#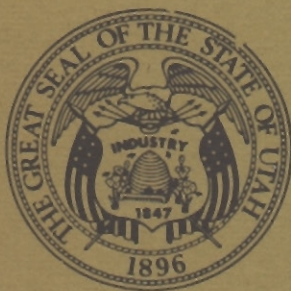 Instrumental Analysis of Tars and Their Correlations in Oil-impregnated Sandstone Beds, Uintah and Grand Counties, Utah

by John Wallace Gwynn
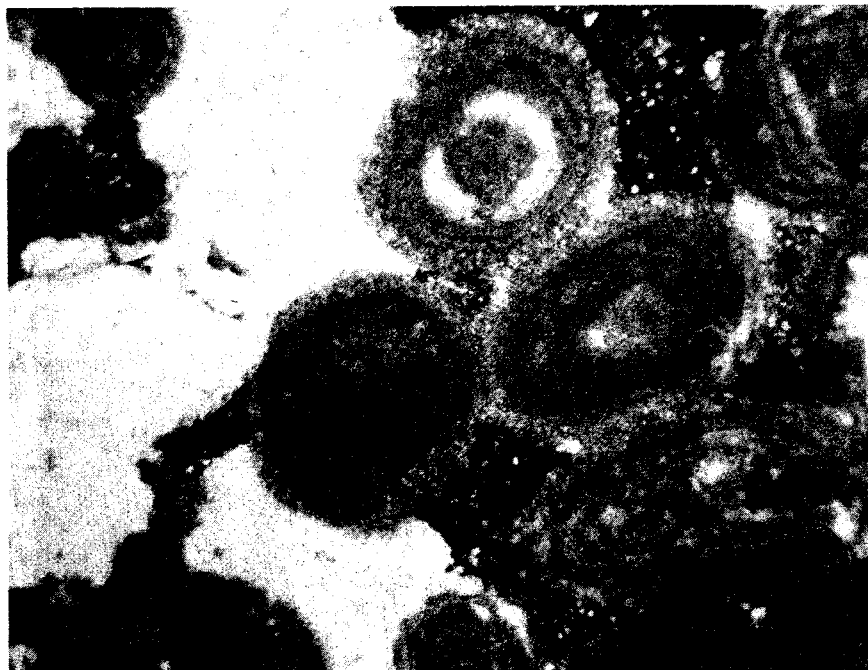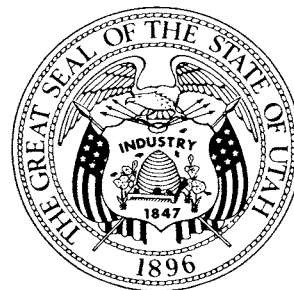
PRICE $3.00

Instrumental Analysis of Tars and Their Correlations in Oil-impregnated Sandstone Beds, Uintah and Grand Counties, Utah

by John Wallace Gwynn

Oil-impregnated oolitic limestone from study area (magnified about 30X).

UTAH GEOLOGICAL AND
MINERALOGICAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

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DIRECTORS:

William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961

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INSTRUMENTAL ANALYSIS OF

TARS AND THEIR CORRELATIONS

IN OIL-IMPREGNATED SANDSTONE BEDS,

UINTAH AND GRAND COUNTIES, UTAH

by John Wallace Gwynn[1]

ABSTRACT

The Wasatch, Green River and Uinta formations, in ascending order make up the normal sequence of exposed Eocene rocks in the southeast Uinta Basin, Uintah and Grand counties, Utah. They dip northward towards the center of the basin, relatively undisturbed by faulting, and exhibit a system of prominent northwest-southeast joints.

The oil-impregnated sandstones occur in five zones in lower Parachute Creek and Upper Douglas Creek members of the Green River Formation, one above and four below the Mahogany oil shale which is in the lower part of the Parachute Creek Member. These zones consist of one or more lenticular beds of lacustrine sandstone, separated by sequences of barren strata.

Tars extracted from the oil-impregnated sandstones were analyzed for their physical and chemical properties: specific and API gravities, viscosity, pour point, distillation fractions, flash and fire points, index of refraction, ash content, carbon residue, organic structural components, nonhydrocarbon elements (oxygen, sulfur, nitrogen and metallic trace elements), sulfur isotope abundances and radioactive elements. No trends or correlations were found on the basis of trace elements or infrared data, but individual zones of oil-impregnated sandstones can be correlated on the basis of sulfur isotope abundances.

The tars in the area appear to be indigenous to the Green River Formation and formed within or near the sandstones they occupy.

INTRODUCTION

The Uinta Basin in northeast Utah is a structural, topographic and depositional depression bounded by several physiographic provinces (figure 1). On the north are the east-west Uinta Mountains which separate the basin from the Green River Basin in Wyoming. The north-south Wasatch Mountains and the Wasatch Pla-

teau form the basin's boundary on the west. On the south, the San Rafael Swell and Canyonlands, accentuated by the Grand Valley at the base of the Book and the Roan cliffs, bound the basin. To the southeast is the Uncompahgre Uplift, and on the east, in western Colorado, is the Douglas Creek arch which separates the Uinta Basin from the Piceance Creek Basin of western Colorado.

The study area, located on the Roan Plateau in the southeast part of the Uinta Basin, extends south to the Roan and the Book cliffs, west to just west of Willow Creek, and east to the Colorado-Utah state line; it merges northward gradually with the basin.

The purpose of this investigation is to: (1) present and discuss physical and chemical data obtained from the instrumental analysis of tars derived from the oil-impregnated sandstone in the area, (2) use these data to establish trends or correlations among tars from different localities and zones within the area, and (3) draw conclusions about the origin of these tars.

Three investigations conducted in the Uinta Basin have dealt with the geology and associated hydrocarbons (Wiley, 1967, Byrd, 1970, Cashion, 1967). No studies relate specifically to the tars derived from the oil-impregnated sandstones within the study area or to their properties.

Physical and chemical data on tars from other areas in the Uinta Basin have been analyzed and reported (Kayser, 1966, p. 26-38). Trace elements in petroleum were discussed by Bonham (1956, p. 897-908), and sulfur isotope studies were discussed by Thode and others (1958, p. 2619-2461), Harrison and Thode (1958, p. 2642-2649) and Jensen (1963, p. 275-284).

GEOGRAPHY

Topography

The Roan Plateau is a relatively flat landform dipping toward the center of the Uinta Basin. It extends from the Wasatch Plateau on the west into Colorado on the east. The basinward dip of the

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[1]Geologist, Salt Lake City, Utah; formerly field party chief, Utah Geological and Mineralogical Survey, Salt Lake City, Utah.
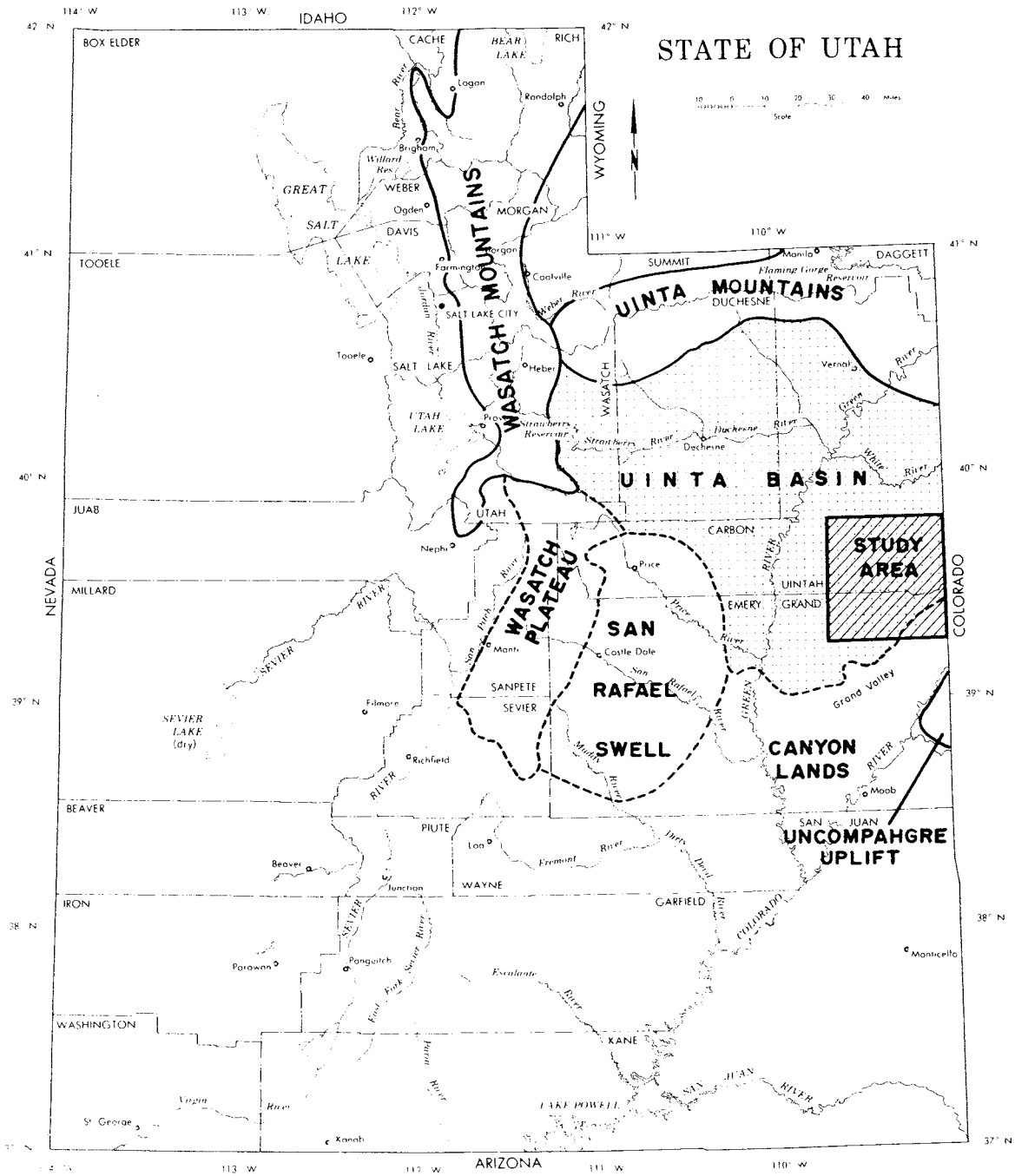
Figure 1. Index map showing study area and surrounding physiographic provinces.
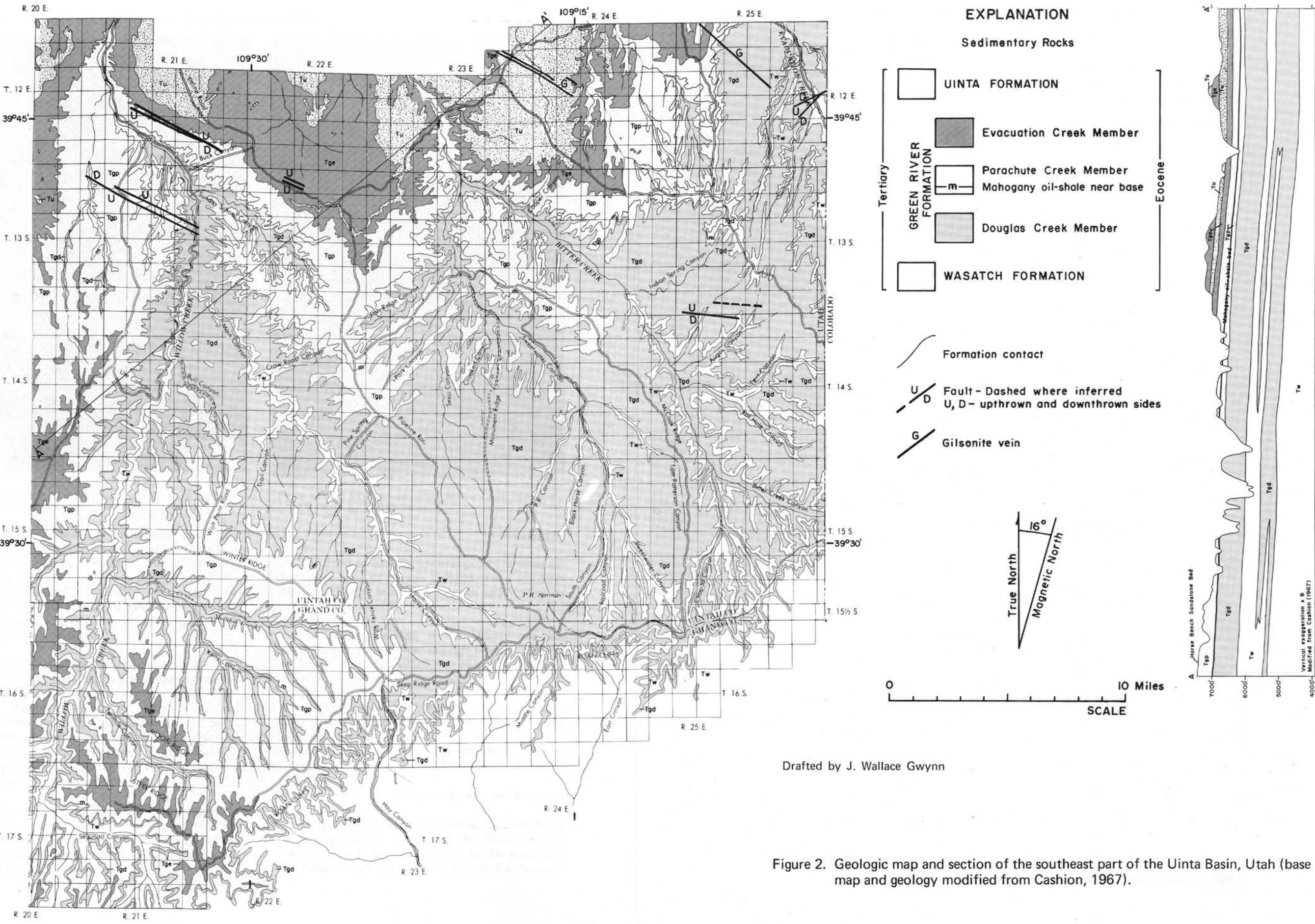
EXPLANATION

Sedimentary Rocks

Figure 2. Geologic map and section of the southeast part of the Uinta Basin, Utah (base map and geology modified from Cashion, 1967).
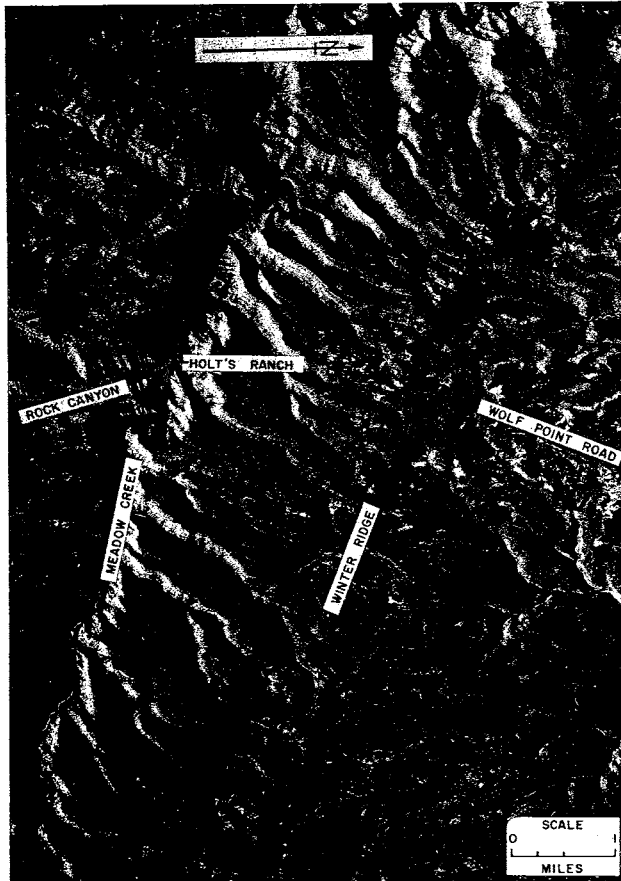
Figure 3. Photograph of Winter Ridge, T. 15 S., R. 21 E., showing its resistance to erosional forces (by U. S. D. A.).
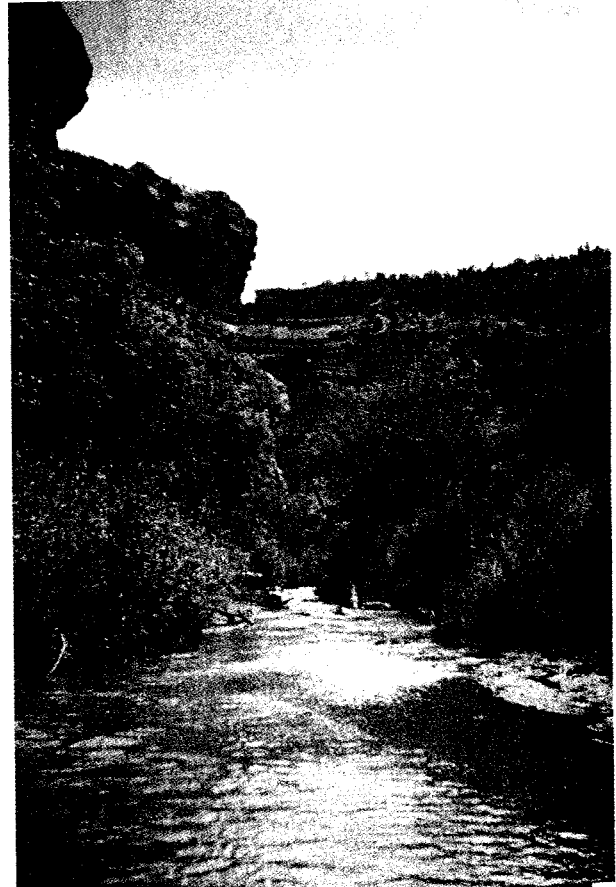
Figure 4. View looking west down Willow Creek, sec. 9, T. 14 S., R. 21 E., Uintah County.

plateau, about one degree, generally conforms to the dip of the underlying Green River strata. The elevation of the plateau within the area ranges from about 8,000 feet near the Colorado-Utah line to 8,600 feet near the head of East Willow Creek Canyon, and in the north about 6,500 feet. Its surface, incised by major north trending drainages and countless branching canyons, is cut into large flat-topped blocks.

Several northwest-southeast trending ridge structures persist in the area, particularly in the central and east portions, and control much of the drainage. Considered by Byrd (1970) to be plunging anticlinal structures, these anticlines form ridges such as Steer, Moon, Winter and McCook ridges (figure 2). Canyons cut laterally from the backs of these ridges (figure 3). In the larger canyons, alluvial fill forms broad flat bottoms, used for agricultural land.

The Roan and the Book cliffs terminate the plateau on the south, descend precipitously 3,000 feet to the lowlands of Grand Valley, and are intricately dissected by deep canyons, many of which rise headward at the rate of 1,500 feet per mile.

Accessibility

The roads in the area are unimproved and usually follow ridge tops or canyon bottoms. They are maintained periodically but become rough and washed by frequent storms.

The nearest railroad is the Denver and Rio Grande Western which runs through Grand Valley 25 air miles south of the plateau rim. The nearest railroad stations are at Cisco and Thompson.

The numerous small airstrips scattered throughout the area were constructed for oil exploration. The nearest commercial airports are in Grand Junction, Colorado and Vernal, Utah. These are also the nearest sources of supplies, vehicle rental and maintainance.

Streams, Springs and Drainages

Six perennial streams flow within the area. These main drainages empty either into the White River to the north or into the Green River to the north and west. Willow Creek (figure 4) is suitable for domestic

Table 1. Summary of surface and subsurface stratigraphic section exposed at surface in study area (modified from Cashion, 1967).

Age	Formation name	Thickness (ft)	Description
TERTIARY	Uinta Formation	400-1,000	Three sequences in ascending order, brown sandstones alternating with greenish-gray claystone, 800 ft; sandstone and claystone, 350 ft; sandstone and claystone; brown and red ferruginous sandstone and claystone, 600 ft.
	Green River Formation — Evacuation Creek Member	135-545	Mainly marlstone and siltstone but also contains some sandstone, tuff, oil shale and oolitic limestone.
	Green River Formation — Parachute Creek Member	365-615	Mainly marlstone, oil shale, siltstone, sandstone and tuff. The thick zones of oil shale are known as the Mahogany Ledge or marker.[1]
	Green River Formation — Garden Gulch Member (not present in immediate study area)	230	Marlstone containing appreciable amounts of organic matter, oil shale and siltstone.
	Green River Formation — Douglas Creek Member	870-1,060	Mainly sandstone, siltstone, shale and oolitic, algal and ostracodal limestones; locally a few oil-shale beds.[1]
	Wasatch Formation	700-3,000	Mainly red and gray shale and siltstone and massive, irregularly bedded fine- to medium-grained gray to brown sandstone containing a few lenticular conglomerates.

Subsurface

Age	Formation name	Thickness (ft)	Description
CRETACEOUS	Mesaverde Formation	1,100	Sandstone and shale
	Mancos Shale	5,070-5,290	Shale, siltstone and sandstone
	Dakota Sandstone	95-135	Sandstone and shale
JURASSIC	Morrison Formation	830-930	Sandstone, mudstone and shale
	Curtis Formation	150-270	Sandstone, shale and limestone
	Entrada Sandstone	105-215	Sandstone
	Carmel Formation	125-390	Shale and sandstone
JURASSIC AND TRIASSIC	Glen Canyon Sandstone	720-1,030	Sandstone
TRIASSIC	Chinle Formation	230-355	Shale, sandstone and conglomerate
	Moenkopi Formation	820-1,120	Sandstone and siltstone
PERMIAN	Park City Formation	70-195	Limestone and shale
PERMIAN AND PENNSYLVANIAN	Weber Sandstone	1,015-1,275	Sandstone
PENNSYLVANIAN	Morgan Formation	1,035-1,450	Limestone and sandstone
MISSISSIPPIAN	Black Shale Unit	0-265	Shale and sandstone
	Limestone Unit	965-1,220	Limestone
CAMBRIAN	Lodore	0-155	Sandstone
PRECAMBRIAN	Uinta Mountain Group	3,000-4,000	Shale and sandstone

[1] Oil-impregnated sandstone
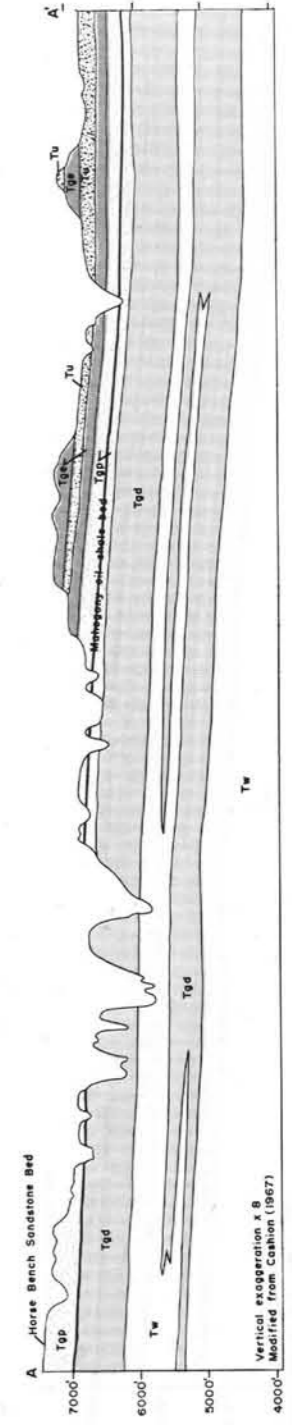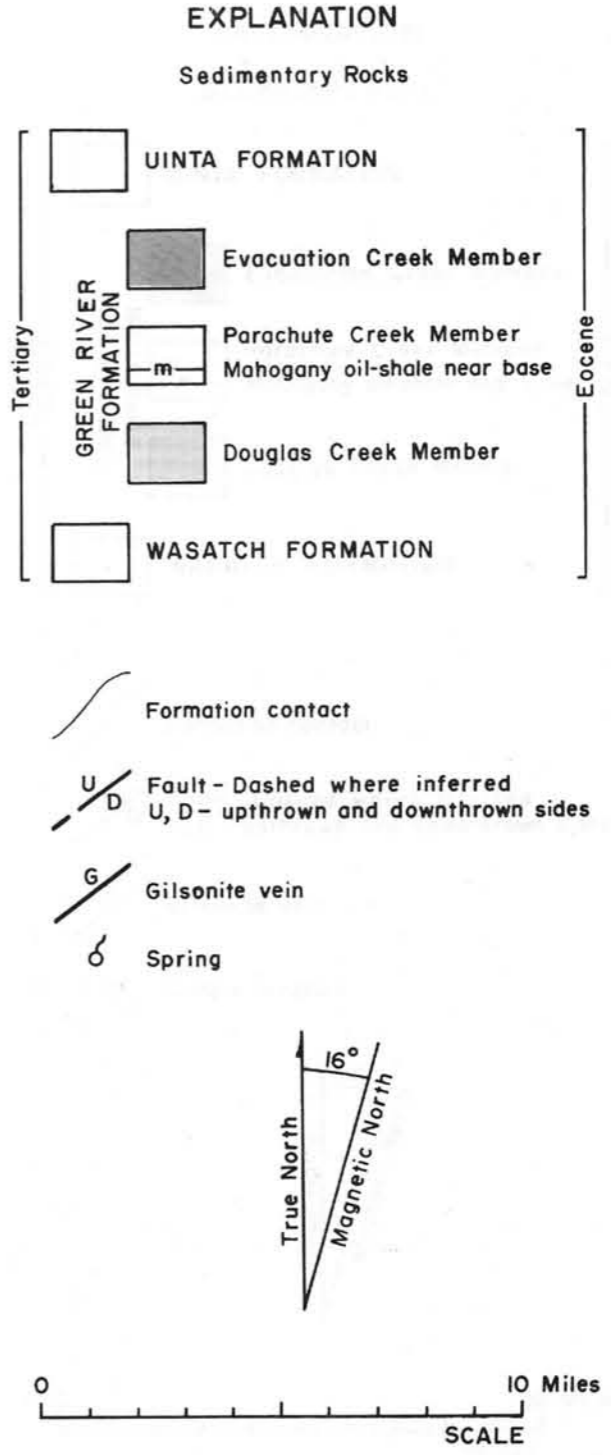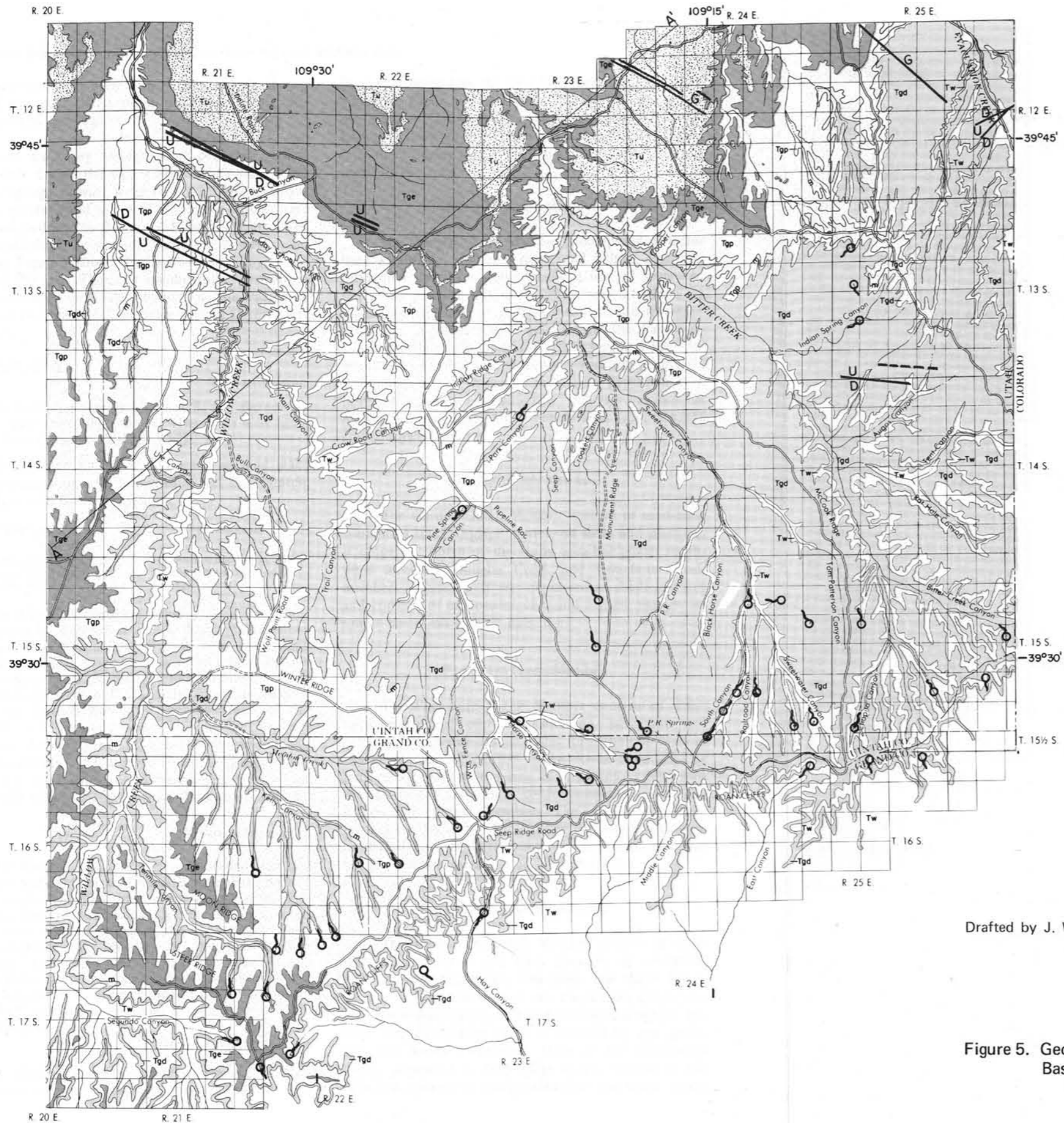
EXPLANATION

Sedimentary Rocks

UINTA FORMATION

Evacuation Creek Member

Parachute Creek Member
m — Mahogany oil-shale near base

Douglas Creek Member

WASATCH FORMATION

GREEN RIVER FORMATION — Tertiary / Eocene

Formation contact

U / D Fault — Dashed where inferred
U, D — upthrown and downthrown sides

G Gilsonite vein

Spring

0   10 Miles
SCALE

Drafted by J. Wallace Gwynn

Figure 5. Geologic map and section showing springs in the southeast part of the Uinta Basin, Utah (base map and geology modified from Cashion, 1967).

and agricultural uses even though it is muddy during most of the year. Most other drainages remain dry during most of the year.

There are many springs, some perennial, others flowing only during the wet seasons. They range from seeps to springs flowing 4 to 10 gpm. Flowing spring water is potable, and many of the larger springs have been developed by the Bureau of Land Management or private individuals to provide water for domestic and stock use. Figure 5 shows the locations of many of the springs in the area. They are usually found just above the impermeable oil shale horizons in the Parachute Creek and Douglas Creek members of the Green River Formation.

STRATIGRAPHY

Tertiary System

The following stratigraphic details and the accompanying chart (table 1) and map (figure 2) were summarized from Cashion (1967, p. 5-22).

The exposed rocks are of Eocene age and make up, in ascending order and decreasing age, the Wasatch, Green River and Uinta formations.

Age-Formation	Environment
Eocene	
Uinta Formation	Lacustrine becoming fluvial
Green River Formation	Dominantly lacustrine
Wasatch Formation	Fluvial

The Wasatch Formation consists of fluvial lithologies formed by deposition on the flood plains and in the stream beds and deltas of a subsiding basin. This basin, which was later filled by Lake Uinta, now consists of the Piceance Creek Basin of western Colorado and the Uinta Basin of eastern Utah. Sediments deposited in Lake Uinta formed the lacustrine lithologies of the Green River Formation which overlie the Wasatch Formation. As the waters of Lake Uinta receded, the Uinta Formation was formed from lacustrine beds deposited in the eastern part of the study area, and from fluvial beds which finally covered the area relicted by the lake.

Wasatch Formation

The Wasatch Formation is composed of red and gray shale and siltstone and massive, irregularly bedded fine- to medium-grained gray to brown sandstone with a few thin lenticular conglomerates. Its two units intertongue with a lower tongue of the conformably overlying Douglas Creek Member of the Green River Formation. The upper unit is the Renegade Tongue and the lower is the main unit of the formation (figure 6). The Wasatch Formation is formed from flood plain, stream bed and deltaic material derived from a south or southwest source.

Green River Formation

The Green River Formation overlies the Wasatch and consists of four lacustrine members which are, from bottom to top, the Douglas Creek, Garden Gulch, Parachute Creek and Evacuation Creek. The outcrop of the Garden Gulch is absent in the area of study. Cashion (1967, p. 12) thinks the Garden Gulch grades into the Douglas Creek and Parachute Creek members north of the area.

Douglas Creek Member

The Douglas Creek Member is composed of lacustrine sandstone, siltstone, shale, and oolitic, algal and ostracodal limestones, and locally a few oil shales. In the upper part are sandstone beds, many of which are oil-impregnated and of prime concern to this investigation. The Douglas Creek grades into the Parachute Creek Member in a basinward direction, and into the Wasatch Formation in a shoreward direction (figure 6). Sediments in the Douglas Creek were deposited in a nearshore shallow environment rich in calcium or magnesium carbonate and were derived from a south and southwest source.

Garden Gulch Member

The Garden Gulch Member consists of marlstone containing much organic matter, oil shale and siltstone. It crops out north of the study area but grades southward into the Douglas Creek and Parachute Creek members (figure 6). It was deposited in shallow water and consists of carbonates, clay and organic matter. Its source lies in no specific direction.

Parachute Creek Member

The Parachute Creek Member consists of dolomitic marlstone, oil shale, siltstone, sandstone and tuffaceous material. Its oil shales form the rich Mahogany Ledge for which the Green River Formation is famous. In most of the area, the Parachute grades into the Douglas Creek and conformably underlies the Evacuation Creek Member. The sediments which formed the Parachute Creek were deposited in shallow to deep lakes and were derived from fine organic and inorganic matter precipitated from the water.

Evacuation Creek Member

The Evacuation Creek Member consists of marlstone and siltstone and small amounts of sandstone, tuff, oil shale and oolitic limestone. The Horse Bench Sandstone, near the base of the Evacuation Creek, is a resistant ledge-forming unit and persists throughout the area. The Evacuation Creek is overlaid by and grades into the Uinta Formation. Most of the Evacuation Creek, deposited in deep quiet water, consists of ash falls and carbonates precipitated from the water. Some
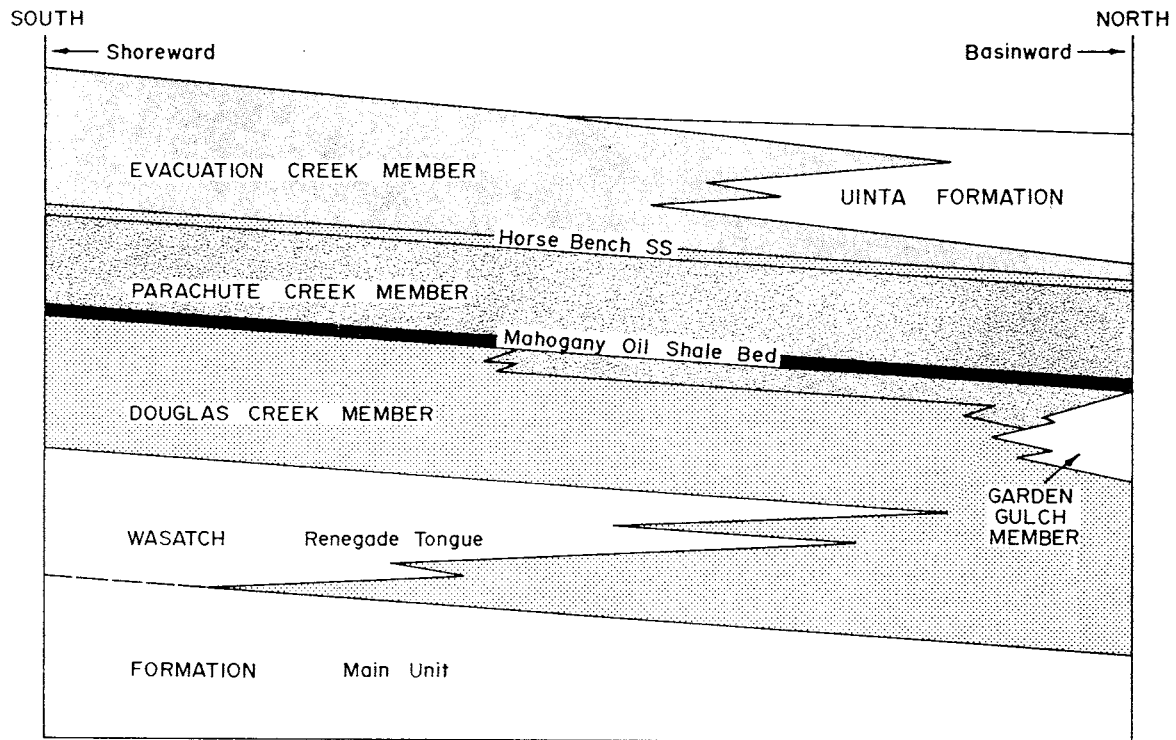
Figure 6. Generalized geologic relationships of Wasatch Formation and members of Green River Formation (modified from Cashion, 1967).

of the material in the south portion of the area is coarser-grained and was derived from a source to the south or southwest.

Uinta Formation

The Uinta Formation conformably overlies and intertongues laterally with the Green River Formation. It underlies the Duchesne River Formation which, however, does not extend into the study area. It consists of three units which are, from bottom to top, 800 feet of hard brown sandstone alternating with greenish gray claystone, 350 feet of soft coarse sandstone and claystone, and 600 feet of brown and red ferruginous sandstone and claystone. Most of the sediments of the formation were deposited in a fluvial environment but in places grade into lacustrine deposits in the east portion of the area. The sediments were derived from sources located to the north or northeast.

Quaternary System

The Quaternary System, represented by alluvial deposits in all major drainage bottoms, is composed of silt- to boulder-sized pieces of marlstone, siltstone and sandstone.

STRUCTURE

The Uinta Basin is an asymmetrical structural basin whose axis trends nearly east-west. The north flank dips steeply southward off the Uinta Mountains, and the south flank dips gently north from the top of the Roan Plateau. Cashion (1967, p. 22) described dips in the south flank, on which the study area is located, of about one degree to the north. Figure 7 shows structure contours drawn on top of the Mahogany oil-shale bed. The principal anticlinal structure is the Hill Creek anticline. the surface expression of which is Winter Ridge. Byrd (1970) considers several small structures such as Steer Ridge and Moon Ridge to be plunging anticlines, but they have little effect on the overall structure.

Faulting plays only a small part in shaping the area. Neither the number of faults nor their displacement is very great according to Cashion (1967, p. 22). Those which do occur bound small grabens and trend northwest.

The major joints of the prominent joint system trend northwest, and a minor complementary set trend northeast. These joints, according to Cashion (1967, p.

Area underlain by oil-impregnated sandstones

Structure contours drawn on top of Mahogany oil shale bed.

Datum is mean sea level
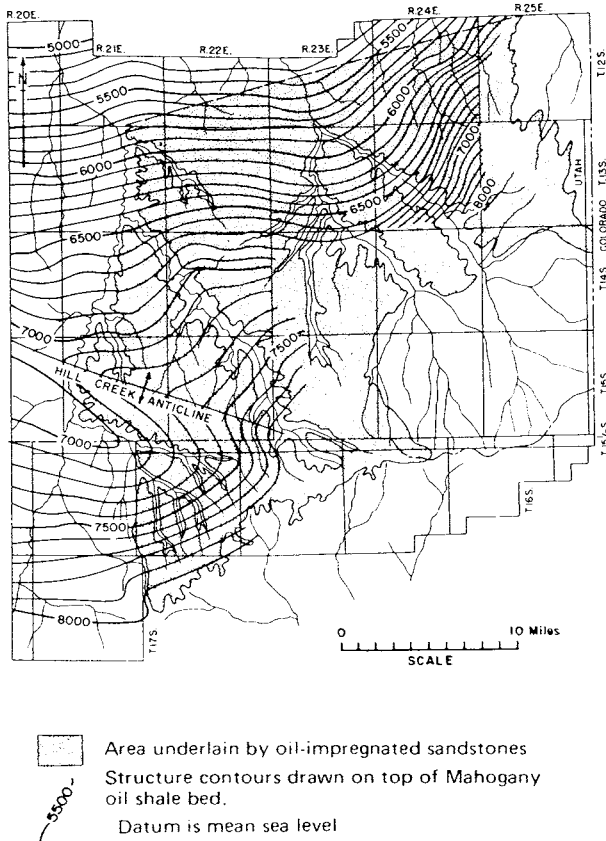
Figure 7. Structure contour map drawn on top of Mahogany oil shale bed (modified from Cashion, 1967).

23), are the result of forces developed during the downwarping of the basin after the deposition of the Uinta Formation. One prominent joint system extending to the northwest from the head of Meadow Creek is considered by the writer to be a major factor in controlling the southward migration of the oil in the oil-impregnated sandstones. Figure 8 shows major northwest trending joints to the west near Hill Creek.

ECONOMIC GEOLOGY

Oil-impregnated Sandstones

The area underlaid by oil-impregnated sandstone, determined from known outcrops, measured sections and sample locations, is shown in figure 9. Within this area are five zones of oil-impregnated sandstone, stratigraphically one above the other (figure 10). They are designated from bottom to top as A, B, C, D and E, and can be correlated throughout the area. The saturated areal extent of each of the five zones is shown in figure 9. The north boundary is arbitrarily drawn between the two farthest north outcrops. These five

zones consist of several sandstone beds which vary in number and thickness and are separated by barren intervals (figure 10).

The five zones consist of lacustrine sandstones deposited in Lake Uinta. The shoreline of the lake during the deposition of zones A, C, D and E extended south to or beyond the present edge of the Roan Plateau. The writer suggests that zone B represents deposition in the lake when its south shoreline was 5 to 10 miles north of the present edge of the Roan Plateau.

The impregnation of individual beds within the five zones is controlled by the lateral extent of the bed, its porosity and permeability, and the distance the oil has migrated within the bed. The local absence of saturation south of Meadow Creek is caused by the persistent east-west joint system in that area.

Anticlinal and synclinal structures are not the main controlling factors in either the emplacement or migration of the tar in the area. Figure 7 shows that the oil-impregnated sandstones underlie a great portion of the area regardless of its structure (excluding joint control).

The abrupt termination of the deposit on the south is caused by the erosion at the Roan Cliffs, and the absence of oil-impregnated sandstones in the southeast is caused by erosion to a level below the impregnated zones.

Figure 8. Jointing in Wasatch Formation, sec. 7, T. 15 S., R. 20 E., Uintah County.

Zone E

Zone D

Zone C

Zone B

Zone A

Total area underlain by all oil-impregnated sandstone zones.

Area underlain by individual oil-impregnated sandstone zone (A, B, C, D, E).

0   10 Miles

Scale
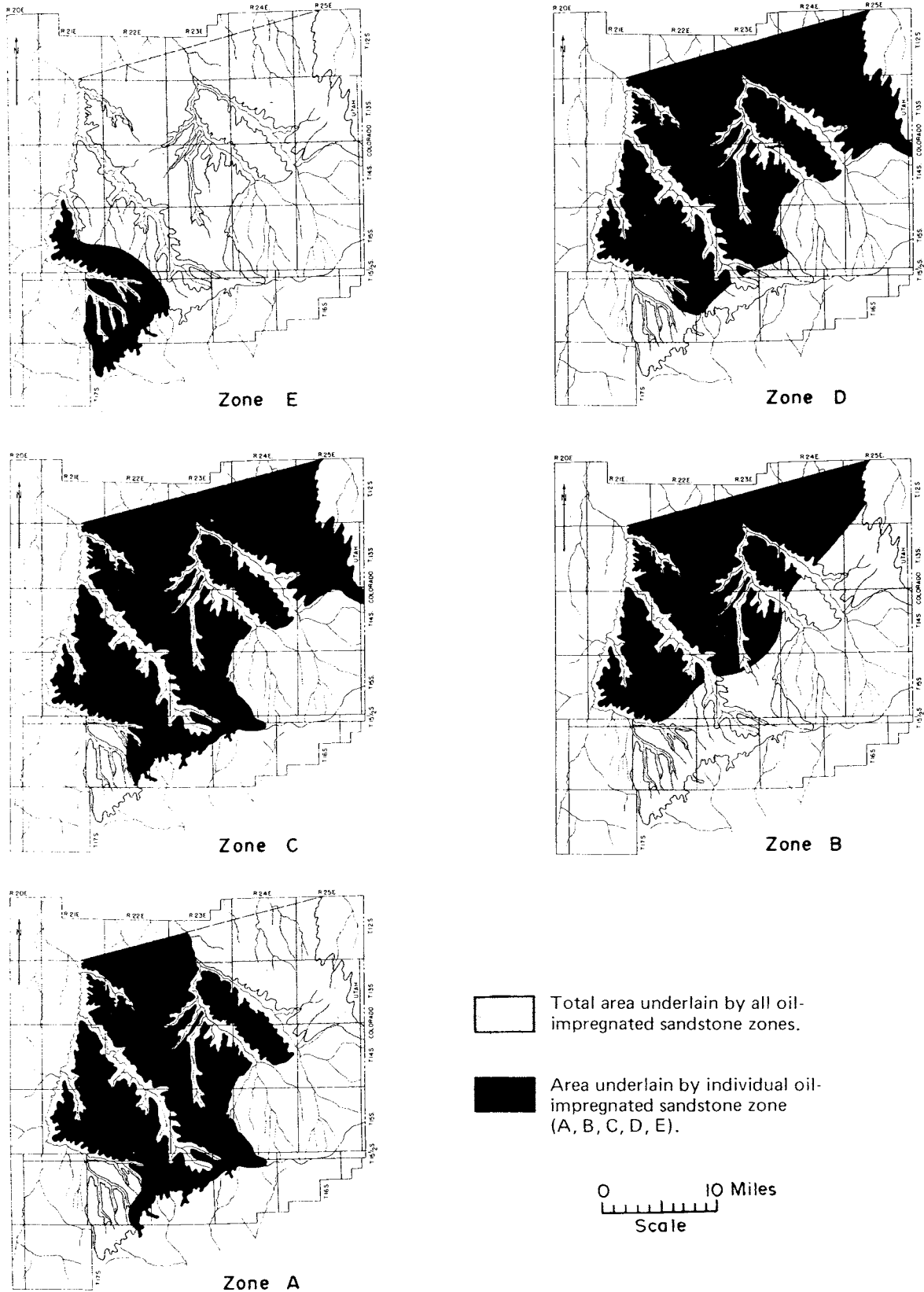
Figure 9. The total area and individual areas underlain by oil-impregnated sandstone zones A, B, C, D and E.
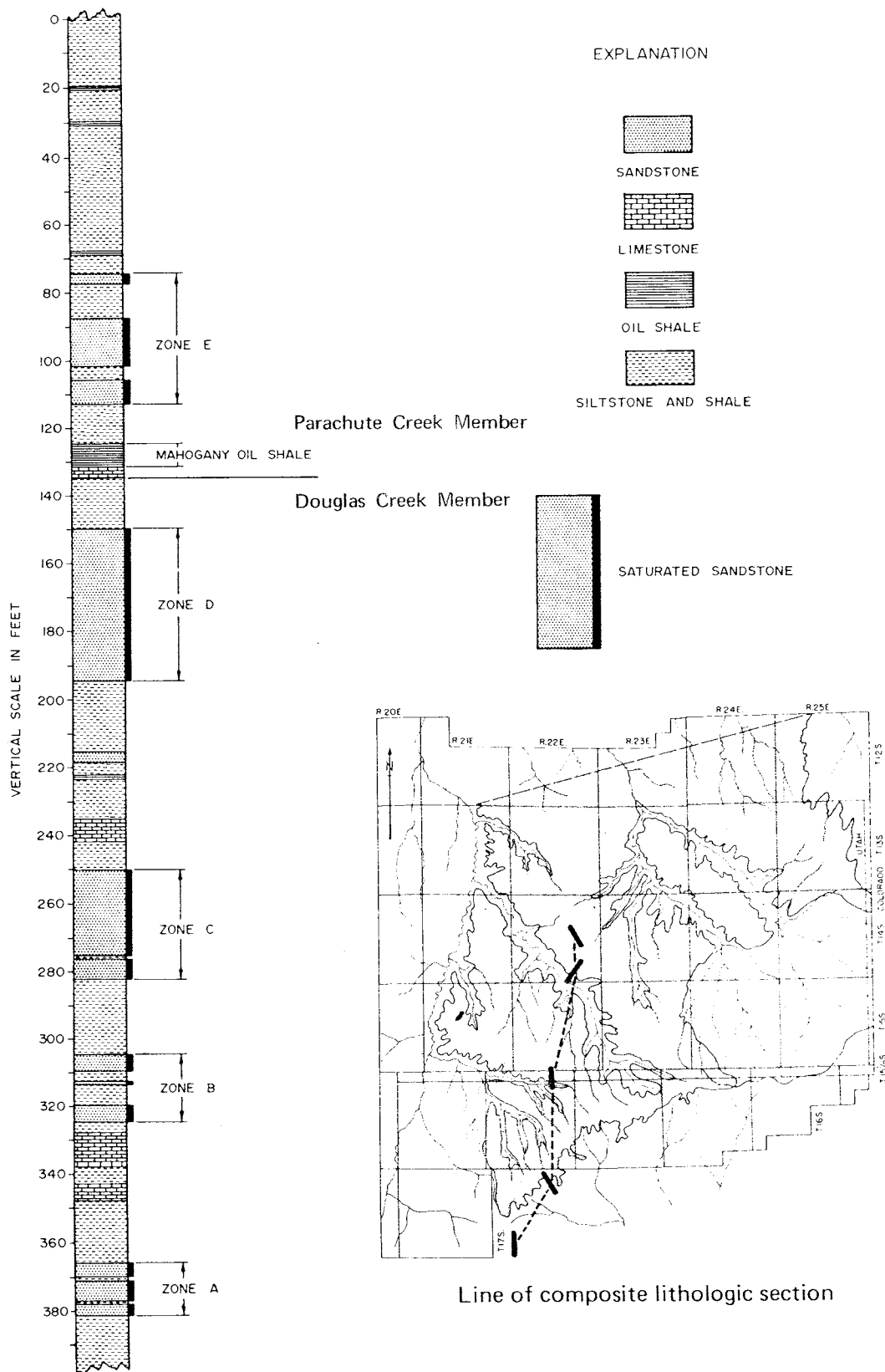
Figure 10. Partial composite lithologic section of the Douglas Creek and Parachute Creek members of the Green River Formation in the area.
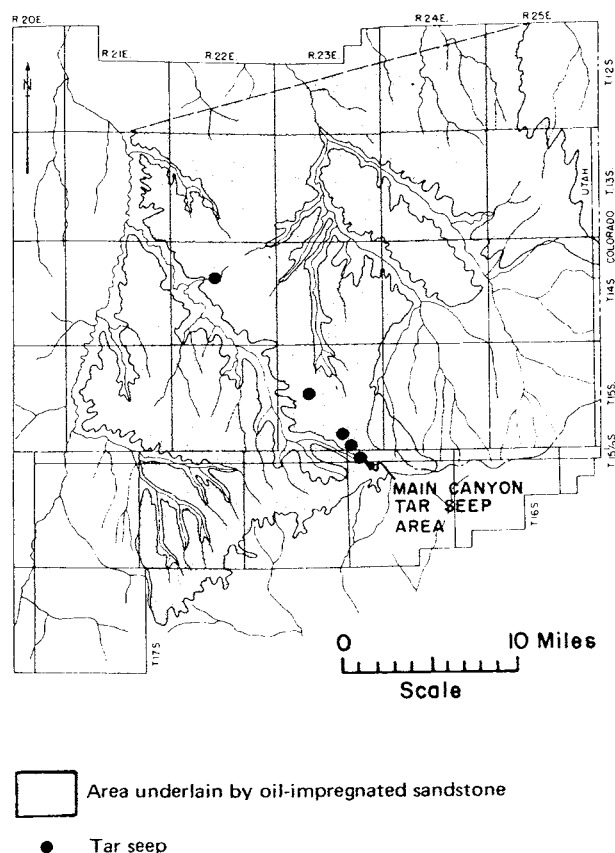
Figure 11. Five of the major tar seeps in the area.

Byrd (1970) discusses the tar seeps in the area and suggests that the tar movement is caused by the light bitumen from the oil-impregnated sandstone, floating up-dip in groundwater that is moving down-dip over the sandstone.

The Main Canyon tar seep, the largest in the area, consists of many small seeps at the head of Main Canyon (figure 11). These seeps appear at the surface within a circular area of several acres. Figures 12 and 13 show two of these. Tar used for many analyses in this report was collected from an active seep near the center of the area. During wet seasons, this and other seeps become active and flow large amounts of water as well as tar. During dry seasons both the tar and water cease to flow. The amount of water moving in the ground rather than the temperature influences the seepage of tar in the area.

Successful exploitation of the oil-impregnated sandstones depends on the economic need for these materials, a knowledge of their physical and chemical

properties, and on their reserves. There has been no demand for them and no development or analytical work has been done except some surface mapping and exploratory drilling. Byrd (1970) calculated the total barrels of oil in place for the area to be about 3.7×10^9. The area underlaid by oil-impregnated sandstones is larger than that estimated by Byrd (figure 14), however, and the estimate of 3.7×10^9 barrels is a conservative figure.

Oil, Gas and Oil Shale

Three other major fuel resources in the area are oil, gas and oil shale.

Cashion (1967, p. 40-43) discusses the possibilities of oil and gas development in the area, and Byrd (1970) lists the wells drilled in the area. Since 1966 seven gas wells have been connected to gathering lines (Frank Salwerowicz, written communication, August 25, 1969). Figure 15, shows their locations and their gathering lines. They are described as follows:

Well description	Unit/field	Placed on line
Pacific Natural Gas Expl. Co.	Segundo Canyon	
NESW 4-17S-21E, well #23-4	field	Mar. 1968
SWSE 33-16S-21E, well #2		Mar. 1968
Texaco Inc.	Fence Canyon	
SWSE 33-15½S-23E, well #3	unit	Dec. 1967
NESE 26-15S-22E, well #2		Jul. 1967
NESE 36-15S-22E, well #1		Mar. 1967
Getty Oil Co.	Horse Point	
NWNE 14-16S-23E, well #1-X	unit	Mar. 1967
Pacific Natural Gas Expl. Co.	Moon Ridge	
NWNE 15-16S-21E, well #31-15	unit	Dec. 1966

Cashion (1967) studied the economic geology of the oil shales in Colorado and Utah, their composition and physical characteristics, development and potential reserves. He estimated the combined indicated and inferred potential reserves of shale oil in Utah from beds in the Mahogany zone at least 15 feet thick containing 30, 25 and 15 gallons per ton to be 73,304 million barrels. Figure 16 shows an outcrop of the Mahogany oil shale zone.

PHYSICAL PROPERTIES
OF TAR AND DISTILLATES

Methods of Extracting Tar
from Host Material

The physical properites of the tar and tar distillates will influence the extraction, refining and trans-

Figures 12 and 13. Active tar seeps within the Main Canyon tar seep area, sec. 31, T. 15½ S., R. 24 E.

O   IO Miles
Scale

☐ Area underlain by oil-impregnated sandstones

▨ Area of Byrd's reserve calculations
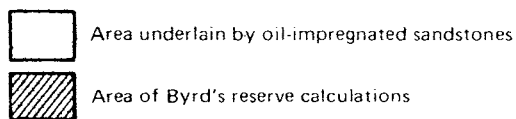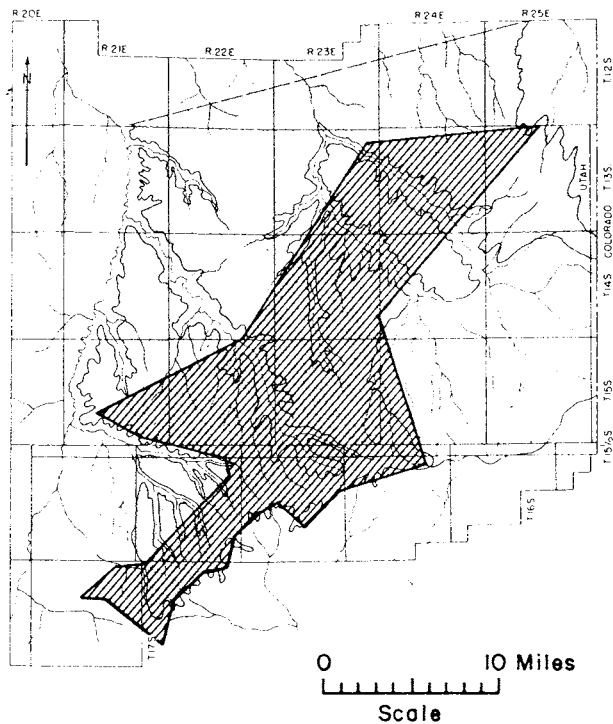
Figure 14. Area of Byrd's (1970) reserve calculations and total area underlain by oil-impregnated sandstones.

O   IO MILES

☐ Area underlain by oil-impregnated sandstones.

Gas collection line, (G.V.T.—3.5) indicates operator of pipeline and size of line in inches.

✳ (G.V.T.)—Grand Valley Transmission Co.
(M.F.S.)—Mountain Fuel Supply, Mesa Pipeline Co.

Figure 15. Producing gas wells and collection lines in area.

Figure 16. Mahogany oil shale delineated in Hells Canyon, sec. 16, T. 10 S., R. 25 E., Uintah County.

portation methods employed in upgrading the tars. This study describes six physical properties of the tar in the area: specific and API gravities, viscosity, pour point, fractional distillation, flash and fire points and the index of refraction.

Large-scale extraction of tar from its host material can be done *in situ* or by mining and subsequent tar removal methods. According to Howard (1965, p. 97-98) four basic *in situ* or thermal recovery methods are: steam flood, hot water flood, forward combustion and reverse combustion. Covington (1965) discussed thermal recovery methods, Cook (1965) described a heated fluid recovery method, and Marx (1967), *in situ* combustion. Doscher and others (1965) discussed steam drive as a possible means of recovery of the Athabasca tars in Canada.

Tar extraction is quite different if the oil-impregnated deposit is mined and processed. Bachman (1967, p. 69-82) describes the hot alkaline water process used today to extract the tar from the Athabasca deposit. This recovery method appears to be preferable to the steam drive method described by Doscher and others (1965). Extraction after mining is done to a limited extent by solvent extraction methods as described by Poettman and Kelly (1967).

Byrd (1970) estimated tar reserves in the study area of 3.7 billion barrels; the present writer considers this figure conservative.

Howard (1965, p. 99-100) enumerated the following considerations for successful thermal recovery processes: depth, oil in place, porosity, lithologic inhomogeneities, sandstone thickness and oil mobility.

Great pressures generated in the oil reservoir in *in situ* recovery make necessary' a closed system

between injection and producing wells. The tar-bearing horizons in the area are shallow, from surface exposures to 300 feet below the surface, and they outcrop in major drainages. This shallow depth and the presence of joints and nearby outcrops may allow leakage in recovery systems. Undissected areas of tar sand are small, usually less than two miles in width and they vary in length. *In situ* recovery programs requiring large areas for high recovery may be restricted in their efficiency by these small areas.

For *in situ* secondary recovery in oil fields to be economical, Howard (1965) suggests that the oil-bearing horizon contain at least 1,000 barrels per acre-foot of oil in place. Calculating the in-place tar in the area from the subsurface data in appendix 1 gives an estimated average of 936 barrels of tar per acre-foot, somewhat less than the suggested minimum.

The average subsurface porosity of the tar-bearing horizons in the area is 26.4 percent, well above the minimum 18-20 percent required for a successful thermal combustion process. Large porosities are desirable in thermal recovery because more energy is used for heating the oil and less is expended heating the host material.

Howard (1965) indicates that lithologic variations such as sandstone lenticularity in the strata make correlation from one area to another and the planning of *in situ* processes difficult.

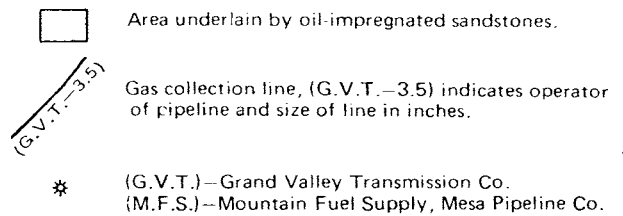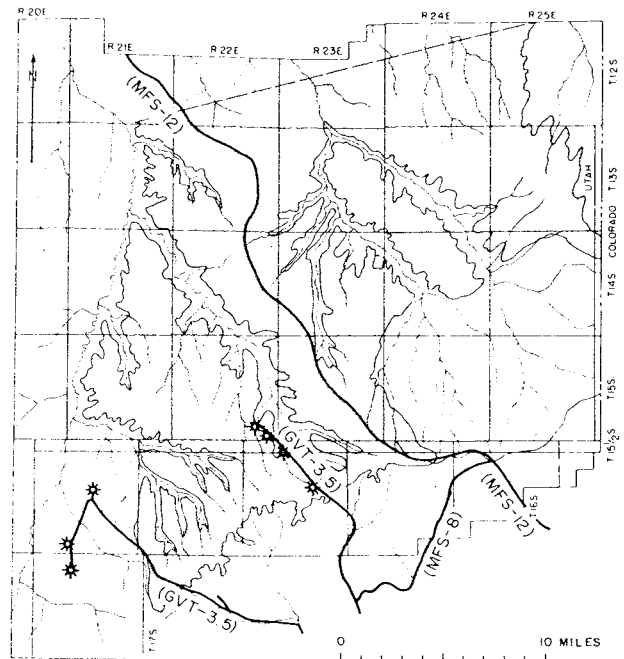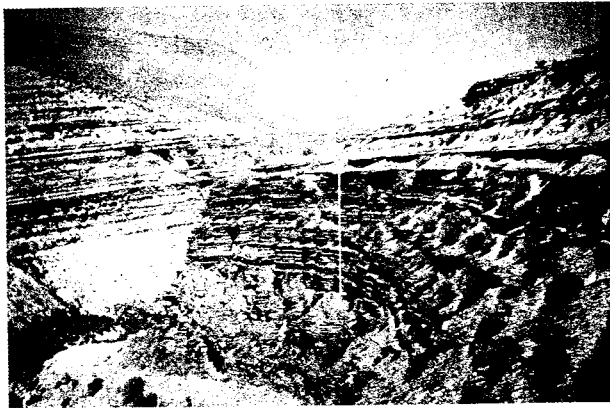Correlation over great distances of individual beds in the area is difficult because they pinch out or grade into nonporous lithologies. The five principal oil-impregnated zones, however, can be traced throughout the area. Recovery processes applicable to zones of oil-impregnated sandstones may be more successful than those restricted to individual beds.

Howard suggests that the thickness and permeability of the oil-bearing sandstones help determine favorable recovery conditions. Thin beds must be highly permeable to be productive. The oil-bearing beds in the area range from 2 to 70 feet in thickness and average less than the 50-foot thickness considered profitable. He does indicate, however, that a 25-foot zone may be of value if the permeability is 2,500 millidarcys (mds). The average permeability within the area is about 1,800 mds, indicating that production from some beds less than 50 feet thick might be profitable.

The mobility of the tar within the host material also influences the success of a thermal process. If the oil or tar is too viscous, it may not move fast enough

to meet production demands or may not move at all. Viscosities of similar tars from Asphalt Ridge and other areas, (Kayser, 1966, p. 33-34, appendix 2), range from 750 to 2,700 Saybolt Furol seconds at 210° F. The viscosity of the tar in the ground would be much greater at lower temperatures.

Economical extraction of tar by mining and subsequent tar removal methods depend on thickness and nature of overburden, thickness, lateral extent and continuity of tar-impregnated beds, physical characteristics of the tar sand, haulage routes and availability of water and fuel.

Thickness of the strata overlying the tar-impregnated horizons varies to 250 feet depending on the horizon. The strata consist of shale, mudstone and sandstone. In most areas the ground is covered by vegetation.

The tar-impregnated beds range in thickness from 2 to 70 feet and are separated by nonsaturated units. The lateral extent of individual beds within the five zones is difficult to determine.

Their average tar content, calculated from data in appendix 1, averages 14.5 gallons per ton.

Most of the tar-bearing sandstones are rubbery and difficult to break. Unlike those at Asphalt Ridge which are cemented mainly by the tar, most of those in the Uinta Basin contain calcium carbonate cement in some amount and Wiley (1967, p. 61) says they contain up to 39 percent calcium carbonate cement.

Major costs in the mining and recovery of tar lie in transportation of ore, water requirements for processing, and fuel for production of steam, hot water or electrical power. The many deep drainages limit road building to ridge tops and to a limited number of canyons, making haulage by road to the separation site costly in terms of time and miles. Conveyor belts could be used in some areas to transport mined material.

Great quantities of water are required for most tar recovery methods. Cohenour (1965, p. 286) cited references indicating that in some operations 5.8 acre-feet of water are required per 10,000 barrels of extracted bitumen.

The water available in the area is limited, and most of it is earmarked for agriculture. The 16-year average flow of Willow Creek, measured in sec. 29, T. 14 S., R. 21 E., is 18.4 cfs or 36.6 acre-feet per day, according to Harold Chase (personal communication), and the flow of P. R. Spring, sec. 36, T. 15 S., R. 23 E., is 4 to 10 gpm or .003 acre-feet per day, according to James Mundorff (personal communication). Other sources of water, of unknown quantities, are Hill, Sweetwater and Bitter creeks. The availability of ground water is unknown.

Tar recovery requires large quantities of fuel for the production of steam, hot water or electrical power used in the process. Bachman and Stormont (1967, p. 70) say the Athabasca tar sand project in Canada is self-sufficient; coke and byproduct fuels supply all the energy requirements of the project. Such a fuel source might be possible for extraction processes in the Uinta Basin. Natural gas is another local source of fuel.

Description of Extracted Tar and Distillate

The tar extracted from its host material is a naturally occurring, brown to black, highly viscous or solid mixture of hydrocarbons, composed mainly of alkane- or paraffin-type hydrocarbons of heavy molecular weight, with minor aromatic consituents. It contains trace amounts of inorganic material and is soluble in carbon tetrachloride and other solvents. The distillate fractions, of equivalent gross composition, are brown liquids.

Specific and API Gravity of Tar and Distillate

The density of an oil or tar can be represented either by its specific gravity, with unity being represented by distilled water, or in terms of degrees Baumé or API. In the latter, water has a density of 10. The conversion from specific gravity to degrees API is:

$$\text{Specific gravity} = \frac{\text{degrees API} + 131.5}{141.5}$$

According to Landes (1959, p. 224) the density of crude oils ranges from 10 to greater than 60 degrees API; the latter contains a greater percentage of light gasoline-type hydrocarbons and a lower percentage of heavy molecular weight compounds.

The specific gravity of the tar in the study area, based on seven samples (appendix 2), ranges from .969 to 1.027 with an average of .990. The gravity of the tar in degrees API ranges from 6.3 to 14.5 with an average of 11.4. The average specific gravities of the tar distillates from the area and the equivalent API gravities are given in table 2.

Viscosity of Tar and Distillate

No viscosity data are available for the tars, but data on similar tars from other areas are reported by Kayser (1966, p. 33-34).

Table 2. Crude oil fraction No., temperature range and distillate-fraction assignment from Burwell and others (1969, p. 6).

		Average	
Product	Percent	Sp. Gr.	°API
Light gasoline	–	–	–
Total gasoline and Naphtha	–	–	–
Kerosene distillate	–	–	–
Gas oil	2.05	.897	23.8
Nonviscous lubricating distillates	4.70	.911	26.2
Medium lubricating distillate	2.68	.926	21.2
Viscous lubrication distillate	14.20	.946	18.2
Residuum	74.00	1.006	9.1

Pour Points of Tar and Distillate

Oils with high pour points, such as the 90° F pour point crude oil from the Red Wash field in the Uinta Basin, must be pumped through heated lines or blended with low pour point oils.

The pour point of the viscous tar collected from the Main Canyon tar seep is about 50° F.

Tests performed by the writer on Main Canyon tar distillates give a pour point of less than 15° F. Bureau of Mines pour point data on tar distillates (appendix 2) show a pour point of less than 5° F in most cases.

Fractional Distillation of Tar

Distillation, U. S. Bureau of Mines routine method, is done in two stages. The first stage is at atmospheric pressure with ten cuts being made ranging from 122° to 527° F. The second stage is accomplished under vacuum (40 mm Hg) with five cuts ranging from 392° to 572° F (appendix 2). The second-stage vacuum distillation is necessary to avoid thermal cracking of the high boil-point hydrocarbons.

Tars in the study area do not contain the lighter, low-boiling-point fractions of stage 1 distillation, or in fractions 1 to 7. The first drop is obtained at an average temperature of 334.2° F during stage 2 distillation (appendix 2). The average percent and sum-percent of the six stage 2 distillation cuts from four samples are shown in table 3.

The large residuum left after conventional distillation is characteristic of low gravity tars and oils and consists of the heavy, hydrogen-deficient hydrocarbons which are not distilled. This residuum constitutes a large percent of the potential value in the tar and could be more fully realized by other types of processing such as hydrogenation.

Three to four liters of tar from the Main Canyon tar seep were supplied to S. A. Qader, Assoc. Professor, Mineral Engineering Department, University of Utah, to conduct hydrogenation tests. As part of a synthetic fuels study, tests were conducted to compare the hydrogenated products of bituminous coal, oil shale oil and tar sand oil. Appendix 5 gives the results of these tests as presented by G. R. Hill, Professor, Mineral Engineering Department, University of Utah, and S. A. Qader.

The breakdown of tar distillation fractions from the study area into product fractions and gravities, by the U. S. Bureau of Mines (appendix 2), is given in table 2.

Flash and Fire Points of Tar and Distillate

The flash and fire points of a sample of tar from the Main Canyon seep and the distillate from the tar were determined in accordance with ASTM designation D92-57. The tar froths on heating. The uncorrected flash point of the tar is between 300° and 310° F and the fire point is between 380° and 410° F. The barometric pressure-corrected flash and fire points of the tar distillate are 178° and 192° F respectively.

Index of Refraction

Hedberg (1937, p. 1465, 1475) showed that the index of refraction of an oil decreases with increasing amounts of volatile matter. Because of the small amount of oil necessary for analysis, the index of refraction is a good test for measuring the gravity of oil. Figure 17 shows the relationship between the API gravity of Main Canyon tar distillates and crude oils and their indexes of refraction.

Index of refraction cannot be obtained from black tars because they do not transmit sufficient light. The index of refraction of tar from the Main Canyon seep was determined by mixing the tar with known

Table 3. Fractional distillation data of six tars from the area.

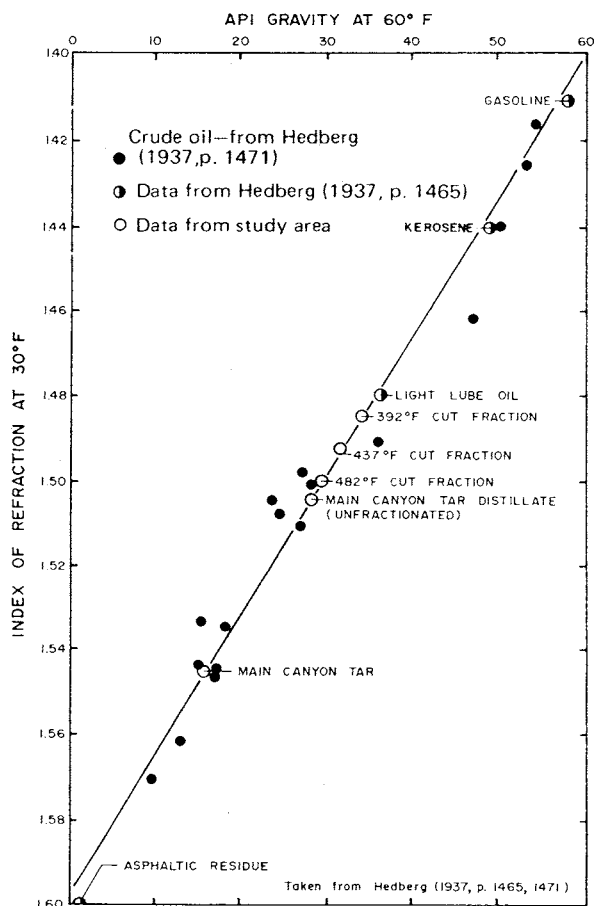| Fraction	Cut Temp. °F	Average Percent	Average Sum-percent
11	392	2.12	2.12
12	437	2.32	4.44
13	482	3.20	7.64
14	527	4.70	12.34
15	572	10.15	22.84
Residuum	–	73.90	96.74

Figure 17. Index of refraction plotted against API gravity for tar and petroleum products.

index oils and noting· either an increase or decrease in the index. The index of refraction of the tar was about 1.545, measured on a Bausch and Lomb Abbe-3L refractometer.

The average indexes of refraction of the 392°, 437° and 482° F cuts (appendix 2) are shown in figure 17, along with the index of the nonfractionated distillate from the Main Canyon seep.

CHEMICAL PROPERTIES AND ANALYSES

Ash Content of Tar and Distillate

The first Main Canyon tar sample (figure 11) contained 1.55 percent ash, about the same ash content reported by Kayser (1966, p. 33) in a sample from Asphalt Ridge. The second sample was heated to 180° C during the flash and fire point test and contained 2.32 percent ash. The third sample, a viscous, almost solid tar, from sample No. 15-02 (figure 12) contained 4.47 percent ash. The fourth, a black, dry,

flakey substance, from sample No. 15-01 contained 6.47 percent ash. The fifth, a distillate of the tar from the Main Canyon tar seep, contained .03 percent ash. The first four samples demonstrate that the weight-percent of ash in a sample increases as the tar becomes heavier and thicker or deficient in volatile constituents. Distillation of the tar produces a product consisting mainly of hydrocarbon fractions containing relatively little inorganic ash-forming substance.

Carbon Residue of Residuum and Distillate

An average of 23 percent of the Main Canyon tar may be distilled; the remaining 74 percent remains as residuum (appendix 2). The amount of carbon residue obtained from the distillate and residuum fractions is indicative of the coke-forming characteristics of the tar.

ASTM Designation D189-52, Note 1 defines carbon residue as follows:

The term "carbon residue" is used throughout this method to designate the carbonaceous residue formed after evaporation and pyrolysis of a petroleum product. The residue is not entirely composed of carbon, but is a coke which can be further changed by pyrolysis. The term "carbon residue" is continued in this method only in deference to its wide common usage.

The average uncorrected carbon residue of Main Canyon distillates (crude) is 13.6 percent, and the average of the residuum is 17.7 percent. Together they form an average of 31.3 percent. Carbon residues reported from tars with high ash content must be corrected to eliminate the contribution of ash.

X-ray Analyses of Tar and Tar Ash

X-ray diffraction analysis of a sample of tar from the Main Canyon seep shows a broad peak (figure 18) characteristic of amorphous or noncrystalline substances, but gives no structural information about the tar molecules.

X-ray diffraction analysis, using copper radiation, of high-temperature tar ash produced by heating Main Canyon tar in an open crucible until completely oxidized, shows the presence of amorphous material in the sample, by the small broad peak between 18-19 degrees 2θ (4.5 and 5 Å). It also shows the presence of crystalline quartz and feldspar (figure 18) in the tar before ashing. Presence of calcite is not confirmed by X-ray diffraction.

X-ray diffraction analysis of low-temperature ash, produced by oxidizing Main Canyon tar in an oxygen plasma furnace, does not show the presence of non-
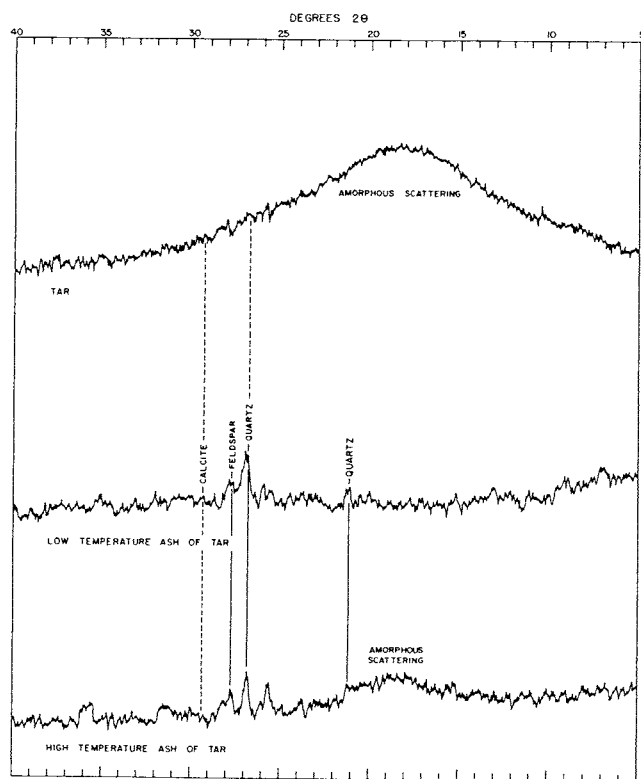
Figure 18. X-ray diffraction spectra of Main Canyon tar and ashes.

crystalline material to any great extent, but does show the presence of small amounts of calcite, quartz and feldspar. Calcite, which is destroyed at high temperatures, was preserved by ashing the tar in the oxygen-plasma furnace which oxidizes the tar at temperatures between 100° and 150° C.

Infrared Analyses of Tar and Distillate Ash

A high- and low-temperature tar ash and one high-temperature tar-distillate ash were analyzed by infrared spectroscopy to further aid in the identification of mineral matter contained in the ash. Figure 19 shows the infrared patterns obtained and the patterns obtained from analyses of calcite, quartz and sanidine feldspar which were used as standards. Some unburned tar left in the ash gives the characteristic aliphatic peaks in traces A and B, about 3.4 and 7 μ. Spectrum A of the high-temperature tar ash shows the presence of a small amount of calcite, with quartz and feldspar dominant. Spectrum B of the low-temperature tar ash shows a larger amount of calcite, quartz and feldspar. Spectrum C of the high-temperature tar-distillate ash indicates a trace of calcite or unburned tar but little if any quartz or feldspar. This pattern indicates that little

mineral matter is carried over with the distillation products. The quartz, feldspar and calcite in the Main Canyon ash may have been in the form of abraded particles suspended in the tar. In trace B at about 2.74 μ, one small peak indicates that kaolinite might be present; no corresponding peak occurs in the other two samples.

Sulfur Content of Tar

Sulfur in an oil or tar sample can be determined quantitatively by three general types of tests, based on combustion, X-ray and reduction techniques (Costantinides and Arich 1967, p. 114). The sulfur content data used in this investigation were obtained by the following combustion techniques: (1) ASTM test: D129–IP61, which employs a high-pressure oxygen bomb, (2) Parr Peroxide Bomb method (Parr Manual, 1948), and (3) Method No. A-8 of U. S. Steel Corporation (Coe and Keller, 1960).

The tars examined in this study were extracted from their host material by solvent extraction. Thirty-four tar samples were analyzed for sulfur (table 4). Sulfur content ranged from .22 to .42 percent with an average value of .323 percent, indicating a low-sulfur variety of crude oil compared to some crude oils and non-Uinta Basin tars (Howard Ritzma, personal communication).
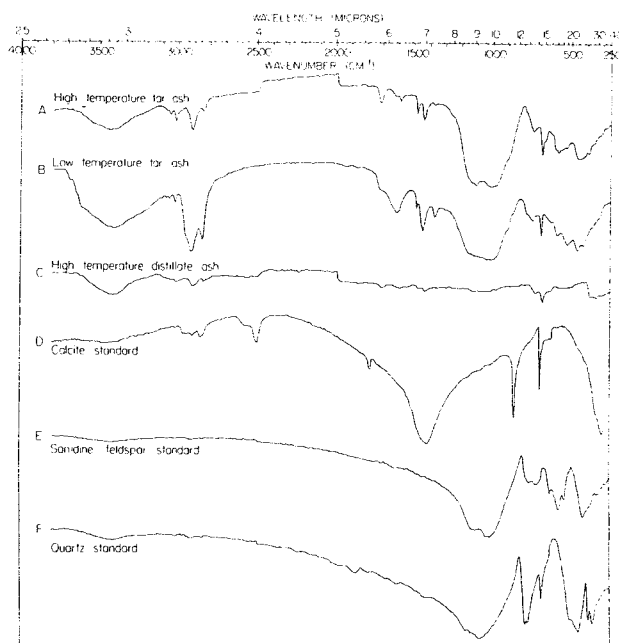

Figure 19. Infrared spectra of Main Canyon tar ashes and mineral standards.

Table 4. Approximate summary data of tar distillates in area.

Sample location, section, township, range	Footage	Percent sulfur
14-14S-22E	73.0	.28
14-14S-22E	77.4	.33
14-14S-22E	79.5	.31
14-14S-22E	82.4	.42
14-14S-22E	96.5	.32
14-14S-22E	135.6	.29
14-14S-22E	139.0	.36
14-14S-22E	144.7	.37
14-14S-22E	220.7	.33
14-14S-22E	227.0	.29
14-14S-22E	232.0	.35
24-14S-22E	55.1	.31
24-14S-22E	63.5	.34
24-14S-22E	67.0	.34
24-14S-22E	70.0	.38
24-14S-22E	81.0	.33
24-14S-22E	86.0	.41
24-14S-22E	119.5	.29
24-14S-22E	127.0	.32
24-14S-22E	139.7	.28
24-14S-22E	171.0	.22
25-14S-22E	99.2	.27
25-14S-22E	110.5	.36
25-14S-22E	139.0	.27
25-14S-22E	192.0	.40
26-13S-22E	92.5	.29
26-13S-22E	116.8	.33
26-13S-22E	121.0	.34
26-13S-22E	124.5	.24
24-14S-19E	Surface	.40
31-13S-23E	Surface	.36
5-16S-24E	Surface	.34
36-15S-22E	30.0	.42
6-15½S-24E	Seep	.34

The amount of sulfur seems to be randomly distributed among the five oil-impregnated sandstone zones. Insufficient surface sulfur content data are available to show reliable horizontal trends.

The percentages of sulfur from locations 65, 14–14S–22E and 64, 24–14S–22E, however, do indicate a slight basinward increase in the average sulfur percentage. Location 75 has an average of .332 percent and location 65, .322 percent. The increase is probably related to the environments of the deposition and their influence on the parent oil-forming materials, or on the oil as it matures and migrates within the rocks.

Average sulfur content of the five surface or near-surface samples (.37 percent) is greater than that of subsurface samples (.32 percent). This difference may result from loss of low or nonsulfur volatiles into the atmosphere as they migrate towards the surface, resulting in concentration of the sulfur.

The sulfur in oil may come from both organic and inorganic sources. Fossil evidence of algae, ostracods and fish was found in the fluvial and lacustrine deposits of the Uinta Basin. If plant and animal remains contributed to oil-forming sapropel, these organisms could have been the source of sulfur during the formation of the oil. Sulfur, according to Mason (1952, p. 200) is assimilated by plants and animals to the extent of one to two percent by weight. Costantinides and Arich (1967, p. 139-41) write, however, that organic sources would not provide sufficient sulfur in some cases and that inorganic sources must have provided the rest. Inorganic sulfides and sulfates available in many rock-forming minerals may then have been incorporated into the oil during secondary processes of oil formation.

Sulfur, whether in oils or tars, occurs both free and combined. Free sulfur occurred in several samples of rich oil-impregnated sandstone in the area in sec. 36, T. 15 S., R. 22 E., and Costantinides and Arich (1967, p. 115-16) establish the presence of free sulfur in some crude oils.

Considerable work has been done in separating and analyzing the numerous sulfur-bearing compounds found in oils. Costantinides and Arich (1967, p. 118) put them in four groups, thiols (mercaptans), disulfides, sulfides and thiophines, and discuss them in their text (p. 116-39). Other workers dealing with sulfur-bearing compounds are Giraud (1967, p. 464-70), Thompson (1966, p. 85-93) and Coleman (1966, 20 p.).

Howard Ritzma (personal communication) reported a correlation between geologic age and percent of sulfur in the tars in oil-impregnated sandstones in Utah. Tars of Tertiary age, which include most of the Uinta Basin tars, contain small amounts of sulfur, usually less than .5 percent. Tars from other localities such as the Circle Cliffs (Triassic) and the Tar Sand Triangle in south Utah (Permian) contain much greater amounts of sulfur, from 3 to 6 percent. Ritzma thinks that tars formed in a nonmarine environment such as the Uinta Basin will in general contain less sulfur than tars formed in a marine environment.

Nitrogen Content of Tar

Nitrogen, another of the nonhydrocarbon impurities found in oils, usually constitutes a small per-

cent of the material from the Uinta Basin. Bestougeff (1967, p. 101) writes that the nitrogen content of crude oils usually ranges between .01 and .2 percent but can be higher.

Twenty-one tar distillate samples from the Uinta Basin were analyzed for carbon, hydrogen and nitrogen. The amount of nitrogen in the samples ranged from .16 to .66 percent with an average of .49 percent (table 5), but shows a random distribution throughout the area.

Costantinides and Arich (1967, p. 156) showed that the amount of nitrogen increases as the API gravity of a crude oil decreases (figure 20). The average nitrogen content and distillate-gravity data from the 21 samples in the area are compatible with the crude oil data shown. Bestougeff (1967, p. 101) says that the nitrogen compounds in a crude oil are concentrated in the residuum during the process of distillation. No data were obtained on nitrogen content in the residuum from tars in the area, but the distillates of these heavy tars do have high nitrogen content.

No definite conclusions have been reached regarding the origin of the nitrogen or its compounds in oils; they may, however, be assumed to originate
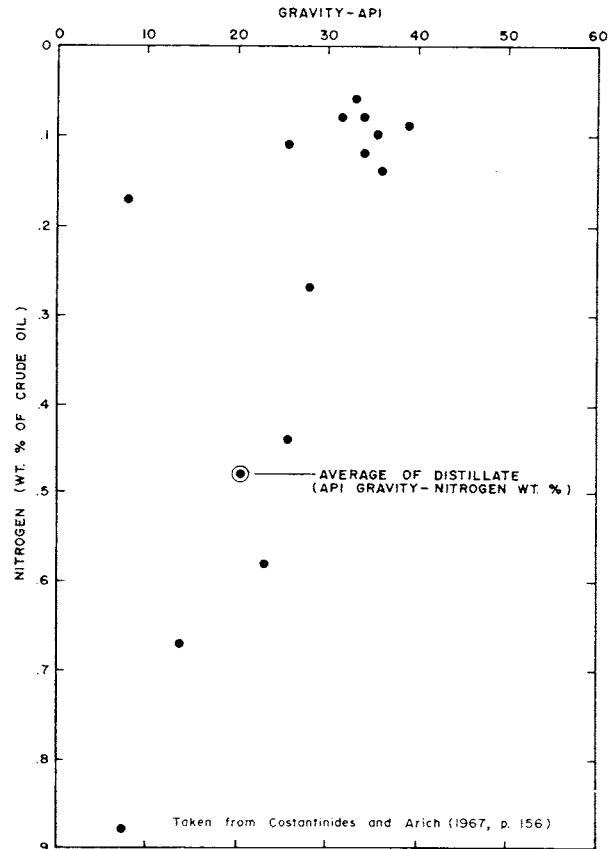
Figure 20. Nitrogen content plotted against API gravity of crude oils and tar distillates from the area.

from animal and/or plant sources that formed the parent oil-forming material (Costantinides and Arich, 1967, p. 162). The compounds of nitrogen found in oils are limited to those of a basic pH nature such as some pyridines and quinolines (Costantinides and Arich 1967, p. 160). Ralph Wood (personal communication) expressed the same views with respect to the tars from the area. The age-content relationship of nitrogen is not as clear-cut as that of the sulfur content. The average nitrogen content of Triassic and Permian tars is about .55 percent; the Tertiary tars from the area average .49 percent.

Oxygen Content of Tar

Oxygen is normally considered to be a minor constituent in crude oils. Landes (1959, p. 223) indicates that some assays report up to 2 percent oxygen, and Costantinides and Arich (1967, p. 143) report up to .44 percent oxygen.

Constantinides and Arich state:

The oxygen compounds in crude oils are apparently mainly acids and phenols; the latter compounds are present in much lower concentrations than the former ones.

Table 5. Percentages of nitrogen, carbon and hydrogen from 21 surface samples from the Uinta Basin.

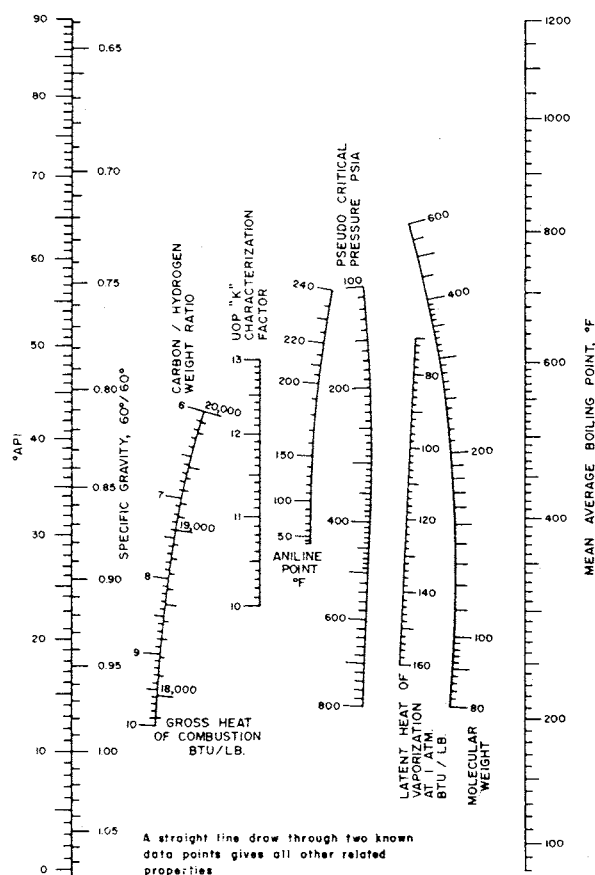| Sample No.	Percent		
	Nitrogen	Carbon	Hydrogen
02-1	.57	79.4	11.1
15-2	.42	78.5	10.7
21-1	.51	80.0	11.2
22-2	.60	87.2	12.3
33-3	.44	82.0	10.9
34-3	.30	72.0	10.2
34-4	.42	74.5	10.6
36-1	.62	80.3	10.9
38-4	.16	84.9	12.0
39-1	.56	86.4	12.4
42-3	.50	79.4	11.2
43-2	.38	83.8	11.8
46-2	.39	85.0	16.7
46-3	.55	83.6	11.5
47-1	.43	79.4	12.1
49-1	.65	85.0	11.5
53-6	.50	73.7	10.3
58-3	.66	86.5	12.1
59-5	.54	84.5	11.8
63-1	.55	85.5	12.1
69-1	.47	84.0	11.6

Figure 21. Nongram showing the relationship of the properties of petroleum fractions (modified from Winn, 1957).

Besides these compounds other oxygen-bearing compounds such as esters, ketones, aldehides and alcohols may be present. Andreev (1960, p. 10) writes that the formation of alcohols, aldehydes and ketones by the oxidation of hydrocarbon molecules is possible.

Andreev (1960, p. 26) suggests that oxygen in petroleum may be derived from several different sources including ground-water saturated with oxygen and microorganisms occurring in deeply buried sedimentary rocks. The subject of petroleum oxidation by anaerobic bacteria and the source of oxygen is treated by Andreev (1960, p. 2-7) who says that possible sources of oxygen found in petroleums are the nitrates and sulfates in sedimentary rocks.

Three samples of tar from the study area were analyzed for oxygen. Sample No. 03-01 contained 6.94 percent by weight of oxygen (figure 27). A sample, from Main Canyon, contained 9.43 percent oxygen, and a viscous tar containing 15.4 percent oxygen was extracted from sample No. 22-02.

Infrared studies show that the amount of oxygen-bearing hydrocarbon compounds in the tar is

greater in surface samples than in subsurface samples. Considerable oxidation probably takes place in the tar as it migrates to the surface.

Andreev (1960) suggests that the formation of tarry substances in petroleums, the result of oxidation of hydrocarbon molecules, increases with amount and rate at which oxygen is supplied. Within the study area, the depth of burial of the oil-impregnated sandstones is not too great for ground water to carry abundant oxygen to the petroliferous horizons. It is conceivable that oxidation, accompanied by the escape of volatile constituents, might produce, from a high-gravity, low-oxygen petroleum, the low-gravity, high-oxygen tar found in the area.

Carbon/Hydrogen (C/H) Ratios of Distillates

The C/H ratio is used to characterize the petroleum fractions found in an oil. Witherspoon and Winniford (1967, p. 265-267) show that the higher ratios (e.g., .8) correlate with the heavier petroleum fractions and the lower ratios (e.g., .5) with the lighter fractions. The C/H ratio can be related to other physical and chemical properties of an oil as shown in the nomogram in figure 21.

The C/H ratios of 23 tar distillates from the study area range from .425 to .895, with an average of .635. The C/H ratios of the tars were not determined, but would probably be higher than the average of the distillates.

The average API gravity, C/H ratio and boiling point of the distillates do not fit the nomogram in a straight-line manner, indicating that the tar distillates differ from general petroleum fractions or may have been changed during distillation from the hydrogen-deficient tars.

Other nomogram relationships indicate that the average molecular weight of the distillate molecules is greater than 200 and that the gross heat of combustion lies between 18,600 and 19,700 Btu/lb of distillate.

Gas Chromatography Data from Tar Distillates

Ten samples of tar distillate from the area were analyzed by gas chromatography. Anderson (1964, p. 27-31) describes the "programmed temperature" gas chromatograph technique used. Figure 22 shows the 10 programmed temperature gas chromatograph patterns obtained.
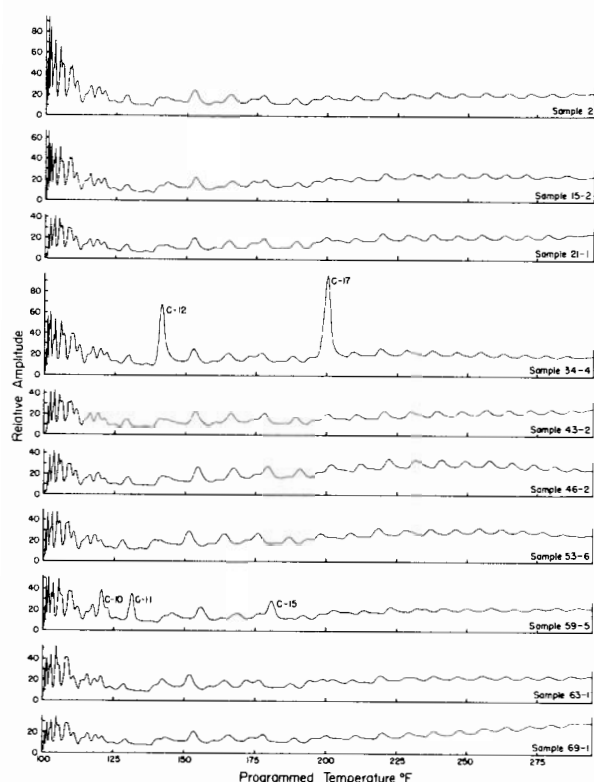
Figure 22. Programmed temperature gas chromatograph spectra from tar samples extracted by distillation.

The major rhythmic peaks on the figure represent the normal saturated hydrocarbons or alkanes in the sample as confirmed by infrared analyses which have the general formula C_nH_{2n+2}. They range from about C_6 or C_7 to C_{27}, the upper limit being set by the range of the equipment. The small peaks between the major ones represent isocompounds. As many as 3.68×10^7 possible isomers are possible for a C_{25} compound.

Carbon numbers less than C_6 or C_7 may be either alkane or aromatic in nature. Both alkanes and aromatics have been identified in the samples by infrared analysis; aromatics are minor.

Samples 34-4 and 59-5 (figure 27) were enriched with known carbon compounds to aid in the identification and location of the peaks on figure 22.

Infrared Analyses of Tars and Distillates

Structural groups and differences in the tars throughout the area and among the five tar-impregnated zones in the vertical direction were identified from infrared spectra obtained from 220 tar samples.

The infrared absorption spectra were evaluated on the basis of ten absorption peaks occurring on each. Each absorption peak was assigned to a general structural group (table 6). The assignment of each of the ten absorption peaks to a general structural group is done in two steps. First, from Silverstein and Bassler (1967) tentative assignments were made. Second, samples of Main Canyon tar and distillate were enriched with known organic compounds representing the tentative group assignments. The peaks, increased by the addition of a known organic compound, assume the general structural group designation of that compound (figure 23) and peaks remaining unchanged kept their tentative assignments. No specific compound assignments were given to the peaks.

A semiquantitative analysis of the 10 absorption peaks was made by measuring the peak heights using a log scale (figure 24). In order to compare the infrared spectra of the tars throughout the area, the first major alkane peak height at (2910 cm^{-1}) was divided by each of the other nine peak heights to standardize each spectrum. These nine ratios may then be compared from sample to sample. The absolute peak heights cannot be used for comparison because the amount of tar used was not the same for each sample analysis. The ratio of the first absorption peak to any of the others will hereafter be designated at 1:3 or ratio infrared 1 to infrared 3, etc.

Analysis of individual peak-height ratios within any one of the five horizons throughout the area does not show significant trends or changes in either surface or subsurface infrared data in a horizontal direction, nor is there an obvious change in the infrared ratios vertically. This lack of variation in the tar components indicates that the tars in all five horizons are similar, either having had a common source or being formed in similar environments.

Table 6. Percentages of nitrogen, carbon and hydrogen from tar samples extracted by distillation.

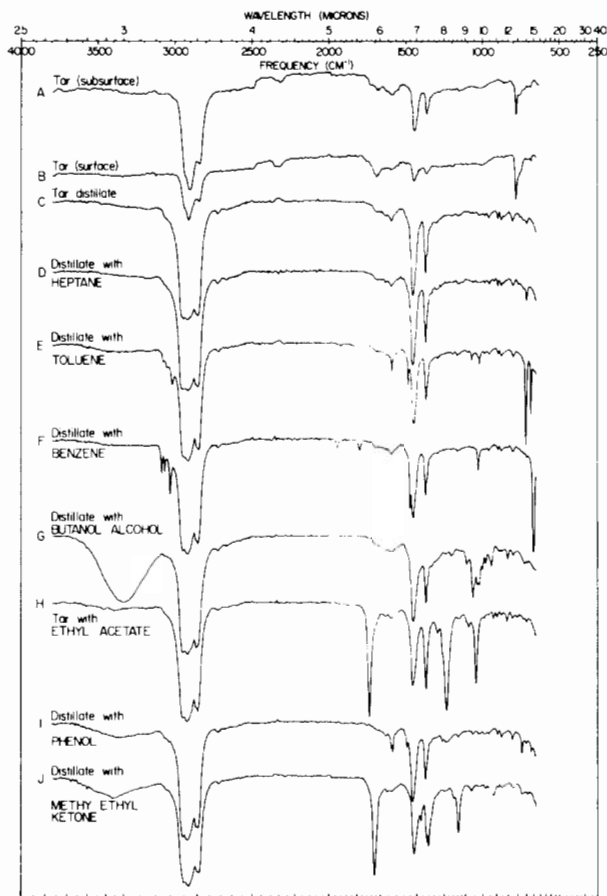| Absorption peak	Frequency (cm^{-1})	General group (s) assignment
1	2910	Alkanes
2	2840	Alkanes
3	1690	Ketones, aldehydes and esters
4	1490	Aromatics, acids, phenols
5	1450	Alkanes
6	1370	Alkanes
7	1140	Esters
8	1010	Aromatics
9	850	Aromatics
10	785	Aromatics

Figure 23. Infrared spectra of tar and reference samples.

Quantitative differences do occur between like structural groups in surface tar samples and the sub-surface tar samples taken from the Skyline core holes (figure 27; T. 13 and 14 S., R. 22 and 23 E.).

In nearly all cases, in the same structural group the average of the subsurface infrared ratios is greater than the surface ratios (table 7), indicating a decrease in certain organic groups in subsurface samples.

Peak-height ratio 1:3 represents oxygen-bearing compounds assigned to ketones, aldehydes and esters. Surface and subsurface samples are distinctly different. In appendix 3, peak-height ratios 1:3 are plotted against the six trace element concentrations. The points S, U, W and Y, generally towards the left, represent surface samples and the points T, V, X and Z generally on the right represent subsurface samples. Points designated by "#" represent the superposition of two points of either surface or subsurface origin.

The other infrared peak-height ratios between surface and subsurface samples vary, but the differences are gradational (appendix 3).

Increase in ratios from surface to subsurface, in the groups in table 7, indicates the presence of oxygen-bearing organic compounds which increase towards the surface of the ground where the supply of oxygen is greatest. Surface samples from active tar seeps are low in oxygen-bearing organic compounds and are similar to the subsurface samples extracted from well cores.

Trace Elements Found in Tar

Metallic trace elements may create problems in refining if they occur in sufficient quantity. Costantinides and Arich (1967, p. 164) state that some metals found in trace amounts in feed stock, when introduced into catalytic cracking units, tend to "poison" the catalyst and increase operating expenses.

The presence, source and mechanisms by which trace elements are tied up in tars and oils give clues to the origin and migratory processes of petroleum.

Costantinides and Arich (1967, p. 164-169) classify the metallic compounds found in oils into three groups: (1) metal-organic compounds unaffected by acid, (2) metal-porphyrin complexes and (3) metal complexes with porphyrin-like systems. They suggest that the origin of metal complexes in oils is probably associated with metal exchange reactions from animal and plant metabolic processes and that these metals must originally come from the environment in which the plants or animals lived.
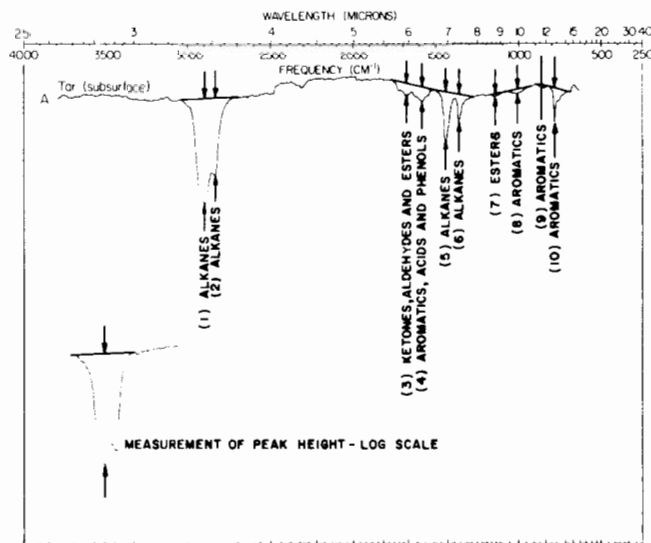

Figure 24. Organic group assignments for tars and measurement of peak-heights.

Table 7. Infrared absorption peaks, frequencies and general organic group assignments for tars from the area.

Average Infrared Peak-height Ratios											
1:3		1:4		1:5		1:6		1:7		1:8	
3.54^1	23.40^2	10.42^1	25.40^2	3.87^1	4.32^2	7.70^1	9.00^2	87.00^1	220.00^2	46.70^1	147.00^2

[1] Average of surface samples
[2] Average of subsurface samples from Skyline core hole

Hodgson and others (1967, p. 177-259) discuss the geochemistry of porphyrins, which are metal-bearing organic complexes, found in petroleums and other substances related to the biosphere, and state that:

> The evidence is strong that the petroleum porphyrin pigments came from precursor pigments present in the source material. The passive role played by the pigments was that in which the precursor molecules underwent a series of systematic changes until they became the stable and easily recognizable trace compounds of crude oil.

Infrared analysis of concentrated liquors containing porphyrins shows (figure 25) the two infrared spectra obtained (a and b) and the infrared spectra of six metal porphyrins or porphyrin derivatives taken from Hodgson and others (1967). Traces a and b are similar to the traces of known porphyrins or porphyrin derivatives, strongly suggesting the presence of porphyrin compounds in the tar.

Two hundred and twenty tar ash samples from the area were analyzed for trace elements. Seventeen elements were identified by emission spectroscopy: aluminum, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, nickel, potassium, silicon, silver, sodium, titanium, vanadium and zinc. Of these the following seven were then determined quantitatively: chromium, cobalt, copper, manganese, nickel and zinc. Average trace element concentrations in parts per million of the 220 tar ash samples are:

Chromium	Cobalt	Copper	Manganese	Nickel	Zinc
102.92	103.10	109.63	547.47	203.00	211.63

Isograd maps failed to show anomalies or trends in any of the five oil-impregnated zones, and no trends or anomalies appeared in the vertical direction among the five zones.

Fifteen computer printer-plots showing each of the six individual trace elements plotted against the others for the 220 tar samples are shown in the left-hand columns of appendix 4. Data points T, V, X and Z represent subsurface samples from the lower four oil-impregnated sandstone zones; S, U, W and Y represent surface samples and "#" represents two superimposed data points. Printer-plots of the same six trace elements from 38 nonsaturated lithologies, whose data points are designated by the letter B, are shown in the right-hand columns. These samples were taken from just above and below oil-impregnated sandstones in the skyline cores.

A comparison of trace element distribution patterns of tar ashes and barren lithologies may help to establish the source of the trace elements in the tar. The abundance of the trace elements from the tar ash (appendix 4) is much greater than from the barren lithologies, possibly because of the concentrating affect of ashing. The distribution pattern of the plotted trace elements comparing tar ash to barren lithologies, however, appears to be random in most cases. This difference suggests that the trace elements in the tar were not absorbed from the adjacent lithologies, but were indigenous to the specific environment of oil
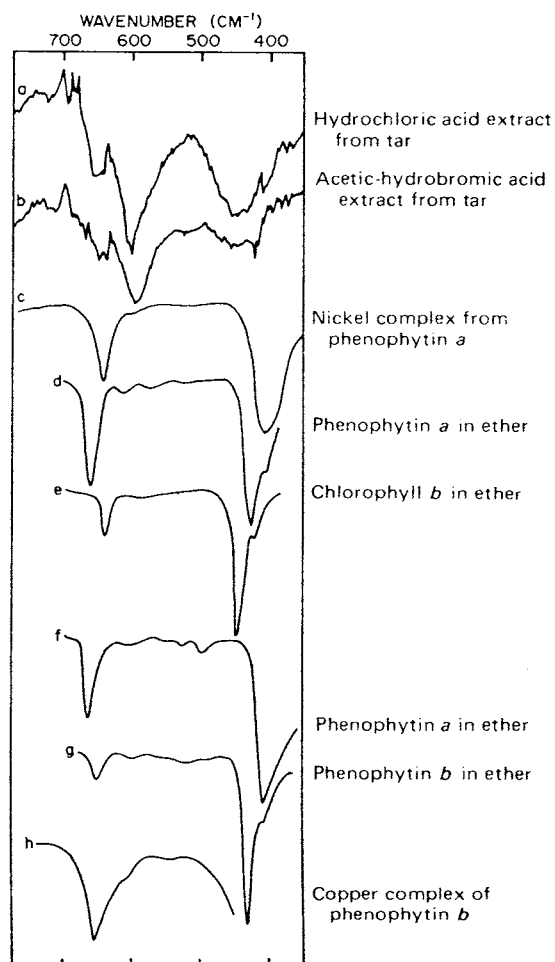

Figure 25. Infrared spectra of tar extracts from the area and known metal-bearing porphyrins (after Hodgson and others, 1967).

Table 8. Sulfur isotope ratios of tar distillates.

Samples	Sulfur isotope ratio S^{34}/S^{32} (δ °/oo)
02-01	+19.6
15-02	+21.9
21-01	+18.0
34-04	+11.3
53-06	+ 8.8
63-01	+27.5
69-01	+11.9

formation. This suggests either that the oil was formed elsewhere and migrated to its present position or that it was formed *in situ* under environmental conditions different from the adjacent lithologies with respect to the trace element ratios.

Sulfur Isotope Analyses of Tar

Thode and others (1958, p. 2637-2640) discuss isotope fractionation, its relationship to petroleum, and the isotope level of source sulfur in petroleums. They suggest that bacteria play a necessary part in the enrichment of waters in the heavy isotope S^{34}, and that the isotope ratios of petroleum samples reflect the sulphate isotope environment in which the petroleum is formed.

Twenty-nine tar and distillate samples from the area were analyzed and the sulfur isotope ratios determined. Twenty-two were tar samples from the four Skyline Oil Company cores (figure 26), and the other seven were tar distillates (table 8) from tars distributed throughout the area.

Isotope ratio data to detect increasing or decreasing isotope ratio trends horizontally throughout the area are not available but the ratios in table 8 do show a wide range, from +8.8 to +27.5. These ratios may be meaningless, however, if isotopic fractionation took place during distillation. In the vertical direction the positive enrichment of the heavy isotope is in agreement with the observations made by Harrison and Thode (1958, p. 2645-2646, 2648), in which there is an enrichment of heavy isotopes with decreasing geologic age.

The decrease in isotope enrichment from zone A to B (figure 11) may indicate a freshening of the water of Lake Uinta accompanied by a basinward shift of its shore line (figure 9, zone B). This shift may represent an increased subsidence rate within the basin. It is interesting to note that limestone was deposited within this stratigraphic interval. The increase in sulfur isotope abundances in zones B to D suggests a resumption in the enrichment of S^{34}, and the expansion of the lake (figure 9, zones B to D) may suggest a decrease in the subsidence rate of the basin.

The increasing isotope ratios of the tars in the four zones represented, from bottom to top, pose a question of the origin of the hydrocarbons. If the tars migrated to their present positions from a common source or if they were formed *in situ*, what caused the differences in their isotopic ratios? Thode and others (1958, p. 2637) suggest:

> The sulphur isotope ratio in petroleum as we find it today will depend on: (1) the initial source of the petroleum sulphur, (2) on the isotope fractionation that occurs during its formation, (3) the isotopic fractionation that occurs in the maturation of the oil, and finally, (4) on the possible addition of new sulphur during its migration in reservoir rock.

They further suggest that the effect of factors (3) and (4) above are either very small or that there is little evidence of their occurrence, and that (1) and (2) are the most important factors to be considered. In this light, migration of the tars from a common source to their present positions does not seem likely, but points to *in situ* formation of the tars.

Radioactivity Associated with Tar Sands

According to Erickson and others (1954, p. 2200) and Bell (1960, p. 45), uranium is often associated with carbonaceous matter and with petroleums and tars. Uranium occurs in the San Rafael Swell region of south and central Utah. Petrified trees and carbonaceous plant remains in the sedimentary rocks are associated with and often contain the uranium mineralization, and in the Temple Mountain area some of the uranium is associated with tar.

Sources of uranium in petroleums are not definitely known (Bell, 1960, p. 55-57), but both organic and inorganic sources are possibilities. The retention mechanism similar to the metal porphyrins for holding the uranium in the oil has not been identified in oils. It has been shown that the uranium is concentrated in asphaltenes and heavy hydrocarbons.

Because of its low arc-sensitivity, uranium was not detected in the tars from the area by spectrographic analyses, but 220 samples of the oil-impregnated sandstone were checked radiometrically, by the U. S. Bureau of Mines, Salt Lake City, Utah, for uranium or other radioactive elements. The average U_3O_8 percent equivalents found in the 220 samples was .00213 and ranged from .0003 to .0037.
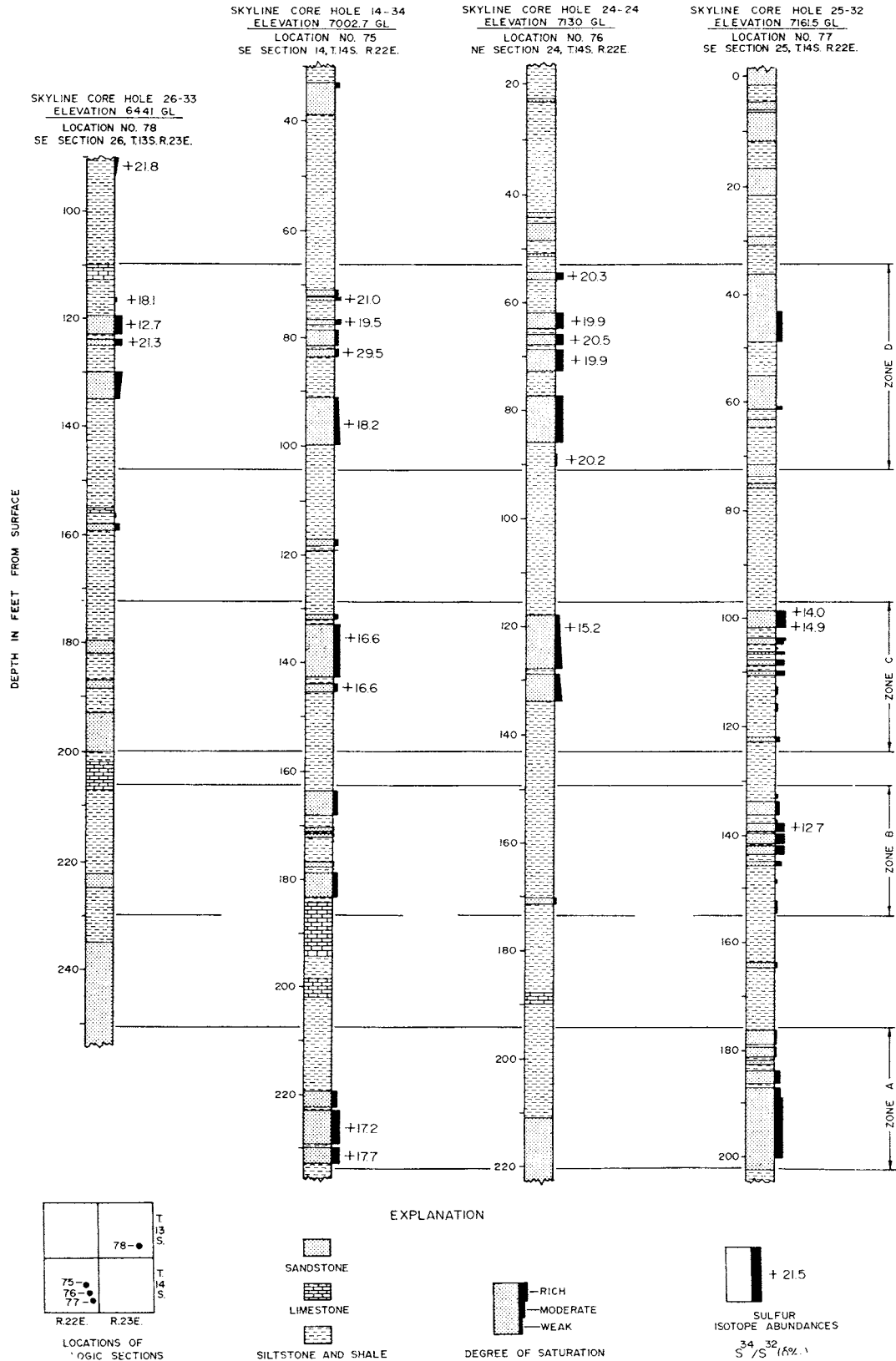
Figure 26. Sulfur isotope abundances in tars from Skyline cores.

Evans and Rampacek (1958) discuss the relationship between the gamma/alpha emission relationship and the radioactive elements in the sample. A gamma/alpha ratio, which is about equal to one, is indicative of uranium and its daughter products present in quantities inversely proportional to the ratio of their half-lives. If the daughter products have been selectively removed from the sample by leaching, the gamma/beta ratio will be less than one. A ratio greater than one indicates that significant quantities of thorium and its daughter products may be present even though uranium and its daughter products may be in equilibrium. The average gamma/beta count ratio of fifteen composite samples from the area is .572, suggesting there has been selective removal of uranium daughter products from the tar sands.

ANALYTICAL DATA CORRELATIONS

Correlation of Oil-impregnated Sandstones

The five zones of oil-impregnated sandstone were identified and correlated by using the 38 measured sections from Byrd (1970, plate 1A to 1), and the measured sections in figure 26. The Mahogany oil shale was used as a reference datum for correlations. In areas where the oil shale is absent, correlations were made by matching similar sequences of barren and oil-impregnated lithologies. The correlation of individual lithologic units throughout the area is difficult, even over short distances. Byrd (1970, plates 2 and 3) shows east-west and north-south lithologic correlations within the area.

Correlation of Tars within Zones by Trace Element Data and Infrared Ratios

The tar analysis for each sample of oil-impregnated sandstone was identified by a sample location number (figure 12) and its number in the ascending sequence of samples collected from that location, as 15–02. Each sample was then systematically assigned to one of the five zones of oil-impregnated sandstone present at that location. Inter- and intra-zone correlations and comparisons were then made using trace element data and infrared ratios.

Isograds of copper, cobalt, nickel, zinc, chromium and manganese drawn for each of the five zones in the area failed to show anomalous concentrations or gradational trends of trace elements within the area, nor were there anomalous differences between the five zones of oil-impregnated sandstone. This lack of anomalous concentrations of trace elements agrees with the observations made by Landes (1959, p. 230).

Correlations Based on Sulphur Isotope Abundances

Figure 26 shows the variation in sulfur isotope abundances among the four zones of oil-impregnated sandstone, A, B, C and D in the area. Correlation of a zone from one location to another based on the average sulfur isotope abundance of the tars within that zone is possible within the area, but the correlation of individual beds within that zone could not be done with the information available.

Correlations Between Trace Element and Infrared Ratio Data

Each of the six quantified trace elements (in ppm) was plotted against each of the nine infrared ratios to observe increase or decrease in trace element concentration with increasing or decreasing infrared ratios. Appendix 3 contains the 54 plots generated for this analysis. No trends appear among the trace element concentrations and the infrared ratios. This fact suggests that the concentrations of trace elements in the oil-forming environment were independent of the tar components or structural groups that were formed or their relative amounts.

ORIGIN OF THE TAR

The origin of the tar impregnating the five zones within the area is not definitely known. Cashion (1967, p. 39) states:

> Source of the bituminous material has not been determined. It is seemingly indigenous to the Green River Formation, although no likely source beds occur adjacent to the impregnated sandstones. There is no evidence that it was derived from the fluid hydrocarbon which filled the gilsonite veins.

Two hypotheses can be entertained regarding the origin of the tars in the area: migration and emplacement from a distant source area or areas, or *in situ* development of the tar with minor migration.

Analysis of infrared, trace element and sulfur isotope data and the relationship of the tars to the sandstones which host them, suggest that the tars are indigenous to the Green River Formation and have had an *in situ* origin.

Infrared studies show that the tars from the area and Red Wash crude oil (basal Green River) are similar. Crude oil from the Wasatch Formation contains appreciable quantities of aromatic material. This difference suggests that the tars in the area originated within the Green River Formation. Landes (1959, p. 229) states:

As a general but not invariable rule, crude oils from the same stratigraphic levels in a single oil province are similar, and those of different ages of rock are dissimilar.

Migration of the tars from the center of the basin into the individual lenticular sandstone beds in the area does not seem likely. Migration would be possible, however, if the hydrocarbons moved from the center of the basin as gases or light petroleum fractions which later condensed to the viscous tar now found in the area.

Bonham (1956, p. 904) observed two phenomena associated with the trace elements in the crude oils of the Seminole area in Oklahoma. First, the concentrations of vanadium and nickel decrease basinward, possibly owing to the removal of metal-bearing porphyrins from the oil during migration. Second, the paleogeographic trends within the producing zone were outlined by high trace element concentrations. Neither of these phenomena was observed in the study area; this fact suggests that little migration of tars has taken place.

The progressive upward increase in the four lower zones (figure 26) of the S^{34} sulfur isotope ratios suggests a difference in geologic age or in the source of original sulfur for the tars. It would be difficult to explain this ratio change if the tars in all five zones had migrated from a common source.

Sulfur isotope ratio data eliminate the gilsonite veins as a major source of the tar in the area. The average sulfur isotope abundance of zone D which extends northeast in the area towards the gilsonite veins is +20. Gilsonite lying north of the area has isotope abundances greater than +20. Thode and others (1958, p. 2634) report an isotope abundance of +24.0 from the Bonanza vein, and Harrison and Thode (1958, p. 2645) report a gilsonite isotope abundance of +27.9. Gilsonite does impregnate some sandstones close to the veins. Sample No. 63–01 (figure 27) in the northeast corner of the study area, is from a sandstone bed cut by a gilsonite vein a short distance to the north. The isotope abundance of this sample is +27.5.

The tars in the area have been migrating through the oil-impregnated sandstones for years as shown by the large buildup of tar near some seeps (figures 12 and 13), but the force driving them appears to be near-surface groundwater rather than pressure from within the reservoir.

Tar migration into unsaturated sandstone through cracks and permeable zones appears to have been facilitated by weak pressure gradients. In some cases migra-

tion has progressed to but not into small joints. In other cases migration takes place obliquely through a uniform sandstone bed, not penetrating the entire unit and often stopping for no apparent reason.

SUMMARY AND CONCLUSIONS

The study area is underlaid by five zones of oil-impregnated sandstone, each zone consisting of one or more beds of sandstone. The saturation of these beds depends upon their porosity and permeability and to local joint control, but does not depend upon structure.

An *in situ* combustion process appears to be the most economical tar recovery method for the area because of the viscous nature of the tar, the favorable porosity and permeability of the thin-bedded sandstones. The lack of water in the area and the variable depth beneath the surface of the oil-impregnated sandstones make mining and subsequent tar removal methods impractical.

Fractional distillation of the low gravity tar yields a medium lubricating distillate averaging 20.6° API with a pour point of less than 5° F. About 74 percent of the tar remains as residuum after distillation. A greater yield of high gravity fractions may be obtained by hydrogenation of the tar. The results of hydrogenation tests show that tar sand oils compare favorably with oil shale oils and bituminous coals as sources of synthetic hydrocarbon products. The weight-percent of ash in the tar increases as the tar becomes more viscous. The tar ash contains quartz, feldspar, calcite, kaolinite and noncrystalline material, but the ash of the distillate, less than .05 weight-percent, contains only a trace of crystalline material. The tar distillate and residuum contain about 31.6 weight-percent carbon residue.

The tar contains an average of .323 percent of free and combined sulfur. Tars of Tertiary age in the Uinta Basin contain much less sulfur than those of Triassic and Permian age elsewhere in Utah.

The nitrogen content of the tar averages .49 percent and does not show the age-content relationship exhibited by the sulfur.

Oxygen combines with the tar as it migrates to the surface, forming such organic compounds as acids, phenols, ketones and aldehydes. This fact accounts for the relatively small amounts of oxygen compounds in subsurface samples compared to surface samples.
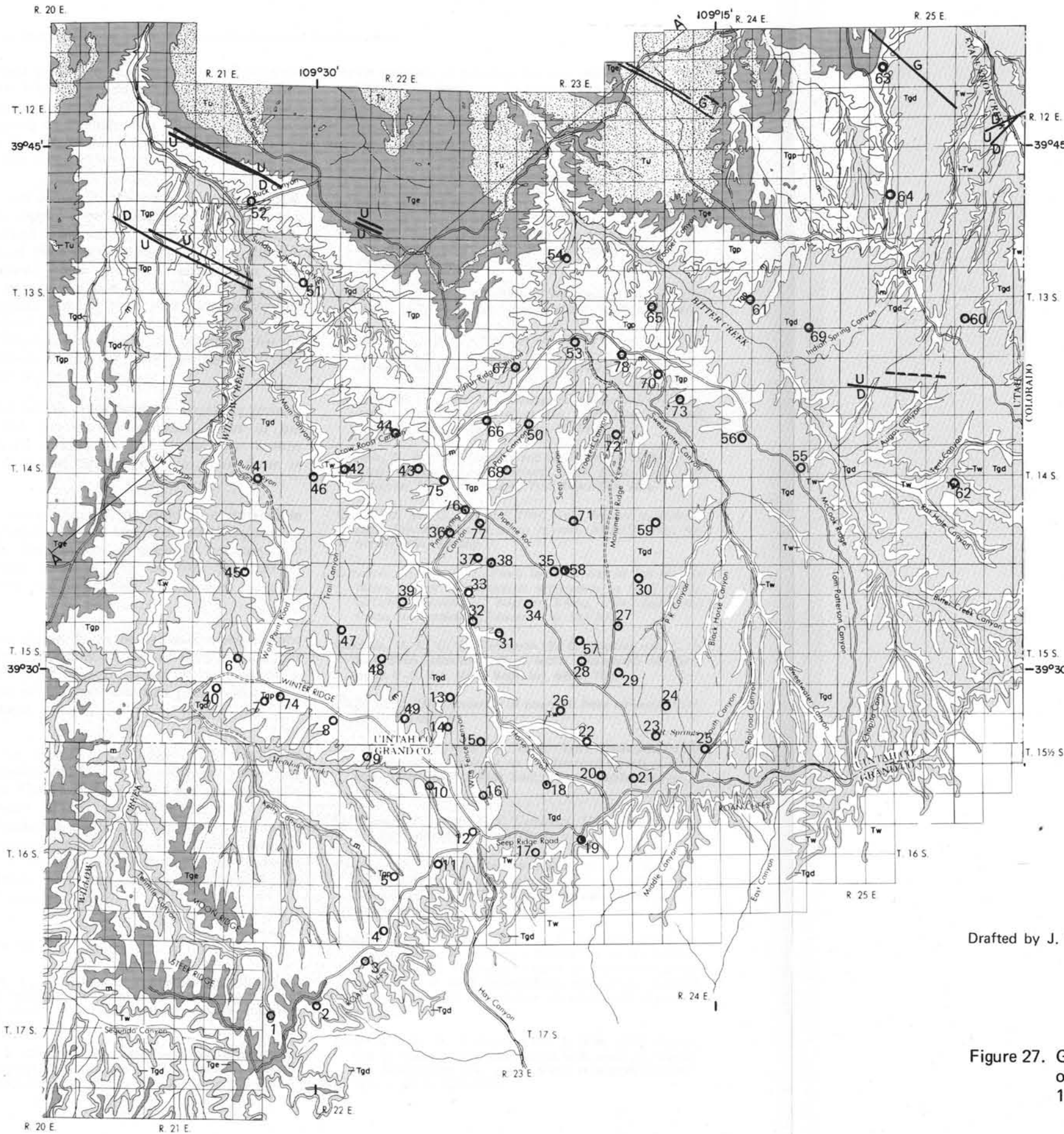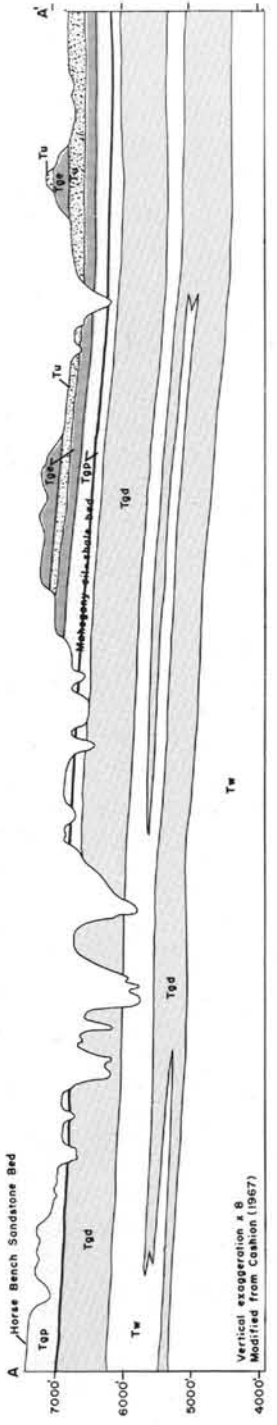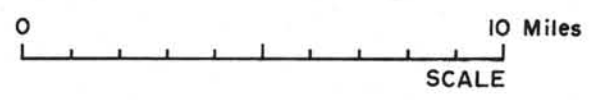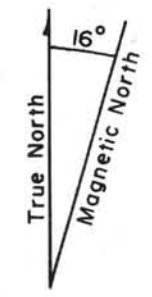
Figure 27. Geologic map and section showing sample locations in the southeast part of the Uinta Basin, Utah (base map and geology modified from Cashion, 1967).

Drafted by J. Wallace Gwynn

Infrared analyses of the tars and distillates show that the tar is composed mainly of alkane or paraffin-type hydrocarbons with small amounts of aromatic and oxygen-bearing compounds. Gas chromatography data show that the alkanes range from C_6 or C_7 to at least C_{27}, and that many isomers are present.

The tars contain 17 trace elements, and of these, chromium, copper, cobalt, manganese, nickel and zinc were measured quantitatively. Porphyrins, which contain some of these trace elements, occur in the tars. No anomalous trace element concentrations were found in any of the five zones. Plots of one trace element against another show that the quantity and distribution of the trace elements in tar ashes and non-saturated lithologies were different, indicating that the trace elements in the tar were not absorbed from adjacent lithologies.

Sulfur isotope ratios suggest a decreasing geologic age for the tars in the individual zones of oil-impregnated sandstone, and that the isotope abundances in the tars are different from those in gilsonite.

The average amount of radioactive material in the oil-impregnated sandstones is .00213 U_3O_8 percent equivalents, and the low gamma/alpha emission ratio suggests that some of the daughter products of uranium have been selectively leached from the sandstones.

There appears to be no correlation between the individual compounds in the tar and the concentrations of trace elements. The formation of tar probably is independent of the trace elements present or of their concentrations.

The tar appears to be indigenous to the Green River Formation and to have formed within sandstones it occupies. The tar apparently did not come from the gilsonite veins to the north; differences in sulfur isotope abundances between the gilsonite and the tar mitigate against this possibility. Low-pressure gradient migration of the tars has moved the tar into some of the sandstones. Tar seeps indicate migration of the tar during wet seasons.

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APPENDIX 1

Table 1A. Core analysis results (from Byrd, 1970; data prepared by Core Laboratories, Inc., Casper, Wyoming), Green River (Eocene) Formation, Skyline cores, Uintah County, P. R. Spring (figure 27).

Sample No.	Depth (ft)	Permeability (millidarcys)	Porosity (percent)	Residual saturation percent pore[1]	
				Oil	Total water
Skyline Core 25-32 – Location 77					
1	101-02	151	25.7	40.1	12.7
2	134-35	257	23.8	29.8	13.4
3	138-39	116	26.5	54.8	8.3
4	185-86	4,446	28.8	45.7	11.1
5	187-88	1,384	25.5	24.7	15.3
6	188-89	2,075	21.6	45.0	10.2
7	189-90	3,755	28.8	29.5	14.9
8	190-91	1,670	28.8	20.2	11.5
9	191-92	1,976	27.4	20.1	15.7
10	192-93	2,570	28.8	23.3	14.9
11	193-94	1,185	22.5	25.8	14.2
12	194-95	4,350	28.3	20.8	14.8
13	195-96	3,260	28.9	25.0	14.2
14	196-97	4,940	26.0	22.7	16.2
15	198-99	4,940	27.1	18.8	15.8
16	200-01	1,037	25.5	16.5	12.6
Skyline Core 24-24 – Location 76					
1	62-63	820	25.5	71.3	7.1
2	63-64	493	25.5	72.9	7.5
3	83-84	6,917	27.0	74.1	4.4
4	84-85	5,930	26.3	74.9	4.6
5	85-86	6,117	30.1	54.2	7.3
6	118-19	145	24.9	28.9	13.8
7	119-20	238	22.5	40.5	9.8
8	120-21	988	28.2	27.6	14.9
9	121-22	22	25.3	37.2	12.7
10	122-23	790	29.6	30.7	14.2

Sample No.	Depth (ft)	Permeability (millidarcys)	Porosity (percent)	Residual saturation percent pore[1]	
				Oil	Total water
Skyline Core 24-24 – Location 76					
11	123-24	800	27.4	33.2	11.7
12	124-25	527	28.8	49.0	7.7
13	125-26	1,384	33.7	79.5	4.7
14	126-27	890	33.6	89.9	3.6
15	127-28	116	25.6	80.5	7.8
16	129-30	440	23.6	71.2	6.4
Skyline Core 26-33 – Location 78					
1	91.5-92.5	295	27.9	67.4	7.9
2	119-20	257	21.0	26.7	10.5
3	120.5-21	3,360	17.0	46.0	7.1
4	121-22	3,656	30.1	88.0	9.0
5	122-23	203	22.1	41.0	10.0
6	124-25	246	23.8	43.3	13.4
7	131-32	220	29.1	80.5	9.3
8	132-33	43	24.5	40.0	9.0
9	133-34	49	24.3	36.6	9.1
10	134-35	20	22.6	24.8	14.3
11	158-59	790	21.4	36.5	11.7
Skyline Core 14-34 – Location 75					
1	82-83	1,581	31.5	58.7	10.2
2	96-97	319	26.6	77.5	8.3
3	133-34	330	25.8	43.7	12.4
4	135-36	1,778	29.4	37.1	10.9
5	233-24	2,470	28.8	60.0	7.6
6	266-27	4,940	28.7	43.5	11.2

[1] Percent oil and water of total porosity.

Table 2A. Outcrop sample analyses (from Byrd, 1970; data prepared by Core Laboratories, Inc., Denver, Colorado), Uintah-Grand counties well outcrop samples, southeast Uinta Basin.

Sample No.	Depth[1] (feet)	Permeability in millidarcys Before ext.[2]	After ext.[2]	Porosity percent	Residual liquid saturation Percent volume	Percent pore[3]	Percent by weight	Total water Percent pore[3]	Oil Gal/ton
1	3		955	31.7		18.6		1.9	7.0
2	4-L	2,578	5,700	32.5	6.4	19.7	3.3	1.5	8.4
3	4-M		1,210	31.0		27.4		1.9	10.6
4	4-U	1,690	1,720	33.6	0.9	2.7	0.5	1.2	1.2
5	5-6L		3,180	28.8		9.7		1.4	3.6
6	5-7M		1,655	29.9		23.1		2.7	8.6
7	5-8U	10	3,120	36.7	23.2	63.2	11.7	2.5	29.6
8	6-2M	218	925	31.5	9.8	31.1	4.9	2.9	12.5
9	6-7U	98	578	31.0	11.3	37.7	6.3	1.3	15.8
10	7-2L		2,610	33.2		53.3		3.0	21.6
11	7-3		Frac plug	35.1		11.1		1.4	5.3
12	7-6		930	30.5		15.7		2.0	6.2
13	7-8	13	Frac plug	29.5	12.4	42.0	6.0	3.4	15.1
14	7-1OU	15	1,425	29.0	10.6	36.6	5.1	2.7	13.0
15	10-4U		Frac plug	31.0		15.8		1.6	6.5
16	11-3L		0.01	7.1		0.0		7.0	0.0
17	11-6		0.07	16.0		54.3		4.4	9.4
18	11-7M	0.8	132	27.3	14.7	53.9	6.8	3.7	17.3
19	11-9		918	24.7		38.1		3.6	10.6
20	11-10		79	24.7		12.6		4.0	3.8
21	11-11U	2.7	2,244	31.6	24.2	76.7	11.0	1.9	27.8
22	12-1L		2,980	28.9		48.1		3.5	17.0
23	12-3M		2,318	23.8		29.4		3.8	7.9
24	12-5U		128	28.8		10.1		3.5	3.8
25	15-L		928	24.6		35.8		2.4	10.6
26	15-U		10	21.5		17.2		4.6	4.3
27	16		990	26.1		31.6		1.5	9.8
28	17-L		Frac plug	29.7		22.9		0.7	8.6
29	17-U		356	24.9		32.1		2.8	8.9
30	21	86	690	25.7	3.5	13.6	1.7	2.3	4.3
31	23-U	69	155	25.3	7.6	30.0	3.5	3.2	8.9
32	24-1L	186	215	24.3	2.6	10.7	1.2	0.8	3.1
33	24-4U		662	27.0		18.9		3.0	6.2

[1] The first number in Depth column is the stratigraphic section number. The second number is the sample number in that section, and L, M, U refer to the lower, middle and upper zones of saturation within that section.

[2] Permeability before and after extraction of bitumen.

[3] Percent oil and percent water of total porosity.

APPENDIX 2

Crude petroleum analysis, Bureau of Mines Laramie laboratory

IDENTIFICATION

P. R. Springs Deposit
Main Canyon Tar Seep

Grand County, Utah
NE1/4NE1/4, sec 5,
T 16 S, R 24E

GENERAL CHARACTERISTICS

Gravity, specific, 0.974
Sulfur, percent,   .34
Viscosity, Saybolt Universal at

Gravity, $^{\circ}$ API, 13.8

Pour point, $^{\circ}$ F.,
Color, brownish black
Nitrogen, percent, 0.77

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Stage 1--Distillation at atmospheric pressure,   mm. Hg

First drop, 343 $^{\circ}$ F. (stage 2)

Fraction No.	Cut temp. $^{\circ}$ F.	Percent	Sum, percent	Sp. gr., 60/60° F.	$^{\circ}$ API, 60° F.	C. I.	Refractive index, n_D at 20° C.	Specific dispersion	S. U. visc., 100° F.	Cloud test, $^{\circ}$ F.
1	122									
2	167									
3	212									
4	257									
5	302									
6	347									
7	392									
8	437									
9	482									
10	527									.

Stage 2--Distillation continued at 40 mm. Hg

11	392	1.9	1.9	0.896	26.4		1.48662	124.8	48	< 5
12	437	2.3	4.2	.901	25.6	54	1.49348	125.9	62	< 5
13	482	3.1	7.3	.912	23.7	56	1.50105	124.1	97	< 5
14	527	3.4	10.7	.925	21.5	59			195	< 5
15	572	9.5	20.2	.936	19.7	61			700	< 5
Residuum		75.8	96.0	.993	11.0					.

Carbon residue, Conradson: Residuum, 14.2 percent; crude, 11.0 percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	$^{\circ}$ API	Viscosity
Light gasoline				
Total gasoline and naphtha				
Kerosine distillate				
Gas oil	1.2	0.895	26.6	
Nonviscous lubricating distillate	4.6	.897-.913	26.3-23.5	50-100
Medium lubricating distillate	3.3	.913-.926	23.5-21.3	100-200
Viscous lubricating distillate	11.1	.926-.944	21.3-18.4	Above 200
Residuum	75.8	.993	11.0	
Distillation loss	4.0			

IDENTIFICATION

P. R. Spring Deposit
79-83 Feet

Uintah County, Utah
Sec 24,
T 14 S, R 22 E (SLM)

GENERAL CHARACTERISTICS

Gravity, specific, 0.995
Sulfur, percent,   .33
Viscosity, Saybolt Universal at

Gravity, ° API, 10.7

Pour point, ° F.,
Color, brownish black
Nitrogen, percent, 0.88

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Stage 1--Distillation at atmospheric pressure,   mm. Hg

First drop, 342 ° F. (stage 2)

Fraction No.	Cut temp. ° F.	Percent	Sum, percent	Sp. gr., 60/60° F.	° API, 60° F.	C. I.	Refractive index n_D at 20° C.	Specific dispersion	S. U. visc., 100° F.	Cloud test, ° F.
1	122									
2	167									
3	212									
4	257									
5	302									
6	347									
7	392									
8	437									
9	482									
10	527									

Stage 2--Distillation continued at 40 mm. Hg

11	392	1.6	1.6	0.893	27.0		1.48441	112.0	45	< 5
12	437	2.2	3.8	.911	23.8	59	1.49146	132.7	55	< 5
13	482	2.9	6.7	.918	22.6	59	1.50004	134.9	85	< 5
14	527	5.6	12.3	.939	19.2	66			320	< 5
15	572	11.8	24.1	.948	17.8	67			1150	< 5
Residuum		74.8	98.9	1.002	9.7					

Carbon residue, Conradson: Residuum,   percent; crude,   percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	° API	Viscosity
Light gasoline				
Total gasoline and naphtha				
Kerosine distillate				
Gas oil	1.8	0.894	26.8	
Nonviscous lubricating distillate	3.7	.903-.920	25.2-22.3	50-100
Medium lubricating distillate	1.8	.920-.929	22.3-20.8	100-200
Viscous lubricating distillate	16.8	.929-.954	20.8-16.8	Above 200
Residuum	74.8	1.002	9.7	
Distillation loss	1.1			

IDENTIFICATION

P. R. Spring Deposit
Surface

Uintah County, Utah
SE1/4SE1/4, sec 36
T 15 S, R 22 E (SLM)

GENERAL CHARACTERISTICS

Gravity, specific, 1.027   Gravity, ° API, 6.3   Pour point, ° F.,
Sulfur, percent,   .42   Color, brownish black
Viscosity, Saybolt Universal at   Nitrogen, percent, 1.26

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Stage 1--Distillation at atmospheric pressure,   mm. Hg

First drop, 360 ° F. (stage 2)

Fraction No.	Cut temp. ° F.	Percent	Sum, percent	Sp. gr., 60/60° F.	° API, 60° F.	C. I.	Refractive index, n_D at 20° C.	Specific dispersion	S. U. visc., 100° F.	Cloud test, ° F.
1	122									
2	167									
3	212									
4	257									
5	302									
6	347									
7	392									
8	437									
9	482									
10	527									

Stage 2--Distillation continued at 40 mm. Hg

11	392	1.9	1.9	0.909	24.2		1.48527	114.9	43	< 5
12	437	2.0	3.9	.907	24.5	57	1.49309	124.3	52	< 5
13	482	2.3	6.2	.927	21.1	63	1.50249	138.1	87	< 5
14	527	5.7	11.9	.934	20.0	63			185	30
15	572	8.0	19.9	.951	17.3	68			1470	80
Residuum		74.1	94.0	1.021	7.1					

Carbon residue, Conradson: Residuum, 21.3 percent; crude, 15.8 percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	° API	Viscosity
Light gasoline				
Total gasoline and naphtha				
Kerosine distillate				
Gas oil	2.5	0.908	24.3	
Nonviscous lubricating distillate	3.0	.909-.928	24.2-21.0	50-100
Medium lubricating distillate	3.6	.928-.935	21.0-19.8	100-200
Viscous lubricating distillate	10.8	.935-.961	19.8-15.7	Above 200
Residuum	74.1	1.021	7.1	
Distillation loss	6.0			

IDENTIFICATION

P. R. Springs Deposit
190-194 feet

Uintah County, Utah
Sec 25,
T 14 S, R 22 E (SLM)

GENERAL CHARACTERISTICS

Gravity, specific, 0.993
Sulfur, percent, .40
Viscosity, Saybolt Universal at

Gravity, $^\circ$ API, 11.0

Pour point, $^\circ$ F.,
Color, brownish black
Nitrogen, percent, 1.08

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Stage 1--Distillation at atmospheric pressure, mm. Hg

First drop, $^\circ$ F. (stage 2)

Fraction No.	Cut temp. $^\circ$ F.	Percent	Sum, percent	Sp. gr., 60/60° F.	$^\circ$ API, 60° F.	C. I.	Refractive index, n_o at 20° C.	Specific dispersion	S. U. visc., 100° F.	Cloud test, $^\circ$ F.
1	122									
2	167									
3	212									
4	257									
5	302									
6	347									
7	392									
8	437									
9	482									
10	527									

Stage 2--Distillation continued at 40 mm. Hg

11	392									
12	437									
13	482									
14	527									
15	572									
Residuum										

Carbon residue, Conradson: Residuum,   percent; crude, 15.2 percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	$^\circ$ API	Viscosity
Light gasoline				
Total gasoline and naphtha				
Kerosine distillate				
Gas oil				
Nonviscous lubricating distillate				50-100
Medium lubricating distillate				100-200
Viscous lubricating distillate				Above 200
Residuum				
Distillation loss				

IDENTIFICATION

P. R. Springs Deposit
137-141 feet

Uintah County, Utah
Sec 14,
T 14 S, R 22 E (SLM)

GENERAL CHARACTERISTICS

Gravity, specific, 1.004
Sulfur, percent,   .36
Viscosity, Saybolt Universal at

Gravity, $^\circ$ API, 9.4

Pour point, $^\circ$ F.,
Color, brownish black
Nitrogen, percent, 0.84

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Stage 1—Distillation at atmospheric pressure,   mm. Hg

First drop, 334 $^\circ$ F. (stage 2)

Fraction No.	Cut temp. $^\circ$ F.	Percent	Sum, percent	Sp. gr., 60/60° F.	$^\circ$ API, 60° F.	C. I.	Refractive index, n_o at 20° C.	Specific dispersion	S. U. visc., 100° F.	Cloud test, $^\circ$ F.
1	122									
2	167									
3	212									
4	257									
5	302									
6	347									
7	392									
8	437									
9	482									
10	527									

Stage 2—Distillation continued at 40 mm. Hg

11	392	3.1	3.1	0.891	27.3		1.48471	128.3	45	< 5
12	437	2.8	5.9	.903	25.2	55	1.49304	141.2	58	< 5
13	482	4.5	10.4	.930	20.7	64	1.50460	134.0	110	< 5
14	527	4.1	14.5	.939	19.2	66			420	< 5
15	572	12.5	27.0	.962	15.6	73			2550	< 5
Residuum		71.0	98.0	1.010	8.6					

Carbon residue, Conradson: Residuum, 16.9 percent; crude, 12.5 percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	$^\circ$ API	Viscosity
Light gasoline				
Total gasoline and naphtha				
Kerosine distillate				
Gas oil	2.7	0.891	27.3	
Nonviscous lubricating distillate	4.7	.896-.925	26.4-21.5	50-100
Medium lubricating distillate	2.0	.925-.933	21.5-20.2	100-200
Viscous lubricating distillate	17.6	.933-.980	20.2-12.9	Above 200
Residuum	71.0	1.010	8.6	
Distillation loss	2.0			

APPENDIX 3

Infrared peak-height ratios between surface and subsurface samples

S, U, W, Y represent surface tar samples from zones Z, B, C and D resp. T, V, X, Z represent subsurface tar samples from zones A, B, C and D resp. B represents non saturated subsurface samples (no specific zone).

APPENDIX 4

Abundance of trace elements from tar ash

S, U, W, Y represent surface tar samples from zones Z, B, C and D resp. T, V, X, Z represent subsurface tar samples from zones A, B, C and D resp. B represents non saturated subsurface samples (no specific zone).

BARREN ROCK

ZINC

CHROMIUM

COPPER

COPPER

TAR ASH

ZINC

CHROMIUM

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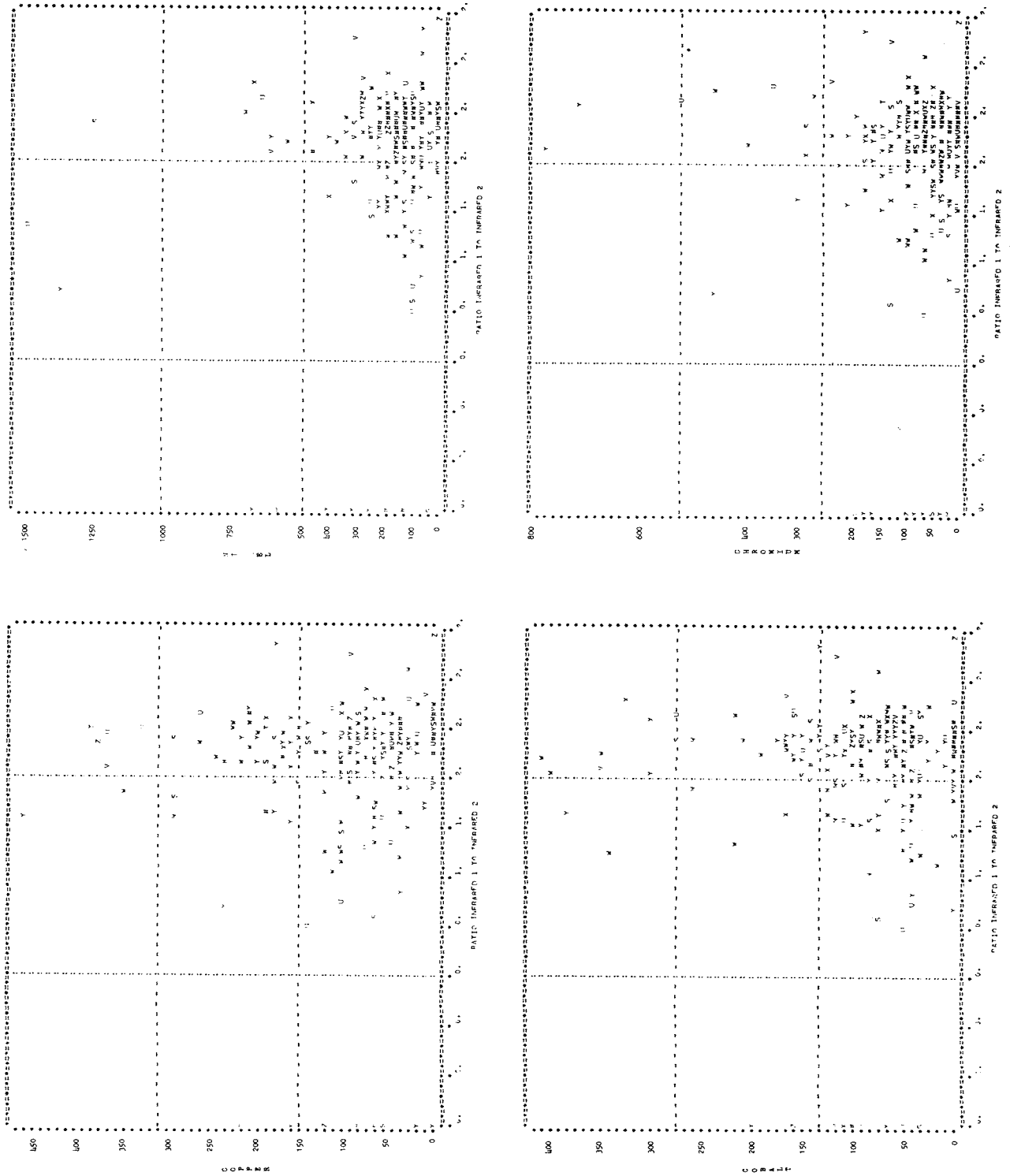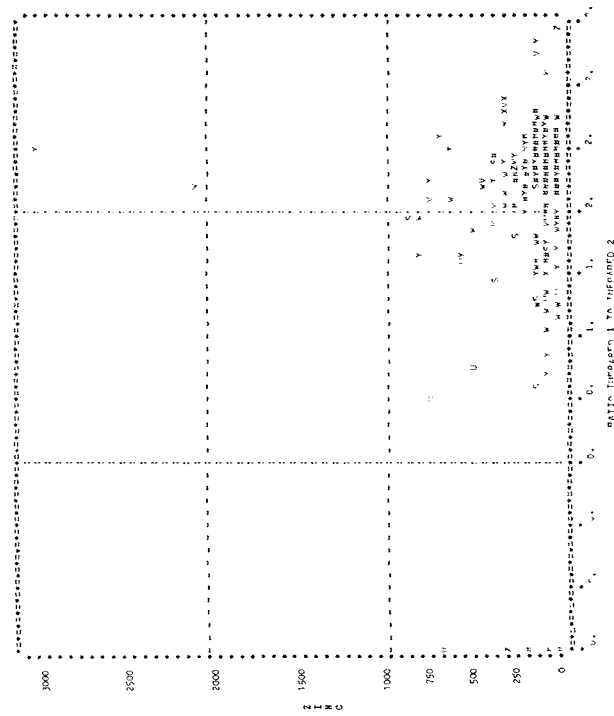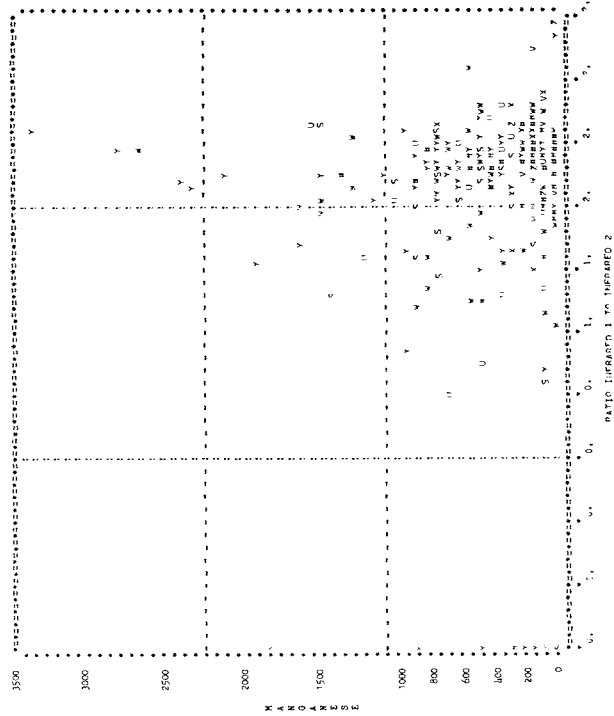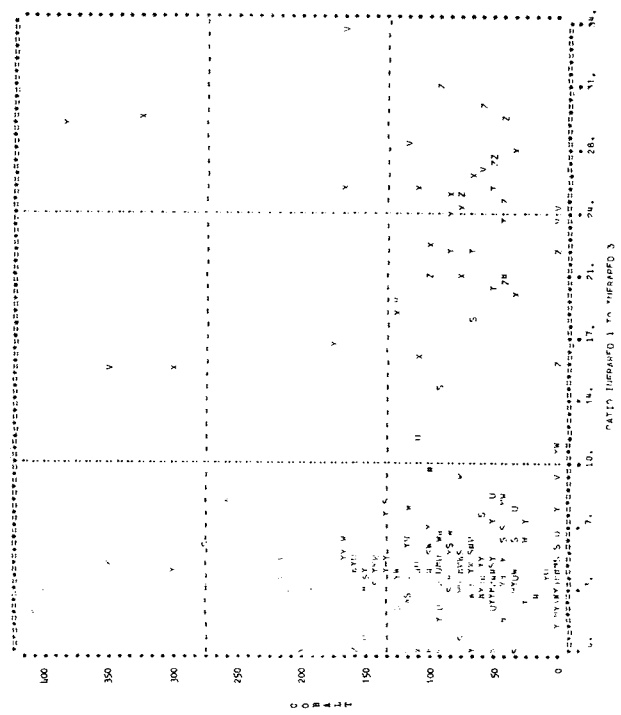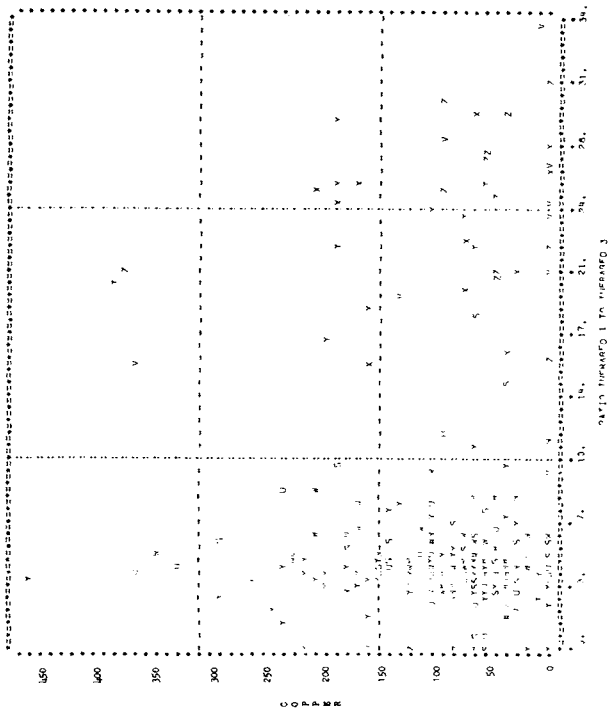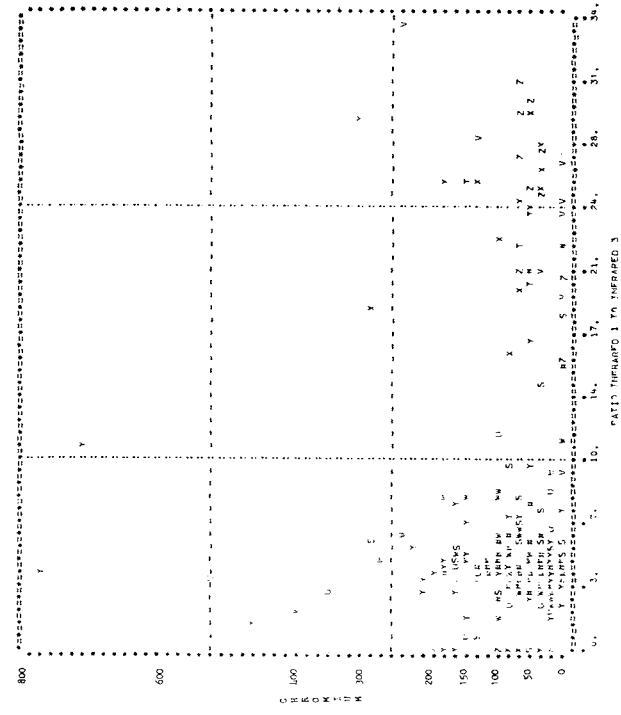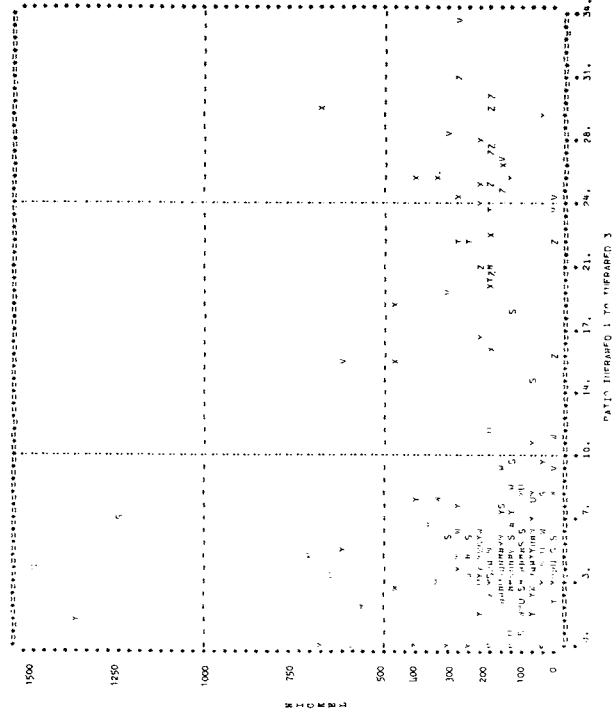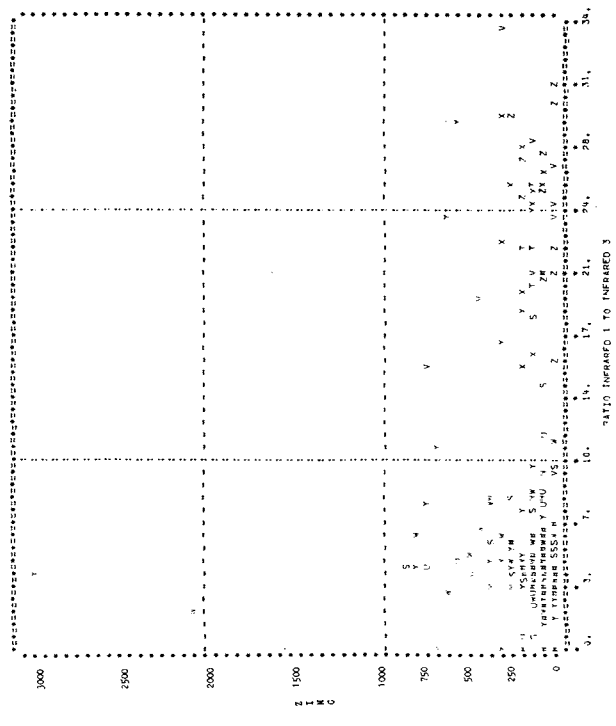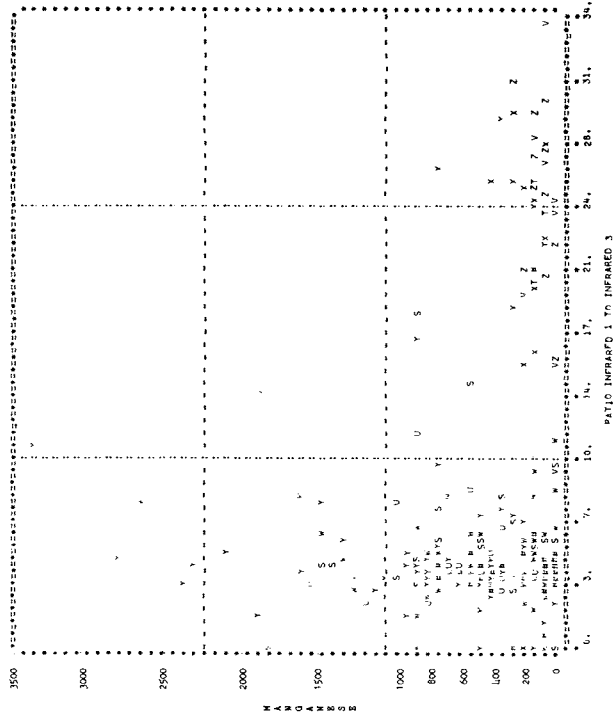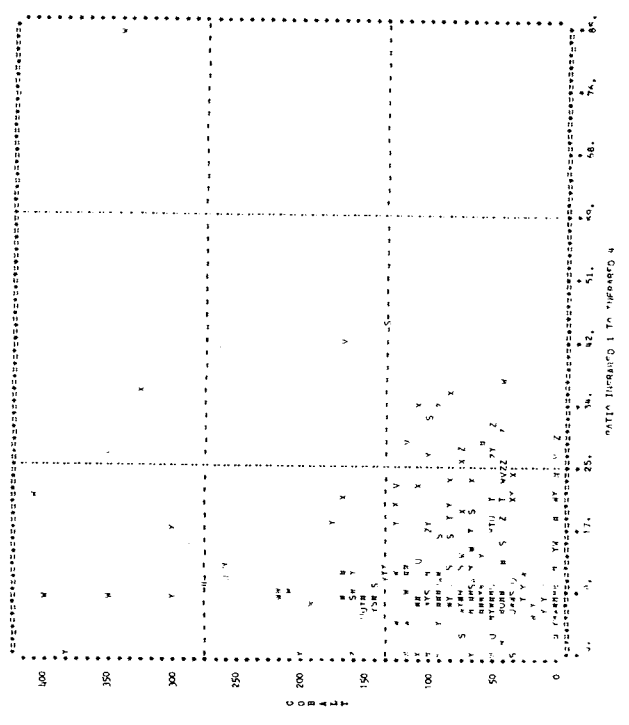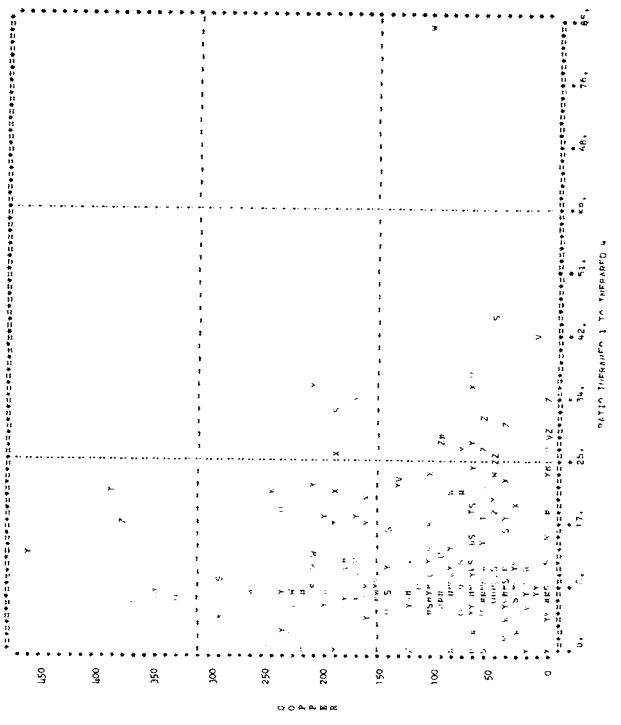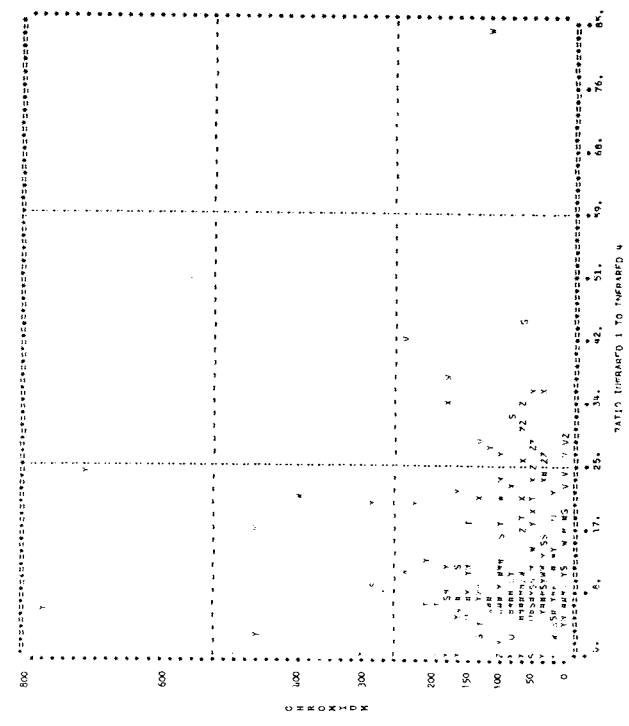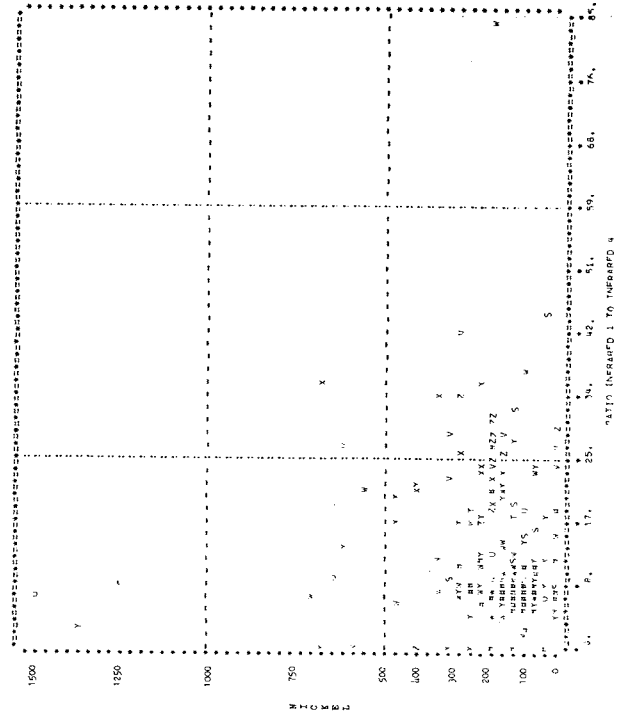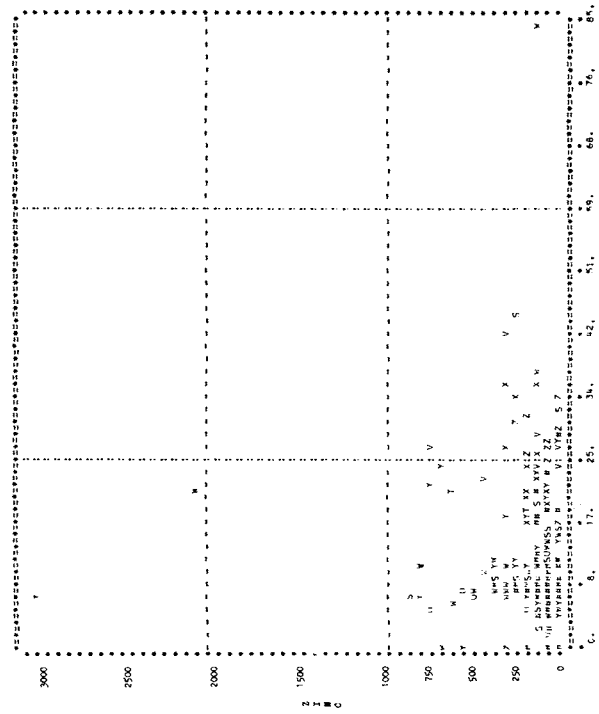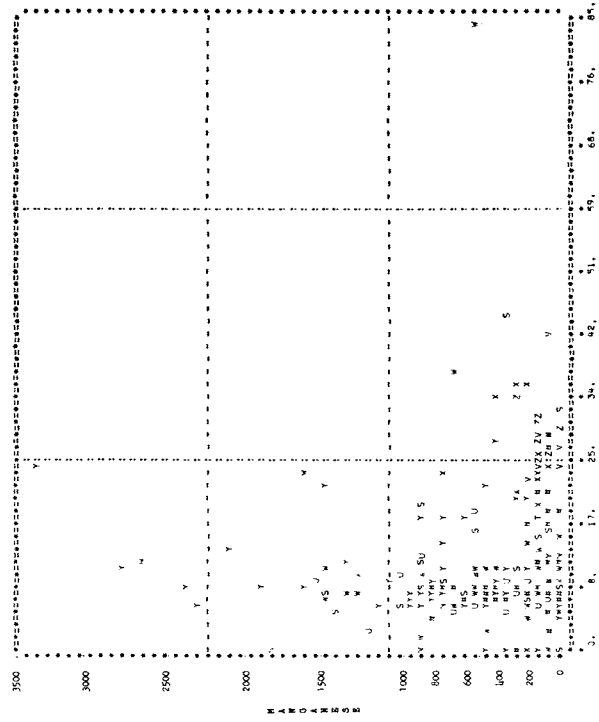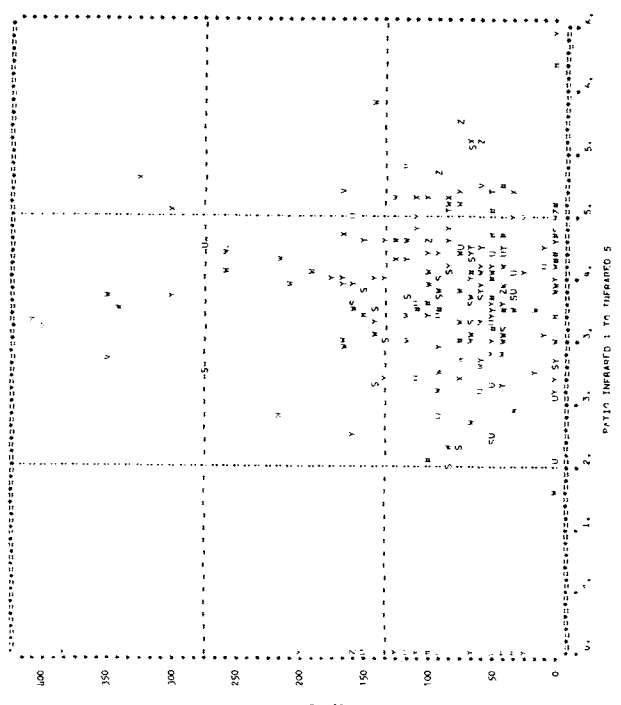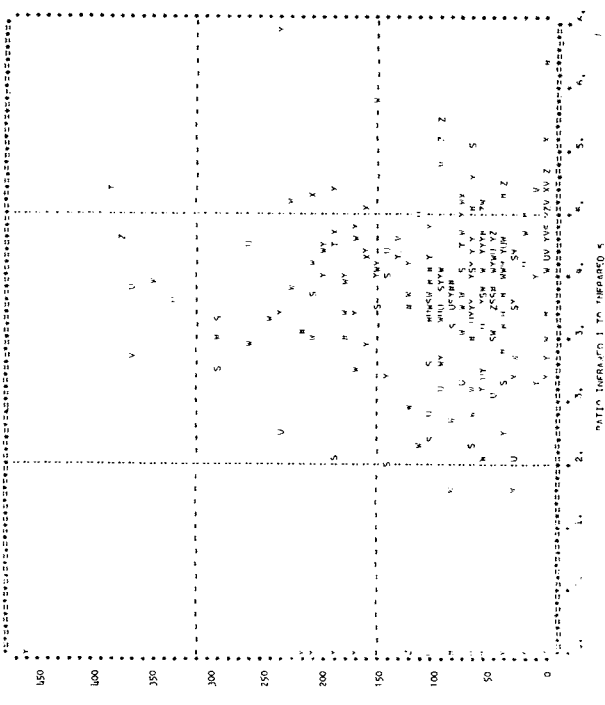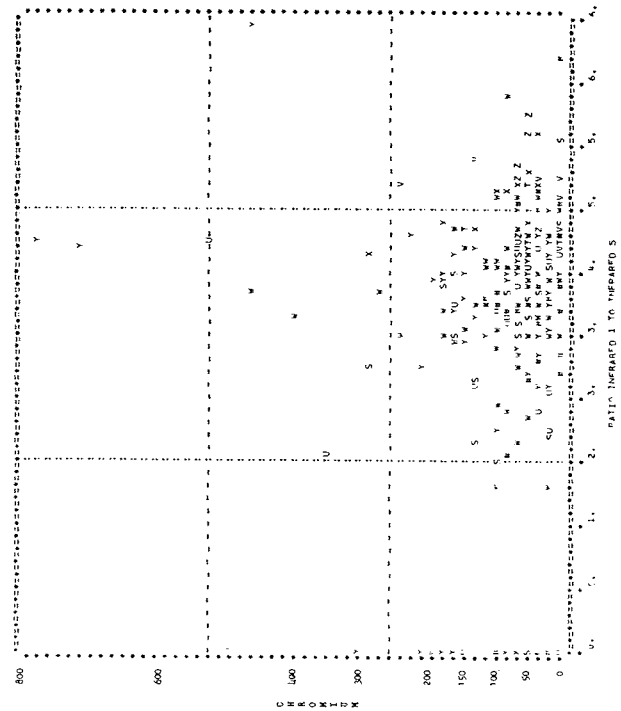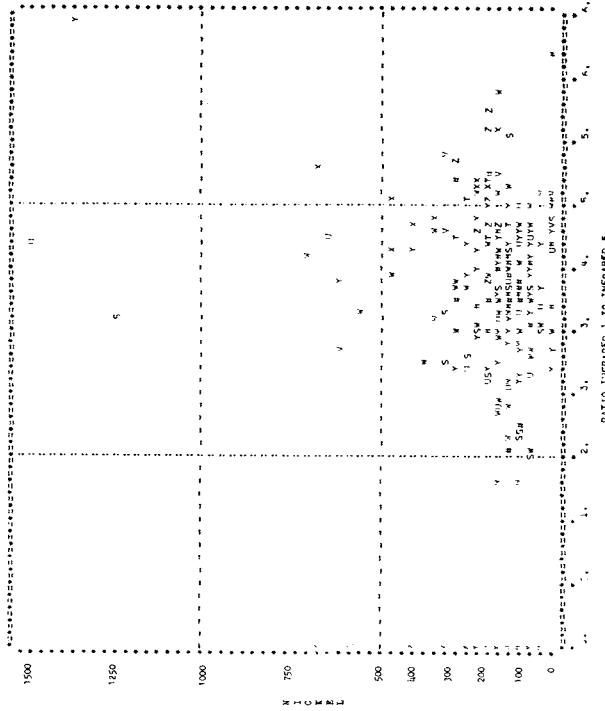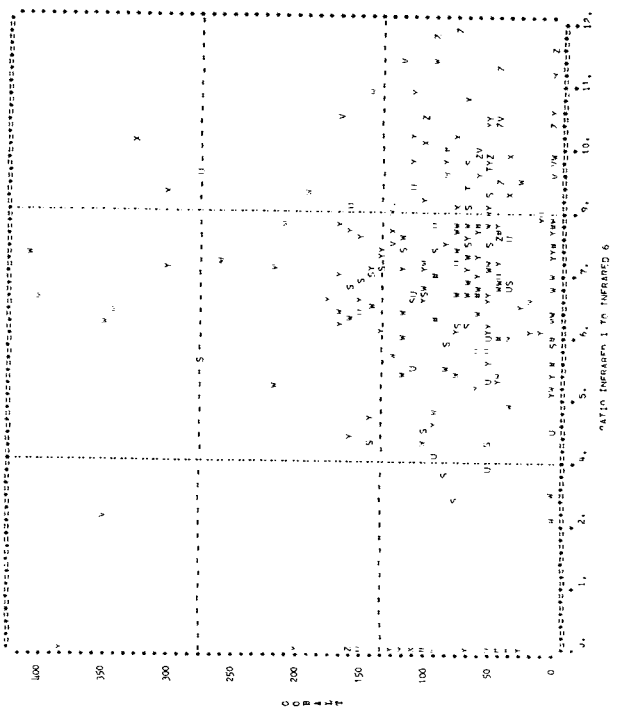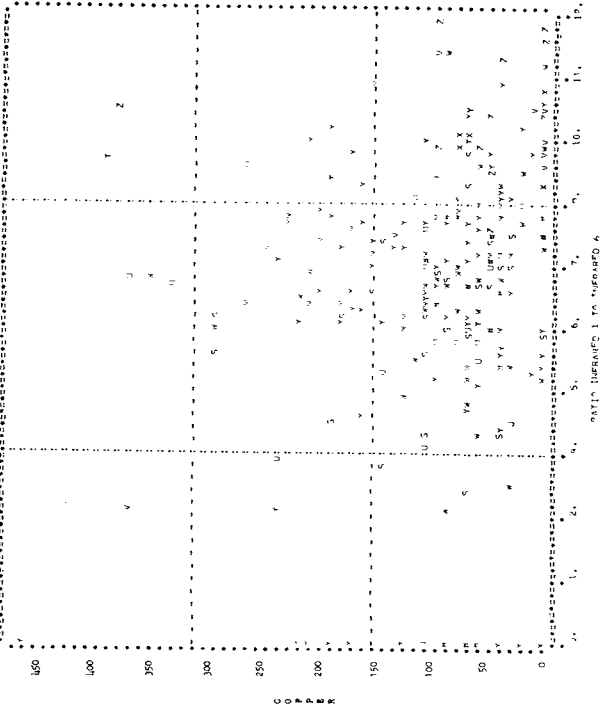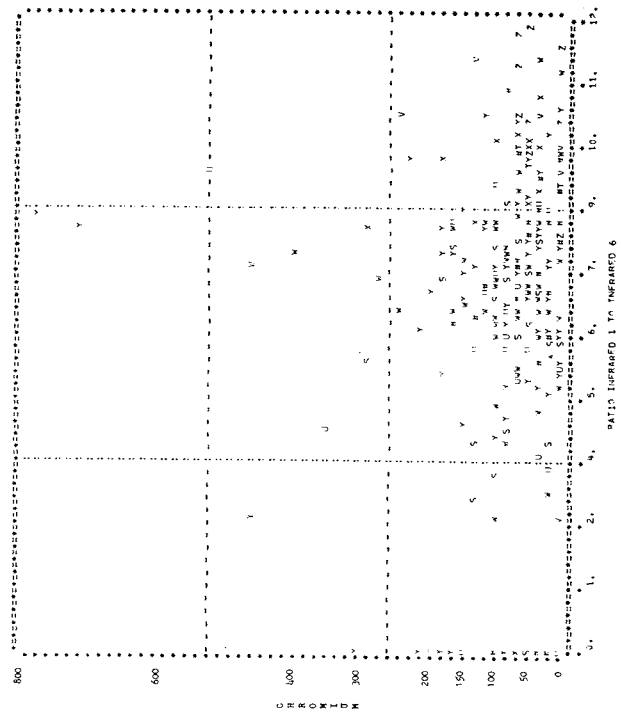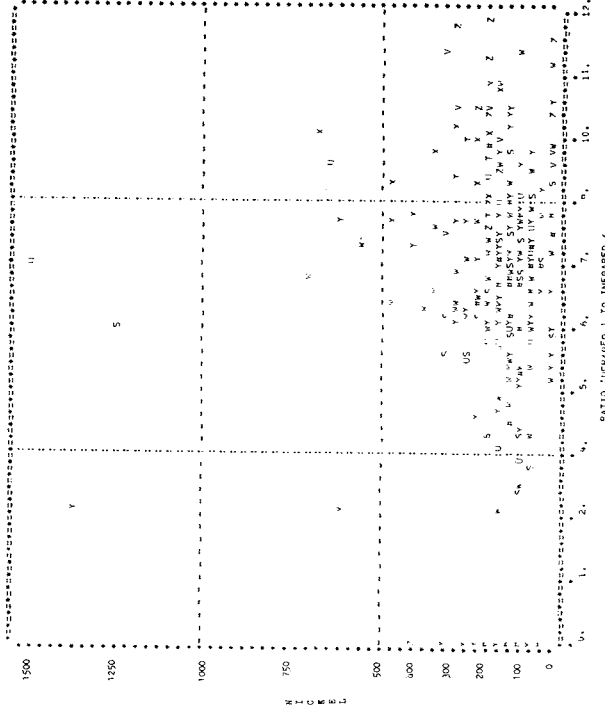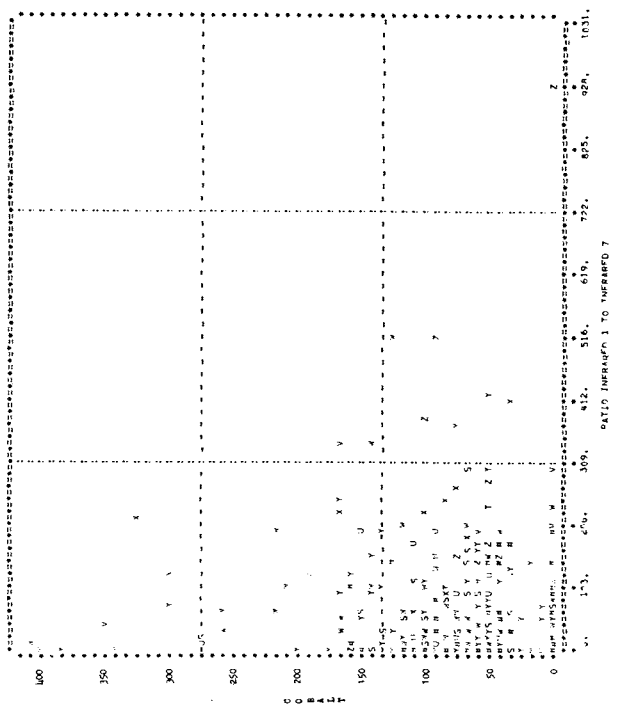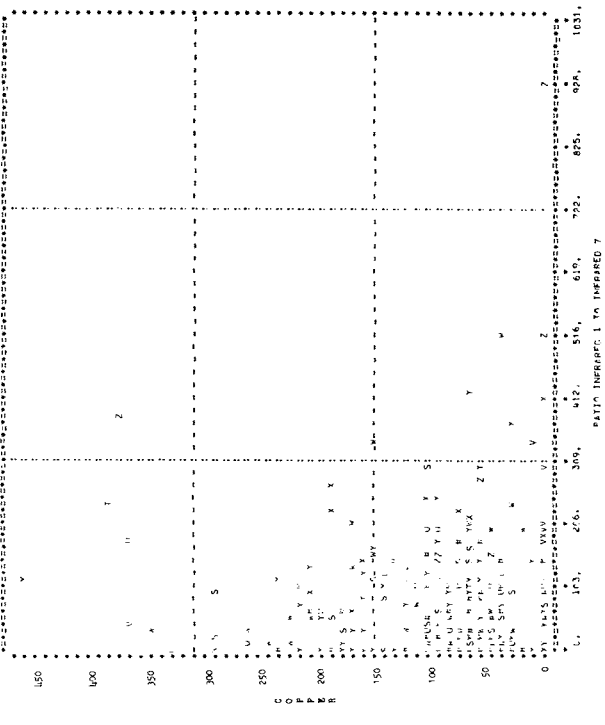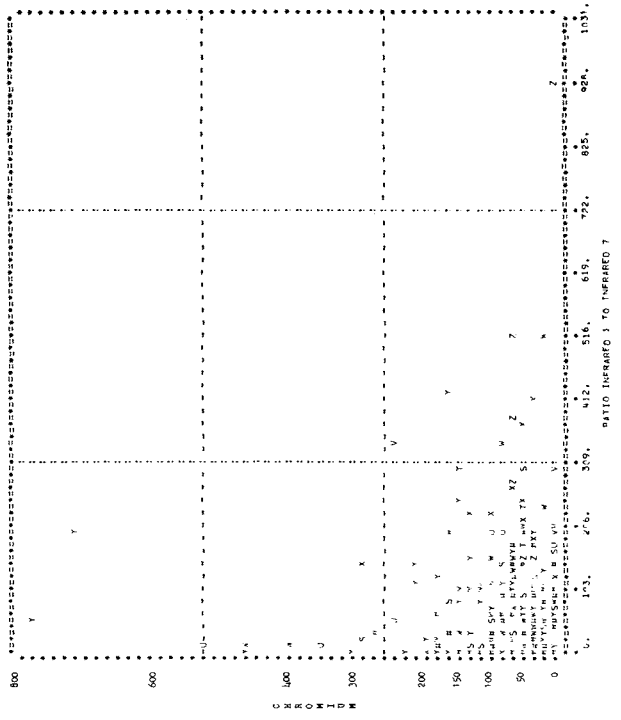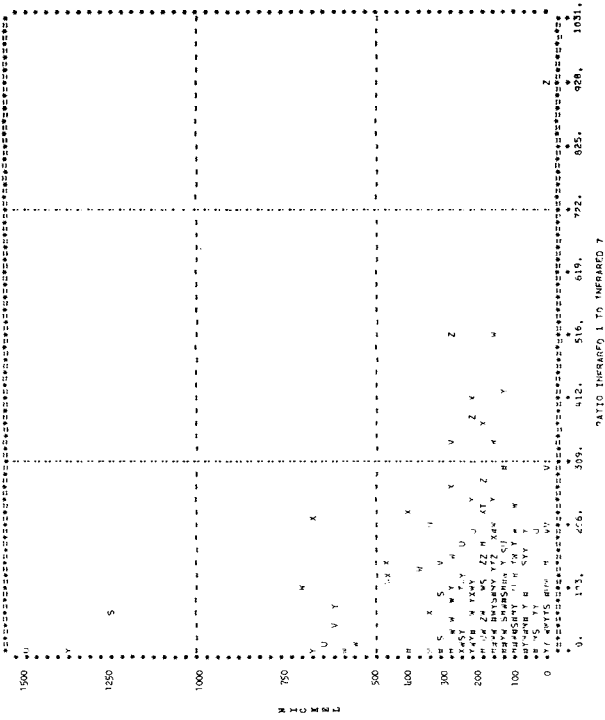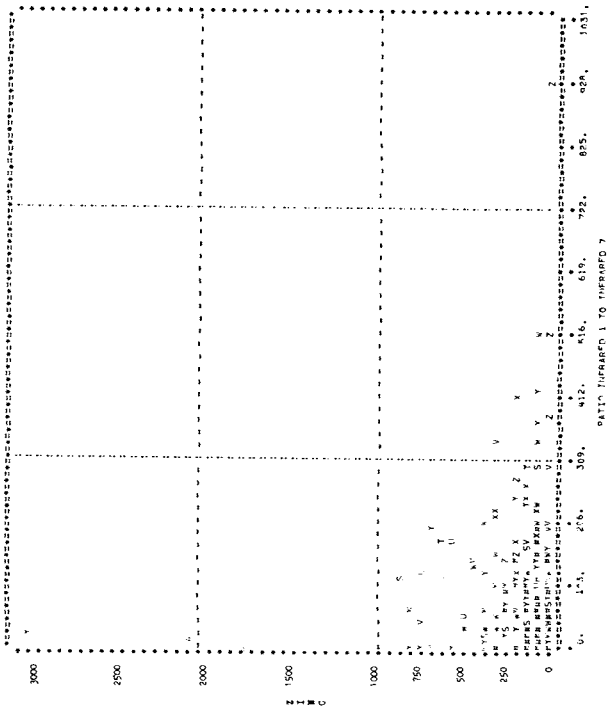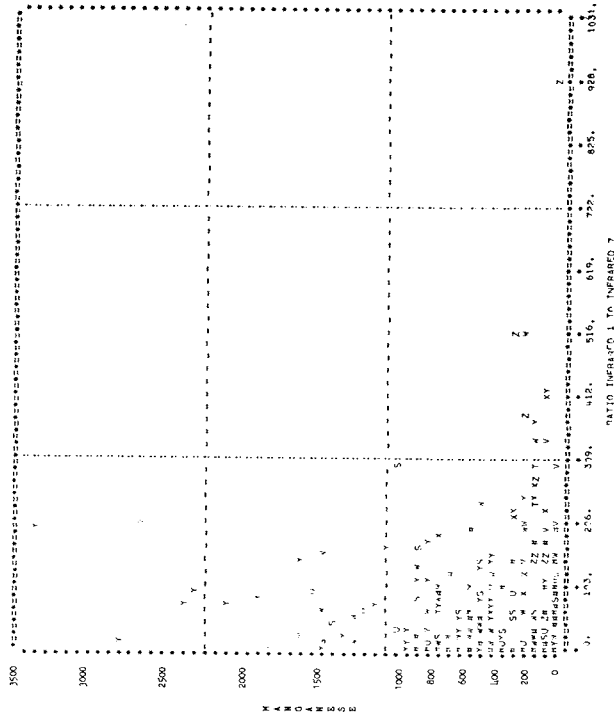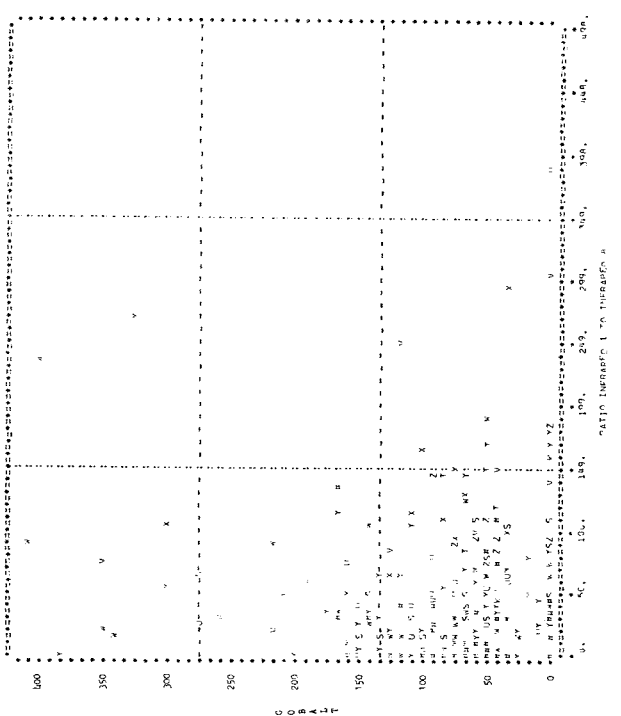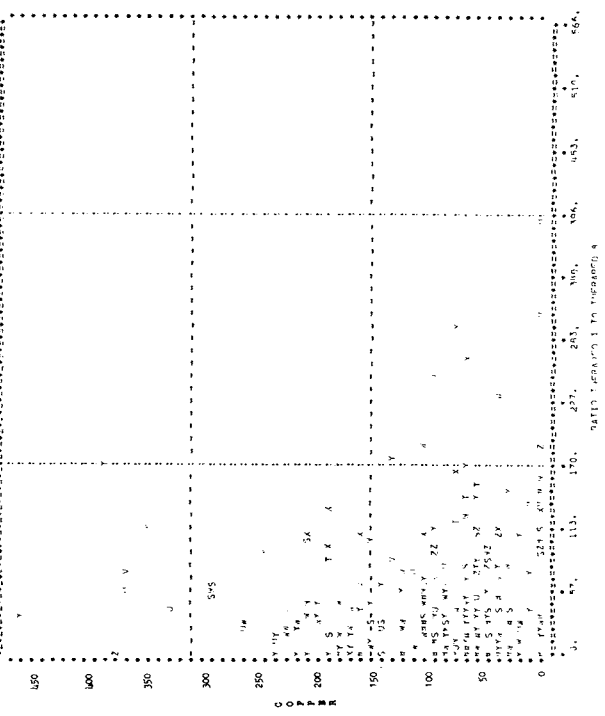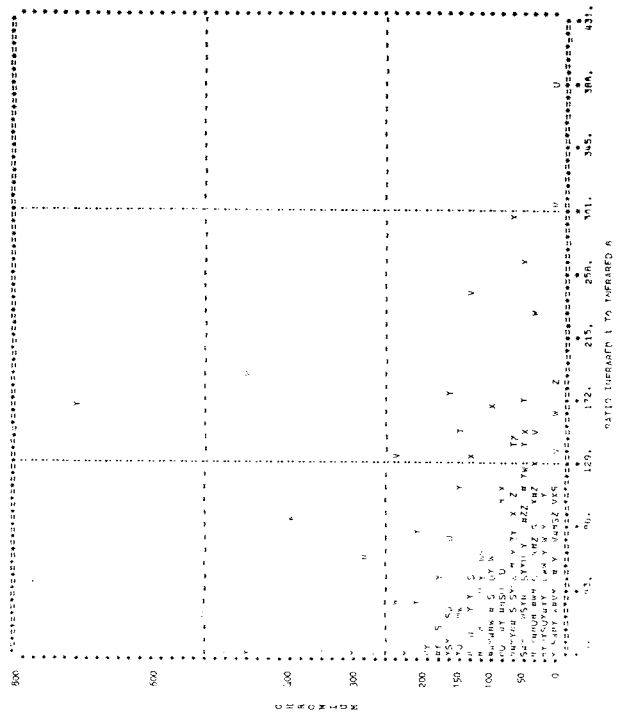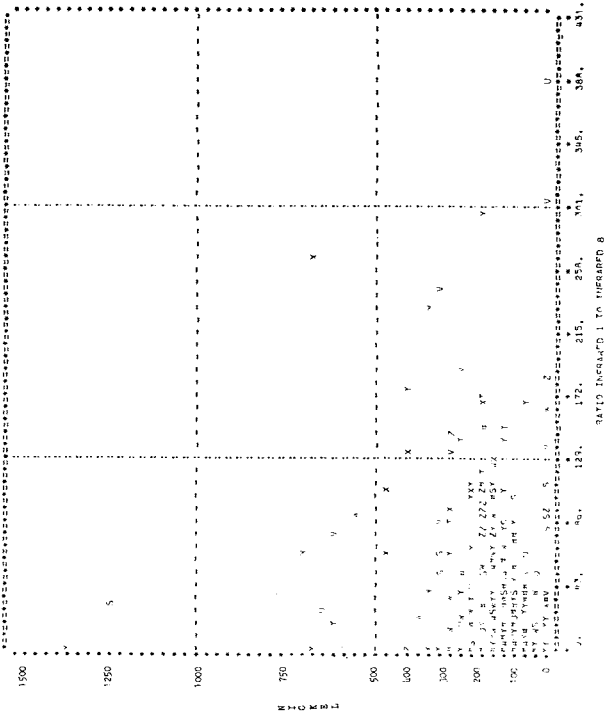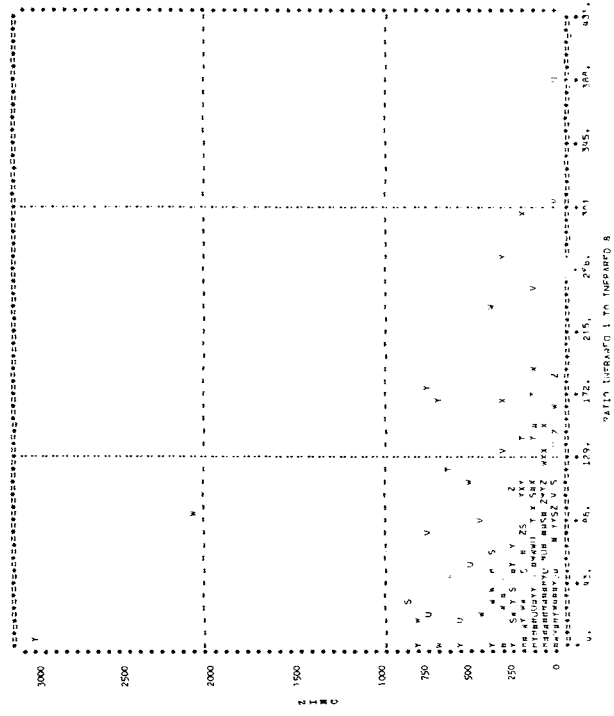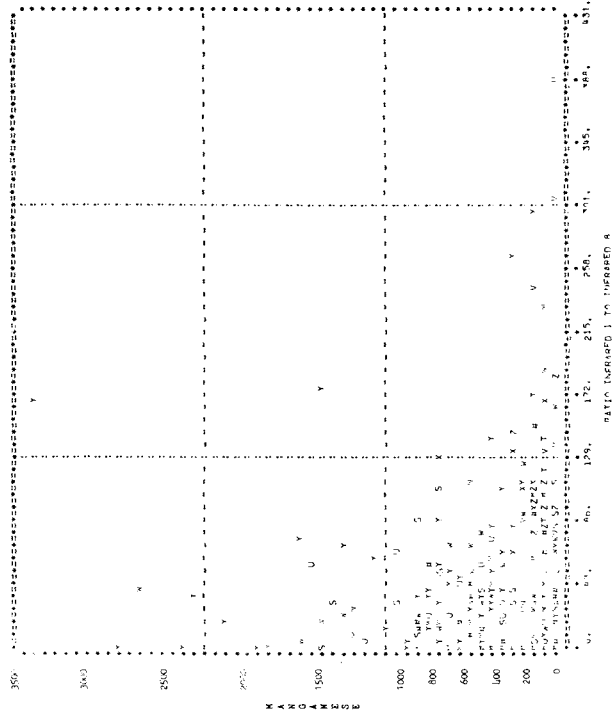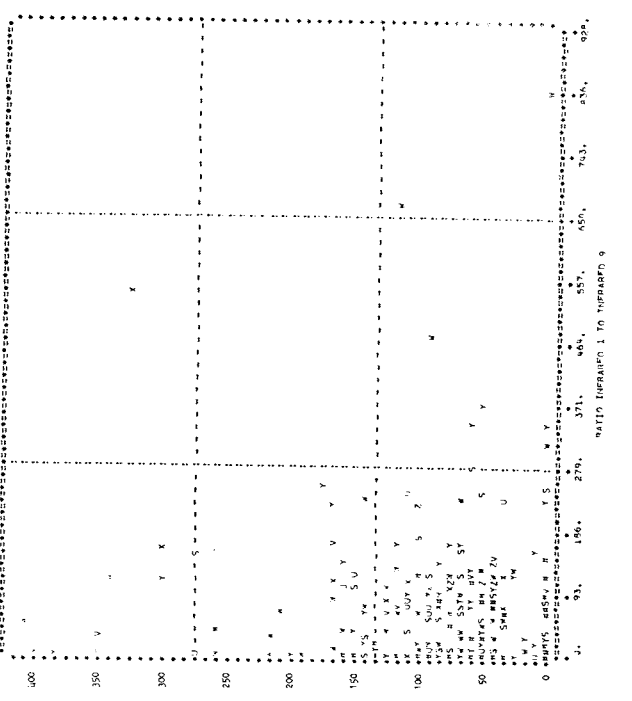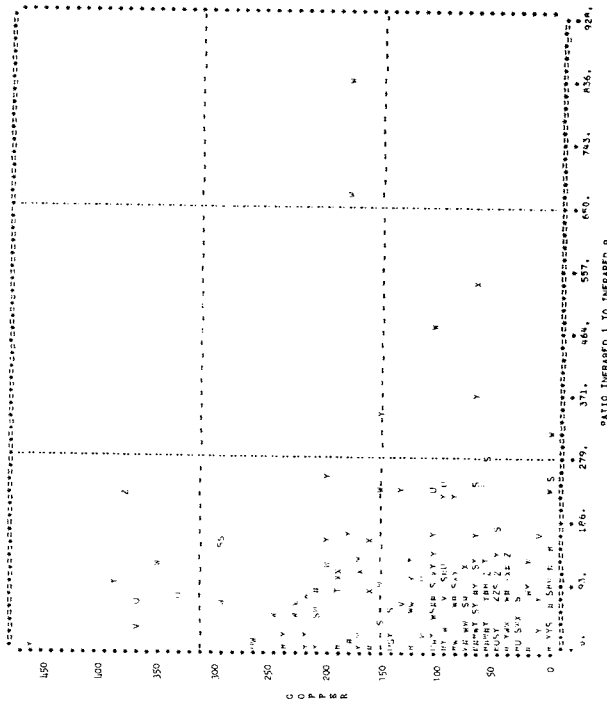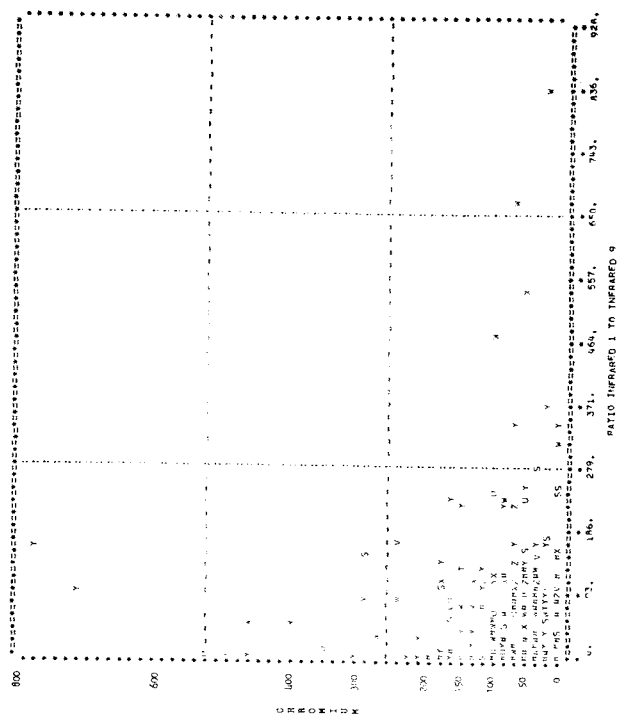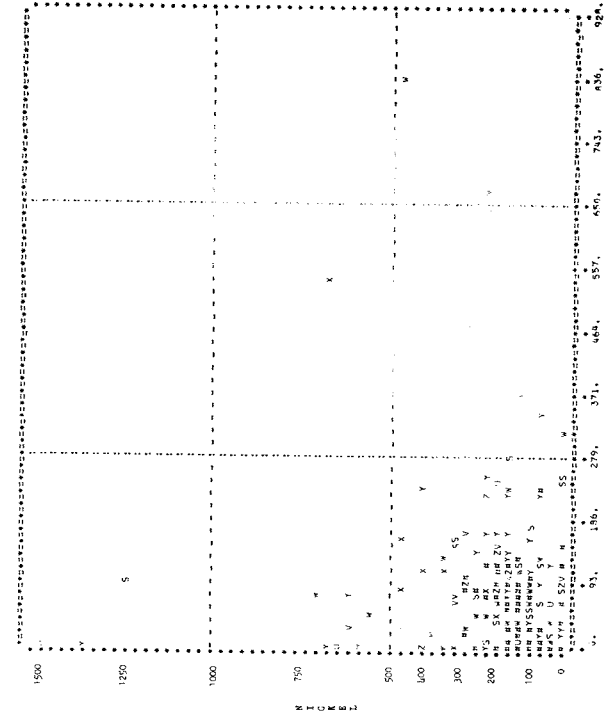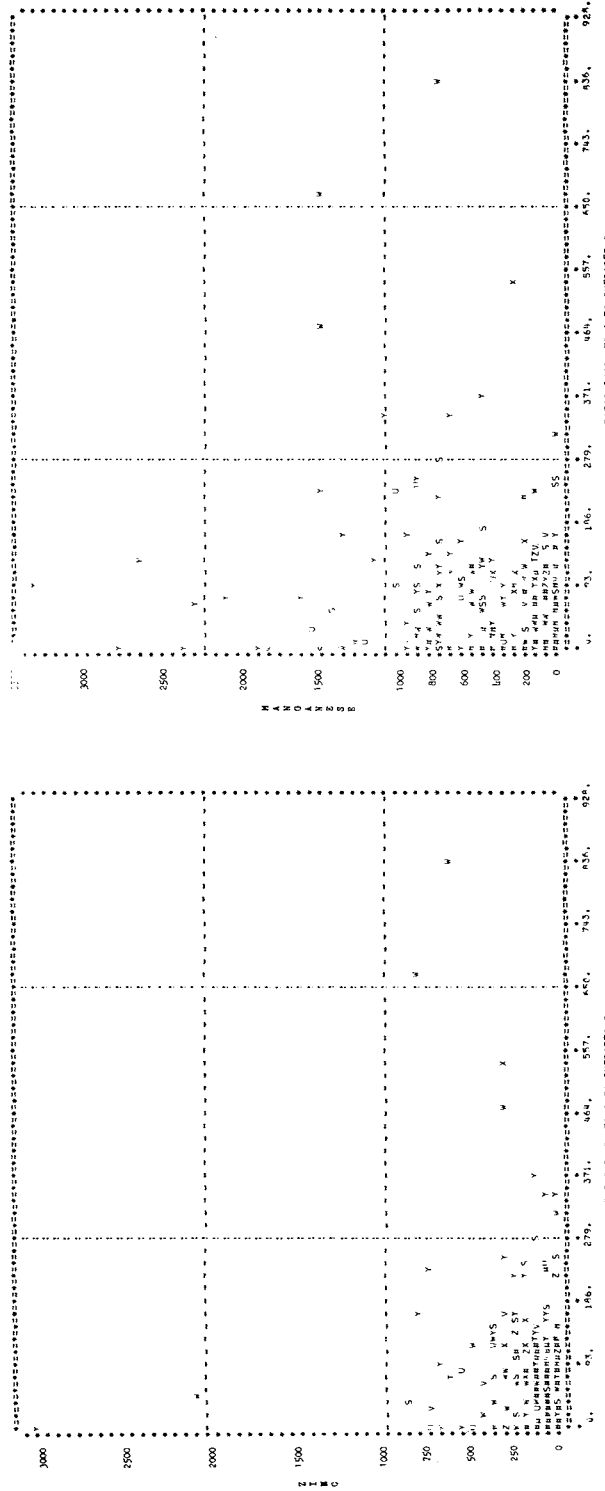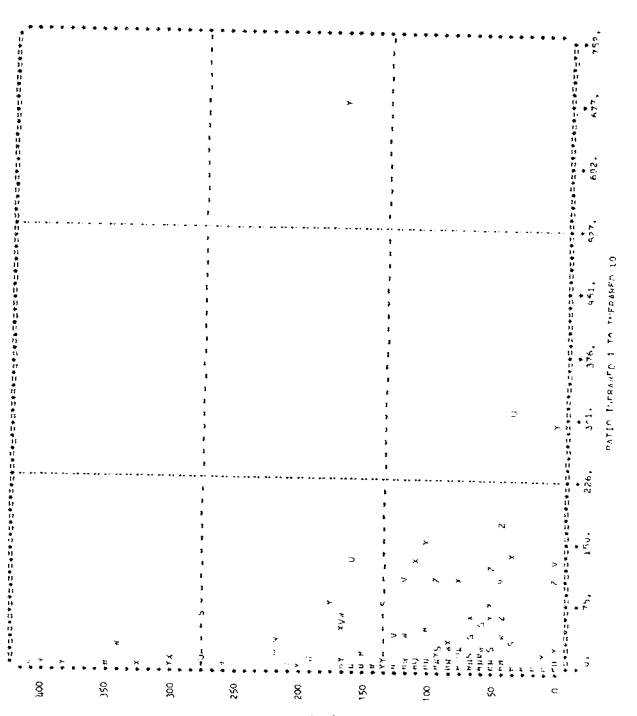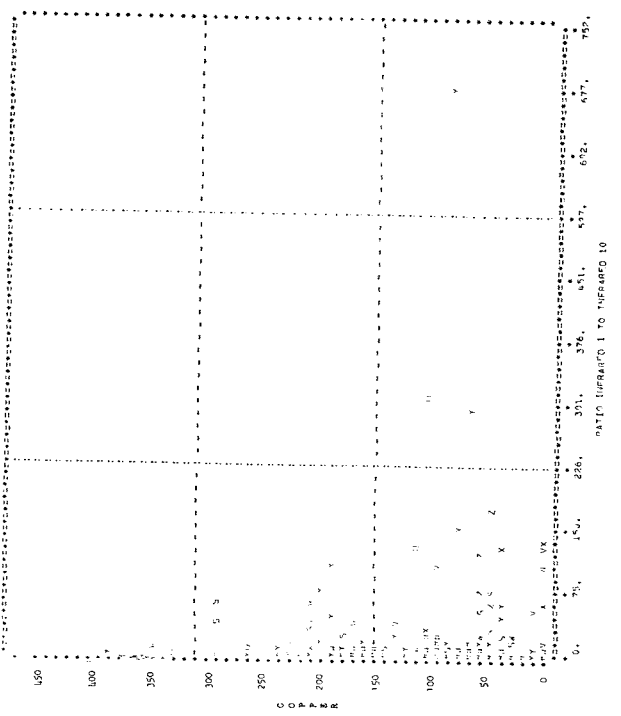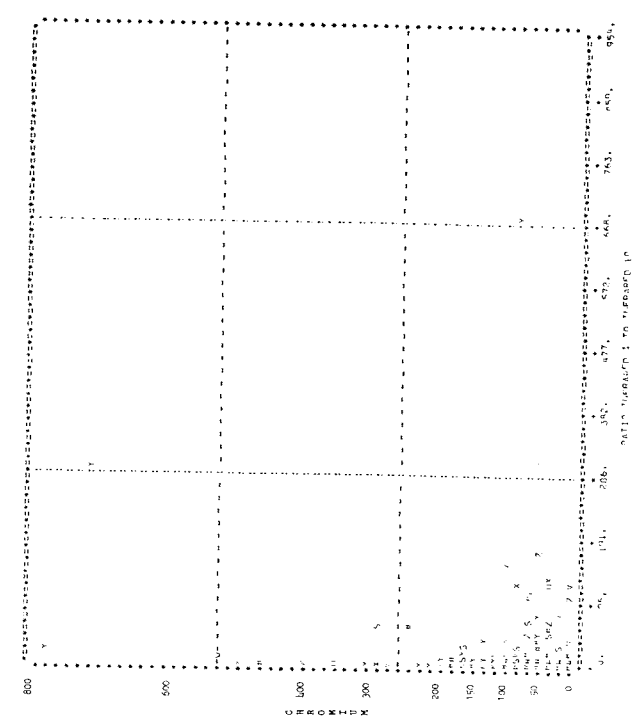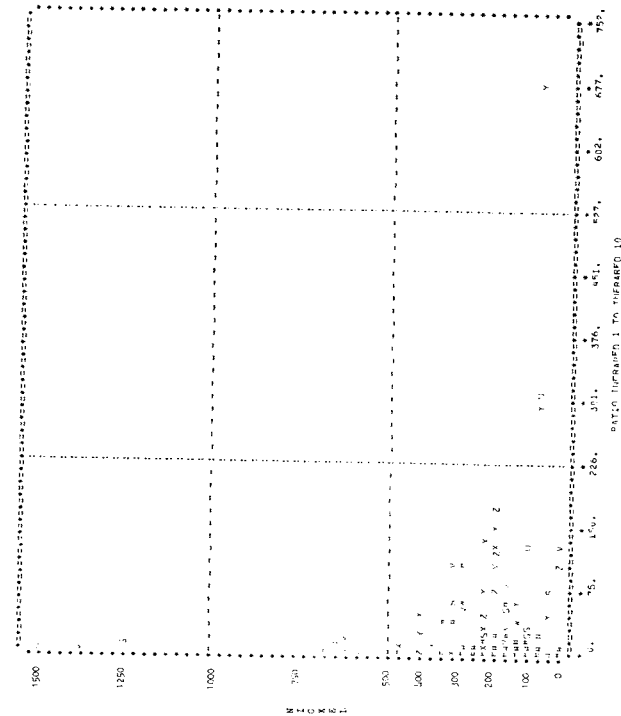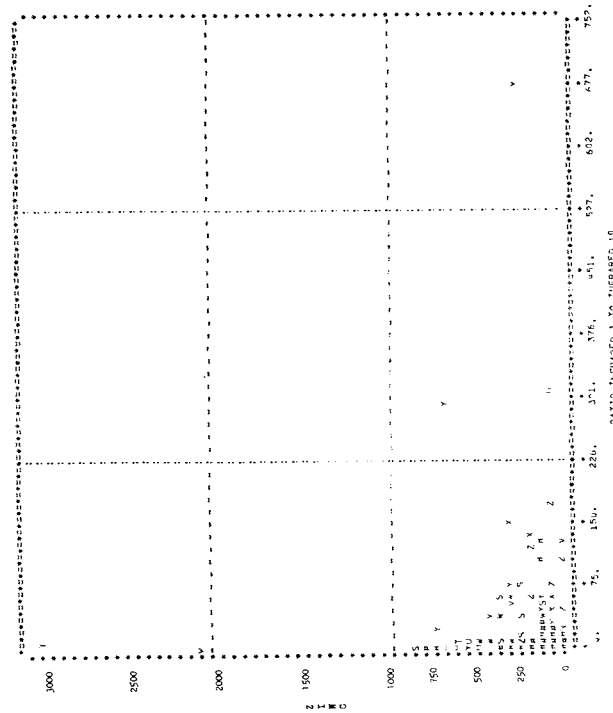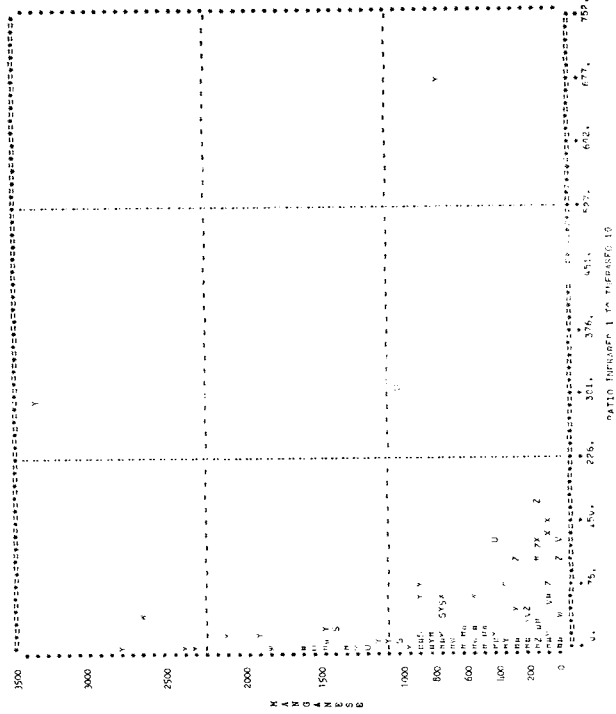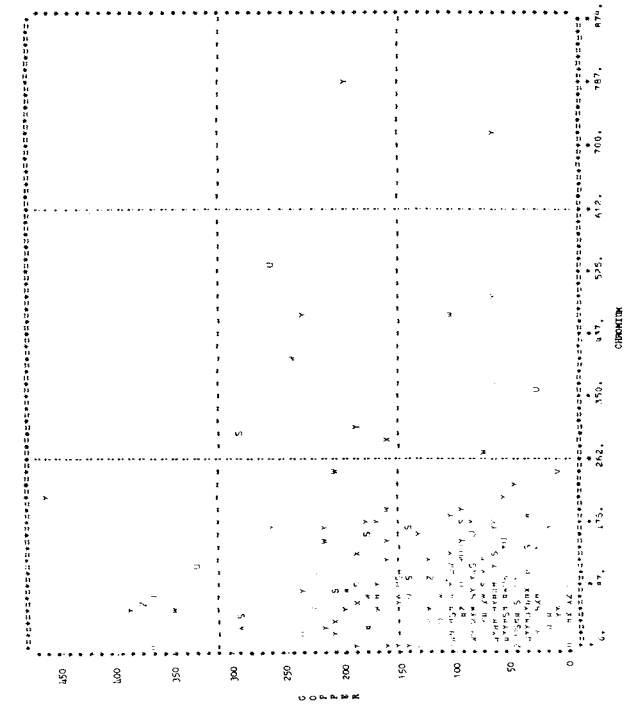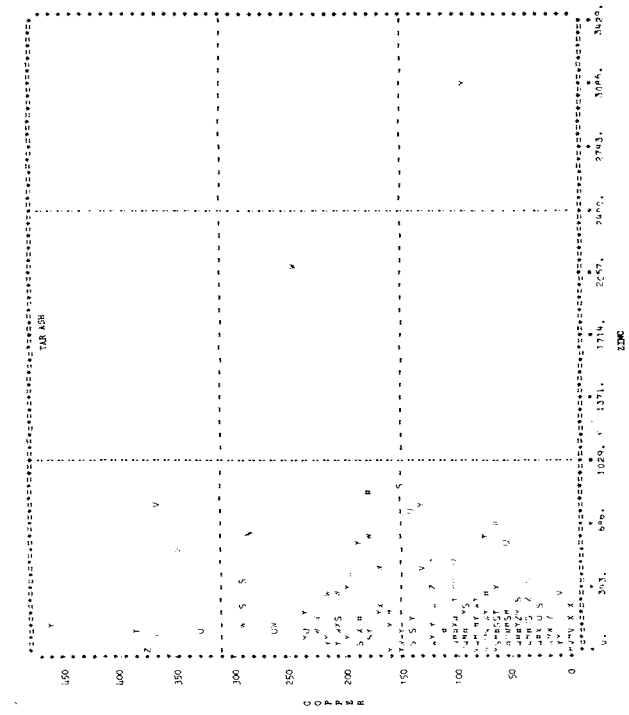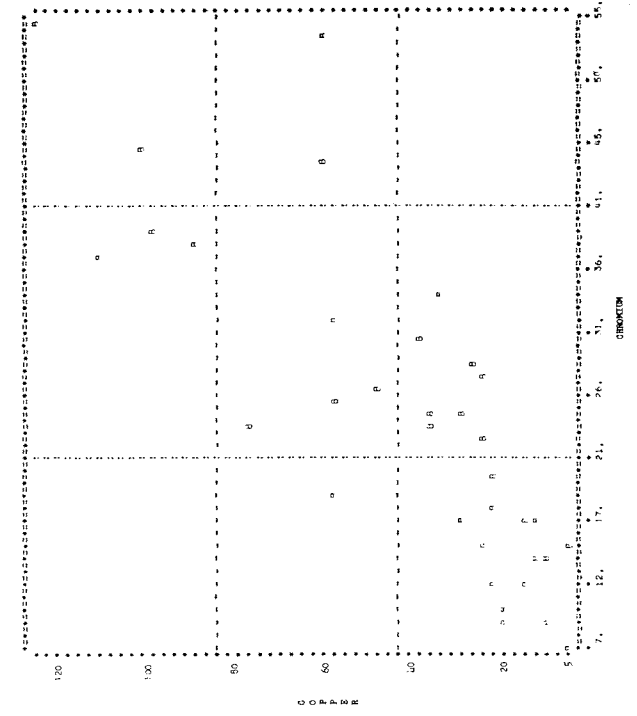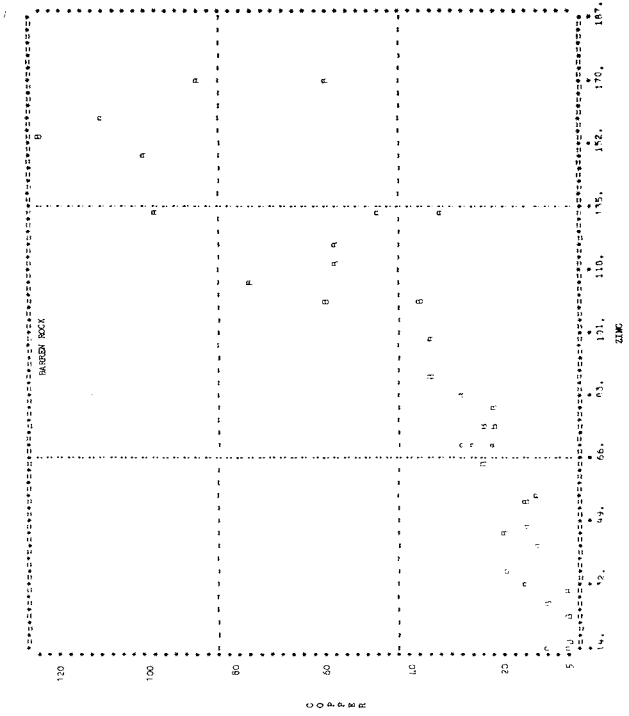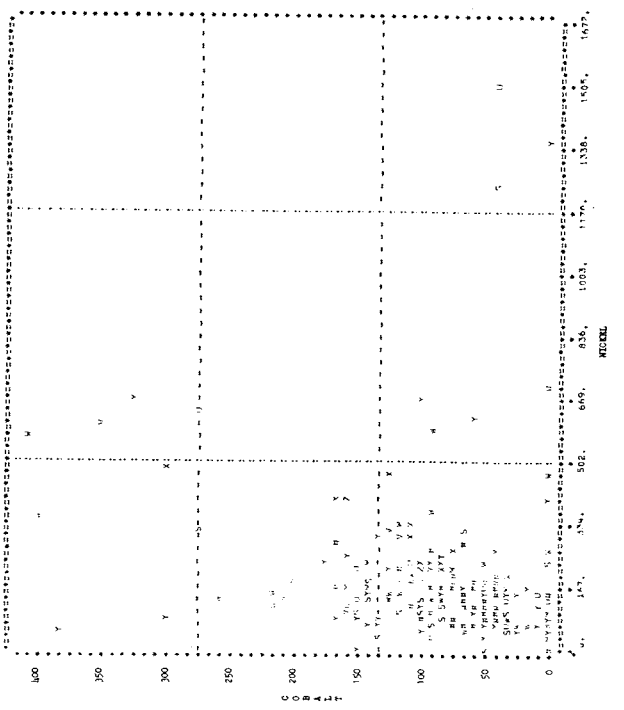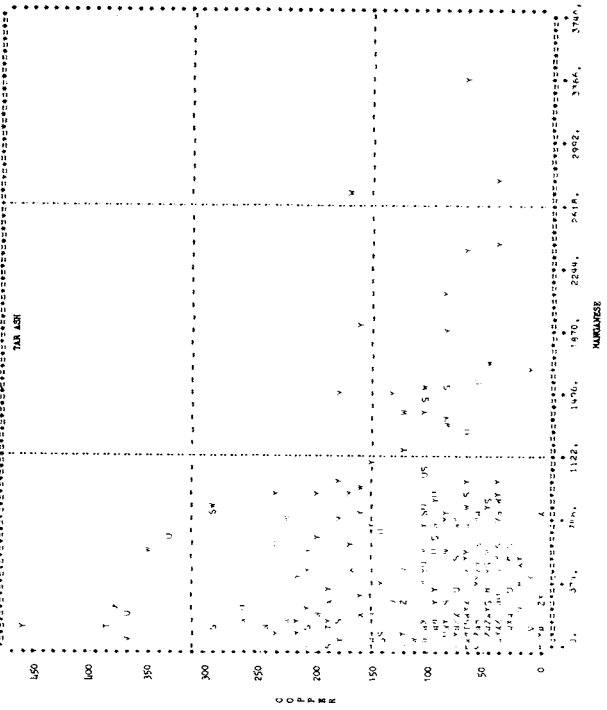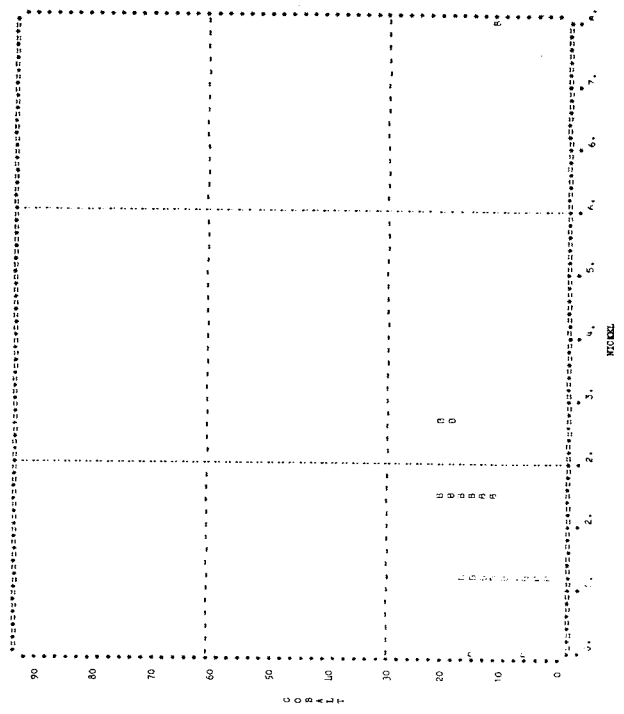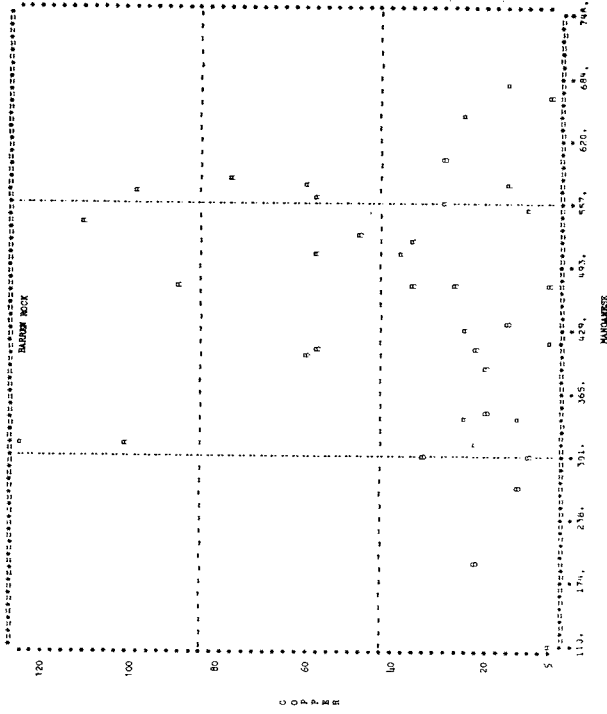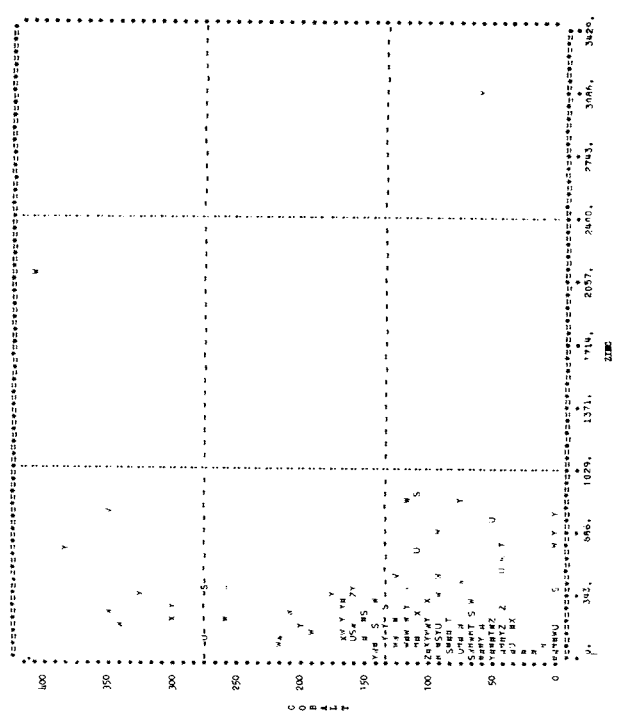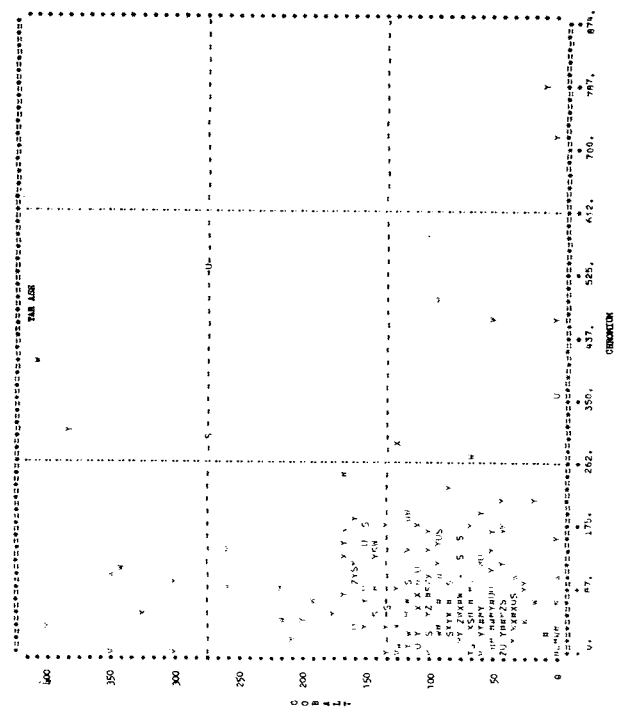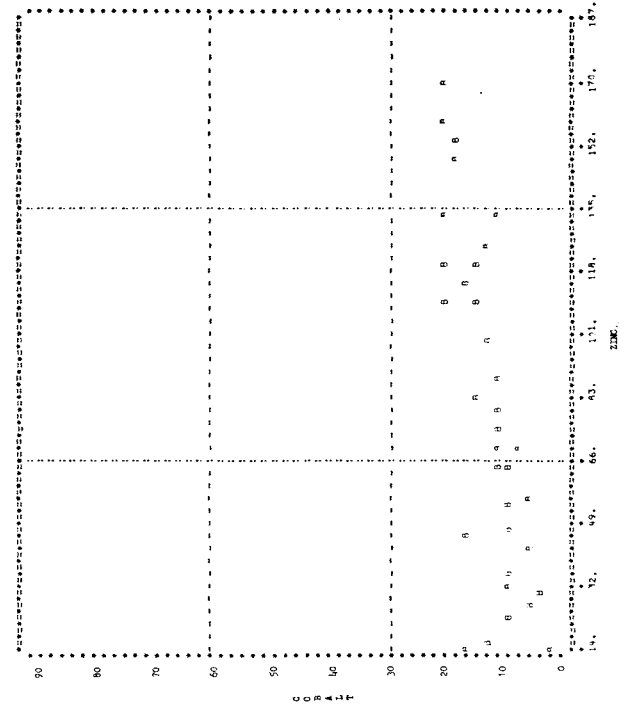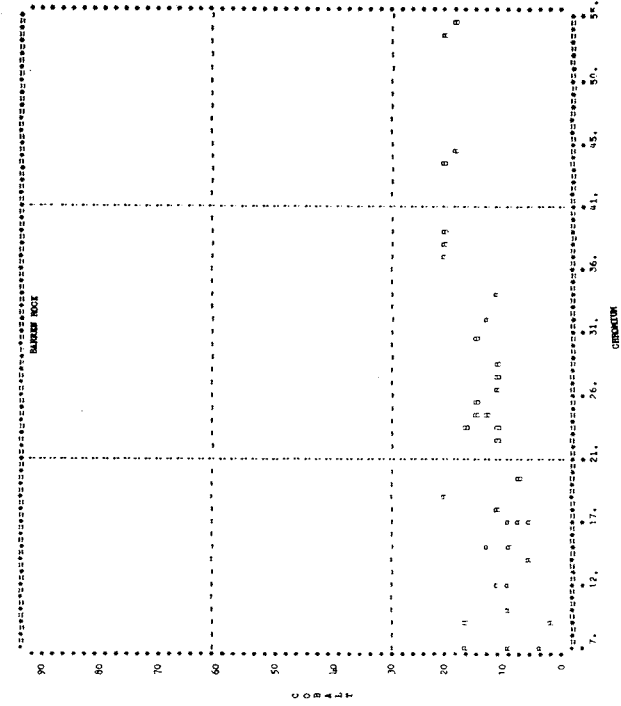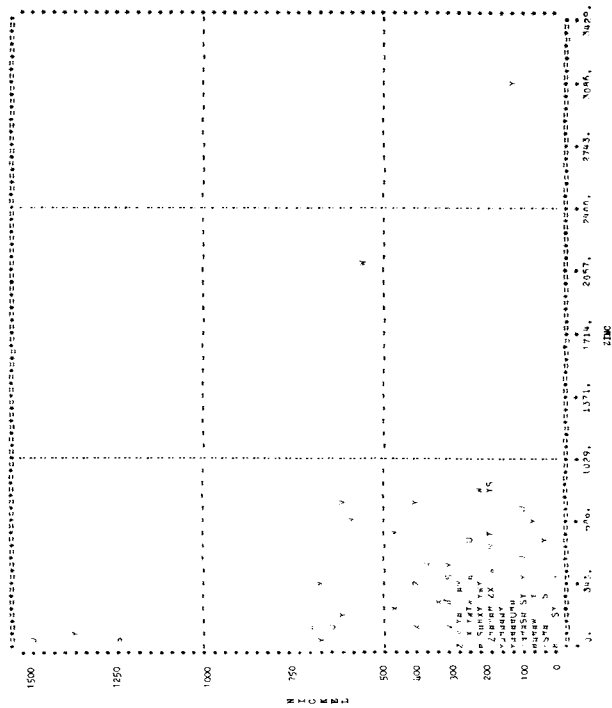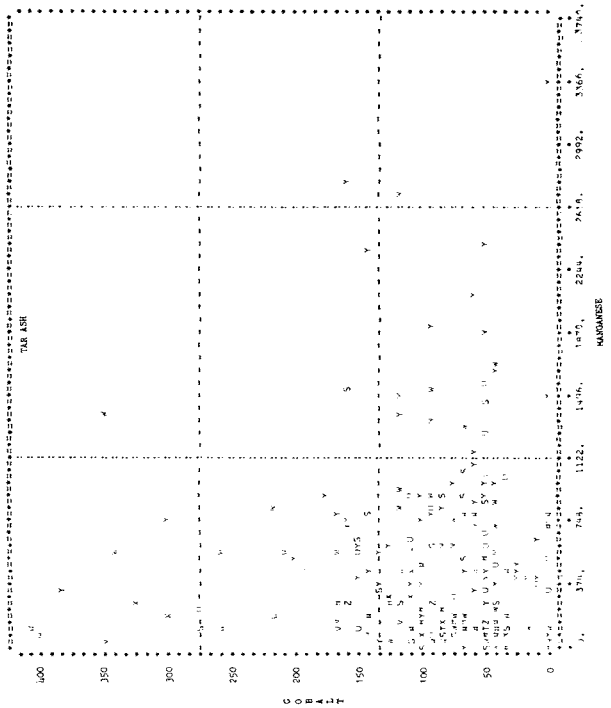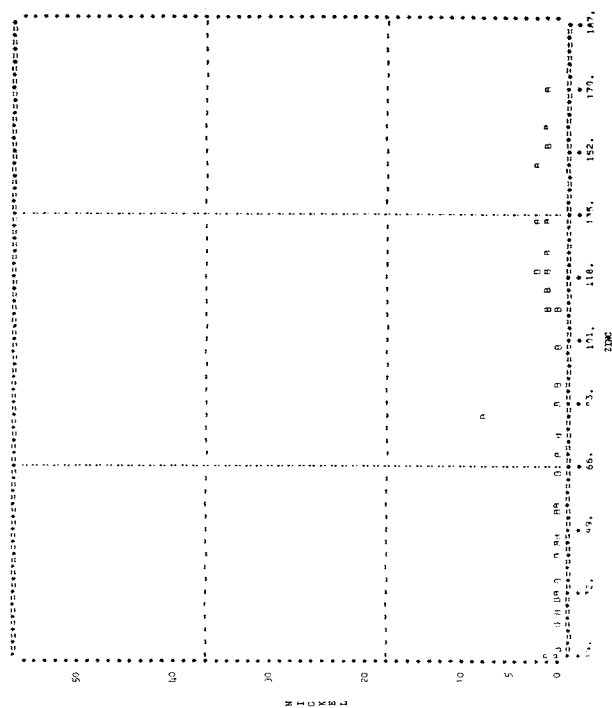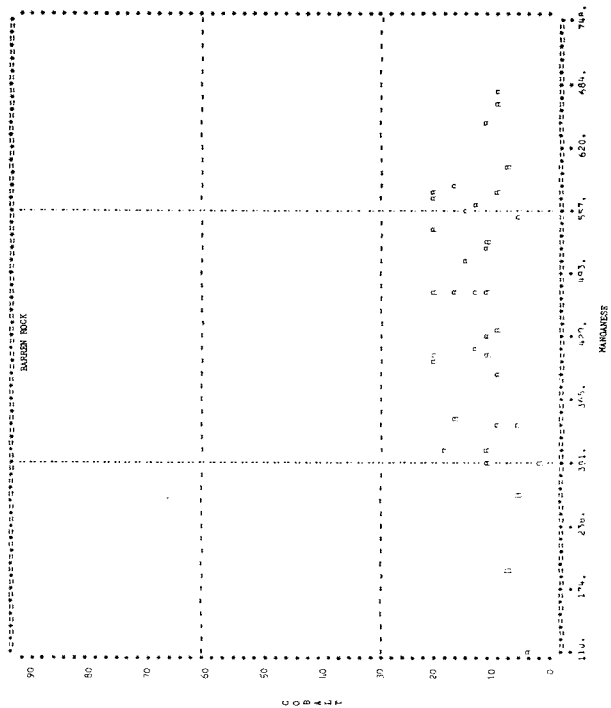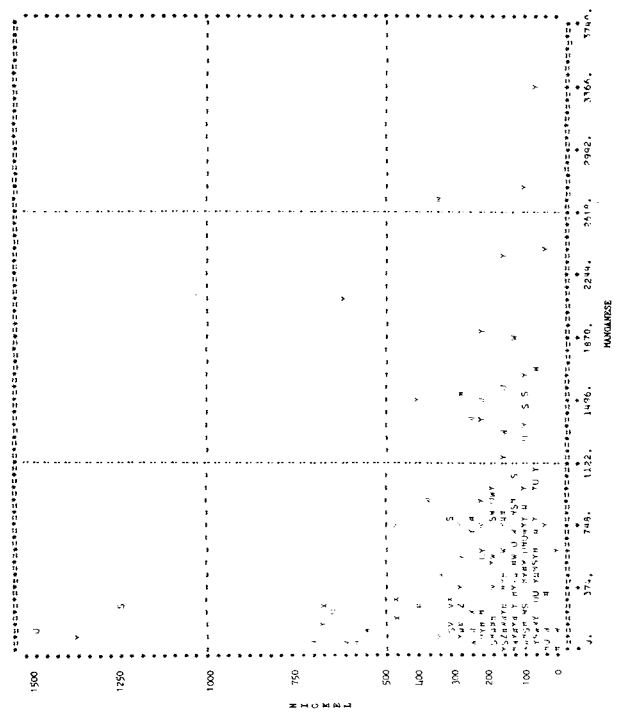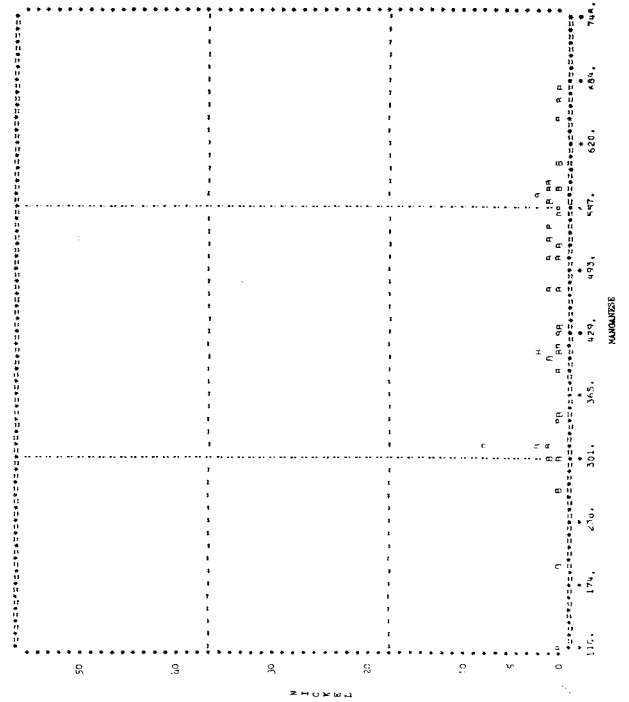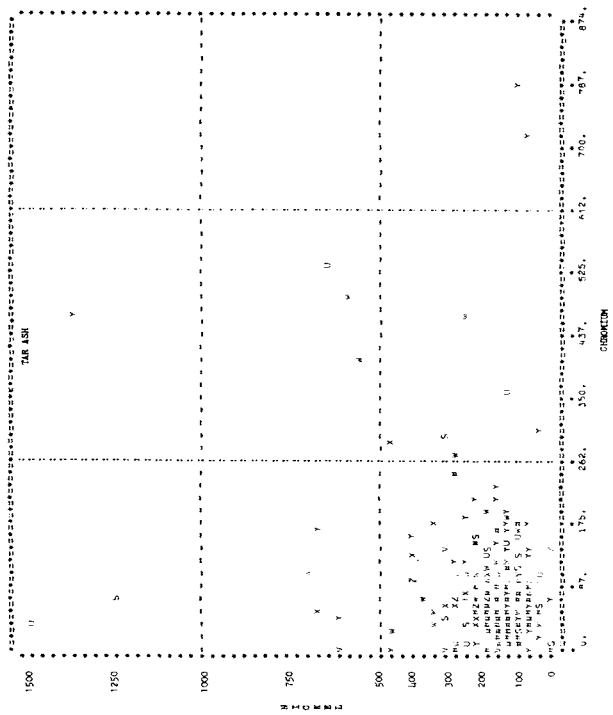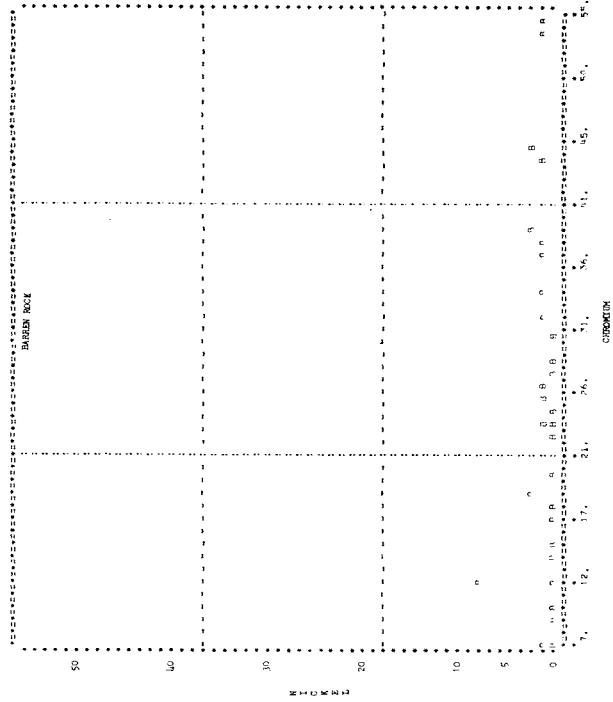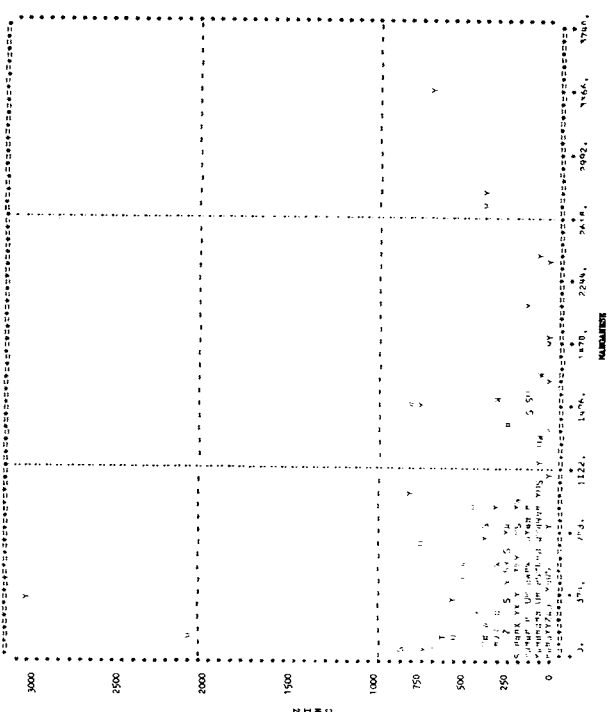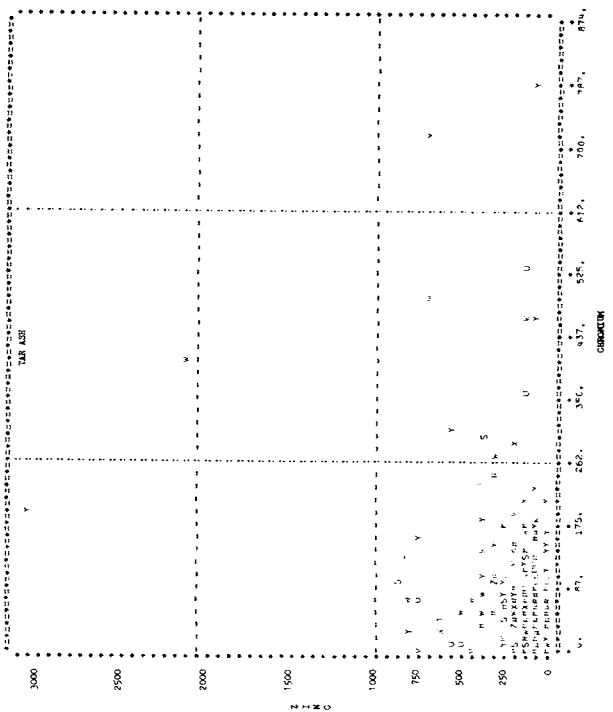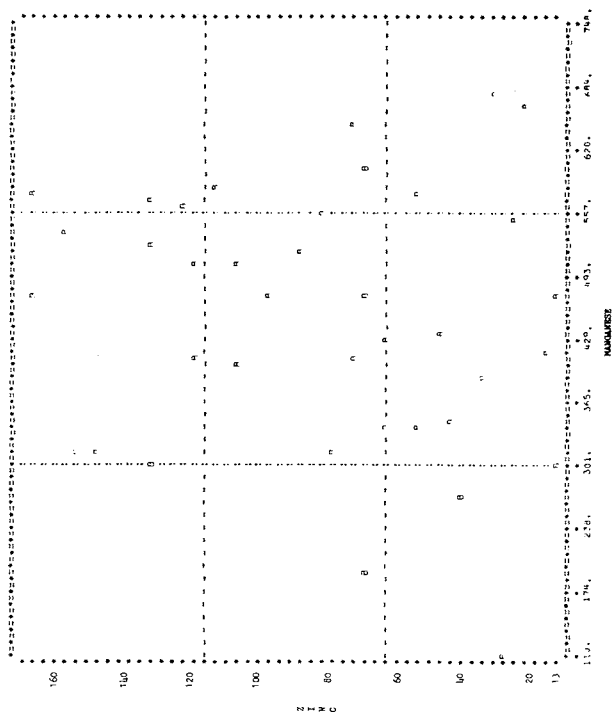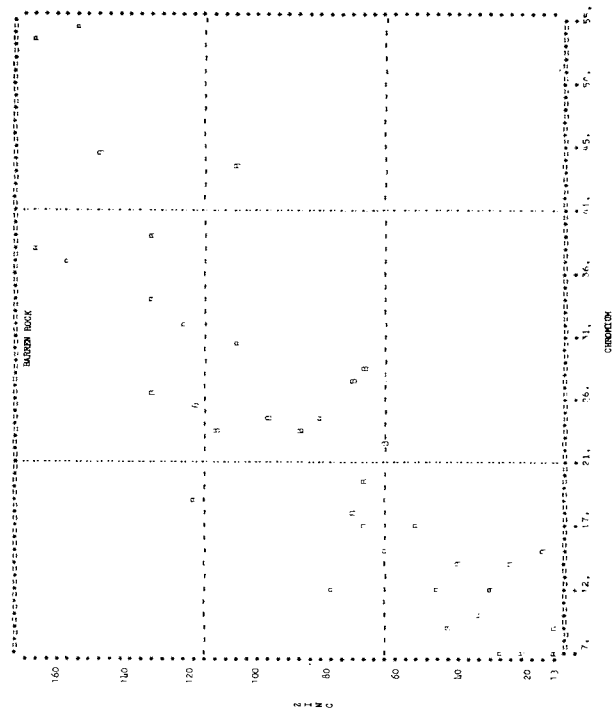
APPENDIX 5

Analytical results of hydrogenation of the Main Canyon tar sample[1]

INTRODUCTION

Synthetic oils derived from coal, oil shale and tar sands differ significantly in composition from petroleum crudes. The coal oils contain large amounts of oxygenated compounds and aromatic hydrocarbons and the shale oils contain large quantities of nitrogen compounds. Because of the differences in composition the synthetic oils may pose some new problems in their processing as compared to the conventional processing of petroleum oils. Hydrocracking is a versatile processing method and it will play an important role in the processing of synthetic oils as evidenced by the published data (Katsobashvili and others, 1966; Zielke and others, 1966; Cottingham and Carpenter, 1967 and Qader and Hill, 1969). In the present communication, the data on some aspects of hydrocracking of coal, shale and tar sand oils are presented.

EXPERIMENTAL

The coal oil was obtained by the hydrogenation of a high volatile bituminous coal from Utah. The shale oil was obtained by *in situ* retorting. The tar sand oil was prepared by solvent extraction of tar sands found in Utah. A dual functional catalyst was used for hydrocracking the synthetic oils.

EQUIPMENT

Hydrocracking was carried out in a continuous bench scale fixed Reactor System (Qader and Hill, 1969). The products were evaluated by standard methods. The head of the reaction was calculated from the heats of combustion of raw materials and products.

RESULTS AND DISCUSSION

The product distributions and the severities of hydrocracking mainly depend upon the composition of the feed stocks and the processing conditions. The data in table 3A indicate that the coal oil is more aromatic in nature when compared to the shale and tar sand oils as shown by the H-C atomic ratios. The coal oil also contains more heterocompounds and asphaltenes. The data in table 4A indicate that the coal oil is a more refractory feed stock when compared to the shale and tar sand oils. This appears to be due to the higher aromatic and asphaltene contents of the coal oil. The hydrocracking severities seem to be somewhat related to the aromaticity of the feed stocks. The data in table 5A

indicate that the yield of naphtha depends upon the total conversion irrespective of the type of feed stock used. The three feed stocks yielded almost the same quantities of naphtha at equal conversion levels. However, the gas yield was high in case of shale oil while the coal oil yielded relatively more coke. The composition of naphtha and gas depend upon the nature of the feed stock as indicated by the data in table 6A. The coal of naphtha is more aromatic and will have a higher octane rating when compared to the naphthas from shale and tar sand oils. It is evident from the foregoing discussion that aromatic feed stocks need more severe process conditions but they produce better quality naphthas.

The data in Table 7A indicate that hydrogen consumption varies with the nature of the feed stock and is directly proportional to the conversion in all the three cases. The consumption of hydrogen in coal oil hydrocracking is higher than the consumption in tar sand oil processing which in turn is more when compared to shale oil processing. This again seems to be related to the aromaticity of the feed stocks. The hydrocracking reactions are exothermic and the heat of the reaction varies with the nature of the feed stock and conversion as shown by the data in table 7A. Coal oil hydrocracking produces more exothermic heat when compared to tar sand oil which in turn gives more heat when compared to shale oil. The reaction heat seems to be also related to the aromaticity of the feed stock.

The first order rate constants of the hydrocracking of coal, shale and tar sand oils were found to be respectively represented by equations 1 to 3.

$$K_c = 0.52 \times 10^4 \, e^{-16,200/RT} \text{ hr.}^{-1} \quad (1)$$

$$K_s = 0.12 \times 10^5 \, e^{-14,300/RT} \text{ hr.}^{-1} \quad (2)$$

$$K_t = 1.05 \times 10^4 \, e^{-15,100/RT} \text{ hr.}^{-1} \quad (3)$$

Where K_c K_s K_t represent reaction rate constants for the hydrocracking of coal, shale and tar sand oils respectively.

ACKNOWLEDGEMENT

---

[1] Results presented by S. A. Qader and G. R. Hill, Mineral Engineering Department, University of Utah, Salt Lake City.

Table 3A. Properties of feed stocks.

	Coal oil	Shale oil	Tar sand oil
Gravity, °API	0.75	20.2	17.3
Viscosity, SUS, 80° C	205	180	220
S, Wt. percent	0.43	0.85	0.34
N + O, Wt. percent	3.84	2.14	1.84
H/C (atomic)	1.06	1.81	1.62
Asphaltene, vol. percent	30.0	2.0	2.5
Distillation, ° C			
1. B. P.	200	200	200
50 percent distillate	348	334	319

Table 4A. Hydrocracking product distribution.

Temperature: 480° C
Pressure: 2,000 P. S. I.
Space velocity: 0.96

Yield of products, volume percent	Coal oil	Shale oil	Tar sand oil
Naphtha	60.0	68.0	66.0
Gas	9.5	14.0	12.0
Coke	5.1	4.0	6.0
Recycle oil	27.0	14.5	17.5
Severity	0.7	0.82	0.78

Table 5A. Hydrocracking product distribution.

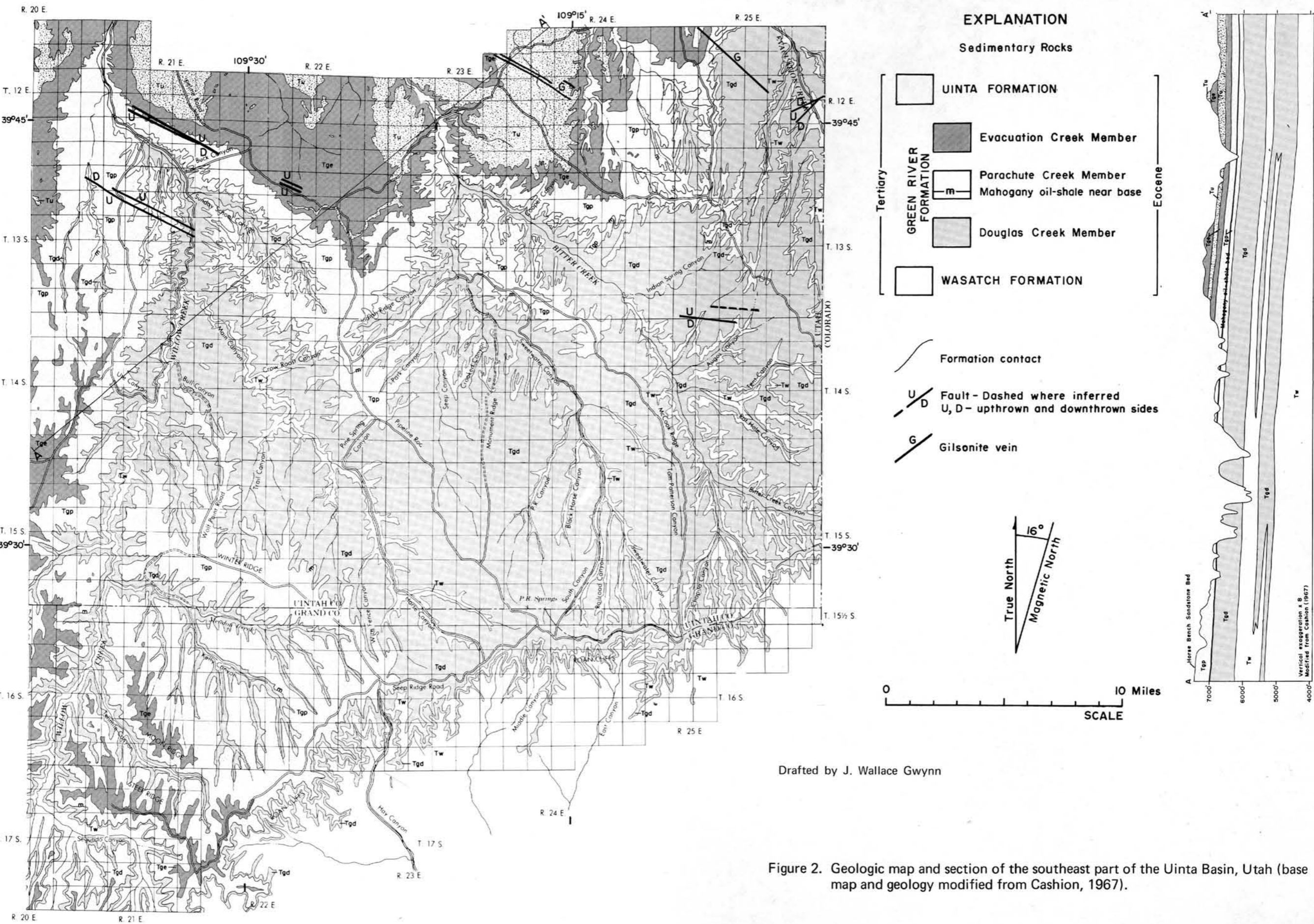| Conversion, volume percent	20	40	60	80
Naphtha yield				
Coal oil	15	32	48	65
Shale oil	16.5	35	48	63.5
Tar sand oil	15.5	32	47.5	64.0
Gas yield				
Coal oil	2.5	5.0	8.0	10.5
Shale oil	2.0	6.0	9.0	13.0
Tar sand oil	3.5	6.0	8.5	11.0
Coke yield				
Coal oil	0.5	2.0	4.0	5.6
Shale oil	0.5	1.6	2.7	4.0
Tar sand oil	0.5	2.0	3.6	5.0

Table 6A. Composition of naphtha and gas.

Temperature: 480° C
Pressure: 2,000 P.S. I.
Space velocity: 0.96

	Coal oil	Shale oil	Tar sand oil
Composition of naphtha, volume percent			
Saturates	75.2	40.2	49.5
Olefins	2.8	3.1	2.5
Aromatics	22.0	56.7	48.0
Composition of gas, volume percent			
CH_4	16.0	13.0	12.0
C_2H_6	28.0	27.0	28.0
C_3H_8	42.0	40.0	37.0
C_4H_{10}	14.0	20.0	22.0

Table 7A. Hydrogen consumption and reaction heat in hydrocracking.

Conversion, volume percent	30	50	60	80
H_2 consumption, SCF/BBL				
Coal oil	600	1,020	1,240	1,660
Shale oil	380	720	900	1,230
Tar sand oil	350	720	910	1,290
$\Delta H \times 10^3$, BTU/BBL				
Coal oil	47	80	96	130
Shale oil	34	58	70	96
Tar sand oil	32	60	75	104

Figure 2. Geologic map and section of the southeast part of the Uinta Basin, Utah (base map and geology modified from Cashion, 1967).

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EXPLANATION

Sedimentary Rocks

UINTA FORMATION

GREEN RIVER FORMATION
- Evacuation Creek Member
- Parachute Creek Member
  Mahogany oil-shale near base
- Douglas Creek Member

WASATCH FORMATION

Tertiary — Eocene

Formation contact

U/D Fault – Dashed where inferred
U, D – upthrown and downthrown sides

G Gilsonite vein

Spring

True North / Magnetic North 16°

0   10 Miles
SCALE

Drafted by J. Wallace Gwynn

Figure 5. Geologic map and section showing springs in the southeast part of the Uinta Basin, Utah (base map and geology modified from Cashion, 1967).