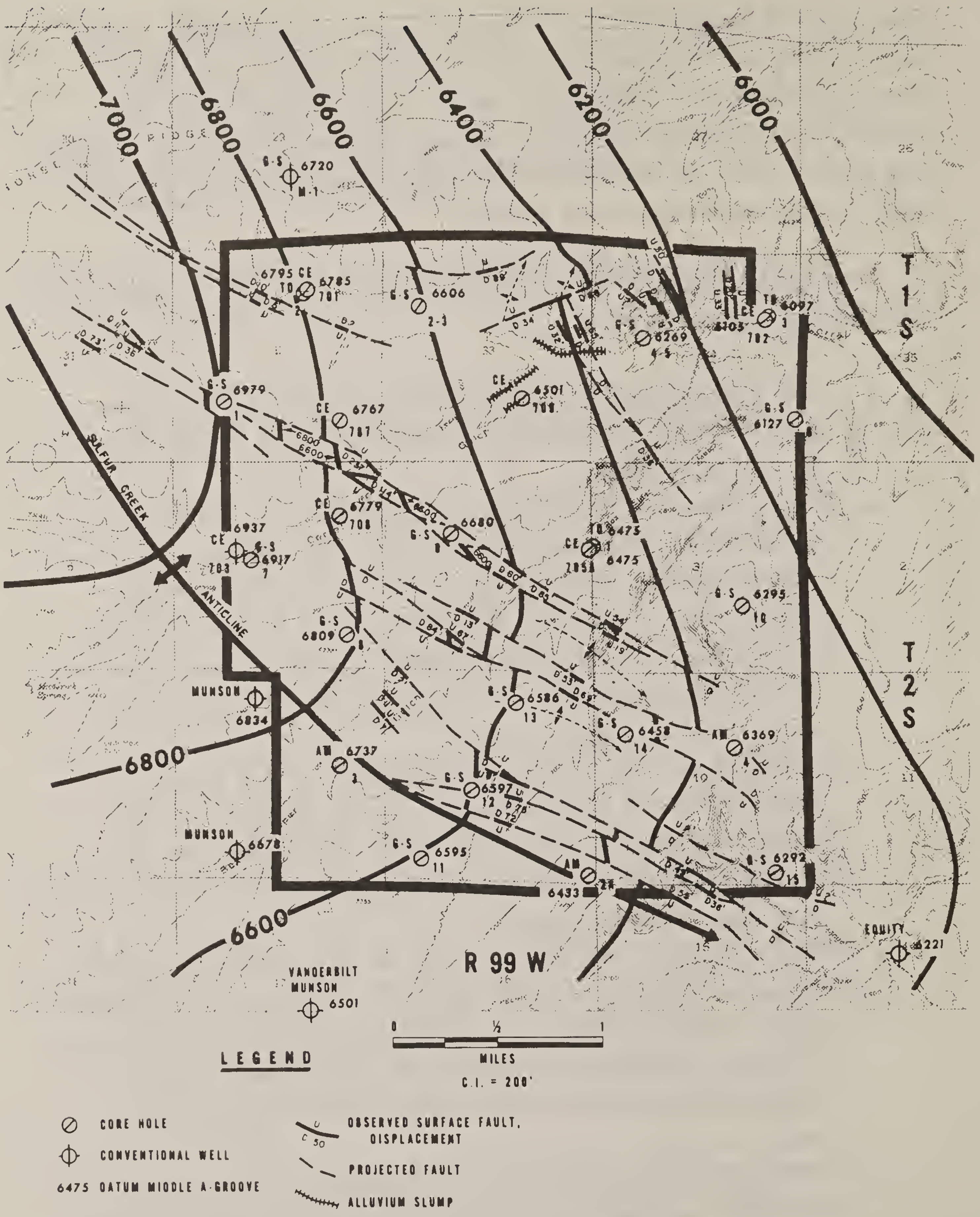

Figure 3-3-5

RBOSP TRACT C-a MIDDLE A-GROOVE STRUCTURE MAP
(Geologic Revision 1)

Considering only the differences in the first four items, with the fifth regarded as new control, both structure maps are in excellent agreement. The only major difference between the two pertains to the faults, their attitudes and displacements in the subsurface. Both maps are geologically reasonable and the actual structure in the tract is probably a combination of the two. However, this report will regard the RBOSP map, Figure 3-3-5, as the structure most representative of the tract at this time.

1. Faults and Folds - Tract C-a is located on the west flank of the Piceance Creek basin about 5 miles east of Cathedral Bluffs. Beds within the tract strike generally to the north and dip basinward to the east and northeast at an average rate of 200 to 350' per mile (2-4°) except where locally disturbed by folds and faults.

The present-day structural framework of Tract C-a is dominated by the Sulfur Creek anticlinal nose and three major en échelon fault systems (graben) on its northeast flank. Four minor folds and multiple subsidiary faults complete the framework.

The Sulfur Creek anticlinal nose is a gentle low relief structure which plunges southeastward (S60°-70°E) through the southern portion of the tract. Its axis enters the tract just south of the middle of its western boundary and exits the tract just west of its southeast corner. Core holes AM 2-A and 3 (Amoco) are located on the axis.

The three northwest-trending en échelon graben are essentially parallel to the Sulfur Creek anticlinal axis. The faults bounding the graben are all very high angle to near vertical (84°+) normal faults as observed at the surface. Fault displacements range from less than 20' to as high as 237', the latter measured on the most northerly graben at its intersection with Corral Gulch. The graben-bounding fault traces are characteristically sinuous with subsidiary sliver faults branching from them. Direct evidence of cross faulting within the graben is present at the surface in the northern graben at Corral Gulch and the minor drainage southeast of Box Elder Gulch, and perhaps in the central graben at Box Elder Gulch.

The northern graben is the most structurally complex of the three. In addition to the cross faulting defined in this graben, displacements on its north-bounding fault are consistently greater than those on its south-bounding fault (237' versus 114' at Corral Gulch, 85' versus 60' at Box Elder Gulch, and 54' versus 19' at the drainage southeast of Box Elder Gulch). The combination of cross faulting together with differential displacement on the graben-bounding faults provide strong evidence that the graben is not one simple downthrown block but rather a series of broken and tilted (rotated) blocks between the graben-bounding faults. Even further evidence of the graben's complexity is furnished in the subsurface section penetrated by core hole G-S 9.

Core hole G-S 9 was intentionally drilled in the northern graben to more fully define its characteristics (fault displacement, fault zone hydrologic conditions, fracture intensity). The core hole prognosis expected the middle A-groove at a datum of +6600' based on fault displacements observed on the graben outcrops at both Corral and Box Elder Gulches. Instead, the middle A-groove was encountered at +6680, 80' structurally higher than anticipated. Based on the known occurrence of cross faulting in this graben and assuming the graben-bounding faults are vertical, two additional cross faults are interpreted on Figure 3-3-5 in the vicinity of core hole G-S 9. These two additional cross faults define a discrete graben block on which the core hole is located which was not dropped as much as other blocks within the graben; namely, those exposed on Corral and Box Elder Gulches.

In addition, core hole G-S 9 encountered three normal faults and one reverse fault, further evidence of the graben's complexity and the multiple discrete fault blocks within it:

- In the vicinity of this core hole, a normal section of the upper Parachute Creek Member (top Parachute Creek to middle A-groove) is about 460' thick. However, the core hole encountered the Uinta Formation-Parachute Creek Member contact at a depth of about 161' and the middle A-groove at 458', an upper Parachute Creek Member thickness of only 297'. About 160' of uppermost Parachute Creek Member section is therefore absent in this core hole. It was removed by a normal fault with up to that amount of displacement cutting the hole at a depth between 110' and 161'. In this 51' thick interval, about 28' of core was lost suggesting the presence of a highly fractured section associated with a fault.

- At depth 339' to 391', an interval 52' thick in the L-8 zone, about 34' of core was lost, again suggesting a highly fractured shale section associated with a fault. Core recovered from depth 358' to 365' is a text book example of a fault breccia (angular to subangular shale fragments of various sizes cemented in a more finely crushed matrix). In addition, core recovered from depth 375' to 377' exhibits bedding dips of 30°. The thickness of the L-8 zone in this core hole is only about 5' less than that present in nearby core holes (see density log cross section B-B', Enclosure 1-A). A normal fault with about 5' of displacement is present in this core hole at depth 360'.
- In the R-6 zone, brecciated and highly fractured shale is associated with about 18' of lost core. The R-6 zone is about 30' thinner in this core hole than in nearby core holes. A normal fault with about 30' of displacement is present at a depth of about 610'.
- In the L-5 zone, breccia, slickensides and badly broken core are associated with about 40' of missing core. This zone is about 25' thicker in this core hole than in nearby core holes. A reverse fault with about 25' of displacement is present at a depth of about 780'.

The last two faults discussed above are clearly discernable on the core hole's density log on cross section B-B' of Enclosure 1-A. The abrupt thinning of the R-6 zone is representative of the normal fault. The abrupt thickening of the L-5 zone portrays the reverse fault. Also posted on the core hole's density log is evidence of faulting and suspected faulting as observed on the core description log. It includes the occurrence of breccia, slickensides, steep dips, highly broken core (rubble) and offset bedding. Evidence of this kind is concentrated over an interval 700' thick from depth 350' to 1050' reflecting a highly disturbed section due to both faulting encountered in the hole and faulting in near proximity to the hole.

Core hole G-S 1 is also located in the northern graben near the west boundary of the tract. In its uppermost cored interval, depth 43.6' to 211', abundant evidence of faulting is present (see cross section B-B', Enclosure 1-A). This evidence includes bedding planes dipping 15-75° and slickensided fractures dipping 60° to vertical. Below depth 211', this evidence abruptly ends and a relatively undisturbed section is present. In addition, the core hole's L-8 zone is about 15' thinner than in nearby core holes. A normal fault with about 15' of displacement is interpreted cutting the core hole at a depth of about 212'. This fault may be the south-bounding fault of the graben and if so, the fault plane dips about 82° to the northeast (A&I map., Enclosure 3).

The central graben appears considerably less complex than the northern graben based on its present definition. Only at its outcrop on Corral Gulch is there possible evidence of major cross faulting and the presence of multiple graben blocks. No great displacement differential has been defined on the graben's north and south-bounding faults to suggest severe tilting (rotation) within the graben.

Core hole AM 4 is located within the central graben near its southeast terminus and adjacent to its north-bounding fault. The core hole encountered five thin intervals of brecciated core from depth 1020' to 1360', the most pronounced of which is from depth 1032' to 1046' (see core hole's density log on cross section C-C', Encl. 1-A). If the uppermost occurrence of breccia at depth 1032' to 1046' is interpreted as the subsurface expression of the north-bounding fault, the fault plane dips 86° to the southwest (A&I Map, Enclosure 3). Assuming the north-bounding fault is vertical, the five occurrences of breccia are interpreted as minor subsidiary faults within the major graben (RBOSP map, Figure 3-3-5). Fault displacement is minimal because the thicknesses of the zones in which the breccia intervals occur (R-6 through R-4) appear normal when compared to thicknesses in nearby core holes.

The southern graben is characterized by a pair of north and south-bounding faults and a third fault within the graben subparallel and in relatively close proximity to the north-bounding fault. This third fault joins the north-bounding fault just outside the tract's southern boundary. The total displacement of the internal-graben fault and the north-bounding fault where they outcrop in the drainage southeast of Box Elder Gulch is 103+, down to the south (28' plus 75'+). Where they outcrop near the tract's south boundary, the total displacement of the faults is 85', down to the south (49' plus 36'). Displacement on the graben's south-bounding fault at the same two outcrop locations are 72'+ and 55', respectively, down to the north. The differential displacement indicated by the relationship of these three faults strongly suggests at least part of the graben is tilted similar to the northern graben. However, no firm evidence of cross faulting has been defined.

Core hole G-S 12 is located within the southern graben just east of the interpreted juncture and terminus of the south-bounding fault with the internal-graben fault. The core hole was intentionally drilled in the graben to more fully define its characteristics. The core hole prognosis expected the middle A-groove at a datum of +6500' based on the vertical faults and their displacements observed at their outcrop about 1000' to the east. Instead, the middle A-groove was encountered at +6597, almost 100' structurally higher than anticipated. Three interpretations are possible:

- The core hole cut the fault immediately to its north at a depth of about 212'. This interpretation is shown on the A&I structure map (Enclosure 3) and is based on a lost core interval about 34' thick from depth 208' to 242'. It requires a fault plane dip of 65° to the south intersecting the core hole at depth 212'. The only other significant fault evidence in this core hole is at depth 1025' where a 6' thick breccia interval is present (see core hole's density log on cross section C-C', Enclosure 1-A).

- An unexposed cross fault is present between the core hole location and the outcrop about 1000' to the east and the core hole was drilled on a graben block considerably less downthrown than the block exposed on the outcrop.
- Fault displacement observed at the surface diminishes with depth at an average rate of about 14' for every 100' of depth in the vicinity of this core hole because it encountered the middle A-groove 97' structurally higher than the prognosis predicted at a depth of 680' rather than 777' (97'/680' = 0.1426'/1' of depth = 14.26'/100' of depth).

Assuming the faults are essentially vertical as indicated on the outcrop just east of the core hole, either the second or third interpretation is favored by RBOSP. Since no cross faulting can be defined supporting the second interpretation, the third interpretation is shown on the RBOSP structure map (Figure 3-3-5).

In support of the above third interpretation, the concept of fault displacement diminishing with depth requires some explanation. Leroy (1951, p. 53) states that faults observed at the surface may be absorbed by beds in the subsurface and thus have restricted vertical downward extension. They are commonly said to "die out" with depth. As the faults are absorbed, their displacements diminish, eventually decreasing to zero where the faults finally die out. Rocks at or near the surface are under relatively low formation temperature and confining pressure thus behaving as brittle material readily susceptible to fracturing. When subjected to tectonic forces, subsequent movement of rock blocks along these fractures result in faults. Rocks deeper in the subsurface are under relatively higher formation temperature and confining pressure, both increasing with depth, and are more prone to plastic deformation rather than fracturing. In plastic deformation, rocks change their original shape without fracturing. The processes that permit plastic deformation are intergranular movements, intragranular movements and recrystallization (Billings, 1942, p. 20-29).

Cross sectional examples of faults dying out with depth are presented by Leroy (1951, p. 53) and Lahee (1952, p. 219). Lahee's example is particularly noteworthy because it also demonstrates fault displacement decreasing with depth. In the northeast part of Tract C-a, several superficial fault systems have been mapped which appear to affect only rocks within the Uinta Formation (A&I, 1975-B, p. III-3). These faults have displacement up to 50' in the Uinta Formation while in the underlying Parachute Creek Member, no displacement is observed on the outcrop.

In addition to the major surface structures within Tract C-a (Sulfur Creek anticline and the three en échelon graben on its northeast flank), four minor anticlinal noses and multiple subsidiary faults are present at the surface. The four minor anticlinal noses are all located in near proximity to fault systems strongly suggesting a direct relationship (see Summary of Tectonic History). Two folds are located in the southeast part of the tract between the three major graben and trend subparallel to them. The other two folds are located in the north central part of the tract and trend northeast. They are confined to an area between a pair of east to northeast-trending step faults, down to the south with surface displacements of almost 90'. In this area, erratic dips, slump and distorted bedding (fault drag?) are associated with these folds mapped in the Uinta Formation (A&I, 1975-B, p. V-3). It is not clear at this time whether the fairly complex surface structure mapped in this local area is confined essentially to the Uinta Formation or extends to an appreciable degree into the underlying Parachute Creek Member. In either case, the two folds are probably related to local compressive forces between the two east and northeast-trending faults.

The remaining surface faults within the tract are all relatively minor with displacements at the surface ranging from less than 2' to 50'.

Some of these faults are small graben and step faults. The faults with 50' of surface displacement have been discussed previously as those mapped in the Uinta Formation in the northeast corner of the tract which appear to die out before reaching the underlying Parachute Creek Member. Again considering the concept of fault displacement diminishing with depth, many of these faults probably die out before the Parachute Creek Member's oil shale sequence is reached or at least have lesser displacement in the subsurface than exhibited at the surface. Also, structural relief on the four minor surface folds can be expected to be subdued with depth.

2. Joint System - Joints are smooth fractures defined as divisional planes or surfaces that divide rocks, and along which there is no visible movement parallel to the planes or surfaces. A joint set consists of a group of more or less parallel joints. A joint system consists of two or more joint sets with a characteristic pattern.

A&I (1975-B, p. V-7 to V-10) determined joint orientations at 42 outcrop locations within Tract C-a. Since the outcrops varied in size, the number or frequency of joints counted per foot was adjusted to determine the number of joints present in a 100' long outcrop, thus equating joint data measured at one outcrop with that measured at all others. This adjustment is known as "normalizing" and is based on the following formula:

$$\frac{100'}{\text{length of outcrop*}} \times \text{number of joints in outrcop} = \text{normalized joints}$$

* length of outcrop measured normal to joint planes

Figure 3-3-6 is a rose diagram which portrays the strikes of joints measured at all 42 outcrop locations or joint stations. The upper half of the diagram shows the average number of normalized joints which strike within each 10° increment of compass direction. This average number was determined by dividing the total number of joints measured which strike within each 10° increment by the number of joint stations. The lower half of the diagram illustrates the equivalent percent of normalized joints which strike within each 10° increment.

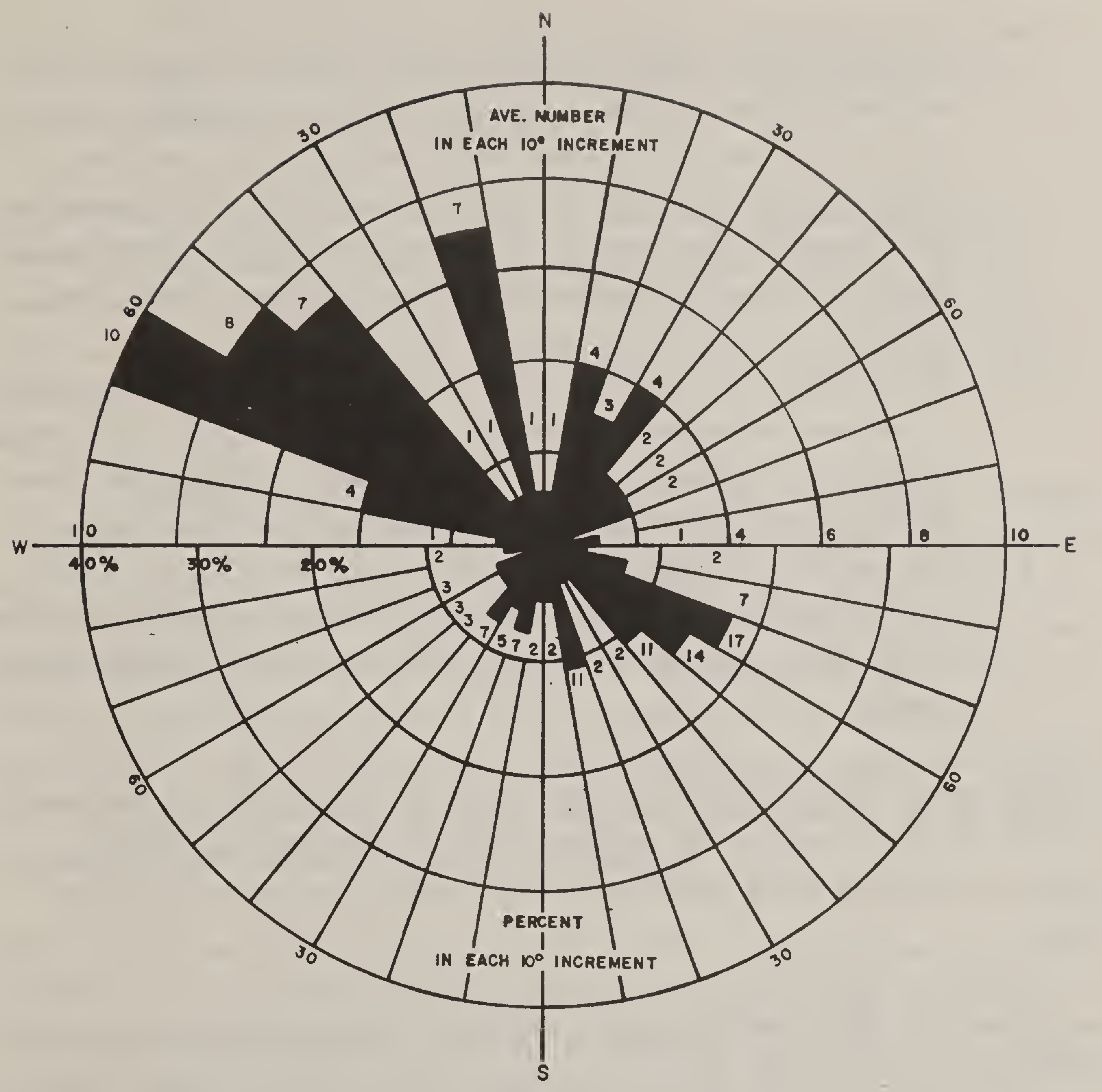

Figure 3-3-6

SURFACE JOINT ORIENTATIONS (STRIKES) WITHIN
TRACT C-a, ROSE DIAGRAM

Analysis of the joint orientation data indicates a joint system consisting of three main joint sets is present within Tract C-a with joints in each set generally spaced 10' or more apart. The average strike and dip of the sets are as follows:

- The dominant or major set strikes N56°-76°W with dips of 74°SW passing through vertical to 86°NE. The set essentially parallels the axis of the Sulfur Creek anticlinal nose and the three major en échelon graben on its northeast flank. It controlled development of the numerous tributary drainages oriented about normal to the major northeast-trending drainages within the tract.
- The secondary set strikes N28°E with a dip of 80°NW. This set is subparallel to and controlled development of all the northeast-trending drainages including the major Corral Gulch, Box Elder Gulch and the one immediately southeast of Box Elder Gulch.
- The tertiary set strikes N15°W with a dip of 75°E. It controlled development of the northerly oriented tributary drainages on the north side of Dry Fork as well as in other parts of the tract.

Development of the east-west oriented Dry Fork drainage in the northwest part of the tract appears to have been controlled by a local fourth joint set striking N84°W and dipping 82°N passing through vertical to 85°S.

Seisviewer log data compiled by A&I (1975-D) in 12 on-tract holes (core holes G-S 2-3, 7, 9, 10, 11, 12, 14, 15 and deep hydrologic test holes D-16, 17, 18 and 19) were analyzed by M-K (1975) for subsurface orientation of joints. Their analysis indicates:

- Joints are widely spaced, strike either northeast or northwest and primarily dip at angles greater than 60°.

- The number of joints tends to decrease with depth.
- Lean zones tend to have slightly more joints per foot of thickness than the rich zones.
- Lateral continuity of joints is poor. Core hole G-S 12 and hydrologic hole D-16, which twin each other, have joints independent of one another.

In reference to the last item above, it should be pointed out that G-S 12 and D-16 are both located in the southern graben near the internal-graben fault. The interpreted lateral discontinuity of joints between these two holes may be the result of differentially developed fracturing associated with this fault.

3. Alluvium Slump - Shown on Figure 3-3-5 are the traces of three very recent valley alluvium slump features in the vicinity of the confluence of Corral Gulch and Dry Fork in the north central part of the tract. The northern trace trends eastward and parallels the Dry Fork road. The two southern traces trend southwestward in the vicnity of core hole CE 709; one immediately adjacent to the core hole location, the other paralleling the Corral Gulch road. These features are cracks or fissures in the alluvium, as much as 6' deep, generally in a zone 7' to 10' wide extending several hundreds of feet in length.

These features were first noted in April, 1975. Investigation concluded that they were not present in late 1974 prior to snow cover (O'Hara, 1975). A search of the tract for similar features disclosed a minor one present in the vicinity of core hole CE 708, about one foot deep and about 85' in length. Further, a discussion with Mr. G. Saulnier of the USGS Water Resources Division revealed that he had observed features similar to and in the same general vicinity of those recently observed on Tract C-a in the late spring of 1973 prior to the lease sale.

The traces of these features appear to be limited to valley alluvium and not associated with bedrock. Displacement along them is horizontal and vertical, both toward the stream bottom side. They appear to be tension cracks along which the alluvium has subsided or collapsed streamward and are perhaps related to spring thaw and run-off.

4. Summary of Tectonic History - The present-day structural framework of Tract C-a was initiated during post-Uinta Formation time by renewed arching of the southeast plunging Sulfur Creek anticlinal nose by either major vertical or compressive tectonic forces. The Sulfur Creek nose is an old feature, pre-Parachute Creek, as evidenced by its isopach thin in the A-groove to Blue marker interval (RBOSP, regional control).

The arching caused tensional forces to develop in the shallow near-surface rocks, a stretching effect, resulting in the development of a major set of joints or fractures oriented in a preferred direction parallel to the Sulfur Creek anticlinal axis. Minor joint sets also developed oriented about north and northeast.

The tensional forces were greater in the near-surface rocks than in progressively deeper buried rocks. Nearest the surface, the more brittle rocks ruptured because of relatively low formation temperature and confining pressure. In the progressively deeper sections, the rocks tended to change their original shape by plastic deformation because of the relatively higher formation temperature and confining pressure, both progressively increasing with depth.

Essentially vertical, high angle normal faults developed in the ruptured near-surface rocks, pairs of which formed the bounding-faults of the three major en échelon graben on the northeast flank of the anticlinal nose. Blocks between the bounding-faults collapsed by gravity, some being rotated (tilted) and broken by cross faulting. The graben served as major relief adjustments to the overstrained near-surface rocks on the anticlinal nose. They formed either during or immediately after the arching.

The other faults within the tract developed as subsidiary relatively minor relief adjustments possibly subsequent to the more major graben.

Locally contained compressive forces between some of the faults caused minor folds to develop as tectonic activity came to rest.

3.4 IN-PLACE TRACT RESOURCES

Using both pre-lease and new core hole data, RBOSP has made an estimate of total oil "resource" contained within Tract C-a. An estimation of total in-place tract resources is believed essential to an evaluation of various mining and processing options considered. Rio Blanco's estimates of total in-place tract resources have been provided, therefore, to the AOSS; however, Rio Blanco believes that this estimate is confidential and proprietary, and therefore these data have been incorporated into the confidential section of this report. It is pertinent to note, however, that our definition of in-place tract resources includes all oil shale intervals 10 feet thick or more and averaging 8 GPT or more of contained oil; further, that all oil shale encountered in the L-8 down through L-00 zones was included if it exceeded this grade cutoff. The horizontal extent of the estimated tract resources was considered to be all material within the vertical projection of the tract boundaries.

3.5 OVERBURDEN

Enclosure 4 is an overburden map showing the thickness between ground surface and the electric log middle A-groove within Tract C-a. The middle A-groove was selected as the base of the overburden interval because it:

- Marks the top of the main oil shale interval as defined on Figure 3-3-4.
- Is in near proximity to the top of the Mahogany zone, the most shallow of the richer shale zones within the tract.
- Is the key structural marker selected for the tract's subsurface structural mapping as shown on Figure 3-3-5.

The map is derived from one which was computer-generated by M-K with input being digitized surface (topographic) elevations and the middle A-groove structure map furnished by Rio Blanco. Output in digital form was contoured by Rio Blanco with some modification in the vicinity of fault zones to more closely agree with the middle A-groove structural interpretation shown on Figure 3-3-5.

Overburden thickness varies considerably throughout the tract dependent upon abrupt local changes in topographic relief. This variable topography together with the general east and northeast gentle dip of the subsurface middle A-groove horizon result in a generally northeast trending "grain" to the overburden.

Overburden ranges from about 60' to 875' with a tract average of 482' as determined by planimeter. The least overburden is on the far west edge of the tract in Dry Fork and Corral Gulch. The maximum overburden is on the tract's north border atop the ridge due north of core hole G-S 4-5.

In the various core hole programs within the tract, the least overburden was encountered in core hole G-S 7 where the middle A-groove was penetrated just 72' below ground surface. This core hole is located near the west edge of the tract in Corral Gulch. The maximum overburden was encountered in core hole AM 2-A where the middle A-groove was penetrated 812' below ground surface. This core hole is located just inside the tract's southern border on a prominent northeast-trending ridge.

Overburden consists of (1), bedrock of the upper Parachute Creek Member of the Green River Formation and the overlying Uinta Formation and (2), unconsolidated sediments comprised of valley alluvium, colluvium and soil cover.

The upper Parachute Creek Member consists of light gray to medium brown marlstone (oil shale) of the upper AG, R-8 and L-8 zones shown on Figure 3-3-4 grading upward into light gray barren marlstone interbedded with gray siltstone and fine-grained sandstone. Outcrops of this unit form the light gray canyon walls in the tract's major drainages. The overlying Uinta Formation consists mainly of brown to light brown fine-grained massive sandstones with lesser amounts of siltstone.

Unconsolidated sediments include valley alluvium consisting of brown soil with varying amounts of poorly sorted rock fragments and colluvium consisting of talus slopes of relatively coarse rock fragments. Soil cover is thickest in the valleys and thinnest on the ridge lines and steep slopes.

3.6 CONVENTIONAL OIL AND GAS TESTS & LEASES

A. Tests - Shown on Figure 3-3-7 are the locations of the 6 conventional oil and gas tests drilled within or in near proximity to Tract C-a. Two wells were drilled within the tract, one each by British American and Occidental. The British American well is located about 20' southwest of the AM 3 core hole in the southwest part of the tract. The Occidental well is located about 300' southeast of the CE 702 core hole in the northeast corner of the tract. Equity drilled one well just southeast of the tract and Munson and Vanderbilt-Munson drilled three just outside the tract near its southwest corner.

Listed below are summaries of these wells. The wells are listed in the sequence drilled to provide a chronologic history of oil and gas exploration in the Tract C-a area. The depth of the Orange marker (OM) is given in each well as a stratigraphic reference point so that the depth of any oil and gas show and drill stem test (DST) can be related to the base of the lowermost zone (L-00) of the tract's oil shale sequence as portrayed on Figure 3-3-4. Also shown in parentheses is the depth of the most shallow reported oil and gas show or test below the Orange marker.

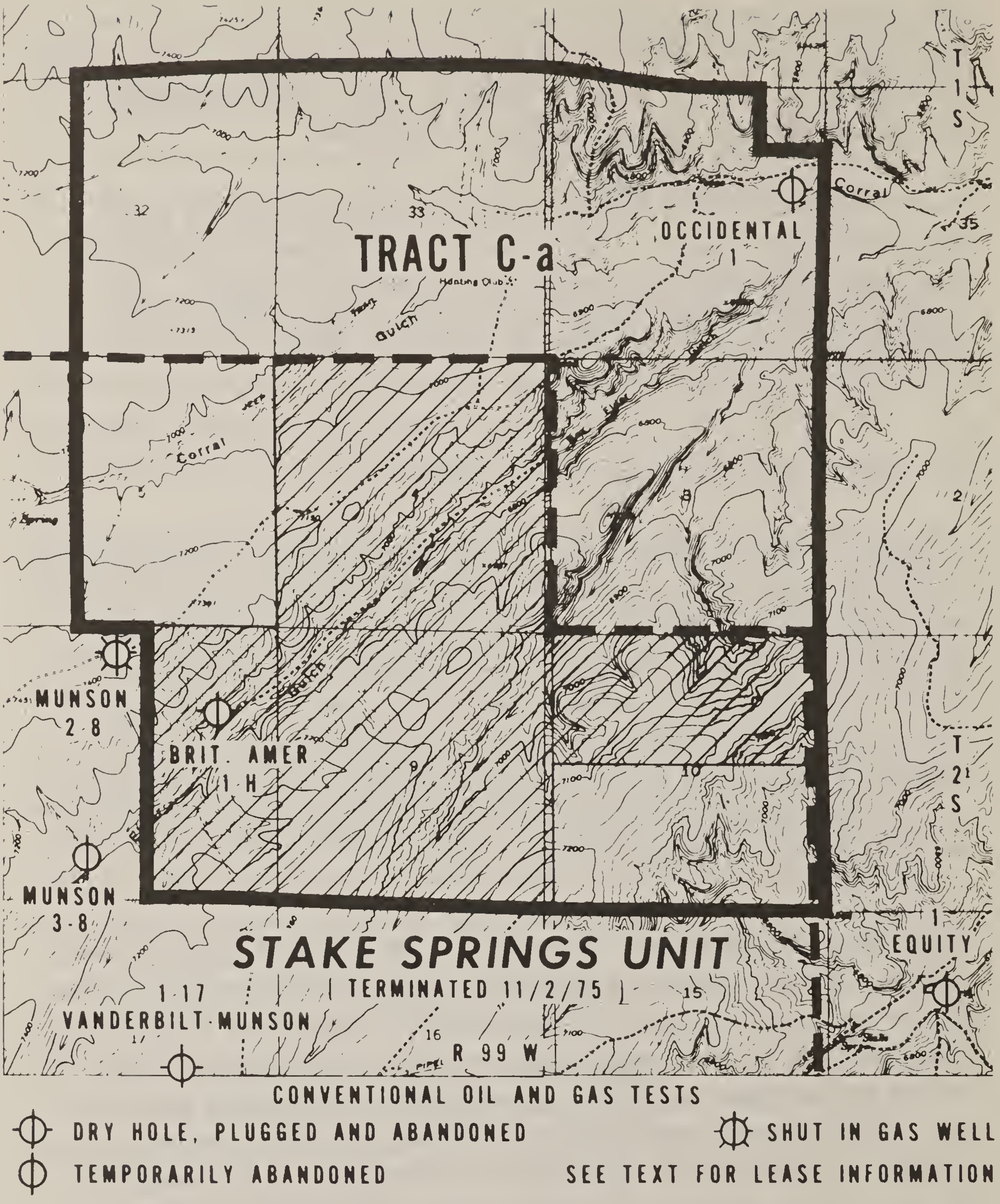

Figure 3-3-7

CONVENTIONAL OIL-GAS TESTS AND LEASES
TRACT C-a

- Equity No. 1 Corral Gulch
  SE NW Sec. 14, T. 2 S., R. 99 W.
  Spud: 8/16/57.
  Completed: 9/14/57, plugged and abandoned.
  TD: 6071' in Mesaverde Fm.
  OM at depth 1615'.
  Shows and Tests:

  - DST 3831-3895' (2216' below OM) in Wasatch Fm.; recovered 120' of slightly gas cut drilling mud.
  - DST 4095-4176' in Fort Union Fm.; gas to surface in 7 min. at 340 MCF/D, decreased to 100 MCF/D; recovered 720' of gas cut drilling mud and 1630' muddy salt water.
  - DST 4737-4820' in Fort Union Fm.; recovered 780' of gas cut and water cut drilling mud.
  - DST 5900-6071' in Mesaverde Fm.; no recovery.
  - DST 5730-6071' in Mesaverde Fm.; gas to surface in 18 min. too small to measure, recovered 240' of gas cut drilling mud.
  - DST 5175-5260' in Mesaverde Fm.; recovered 200' of drilling mud, no shows.

- British American No. 1-H Govt. Carter
  SE NE Sec. 8, T. 2 S., R. 99 W.
  Spud: 7/15/58.
  Completed: 8/31/58, plugged and abandoned.
  TD: 5526' in Mesaverde Fm.
  OM at depth 1284'.
  Shows and Tests:

  - Questionable oil stain at 2250' (966' below OM) in lower Green River Fm. or upper Wasatch Fm.; no test.
  - Spotty oil stain at 2500' in lower Green River Fm. or upper Wasatch Fm.; no test.
  - Slight oil stain and gas odor at 3050' in Wasatch Fm.; DST 3034-3071'; recovered 60' of drilling mud and 30' of slightly gas cut drilling mud with a scum of oil.
  - Dead oil stain at 4380' in Fort Union Fm.; DST 4295-4390'; flowed gas to surface in 25 min. at 180-230 MCF/D, recovered 350' of gas cut drilling mud.

  - Dead oil stain at 5300' in Mesaverde Fm.; two DST's, 5072-5326' and 5067-5326' recovered 420' and 300' of gas cut drilling mud, respectively.

  - Ran pipe to 5513', perforated 3 zones, stimulated with sand-frac, ran production tests:
    .From 5288-5502', Mesaverde Fm.; flowed gas, too small to measure.
    .From 4172-4478', Fort Union Fm.; swabbed water with some gas.
    .From 3840-4120', Fort Union Fm.; swabbed, no fluid recovered.

- Occidental No. 1 Cascade-Govt.
  SE NE Sec. 34, T. 1 S., R. 99 W.
  Spud: 9/3/69.
  Completed: 10/26/69, plugged and abandoned.
  TD: 6433' in Mesaverde Fm.
  OM at depth 1720'.
  Shows and Tests:

  - Oil stain at 2860-2870' (1150' below OM) in Wasatch Fm., no test.

  - Oil fluorescence at 5990-6080' in Mesaverde Fm., no test.

- Vanderbilt No. 1-17 Munson
  NW SE Sec. 17, T. 2 S., R. 99 W.
  Spud: 7/27/72.
  Completed: 8/16/72, plugged and abandoned.
  TD: 5260' in Mesaverde Fm.
  OM at depth 2030'.
  Shows and Tests:

  - DST 2856-2906 (826' below OM) in Wasatch Fm.; recovered 40' of drilling mud, no shows.

  - DST 3697-3720' in Wasatch Fm.; recovered 240 barrels of drilling mud and mud cut salt water, no shows.

- Munson No. 2-8 Stake Springs Unit
  NE NW Sec. 8, T. 2 S., R. 99 W.
  Spud: 7/1/73.
  Completed: 7/31/73, temporarily abandoned.
  TD: 5033' in Mesaverde Fm.
  OM at depth 1706'.
  Shows and Tests: None reported.

- Munson No. 3-8 Stake Springs Unit
  SE SW Sec. 8, T. 2 S., R. 99 W.
  Spud: 7/15/74.
  Completed: 5/21/75, shut in gas well.
  TD: 5080' in Mesaverde Fm.
  OM at depth 1430'.
  Shows and Tests:

  - DST 4908-4975' (3478' below OM) in Mesaverde Fm.; recovered 93' of slightly gas cut drilling mud and 97' of drilling mud.

  - Ran pipe to 5050', perforated 4914-4924', 4962-4970', 4990-4996', stimulated with acid and sand-frac, initial potential 15 MCF/D gas from Mesaverde Fm.

B. Leases - Tract C-a is covered entirely by conventional Federal oil and gas leases. The northeastern part of the Federal Stake Springs Unit extends into the tract's southern portion as shown by its dashed outline on Figure 3-3-7. This unit was formed effective July 7, 1972, with D. M. Munson as the unit operator. The unit was automatically terminated effective November 2, 1975.

All Federal leases within Tract C-a, except those shown diagonally lined on Figure 3-3-7 contain the following four-part stipulation pertaining to oil shale:

- No wells will be drilled for oil or gas except upon approval of the Regional Oil and Gas Supervisor of the Geological Survey, it being understood that drilling will be permitted only in the event that it is established to the satisfaction of the Supervisor that such drilling will not interfere with the mining and recovery of oil shale deposits or the extraction of shale oil by in situ methods or that the interest of the United States would best be served thereby.

- No wells will be drilled for oil or gas at a location which, in the opinion of the Regional Oil and Gas Supervisor of the Geological Survey, would result in undue waste of oil shale deposits or constitute a hazard to or unduly interfere with mining or other operations being conducted for the mining and recovery of oil shale deposits or the extraction of shale oil by in situ methods.

- When it is determined by the Regional Oil and Gas Supervisor of the Geological Survey that unitization is necessary for orderly oil and gas development and proper protection of oil shale deposits, no well shall be drilled for oil or gas except pursuant to an approved Unit plan.

- The drilling or the abandonment of any well on this lease shall be done in accordance with applicable oil and gas operating regulations including such requirements as The Regional Oil and Gas Supervisor of the Geological Survey may prescribe as necessary to prevent the infiltration of oil, gas, or water into formations containing oil shale deposits or into mines or workings being utilized in the extraction of such deposits.

The Federal leases which are diagonally lined have an expiration date of August 2, 1977.

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COMPARISON OF EXTRACTABLE ALUMINA ANALYSES

CORE LAB VERSUS USGS

COREHOLE G-S 7, TRACT C-a

INTRODUCTION:

By letter dated September 8, 1976, Mr. J. R. Donnell (USGS) requested permission from RBOSP to perform acid-extractable alumina analyses on oil-shale core samples from corehole G-S 7. Analysis samples to be used in this program were surplus samples remaining from the USGS trace element quantitative analysis program in this corehole. The interval to be analyzed for alumina was given as depth 200' to 950' (750' thick). By letter dated September 10, 1976, permission to perform the alumina analyses was granted to the USGS by RBOSP.

Corehole G-S 7 is one of eight G-S coreholes on Tract C-a in which Core Laboratories, Inc., performed acid-extractable alumina analyses on composite core intervals of spent shale as described in our March-1976 DDP (Chapter 3, Geology, page 3-3-13). However, the USGS wished to perform analyses on much smaller core intervals in the range of one to two feet long.

On January 10, 1977, a set of 220 USGS alumina analyses of one-foot core intervals from depth 728' to 948' in corehole G-S 7 was received from Mr. Donnell. They were identified as caustic-extractable (base-leach) analyses rather than acid-extractable (acid-leach) as originally described in his letter of September 8, 1976. By telephone call to Mr. Donnell, it was confirmed that the USGS analysis method was caustic rather than acid-extractable and that the analyses were performed on fresh (unretorted) shale rather than on retorted shale. Further, the USGS plans to run at least 200 more such analyses in other zones of corehole G-S 7 sometime this year. This additional program is presently contingent upon federal funding yet to be authorized.

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OBJECTIVE:

The objective of this report is to compare the results of the Core Lab acid-leach alumina analyses on spent shale with those of the USGS base-leach alumina analyses on fresh shale in equivalent intervals of corehole G-S 7 and correlate the results in terms of oil-shale mineralogy. It is beyond the scope of this report to track what geothermal or geochemical alterations occur during the retorting process to the individual minerals contributing base-extractable alumina in fresh shale and acid-extractable alumina in spent shale.

METHOD:

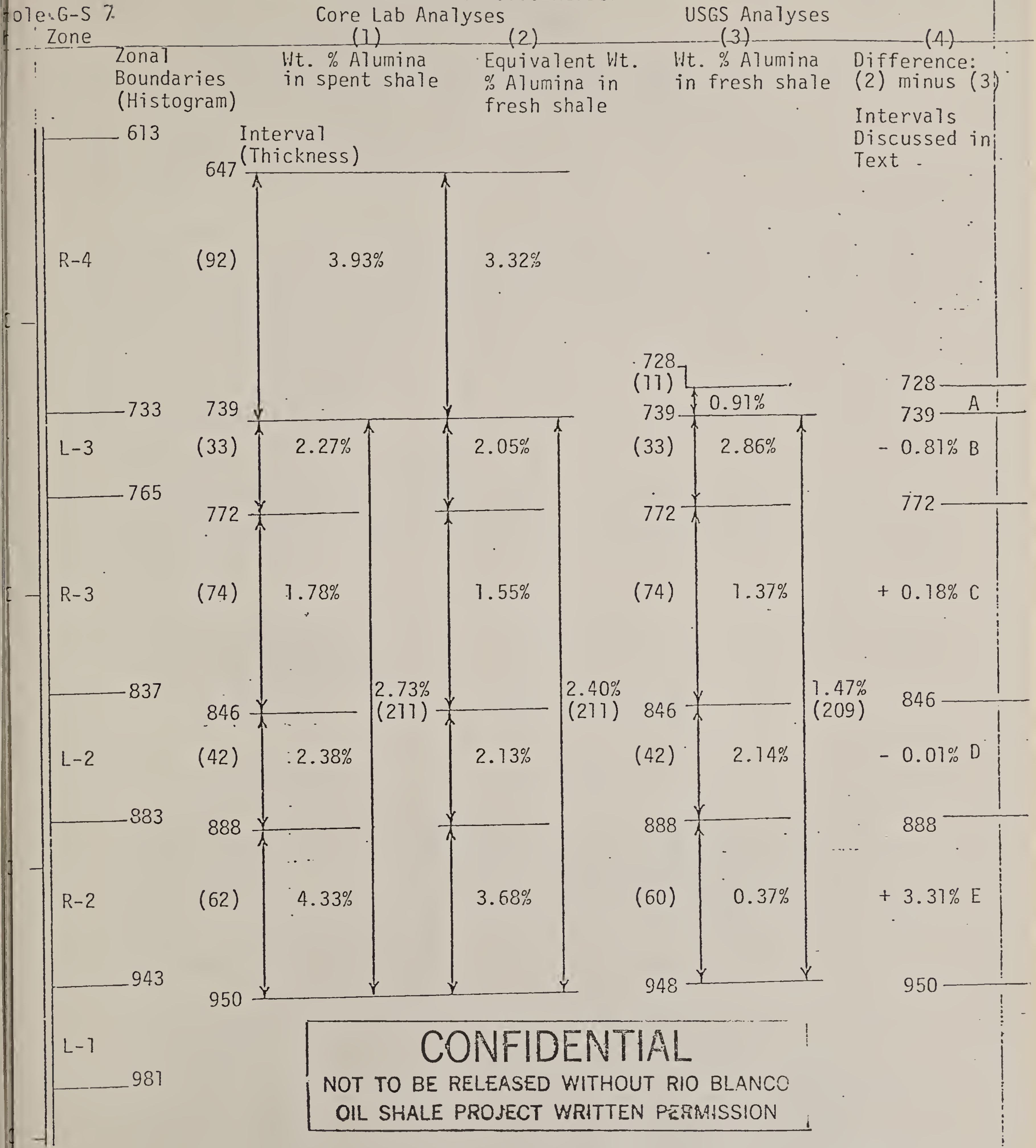
Table 1 is a comparison summary of Core Lab alumina analyses versus those of the USGS in corehole G-S 7. Intervals analyzed by both are correlated to the stratigraphic oil-shale zonation established in this corehole as shown on the table's left.

Core Lab analysis results (acid-leach, spent shale) are listed in column 1. The intervals shown are the actual composite intervals analyzed by Core Lab as selected by RBOSP from density log responses prior to Fischer assaying. Only those intervals are posted which correlate wholly or in part to equivalent intervals analyzed by the USGS.

In column 2, the Core Lab weight percents of alumina in spent shale (column 1) are converted to their equivalent weight percents in fresh shale based on Fischer assay weight loss of spent shale. Since the USGS analyses were performed on fresh shale samples, the weight percents of alumina in Column 2 are more representative than those in column 1 to compare with the USGS analyses.

USGS analysis results (base-leach, fresh shale) are listed in column 3. The 220 one-foot sample analyses from depth 728' to 948' are composited into intervals for comparison with equivalent composite intervals analyzed by Core Lab.

COMPARISON SUMMARY
EXTRACTABLE ALUMINA ANALYSES: COREHOLE G-S 7
CORE LAB VERSUS USGS RESULTS



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(1) Acid-extractable alumina in spent (retorted) shale, composite interval samples.
(2) Analyses of (1) converted to equivalent acid-extractable alumina in fresh (unretorted) shale based on Fischer assay weight loss.
(3) Caustic-extractable alumina in fresh shale, 220 one-foot interval samples; weight % alumina shown are composites to compare with intervals analyzed by Core Lab.

Also shown in columns 2 and 3 is the weighted average alumina content of a fairly thick stratigraphic interval essentially equivalent in all three columns (Core Lab analyses, interval 739' to 950', 211' thick; USGS analyses, interval 739' to 948', 209' thick).

Lastly, column 4 lists the difference in alumina weight percent of equivalent intervals analyzed by Core Lab and the USGS (column 2 minus column 3). Intervals identified as A through E key these intervals to the text for convenience in discussing them.

DISCUSSION AND CONCLUSIONS:

1. Mineralogy and Analysis Method:

As stated in our March-1976 DDP (Chapter 3, Geology, page 3-3-37), the main minerals in oil shale which contribute acid-extractable alumina are:

1.	Dawsonite	$NaAl(OH)_2CO_3$
2.	Nordstrandite	$Al(OH)_3$
3.	Analcime	$NaAlSi_2O_3 \cdot H_2O$
	or	
	Analcite	$NaAlSi_2O_6 \cdot H_2O$

Dawsonite and nordstrandite always occur with each other. They do not generally occur stratigraphically with analcime (or analcite). However, stratigraphic intermixing of dawsonite and nordstrandite with analcime was recognized at Tract C-a as discussed in our March-1976 DDP (pages 3-3-37 to 3-3-40).

The thickest and richest dawsonite and nordstrandite deposits occur in the lower part of the Parachute Creek Member oil-shale interval basinward to the northeast of Tract C-a. Dawsonite and nordstrandite contents decrease to zero at the basin's west margin with analcime present peripheral to dawsonite and nordstrandite in stratigraphically equivalent sections on the outcrop at Cathedral Bluffs west of Tract

C-a. Tract C-a lies geographically between these two areas, the two extremes, and is a stratigraphic compromise of the two. In other words, Tract C-a lies in an area of transition between the two extremes and has some characteristics of both.

The analysis method (acid-leach) used by Core Lab in their entire Tract C-a program, including corehole G-S 7, measures alumina extractable from dawsonite, nordstrandite and analcime (J. W. Smith, USBM; personal communication). This method is outlined in USBM Report of Investigations 7286 (1969).

The analysis method (base-leach) used by the USGS in their program on samples from corehole G-S 7 measures alumina extractable only from dawsonite and nordstrandite (J. R. Donnell, USGS; personal communication). Alumina present in analcime is not detected.

Since the Core Lab method (acid-leach) measures alumina extractable from dawsonite, nordstrandite <u>and</u> analcime, and the USGS method (base-leach) measures alumina extractable from <u>only</u> dawsonite and nordstrandite, the difference between the two (Core Lab results minus USGS results), if any, is a measure of alumina extractable from analcime.

2. Comparison of Core Lab versus USGS Analyses, Corehole G-S 7 (Table 1):

As previously stated under Method, original Core Lab acid-leach analyses of spent shale (column 1) are converted to their equivalents in fresh shale (column 2) based on Fischer assay weight loss of spent shale. These fresh shale equivalents are more appropriate to compare with the USGS base-leach analyses of fresh shale (column 3) because they are placed on a more representative "common denominator". The difference between the two (column 2 minus column 3) is shown in column 4 for several discrete intervals which are identified A through E for convenience in the following discussion:

Interval A: The interval analyzed by the USGS is only 11' thick and cannot be reasonably compared to the 92' thick composite interval analyzed by Core Lab.

Interval B: The USGS 2.86 wt. % alumina is higher than Core Lab's 2.05 by a difference of 0.81 wt. %. However, the difference is in the wrong direction for explanation in terms of which minerals are contributing alumina (see Conclusion 1, last paragraph). It is suspected that an analytical error may be present in either the USGS or Core Lab results. In any event, only dawsonite and nordstrandite appear to be the source minerals. Analcime is probably totally absent.

Interval C: The USGS 1.37 wt. % alumina is lower than Core Lab's 1.55 by a difference of only 0.18 wt. %. Dawsonite and nordstrandite are the dominant source minerals contributing just over 88% of the alumina with analcime contributing the remaining 12%.

Interval D: The USGS and Core Lab wt. % alumina are virtually identical (2.14 and 2.13, respectively). Only dawsonite and nordstrandite are the source minerals. Analcime is totally absent.

Interval E: The USGS 0.37 wt. % is considerably lower than Core Lab's 3.68 by a difference of 3.31 wt. %. Analcime is the dominant source mineral contributing 90% of the alumina with dawsonite and nordstrandite contributing the remaining 10%.

Intervals B, C, D and E Combined: For this overall interval (essentially equivalent; 209' thick, USGS; 211' thick, Core Lab), the USGS 1.47 wt. % is lower than Core Lab's 2.40 by a difference of 0.93 wt. %. Dawsonite and nordstrandite are the dominant source minerals contributing 61% of the alumina with analcime contributing the remaining 39%.

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With the exception of Interval B, discussed above, the differences between alumina analysis results (Core Lab versus USGS), are explainable by oil-shale mineralogy related to analysis method (acid-leach versus base-leach). Considering the geographic location of Tract C-a with its associated stratigraphic intermixing as discussed in Conclusion 1, the explanations appear geologically reasonable.

3. Effect on Tract C-a Alumina Resource Estimates:
Subsequent to the completion of the Core Lab alumina-analysis program at Tract C-a, investigations indicated that potential commercial extraction of alumina from oil shale by an acid-leach method yields an undesirable silica gel derived from any analcime present. A base-leach extraction method eliminates this problem by recovering alumina only from dawsonite and nordstrandite with analcime remaining chemically stable or inert during the processing.

There is no question that the potentially recoverable alumina resource at Tract C-a using a base-leach method is less than that using an acid-leach method. For this reason, the stratigraphic occurrance of dawsonite and nordstrandite-bearing oil shale within Tract C-a (R-2 through R-5 zones) was discussed in detail in our March-1976 DDP (Chapter 3, Geology, pages 3-3-37 to 3-3-40) as based on USBM X-ray diffraction data in coreholes CE 702, CE 707, and G-S 15. Further, in the Confidential Volume of the DDP (Table 3-3-12), the alumina resource within the dawsonite and nordstrandite-bearing oil-shale interval (R-2 through R-5 zones) was segregated from the analcime-bearing intervals stratigraphically above and below it. However, the Core Lab acid-leach analyses used as input to this table in the R-2 through R-5 interval do not distinguish between oil shale bearing only dawsonite and nordstrandite; only analcime; or a stratigraphic intermixing of dawsonite and nordstrandite with analcime (stratigraphic intermixing discussed previously in Conclusion 1).

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Zonal correction factors which can be developed in corehole G-S 7 converting Core Lab (acid-leach) analysis results to equivalent USGS (base-leach) analysis results cannot be applied to all other Core Lab-analyzed coreholes spaced across Tract C-a (G-S 1, 2-3, 4-5, 9, 10, 11 and 15). This is because the stratigraphic intermixing of dawsonite and nordstrandite with analcime in the R-2 through R-5 interval is not constant across the tract but rather increases southwestward across the tract, probably parallel to isopach strike of this stratigraphic interval. Corehole GS 7 is on the far west edge of Tract C-a where the stratigraphic intermixing is the greatest. Basinward, to the northeast across the tract, this intermixing becomes less and less pronounced.

REFERENCE:

Smith, J.W., and Young, N.B., 1969, Determination of Dawsonite and Nahcolite in Green River Formation Oil Shales: U.S. Bureau of Mines Rpt. Invest. No. 7286, 20 p.