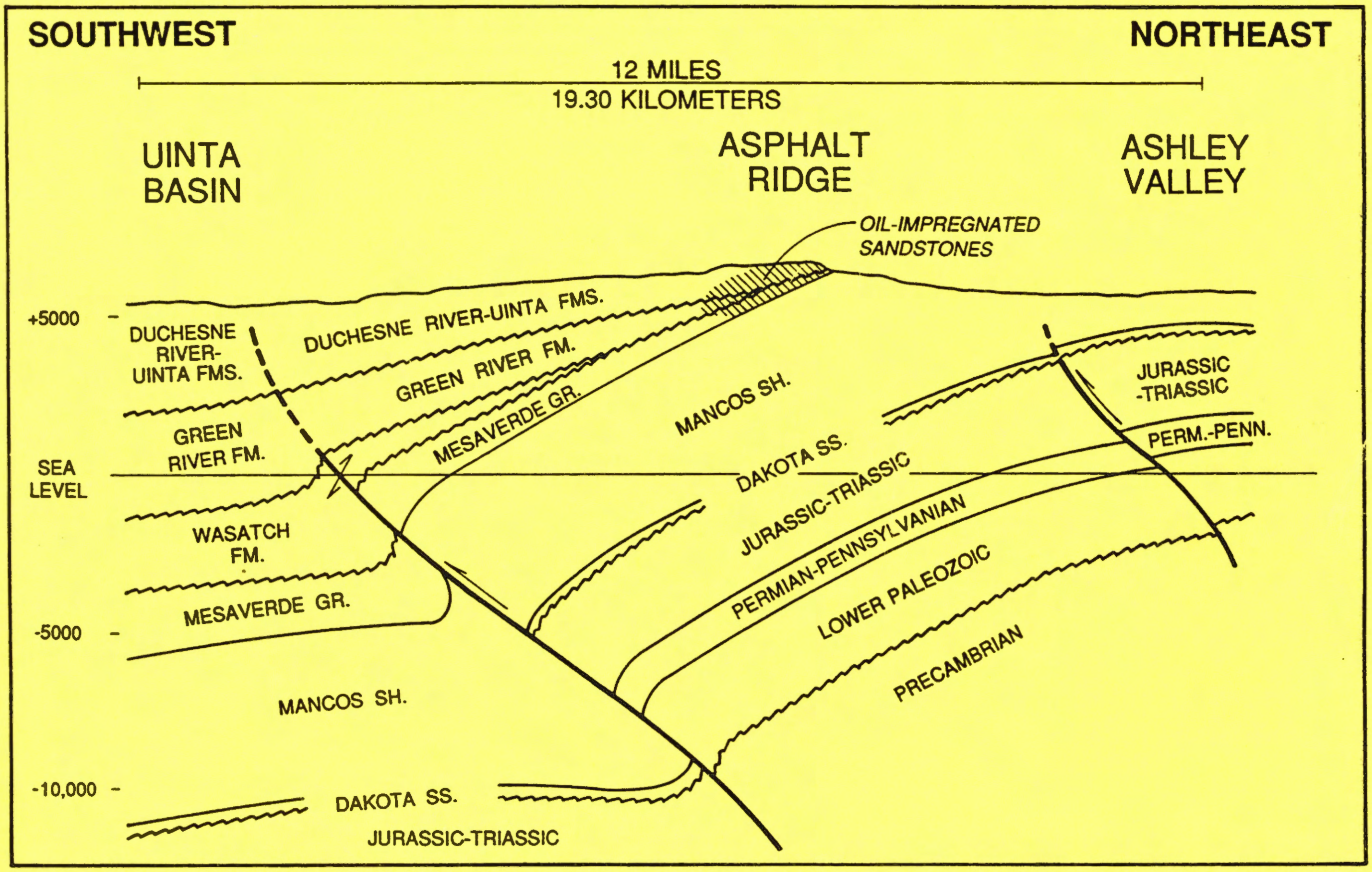
TAR-SAND RESOURCES OF THE UINTA BASIN, UTAH

A CATALOG OF DEPOSITS

compiled by
Robert E. Blackett
Utah Geological Survey



Open-File Report 335 **May 1996**
UTAH GEOLOGICAL SURVEY
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Prepared for:
State of Utah
Department of Community and Economic Development
Permanent Community Impact Board

Prepared by:
Utah Geological Survey
and
Utah Engineering Experiment Station
University of Utah

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ABSTRACT

Tar-sand, or oil-impregnated sandstone, deposits and occurrences of the Uinta Basin, Utah are summarized and presented. Twenty five tar-sand deposits/occurrences are reviewed with respect to geology, locations of bitumen-saturated outcrops, land ownership, physiography, bitumen-analyses, development histories, and other aspects. Background information on the physical setting and regional geology of the Uinta Basin is presented along with discussions of theories on the sources of the bitumen. Four areas--Asphalt Ridge, P.R. Spring, Hill Creek, and Sunnyside are presented as the principal areas containing most of the tar-sand resource. The Asphalt Ridge tar-sand deposit, located on the north flank of the Uinta Basin and enclosed in steeply dipping rocks of the Mesaverde Group (Cretaceous) and Duchesne River Formation (Eocene-Oligocene), is estimated to contain more than 1 billion barrels of oil. The P.R. Spring and Hill Creek deposits, located along the southeast margin of the basin and enclosed by gently dipping rocks of the Green River Formation (Eocene), are estimated to comprise a resource in excess of 4 billion barrels of oil. The Sunnyside deposit, located along the south margin of the basin enclosed by rocks of the Wasatch and Green River Formations (Eocene) is the largest of the deposits, estimated to contain more than 5 billion barrels of oil.

The remaining 21 areas discussed are scattered along the northern and southwestern margins of the basin. Along the northeastern side of the basin lies the Raven Ridge, Cow Wash, Rimrock, Spring Hollow, and Upper Kane Hollow deposits. The Chapita Wells and Pariette deposits, located in the central part of the basin are contained in rocks of the Uinta Formation (Eocene), but may be related to near-vertical faults and fractures. Deposits along the southwestern side of the Uinta Basin that may be genetically related to the Sunnyside deposit include Argyle Canyon, Minnie Maud Creek, Ninemile Canyon, and Willow Creek. The Whiterocks deposit, along the north basin margin is unique because it occurs in the Navajo Sandstone of Jurassic age. The Daniels Canyon deposit, located just outside of the western margin of the basin, is associated with fractures in Paleozoic rocks. The Thistle and Oil Hollow deposits, located at the extreme western end of the basin, are contained in oolitic limestone of the Paleocene Flagstaff Limestone and the Green River Formation, respectively.

INTRODUCTION

Background

As part of an effort to assess the commercial potential of Utah's solid hydrocarbon deposits, the University f Utah Engineering Experiment Station initiated a project in 1985 with support from the Department of Community nd Economic Development, Community Impact Board, to analyze aspects of tar-sand deposits of the Uinta Basin f northeastern Utah (figure 1). The Utah Geological Survey (UGS) later became involved in the effort in order to ımmarize available geological information on Uinta Basin tar-sand deposits. Often referred to as "bituminous ındstones" or "oil-impregnated rock," tar sands are found throughout the Uinta Basin in rocks ranging in age from ermian to Tertiary. It has been estimated that the tar-sand deposits of Utah contain roughly 25 billion barrels of itumen in-place (Ball Associates Ltd., 1964). When compared to estimates of proven United States crude-oil serves of 25.9 billion barrels, this represent a significant fossil energy resource (U. S. Department of Energy, 1993).

Tar-sand deposits in 24 states, which contain a resource estimated at 54 billion barrels (figure 2), have been ocumented by Ball Associates Ltd. (1964) and Kuuskraa and others (1984). Moreover, Kuuskraa and others (1984) ıd Campbell (1975a) estimated that tar-sand deposits in Utah contain between 40 and 95 percent of the total tar-ınd resource in the United States. The Uinta Basin contains roughly half of Utah's tar-sand resource, consisting ̇ 27 tar-sand deposits (figure 3; table 1).

The Uinta Basin is among the nations' most hydrocarbon-rich basins, it has produced over 377 million ırrels of oil and more than 988 billion cubic feet of nonassociated gas (Utah Division of Energy, 1991). Rocks ̇ Paleozoic, Mesozoic, and Cenozoic age in the basin have produced commercial quantities of oil and gas. In ldition to tar sand, some unique, solid hydrocarbons, such as gilsonite, oil shale, ozokerite, wurtzilite, tabbyite, bertite, and native asphalt are found within the Uinta Basin (Barb, 1944). Gilsonite had been recognized and was production in the eastern Uinta Basin by the late 1800s. By the early 1900s, several attempts had been made to oduce oil shale, and ozokerite was produced from the Soldier Summit area (Robinson, 1916). Early oil exploration the basin was concentrated in the vicinity of well-exposed outcrops of tar sand (Covington, 1964).

Development of Uinta Basin tar sands on a large scale has never proceeded past the demonstration stage, though advancement of recovery technologies has continued. As new technologies evolved that were applicable tar-sand development, they were generally tested in the Uinta basin. As a result, much literature on tar-sand covery from government, academic, and private company research has been published over the last 20 years ampbell and Ritzma, 1979; Dana, 1983). The technology base for the tar-sand industry has improved based on e experience of Canadian tar-sand operators. With the success of the Canadian tar-sand industry, renewed interest s occurred in the Utah deposits. The availability of adequate and secure supplies of comparatively cheap nventional petroleum has been related to interest in possible tar-sand development in Utah since the early 1950s.

Previous Work

Due to its extensive hydrocarbon resources, the Uinta Basin has been the subject of numerous geological vestigations. Literature on the tar-sand deposits of the Uinta Basin, however, has been somewhat descriptive d repetitious of earlier work. Some earliest reconnaissance surveys of the Uinta Basin tar-sand deposits are vington (1963) where he reviewed the known bituminous sandstone and limestone deposits in Utah and Covington 964) where he described the bituminous sandstones in the Uinta Basin. Ritzma (1979) prepared the most mprehensive compilation of tar-sand deposits in Utah. This work presented the general extent of each deposit and luded a map with location, stratigraphic position, lithology, size, and indicated grade of each deposit. This blication superseded two earlier maps by Ritzma (1968 and 1973). Campbell and Ritzma (1979) provided more ailed descriptions of some major tar-sand deposits in Utah; however, this also was essentially a presentation of viously published work.

Although known of for nearly a century, workers for the most part have done only reconnaissance studies most tar-sand deposits of the Uinta Basin. Spieker (1930) prepared the first detailed study of the geology of the nta Basin that addressed aspects of the tar-sand deposits. Spieker described in detail the bituminous sandstones Asphalt Ridge, near Vernal. Bradley (1931), referred to tar-sand deposits and associated geological features in

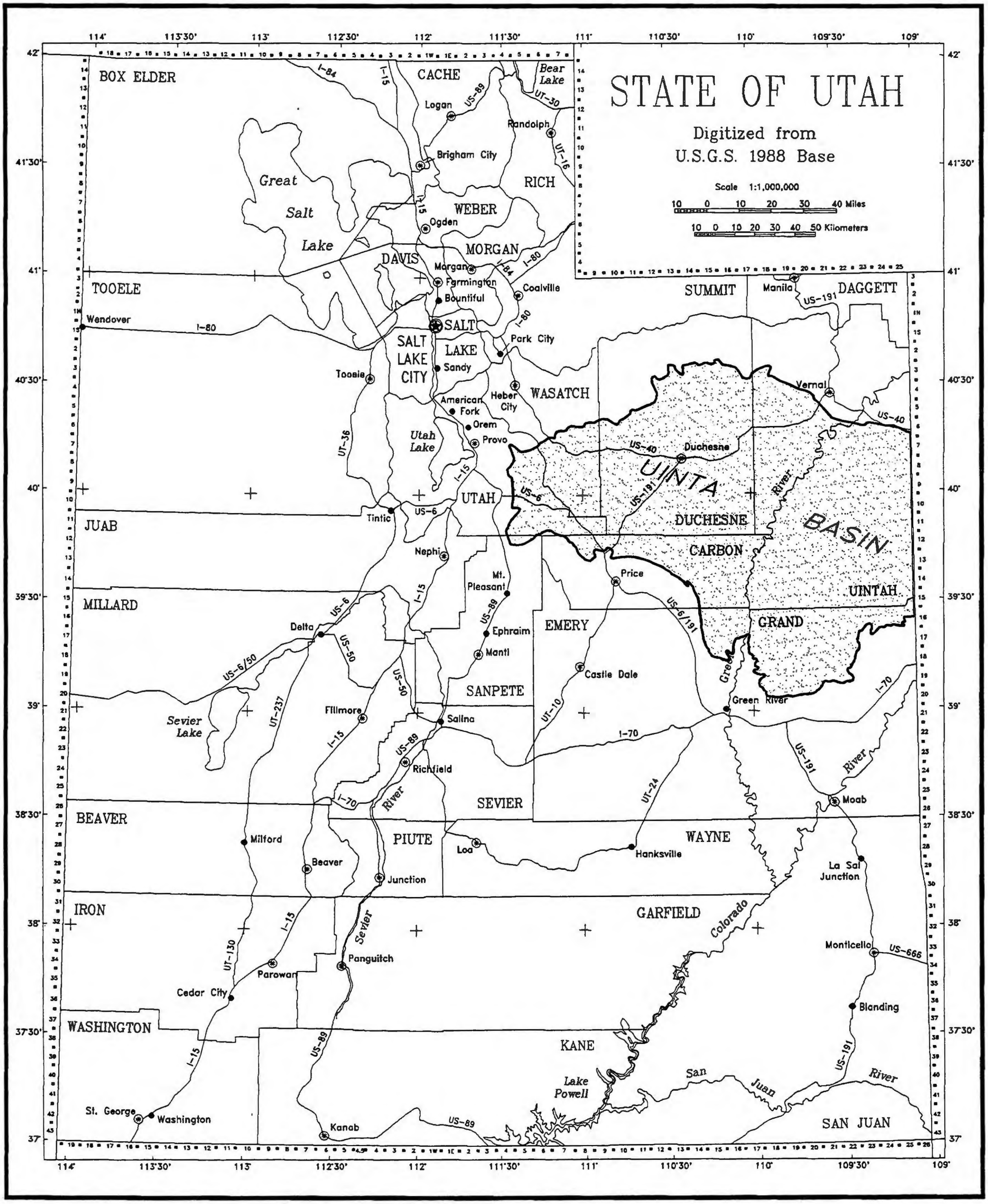


Figure 1. *Index map of Utah, showing the location of the Uinta Basin.*

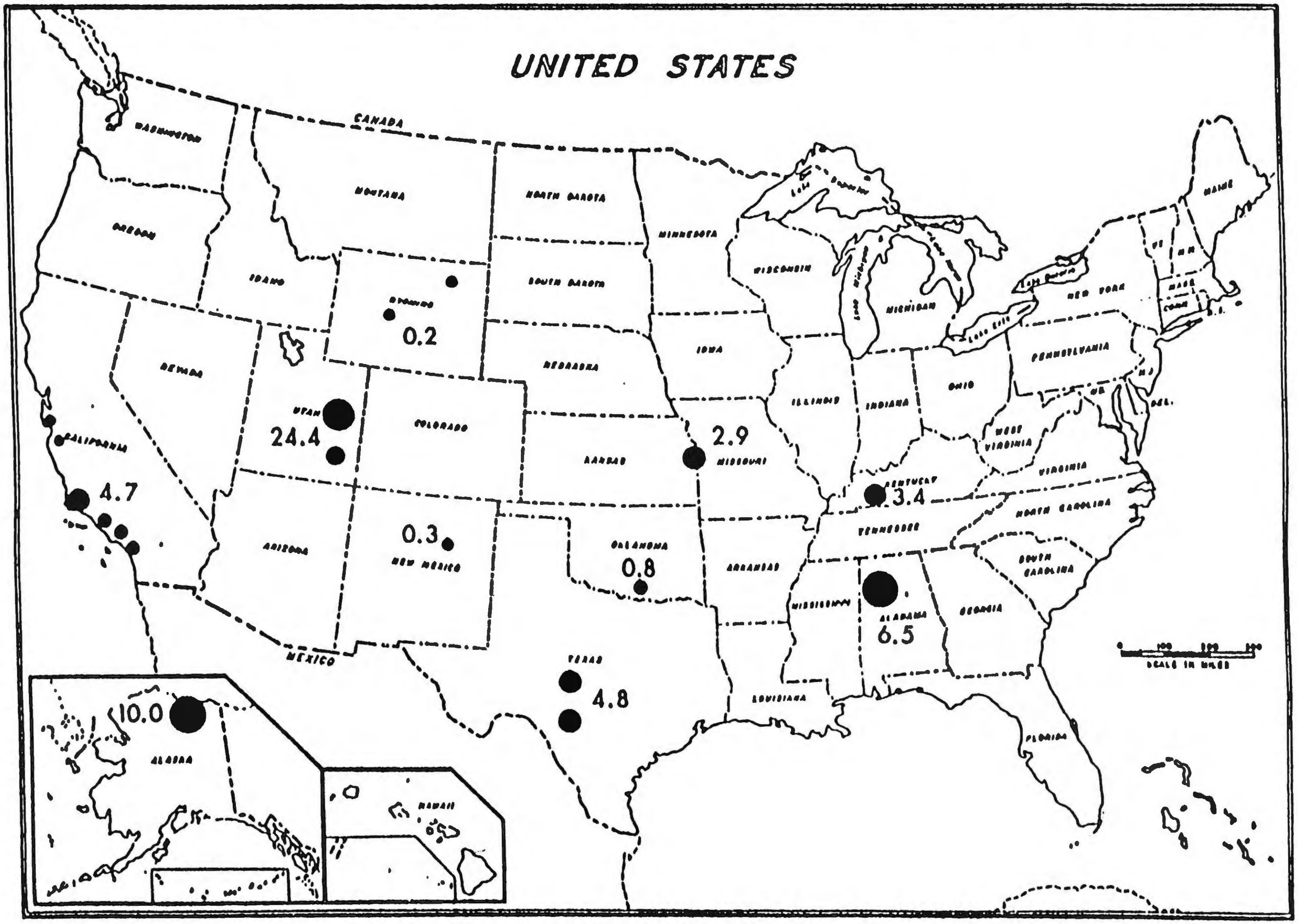


Figure 2. *Location of tar-sand deposits in the United States, with estimated reserves/resources in billions of barrels (from Lewin and Associates, 1984).*

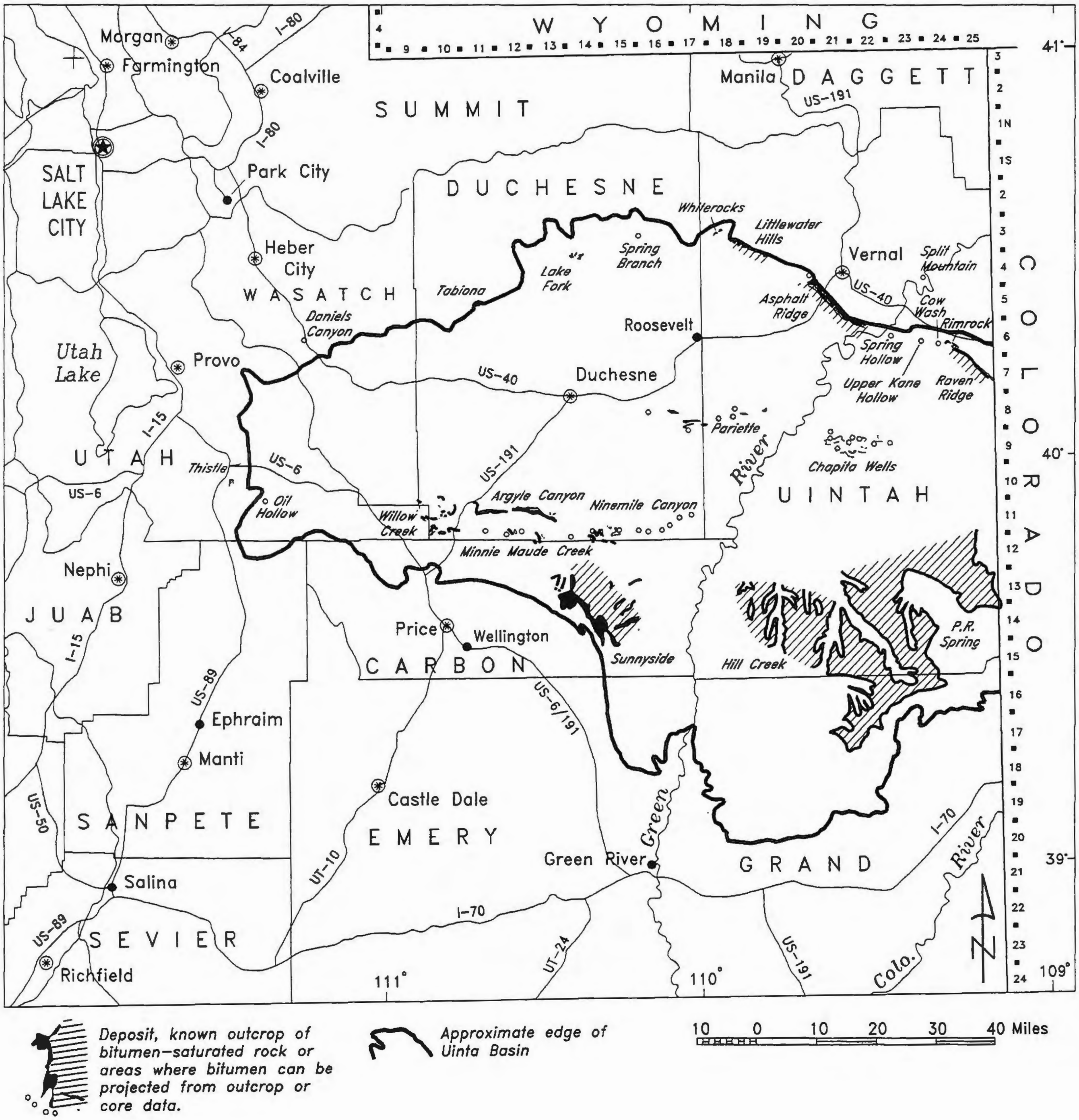


Figure 3. Distribution of tar-sand deposits within the Uinta Basin (from Ritzma, 1971).

Table 1. Summary of tar-sand resources of the Uinta Basin (after Ritzma, 1979 and 1987)

DEPOSIT	FORMATION(S) IN WHICH DEPOSIT OCCURS	DOMINANT LITHOLOGIES	RANGE OF RESOURCE ESTIMATE (millions of barrels)
ARGYLE CANYON	Green River Fm.	Sandstone, Siltstone, Limestone	100 - 125 *
ASPHALT RIDGE	Mesaverde Fm. - Duchesne River Fm.	Sandstone, Siltstone	1,148 - 1,173 **
CHAPITA WELLS	Uinta Fm.	Sandstone	7.5 - 8 *
COTTONWOOD-JACKS CANYON	Green River Fm.	Sandstone, Siltstone	80 - 100
COW WASH	Green River Fm.	Sandstone, Conglomerate	
DANIELS CANYON	Oquirrh Fm.	Limestone	100 - 125 *
HILL CREEK	Green River Fm.	Sandstone, Siltstone	6.5 - 10 *
LAKE FORK	Duchesne River Fm.	Sandstone	
LITTLEWATER HILLS	Duchesne River Fm.	Sandstone, Conglomerate	10 - 20 *
NINE MILE CANYON	Green River Fm.	Sandstone, Siltstone	5 - 10 *
P.R. SPRING	Green River Fm.	Sandstone, Siltstone	4,250 **
PARIETTE	Uinta Fm.	Sandstone, Siltstone	12 - 15 *
RAVEN RIDGE	Green River Fm.	Sandstone, Siltstone	125 - 150 *
RIM ROCK	Wasatch Fm. - Green River Fm.	Sandstone	30 - 35 *
SPRING BRANCH	Duchesne River Fm.	Sandstone, Conglomerate	1.5 - 2 *
SUNNYSIDE	Wasatch Fm. - Green River Fm.	Sandstone, Siltstone	5,200 - 5,850 **
TABIONA	Currant Creek Fm. - Duchesne River Fm.	Sandstone	4.6 *
THISTLE	Green River Fm.	Sandstone, Limestone	
WHITEROCKS	Navajo Ss.	Sandstone	125 - 140 **
WILLOW CREEK	Green River Fm.	Sandstone, Siltstone, Limestone	20 - 25 *

* Ritzma, H.R., 1979, Oil-impregnated rock deposits of Utah, Utah Geological and Mineral Survey Map 47, scale 1:100,000, 2 sheets
** Ritzma, H.R., 1987, Utah Tar Sands in Hollander, J.M., editor, Annual Review of Energy Annual Reviews Inc., p. 286-355

the Uinta Basin. Holmes and others (1948) studied the Sunnyside deposit in detail, and mapped bitumen-saturated outcrops within the Wasatch and Green River Formations. Their interpretations were general, but their work provided a framework that could be used in later studies. Crawford (1949) was one of the first to describe or speculate on the origin of the bituminous material in the Uinta Basin. Bass (1964), and Covington (1964) studied the solid hydrocarbons and bituminous sandstones of the Uinta Basin. Wiley (1967) studied the petrology of the oil-impregnated sandstone at P. R. Spring. Byrd (1967) studied the geology and its relationship to the oil-impregnated sandstones at P. R. Spring, and Clem (1984) investigated the development potential of the P. R. Spring deposit. Cashion (1967) studied the geology and fuel resources of the P. R. Spring area. Jacob (1969) measured some stratigraphic sections at the Sunnyside deposit as part of a study of delta facies in the Green River Formation.

Barb (1944) discussed bituminous deposits in the basin and possible future uses. Kayser (1966) produced physical and chemical data on tars from the basin. Wood and Ritzma (1972) determined the elemental composition of Utah tar sands from many of the deposits in the Uinta Basin. Reservoir characteristics and reserves for many of the deposits have been published by various authors. Some of these are Marchant and others (1974), Byrd (1970), Peterson (1975), Peterson and Ritzma (1974), Johnson and others (1975a), Johnson and others (1975b), Kayser (1966), and Holmes and Page (1956).

PHYSICAL ENVIRONMENT

Physiography

The Uinta Basin is an elongated east-west trending asymmetrical basin, roughly elliptical in shape. It measures about 130 miles (209 km) long by about 100 miles (161 km) wide, and the surface area covers more than 9,000 square miles (23,310 km^2). The topographic axis of the basin lies 10 to 15 miles (16-24 km) south of its structural axis (Hansen, 1963). Fluvial processes have been predominant in the basin during the Quaternary and are responsible for its present configuration.

Stokes (1977) defined the physiographic basin based on its topographic form and shape. This included the flatter, less eroded central parts of the basin and divided the rest of the geographic basin into two physiographic provinces, which he called the Book Cliffs-Roan Plateau and the Marginal Benches subsection of the Uinta Mountains (figure 4). The Book Cliffs-Roan Plateau province is an area with rugged topography, with strata of Cretaceous and Tertiary age that rise gradually southward to elevations of 8,000 to 10,000 feet (2,438-3,048 m) then terminate abruptly at south-facing cliffs. Drainages are deeply incised forming benchlike mesas and steep-walled canyons 500 to 1,000 feet (152-304 m) deep and as much as a 1 mile (1.6 km) wide. The Marginal Benches of the Uinta Mountains are benchlike remnants of old erosional surfaces that merge with the more rugged mountains to the north and the adjacent lowlands of the basin to the south. For purposes of this report, the Uinta Basin is defined to include the Uinta Basin proper, the Book Cliffs, Roan Plateau, and the southern part of Stokes's Marginal Benches subsection.

The Uinta Basin is a topographic basin in the sense that the surrounding regions are higher. The altitude of the land surface at the basin's lowest point on the Green River is about 4,300 feet (1,310 m) above sea level. The central portion of the present-day basin ranges in elevation generally between 5,000 and 6,000 feet (1,524-1,829 m). The Marginal Benches to the north commonly achieve elevations as much as 7,000 feet (2,133 m), while elevations along the southern margin range from 5,700 to over 9,000 feet (1,737-2,743 m). Because of the deep dissection by the drainage systems, differences in elevation of 1,000 feet (300 m) or more can occur over short distances.

The network of channels and tributaries that drain the basin define its physiographic boundary. Smaller rivers drain into the Green River. These streams, with headwaters on the highest parts of the dissected uplands to the north and east, cross the basin to enter either the Duchesne River or the White River. The Duchesne River, with headwaters in the Uinta and Wasatch Mountains, flows eastward and enters the Green River near Ouray, Utah. Its tributaries, the Uinta River, and the Whiterocks River drain the western parts of the Basin. The White River flows west, draining the eastern parts of the basin and also enters the Green River near Ouray, Utah.

Trellis drainage patterns are common; some areas of the basin have intense canyon-development and entrenched meanders. Each drainage varies widely in discharge and is flash-flood prone. In the southern part of

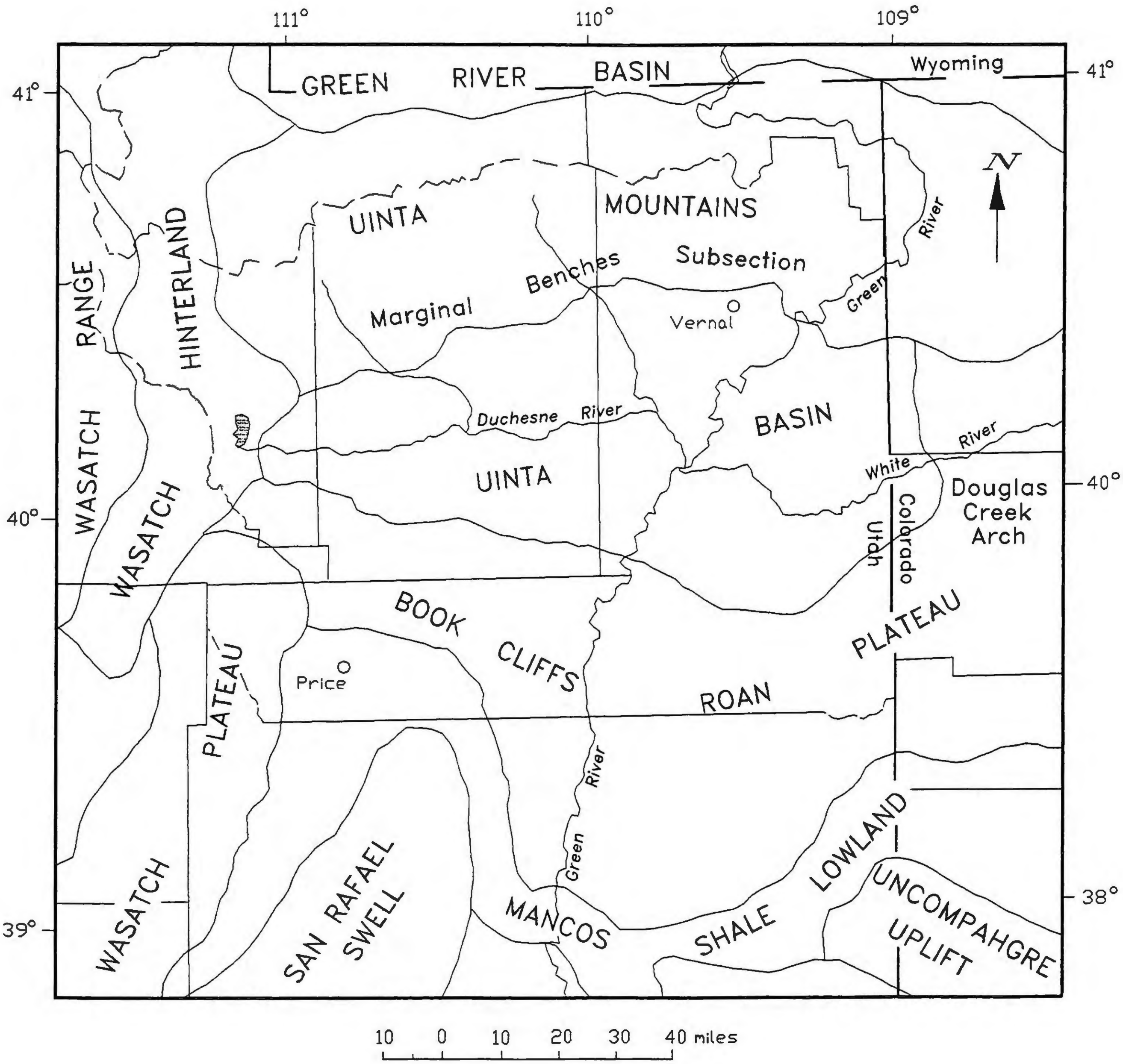


Figure 4. Physiographic provinces and principal rivers of the Uinta Basin (from Stokes, 1977).

the basin, some streams (such as Hill Creek and Willow Creek) are direct tributaries to the Green River. These tributaries flow into the Green River, the main drainage of the basin, which flows southward through a deep gorge named Desolation Canyon.

Climate

The overall climate of the Uinta Basin is moderate with respect to temperature, and arid to semiarid with respect to precipitation. Much of the basin is arid with precipitation less than ten inches (25 cm) annually. The higher-altitude margins of the basin receive from 12 to 16 inches (30-41 cm) of precipitation annually, while the nearby Uinta and Wasatch Mountains often receive more than 40 inches (102 cm) annually (Richardson and others, 1981). The marginal lands of the basin are semiarid and support pinyon-juniper forests. Lower lands are arid supporting primarily desert-shrubs. The basin proper is characterized by warm summers, cold winters, and relatively low precipitation. Average precipitation for the watershed as a whole is probably about 25 inches (63 cm), which falls mainly as snow at higher altitudes (Clark, 1957; Marsell, 1964; Richardson and others, 1981).

In the middle of the Uinta Basin, daily and seasonal temperature range is wide, relative humidity is low, and evaporation is rapid. Summers are extremely hot and dry with occasional short-duration, localized thunderstorms. Winter is generally cold and dry with little snowfall. Typical of deserts, diurnal temperatures have a wide range, due to the rapid radiation at night from the dry earth to the atmosphere. Daily July temperatures average near 70°F (21°C), with a maximum of 108°F (42°C) reported. Daily January temperatures average about 14°F (-10°C) with minimums as low as -40°F (-40°C) (Marsell, 1964).

GEOLOGY

Regional Setting

The Uinta Basin is a geographic and a structural basin that is a subdivision of the Colorado Plateau Province (figure 4). The basin is bounded on the west and northwest by the High Plateaus Province and eastern slopes of the Wasatch Mountains. The Uinta Mountains form the north boundary. The eastern boundary is generally taken to be the Douglas Creek arch, which separates the Uinta Basin from the Piceance Creek basin of western Colorado. The basin is bounded to the south by the Book Cliffs and Roan Plateau.

Geologic History

A number of workers have described Uinta Basin geology and energy potential in detail. Comprehensive discussions are found in Bruhn and others (1986), Fouch (1975), Hansen (1963), Johnson (1992), Osmond (1965), Osmond and others (1968), Picard (1955), Porter (1963), Ritzma (1972), Ryder and others (1976), Tissot and others (1978), and Wells (1958). The complex history of the Uinta Basin region records seven episodes of development as defined by major changes in depositional processes, subsidence patterns, structural controls, and basin geometry. These episodes have allowed the region to accumulate a sequence of Precambrian to Recent sediments, resting upon Precambrian crystalline basement (Osmond, 1965). Johnson (1992) summarized these seven episodes as: (1) Precambrian basement development, (2) Cambrian through Middle Devonian passive margin development, (3) Late Devonian through early Late Mississippian western orogenic influences, (4) mid-Late Mississippian through early Early Permian Rocky Mountain orogenic influences, (5) late Early Permian through Early Jurassic orogenic influences, (6) a Middle Jurassic through early Early Cretaceous western thrusting episode, and (7) late Early Cretaceous through late Eocene basin evolution. The present-day basin developed during the last period.

Most of the present structural features of the area are of Laramide age (Late Cretaceous to Early Tertiary) or younger. In general terms the Paleozoic and Mesozoic rocks of the area are predominantly marine and continental-margin sequences, with tectonic- and eustatic-induced transgressive-regressive cycles. During the Late Cretaceous the Sevier orogenic belt was active and sediment transport was primarily to the east and south (Bruhn and others, 1983). In latest Cretaceous the dominant east-west tectonic and sedimentation patterns shifted to north-south in response to the rapid uplift of the Uinta Mountains. The sea had retreated from central Utah and the thrusting to the west had resulted in deposition of coalescing alluvial fans and marginal marine sediments. The area had low to moderate relief for an interval of time during late Late Cretaceous, preceding Uinta Basin development (Franczyk and others, 1992). Formation and subsidence of the basin were contemporaneous with the uplift of adjacent highlands, the San Rafael Swell, Uinta Mountains, and Wasatch Range of Utah, the Sierra Madre Park uplift in Colorado and Wyoming, the Park, Sawatch, Douglas Creek arch, and White River uplifts in Colorado, and the reactivation of the Uncompaghre uplift in Utah and Colorado. Subsidence curves by Johnson (1992) suggest that the Uinta Basin formed as a consequence of tectonic and sedimentary loading. Rapid subsidence and sedimentation in the basin began in the Early Tertiary. The fluvial-alluvial sandstone architecture of lenticular sandstone and shale sequence suggests relatively high subsidence rate. These deposition patterns were dominant in the Early Tertiary but gave way to lacustrine sedimentation by Eocene time.

The Uinta Basin was occupied by a series of lakes of varying sizes during the Paleocene and most of the Eocene. Formations accumulated in and around ancestral Lake Uinta. These lakes existed for about 35 million years and underwent many fluctuations leading to a complex interfingering of fluvial, deltaic, and lacustrine deposits (Picard and High, 1972). The depositional axis of the Uinta Basin occurs a few miles south of the structural axis, along which is the most continuous section of lacustrine rocks (Osmond, 1965; Ryder and others, 1976). Alluvial and lacustrine sediments in the deeper parts of the basin, adjacent to the Uinta Mountains, were as much as 21,000 feet (6,000 m) thick. Up to 12,000 feet (3,600 m) of these sediments are of Paleocene and Eocene age. In Eocene and Early Oligocene time an additional 1,200 feet (360 m) of sediment was deposited adjacent to early sediments. This brings the thickness of early Tertiary sediments in the deepest part of the basin to about 22,000 feet (5,500 m) (Osmond, 1965). Tertiary through Upper Cretaceous rocks (exposed on the flanks of the basin) characterize the surface geology of the basin (figure 5).

Development of the Uinta Basin proper essentially ended in the late Eocene or early Oligocene. Some additional uplifting of the region has occurred since the middle Miocene (Gable and Hatton, 1983; Nelson and Weisser, 1985).

Structure

Structurally the basin is a simple asymmetric syncline, and is not highly deformed. Figure 6 is a structure map contoured on the Colton/Wasatch Formation (or equivalent units), showing the asymmetry of the basin (Osmond, 1965). Dips on the southwest and southeast flanks range from a few degrees to 15°; dips on the north flank are between 10° and 35°. A northwest structural trend is common throughout the southeastern and eastern parts of the basin, possibly reflecting the buried older Uncompahgre and Paradox trends (figure 7). This is manifested in northwest plunging anticlinal folds and the gilsonite dikes found in the basin. A dominant west-east structural trend is found in the central part of the basin, possibly showing a relationship to the Uinta Mountains. A regional fracture system, the Duchesne fault system trends east-west and roughly parallels the trend of the Uinta Mountains. Numerous faults compose the Duchesne fault system, displacement across the zone is not large. The north flank is highly complex with major faulting, steep to overturned beds, and multiple successive unconformities that allow youngest Eocene sediments to lie unconformable on Precambrian sediments (Ritzma, 1971).

Stratigraphy

The uppermost Cretaceous and Tertiary strata in the Uinta Basin have been the subject of extensive investigations ranging from detailed studies of specific strata to regional treatises on sedimentation. Summaries of pre-Uinta Basin stratigraphy are found in Osmond (1965), Picard (1985), Clem (1985), Hintze (1988), and Sanborn (1977). A sedimentary succession of Paleozoic and Mesozoic rocks (figure 8) is found on the northern and western flanks of the Uinta Basin and exposed in areas surrounding the basin. It is reasonable to project these under the basin. This study will deal largely with the sediments deposited in the Uinta Basin proper.

Cretaceous sedimentary rocks crop out along the margins of the Uinta Basin. Cretaceous units found in the region are the Mancos Shale and the Mesaverde Group. The Mancos Shale intertongues from east to west with the overlying Mesaverde Group. The Mesaverde Group was deposited in fluvial, deltaic, and shallow marine environments during the final marine regression of the Createaous sea. A basin-wide unconformity marks the

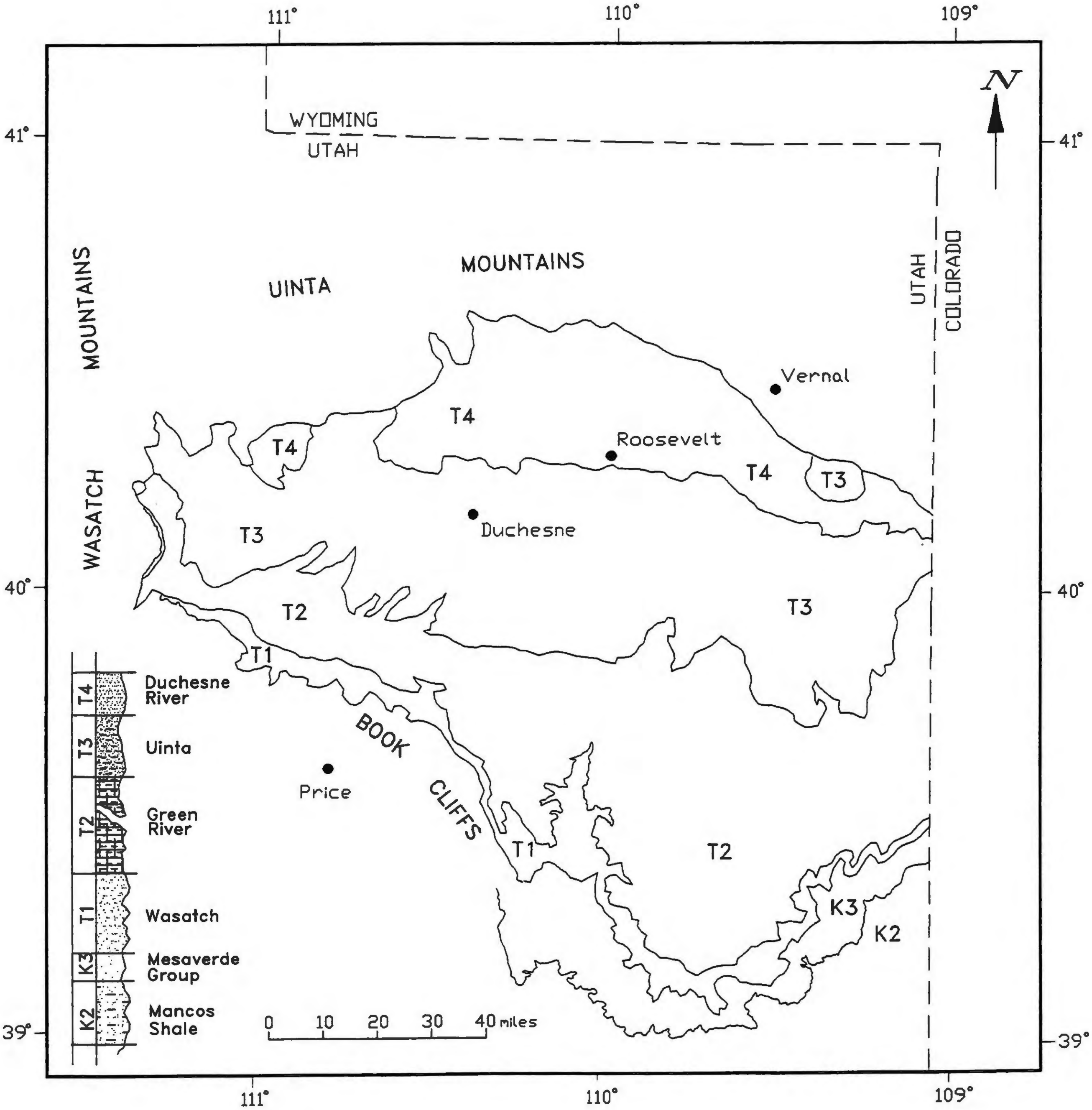


Figure 5. Generalized geologic map of the Uinta Basin region (from Hintze, 1980).

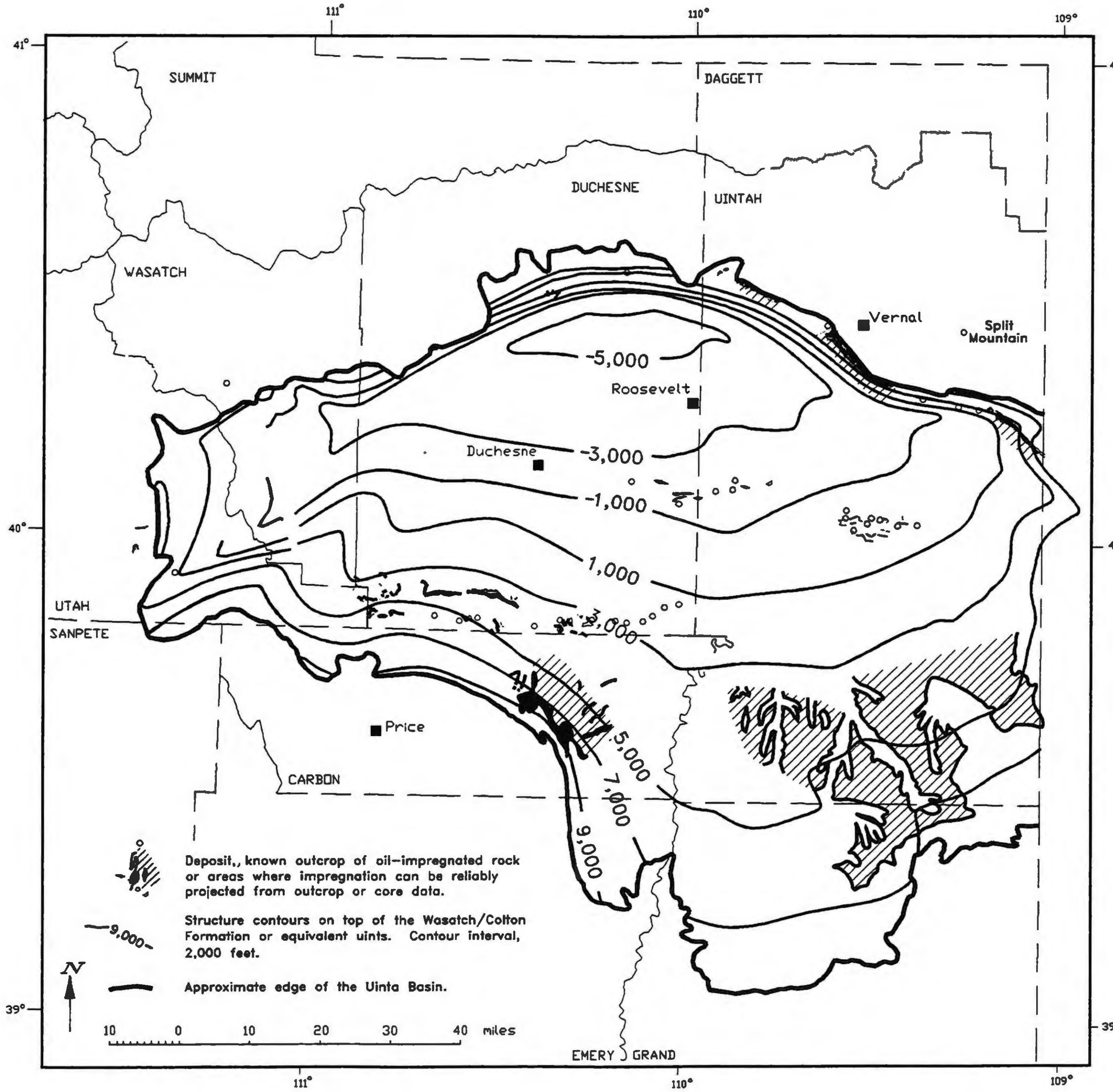


Figure 6. *Structure contour map of the Uinta Basin. Contours are elevations, in feet above msl, of the top of the Wasatch/Colton Formation or equivalent units.*

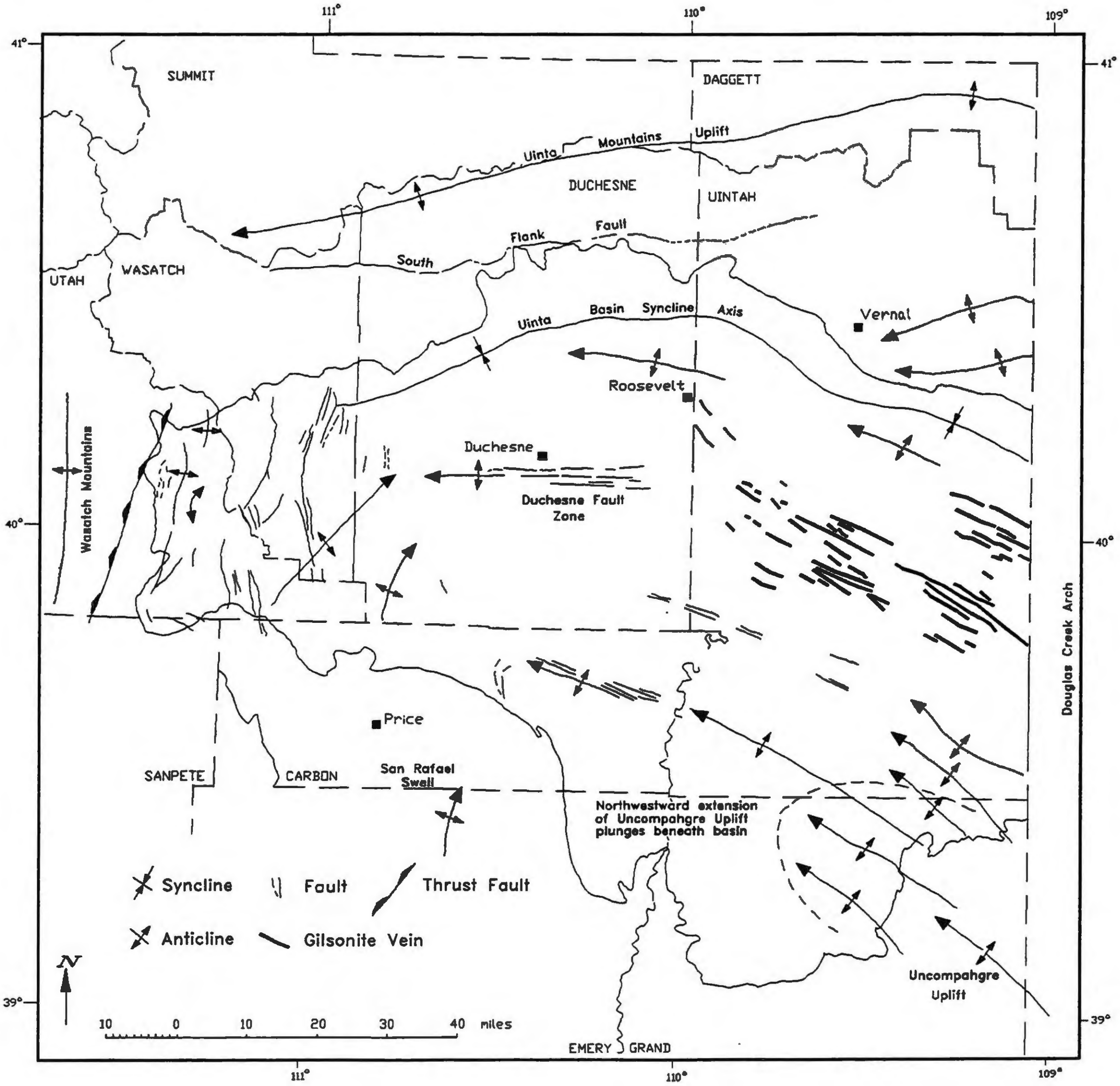


Figure 7. Tectonic features of the Uinta Basin (from Osmond, 1965).

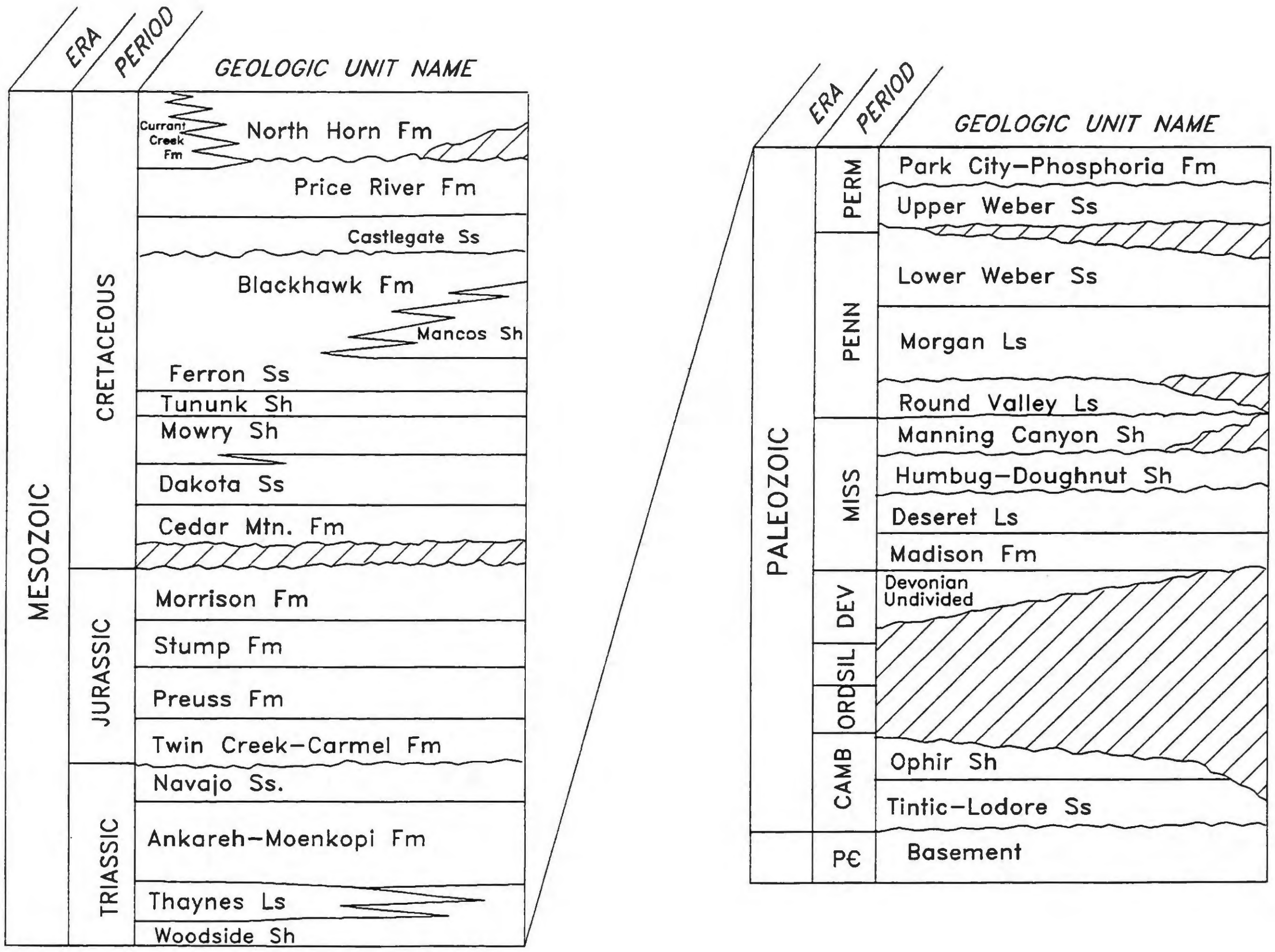


Figure 8. *Generalized stratigraphic framework of Paleozoic and Mesozoic rocks in the Uinta Basin (from Sandborn, 1977).*

transition from deposition associated with the Cretaceous sea to deposition associated with the Uinta Basin. The unconformity is represented by slight angular discordance and basal conglomerates. Alluvial and fluvial deposition followed this hiatus on a basin-wide scale. The continual thrusting to the west had resulted in the deposition of extensive coalescing alluvial fans that prograded eastward. These alluvial fan facies broadly graded into an extensive alluvial braid-plain depositing the Current Creek Formation, North Horn Formation, and Wasatch Formation. The rising Uinta Mountains, San Rafael Swell, and Uncompahgre uplift supplied the alluvial sediments. These formations can be characterized as clastic wedges of alluvium derived from source areas undergoing rapid uplift and erosion (Ryder and others, 1976; Isby and Picard, 1985). These upper Cretaceous to lower Eocene formations consist of variegated sandstone, mudstone, and minor limestone.

The Tertiary stratigraphy of the Uinta Basin is complex; numerous lithostratigraphic units have been defined and correlated within the basin. The treatment of the stratigraphy follows a more or less conventional systematic description of the named units, this in itself is difficult since the lateral relationships between units are as much a factor as are the vertical relationships. The general stratigraphy of the Uinta Basin based on Ryder and others (1976) is diagrammatically shown in figure 9. Terminology usage involves the designated facies and members of the Green River Formation and conventional names for other formations (Bradley, 1931; Dane, 1954; Dane, 1955; Picard, 1959; Cashion and Donnell, 1974). Ryder and others (1976) and Fouch and others (1992) dispensed with conventional names for the Green River Formation, using a terminology based on a depositional environment classification for the siliciclastic and carbonate sediments that accumulated in the basin.

In early Tertiary to late early Tertiary time the Uinta Basin became a topographic basin and lakes occupied the depositional basin (Isby and Picard, 1985). A complicated nomenclature has developed for the lakes that occupied the basin, but generally the name Lake Uinta is appropriate. Beginning of Green River Formation deposition was marked by a relatively rapid growth of Lake Uinta to its maximum size. Clastic deposition around the periphery of this lake continued, depositing the Wasatch Formation (Ryder and others, 1976). The lacustrine environment usually was restricted to the interior of the basin, where accommodation exceeded sedimentation. Frequent lake expansions and contractions resulted in large variations in the lake size. Repeated fluctuation of the lake level produced extensive shore deposits. On the northern side, where regional slopes were high, there was an abrupt transition from fluvial to lacustrine deposition. On the southern side of the lake, where the regional slopes were low, extensive deltaic facies developed (Picard and High, 1968). Lacustrine morphological features included wide zones of intertonguing deltaic and fluvial facies. Subsidence rates were most likely greater during deposition of the delta facies, and appears to have varied across the basin. The size of the delta front sequences represents progradation into the relatively shallow lake water. Lacustrine facies within the Uinta Basin fluctuated laterally in response to changes in the lake's base level (Franczyk and others, 1992). The Green River Formation reaches maximum thickness in the western and west-central Uinta Basin (Cashion, 1967).

The Uinta Formation was deposited in the final phase of Lake Uinta, consisting mostly of fluvial deposits. Lake Uinta was isolated and had become more saline, depositing evaporite minerals (Dyni and others, 1985). An influx of volcaniclastic in the late Eocene contributed to a shift of the depocenter of the lake westward. The Uinta Formation consists of marlstone, claystone, cross-stratified sandstone, siltstone and minor, poorly stratified oil shale. Contact between the Uinta and Green River Formation is gradational and irregular. During latest Eocene or earliest Oligocene time, Lake Uinta disappeared leaving scattered wet lands. The Duchesne River Formation is a fluvial sedimentary rocks consisting of laterally discontinuous sandstone lens with varying amount of conglomerate and poorly stratified fine-grained rocks (Anderson and Picard, 1972).

UINTA BASIN TAR-SAND DEPOSITS

Definition, Origin, and Classification

Not precisely defined in a physical, chemical, or geological manner the term "tar sand" is a commonly used name to describe a sedimentary rock reservoir impregnated with a very heavy viscous crude oil which cannot be produced by conventional production techniques (Tissot and Welte, 1984). Tar sand infers a sandy sedimentary rock as the host, but this is not always the case and other porous rocks such as siltstone and fractured carbonates have also

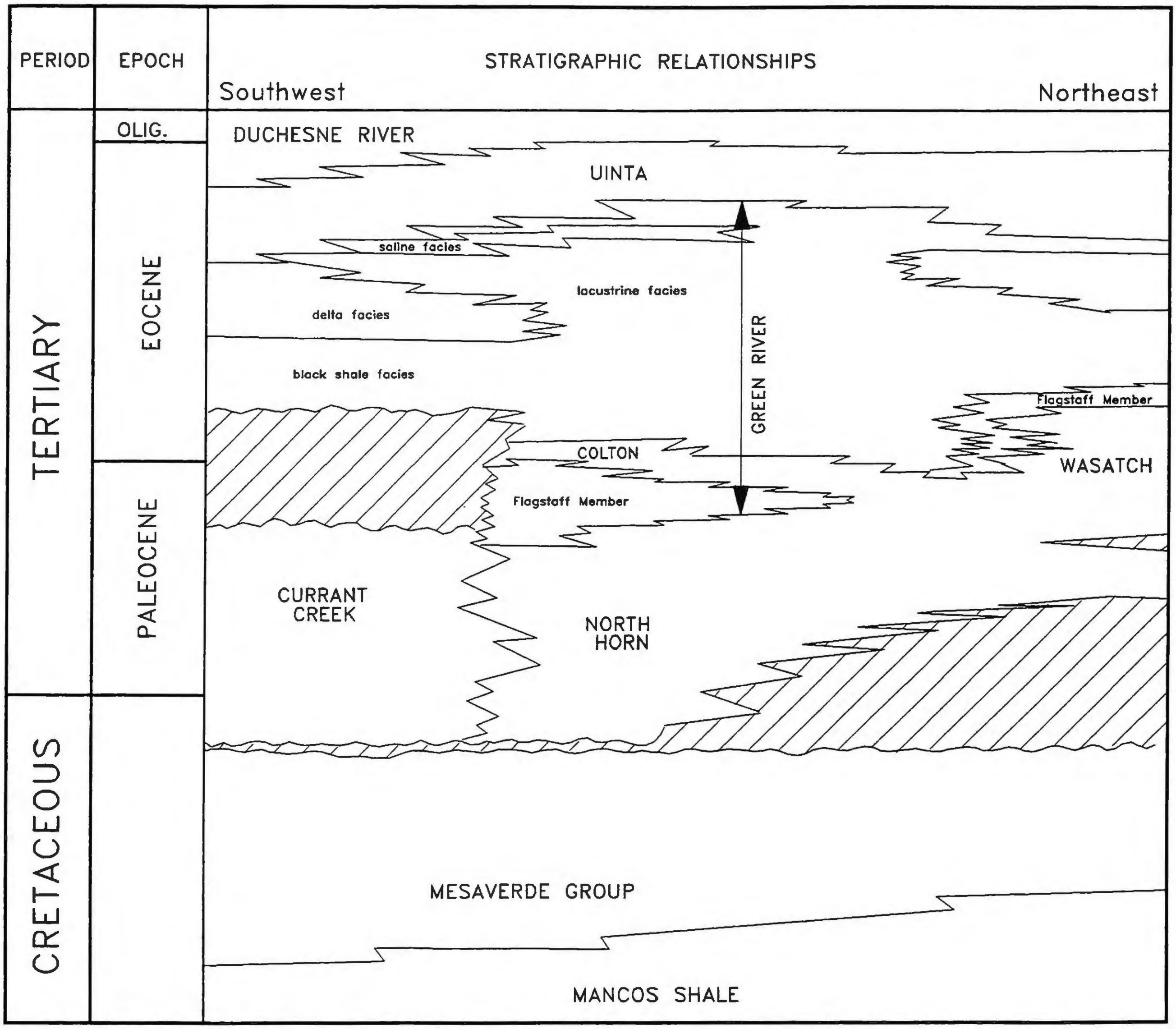


Figure 9. Stratigraphic relationships and nomenclature of late Cretaceous and early Tertiary (Paleogene) rocks in the Uinta Basin (from Ryder and others, 1976).

been classified as tar sand. For the purposes of this report tar-sand deposits have zero economic primary production, and an external source of energy is required to mobilize the oil.

While "tar sand" refers to the type of resource, the heavy oil substance impregnating the rock mass is more accurately called "bitumen," a dense viscous substance exhibiting chemical characteristics similar to petroleum and other hydrocarbons. Natural bitumens comprise a very large family of hydrocarbon substances, of which crude oil is only one example. Their chemical composition is characterized by a low carbon to hydrogen ratio compared with conventional petroleum.

The bitumen in tar sand is thought to be derived from crude oil that accumulated in conventional petroleum reservoirs near the land surface. These reservoirs were breached by streams or other erosion processes which cut through the reservoir cap-rocks, thereby allowing the volatile components of the crude oil to escape. The viscous bitumens from the crude oil, which remained in the deposit, were then altered by the combined action of ground water, air, and bacteria. Other terms such as "bituminous sands," "oil sands," and "oil-impregnated sandstone" have also been used interchangeably in the description of such deposits. Despite the ambiguity of the term "tar sand," it is firmly entrenched in the technical and industrial literature and in legislative documents. The U.S. Department of Energy defined tar sand in 1980 as any consolidated or unconsolidated rock, excepting coal, oil shale, and gilsonite which contains hydrocarbons (bitumen) and has a gas-free viscosity greater than 10 pascal seconds, or 10,000 centipoise, at original reservoir temperature. Following passage of the 1981 Federal Combined Hydrocarbon Leasing Act, the U.S. Bureau of Land Management added the phrase "or is produced by mining or quarrying" to the definition.

Classification schemes for bitumens have traditionally depended on differences in solubility, fusibility, and the hydrogen to carbon ratios. An example of such a classification scheme is shown in figure 10. Hydrocarbons are composed of hydrogen and carbon atoms and form a continuous series of organic compounds; natural bitumens are just one of these compounds. Precise boundaries do not exist between hydrocarbons and natural bitumens. However, viscosity is normally the first classification criterion. Hydrocarbons with viscosity more than 10,000 centipoise are called natural bitumens. Natural bitumens are semisolid or solid mixtures of hydrocarbons and may be divided into two groups on the basis of their solubility in various organic solvents, such as carbon disulfide (CS_2) (Hunt, 1979). These two groups are (1) the soluble "true bitumens" (oils, asphalts, mineral waxes, and asphaltites) and (2) the insoluble "pyrobitumens." Pyrobitumens are divided into two subgroups based on hydrogen to carbon ratio. The soluble natural bitumens generally contain various amounts of mineral matter. The true bitumens occur in three groups based on their relative fusibility, with the mineral waxes being the most readily fusible and the asphaltites being the least fusible. Tar sands are natural asphalts and are moderately fusible (Meyer and De Witt, 1990).

Distribution of Deposits

The Uinta Basin tar-sand deposits practically encircle the more than 9,000 square miles (23,310 km^2) of the Uinta Basin, as well as occur within it. Deposits range in size from giant (containing more than 500 million barrels of in-place bitumen) to minor (containing less than 0.5 million barrels of in-place bitumen) (Ritzma, 1979). Tar sands are found in strata that range in age from Pennsylvanian to Oligocene. Most of the tar sands are in Tertiary stratigraphic and structural sandstone traps. Tar-sand deposits are not homogeneous; bitumen distribution in a deposit varies depending on the permeability and porosity of the host rocks. Large accumulations of tar sands occur in sandstone of Eocene age, deposited in a fluvial-deltaic environment. Other tar-sands are found in alluvial and fluvial sandstone throughout the basin. The tar-sands resource of the Uinta Basin is thought to exceed eight billion barrels of oil (Ritzma, 1979). Data on the size of most of these deposits are sparse and, therefore subject to revision. At least four of the deposits are giant deposits, each containing in excess of one billion barrels of bitumen in-place. Another thirteen deposits contain more than 10 million barrels, with six deposits having more than 100 million barrels of bitumen in-place.

Chemical Properties and Thermal Maturity

Wood and Ritzma (1972) studied analyses of Uinta Basin tar sands and concluded that hydrocarbon varied considerably in some basic physical properties among deposits (table 2). The most variable characteristic they

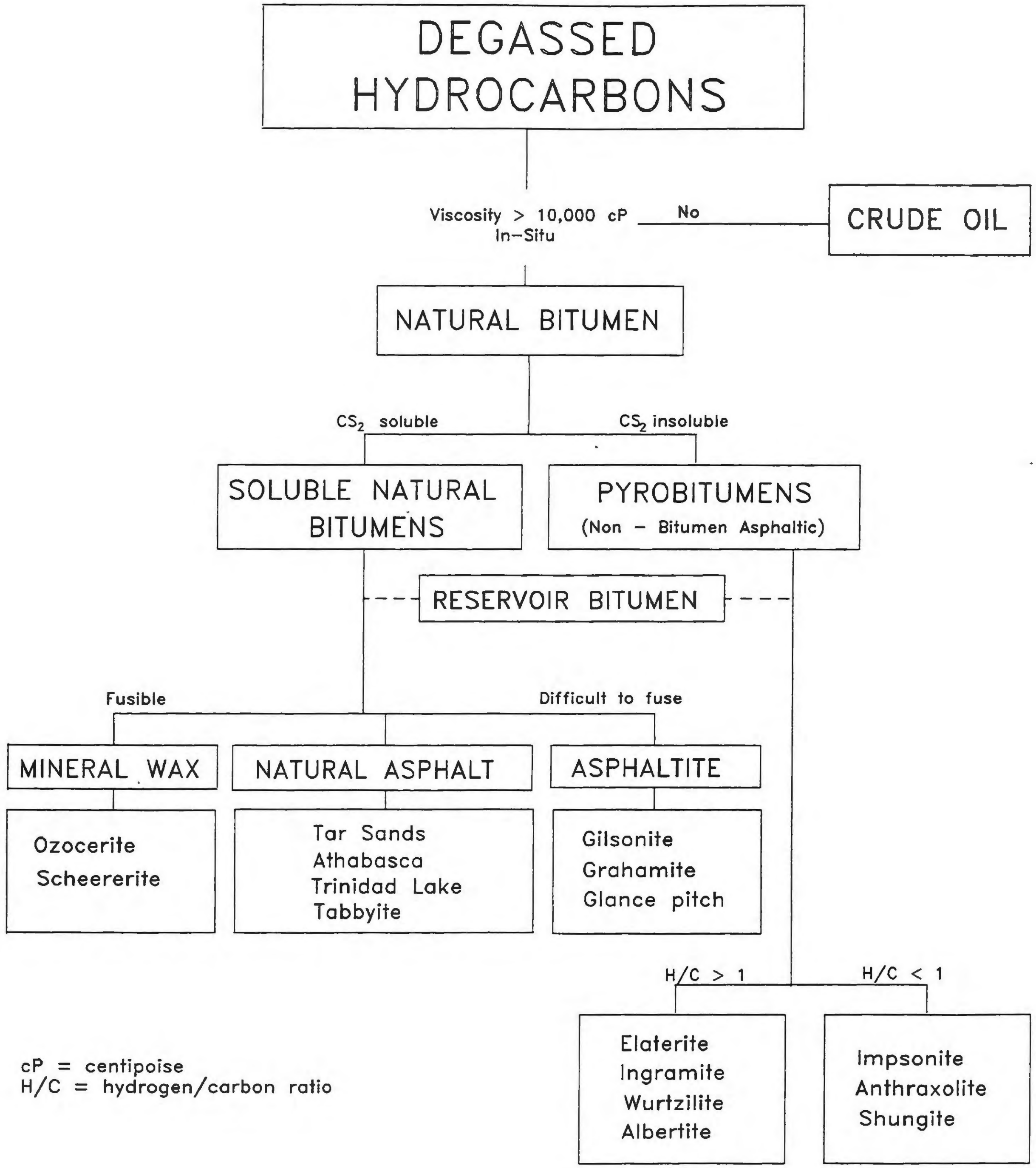


Figure 10. Physical classification scheme for natural bitumens (from Hunt, 1979; and Meyer and DeWitt, 1990).

Table 2. Analytical data for tar-sand deposits of the Uinta Basin (after Wood and Ritzma, 1972; and Mauger and others, 1973).

SAMPLE NO.	DEPOSIT	FORMATION (AGE)	PERCENT					SP. GR. G/CC.	GRAVITY •API	$\delta^{34}S$
			TAR	C	H_2	N_2	S			
69-19E	Asphalt Ridge	Rim Rock Mbr., Mesaverde Gp. (Upper Cretaceous)	17.0	71.0	10.3	0.9	0.19	0.980	12.9	
PC-65-5	Asphalt Ridge	Rim Rock Mbr. of Mesaverde Gp. (Upper Cretaceous)	85.3	11.2	1.01	0.28	0.99		12.0	
PC-65-6	Asphalt Ridge	Duchesne River Fm. (Eocene)	83.6	11.0	0.96	0.62	1.01		8.2	
RK-I-3	Asphalt Ridge	Rim Rock Mbr., Mesaverde Gp. (Upper Cretaceous)					1.0			+19.8
RK-I-4	Asphalt Ridge	Rim Rock Mbr., Mesaverde Gp. (Upper Cretaceous)					1.0			+21.6
RK-II-4	Asphalt Ridge	Duchesne River Fm. (Eocene)					0.2			+14.0
RK-III-2	Asphalt Ridge	Duchesne River Fm. (Eocene)					0.9			+13.5
RK-IV-1	Asphalt Ridge	Duchesne River Fm. (Eocene)					0.2			+21.2
RK-IV-4	Asphlat Ridge	Duchesne River Fm. (Eocene)					0.2			+14.1
RK-IV-5	Asphalt Ridge	Duchesne River Fm. (Eocene)					0.4			+17.8
RK-V-4	Asphalt Ridge	Uinta Fm. (Eocene)					0.5			+15.6
RK-V-5	Asphalt Ridge	Uinta Fm. (Eocene)					0.9			+7.0
1836	Asphalt Ridge	Rim Rock Mbr., Mesaverde Gp. (Upper Cretaceous)					0.3			+21.0
1835	Asphalt Ridge	Uinta Fm. (Eocene)					0.6			+20.1
69-18E	Asphalt Ridge, Northwest	Asphalt Ridge Mbr. of Mesaverde Gp. (Upper Cretaceous)	13.4	84.0	10.2	1.4	0.40	0.970	14.3	
69-15E	Chapita Wells	Uinta Fm. (Eocene)	1.7	82.0	10.6	1.2	0.28	1.013	8.2	
69-1A	Cow Wash	Parachute Creek Mbr., Green River Fm. (Eocene)	2.7	85.1	10.3	1.1	0.39	1.025	6.6	
70-22D	Daniels Canyon	Oquirrh Fm. (Penn-Perm)	2.79	67.3	11.0		0.62	0.985	12.2	
74-1A	Daniels Canyon	Oquirrh Fm. (Penn-Perm)	2.1	78.3	9.46		0.25	1.027	6.3	
74-2A	Daniels Canyon	Oquirrh Fm. (Penn-Perm)	0.4	79.5	9.77		0.29	1.031	5.7	
910	Daniels Canyon	Oquirrh Fm. (Penn-Perm)					0.59			
911	Daniels Canyon	Oquirrh Fm. (Penn-Perm)					0.57			
69-11C	Hill Creek	Douglas Creek Mbr., Green River Fm. (Eocene)	11.2	81.5	11.8	1.4	0.40	1.017	7.6	
68-21D	Lake Fork	Duchesne River Fm. (Eocene)	63.9	90.0	3.6	0.7	0.44	0.979	13.0	+8.1
68-22D	Lake Fork	Duchesne River Fm. (Eocene)	13.5	82.4	3.1	0.0	0.46	1.039	4.8	+8.3
68-14C	Littlewater Hills	Duchesne River Fm. (Eocene)	11.1	75.5	10.3	0.6	0.41	1.078	-0.2	+2.7
69-13E	P.R. Spring (Dragon-Asphalt Wash	Douglas Creek Mbr., Green River Fm. (Eocene)	12.4	80.0	9.5	1.0	0.45	1.012	8.3	

Table 2. (continued)

SAMPLE NO.	DEPOSIT	FORMATION (AGE)	PERCENT					SP. GR. G/CC.	GRAVITY •API	$\delta^{34}S$
			TAR	C	H_2	N_2	S			
67-1A	P.R. Spring	Douglas Creek Mbr., Green River Fm. (Eocene)	97.6	86.0	10.9	0.67	0.36	0.969	14.5	
67-5A	Raven Ridge	Parchute Creek Mbr., Green River Fm. (Eocene)	8.6	79.2	9.74	1.07	1.31	1.041	4.4	
67-8A	Raven Ridge	Green River Fm. (Eocene)	7.0	85.0	11.2	0.33	0.27	1.001	9.9	+5.3
67-10A	Raven Ridge	Parachute Creek Mbr., Green River Fm. (Eocene)	7.3	78.2	10.3	0.90	0.43	1.014	8.0	+20.6
67-4A	Rim Rock	Wasatch Fm. (Eocene)	12.6	72.9	9.76	0.55	0.38	1.045	3.9	+4.7
67-6A	Rim Rock	Green River Fm. (Eocene)	10.6	81.5	9.95	0.61	0.43	1.027	6.3	+6.9
67-7A	Rim Rock	Green River Fm. (Eocene)	9.0	78.1	9.62	0.34	0.33	1.037	5.0	+6.5
67-9A	Rim Rock	Wasatch Fm. (Eocene)	11.3	81.8	10.1	0.49	0.43	1.024	6.7	+5.7
68-17D	Split Mountain	Park City Fm. (Permian)	1.12	85.6	3.4	0.0	2.94	1.055	2.7	-2.0
68-23D	Spring Branch	Duchesne River Fm. (Eocene)	10.7	76.2	7.9	0.9	0.47	1.022	7.0	+3.1
68-24D	Spring Branch	Duchesne River Fm. (Eocene)	14.1	83.6	3.2	1.0	0.82	1.061	1.9	+7.4
68-18D	Spring Hollow	Duchesne River Fm. (Eocene)	2.6	87.5	3.3	0.60	0.76	0.968	14.7	+7.0
68-15C	Tabiona	Uinta (?) Fm. (Eocene)	5.45	74.9	10.1	0.40	0.20	1.038	4.9	+5.5
68-16C	Tabiona	Currant Creek Fm. (Paleocene-Eocene)	2.55	81.3	10.8	0.10	0.21	1.025	6.5	+5.9
68-20D	Tabiona	Currant Creek Fm. (Paleocene-Eocene)	8.25	83.0	3.2	0.80	0.29	1.004	9.8	
69-2A	Upper Kane Hollow	Parachute Creek (?) Mbr., Green River Fm. (Eocene)	1.3	86.4	9.9	1.35	0.32	1.017	7.6	
WR-1	Whiterocks	Navajo Ss. (Jurassic)					0.2			+21.2
WR-2	Whiterocks	Navajo Ss. (Jurassic)					0.3			+21.2
WR-3	Whiterocks	Navajo Ss. (Jurassic)								+21.4
68-10A	Whiterocks	Navajo Ss. (Jurassic)	7.8	84.4	11.2	1.3	0.48	0.996	10.6	

observed was sulfur content. Sulfur compounds generally form the largest group of non-hydrocarbons in oil, and Wood and Ritzma (1972) showed that sulfur content of Uinta Basin tar sands commonly varied between 0.19 to 0.62 percent. Five deposits had relatively higher values (figure 11). They observed that sulfur contents of these deposits was low, suggesting they were derived from low-sulfur oil.

Palacas and others (1988) analyzed some of the tar sands in the Uinta Basin to determine the level of maturity and to postulate the source of the hydrocarbons. They observed that these deposits were commonly depleted in some standard compounds called "biomarkers" (steranes, isoprenoids, and alkanes), which they attributed to extensive biodegradation. They studied other biomarkers, more resistant to biodegradation, and concluded that Uinta Basin tar sands are characterized by low triaromatic-enrichment ratios. Other biomarkers reflect low maturity. Together, these observations suggest that Uinta Basin tar sands are likely to have been derived from a shallow,

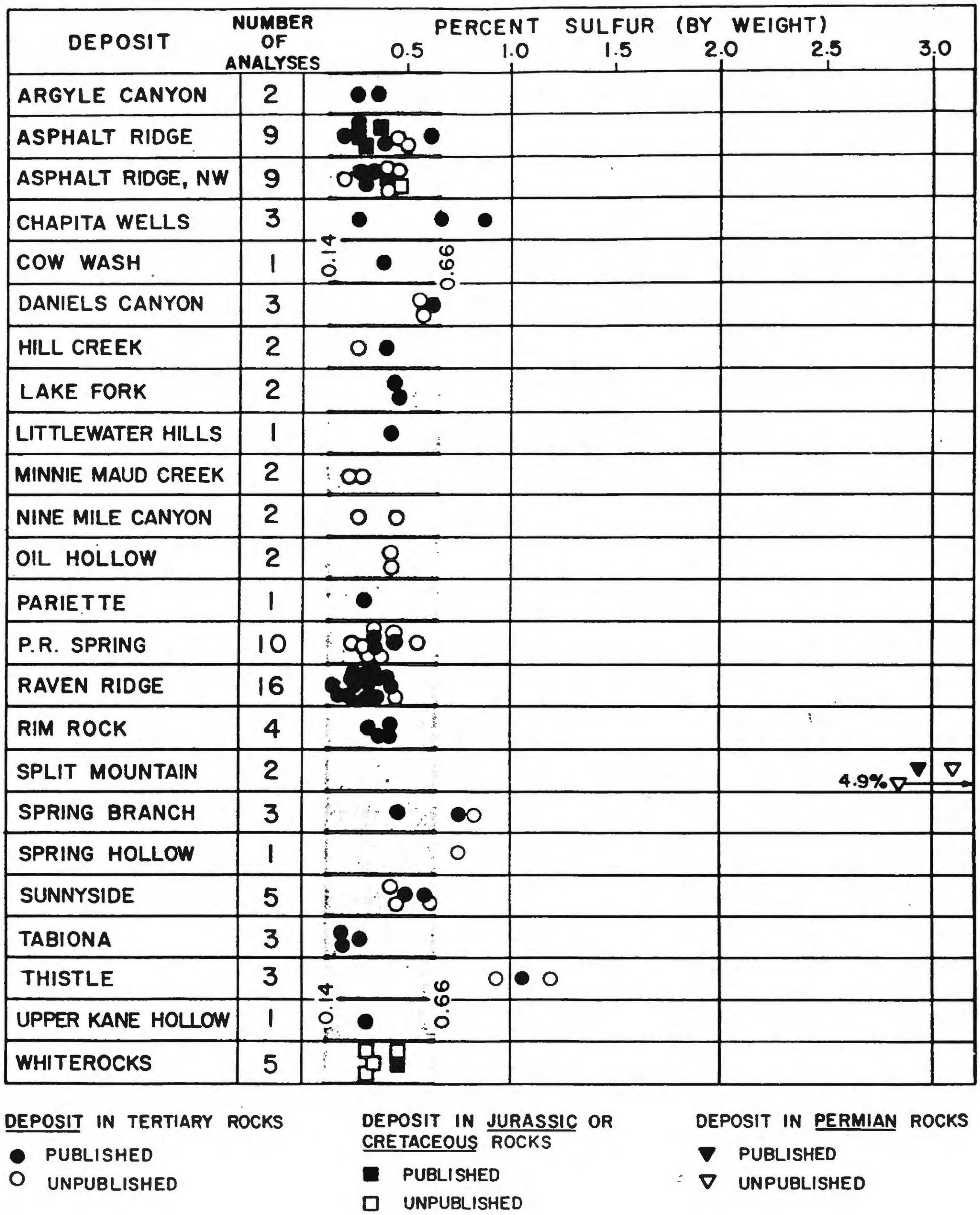


Figure 11. *Percent sulfur (by weight) in bitumen extracted from tar sands in the Uinta Basin (from Wood and Ritzma, 1972).*

immature source. Palacas and others (1988) concluded that the Green River Formation units that acted as the source of hydrocarbons generated and expelled immature to marginally mature oils and heavy oils. Biodegradation of the heavy oils led to formation of the tar sand and deposits of other solid hydrocarbons, such as gilsonite. According to biomarker signatures, the Sunnyside, P. R. Spring, and Asphalt Ridge deposits are thermally immature, while the Raven Ridge deposit is thermally mature.

Source, Migration, and Degradation

Lacustrine rocks are the most important petroleum source beds in continental sedimentary sequences. Organic matter on lake bottoms is normally derived from fresh-water algae and bacteria that tend to be oil-prone and waxy. In deep lakes, surface winds do not disturb the lower layers of water and, therefore, stagnant conditions, favorable to the accumulation of organic matter, exist. As a lacustrine basin evolves by sediment accumulation and subsidence, oil generation occurs and migration tends to move oil upward within a homogeneous carrier bed. Bitumen moves out of the fine-grained lacustrine source rocks, through the more permeable carrier beds, and finally into porous traps. There appear to be no distance constrains on migration, as the distances from likely source beds to individual deposits vary. Migration continues until a trap is reached, or until the organic material is destroyed by oxidation and biodegradation.

Tar-sand deposits are a product of biodegradation and water-washing (dissolution of oil by meteoric water) of crude oils after migrating from sources and accumulating in traps. Biodegradation and water washing occur when crude oil contacts bacteria and oxygen-laden meteoric water at low temperatures (below 93°C [199°F]), and usually at shallow depths (Demaison, 1977). The bacteria consume the light-hydrocarbons in the crude oil, resulting in density and viscosity increases in the residual oil. Water-washing removes the water-soluble hydrocarbons, whereas, biodegradation removes paraffins and isoprenoids. These processes have caused the tar sands to be partially to totally depleted in some standard hydrocarbon compounds such as n-alkanes, isoprenoids, alkylcyclohexanes, and alkylbenzenes.

Land Status

State, private, tribal, and federal lands are found in the Uinta Basin (Bureau of Land Management, 1977). Oil and gas, tar sands, and other solid hydrocarbons are generally part of mineral rights associated with the land. Utah State lands normally include state-owned mineral rights and are subject to lease. Private lands commonly include rights to minerals, but there are exceptions. Mineral rights on privately held lands and valid mining claims are sold or leased in any way the owner feels appropriate. Minerals on tribal lands are held in trust by the federal government and are the property of the tribes and managed by them. Federal lands require a lease to develop minerals. Acquisition or leasing of mineral rights in the Uinta Basin involve the following:

(1) Most of Utah State Lands within the Uinta Basin are managed by the Utah School and Institutional Trust Lands Administration (SITLA). The Division of Sovereign Lands and forestry administers the mineral rights within Utah sovereign lands.

(2) Mineral rights for private Lands (Fee Lands) are normally conveyed through sale or leasing by the individual land owners or their agents. Sometimes with land transfers, mineral rights are reserved by federal, state, or tribal agencies.

(3) The Ute tribe and the Bureau of Indian affairs, which has the right to negotiate and issue leases on mineral commodities including tar sand, administers land within the Ute and Ouray Reservation.

(4) Federal lands include mainly public domain administered by the Bureau of Land Management and National Forests administered by the U.S. Forest Service.

History of Leasing and Land Ownership

Prior to 1926 tar sands on Federal lands could be located as placer mining claims under the General Mining Law of 1872, although the mining law was awkward for these types of deposit. The Petroleum Placer Act of 1897 confirmed the applicability of the mining law in the locating of mining claims for petroleum deposits on vacant Federal lands (Pruitt, 1964). Tar-sand claims could also be patented or they could be held as unpatented mining claims (until the Combined Hydrocarbon Act of 1981). Tar-sand mining claims generally covered 160 acres per claim. The federal government first attempted to remove tar sands (along with oil and gas) from the mining law in 1909-1910, when a presidential order closed large areas of the western U. S. (known or believed to contain petroleum) to mining claims. The Uinta Basin was not considered a petroleum province and not adversely affected by this action (Pruitt, 1964).

The federal government first distinguished between oil and gas fields and tar-sand deposits beginning on July 17, 1914 with an Act of Congress. Congress authorized the reservation to the United States of all deposits of "phosphate, nitrate, potash, oil, gas, or asphaltic minerals" in agricultural land patents. The Mineral Leasing Act of 1920 did not specifically identify tar sands, but provided that deposits of oil, oil shale, and gas on federal lands be disposed of exclusively by separate mineral leases. The Mineral Leasing Act was directed toward certain well-known commodities, where it was felt that greater government control for their orderly development was needed. The Department of the Interior interpreted the Mineral Leasing Act to exclude tar sands which remained subject to the General Mining Law of 1872.

Lands known to contain deposits of tar sands and other like substances were withdrawn from consideration for location as placer mining claims under the General Mining Law, by Executive Order No. 4371 in 1926 (Pruitt, 1964). Congress amended the Mineral Leasing Act in 1960 to allow leasing of tar-sand deposits on Federal lands. This amendment provided for separate oil and gas and tar-sand leases. Conversion of mining claims to tar-sand leases within a one-year period was provided for by the act, but delays in publishing the regulations effectively did away with this conversion period (Pruitt, 1964). The 1960 amendment made reference to "materials from which oil is recoverable only by special treatment after the deposit is mined or quarried". A conflict soon developed over in-situ recovery of hydrocarbons from the tar-sand deposits and other wording in the amendment. This conflict caused the Department of the Interior to cease tar-sand leasing in 1965, thereby creating an obstacle to tar-sand development. Even the tumultuous events in the oil market during the 1970s did not result in any serious change in the situation. Companies were prevented from establishing significant land plays due to the lack of federal leasing policy.

The U.S. Congress enacted the Combined Hydrocarbon Leasing Act (Public Law 97-78) in 1981 (Kerns, 1984). The Act provides for combined hydrocarbon leases applicable only in specified areas purportedly containing the bulk of the federally owned tar sands. In Utah, 11 areas were specified for combined-hydrocarbon leases. Congress's intent was to "facilitate and encourage the production of oil from tar sand and other hydrocarbon deposits." Passage of the Combined Hydrocarbon Leasing Act accomplished the following:

(1) Redefined oil to include tar sand.

(2) Provided for conversion of existing oil and gas leases and certain valid mining claims to Combined Hydrocarbon Leases.

(3) Provided for issuance of new Combined Hydrocarbon Leases, on a competitive basis.

Combined Hydrocarbon Leases are offered in areas designated by Congress as Special Tar-Sand Areas (STSAs). All current STSAs are located in Utah (figure 12). Table 3 shows the distribution of land ownership within the STSAs. Despite the apparent intent of Congress to encourage tar-sand development, neither extensive leasing nor commercial development has taken place. Although beyond the scope of this report, a combination of factors--economic, technical, legal, and policy--appear to be responsible for lack of development. Interest in possible tar-sand development has fluctuated widely since the early 1950's and has generally been related to availability of adequate, secure supplies of comparatively cheap conventional petroleum.

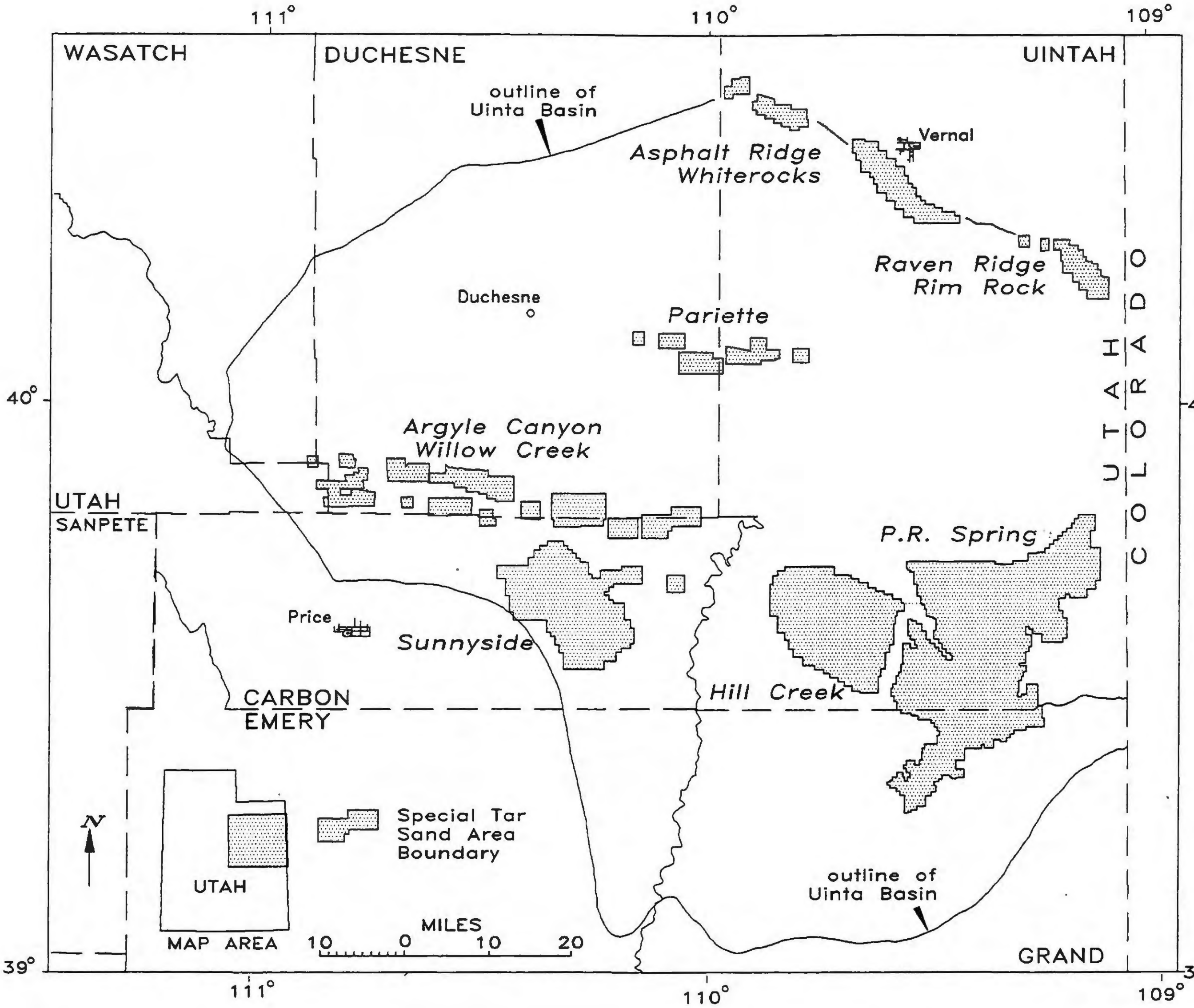


Figure 12. *Geographic distribution of Special Tar Sand Areas (STSAs) in the Uinta Basin (after Bureau of Land Management, 1984).*

Table 3. Distribution of Lands in Special Tar Sand Areas in the Uinta Basin (from U.S. Bureau of Land Management, 1980).

STSA	Public	Forest	State	Private	Indian
Asphalt Ridge-Whiterocks	5,120	1,920	17,976	1,600	9,920
Hill Creek	32,256		2,560	8,160	63,664
P.R. Spring	196,480		63,696	14,384	
Sunnyside	83,872		9,600	53,000	
Pariette	12,480		1,440		2,240
Argyle Canyon-Willow Creek	640	5,312	2,240	6,400	13,760
Raven Ridge-Rim Rock	13,960		2,080		
Total	**344,808**	**7,232**	**99,592**	**83,544**	**89,584**

The State of Utah has long encouraged a tar-sand industry in Utah. It has actively pursued land selection and exchange opportunities to establish a major presence in tar-sand localities in eastern Utah. Prior to 1952 the State of Utah issued leases covering asphalt, oil, and gas on state lands. After 1952, tar sands (asphalt or bituminous sand) were leased separately. A version of the federal combined-hydrocarbon lease is presently used to lease tar sands on state lands. In a few instances, where the State owns tar sands, but not oil and gas rights, leasing is accomplished with an "asphaltic sands" lease.

SUMMARIES OF PRINCIPAL TAR-SAND DEPOSITS

The following sections briefly describe the four principal tar-sand deposits of the Uinta Basin. These include Asphalt Ridge, P.R. Spring, Hill Creek, and Sunnyside. More complete descriptions and information are included in the references to these deposits. The reader is urged to consult these publications and articles for more details. Figure 13 shows the locations of the principal tar-sand areas with respect to primary roads and communities.

Asphalt Ridge and Asphalt Ridge Northwest

Location and Access

The Asphalt Ridge and Asphalt Ridge Northwest tar-sand deposits are located on the north-northeast flank of the Uinta Basin, about 3.5 miles (5.6 km) southwest of the town of Vernal, Uinta County, Utah (figure 13). The deposits crop out on the northeast side of Asphalt Ridge from the Maeser-Lapoint road to the north to the Green River to the south. Bitumen-saturated outcrops are exposed along broad, northeast-facing cliffs of Asphalt Ridge and lie in T.4-6S., R.20-22E. (SLM).

U.S. Highway 40 crosses the north part of Asphalt Ridge. Several unimproved roads provide vehicle access from U.S. 40 to various parts of the deposit.

Physiography and Land-Use

Asphalt Ridge is situated along the northeast edge of the Uinta Basin physiographic subprovince (Stokes, 1977). The Marginal Benches/Uinta Mountains subprovince of the Middle Rocky Mountains lies less than 10 miles (16 km) to the north. The ridge forms the southwest limit to the low-lying farm lands of Ashley Valley. The Green River, which flows southwestward through the Uinta Basin, meanders around the southeast extension of Asphalt Ridge. The ridge is a northwest-southeast trending cuesta, where Cretaceous and Tertiary formations dip to the southwest (Kayser, 1966). Bitumen-saturated outcrops extend for about 12 miles (19 km) northwest-southeast along the strike of the outcrops.

The town of Vernal is less than 4 miles (6.4 km) to the northeast in Ashley Valley where elevations range generally between 5,200 and 5,500 feet (1,585 and 1,676 m). Asphalt Ridge rises from 500 to 1,000 feet (152 to 305 m) above Ashley Valley, forming a prominent escarpment. The highest point on the ridge, located near the northwest end, is slightly more than 6,400 feet (1,951 m) in elevation. The Ashley Valley oil field, a Permian-Pennsylvanian oil reservoir, lies 8 to 10 miles (13 to 16 km) to the southeast.

The Uintah and Ouray Indian Reservation boundary lies about 8 miles (15 km) west of the Asphalt Ridge deposit. Ashley Valley, northeast of the ridge, is mostly privately owned, while Asphalt Ridge is federal and state owned (figure 14). Most of area comprising the tar-sand outcrops is administered by the Bureau of Land Management. Lands making up the "down-dip" (southwest) portion of the deposit are primarily Utah State lands managed by SITLA.

Geologic Setting

Exposed strata consist of the Asphalt Ridge Sandstone and the overlying Rim Rock Sandstone, both of the Mesaverde Group (Cretaceous), and the Duchesne River Formation (Eocene-Oligocene) (figures 15 and 16). The Asphalt Ridge Sandstone and the Rim Rock Sandstone are separated by a thin tongue of Mancos Shale. All Cretaceous units are of marine origin. At Asphalt Ridge the Duchesne River Formation, containing interbedded fluvial sandstones with associated shales and conglomerates, lies unconformably atop the Rim Rock Sandstone (Campbell and Ritzma, 1979). The Rim Rock Sandstone (Mesaverde) ranges from about 100 feet (30 m) to more than 300 feet (90 m) in thickness, due to erosion of the unit prior to deposition of the overlying Duchesne River Formation (Kayser, 1966). Elsewhere, the Duchesne River Formation successively overlies the Uinta, Green River, and Wasatch Formations. The Green River and Wasatch Formations are not present in the section at Asphalt Ridge

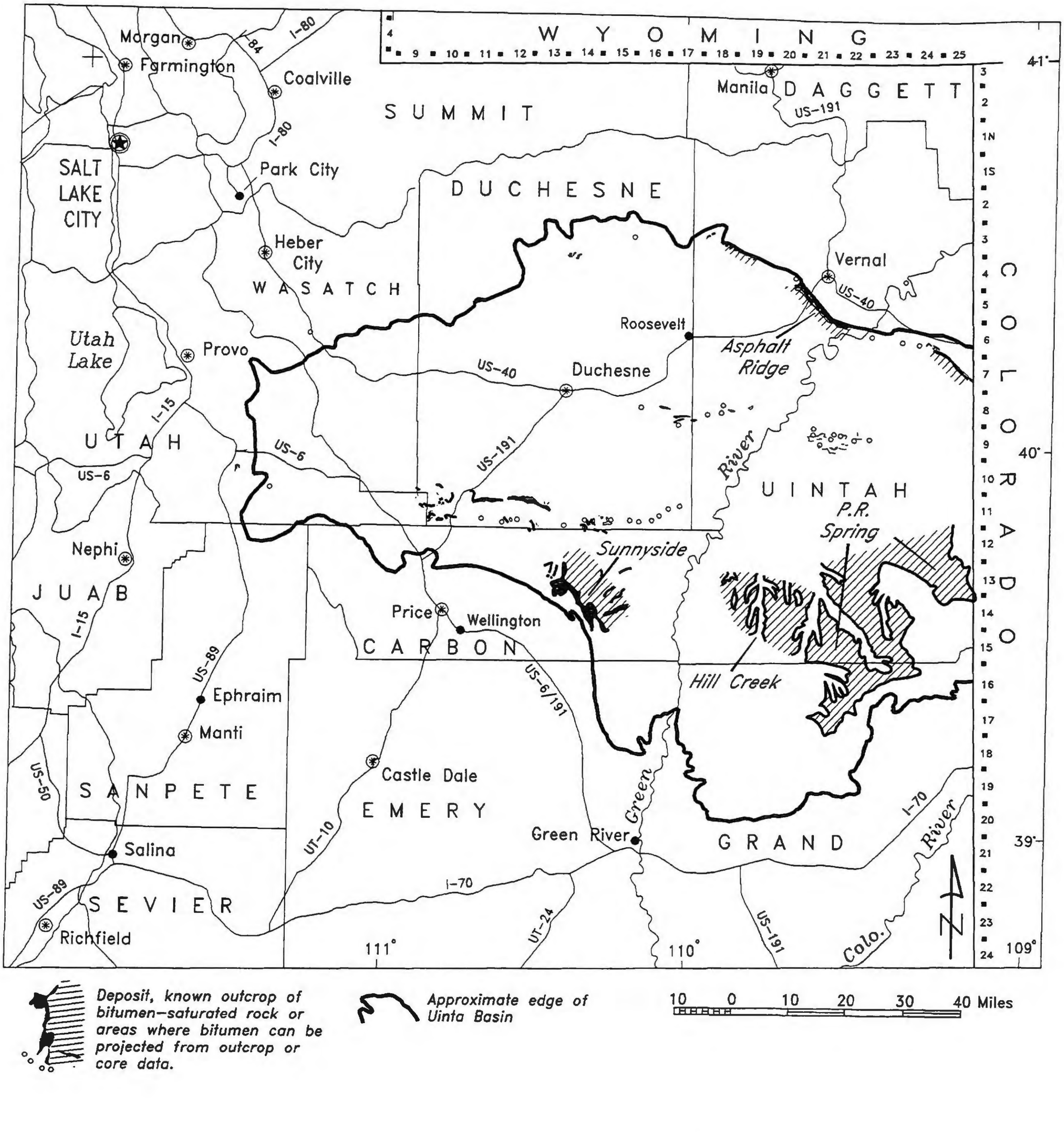


Figure 13. Locations of primary tar-sand deposits of the Uinta Basin.

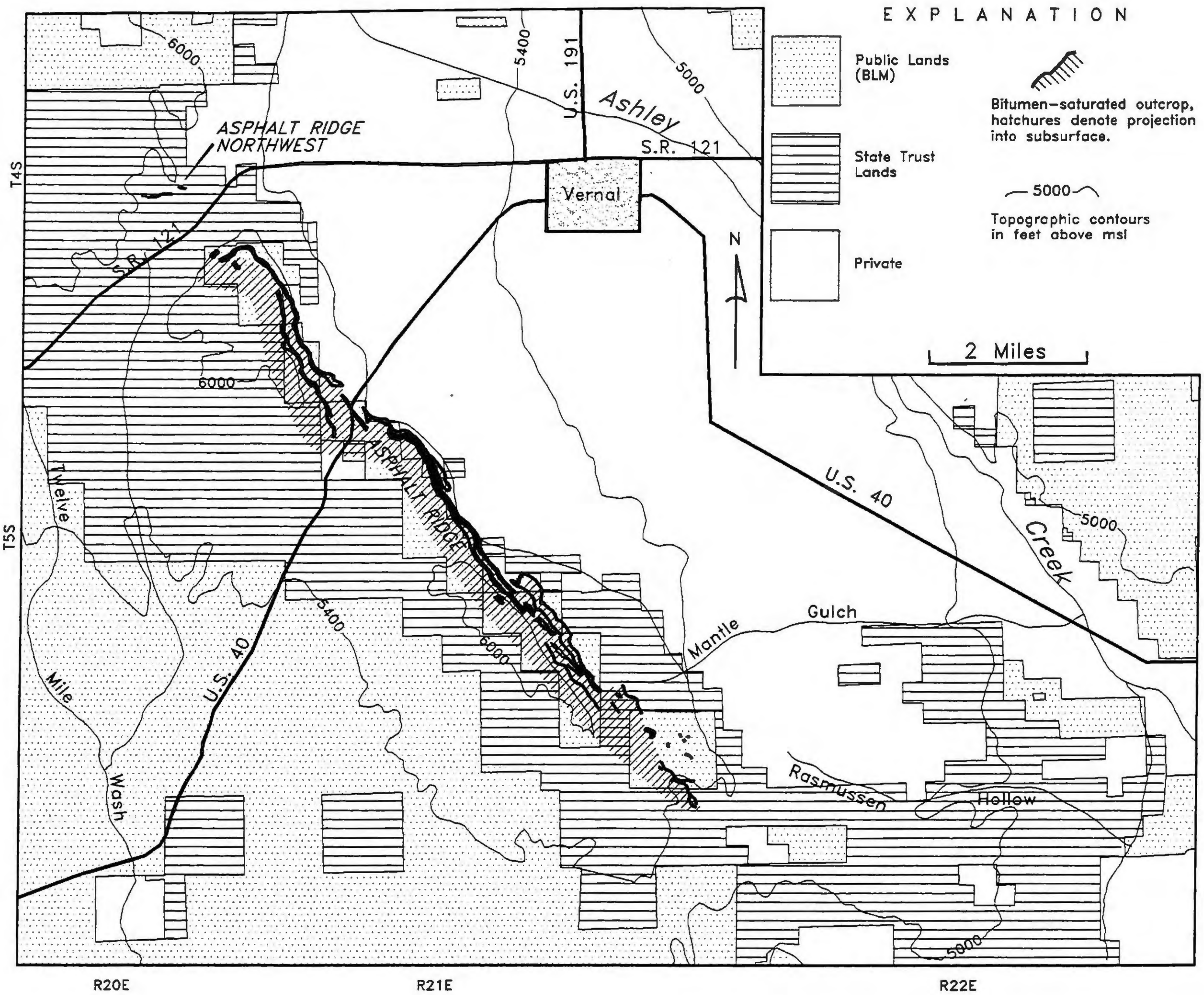


Figure 14. Land-ownership map of the Asphalt Ridge tar-sand deposit area.

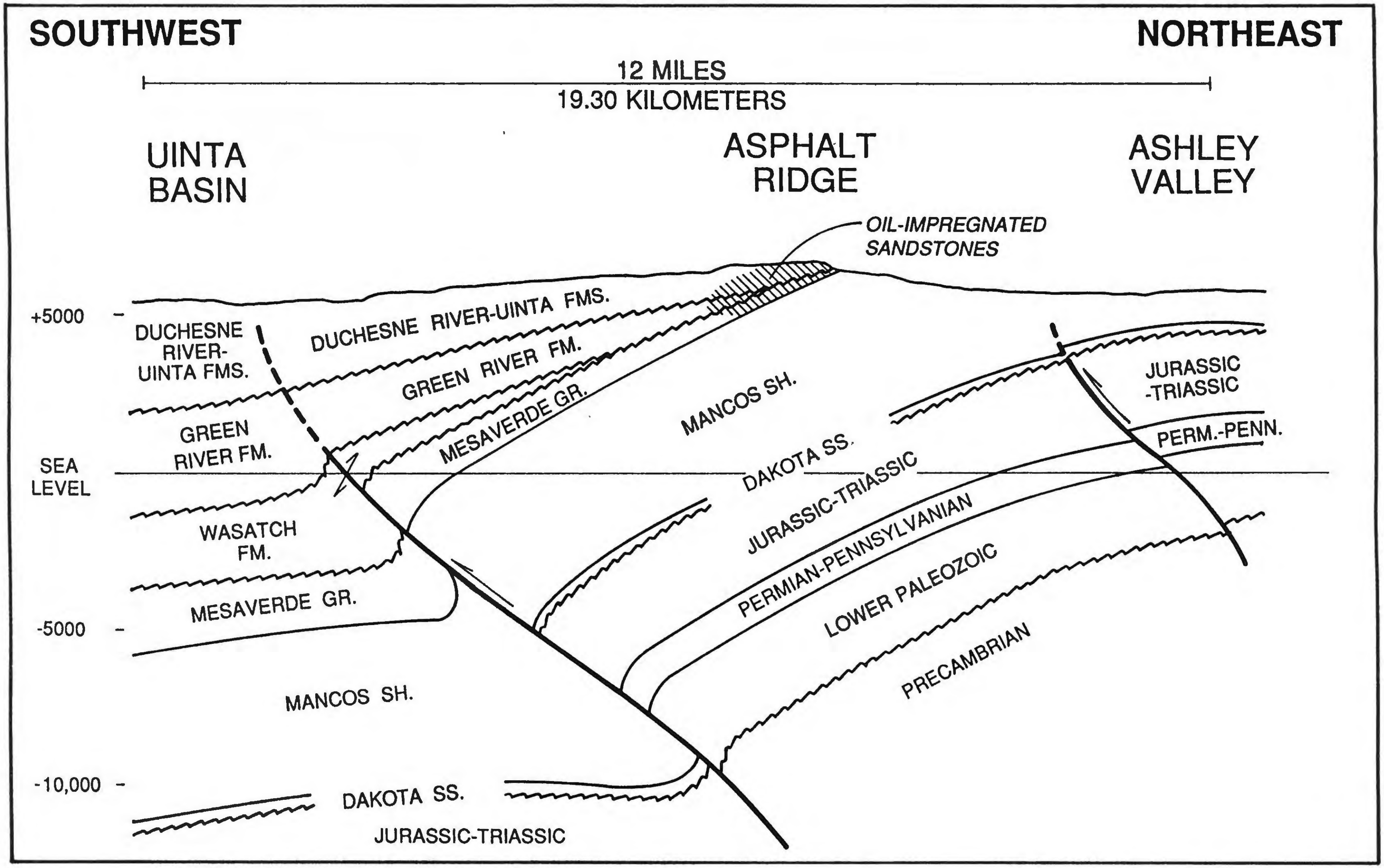


Figure 15. *Geologic cross section of the Asphalt Ridge tar-sand area (after Campbell and Ritzma, 1979).*

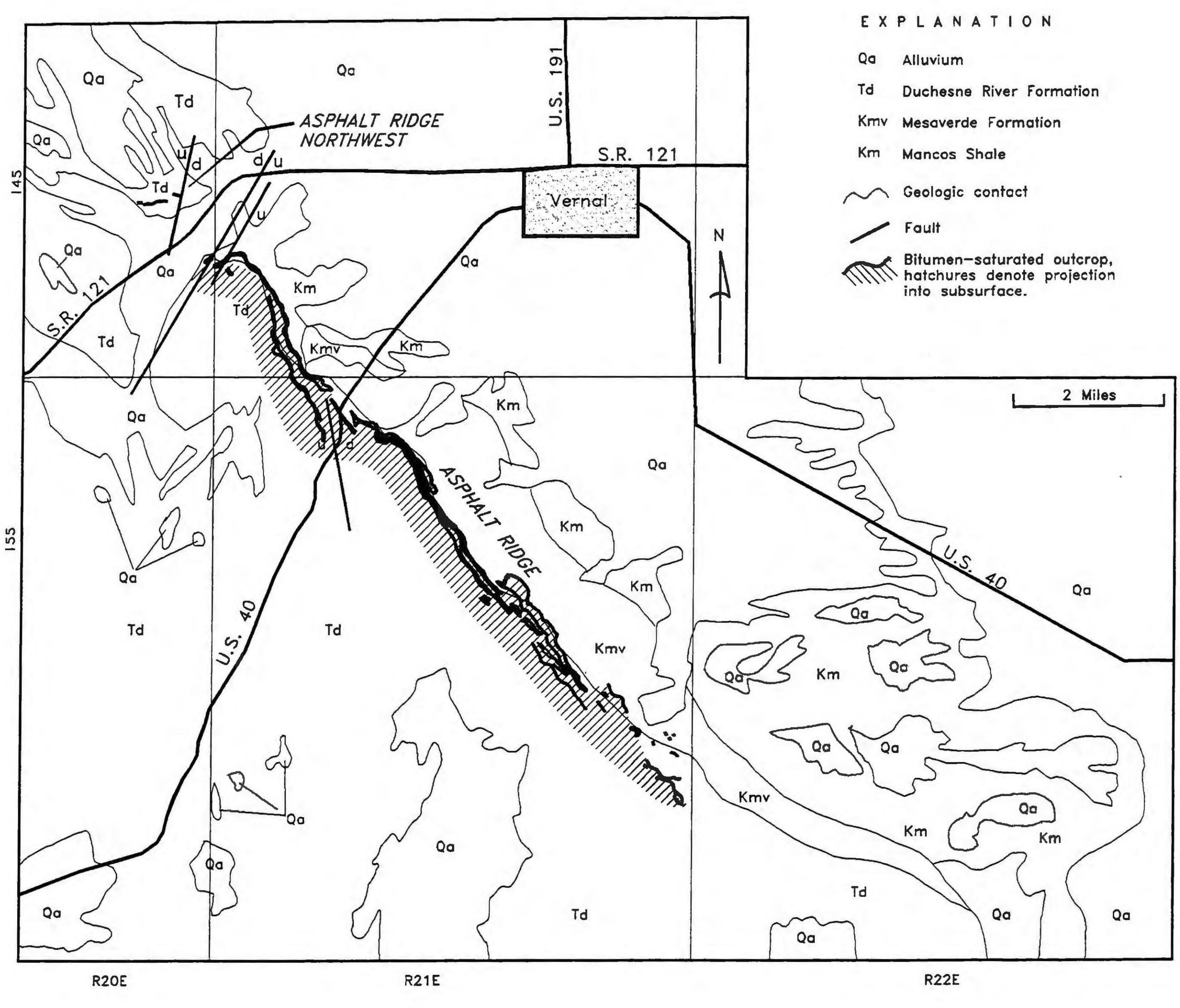


Figure 16. *General geology of the Asphalt Ridge tar-sand area (after Hintze, 1980; tar-sand outcrops from unpublished UGS file data).*

either due to erosion or nondeposition. The Uinta Formation may be present, but the Uinta Formation-Duchesne River Formation contact is gradational and difficult to recognize (Spieker, 1930).

Attitudes measured on outcrops of the Rim Rock Sandstone indicate dips ranging from 8 to 30 degrees south-southwest, while beds of the Duchesne River Formation dip 9 to 20 degrees south-southwest. The angular unconformity between these two rock-units probably represents several thousand feet of the Wasatch, Green River, and Uinta Formations either eroded or never deposited in this area. Asphalt Ridge is one of several hogback ridges trending northwest-southeast and extending southeast to Raven Ridge.

Minor faults within the deposit area are confined to rocks of the Mesaverde Group and do not pass upward into the Tertiary units. A prominent fault, exposed at an asphalt pit in sections 30 and 31, T.4S., R.21E., strikes N.24°W. The fault surface is nearly vertical and the displacement is 150 feet (46 m) down on the west side. A fault at the north end of the ridge in section 25, T.4S., R.20E., trends north and drops the Rim Rock Sandstone to the west. This fault intersects and offsets another fault, which separates the Asphalt Ridge Northwest deposit from the Asphalt Ridge deposit and trends north-northeast with the down-thrown side to the northwest. Numerous minor faults and joints occur along the length of the ridge and trend from N.50°W. to N.70°W. (Kayser, 1966).

The Asphalt Ridge deposit is separated from the Asphalt Ridge Northwest deposit by a northeast-trending fault. This high-angle fault, located in section 24, T.4S., R.20E. (SLM), strikes N5°E and crosscuts the outcrops perpendicular to the bedding strike. This fault has apparently acted as a barrier to oil migration. While both deposits are essentially continuous, the Asphalt Ridge Sandstone is saturated in the Northwest deposit and unsaturated in the Asphalt Ridge deposit.

Bitumen-saturated strata south and west of the Asphalt Ridge are covered by Tertiary sedimentary units. Drilling has revealed bitumen-saturated sections of up to 2,000 feet (610 m) in thickness (Campbell and Ritzma, 1979).

Bitumen occurs along the strike of Asphalt Ridge, within the Rim Rock Sandstone of the Mesaverde Group (Cretaceous), the Uinta Formation (Eocene), and the Duchesne River Formation (Oligocene). Kayser (1966) describes the Rim Rock Sandstone as cropping out along the entire length of Asphalt Ridge and mostly saturated by bitumen, thereby masking lithologies. In bitumen-free areas, the Rim Rock Sandstone is light gray, fine to medium-grained, and speckled with numerous black chert grains.

The Uinta Formation consists of fluvial, interbedded sandstone, mudstone, and shale, with lenses of grit and conglomerate. Bitumen in the Uinta Formation occurs mostly in the southern part of Asphalt Ridge in thin sand beds (Kayser, 1966).

Bitumen-saturation within clastic beds of the Duchesne River and Uinta Formations varies both laterally and vertically. Rock-type ranges from shale to conglomerate, but in general, the most saturated zones are in medium- to coarse-grained sandstone. Sandstone is mostly comprised of detrital, poorly sorted quartz and chert, and cemented with calcite, hematite, and silica (Kayser, 1966). Covington (1964) suggested that the oil probably originated from the Green River Formation and migrated updip along the Tertiary-Cretaceous unconformity. Sulfur isotope studies by Mauger and others (1973) support this theory.

Spieker (1930) estimated total tar-sand resources at Asphalt Ridge of nearly 2 billion cubic yards extending from the outcrop downdip 1.5 miles (2.4 km) into the subsurface. He calculated that proven reserves were nearly 900 million barrels of bitumen, of which 400 million barrels were in the Rim Rock Sandstone and 500 million barrels were in the Duchesne River Formation. Kayser (1966) estimated that nearly 700 million barrels of bitumen were contained in the Rim Rock Sandstone within two tracts comprising 5,250 acres within the deposit. Ritzma (1979) classified the deposit as "giant," and estimated that 1,048 million barrels of bitumen were contained in-place. Of this total, he categorized 435 million barrels as measured and 438 million barrels as indicated, with the remaining 175 million barrels as inferred.

Bitumen Analyses

Analyses of bitumen extracted from samples of the deposit were reported by Kayser (1966), Wood and Ritzma (1972), and Mauger and others (1973). These analyses show that bitumen here is low-sulfur and high-gravity (table 2). Asphalt Ridge Northwest sample 69-18E was collected from an adit located in SE¼SE¼ section 23, T.4S., R.20E. in the Asphalt Ridge Sandstone.

Development History

Mining of the Asphalt Ridge deposit for paving streets and sidewalks in the town of Vernal dates back to at least the 1920s (Spieker, 1930). A number of unsuccessful shallow wells were drilled into the bitumen-saturated outcrops between 1910 and 1950 in an apparent attempt to locate liquid petroleum below the asphaltic seal (Kayser, 1966; Campbell and Ritzma, 1979). During the 1930s a tar-sand extraction plant utilizing a hot water separation process was built at the present site of the Uinta County asphalt pit. In the early 1950s, Knickerbocker Investment Company and W.M. Barnes Engineering Company acquired a large block of patented and unpatented oil placer mining claims and began the first comprehensive evaluation program (drilling and mapping) on the ridge. Bituminous sand was shipped to a pilot extraction plant in California. The claims were then leased to Sohio Petroleum Company, which completed its own extensive mapping and drilling program.

In the early 1970s, Major Oil Company obtained a working agreement with Sohio Natural Resources Company to strip mine the tar sands and build and operate an extraction plant on a tract at the southeast end of Asphalt Ridge. The material was crushed and packed into flotation cells where a hot-water-solvent process was used to strip the bitumen from the sand. The bitumen was shipped to a refinery located in Roosevelt, Utah. Aminoil Company provided technical assistance for this project, which was acquired in 1972 by Arizona Fuels Corporation and Fairbrim Company (Anonymous, 1974; Covington and Young, 1985).

Sun Oil Company drilled a series of test wells on the south end of the ridge, while Texaco and the Phillips Petroleum Company performed exploratory drilling in the central part. Shell Oil Company and others drilled test wells on the north end of the ridge during the early 1970s (Campbell and Ritzma, 1979).

The Laramie Energy Technology Center of the U.S. Department of Energy conducted extensive field experiments in the Asphalt Ridge Northwest deposit between 1971 and 1982. A series of in-situ reverse combustion field experiments were conducted on a ten-acre site provided by Sohio Petroleum company. Uinta County presently excavates the material from an asphalt pit and uses it for road surfacing (Covington and Young, 1985).

P.R. Spring

Location and Access

The P.R. Spring tar-sand deposit is located on the southeast flank of the Uinta Basin, about 50 miles (80 km) northwest of Grand Junction, Colorado, and about 50 miles south of the town of Vernal (figure 13). The deposit area is remote, whereby vehicle access is gained from two primary routes. The area may be approached from the north by driving east from Vernal on U.S. Highway 40 for about 20 miles (32 km) to the junction with State Route 45, then south on SR-45, passing the town of Bonanza, and continuing south and southwest for about 25 miles (40 km). Two roads provide access to the area from the south. The San Arroyo Canyon road and the Hay Canyon road join Interstate Highway 70 near the Utah-Colorado state line. The roads within the area are unimproved and mostly follow stream-courses in canyons and along ridge-tops. Numerous oil-well maintenance roads connect canyons and ridges.

Physiography and Land-Use

The P.R. Spring tar-sand deposit extends along the length of the eastern Book Cliffs from Willow Creek on the west to the Utah-Colorado border on the east. The deposit is within the Book Cliffs-Roan Plateau physiographic subdivision of the Uinta Basin, and encompasses an area of 240 to 270 mi^2 (614 to 691 km^2) in southern Uintah and northern Grand Counties (Ritzma, 1979).

Tar-sands crop out at elevations ranging from 6,500 feet to 8,800 feet (1,981-2,682 m). The land surface is relatively flat, with pediments that slope gradually northwestward toward the center of the Uinta Basin. Gently sloping, narrow plateaus and mesas are incised by intermittent and perennial streams forming dendritic drainage patterns. Canyons are steep and trend generally northwest. Several prominent northwest-southeast trending ridges persist within the area. Vegetation, typical of the arid and semiarid climate, consists of grasses and shrubs on mesas and canyon bottomlands and mixed conifer forests on north-facing mountain slopes and ridges.

Most of the land in the area is public land administered by the Bureau of Land Management. A large block of Utah State land, known as the Book Cliffs Planning Unit, plus scattered sections, are administered by SITLA. The Hill Creek Extension of the Uinta and Ouray Reservation covers much of the Hill Creek tar-sand area to the west. Smaller tracts of private lands are also present (figure 17).

The Book Cliffs Conservation Initiative (BCCI), an initiative to improve wildlife habitat in the southeastern Uinta Basin, is a cooperative effort between the BLM, the Rocky Mountain Elk Foundation (RMEF), The Nature Conservancy (TNC), and the Utah Division of Wildlife Resources (DWR). The portion of the Book Cliffs covered by the BCCI encompasses about 450,000 acres in the P.R. Spring area: about 319,000 acres (71 percent) are administered by the BLM; 114,000 acres (25 percent) are School Trust Lands administered by SITLA; and about 20,000 acres are privately owned (information pamphlet on the BCCI prepared by BLM, RMEF, TNC, and DWR; Utah Division of State Lands and Forestry, 1992). The effects of the BCCI on future development-potential of tar-sand resources is unclear.

Geologic Setting

The P.R. Spring deposit is located on the southeastern limb of the Uinta Basin and contained within the Green River Formation (Eocene) (figure 18). The Green River Formation in this area is composed of oil shale beds, marlstones, shales, siltstone, sandstones, limestones, and tuff, deposited primarily in a lacustrine environment. Clastic sediments of the Green River and Wasatch Formations in this area are thought to be derived from the Uncompahgre Uplift to the south (Picard, 1971).

Stratigraphic nomenclature for the Green River Formation, proposed initially by Bradley (1931) and modified by subsequent investigators, is complicated. Cashion (1967) defined the current terminology used in the P.R. Spring area (southeastern Uinta Basin). Ryder and others (1976) redefined the terminology generally used in the Uinta Basin, but did not work in the P.R. Spring area. Cashion's terminology is, therefore, generally used in describing the P.R. Spring deposit. Cashion (1967) named three mappable units, in ascending order, as the Douglas Creek, Parachute Creek, and Evacuation Creek Members of the Green River Formation (figure 19). The Mahogany Bed, a kerogen-rich unit recognized as an "oil-shale" resource, separates the Douglas Creek and Parachute Creek Members. Campbell and Ritzma (1979) recognized as many as 13 fluvial-deltaic sandstone bodies in the deposit area.

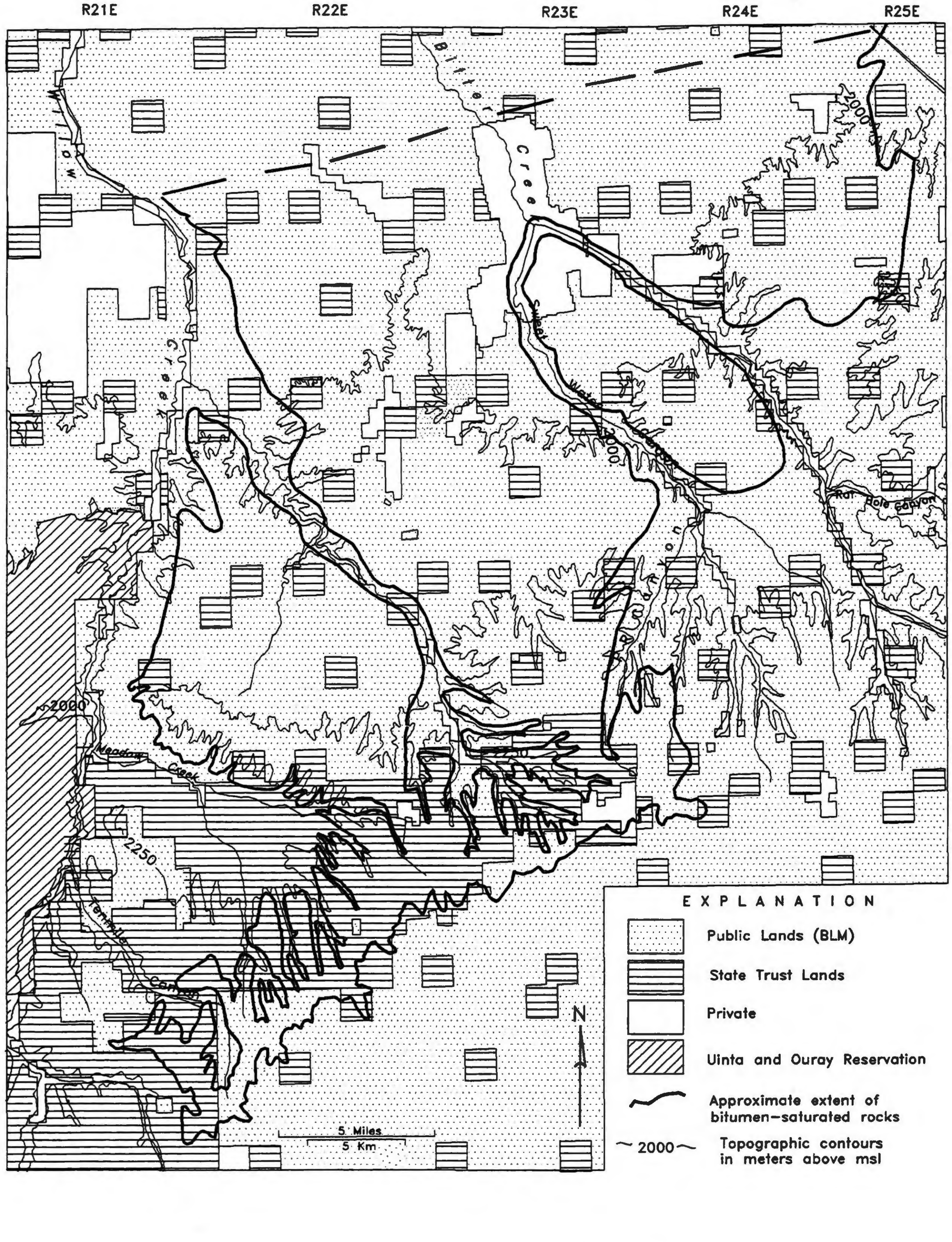


Figure 17. Land-ownership map of the P.R. Spring tar-sand area.

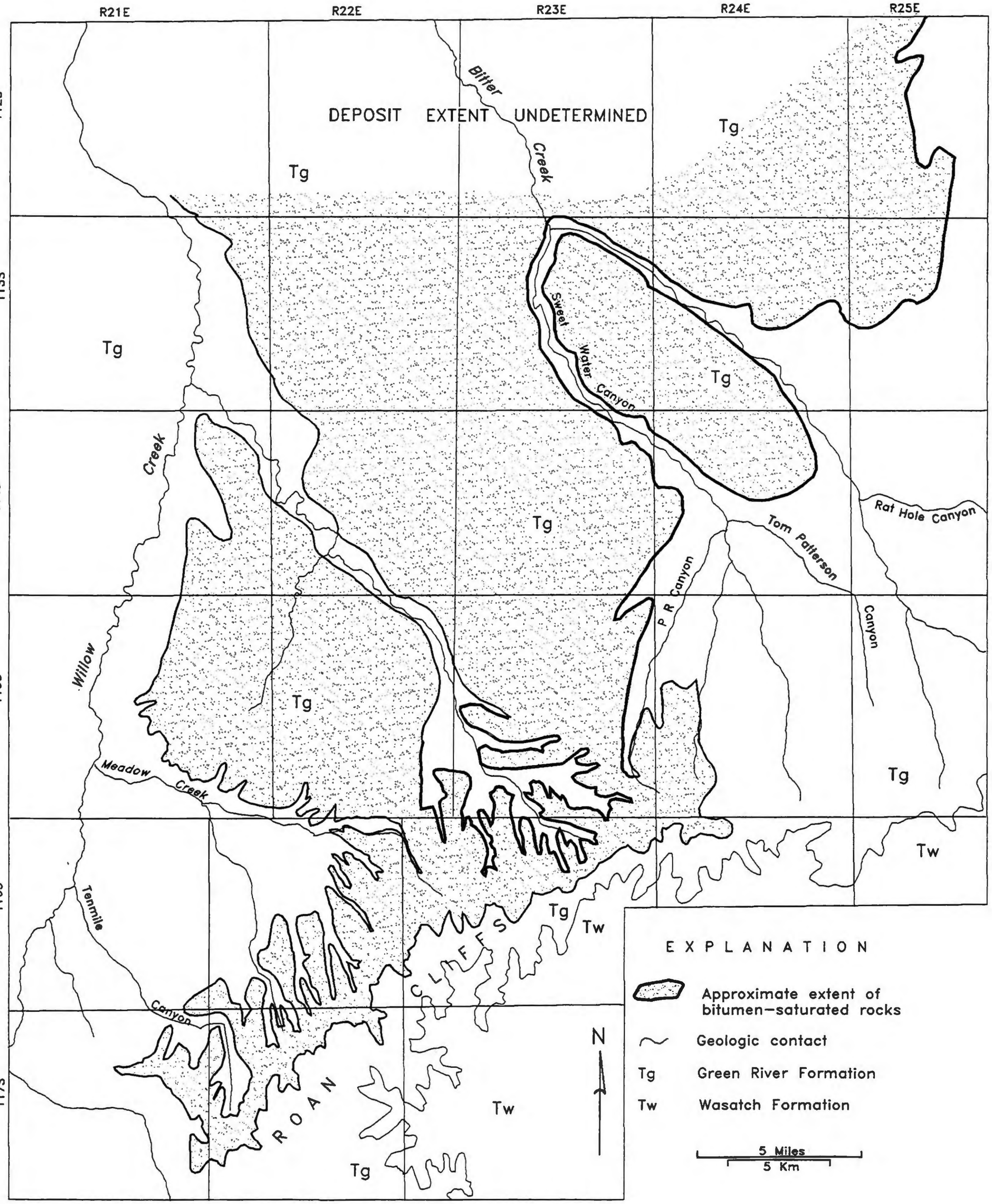


Figure 18. *General geology of the P.R. Spring area (after Campbell and Ritzma, 1979).*

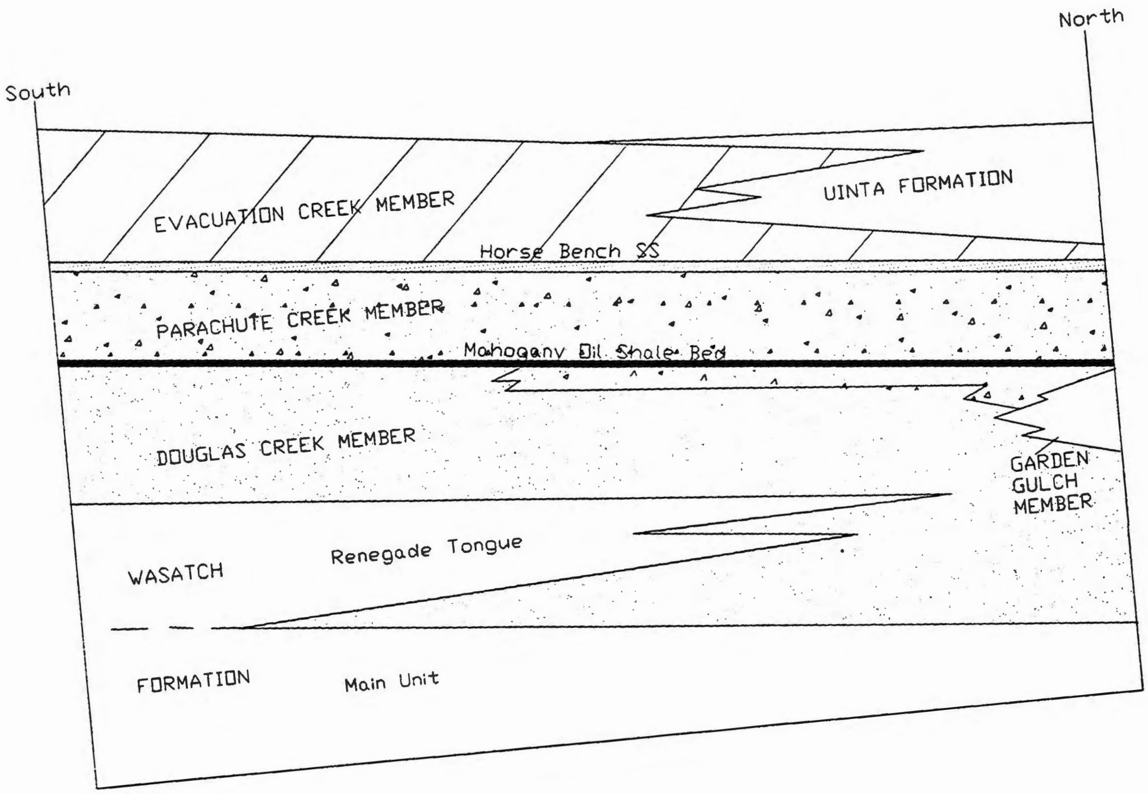


Figure 19. *Generalized geologic relationships of the Wasatch Formation and members of the Green River Formation in the southeastern Uinta Basin (after Cashion, 1967; and Gwynn, 1971).*

The deposit overlies the northwest flank of the Uncompahgre Uplift, a regional northwest-trending basement uplift. Regional dip is toward the northwest at 2 to 6 degrees. Although shallow folds related to the Uncompahgre Uplift are present on the surface, they apparently have not affected the emplacement or migration of bitumen. Byrd (1970) recognized six northwest plunging anticlinal noses and some minor faulting in the area.

Bitumen has impregnated five zones--four in the upper portion of the Douglas Creek Member and one in the lower portion of the Parachute Creek Member (figure 20). In ascending order, these zones have been designated A, B, C, D, and E and can be correlated throughout the deposit (Gwynn, 1971). Degree of bitumen saturation varies laterally and vertically in each of the zones. The deposit becomes progressively deeper northward and may extend in the subsurface farther than indicated by previous work (Campbell and Ritzma, 1979). Lateral correlation of individual rock units, even over short distances, is difficult. Individual sandstone beds range from 6 inches (15 cm) to 30 feet (9 m) in thickness. The P.R. Spring tar-sand deposit occupies the same stratigraphic position as the Hill Creek deposit to the west. The Willow Creek drainage is the arbitrary boundary between the two deposits (figure 18).

The sandstone units enclosing the tar-sand deposits in the P.R. Spring area are heterogeneous with extremely variable gross textures and lithologies (Wiley, 1967). The most common variations are grain-size and shape, type and degree of cementing, bitumen content, degree of sorting, and porosity. The sandstones are primarily arkosic, with primary constituents of quartz (60 percent) and orthoclase (32 percent), and minor amounts of heavy minerals (tourmaline, zircon, sphene, chlorite, hornblende, and garnet). Picard (1971) classified most of the sandstone as arkose, with some subarkose and lithic arkose.

Bitumen impregnation appears controlled by lateral extent, porosity, and permeability of individual sandstone beds. The degree of bitumen-saturation varies laterally and vertically. Vertically, all degrees of saturation are visible in an individual bed at any one locality. Horizontally, variations from slight to rich may occur within a distance of a few hundred feet along the outcrop.

Numerous tar seeps occur in the P.R. Spring deposit. Hydrologic head-gradients from the Roan Cliffs cause bitumen to move downdip toward canyons incised in dip-slopes. During wet seasons, these seeps become active, and large amounts of water flow from the seeps as well as bitumen. During dry seasons, both bitumen and water cease to flow.

Resource Estimates

Investigators have estimated that the P.R. Spring tar-sand deposit contains from 3.3 to 4.5 billion barrels of oil. Byrd (1970) calculated that the P.R. Spring area contains about 3.7 billion barrels of oil in-place. Ritzma (1979) estimated that the deposit contains between 4.0 and 4.5 billion barrels of oil. And, Clem (1984) calculated that the P.R. Spring deposit contains about 3.3 billion barrels of oil.

Bitumen Analyses

Wood and Ritzma (1972) reported the results of analyses on three samples collected from the P.R. Spring deposit. Results of the analyses are shown on table 2, and the location and sample descriptions are as follows:

Sample 69-13E -- Douglas Creek Member, Green River Formation, SW¼NE¼ section 8, T.12S., R.25E.
Sample 69-14E -- Parachute Creek Member, Green River Formation, NW¼NW¼ section 5, T.12S., R.25E.
Sample 67-1A -- Main Canyon Seep in the Douglas Creek Member, Green River Formation, center of NE¼ section 5, T.16S., R.24E.

Development History

The earliest known operation for petroleum recovery from the P.R. Spring area was an oil test well drilled in section 35, T.15S., R.23E., by John Pope in 1900. Another early venture consisted of a 50-foot-long adit, located in section 34, T.15S., R.23E., which was driven into a tar-sand outcrop. A steel pipe was run from the adit to a metal trough to collect the gravity-drained oil.

The P.R. Spring tar-sand deposit was the subject of intense activity during the late 1970s and early 1980s. While very few on-site operations were conducted, numerous companies and government agencies studied the

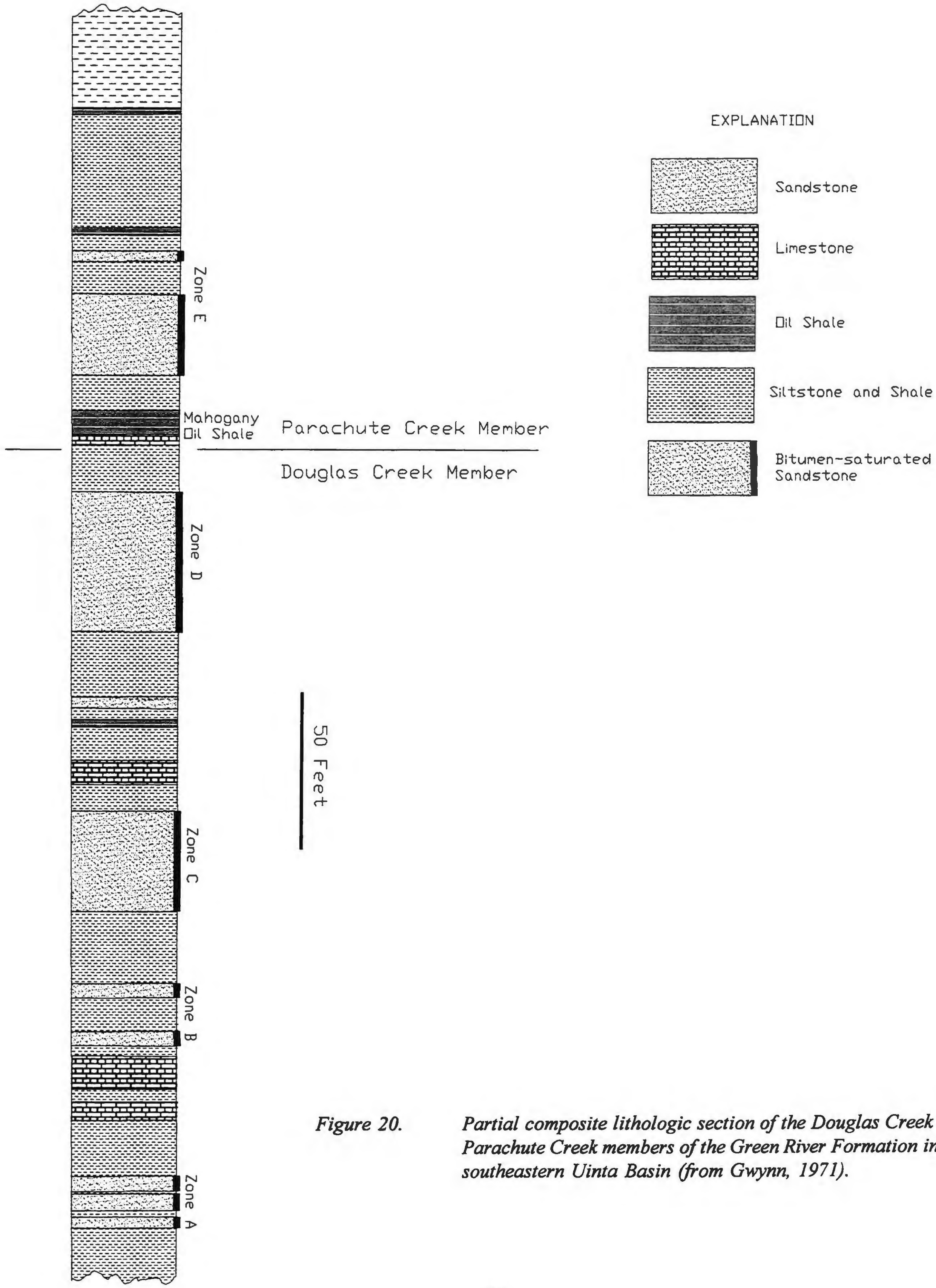


Figure 20. ***Partial composite lithologic section of the Douglas Creek and Parachute Creek members of the Green River Formation in the southeastern Uinta Basin (from Gwynn, 1971).***

resource and extraction potential. During 1983, the U-tar Division of Bighorn Oil Company of Salt Lake City, operated a 100 barrels-per-day pilot processing plant. Located in section 5, T.16S., R.24E., the pilot plant used a solvent solution for extraction. Several companies have reportedly proposed development operations for both in-situ extraction and surface mining of tar sand (Covington and Young, 1985). As of 1995, no viable commercial production of tar sand from the P.R. Spring area has taken place.

Hill Creek

Location and Access

The Hill Creek deposit is located on the southern flank of the Uinta Basin, about 55 miles (88 km) east of the town of Price and about 50 miles (80 km) south of the town of Roosevelt in T.13-15S., R.18-21E. (SLM), Uintah County (figure 13). Access is gained via State Highway 88, southward from its junction with U.S. Highway 40 through the town of Ouray. From Ouray, SR-88 continues south for about 4 miles (6.4 km), and branches into secondary oil-field access roads and trails. Numerous oil-well maintenance roads connect the canyons and ridges that expose the deposit.

Physiography and Land-Use

The Hill Creek tar-sand deposit lies near the south-central part of the Uinta Basin. Situated between the Sunnyside deposit to the west and the P.R. Spring deposit to the east, the Hill Creek deposit extends along the Roan Cliffs from Willow Creek on the east to Tabyago Canyon on the west. Willow Creek and Hill Creek, which flow northward, are the only perennial streams in the region. While Willow Creek forms the eastern boundary of the deposit, Hill Creek divides the deposit into east and west halves.

About two-thirds of the deposit is located on the wilderness land reserve of the Hill Creek Extension, Uinta and Ouray Indian Reservation (figure 21). The remainder lies on BLM-administered public lands, and scattered parcels of SITLA-administered state lands. A relatively large (30 mi^2; 77 km^2) contiguous tract of private-owned land is situated on the northern edge of the deposit. The northwest quarter of the deposit extends into the U.S. Naval Oil Shale Reserve No. 2. Surface elevations range from about 7,200 feet (2,195 m) to about 5,800 feet (1,767 m).

Geologic Setting

The deposit is located on the central part of the southern limb of the Uinta Basin where Cenozoic strata dip gently about 2 degrees northward. The Hill Creek anticline, an expression of the underlying Uncompahgre Uplift, trends northwest in the southeast part of the deposit area (figure 22). High-angle faults and joints have been mapped along the southern flank of the Hill Creek anticline (Gwynn, 1985). These structures together form a northwest-trending fractured zone, approximately 10 miles long, that marks the southern limit of the deposit.

Exposed strata in the Hill Creek area include the Green River Formation (Eocene) and Wasatch Formation (Eocene-Paleocene). The Green River Formation in this area is composed of marlstones, kerogen-rich shales, siltstone, sandstones, limestones, and tuffs, deposited in a lacustrine environment. The Wasatch Formation is composed of shales, siltstone, and sandstones deposited in a fluvial environment.

The Green River Formation is divided into, in ascending order, the Douglas Creek, the Parachute Creek, and the Evacuation Creek Members. The Mahogany oil-shale bed lies at the base of the Parachute Creek Member and conformably overlies the Douglas Creek Member (Gwynn, 1985).

Bitumen-saturated sandstone lenses are in the upper portion of the Douglas Creek Member and the lower portion of the Parachute Creek Member, both below and above the Mahogany oil-shale zone, respectively. The degree of saturation and extent of bitumen in these sandstone lenses is controlled largely by porosity, permeability, and lateral extent of individual lenses. Correlation of individual rock units throughout the area is difficult, even over short distances, as individual sandstone beds range from 6 inches (15 cm) to 30 feet (9 m) in thickness. Within these beds, grain size and shape vary widely along with the type and degree of cementing.

Using the Mahogany zone as a datum, Gwynn (1985) reported that apparent overburden (overlying, non-saturated rock) thickness varies from less than 100 feet (30 m) to more than 1,000 feet (300 m). Locally, however, actual overburden thicknesses can be much less than apparent thicknesses due to the highly variable nature of bitumen saturation. The degree of saturation varies both laterally and vertically. Vertically, all degrees of saturation are visible in an individual bed. Horizontally, variations from slight to rich may occur within a distance of a few hundred feet along the outcrop. Ritzma (1979) classified the Hill Creek deposit as giant sized, and estimated that 1.6 billion barrels of bitumen are in-place.

The Hill Creek deposit is contained in rocks that are stratigraphically equivalent to those of the P.R. Spring deposit. The two deposits are separated arbitrarily along the Willow Creek Canyon drainage.

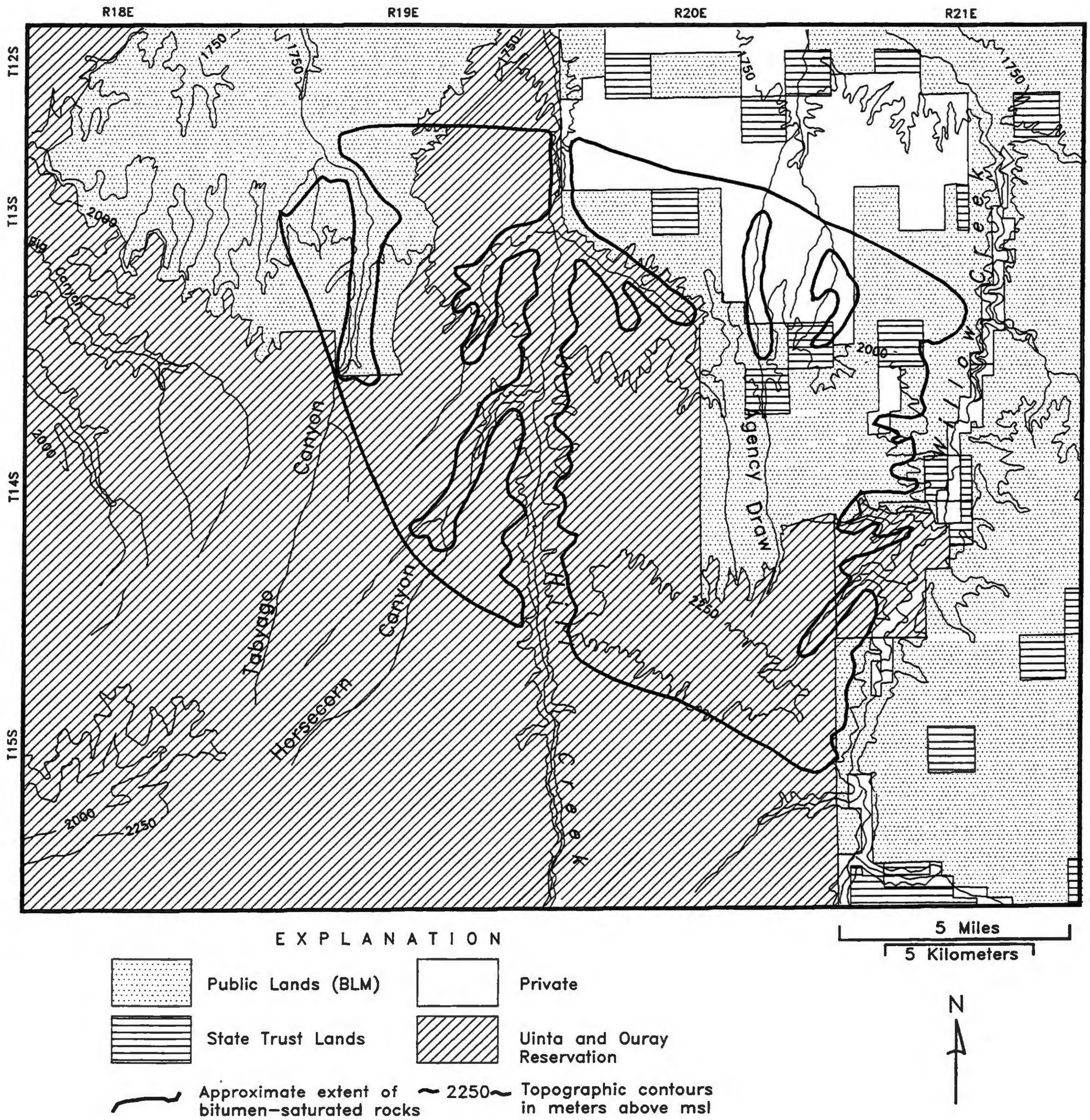


Figure 21. Land-ownership map of the Hill Creek tar-sand deposit area.

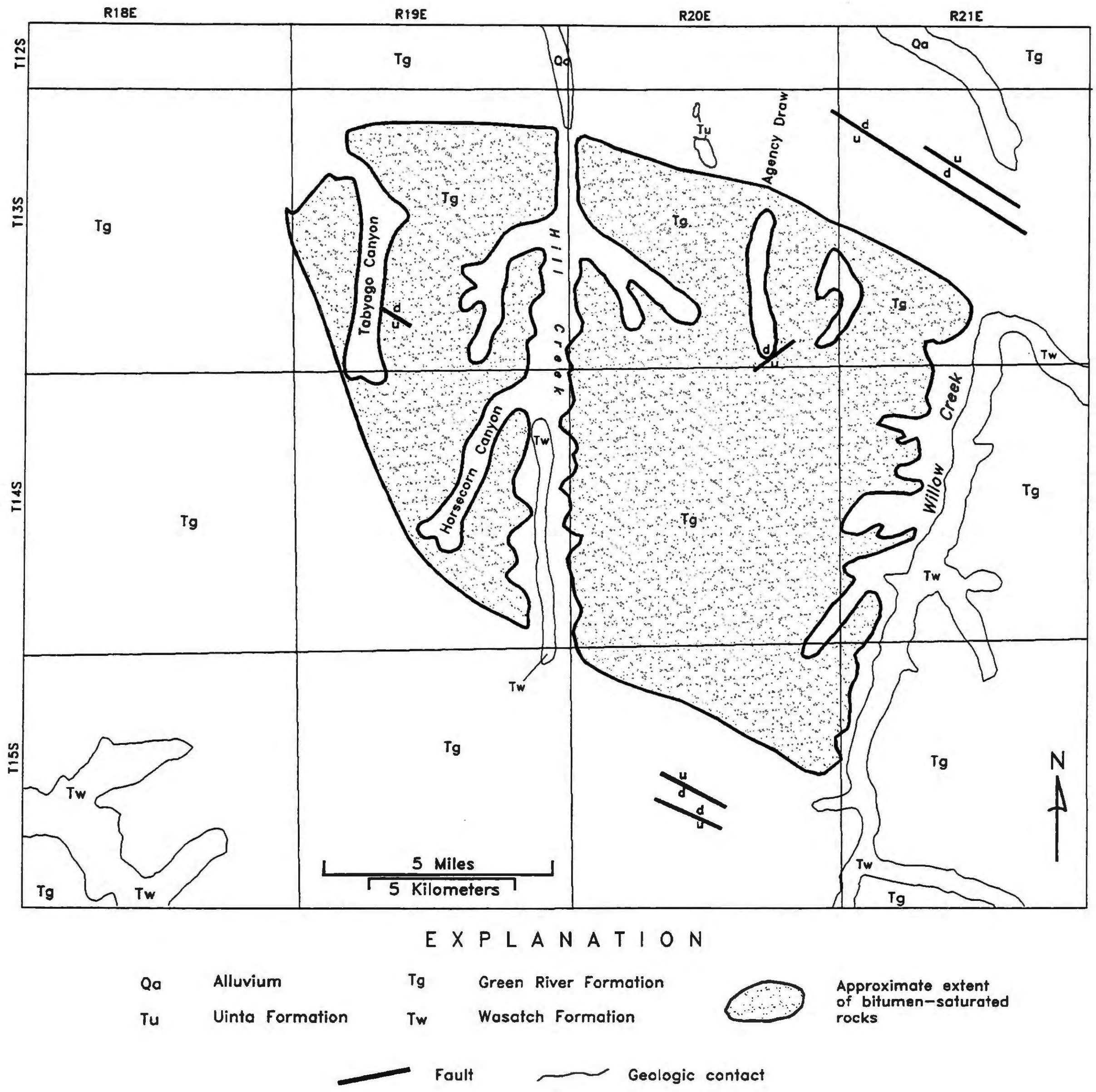


Figure 22. General geology of the Hill Creek area (after Cashion, 1973).

Bitumen Analyses

Wood and Ritzma (1972) reported results of bitumen analyses on one sample collected from the Douglas Creek Member within the Hill Creek deposit (table 2). Sample 69-11C from the upper part of the Douglas Creek Member, was taken along Oil Sand Canyon, located in the SW¼SW¼ section 30, T.14S., R.20E.

Johnson and others (1976) presented results of analyses of three drill cores from the Flat Rock Mesa area in the Hill Creek tar-sand deposit (table 4). They described two major tar-sand zones with a net thickness of 55 to 81 feet (17 to 25 m). Other information from this study included porosity (average 20.2 percent of bulk volume); permeability before and after oil extraction (averaging 150 and 325 md respectively); low oil-saturation (average of 29.7 percent of pore volume); and sulfur and nitrogen contents (average 0.45 and 0.73 percent respectively). The analyses of bitumen from core holes HC-1, HC-2, and HC-3 are composites from both members. HC-1 was located in the SE¼NW¼NE¼ section 31, T.14S., R.20E. HC-2 was located in the SE¼NW¼SW¼ section 33, T.14S., R.20E. HC-3 was located in the NE¼NE¼NE¼ section 3, T.15S., R.20E.

Development History

Because the majority of the Hill Creek tar-sand deposit lies within an area set aside for preservation by the Ute Tribe, no development has taken place. Moreover, it is unlikely that any development of tar sands will take place in the foreseeable future. The Flat Rock oil field, located in T.14S., R.20E., is the only known petroleum development in the area.

Table 4. Technical data from core holes HC-1, HC-2, and HC-3 of the Hill Creek tar-sand deposit (after Johnson and others, 1976).

Corehole	Units	HC-1	HC-2	HC-3	Overall Avg.
Location*	---	(D-14-20)31abd	(D-14-20)cbd	(D-20-15)aaa	---
Surface elevation	ft.(above sea level)	7260	7485	7410	---
Top of tar sand (depth)	ft.	41	327	307	---
Bottom of tar sand (depth)	ft.	230	461	461	---
Net thickness of tar sand	ft.	81	55	67	68
Porosity, saturated	pct.	10.9	13.3	16.6	13.4
Porosity, extracted	pct.	19.7	20.1	21	20.2
Permeability, saturated	md	59	120	286	150
Permeability, extracted	md	325	264	375	325
Oil saturation	pct. of pore vol	42.2	29.7	15.5	29.7
Oil saturation	pct. of sample wt.	3.9	2.8	1.4	2.8
Water saturation	pct. of pore vol.	2.8	1.6	1.7	2.1
Bulk density, saturated	g/cm3	2.209	2.173	2.133	2.174
Bulk density, extracted	g/cm3	2.12	2.107	1.087	2.106
Sand grain density	g/cm3	2.641	2.636	2.641	2.64
Compressive strength, saturated	psi	5826	8438	5949	6555
Compressive strength, extracted	psi	4579	6454	4681	5130
Oil Specific gravity at 60°	g/cm3	1.004	1.025	0.994	1.004
Oil gravity	°API	9.4	6.6	10.9	9.4
Sulfur	wt. pct. oil	0.48	0.42	0.42	0.45
Nitrogen	wt. pct. oil	0.75	0.81	0.8	0.73

* Well and Spring Numbering System for Utah. The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number designates a location and describes its position in the land net. The land-survey system divides the state into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by uppercase letters as follows: A, northeast; B, northwest: C, southwest; and D, southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by the three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section (generally 0.04 km2 or 10 acres). The quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast.

Sunnyside

Location and Access

The Sunnyside deposit is located on the southwest flank of the Uinta Basin, about 18 miles (29 km) east of the town of Price, Utah in T.12-13S., R.13-15E. and T.14S., R.14-15E. (SLM), Carbon County (figure 13). Access from the west is via U.S. Highway 6 heading southeast from Price, then east on State Highway 123 past the town of Sunnyside. Numerous ranching and oil-well maintenance roads provide access to canyons and ridges where the deposit is exposed. The deposit is located less than 10 miles (< 16 km) from a spur of the Rio Grande Railroad.

Physiography and Land Use

The Sunnyside deposit is situated in the Book Cliffs-Roan Cliffs physiographic subprovince of the Uinta Basin. The deposit is exposed along the western side of the Roan Cliffs, from Rock Creek on the south to Nine Mile Creek on the north. Elevations of bitumen-saturated outcrops range from about 8,900 feet to about 9,700 feet (2,713-2,957 m). Topography is characterized by high-relief and rugged terrain. The deposit covers an area of approximately 122 mi^2 (316 km^2).

Land ownership for the Sunnyside deposit is mostly private with some federal and state land (figure 23). Land use is limited to primarily cattle and sheep grazing. The Sunnyside underground coal mines near East Carbon City used to produced large tonnages of metallurgical-grade coal, but are now shut down.

Geologic Setting

The Sunnyside tar-sand deposit lies on the western part of the southeast lobe of the Uinta Basin. Regional dip is northeastward at 3 to 12 degrees. Small-scale structures (minor faulting and fracturing) found in the area do not appear to have affected bitumen emplacement. The Sunnyside tar sands occur within the lower part of the Green River Formation (Eocene) in the marginal lacustrine facies, and in the upper part of the Colton Formation (Paleocene/Eocene) (figure 24). The deposit represents deposition of several stacked channels, downcutting, and subsequent in-filling (Schenk and Pollastro, 1987). Sandstone of the Sunnyside deposit was deposited in meandering-stream, fluvial environments on the southern margin of Lake Uinta (Banks, 1981).

At Sunnyside, bitumen-saturated units occur within both the Green River and Colton Formations (Schenk and Pollastro, 1987). Distinction between the two formations is difficult due to intertonguing and similar lithologic types. The Green River Formation consists of shale, marlstone, siltstone, sandstone, limestone, and tuff, deposited in lacustrine environments. Beds of shale, siltstone, and sandstone, deposited in a fluvial-deltaic environment, compose the Colton Formation. Bitumen-bearing sandstone bodies in both formations are interbedded with mudstone, shale, siltstone, and carbonate that do not contain significant bitumen (Schenk and Pollastro, 1987).

The Peters Point-Stone Cabin gas fields, located in a northwest to southeast trend from T.12S., R.14E. to T.13S., R.17E., produce primarily gas and some oil from the Green River and Wasatch Formations at depths of 2,800 to 4,300 feet (853 to 1,311 m). This interval is stratigraphically equivalent to the saturated interval at Sunnyside. Some workers believe that the Jacks Canyon anticline and associated faults trapped hydrocarbons thereby preventing their movement updip to Sunnyside.

Bitumen-saturated sandstone bodies occur within the lower part (marginal lacustrine facies) of the Green River Formation and in the upper part of the Colton Formation. These bodies are more prevalent in the western part of the deposit, nearest to the delta complexes. Holmes and Page (1956) reported that porosities of these sandstones range between 25 and 30 percent, and permeabilities range between 154 and 677 md (based on four determinations).

Up to 32 saturated beds have been identified from surface mapping of outcrops. Lateral extent, porosity, and permeability control the degree of saturation of the individual beds. Vertically, all degrees of saturation are visible in a bed at any one locality. Horizontally, variation from barren to highly rich may occur within a distance of a few hundred feet. Channeling, irregular thickness, pinchout, and interfingering with neighboring beds make correlations of individual beds very difficult (Clem, 1985).

Two zones of saturation have been identified in the subsurface. The upper zone crops out in several drainages and may have a gross thickness of up to 1,000 feet (305 m). The lower zone, 800 to 900 feet (244-274

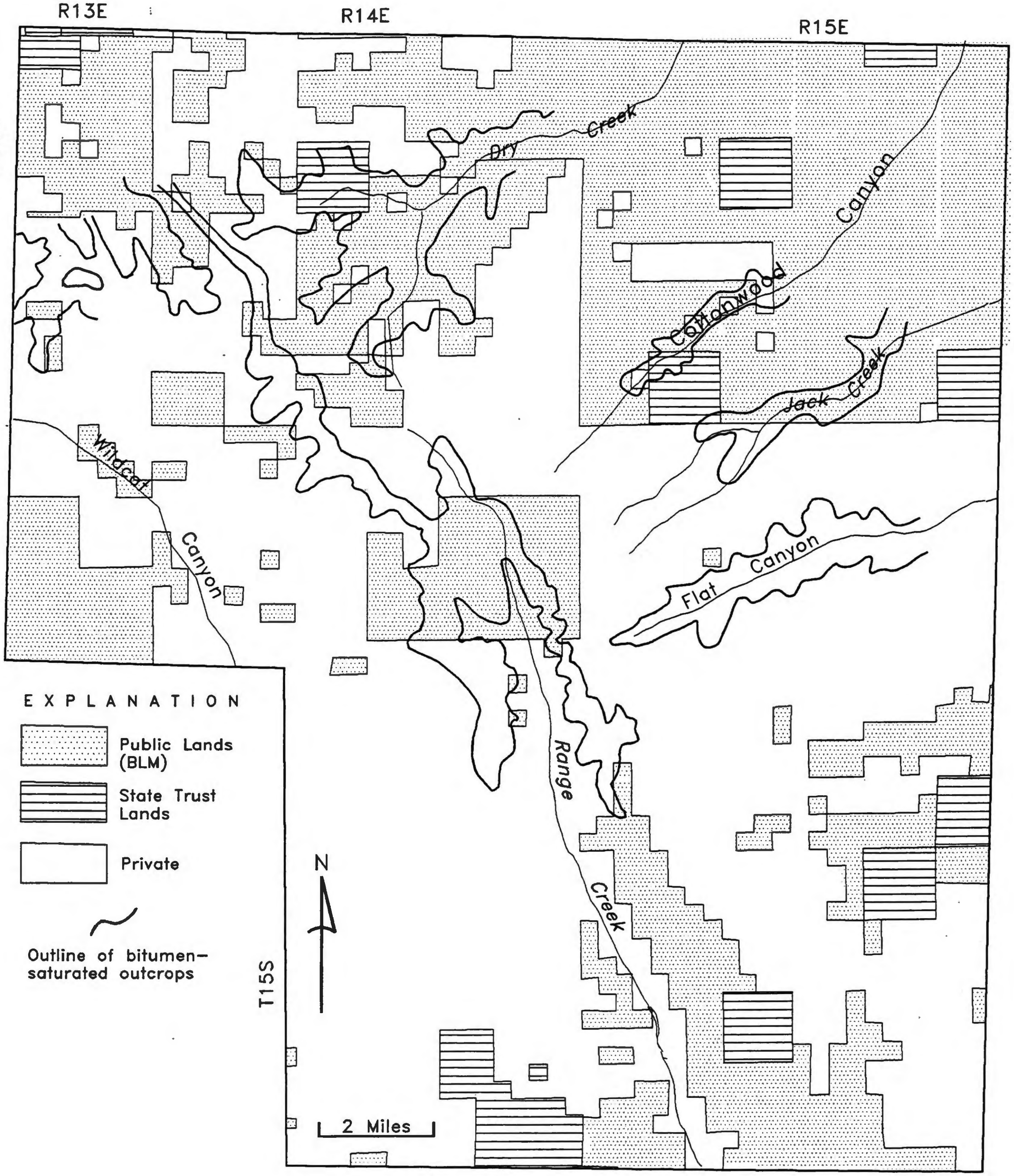


Figure 23. Land-ownership map of the Sunnyside tar-sand deposit area.

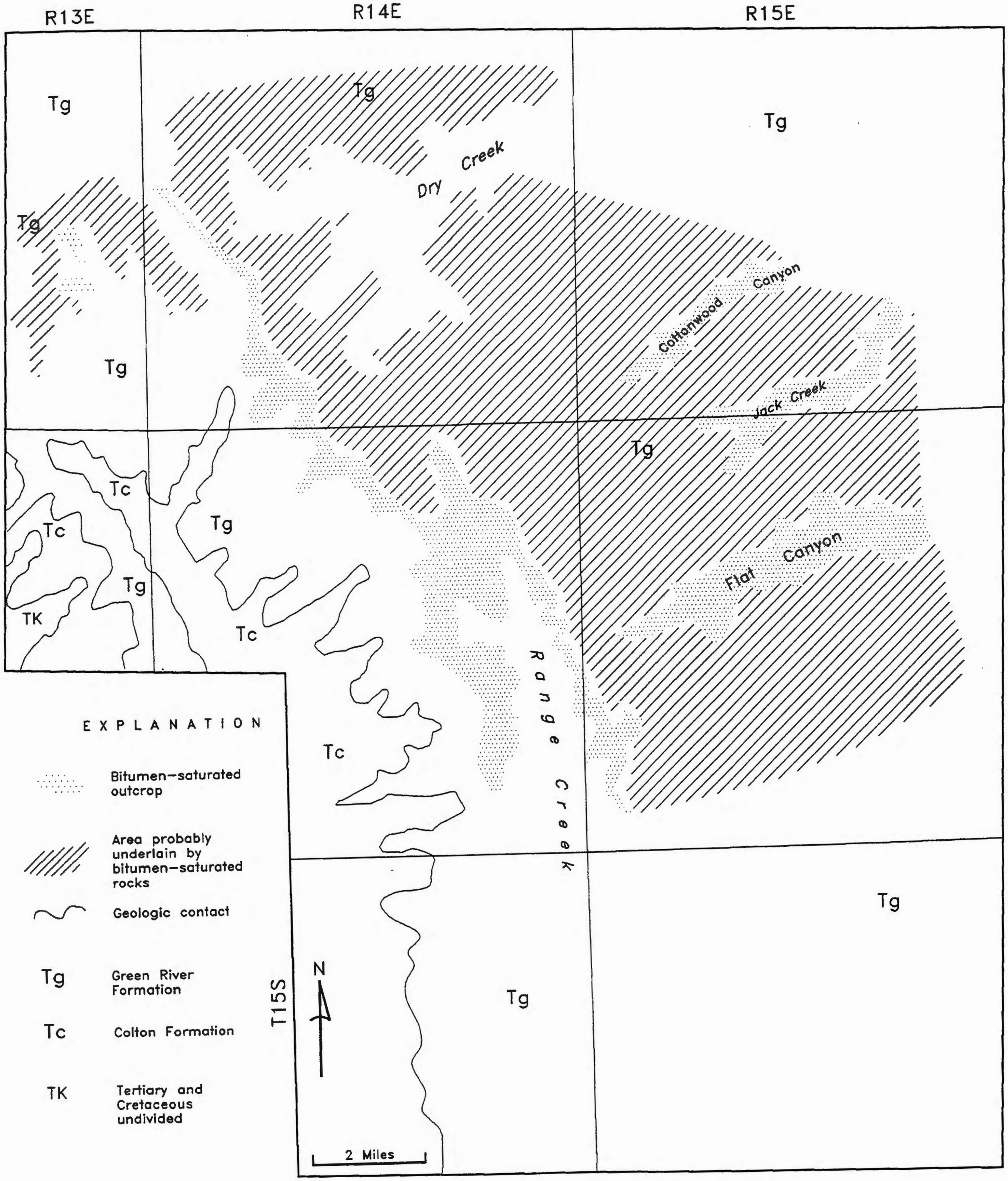


Figure 24. General geology of the Sunnyside tar-sand area (after Campbell and Ritzma, 1979).

m) below the upper zone, is between 1,300 and 1,900 feet (396-579 m) thick. In the outcrops along the cliff side of Bruin Point, there is no distinction between these two zones (Gwynn, 1986).

The individual sandstone beds range from 0.5 to more than 100 feet (0.15 m - 30.5 m) in thickness. Characteristics such as size and shape of sand grains, sorting, porosity, and type and degree of cement all vary from one bed to another (Clem, 1985).

In 1945, the U.S. Geological Survey (USGS) estimated that the Sunnyside bituminous-sandstone resource consisted of about 1.6 billion cubic yards (1.22 billion m^3) of material. Of this, they estimated that 0.9 billion cubic yards (0.69 billion m^3) included measured plus indicated resources, with 0.7 billion cubic yards (0.54 billion m^3) as inferred resources (Holmes and others, 1948; Holmes and Page, 1956). The U.S. Bureau of Mines translated this estimate into 728 million barrels of oil equivalent, of which 409.5 million barrels included measured plus indicated resources, and 318.5 million barrels were inferred resources (Ball Associates, Ltd., 1964).

Ritzma (1979), using additional data, classified the deposit as "giant," and estimated that between 3.5 and 4.0 billion barrels of oil were contained in-place. Of this estimate he classified 1.25 billion as measured, 1.75 billion as indicated, and the remaining 0.5 to 1.0 billion as inferred.

Bitumen Analyses

Wenger and others (1952) reported complete analyses using fractional distillation for "extracted" and "recovered" bitumen from Sunnyside. Specific gravity was 0.922 and 1.024, API gravity was 22.0 and 6.7, and sulfur content was 0.47 and 0.50 percent, respectively. Nitrogen content was reported as 0.96 percent. Presentation of their analyses of distilled fractions is beyond the scope of this report.

Development History

The Sunnyside deposit was mined intermittently from 1892 to the late 1940s, mostly for roadbase construction. Holmes and others (1948), stated that 335,000 tons (304,000 mt) of rock had been quarried by the time of their study. Between 1931 and 1945, the material was used for road paving in Utah and five other western states. The ore was carried from the quarry by a 3-mile (4.8-km) long aerial tramway and then trucked to the railhead at Sunnyside.

Several companies performed resource assessments, and tested tar-sand pilot projects at the Sunnyside deposit. In 1963 to 1964, Shell Oil Company collected cores from numerous boreholes as part of an evaluation program that eventually lead to an experimental (five spot) in-situ steamflood in 1966. Shell continued evaluation of the deposit and drilled additional core holes in 1967 (Thurber and Welbourn, 1977). Signal Oil and Gas Company, in 1966 and 1967 tried an in-situ steam process using horizontal holes to recover oil. Pan-American Petroleum Corporation also performed an in-situ steamflood at the Sunnyside deposit in 1966. Texaco and Gulf later conducted coring operations within the deposit. During 1982, Enercor did preliminary mining feasibility studies on leases they had acquired. Phillips Petroleum, Sabine Resources, Cities Service, and Amoco all considered development of tar-sand resources at Sunnyside. Gulf Oil Corporation had a land interest in the area and drilled one test hole. Mono Power Company's Utah Tar Sand Project entered into an agreement with Amoco to evaluate the Sunnyside deposit in the early 1980s (Charles Bishop, 1996, verbal communication--various news releases).

Chevron Resource Company signed an operating agreement with Great National Corporation (GNC) for the development of 2,000 acres of the Sunnyside deposit in 1982. GNC had been involved in development of the Sunnyside deposit since the late 1970s and had also proposed to build a pilot plant. Under the Chevron/GNC agreement, bitumen-saturated material was mined and test-processed at Chevron's pilot plant located next to Chevron's refinery north of Salt Lake City (Covington and Young, 1985).

SUMMARIES OF SECONDARY TAR-SAND DEPOSITS

The following section briefly describes 20 tar-sand deposits in the Uinta Basin that we classify as secondary due to their relatively small size, inaccessible nature, or because they are not well defined. More complete descriptions are included in the many references to these deposits. The reader is urged to consult these publications and articles for more details. Figure 25 shows the locations of these areas with respect to primary roads, geographic features, and communities.

Argyle Canyon

Location and Access

The Argyle Canyon tar-sand deposit is situated along the southwest side of the Uinta Basin (figure 25) in an area known as the Bad Land Cliffs. The deposit is located in sections 11 and 12, T.11S., R.12E. and in sections 7 through 26, T.11S., R.13E. (SLM), Duchesne County. The area lies about 20 miles (32 km) northeast of the town of Price, Utah. Access is via State Highway 33 from its junction with U.S. Highway 6 in Price River Canyon. Utah-33 intersects a gravel road about 14 miles (22 km) northeast from the junction with US-6, opposite the Avintaquin Campground road, and leading east to Argyle Canyon. From this intersection, the gravel road winds east-southeast along Argyle Creek. The westernmost outcrops of the Argyle Canyon tar-sand deposit are encountered about 12 miles (19 km) eastward along this road. From here, the deposit outcrops extend east-southeast along the north side of the canyon for another 14 miles (23 km), parallel to the road. At the east end of the deposit, the Argyle Canyon road intersects the Nine Mile Canyon road, which also intersects US-6 about 21 miles (34 km) to the southwest near the town of Wellington.

Physiography and Land-Use

The Argyle Canyon deposit lies along the southwest margin of the Uinta Basin along a geographic feature known as the Bad Land Cliffs. The Bad Land Cliffs are an east-west trending set of cliffs, highly dissected by north-south trellis-type drainage. Although in stratigraphically younger rocks, outcrop patterns in the Bad Land Cliffs somewhat mimic those of the Roan and Book Cliffs located a few miles to the south. Argyle Creek flows eastward and converges with Minnie Maud Creek and Nine Mile Creek, which together form the main-stem of Nine Mile Creek. Elevations of bitumen-saturated outcrops range generally between 7,100 and 8,000 feet (2,164-2,500 m).

Land ownership in the Argyle Canyon area is mainly public land and private land with a few scattered parcels of School Trust Lands (figure 26). Part of the Ashley National Forest lies less than two miles north of the tar-sand outcrops. Most mineral ownership of the private land, however, has been reserved by the Federal Government. The land is used mainly for grazing and for summer home sites.

Geologic Setting

The Argyle Canyon deposit occurs within interbedded open lacustrine and marginal lacustrine rocks of the Green River Formation (Eocene) (Ryder and others, 1976). Sandstone (marginal lacustrine facies) of the Delta facies and interfingering, fine-grained source beds (open lacustrine facies) of the Parachute Creek Member dip gently northward toward the center of the Uinta Basin (figure 27). The Green River Formation is overlain by mainly fluvial deposits of the Uinta Formation (Eocene).

The Delta facies consists of irregularly bedded, lenticular micaceous sandstone with interbedded mudstone. In the eastern part of Argyle Canyon, this unit is dominantly sandstone and is about 1,500 feet (457 m) thick. To the west the Delta facies becomes somewhat thicker but more dominated by mudstone and siltstone (Tripp, 1986c).

The Parachute Creek Member is regularly bedded and contains siltstone, mudstone, and kerogen-rich shale sequences with several prominent tuff beds. In the Argyle Canyon area there are numerous lenticular sandstones with unconformable channeling along their bases. The Parachute Creek Member is about 500 feet (152 m) thick (Tripp, 1986c).

Most of the bitumen is contained in delta facies sandstone tongues which pinch-out within the Parachute Creek Member. Deposits with the highest bitumen saturation appear to be in the central part of Argyle Canyon

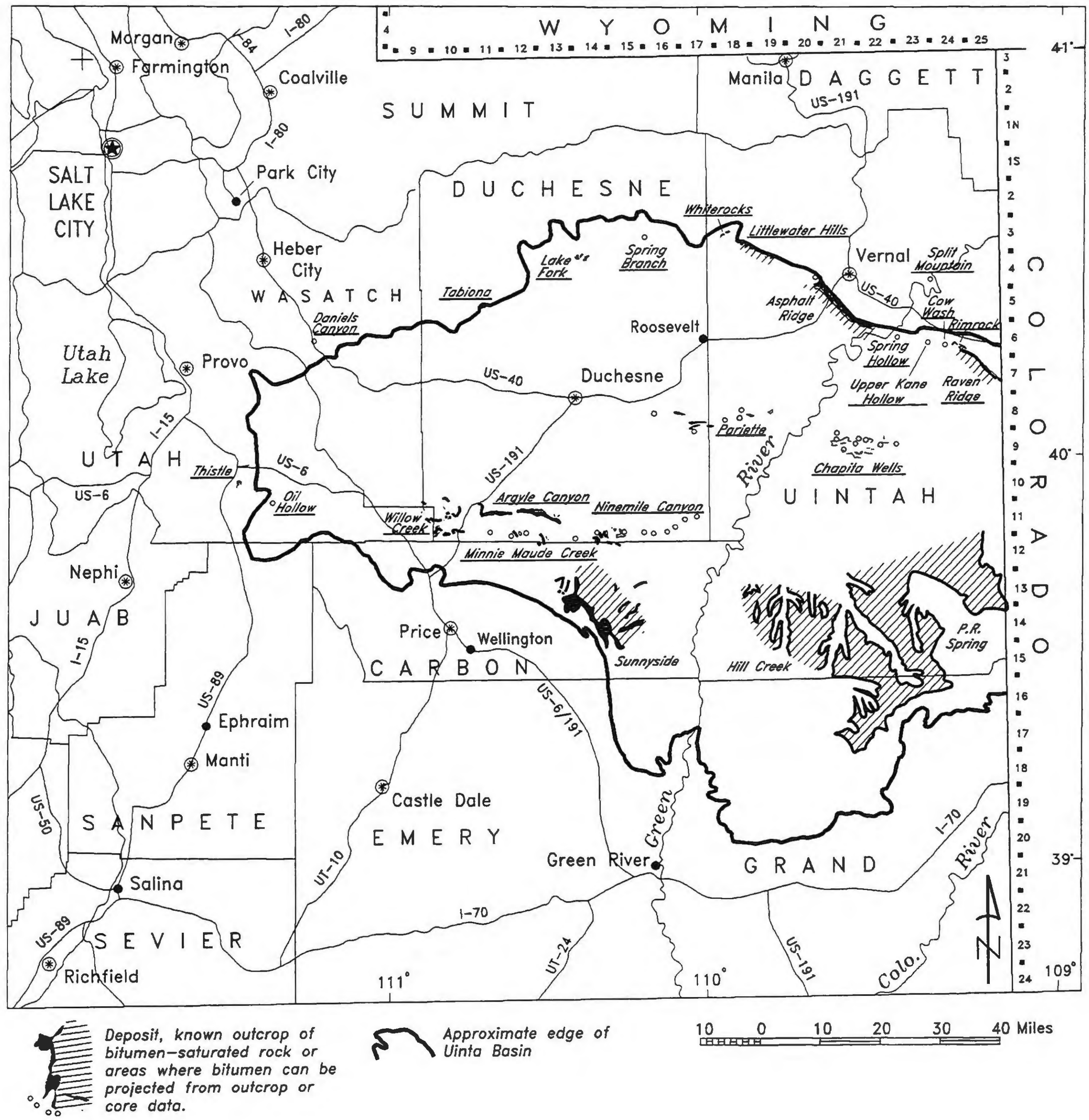


Figure 25. Locations of secondary tar-sand deposits of the Uinta Basin (underlined).

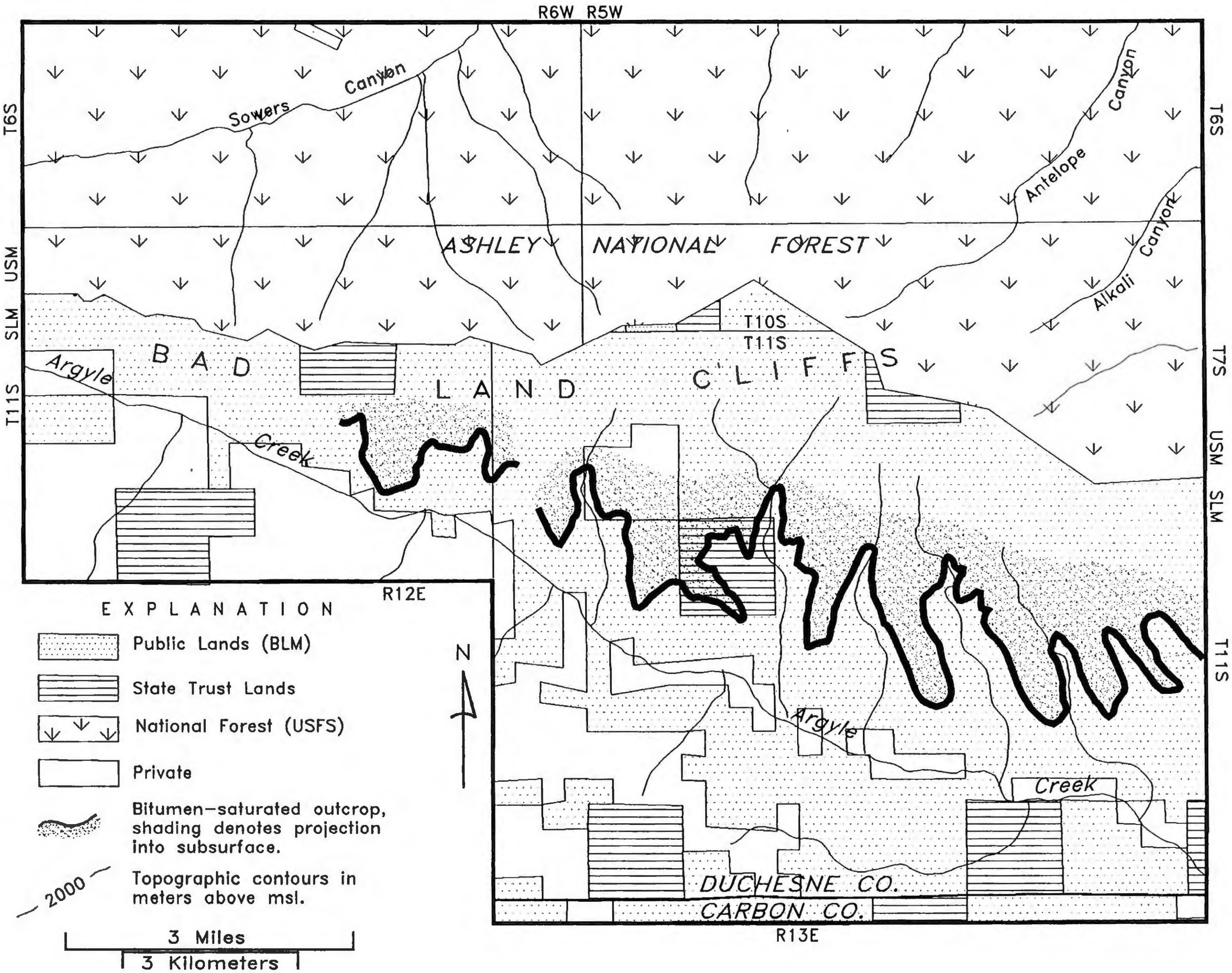


Figure 26. *Land-ownership map of the Argyle Canyon tar-sand deposit area.*

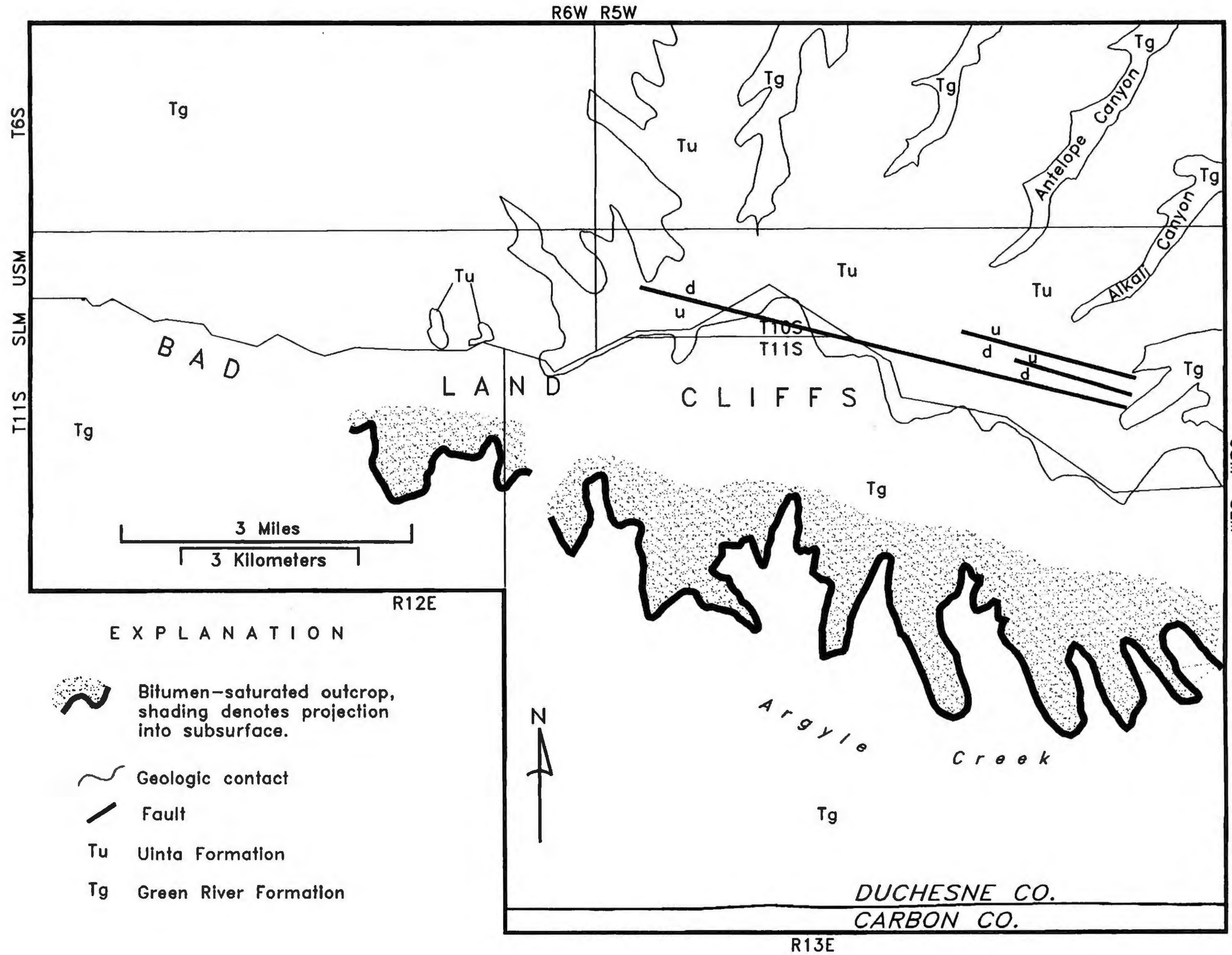


Figure 27. *General geology of the Argyle Canyon tar-sand area (after Weiss and others, 1990; tar-sand outcrops from Tripp, 1986).*

where intertonguing is more prevalent. Tripp (1986a) estimated the thickness of the saturated zone in the central part of the canyon at about 400 feet (122 m).

The only structural feature in the deposit area is a set of west-northwest trending, high-angle faults that cross-cut Green River and Uinta Formation beds 2 to 3 miles (3.2-4.8 km) north of the bitumen-saturated outcrops of Argyle Canyon (Doelling and Graham, 1972). The longest mapped fault-trace extends for about 6 miles (9.6 km).

Development History

The Argyle Canyon deposit was reportedly mined for local use as asphalt for road pavement (Tripp, 1986c). No large-scale mining of this deposit has been reported. Isopach and overburden maps, prepared by Tripp (1986a, 1986b) showed that overburden would likely be a determining factor in the viability of any future mining operation. Because of the highly dissected, steep-walled canyons, the terrain does not lend itself to surface mining operations.

Chapita Wells

Location and Access

The Chapita Wells deposit is located on the south flank of the Uinta Basin, about 28 miles (45 km) south of the town of Vernal and 11 miles (18 km) west of the town of Bonanza in T.8-9S., R.22-23E. (SLM), Uinta County (figure 25). The eastern edge of the deposit area is near the confluence of Kennedy and Coyote Washes and the western boundary is the White River. Elevations of bitumen-saturated outcrops range from about 4,800 feet to about 5,200 feet (1,463-1,585 m). Access to the area is gained along State Highway 45, south from the town of Vernal, then west via oil-well maintenance roads. The deposit consists of many scattered, bitumen-saturated outcrops extending intermittently for 10 miles (16 km) along Coyote Wash.

Physiography and Land-Use

The deposit is near the center of the Uinta Basin among generally low-lying hills and meandering washes. Land ownership is comprised mostly of Public Land administered by the BLM with scattered sections of School Trust Land administered by SITLA (figure 28). The western part of the deposit is within the Uinta and Ouray Reservation. A number of gas fields are located in the vicinity, and several gas pipelines cross the deposit area. Gilsonite mining has taken place on the east and southeast edges of the deposit area.

Geologic Setting

The Chapita Wells area is situated on the southern limb of the Uinta Basin in a belt of gently, west-dipping and northwest-dipping beds. Gilsonite veins occur on the east and southeast edges of the deposit area (figure 29). Bitumen impregnates fluvial sandstone channels within the Uinta Formation (Eocene). The host sandstone units are coarse-grained and poorly sorted and are gray at the outcrop. The degree of saturation of individual sandstone beds varies. Although the degree of saturation depends, in part, upon porosity and permeability, the proximity of the beds to fault and fracture zones appears to be the primary control (Covington, 1964). Ritzma (1979) classified the deposit as medium-small, with a gross resource of 7.5 to 8 million barrels of bitumen.

The bitumen-saturated rocks at Chapita Wells, similar to rocks at the Pariette deposit, appear to be spatially related to gilsonite veins in the area suggesting a common origin. The Pariette deposit is located about 20 miles (32 km) west of Chapita Wells.

In the Chapita Wells area, Fantasy Canyon (NW corner, section 12, T.9S., R.22E.) contains some of the most intricately carved erosion forms in Utah. Wind and rain have etched out the softer parts of a sandstone lens, leaving an array of pillars, pinnacles, arches, knobs and projections. These sandstone "goblins" are cemented with the yellow-brown bitumen.

Bitumen Analyses

Wood and Ritzma (1972) reported an analysis of bitumen extracted from the deposit. Sample 69-15E (table 2) was collected from a channel sandstone in the Uinta Formation near a gilsonite vein. The sample location was in the NE¼NW¼ section 12, T.9S, R.23E. The sandstone was reportedly stained yellow-brown and contained a waxy, volatile oil.

Development History

Bituminous sandstones of the Chapita Wells area were first mentioned in geologic literature in 1963, although they were well known to early settlers and to the Ute Indians (Covington, 1964). The only known development of the deposit was undertaken by NESCO Corporation and Oil Sands Exploration Company, both of Salt Lake City, Utah. In 1975, these companies leased ten, pre-1920 placer claims, which covered 1,600 acres in sections 15, 21, and 22 of T.9S., R.22E. They reportedly developed plans to construct processing equipment to extract oil and perform core drilling. In early 1976, the venture was abandoned (UGS internal files).

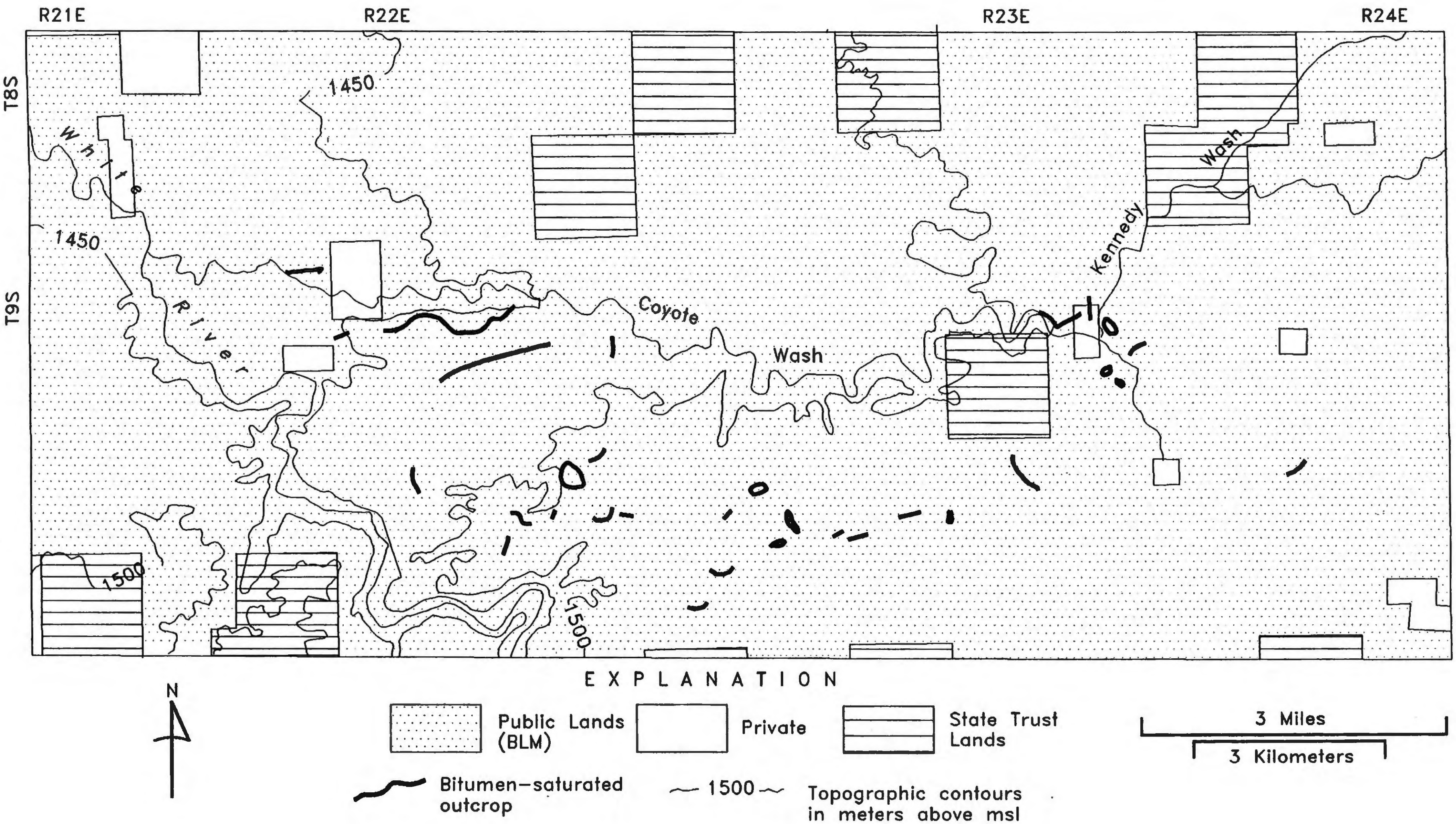


Figure 28. ***Land-ownership map of the Chapita Wells tar-sand deposit area.***

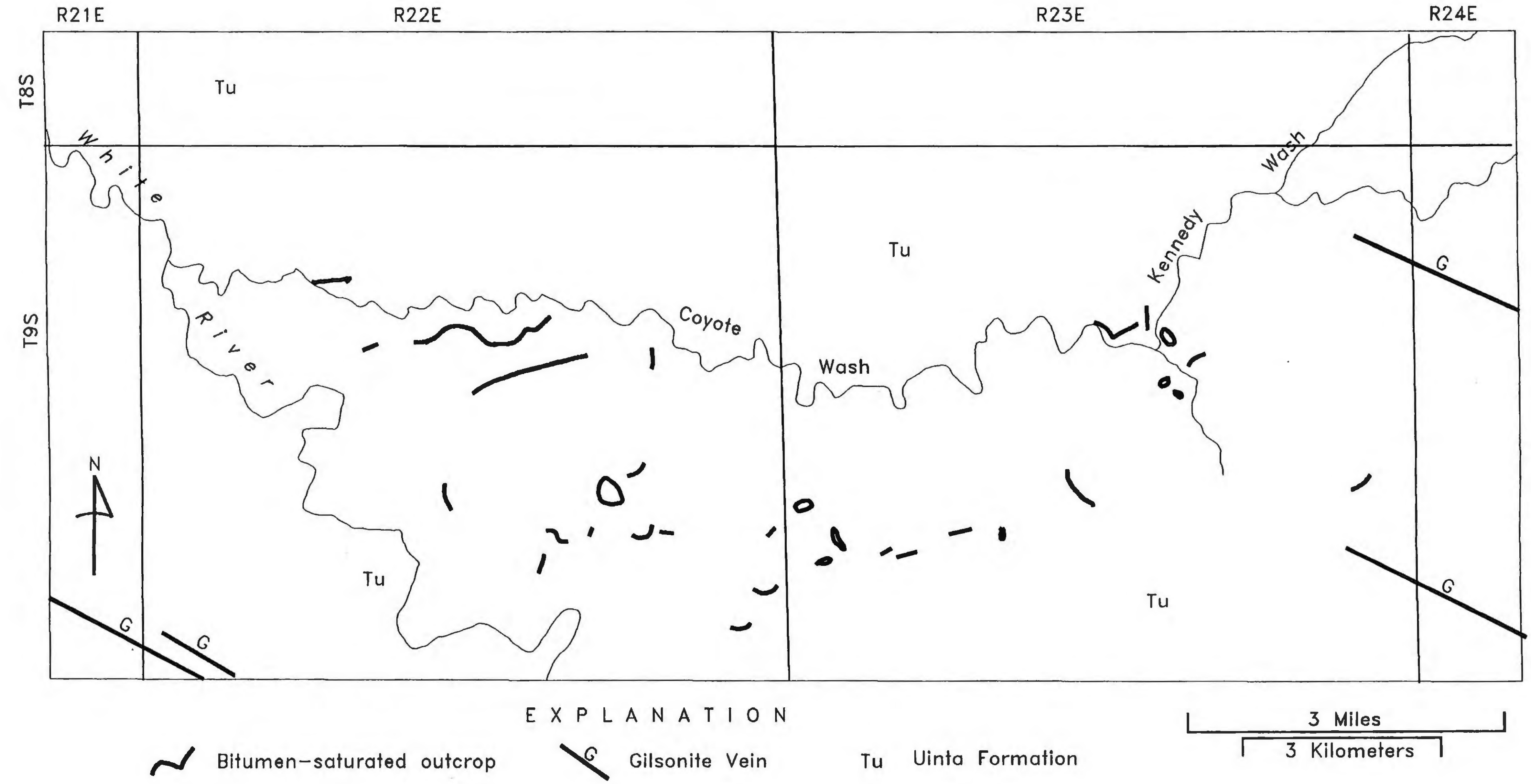


Figure 29. *General geology of the Chapita Wells tar-sand area (after Rowley and others, 1985; tar-sand outcrops from K. Clem, unpublished data).*

Cow Wash

Location and Access

The Cow Wash tar-sand deposit is located just northwest of the Raven Ridge and Rimrock deposits in sections 20 and 21, T.6S., R.24E. (SLM), Uinta County (figure 25). Access to the area is by U.S. Highway 40, southeast from Vernal for about 20 miles (32 km), and then southwest for about 2 miles (3.2 km) by unimproved pipeline-access roads. The deposit consists of two beds of bitumen-saturated sandstone which crop out for about 1 mile (1.6 km) along an east-southeast alignment between a pipeline road and Cow Wash. The Utah-Colorado border is about 10 miles (16 km) to the south-southeast along U.S. 40.

Physiography and Land-Use

The Cow Wash deposit is located on the northeast margin of the Uinta Basin in an area characterized by low-lying hogback ridges (The Rim Rock) and bad-land type topography. Dinosaur National Monument and Split Mountain, comprised of deeply eroded Mesozoic and Paleozoic sedimentary rocks, lie about 15 miles (24 km) to the north. The Walker Hollow, Red Wash, White River, and Wonsits Valley oil and gas fields lie between 6 and 18 miles (10-29 km) southwest of the area. The Powder Springs gas field and the Coyote Basin oil field lie about 10 miles (16 km) to the southeast.

Land ownership is mostly Public (BLM-administered) Lands with isolated state sections, outside of the deposit area, administered by (figure 30). Land use is mainly livestock grazing and activities related to oil-field development.

Geologic Setting

The deposit is contained in interbedded sandstones and conglomerates, within the Parachute Creek member of the Green River Formation (figure 31). These bedded units dip 65 degrees south-southwest toward the basin axis. The Green River Formation (Eocene) rests unconformably upon the Wasatch Formation (Paleocene-Eocene) and is overlain by the Uinta Formation (Eocene). Bitumen is trapped in pinchouts of lenticular, medium-grained sandstones and, to a lesser extent, conglomerates. Ritzma (1979) classified the deposit as small, and calculated the total resource at 1.0 to 1.2 million barrels.

Bitumen Analyses

Sample 69-1A (table 2) was collected from an outcrop of the Parachute Creek Member of the Green River Formation west of a pipeline-cut between Cow Wash and the pipeline road in the SW¼NE¼NW¼ section 21, T.6S., R24E. (SLM).

Development History

No exploration or development of this deposit is known. The Cow Wash tar-sand deposit is one of several minor deposits located in the area between the Asphalt Ridge and Raven Ridge deposits. The discovery of these tar sands was reportedly instrumental in triggering exploration that led to the discovery of Green River Formation petroleum (depth of 5,300 feet) in the Red Wash Field to the southwest (Quigley, 1972).

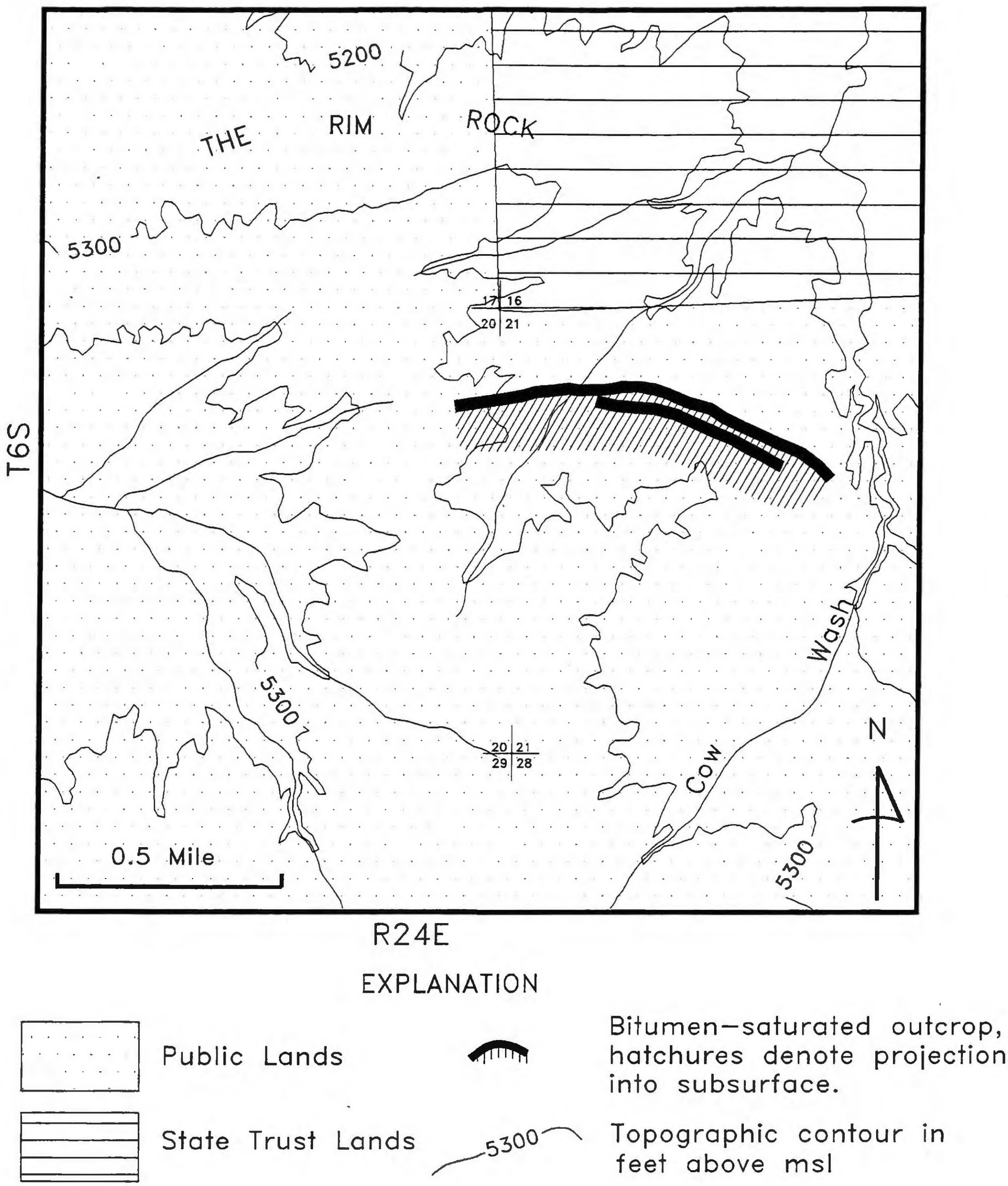


Figure 30. Land-ownership map of the Cow Wash tar-sand area.

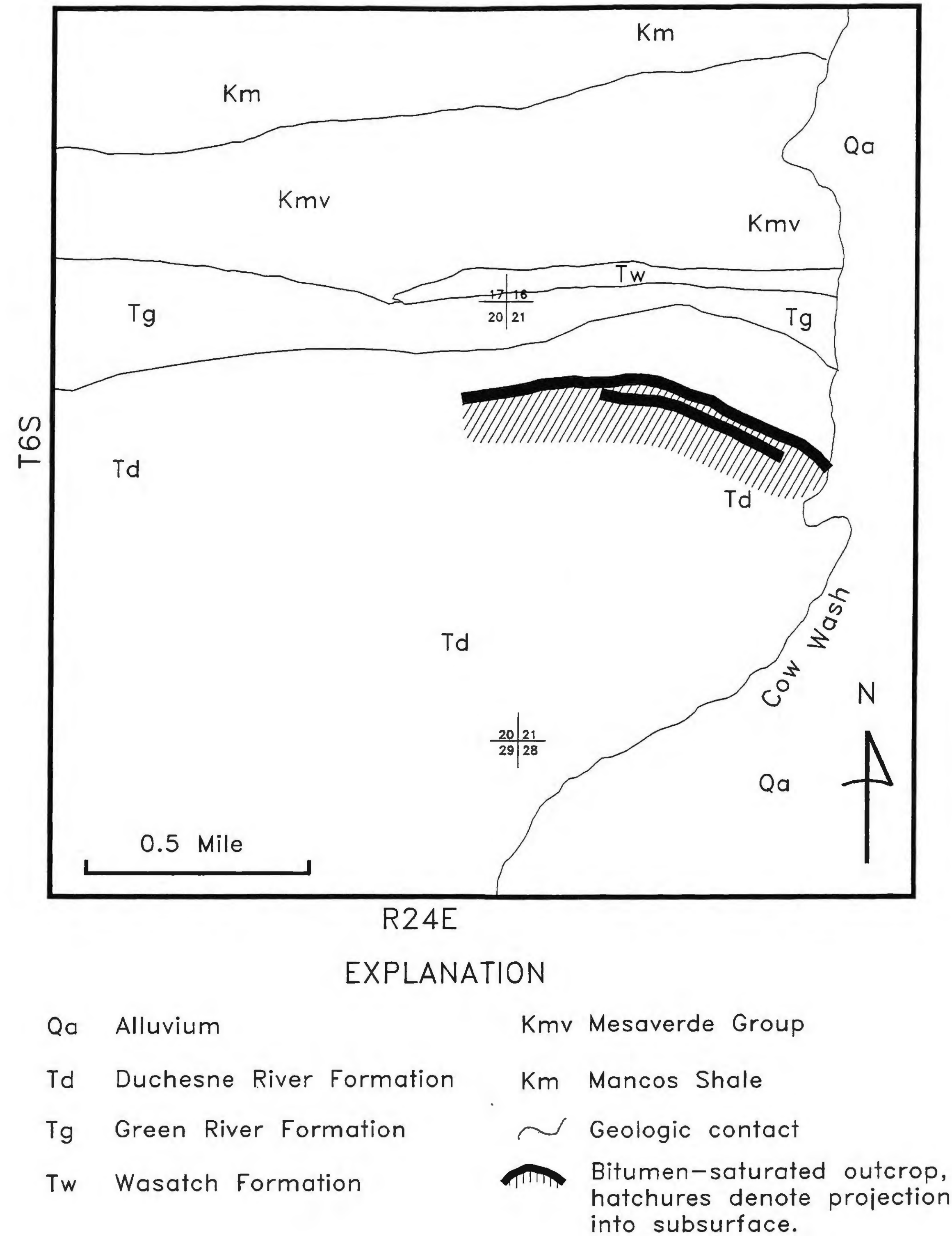


Figure 31. General geology of the Cow-Wash tar-sand area (after Rowley and others, 1985).

Daniels Canyon

Location and Access

The Daniels Canyon deposit lies slightly west of the western flank of the Uinta Basin, 17 miles (27 km) southeast of Heber City, Utah, near the summit of Daniels Canyon, Wasatch County (figure 25). It is about 200 to 300 feet (60-90 m) east of U.S. Highway 40 and about 1.0 mile (1.6 km) north of Daniels Pass in the SE¼NE¼NE¼SW¼ section 10, T.6S., R.6E. (SLM), Wasatch County, Utah. A short trail starting from U.S. Highway 40 and leading east along the north side of a minor, unnamed tributary of Daniels Canyon provides access to the deposit.

Physiography and Land-Use

The area is in the Wasatch Hinterland physiographic subprovince of the Uinta Basin. The deposit consists of an east-west alignment of bitumen-saturated exposures located in mountainous, forested terrain. The deposit covers about 2,000 square feet (186 m^2) at an elevation of 7,900 feet (2,408 m). The best exposures are at an abandoned mine, called the Chinese Wax Mine (Ritzma, 1975). The deposit is entirely within the Uinta National Forest (figure 32).

Geologic Setting

The deposit occurs in the highly fractured, brecciated Oquirrh Formation (Pennsylvanian-Permian) on the west flank of the Uinta Basin where the Paleozoic and Mesozoic formations of west-central Utah have been thrust along a low-angle plane over the west margin of the basin. The Oquirrh Formation was deposited in the Oquirrh basin, an important depocenter in the mid-Paleozoic foreland basin. The geometry of the Oquirrh basin is obscure because of Cretaceous thrust faulting during the Sevier orogeny. The Strawberry Valley (or Charleston) thrust is exposed 4.7 miles (7.6 km) to the east and dips at a low angle to the west. The sole of the thrust may lie more than 5,000 feet below the Daniels Canyon deposit (Ritzma, 1975). The rocks surrounding the deposit are likely of Permian age (figure 33). They are overturned and dip from 60 to 75 degrees to the north and northeast (Ritzma, 1975).

Bitumen saturates interstices of the intensely fractured and brecciated siliceous limestone and quartzite of the Oquirrh Formation. The strike of this fractured zone, from alignment of the mine entries and dumps, is about N.70°E. The fractures dip about 25 degrees to the north. Clasts of the limestone and quartzite are impermeable and mostly devoid of bitumen.

The oil is a shiny black solid at temperatures up to 100°F (38°C). On surfaces warmed by the sun, it becomes tacky and oozes in tiny rivulets. The material resembles a mineral wax more than a tar.

Bitumen Analyses

Analyses of three samples of bitumen extracted from the mined material are listed in table 2. Sample 70-22D came from the mine dump, while samples 74-1A and B were cut from the walls of the mine entry.

Extensive analyses of the two samples indicate that the bitumen has been moderately degraded by weathering and bacterial action, and is similar in composition to ozocerite. Ozocerite, a mineral of solid hydrocarbon, is found in the Wasatch and Green River Formations elsewhere in the Uinta Basin.

Development History

The Daniels Canyon deposit is the only deposit in Utah exploited solely as a source for petroleum products. It was discovered in about 1900 and the first claims were recorded in early 1909. The mine was operated sporadically for a number of years following discovery until it was shut down in the early 1920s. In the late 1920s interest revived in the mine, and in 1929 and 1930 the Daniel Mining and Refining Company re-opened the mine. The mine came to be known as the Chinese Wax Mine because much of the investment capital came from several residents of Park City who were of Chinese descent (Ritzma, 1975).

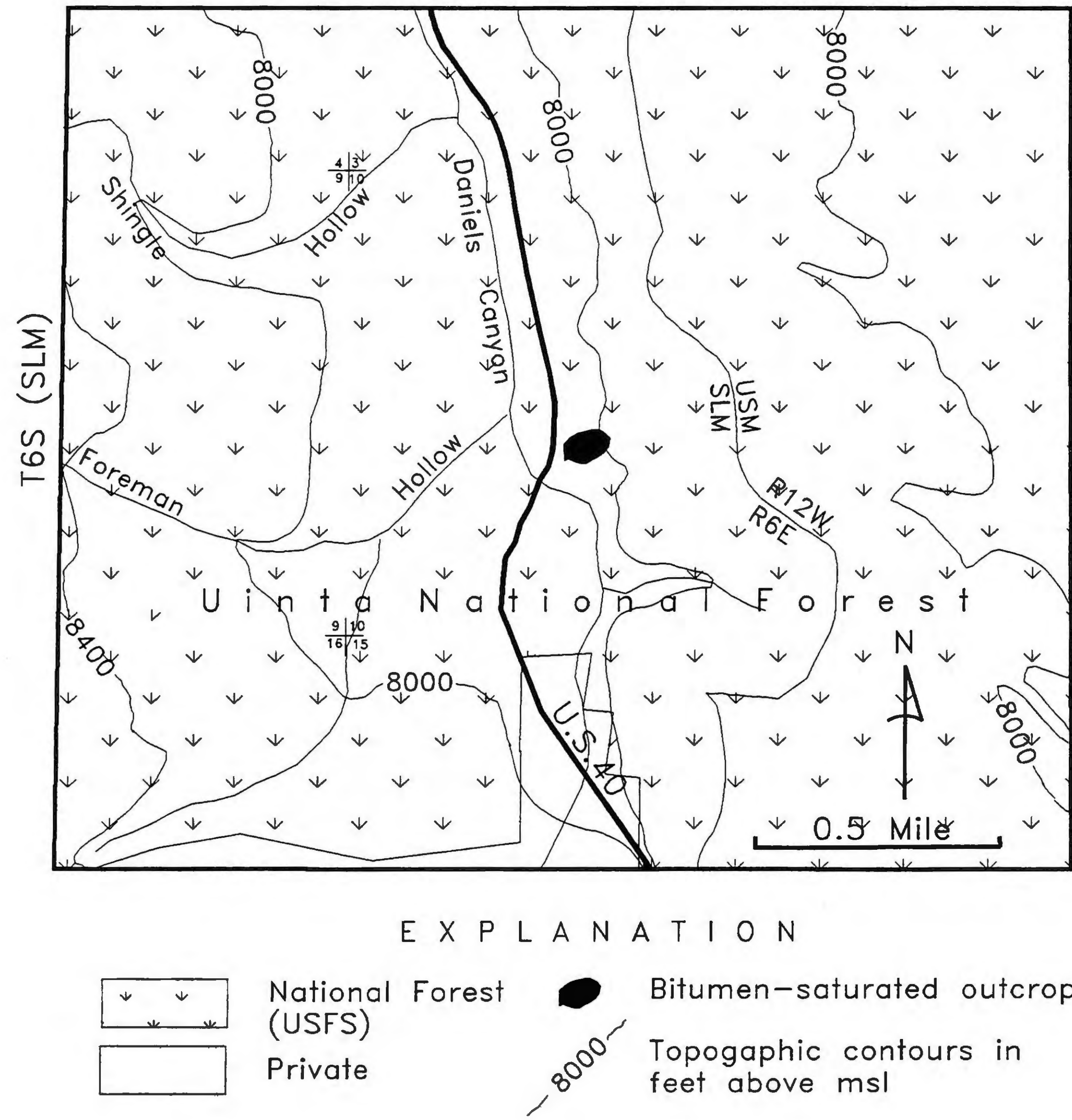


Figure 32. *Land-ownership map of the Daniels Canyon tar-sand area.*

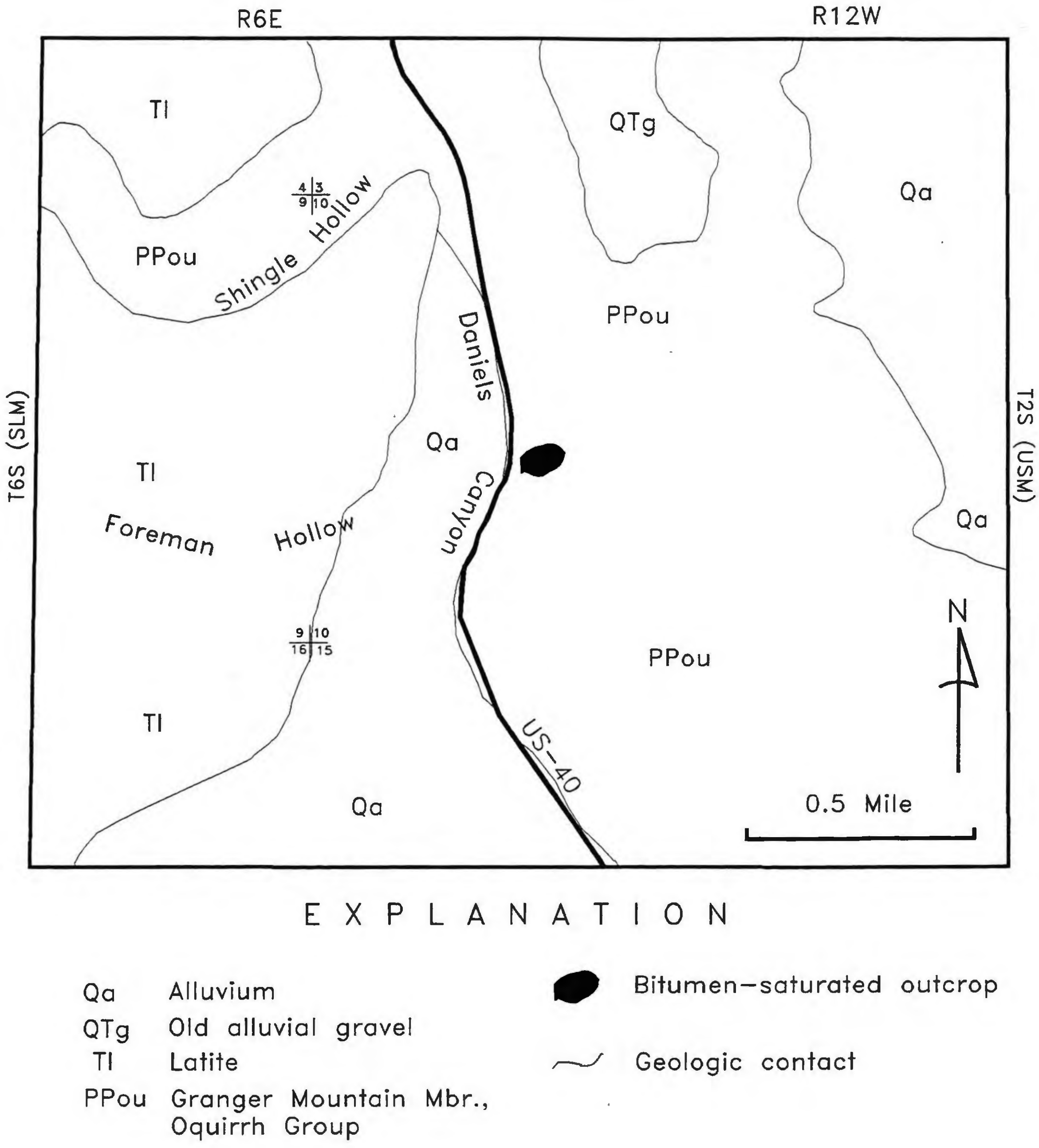


Figure 33. *General geology of the Daniels Canyon tar-sand area (after Bryant, 1992; Ritzma, 1975; tar-sand outcrops from K. Clem, unpublished data).*

Examination of the mine site in the 1970s by UGS geologists showed that the mine was a steeply inclined shaft following the "vein" of bitumen-saturated, fractured and brecciated rock. Several short drifts were driven outward from the shaft until encountering barren rock. Ritzma (1975) reported that one entrance to the shaft was located on top of a hill at the highest bitumen-saturated outcrops, while another entrance was located about 120 feet (37 m) downslope. A retort, reportedly moved from an oil-shale plant near Carlin, Nevada, was erected at the bottom of the shaft next to the lower entry. The crumbly, brecciated rock in the "vein" was retorted and yielded a black waxy substance which was further distilled or refined at the site. Products from the retort included (1) high-grade, pale-yellow oil, used in automobiles and machinery; (2) lamp oil; and (3) candle wax. The market for these products was local, therefore, only a small amount was produced. The mine and plant closed after about two years of operation, and the retort was dismantled and moved to DeBeque, Colorado, during World War II (Ritzma, 1975).

Lake Fork

Location and Access

The Lake Fork deposit is located on the south flank of the Uinta Mountains, about 25 miles (40 km) north of the town of Duchesne in sections 5 and 6, T.1N., R.4W., and section 1, T.1N., R.5W. (USM), Duchesne County (figure 25). Formerly referred to as Lake Fork-Yellowstone, Yellowstone, and Black Diamond, the deposit is situated along low-lying slopes about 1 mile (1.6 km) west of the Yellowstone River. Although not maintained, numerous forest-fire control roads cross the area.

Physiography and Land-Use

The deposit is located on the northwest flank of the Uinta Basin in a belt of south-dipping beds that marks the basin margin. Bitumen-saturated rocks crop out at an elevation of about 8,000 feet (2,438 m) on wooded lands belonging to the Uinta and Ouray Reservation (figure 34).

Geologic Setting

The Duchesne River Formation, the host rocks for the deposit, dips from 4 to 6 degrees southward in this area (figure 35). Within the Duchesne River Formation (Eocene), bitumen is confined to a fluvial-channel interval comprised of four beds with a gross thickness between 15 and 20 feet (5-6 m). These sandstone bodies are cross-bedded, poorly sorted, and weather to grey and white. The complete deposit may be obscured by younger Quaternary gravel and dense brush (K. Clem, unpublished data). Ritzma (1979) classified the deposit as small and calculated the gross resource to be 6.5 to 10 million barrels.

Bitumen Analyses

Wood and Ritzma (1972) collected two samples from the Lake Fork deposit and reported the results of analyses (table 2). Sample 68-21D was collected from an oil seep in the Duchesne River Formation, located in the center of the SW¼ section 5, T.1N., R.4W. Sample 68-22D was collected from a prospect pit in the Duchesne River Formation, located in the center of the SW¼ of section 5.

Development History

In 1957 and 1958, the Duchesne County Road Commission conducted a coring program to assess the Lake Fork deposit for possible use as road-surfacing material. The Commission determined that the deposit was not sufficiently rich for use as paving material. In addition to land and mineral title disputes, the results of the coring program led the commission to abandon the project.

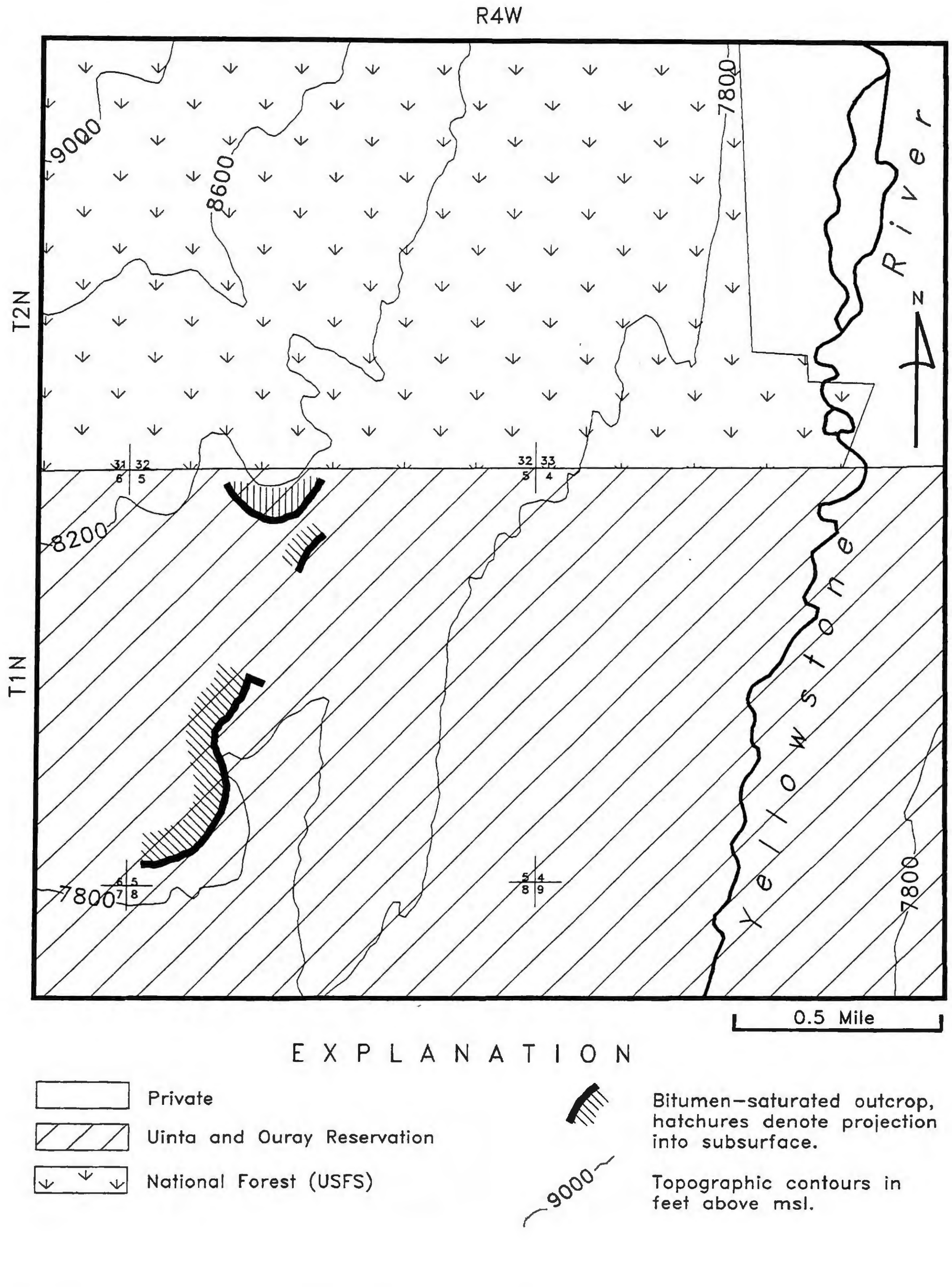


Figure 34. *Land-ownership map of the Lake Fork tar-sand area.*

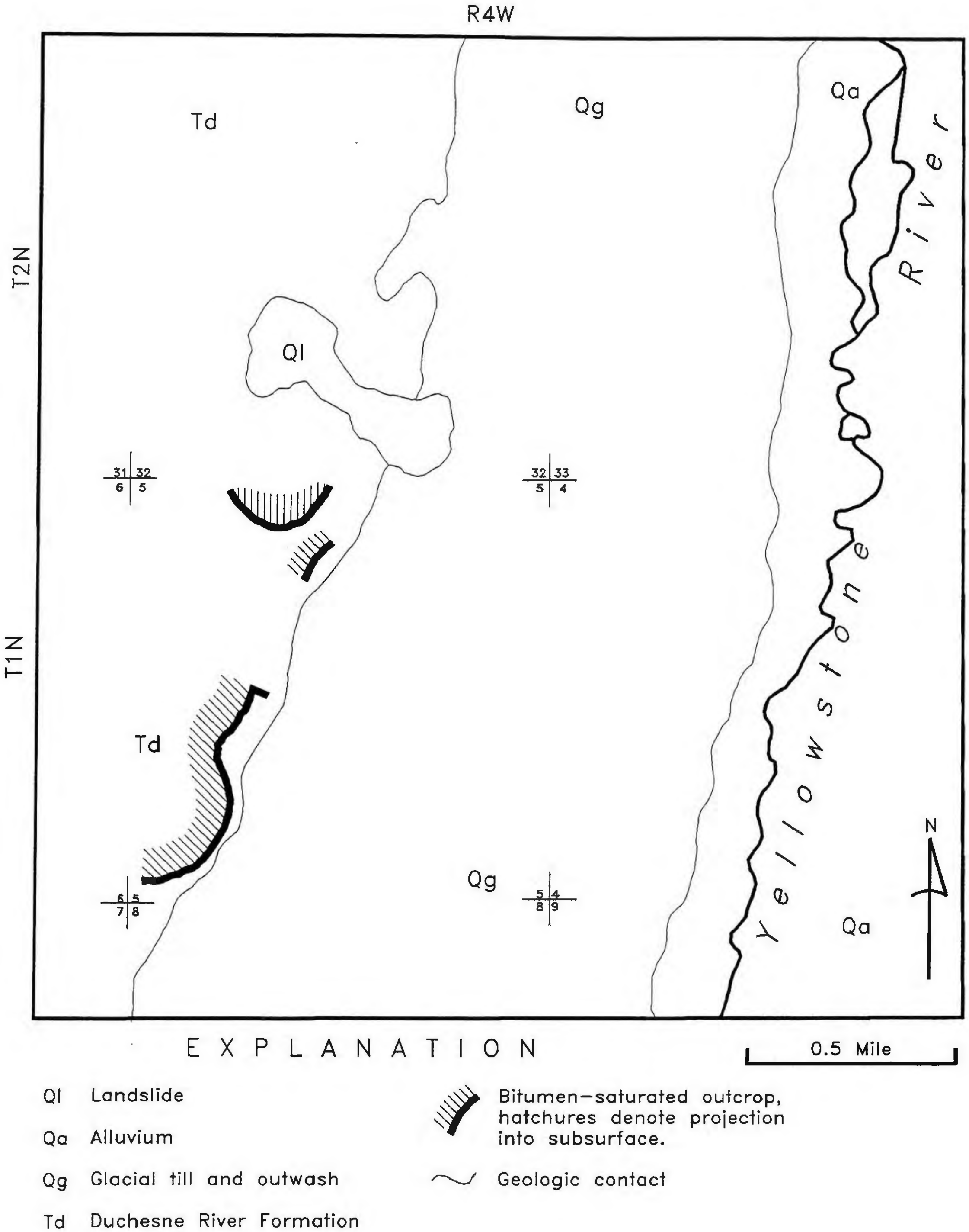


Figure 35. *General geology of the Lake Fork tar-sand area (after Bryant, 1992; tar-sand outcrops from unpublished UGS file data).*

Littlewater Hills

Location and Access

The Littlewater Hills deposit consists of two areas of numerous, small bitumen-saturated sandstone outcrops located in sections 26, 27, 35, and 36 of T.2N., R.1E. (USM); in sections 4 and 5 of T.1N., R.2E. (USM); in section 31 of T.2N., R.2E. (USM); and in section 34, T.3S., R.19E. (SLM), Uintah County (figure 25). Former names of the deposit include Deep Creek and Deep Creek Nose (Ball Associates, Ltd., 1964). Located about 15 miles (24 km) north of the town of Roosevelt, the deposit is accessed by paved county roads and unimproved ranch roads.

Physiography and Land-Use

The western part of the deposit extends about 2 miles (3.2 km) in an east-southeast alignment along the north side of the Littlewater Hills, ending near Grouse Creek (Little Water Creek). The eastern part of the deposit extends about 1 mile (1.6 km) in a southeast alignment also along the north side of the Littlewater Hills, ending near Deep Creek (figure 36). The deposit crops out at an elevation of 6,600 to 7,200 feet (2,012-2,196 m) and is somewhat obscured by vegetation.

Nearly the entire deposit area is contained on lands belonging to the Uinta and Ouray Reservation. Adjacent to the north lie tracts of private, Public, and National Forest lands.

Geologic Setting

The deposit is located on the north flank of the Uinta Basin in the belt of south-dipping beds that mark the basin margin in this area. Upper Cretaceous rocks in the vicinity dip to the south from 15 to 17 degrees (Kinney, 1955). Dips generally decrease through successively younger beds southward toward the basin axis.

In the deposit area (figure 37), the Duchesne River Formation rests unconformably upon the Mancos Shale (Upper Cretaceous). Both units are poorly exposed. The basal strata of the Duchesne River Formation are white to grey, medium-grained sandstones with occasional lenses of conglomerate. The conglomerate lenses contain grit- to cobble-size clasts. Bitumen of varying saturation is primarily within this basal strata. These saturated units are unconformably overlain by massive conglomerates of Duchesne River Formation. The conglomerate contains cobble- to boulder-sized clasts. Bitumen occasionally extends up into the conglomerates.

Covington (1964) stated that the Littlewater Hills deposit had no economic significance, but was of geologic interest. Ritzma (1979) classified the deposit as large, containing 10-12 million barrels.

The Littlewater Hills deposit is geologically important because of its location between the Asphalt Ridge deposit, located 3 miles (4.8 km) to the southeast, and the Whiterocks deposit, located 4 miles (5.4 km) to the west.

Bitumen Analyses

Chemical analyses suggest that the origin of the oil was the Green River Formation (Eocene). Sample 68-14C, shown in table 2, was taken from an outcrop and bulldozer cut on the east bank of Deep Creek (SW¼SW¼SW¼ section 4, T.1N., R.2E.).

Development History

There has been no known exploration or attempt at development of this deposit. A test well for oil and gas was drilled just north of the deposit by Cotton Petroleum Company in 1974. The No. 1 Bruchez, located in the NW¼NW¼NW¼ section 32, T.2N., R.2E. (USM), penetrated the Weber Sandstone (Permian) at a depth of 4,555 feet. Two formation tests, one within the Mancos Shale produced 5 MCF of gas per day; and the other, within the Weber Sandstone, produced water. The well was subsequently plugged and abandoned.

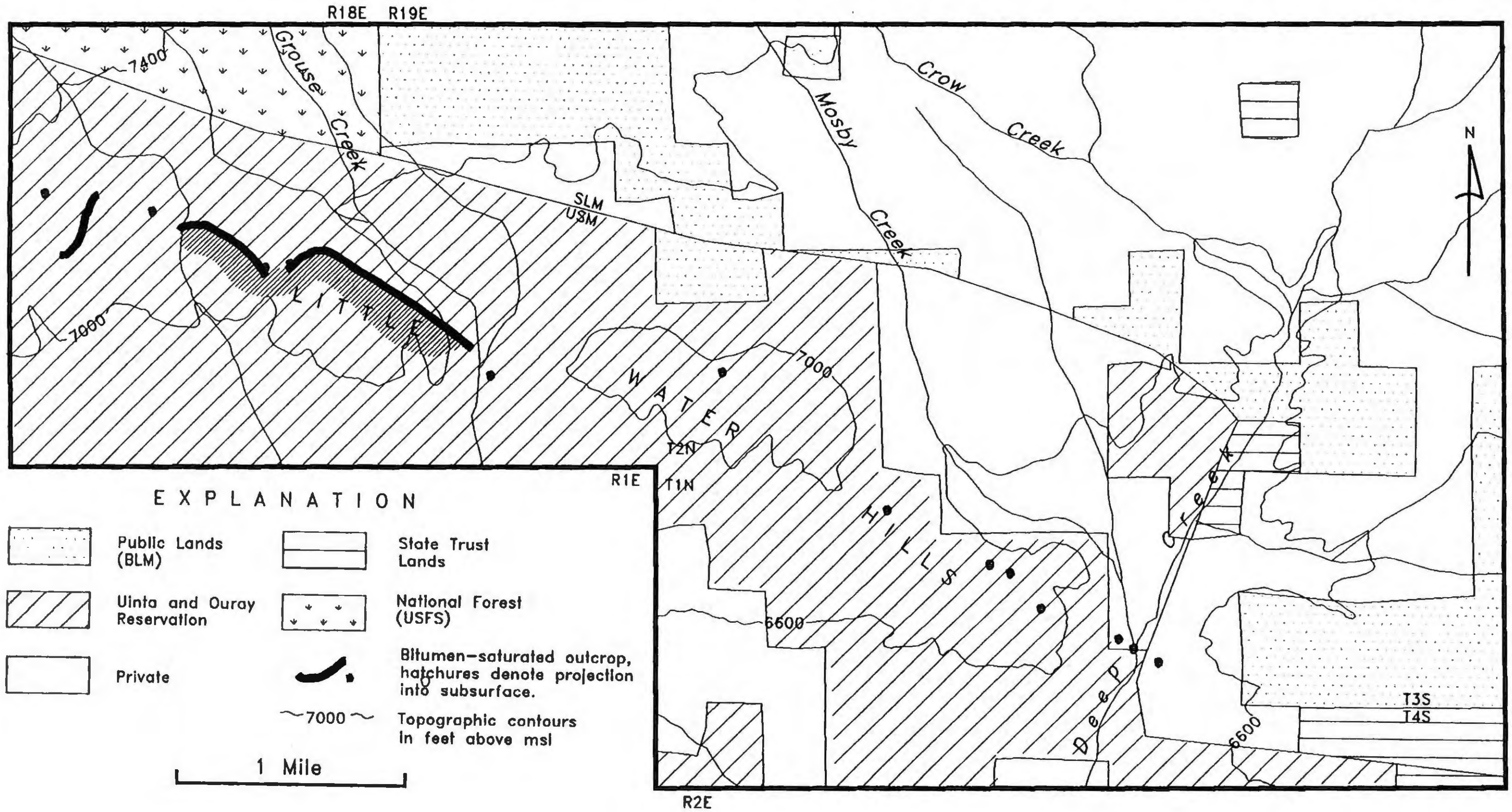


Figure 36. *Land-ownership map of the Littlewater Hills tar-sand deposit.*

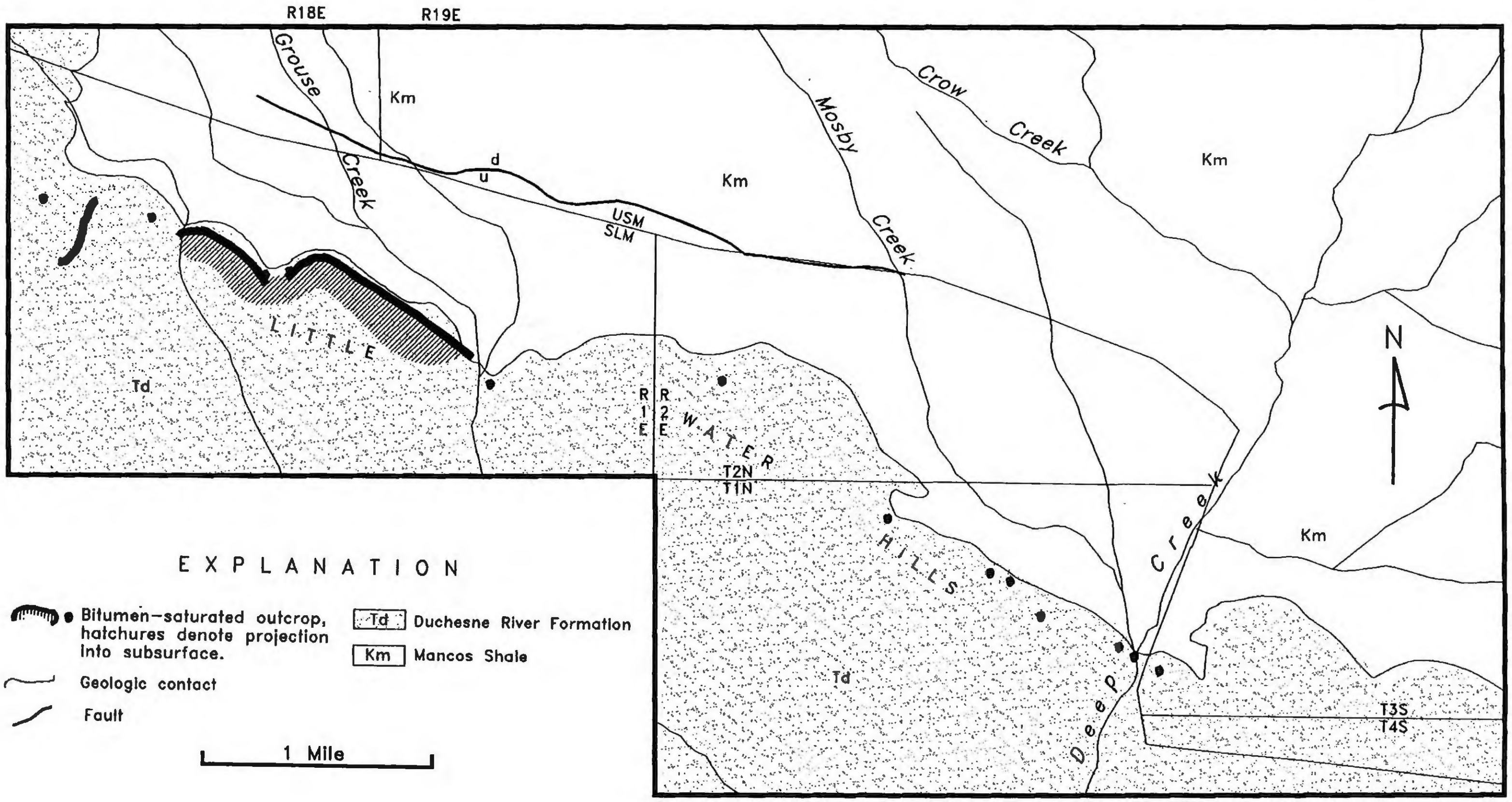


Figure 37. *General geology of the Littlewater Hills tar-sand area (after Doelling and Graham, 1972; tar-sand outcrops from K. Clem, unpublished data).*

Minnie Maud Creek

Location and Access

The Minnie Maud Creek deposit is located on the southwest flank of the Uinta Basin, about 18 miles (29 km) northeast of the town of Price in T.11-12S., R.12-13E (SLM), Carbon and Duchesne Counties, Utah (figure 25). The deposit extends east-west on the north side of Minnie Maud Creek, a tributary of Nine Mile Creek. Bitumen-saturated beds generally crop out at elevations around 7,300 feet (2,225 m).

Access to the area is via U.S. highway 6 southeast from Price then north on the Nine Mile Canyon Road, just past the town of Wellington. This road follows Soldier Creek northeastward for about 20 miles (32 km) to Nine Mile Canyon. Minnie Maud Creek extends to the northwest from the head of Nine Mile Canyon. Several ranch maintenance roads connect the numerous side canyons and ridges where the deposit is exposed.

Physiography and Land-Use

The deposit area lies just northeast of the Roan Cliffs. Minnie Maud Creek is mostly a homoclinal valley following the geologic strike (east-southeast) of gently dipping sedimentary rocks. Many side canyons trend generally northeast-southwest forming a trellis-type drainage pattern.

Although mineral rights have been reserved by the Federal Government, much of the surface ownership is private (figure 38). Land in the area is used mostly for grazing, for recreational use, and summer homes.

Geologic Setting

The Minnie Maud Creek tar-sand deposit is located on the southwest limb of the Uinta Basin, where strata generally dip northward from 4 to 12 degrees. Sedimentary formations exposed in the canyon include the Garden Gulch and Parachute Creek Members of the Green River Formation, and the Wasatch Formation (figure 39). Bitumen-saturated rocks occur within both the Garden Gulch and Parachute Creek Members of the Green River Formation. Between one and four principal saturated zones are reported, with a gross thickness ranging from 5 to 15 feet (1.5-4.6 km) (Ritzma, 1979). Ritzma (1979) classified the deposit as "large," containing between 10 and 15 million barrels of oil-in-place.

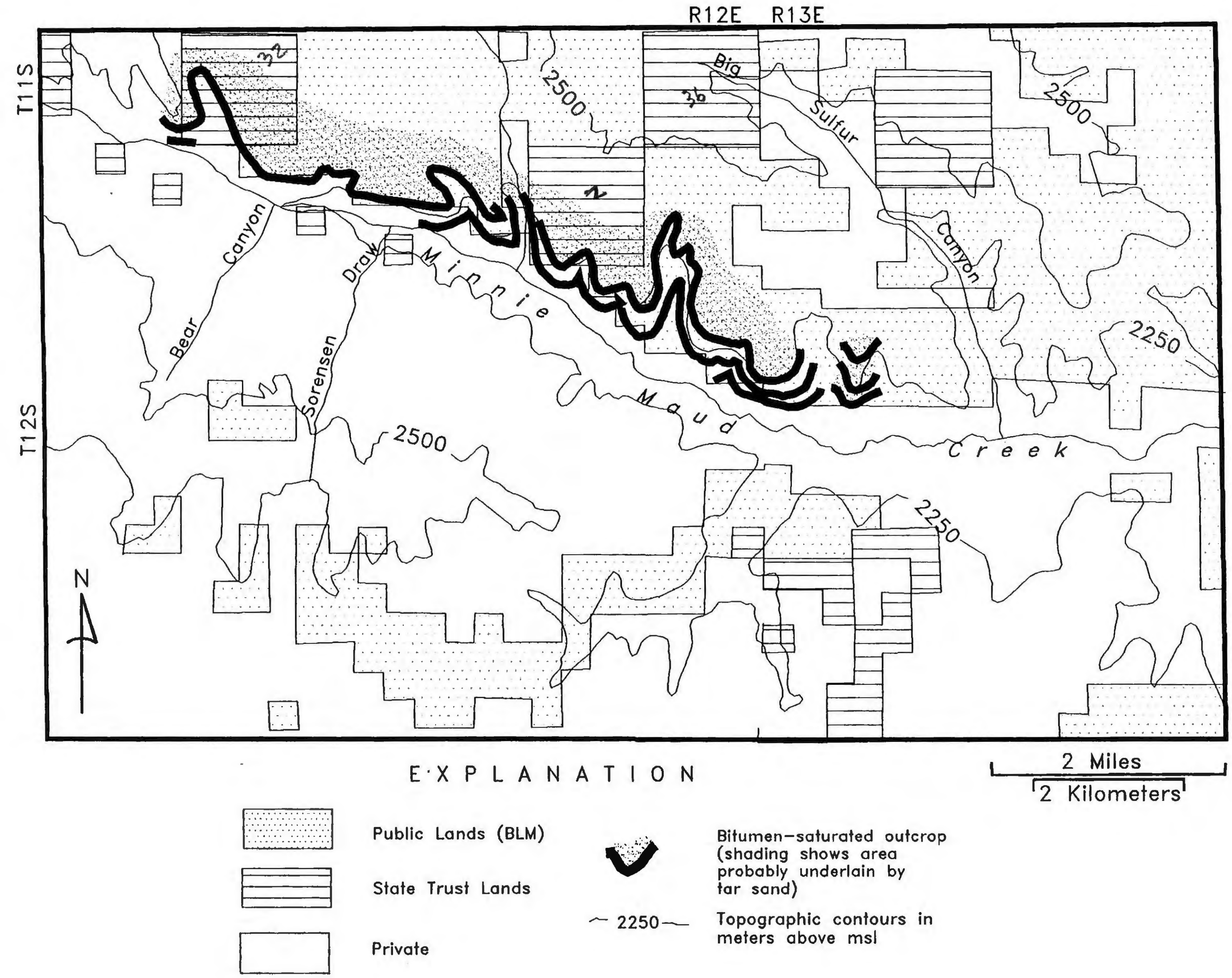
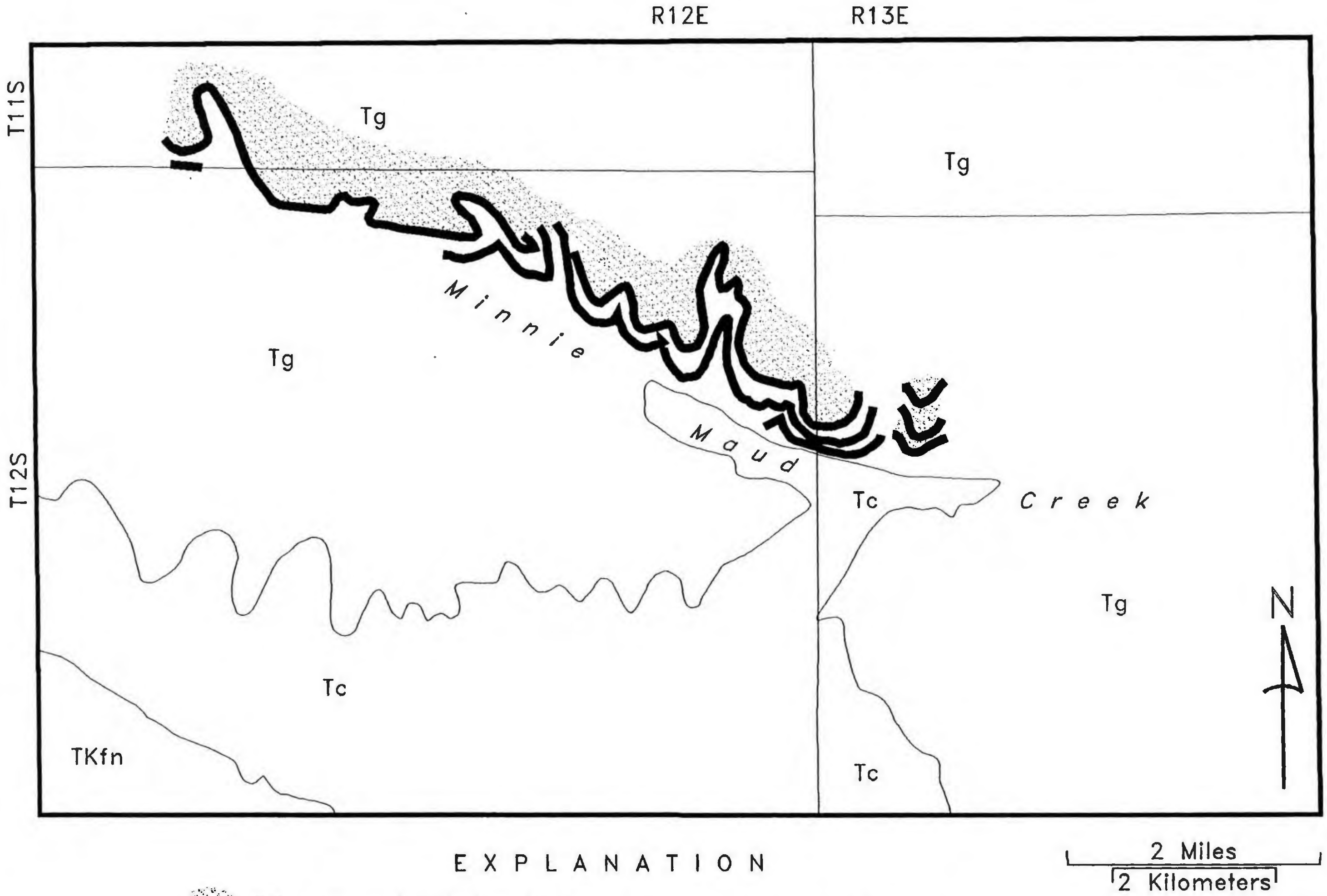


Figure 38. Land-ownership map of the Minnie Maud Creek tar-sand deposit area.



EXPLANATION

Bitumen-saturated outcrop (shading shows area probably underlain by tar sand)

Geologic contact

Tg	Green River Formation
Tc	Colton Formation
TKfn	Flagstaff Limestone and North Horn Formation

Figure 39. *General geology of the Minnie Maud Creek tar-sand deposit area (after Weiss and others, 1990; tar-sand outcrops from K. Clem, unpublished data).*

Nine Mile Canyon

Location and Access

The Nine Mile Canyon deposit is located on the southwest flank of the Uinta Basin, about 24 miles (39 km) northeast of the town of Price, Utah, in T.11S., R.14-17E. (SLM), Duchesne County (figure 25). The deposit is expressed as scattered outcrops and extends in an east-west direction for about 20 miles (32 km) on the north side of Nine Mile Canyon. Bitumen-saturated rocks crop out at elevations of about 6,500 feet (1,981 m).

Access is via U.S. Highway 6 southeast from Price, then north onto Nine Mile Canyon Road just past the town of Wellington. This road follows Soldier Creek northeastward for about 20 miles (32 km) to Nine Mile Canyon. Several ranch-maintenance roads connect numerous side canyons and ridges where the deposit is exposed.

Physiography and Land-Use

The Nine Mile Canyon tar-sand deposit is situated on the southwest margin of the Uinta Basin in the Bad Land Cliffs area where tributaries to Nine Mile Creek have eroded nearly flat-lying sedimentary rocks. The Bad Land Cliffs extend roughly 35 miles (56 km) from Argyle Canyon to the west across the north side of the Nine Mile Canyon area. Elevations range from about 5,700 feet (1,737 m) to 6,500 feet (1,981 m).

Surface ownership is mostly Public Lands with scattered sections of School Trust Lands. Small tracts of private lands are located mainly along Nine Mile Creek and in the Water Canyon drainage (figure 40). The lands are used mainly for grazing with some private lands serving as summer home sites.

Geologic Setting

The Nine Mile Canyon tar-sand deposit is located on the southwest limb of the Uinta Basin, where strata generally dip northward from 4 to 12 degrees. Sedimentary rock units exposed in the canyon include the Garden Gulch and Parachute Creek Members of the Green River Formation and the Wasatch Formation. Bitumen-saturated rocks occur within both the Garden Gulch and Parachute Creek Members of the Green River Formation. Outcrops of bitumen-saturated rocks are discontinuous and extend for about 17 miles (27 km) along Nine Mile Creek, Gate Canyon, Petes Canyon, Currant Canyon, and Parley Canyon (figure 41).

Ritzma (1979) classified the deposit as "medium" to "small," and estimated that 5 to 10 million barrels of oil were in-place.

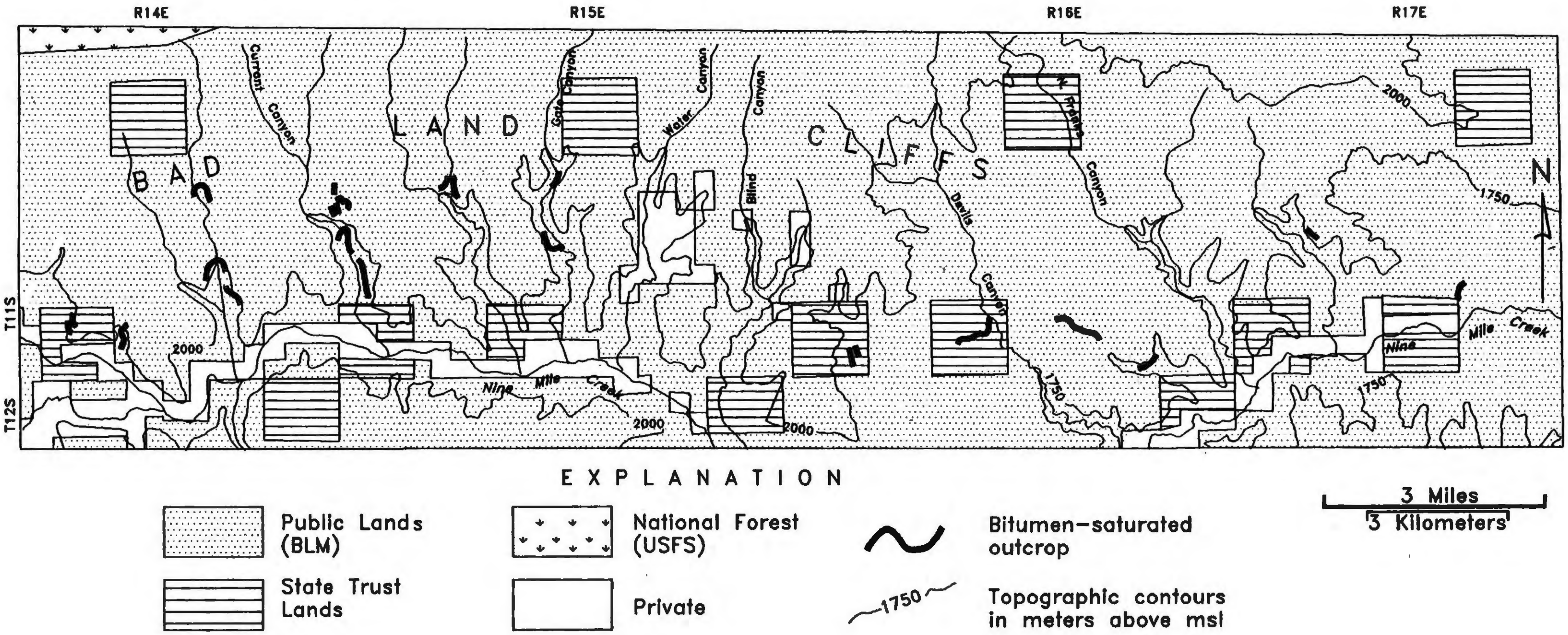


Figure 40. Land-ownership map of the Nine Mile Canyon tar-sand deposit area.

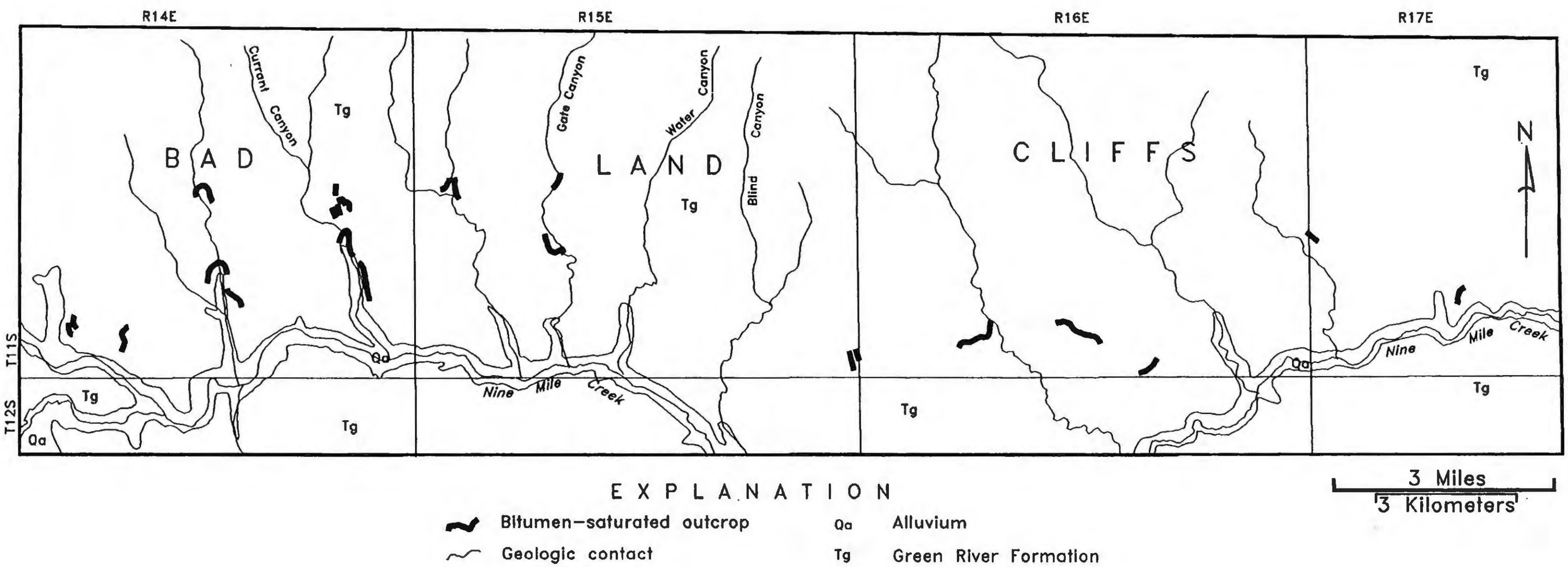


Figure 41. *General geology of the Nine Mile Canyon tar-sand area (after Weiss and others, 1990; tar-sand outcrops from K. Clem, unpublished data).*

Oil Hollow

Location and Access

The Oil Hollow tar-sand deposit is located in the W½W½ section 28, T.10S., R.5E, (SLM), Utah County (figure 25). Numerous small outcrops of oil-impregnated sandstone occur for about 0.6 miles (1 km) in a north-south alignment on the east side of the valley at the head of Oil Hollow and to the south across a sharp divide in the head of an unnamed north fork of Spring Hollow. The area is accessed from U.S. Highway 6 near Thistle Junction in Spanish Fork Canyon. From here a 4-wheel-drive road continues southeastward "up" Lake Fork for about 7 miles (11 km). A 4-wheel-drive road from Dairy Fork to the northeast crosses the deposit and connects with the Lake Fork road about 2 miles (3.2 km) south of the deposit.

Physiography and Land-Use

The Oil Hollow deposit is located at the extreme west margin of the Uinta Basin near the north end of the Wasatch Plateau. The deposit crops out at an elevation of about 7,100 feet (2,164 m) in mountainous, forested terrain. The land surface is administered by the Forest Service, minerals are owned by the Federal Government, but have apparently been withdrawn from leasing. An isolated state section less than 1 mile (1.6 km) south of the occurrence is administered by SITLA. The southernmost exposure is located on private lands, which are probably patented mining claims. Land use is mainly for summer grazing and for harvesting forest products (figure 42).

Geologic Setting

The Oil Hollow deposit occurs in sandstone units of the Green River Formation (Eocene) which dip 10 to 15 degrees northeast (figure 43). In the deposit area, the Green River Formation has been down-dropped more than 500 feet (150 m) along the Martin Mountain fault, and placed adjacent to the Flagstaff (Paleocene) and North Horn (Cretaceous-Paleocene) Formations to the west (Pinnell, 1972).

The host sandstone units, although discontinuous, are grouped within a sequence of green shale and claystone that is about 50 feet (15 m) thick. Some adjacent shale is also saturated with bitumen. The sandstone is fine- to medium-grained, well-sorted, variably calcareous, and weathers to a characteristic light bluish gray color (K. Clem, unpublished data).

Bitumen Analyses

Analyses of two samples from the deposit yielded an average of 10.1 percent of oil by weight. Sulfur content was 0.42 and 0.44 percent (K. Clem, unpublished data). No laboratory report or other reference to these analyses were available, however.

Development History

Peterson and Ritzma (1972) reported that several pits and tunnels (adits) were observed in the deposit area. They also reported that a simple retort was apparently operated at the site.

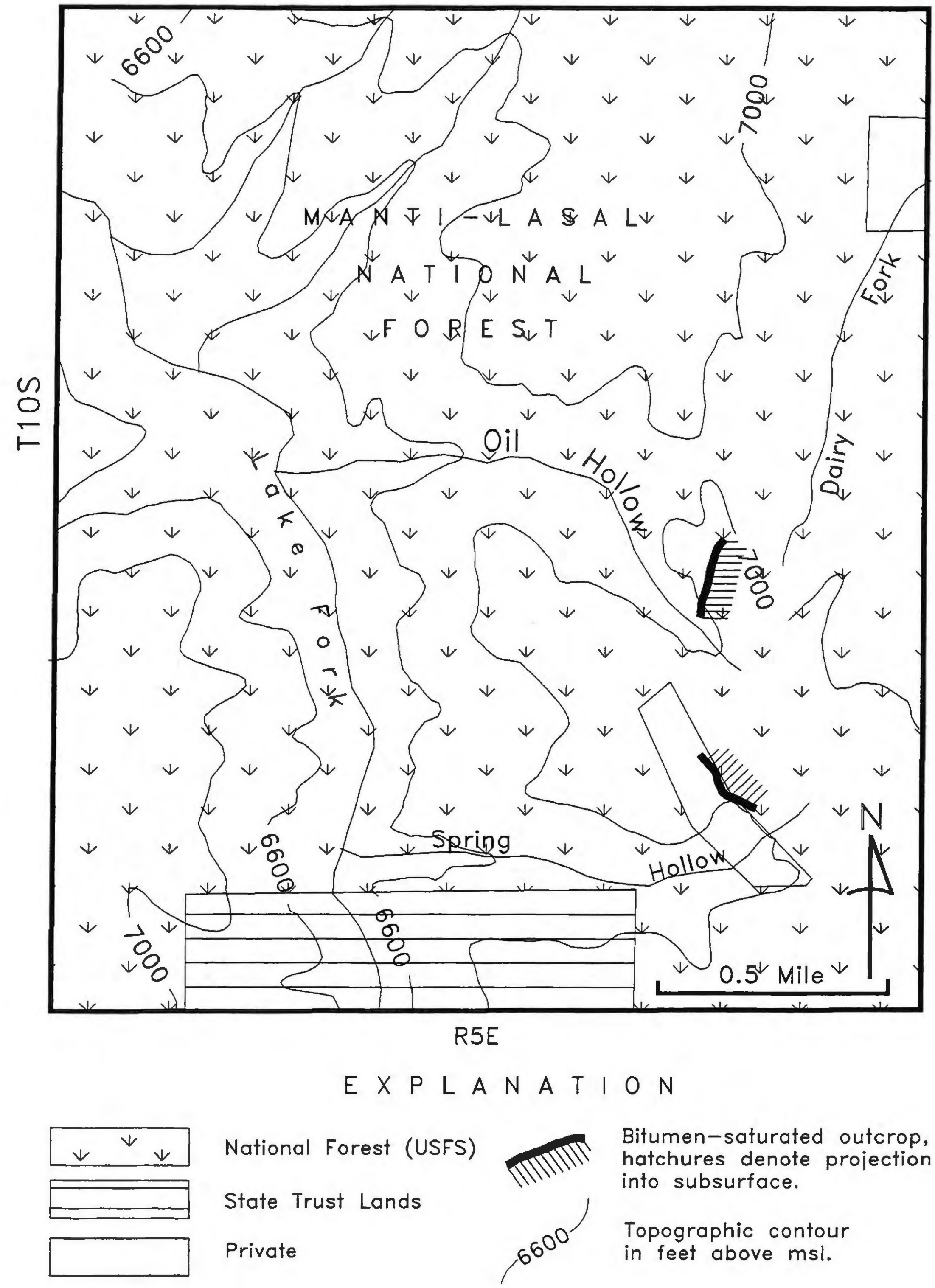


Figure 42. Land-ownership map of the Oil Hollow tar-sand deposit area.

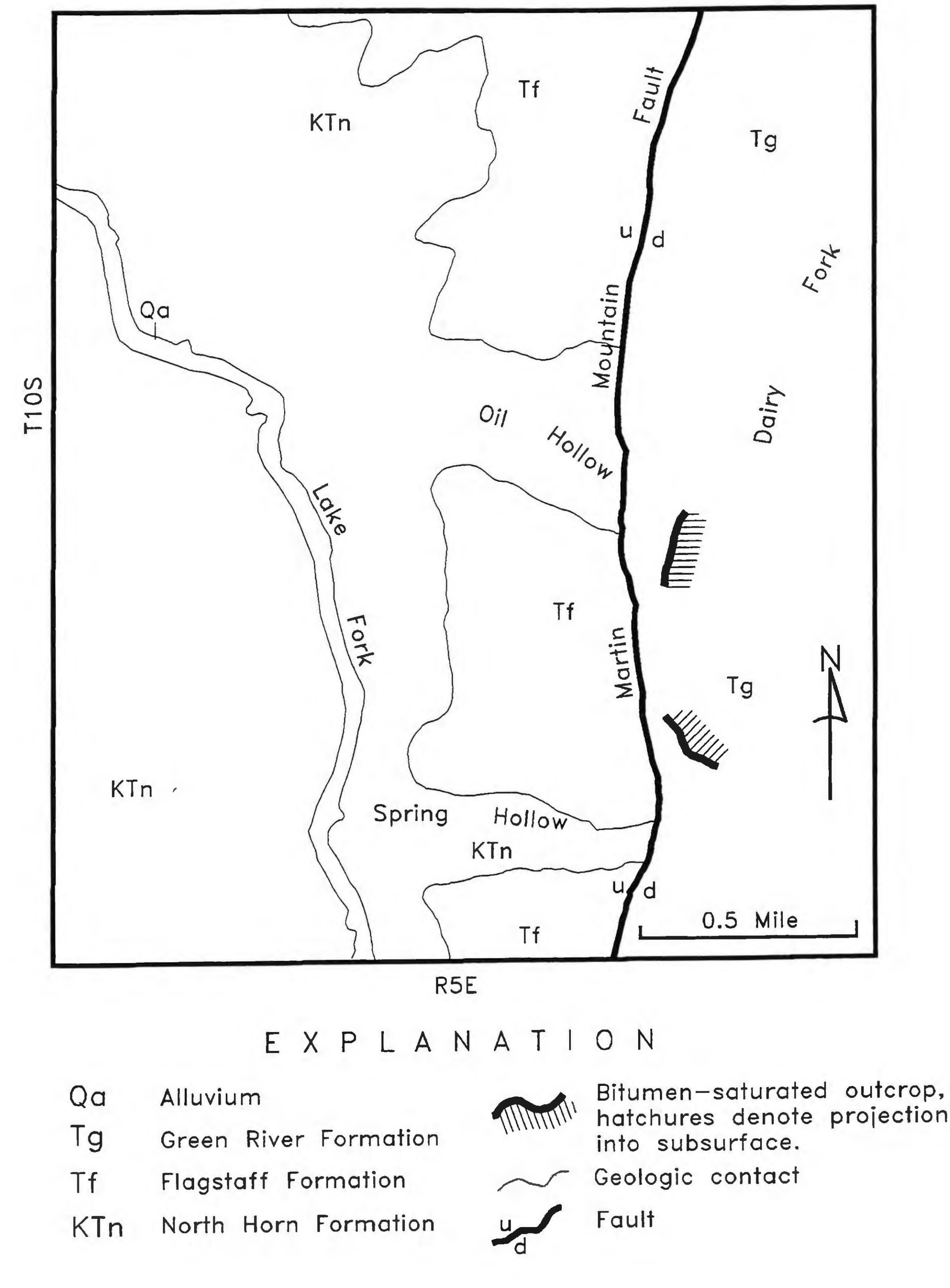


Figure 43. General geology of the Oil Hollow tar-sand area (after Pinnell, 1972; tar-sand outcrops from unpublished UGS file data).

Pariette

Location and Access

The Pariette deposit is located on the south flank of the Uinta Basin, about 15 miles south of Roosevelt and Fort Duchesne, in Duchesne and Uintah Counties (figure 25). The deposit consists of numerous scattered outcrops extending about 20 miles (32 km) intermittently along Pariette Bench. The deposit area includes T.4S., R.1-2E., and R.2W. (USM), and T.8S., R.17-18 E. (SLM). Elevations of the outcrops range from about 4,850 feet to about 5,350 feet (1,478-1,631). Access to the area is via state highway 161 and oil-well maintenance roads southward from the town of Myton for about 10 miles (16 km).

Physiography and Land-Use

The deposit is located in an area of low relief near the topographic center of the Uinta Basin. The area lies partly within the Uinta and Ouray Indian Reservation, and includes a combination of Reservation lands, private lands, Public (BLM-administered) Lands, and isolated State sections (figure 44). Land is used mostly for irrigated crops and stock grazing.

Geologic Setting

Geologic units present (figure 45) in the area include the Uinta Formation (Eocene), which dips gently from 1 to 4 degrees northward in this area, and Quaternary surficial deposits (Hintze, 1980). Several scattered, lenticular fluvial-sandstone units of the Uinta Formation in the Pariette area are bitumen-saturated. Individual saturated zones are up to 15 feet (4.6 m) thick, and commonly pinch-out laterally within a few feet. Bitumen-saturated outcrops are normally buff to gray in color, while the surrounding rocks are red to orange. Saturated sandstones are typically medium-grained, crossbedded, and well sorted (UGS, unpublished file data). The Pariette deposit lies about 5 to 10 miles (8-16 km) southeast of the Duchesne fault zone and in the proximity of several gilsonite veins (Gurgel, 1983).

The position of bitumen-saturated zones vary horizontally and vertically, making correlations of individual zones difficult. Bituminous outcrops along Pleasant Valley appear higher in the section compared to bituminous outcrops along Pariette Bench and Uteland Butte. Visual inspections of the Pariette Bench-Uteland Butte outcrop indicate that these tar-sands are generally of a better grade and more extensive than those along Pleasant Valley.

Bitumen saturation varies from weak to rich, with reported "dry" tar occurrences (Covington, 1963). While the areal extent of saturation is large, the majority of the outcrops are of less than a rich grade. Covington (1963) postulated that the origin of bitumen is related to the Duchesne Fault zone, as oil could have migrated upward along the fault zone and into the Uinta Formation from the underlying Green River Formation. Gilsonite veins, which are in close proximity, also cannot be discounted as a source.

Ritzma (1979) classified the Pariette deposit as "large," and estimated that the area contains from 12 to 15 million barrels of bitumen. Covington (1963, 1964) suggested that, due to the lenticular nature of the host sandstone units, the deposit does not have great commercial value.

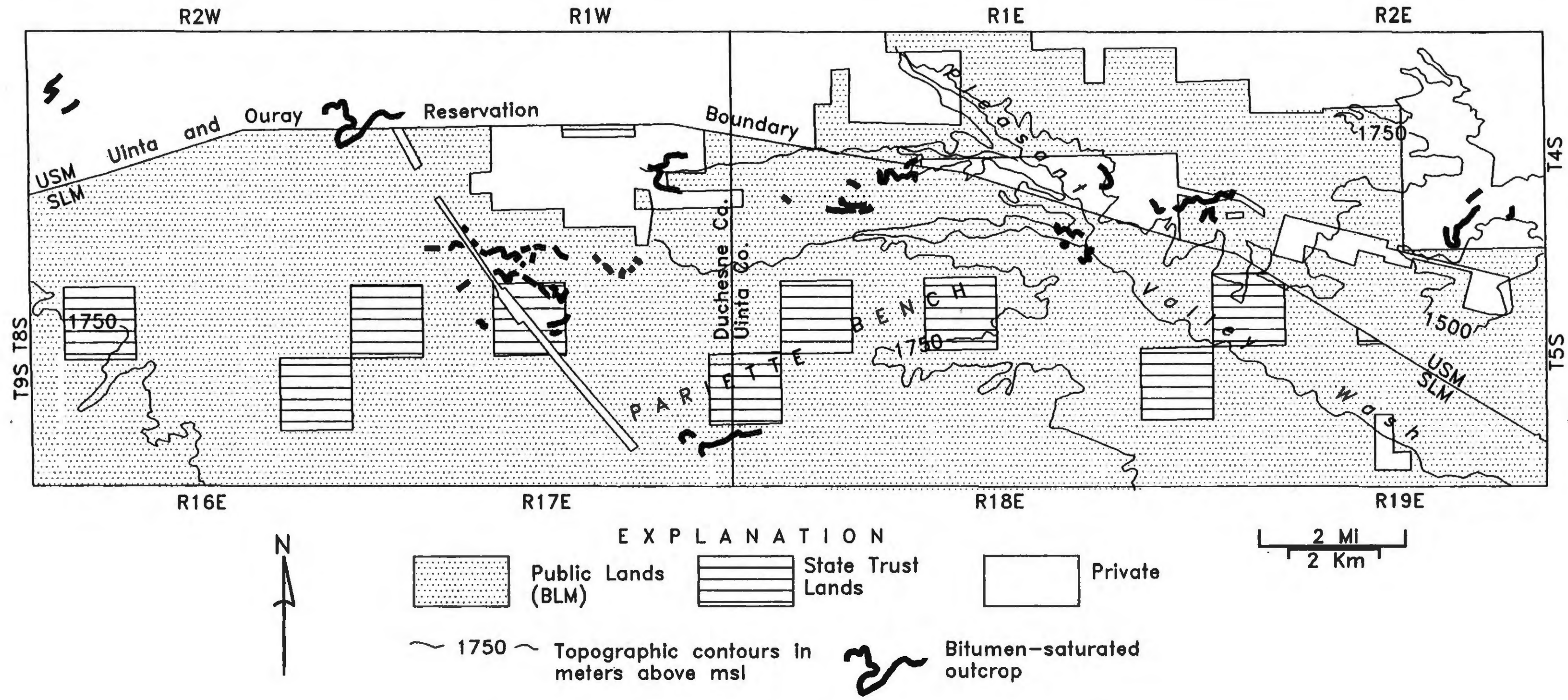


Figure 44. Land-ownership map of the Pariette tar-sand area.

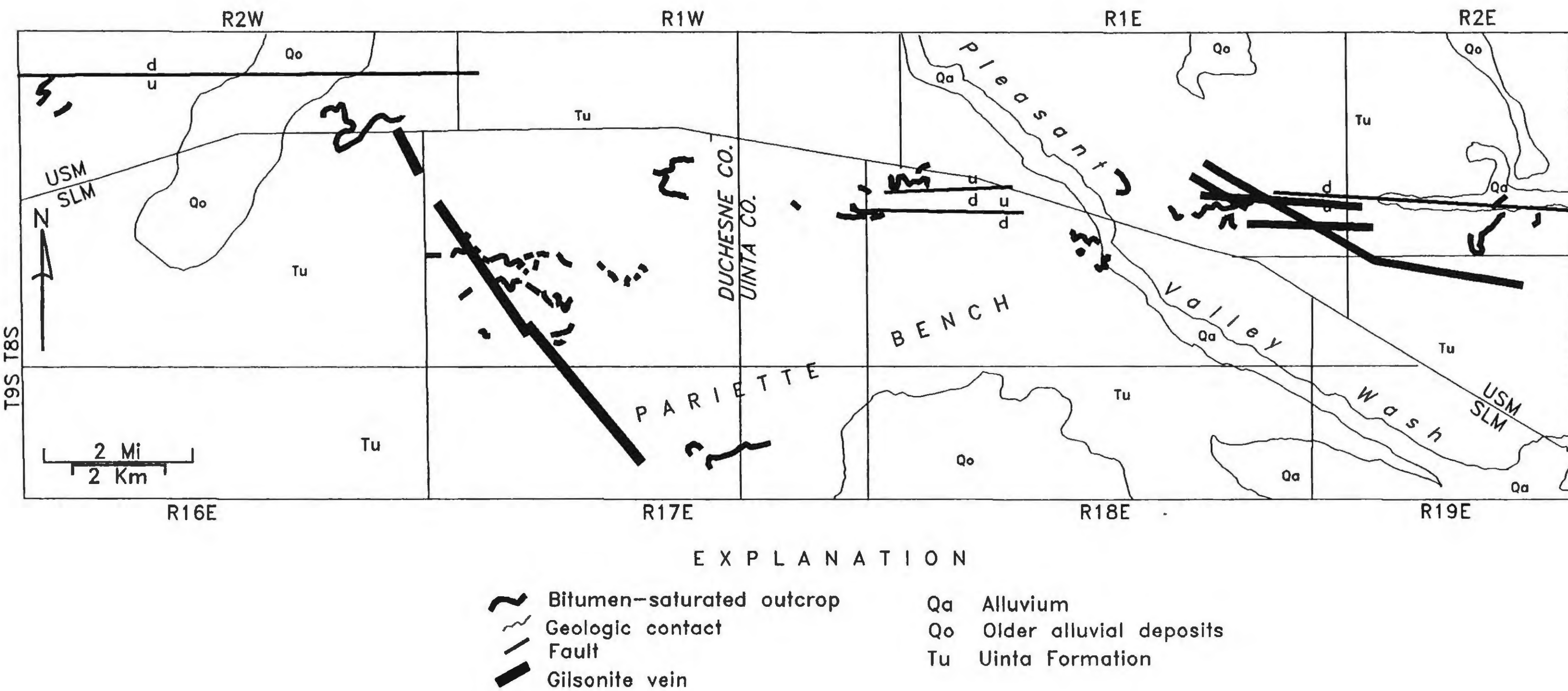


Figure 45. *General geology of the Pariette tar-sand area (after Rowley and others, 1985; tar-sand outcrops from K. Clem, unpublished data), and unpublished UGS file data).*

Raven Ridge

Location and Access

The Raven Ridge deposit is located on the north flank of the Uinta Basin, about 25 miles (40 km) southeast from the town of Vernal, along U.S. Highway 80, in T.6-7S., R.24E. (SLM), Uintah County (figure 25). Access is gained via a secondary road which branches southward from U.S. Highway 40 about 3 miles (4.8 km) east of the intersection of U.S. 40 and State Highway 45. This road provides access to the northern and western portions of the deposit. Several seismic-line roads crisscross the deposit area.

Physiography and Land-Use

The deposit lies along and adjacent to a series of northwest-trending hogbacks known as Raven Ridge and Squaw Ridge that extend from the Colorado-Utah border westward to Powder Springs Wash. Elevations of bitumen-saturated outcrops range from 5,400 to 6,000 feet (1,646 to 1,829 m). The surface ownership in the area is mainly Public Land (BLM administered) with scattered State sections (SITLA administered) (figure 46). Land is used mainly for stock grazing and oil and gas development.

Geologic Setting

The Raven Ridge tar-sand deposit is located on the northern and northeastern flank of the Uinta Basin. Raven Ridge and Squaw Ridge are part of a northwest-southeast trending set of hogbacks, where Tertiary strata dip from 10 to 85 degrees southwest and average about 30 degrees southwest (figure 47). Bitumen-saturated sandstone units are primarily within Douglas Creek, Parachute Creek, and Evacuation Creek Members of the Green River Formation (Eocene) and also within the basal part of the Uinta Formation (Eocene). The Green River Formation in this area is composed of sandstone, limestone, and shale deposited mainly in shoreline and delta facies (marginal lacustrine). The Uinta Formation consists of fluvial-deltaic shales, sandstones, and pebble conglomerates with source areas to the east (Quigley, 1972).

Bitumen-saturated units in the Douglas Creek Member are exposed in the northern part of the deposit along Raven Ridge. Bitumen occurs within a zone about 90 feet (27 m) thick at the base of the Douglas Creek Member. This zone contains many thin, cross-bedded sandstone lenses, most of which are well sorted and fine to medium grained. The degree of saturation ranges from very rich to moderate, with the greatest saturation at the base of the interval.

Bitumen-saturation in the Parachute Creek Member ranges from weak to very rich. Two places are saturated: (1) patchy, weakly saturated occurrences along the Colorado-Utah border, and (2) a zone of rich saturation in the central part of the deposit along Squaw Ridge. Individual sandstone beds range between 30 and 50 feet (9-15 m) thick, while saturated zones occupy only 4 to 16 feet (1.2-5 m) of the beds. The sandstone units are all well sorted with subrounded grains ranging in size from fine to medium grained (Quigley, 1972).

Bitumen-saturated beds in the Evacuation Creek Member are discontinuous and commonly less than 4 feet (1.2 m) thick. Bitumen-saturated zones in this member extend from the central part of Squaw Ridge northeastward for about 3 miles (4.8 km) to the south side of Powder Springs Wash. The beds are fine- to very fine-grained, well-sorted sandstones, ranging from rich to weakly saturated.

Bitumen-saturated zones are rare in the Uinta Formation, but where present, typically occur near the base. These beds are commonly medium to coarse grained, well sorted, and cross stratified. Ritzma (1979) classified the deposit as "large," with 75 to 100 million barrels of bitumen in-place.

Surface mining methods may not be applicable to the Raven Ridge deposit because of steeply dipping strata and the relatively thin nature of bitumen-saturated units.

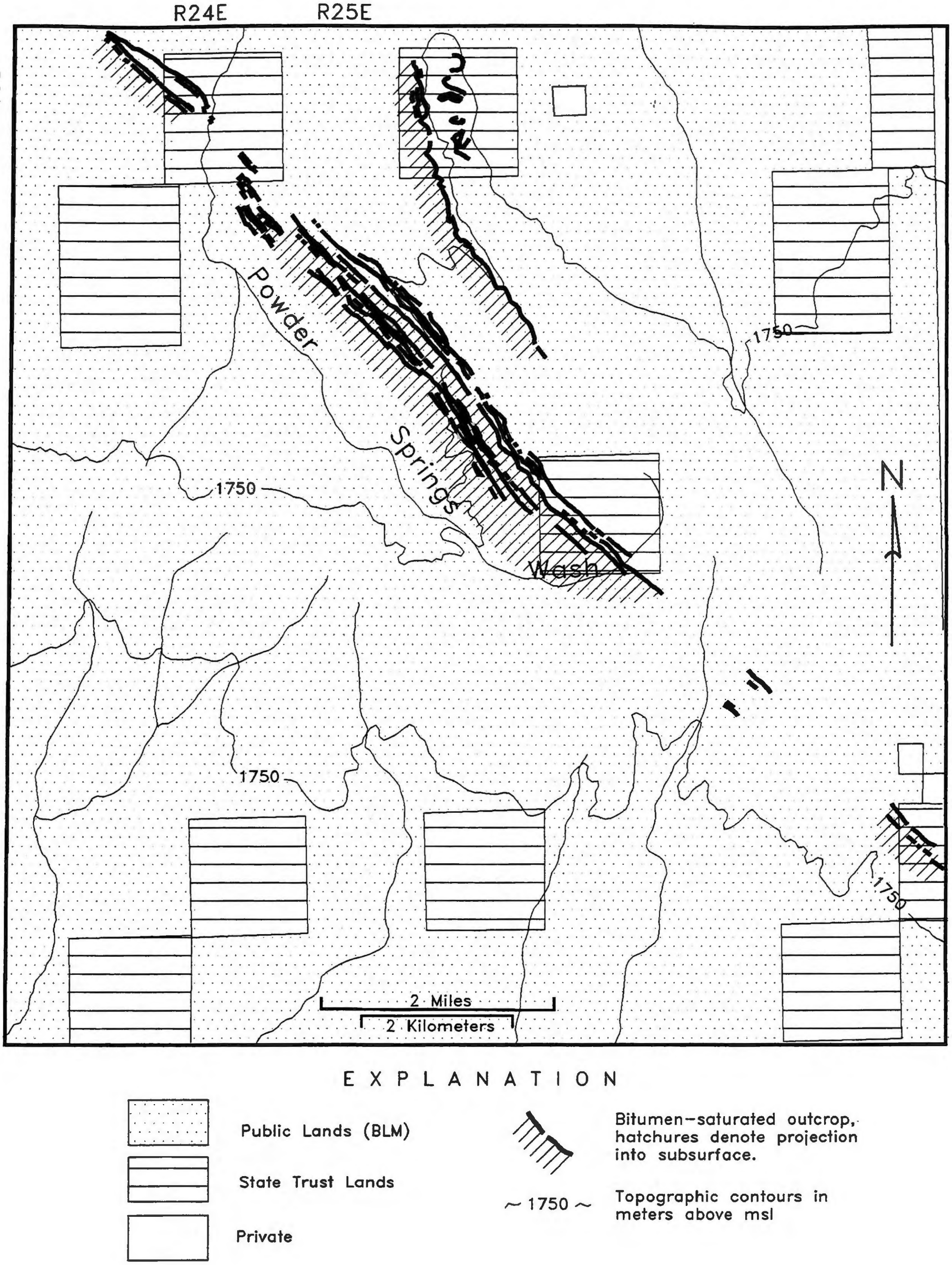
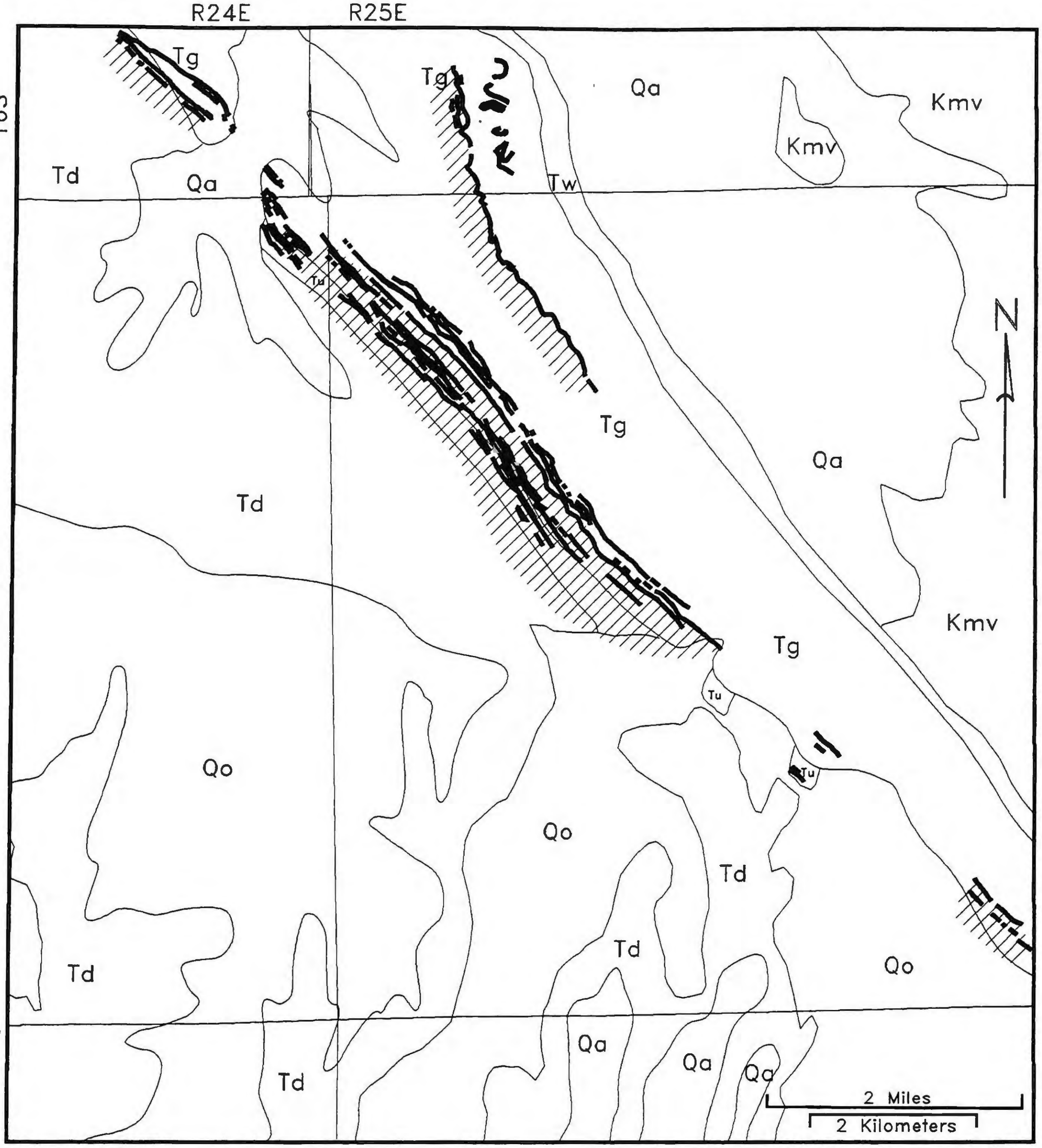


Figure 46. Land-ownership map of the Raven Ridge tar-sand deposit area.



E X P L A N A T I O N

Qa Alluvium
Qo Older alluvial deposits
Td Duchesne River Formation
Tu Uinta Formation
Tg Green River Formation
Tw Wasatch Formation
Kmv Mesaverde Group

Geologic contact

Bitumen-saturated outcrop, hatchures denote projection into subsurface.

Figure 47. General geology of the Raven Ridge tar-sand area (after Rowley and others, 1985; and Quigley, 1972).

Bitumen Analyses

Wood and Ritzma (1972) reported the results of analyses of three samples of oil extracted from the Raven Ridge tar-sand deposit (table 2). The location and description of the three samples are as follows:

Sample 67-5A is from a sandstone within the Parachute Creek Member, located in the SE¼SW¼ section 8, T.7S., R.25E.

Sample 67-8A is from a basal sandstone within the Green River Formation and in a zone of sharp flexure immediately west of Powder Springs Wash, located in the SW¼NE¼SW¼ section 25, T.6S., R.24E.

Sample 67-10A is from a sandstone from the Parachute Creek Member, located in the NW¼NE¼ section 21, T.7S., R.25E.

Development History

Ball Associates Ltd. (1964) described sporadic attempts to develop the Raven Ridge deposit principally for paving material. In the summer of 1980, Western Tar Sands, Inc. tested strip-mining of a 22-foot, saturated sandstone zone within a 23-acre site in section 15, T.7S., R.24E. Results from this test-mining indicated that bitumen reserves were 348,000 barrels within the test site (Anonymous, 1981). The company planned to build a 100 BPD pilot plant for the extraction of oil from the site using a patented process, but, the plant was never built.

Occurrences of the oil sands in the area from Asphalt Ridge to Raven Ridge were instrumental in triggering exploration that led to the discovery of petroleum in the Green River Formation in the Red Wash oil and gas field located a few miles to the southwest (Koesoemadinata, 1970).

Rimrock

Location and Access

The Rimrock tar-sand deposit is exposed along the Raven Ridge-Asphalt Ridge trend of hogbacks between the Raven Ridge and Cow Wash deposits (figure 25). The deposit is located in T.6S., R.24E., sections 22, 23, 25, and 26 (SLM), Uintah County. The Rimrock deposit has also been referred to as the Northwest Raven Ridge deposit. U.S. Highway 40 and State Route 45 provide access to the area, located about 20 miles (32 km) southeast of the town of Vernal. From the junction of US-40 and SR-45, the area lies south along SR-45 about 1.5 miles (2.4 km) and northwest about 1 mile (1.6 km) along powerline and pipeline access roads.

The Rimrock deposit is one of several "minor" deposits located in the area between the Asphalt Ridge and Raven Ridge deposits. Occurrence of these tar-sand deposits helped lead to the discovery of Green River Formation petroleum in the Red Wash oil and gas field located a few miles to the southwest.

Physiography and Land Use

The deposit lies at the east end of a number of low-lying, west-northwest-trending hogbacks collectively called the Rim Rock that extend from Powder Springs Wash westward to upper Kane Hollow. The Rimrock, Cow Wash, and upper Kane Hollow tar-sand deposits occur along this trend. Elevations of bitumen-saturated outcrops lie at about 5,400 feet (1,646 m). The surface ownership in the area (figure 48) is mainly Public Land (BLM administered) with scattered State school sections (SITLA administered). A contiguous tract of 640 acres of private land is situated within 1 mile (1.6 km) northeast of the deposit. Land is used mainly for stock grazing and oil and gas development.

Geologic Setting

The Rimrock tar-sand deposit consists of numerous beds of bitumen-saturated sandstone that crop out for about 2 miles (3.2 km) in a southeast alignment between Pole Line Wash and Powder Springs Wash (figure 49). The area is along the northeast flank of the Uinta Basin in a belt of southwest-dipping beds that mark the basin margin. Beds of the Parachute Creek and Douglas Creek Members of the Green River Formation and the Wasatch Formation dip up to 67 degrees southwest toward the basin axis. The Parachute Creek Member overlaps and truncates the Douglas Creek Member with angular discordance. Similarly, the Douglas Creek Member overlaps and truncates the Wasatch Formation. Wasatch strata dip more steeply toward the center of the basin than the Green River strata.

Bitumen is localized in units of the Wasatch Formation and in Green River sandstones that truncate underlying Wasatch strata. Bitumen is primarily contained in lenticular sandstones within a 90 foot interval above the base of the Douglas Creek Member of the Green River Formation. Degree of saturation ranges from very rich to moderate, and saturated units are exposed for a distance of 0.75 mile (1.2 km). The saturated sandstone units are commonly thin, blocky, and cross-stratified. Grain sizes range from fine to medium, and most of the sandstones in the interval are well sorted (Quigley, 1972). Ritzma (1979) classified the deposit as large, with an estimated total resource of 25 to 30 million barrels.

Bitumen Analyses

Bitumen in the Rimrock deposit has similar chemical characteristics to oil extracted from lacustrine shale of the upper part of the Wasatch Formation. Sulfur isotope data show that Rimrock oil is very similar to other Tertiary-age, north rim deposits, except Raven Ridge, Asphalt Ridge, and Whiterocks (Mauger and others, 1973). Hydrocarbons evidently moved updip within sand units of the Wasatch Formation and then spread laterally through lower Green River units.

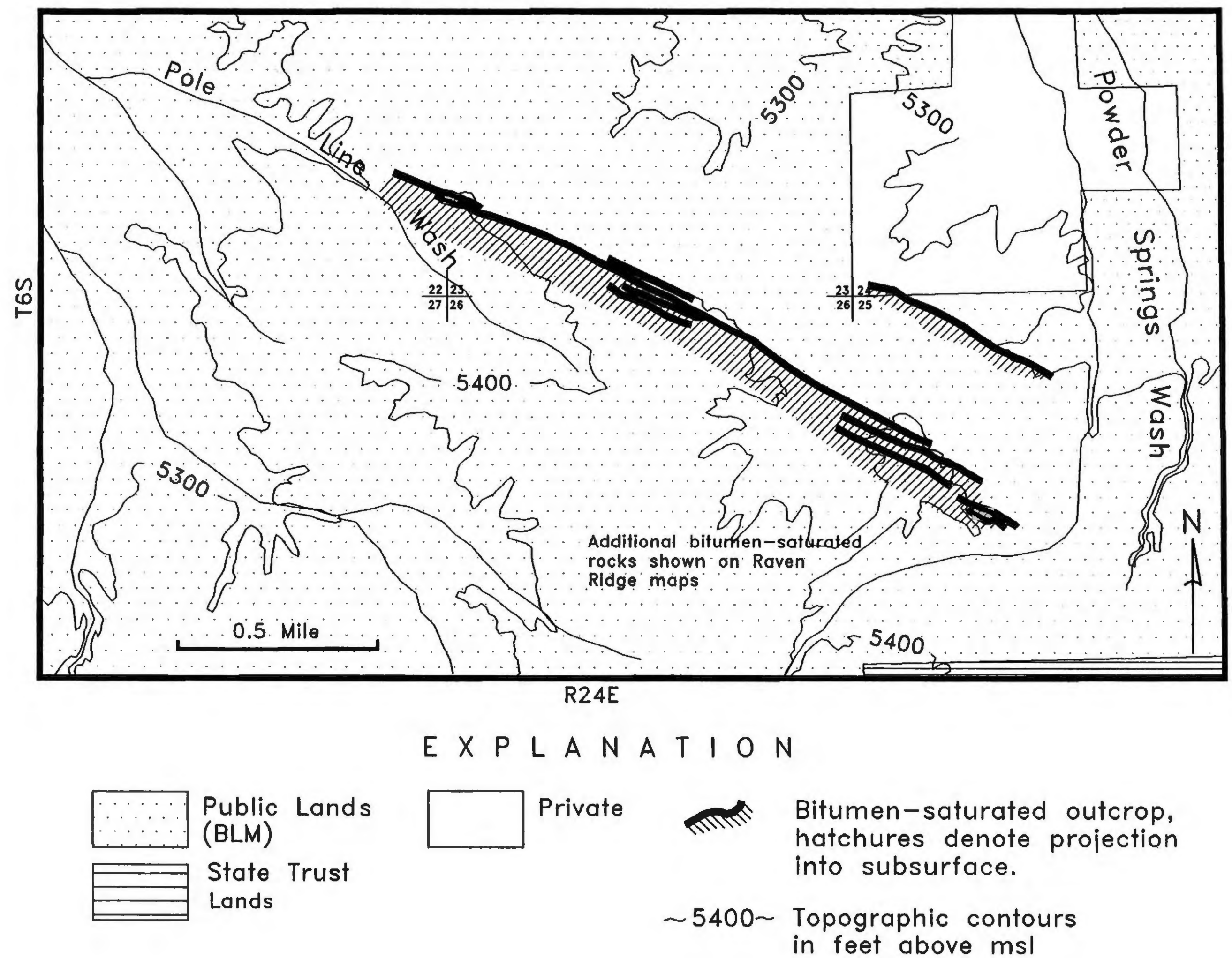
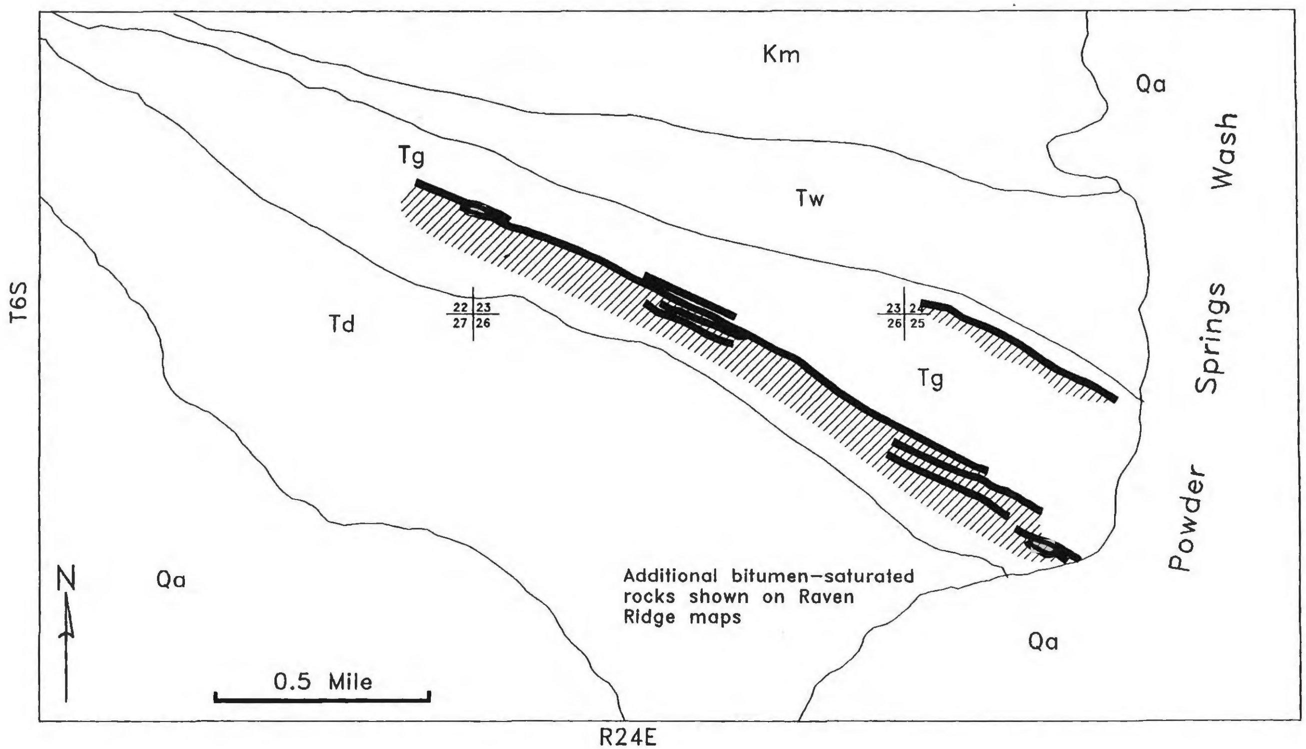


Figure 48. *Land-ownership map of the Rimrock tar-sand deposit area.*



EXPLANATION

Qa Alluvium

Td Duchesne River Formation

Tg Green River Formation

Tw Wasatch Formation

Km Mancos Shale

Bitumen-saturated outcrop, hatchures denote projection into subsurface.

Geologic contact

Figure 49. *General geology of the Rimrock tar-sand area (after Rowley and others, 1985; tar-sand outcrops from unpublished UGS file data).*

Extracted oil has been analyzed by fractional distillation methods (Wood and Ritzma, 1972) and for sulfur isotopes (Mauger and others, 1973). Wood and Ritzma (1972) reported analytical results of four samples from the Rimrock area. The analyses are shown on table 2 and the locations of the samples are listed below.

Sample 67-4A is from the Wasatch Formation in the center of NE¼NE¼ of section 26.

Sample 67-6A is from the SE¼SE¼SW¼ of section 23.

Sample 67-7A is from the upper part of the Green River Formation occurrence, and is from the SE¼SE¼SW¼ section 23.

Sample 67-9A is from the Wasatch Formation in the north half of SE¼SE¼NW¼ of section 25.

Split Mountain

Location and Access

The Split Mountain tar-sand occurrences are located 1 to 3 miles (1.6-4.8 km) west-northwest of the Split Mountain Campground in Dinosaur National Monument. Bitumen-saturated outcrops are located in the S½SW¼ section 24; the NW¼NE¼ section 25; and the center and E½SE¼ section 23, T.4S., R.23E.; and in the W½NW¼ section 30, T.4S., R.24E. (SLM), Uintah County (figure 25). Access is by foot trail northwest from the campground along Cottonwood Wash and Red Wash, and then northward along narrow canyon-bottoms that issue off Split Mountain. The dinosaur quarry from which the monument is named is about 1.1 miles (1.8 km) southwest.

Physiography and Land Use

The tar-sand occurrence lies entirely within Dinosaur National Monument on the southwest flank of Split Mountain. The area is characterized by deeply incised canyons and flatirons along the plunging west end of the Split Mountain anticline. The Green River, a major tributary of the Colorado River system, flows through Split Mountain Canyon less than 1 mile (1.6 km) to the east. The tar-sand occurrences lie entirely within Dinosaur National Monument on land administered by the National Park Service.

Geologic Setting

Isolated, bitumen-saturated outcrops are within the Park City Formation (Permian) along rugged flatirons caused by deeply incised canyons that cross-cut the formation (figure 50). The Park City Formation rests conformably upon the Weber Sandstone (Permian-Pennsylvanian).

The Split Mountain tar-sand occurrences are located on the plunging west end, south flank of the Split Mountain anticline, an east-west trending fold lying south of and parallel to the Uinta Mountain arch. On the southwest flank in the occurrence area, the Park City Formation dips from 65 to 72 degrees south-southwest (Untermann and Untermann, 1954).

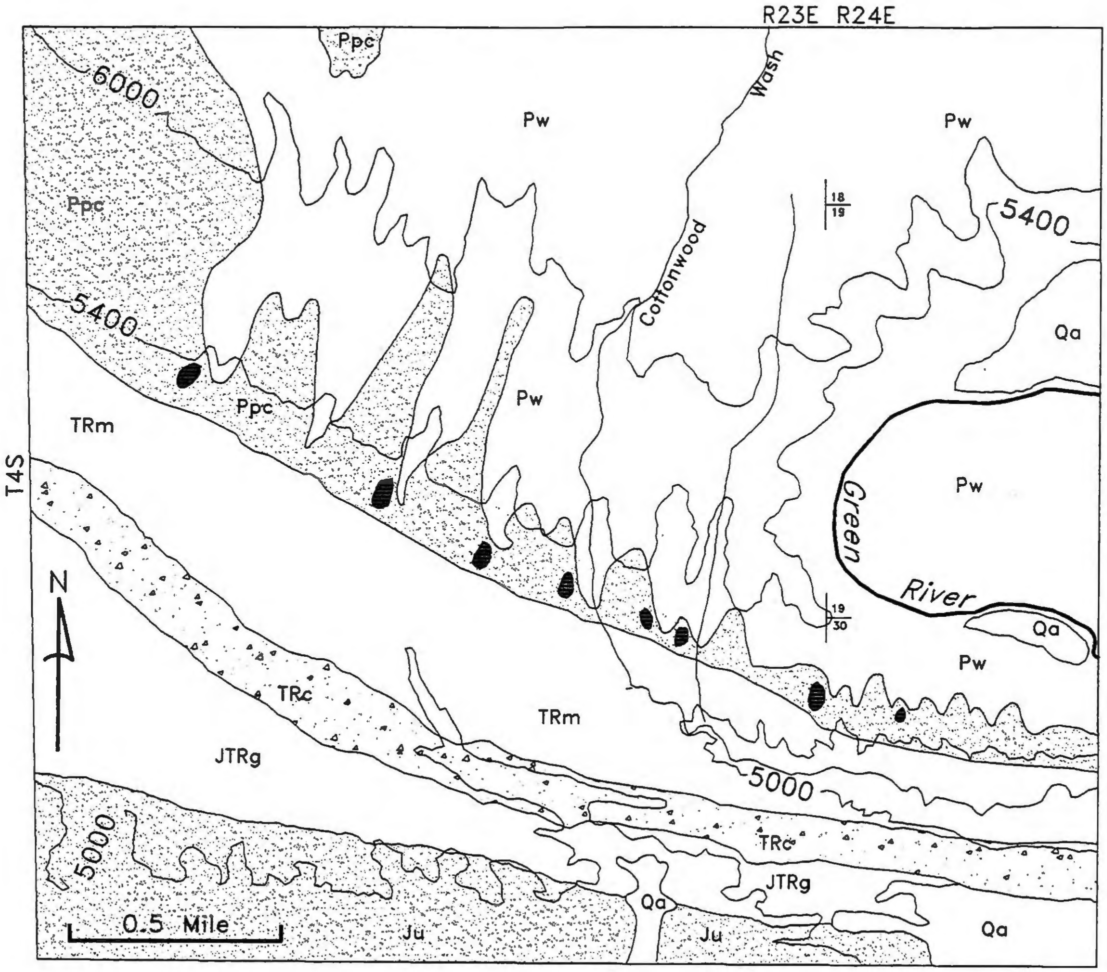
Bitumen-saturated, platy limestone from 2 to 3 feet (0.6-0.9 m) thick occurs immediately beneath the Moenkopi Formation (Triassic). Because of irregularities along the unconformable Park City-Moenkopi contact, the bitumen may occur as much as 10 feet (3 m) below the Moenkopi or may be cut out by erosion.

Bitumen is commonly found saturating pods of coarsely crystalline, vugular limestone developed roughly parallel to the bedding planes of the Park City Formation. Where it is not bitumen-saturated, the Park City Formation emits a petroliferous odor on fresh fractures. Crystalline masses and vugs are heavily stained with viscous, fresh oil with a strong oily, sulfurous odor. Sandstones in the Moenkopi Formation immediately above the Park City are also lightly and spottily stained with oil, and the beds are tan in color suggesting that the hydrocarbons have altered the rock from its normal red color. Spotty impregnation of oil is also found in a few limestone beds in the lower Park City Formation, but the oil is dead and where found in vugs disintegrates to powder (K. Clem, unpublished data).

Total thickness of the Park City in the area of the deposit ranges from 50 to 60 feet (15-18 m) with most of the variation occurring at the irregular upper contact. Regionally the Park City Formation thins from west to east across this area. The unit in which the deposit occurs thins gradually from west to east and pinches out between the deposit area and Split Mountain Canyon to the east. To the west the unit grades into dense, sandy, nonpetroliferous limestone. The lateral extent of the deposit is about 1.8 miles (2.9 km) (K. Clem, unpublished data).

Bitumen Analyses

Wood and Ritzma (1972) reported the results of analysis of one sample of bitumen (table 2; sample no. 68-17D) collected from the Split Mountain tar-sand occurrence. Of particular interest is the high sulfur content (2.94 percent), which contrasts with an average of 0.4 percent sulfur for bitumen extracted from deposits in Tertiary formations or for bitumen migrated from Tertiary rocks to older formations. Moreover, bitumen from this occurrence is much more sulfurous than that produced from the Weber Sandstone (Permian-Pennsylvanian; 0.83 percent) in the



EXPLANATION

Qa	Alluvium	TRm	Moenkopi Formation
Ju	Jurassic undivided	Ppc	Park City Formation
JTRg	Glen Canyon Sandstone	Pw	Weber Sandstone
TRc	Chinle Formation		

Bitumen–saturated outcrop

Geologic contact

5000 Topographic contours in feet above msl

Figure 50. *General geology of the Split Mountain tar-sand area (after Rowley and others, 1979; tar-sand outcrops from K. Clem, unpublished data).*

Ashley Valley field located 10 miles (16 km) to the southwest and in the Rangely field in Colorado located 30 miles (48 km) to the southeast (0.72 percent).

The Split Mountain deposit, although of minor importance, was studied and sampled carefully because it appears to contain the only indigenous Permian or (Paleozoic) crude oil of all Uinta Basin tar-sand deposits.

Development History

No attempt has been made to develop this deposit. The presence of oil in outcrops of the Park City Formation here and elsewhere in northeast Utah has encouraged drilling for oil and gas in the Weber Sandstone along the Ashley Valley-Rangely trend.

Spring Branch

Location and Access

The Spring Branch deposit is located on the north flank of the Uinta Basin, about 20 miles (32 km) northeast of the town of Roosevelt in sections 13 and 24, T.2N., R.3W., (USM), Duchesne County. The deposit lies near the headwaters of Spring Branch Creek (figure 25). The elevation of the deposit is about 8,600 feet (2,621 m).

Hiking trails provide the only access, as the closest maintained road is 2 miles (3.2 km) to the south. This county road connects the communities of Altonah and Neola with the turnoff to Spring Branch approximately halfway between the two towns.

Physiography and Land-Use

The Spring Branch deposit is situated along the marginal benches subsection of the Uinta Basin along the southern flank of the Uinta Mountains. The area is entirely enclosed within the Uintah and Ouray Reservation. The Reservation boundary with the Ashley National Forest lies 3 miles (5 km) north of the deposit. The area is mountainous, forested terrain used mainly for summer-range livestock grazing.

Geologic Setting

The Spring Branch deposit is located on the northern flank of the Uinta Basin, and consists of one exposure of bitumen-saturated rocks within the Upper Eocene Duchesne River Formation (figure 51). The Duchesne River Formation in this area is composed of fluvial sandstone and conglomerate.

A small-displacement reverse fault, which crosscuts the deposit, may have controlled the accumulation of bitumen. The fault is oriented northeast-southwest, and is traceable for about 1,000 feet (305 m). Clem (unpublished data) suggested that the fault displaces the Duchesne River Formation probably more than 200 feet (60 m); however, he could trace no mappable units across the fault. The hanging-wall block is on the northwest side of the fault, and the fault plane dips about 80 degrees to the northwest.

Located within the Duchesne River Formation (Eocene), bitumen is in two zones, separated by the reverse fault. The host strata southeast of the fault is sandstone, while the host strata on the northwest side of the fault is mainly conglomerate. The bitumen-saturated zone on the southeast side of the fault is 180 to 200 feet (55-61 m) thick, while the saturated zone on the northwest side is 50 to 60 feet (15-18 m) thick. Saturation along the fault zone is very rich and small seeps along the trace ooze oil (K. Clem, unpublished data).

Ritzma (1979) classified the deposit as "medium-small," and estimated that 1.5 to 2 million barrels of oil are in-place.

Bitumen Analyses

Wood and Ritzma (1972) and Mauger and others (1973) reported analyses of oil extracted from the deposit (table 2). Sample 68-23D was taken from sandstone in the footwall (southeast side) of the fault, located in the NE¼NE¼NW¼ section 24. Sample 69-24D was taken from a conglomeratic sandstone in the hanging-wall of the fault, located in the NE¼NE¼NW¼ section 24.

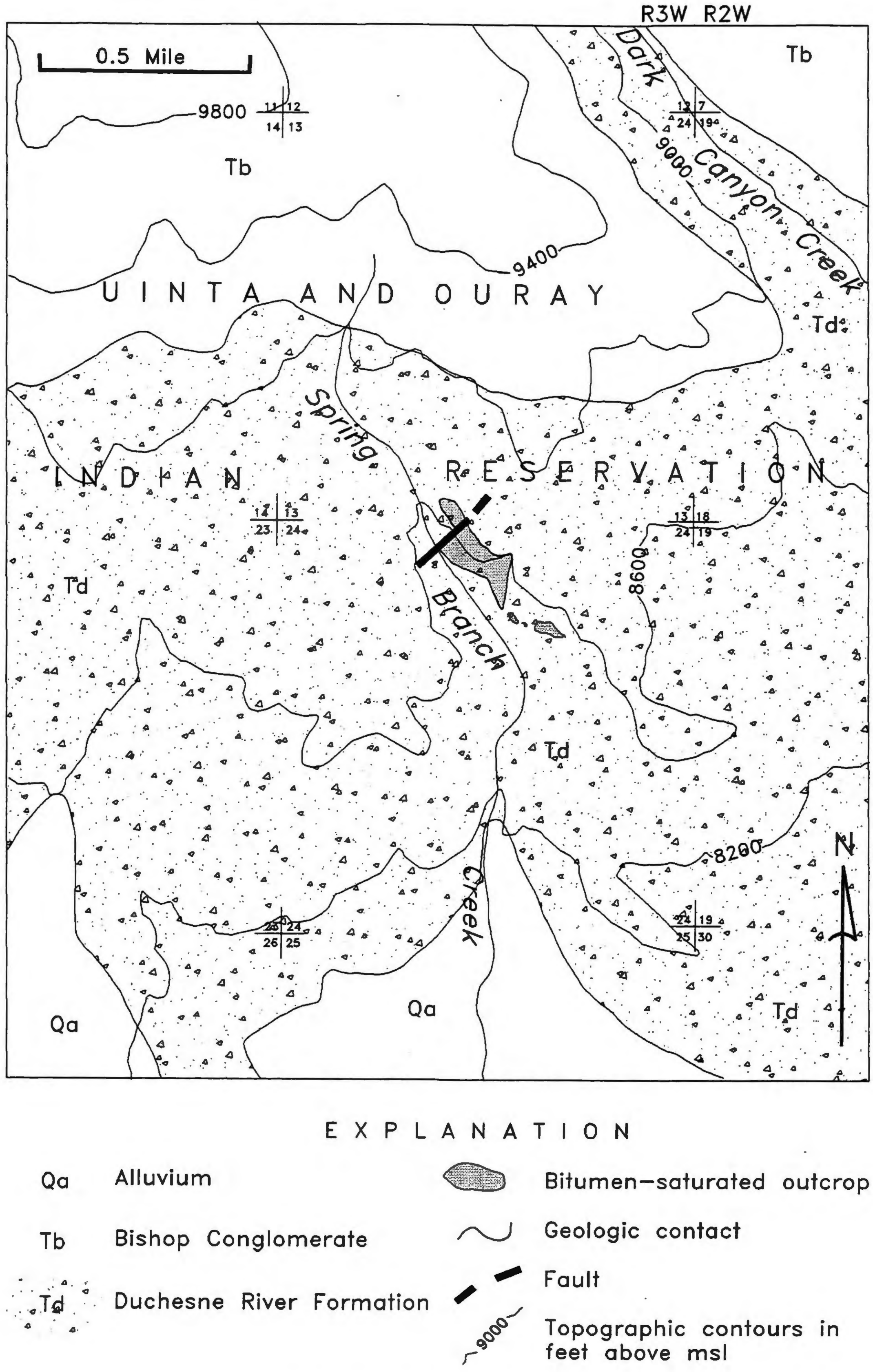


Figure 51. General geology of the Spring Branch tar-sand area (after Bryant, 1992; tar-sand outcrops from K. Clem, unpublished data).

Spring Hollow

Location and Access

The Spring Hollow tar-sand deposit consists of two small isolated outcrops of oil-impregnated sandstone, positioned halfway between the southeastern end of the Asphalt Ridge deposit and the Upper Kane Hollow deposit (figure 25). The deposit is within Spring Hollow, a minor tributary of the Green River, located about five miles south of the town of Jensen in section 18, T.6S., R.26E., and in section 13, T.6S., R.22E. (SLM), Uintah County. Access is by way of a county road southwest from Jensen for about 6 miles (9.6 km), then east along an agricultural road for less than 0.5 mile (0.8 km).

Physiography and Land-Use

The deposit is situated less than 1 mile (1.6 km) east of the Green River, a major tributary of the Colorado River, which meanders generally northeast to southwest along its course. Low-lying hills and valleys compose the landscape elsewhere. Along and adjacent to the course of the Green River, land is mainly irrigated cropland mostly in private ownership. Northwest of the Green River, SITLA administers a large, contiguous tract of state land that adjoins the Asphalt Ridge tar-sand deposit area. East of the Green River, land-ownership is primarily Public Land administered by the BLM and scattered school sections administered by SITLA.

Geologic Setting

Untermann and Untermann (1964) mapped the rocks in the deposit area as the Uinta Formation (Eocene), which overlies the Mesaverde Group (Cretaceous) with angular discordance. Ritzma (1979), however, listed the deposit as hosted by the Duchesne River Formation (Eocene), which is similar in character but overlies the Uinta Formation. Figure 52 illustrates the geologic interpretation of Rowley and others (1985). A few miles east of Spring Hollow, the Uinta Formation rests atop the Green River Formation (Eocene), which unconformably overlies the Mesaverde Group. The deposit area is situated less than a mile northeast of the axis of the Uinta Basin syncline. Untermann and Untermann (1964) projected the Uinta and Green River Formations in this area to be more than 6,000 feet (1,829 m) thick.

Bitumen has saturated either the basal part of the Duchesne River Formation or the Uinta Formation and near the trace of a small-displacement fault (K. Clem, unpublished data). Ritzma (1979) classified this deposit as "minor," and did not estimate resources.

Bitumen Analyses

Wood and Ritzma (1972) and Mauger and others (1973) reported the results of analyses on samples from the Spring Hollow deposit. Although Untermann and Untermann (1964) mapped the area as Uinta Formation, Wood and Ritzma (1972) reported that sample 68-18D (table 2) was collected in a fault zone from sandstone of the Duchesne River Formation in the center of the SE¼ section 18, T.6S., R.23E.

Development History

There has been no known exploration or attempt at development of this deposit. The Spring Hollow deposit is one of several "minor" deposits located in the area between Asphalt Ridge and Raven Ridge deposits. Occurrences of these oil sands were instrumental in triggering exploration that led to the discovery of petroleum in the Green River Formation in the Red Wash field 6 miles (9.6 km) to the southeast.

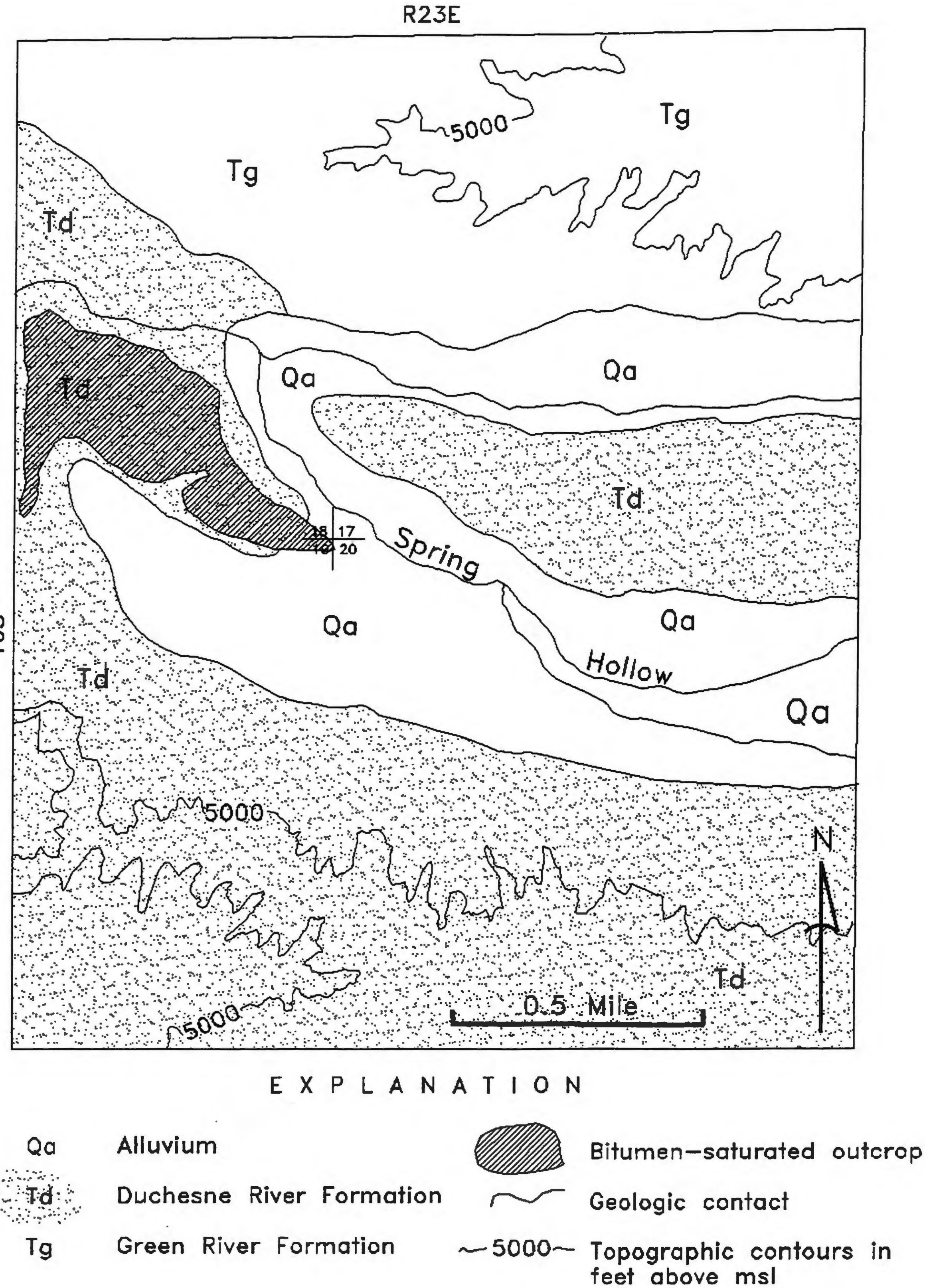


Figure 52. *General geology of the Spring Hollow tar-sand area (after Rowley and others, 1985; tar-sand outcrops from unpublished UGS file data).*

Tabiona

Location and Access

The Tabiona deposit lies on the northern flank of the Uinta Basin, and is about 2.5 miles (4 km) north of the town of Tabiona (figure 25). The deposit consists of two separate areas; one area is located near the head of a small canyon off of Little Valley, and the other near the bottom of Little Valley. The deposit is located in the SE¼ section 16 and S½S½ section 17, T.1S., R.7W., (USM), Duchesne County.

Access to the area is gained from State Highway 35 about 2 miles (3.2 km) northwest of the town of Tabiona. From here, travel is by unimproved roads and trails for 1 to 2 miles (1.6-3.2 km) east from SR-35.

Physiography and Land-Use

Bitumen-saturated outcrops are found in rugged and wooded terrain within the marginal benches subsection of the Uinta Mountains physiographic province. Outcrops in the eastern area are in a narrow, heavily wooded canyon between 7,150 and 7,400 feet (2,179-2,256 m) elevation, and are about 0.7 miles (1.1 km) from the nearest 4-wheel-drive access road. The western outcrops are in open, brush-covered terrain at about 7,000 feet (2,134 m) elevation, and are generally along the north face of an east-west trending ridge along the north side of Little Valley. Lands involved are part of the Indian Lands within the Uinta and Ouray Indian Reservation. Total surface area for both parts of the deposit is less than 0.5 square mile (1.3 km^2).

Geologic Setting

The deposit is located along the northern margin of the Uinta Basin in a belt of south-dipping beds that mark the basin margin. The Mesaverde Group (Upper Cretaceous), which crops out about one mile (1.6 km) north of the deposits, dips 45 to 50 degrees southward (figure 53). The Current Creek Formation (Tertiary-Cretaceous) overlies the Mesaverde Group, and the Duchesne River Formation (Eocene) lies unconformably above the Current Creek Formation. The Current Creek dips 26 degrees southward. Bedding attitudes generally flatten through successively younger formations southward toward the center of the basin.

Bitumen-saturated rocks are in the Current Creek and Duchesne River Formations in the two areas. The eastern part of the deposit is in the Current Creek Formation at the north end of a short lineament traceable on aerial photographs from Tonigut Spring in the NE¼SW¼ section 23, and trending N.60°W. through a spring near the SW corner of section 15. Garvin (1969) noted anomalous steep dips and fracturing in the deposit area. Part of this deposit occurs along the contact between the Current Creek and Duchesne River Formations. Average difference in dip between the Currant Creek and Duchesne River Formations is between 10 and 15 degrees. At the intersection of the lineament with the unconformable contact, however, near-vertical Current Creek rocks are overlapped by Duchesne River rocks that dip southward 30 degrees. Garvin (1969) suggested the lineament appears to be the surface expression of deep-seated faulting.

The eastern part is near the bottom of a narrow, unnamed canyon where steeply dipping sandstones of the Currant Creek Formation are impregnated with yellow-brown, waxy oil. The sandstones are fine to medium grained, friable, porous, and weather to a light gray and tan color. The sandstone is moderately saturated, yellow-brown, and has a strong odor of oil on fresh fractures. Bitumen is spotty and decreases away from fractured zones. Clay-gouge in zones of small-scale faulting is normally unsaturated. Fractures and bedding planes appear to be the principal conduits for migration of the oil.

Bitumen extends upward from Currant Creek sandstones into the basal sandstone of the Duchesne River Formation [previously called the Uinta Formation by Garvin, (1969)]. Bitumen-saturation in the Duchesne River sandstones ranges from moderate to very rich and continues upward to the top of the canyon wall where the Duchesne River Formation is capped by unconformable coarse conglomerate, probably Bishop Conglomerate.

Basal sandstone units of the Duchesne River Formation are saturated for about 1,000 feet (305 m) east to west along the outcrop and for 100 to 150 feet (30-45 m) above the base of the formation. The lateral limits of the deposits are sharp. In contrast to the Currant Creek Formation occurrence, bitumen in the Duchesne River is black, less waxy, volatile, and imparts a tough, rubbery cement to the otherwise friable sandstone. Tar sands in the Duchesne River are medium to coarse grained and contain lenses of coarse sandstone and conglomerate.

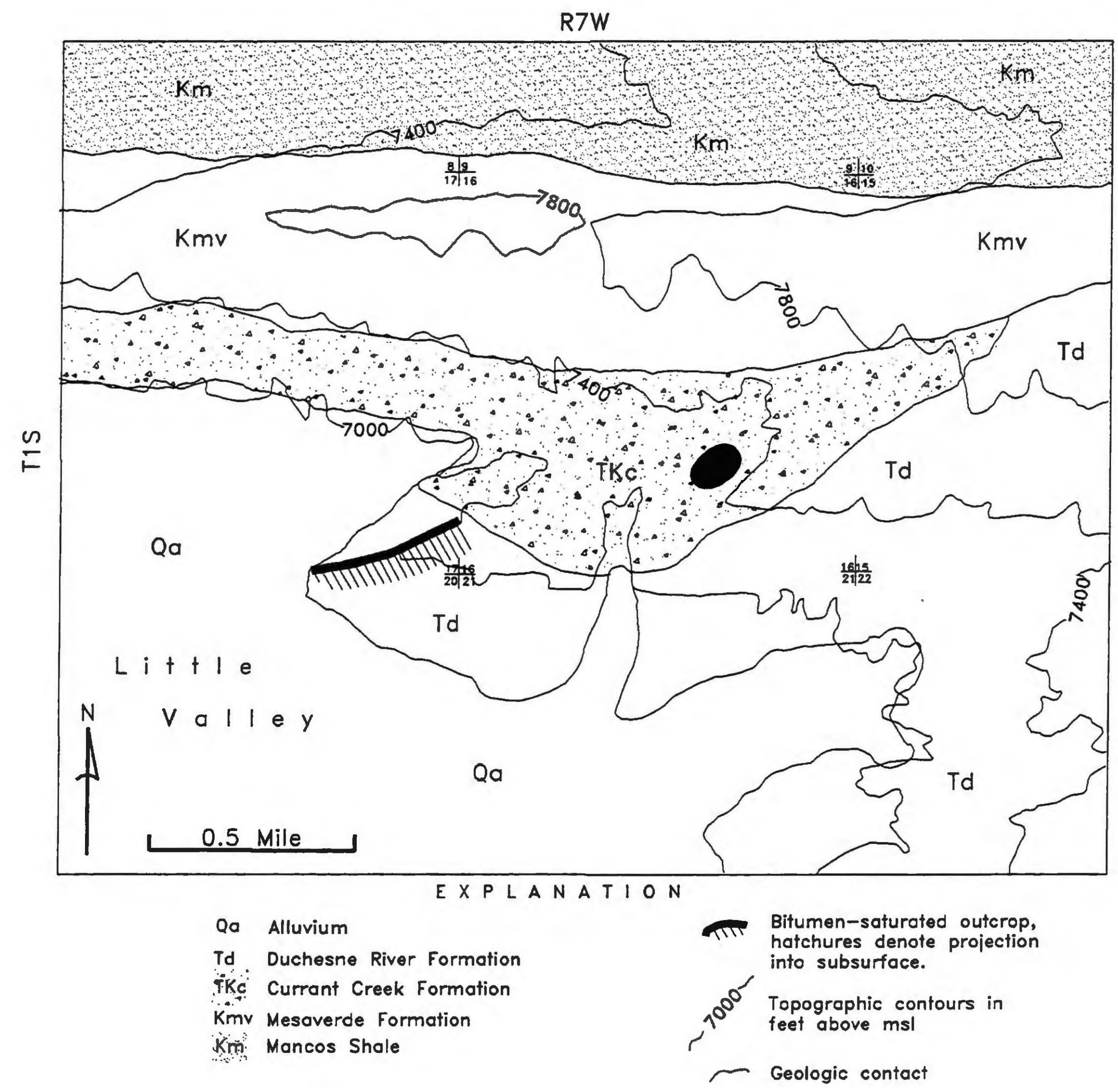


Figure 53. *General geology of the Tabiona tar-sand deposit (after Bryant, 1992; tar-sand outcrops from K. Clem, unpublished data).*

Tar sands crop out in the western part of the deposit along the north face of a ridge of south-dipping Duchesne River sandstone. Bitumen occurs in three zones, about 85 feet thick (26 m), of alternating sandstone, siltstone, and shale. Bitumen is more persistent in the lower two zones, which comprise about 45 feet (14 m) of the section. In friable, porous sandstones the rock is deeply weathered and dry. The lithified zones are more saturated and show sheens of liquid oil on fresh fractures. Conglomerate lenses in the upper zone contain cobbles and pebbles of sandy limestone with vugs filled with bitumen. In the western part of the deposit, no bitumen was found in the Currant Creek Formation where it is exposed below the Duchesne River Formation. The deposit is mostly in fine- to coarse-grained sandstone and conglomerate.

Ritzma (1979) estimated that 1.3 million barrels of oil are contained in both eastern and western deposits.

Bitumen Analyses

Wood and Ritzma (1972) reported the results of analyses of three bitumen samples from different parts of the deposit (table 2). API gravity ranged from 4.9 to 9.8 and sulfur contents ranged from 0.20 to 0.29 percent. Sulfur isotope analysis of one sample yielded a value for $\delta^{34}S$ of +5.9 permil (Mauger and others, 1973).

Development History

The Tabiona deposit is an important occurrence in the context of migration and entrapment of oil. Presence of a possible trap of live oil in the subsurface has also attracted interest as a possible exploration target. No exploration or development, however, has taken place for the tar-sand resource.

Thistle Area

Location and Access

The Thistle tar-sand deposit consists of two areas of bitumen-saturated outcrops, located about 2 miles (3.2 km) apart and separated by Spanish Fork Canyon (figures 25 and 54). The locality is named for a small town in the southern part of Utah County which was destroyed in 1983 by a flood caused by a landslide-dam near the confluence of Thistle and Soldier Creeks. The northern tar-sand outcrop area is in sections 26-28, T.9S., R.4E. The southern tar-sand outcrop area is in sections 3, 4, 9, and 10, T.10S., R.4E. In the northern area the tar-sand outcrops extend east-west for 1.3 miles (2 km) along the north wall of the canyon within one mile (1.6 km) of U.S. Highway 6 and a main line of the Denver and Rio Grande Western Railroad. In the southern area, bitumen-saturated outcrops extend from high ledges along the west side of Lake Fork Canyon northward, then southwestward in Wildcat Canyon. Access to the two areas is by Jeep trails and foot paths from U.S. Highway 6.

Peterson and Ritzma (1972) briefly discuss tar-sand deposits at Oil Hollow, a tributary to upper Lake Fork Creek where small exposures of bitumen-saturated sandstone crops out at the head of the tributary. This occurrence, described earlier in this report, is located about 6 miles (9.6 km) southeast of the confluence of Soldier Creek (Spanish Fork Canyon) and Lake Fork Creek.

Physiography and Land-Use

The area is mountainous, situated near the southern margin of the Middle Rocky Mountains physiographic province. Elevations in the northern outcrop area are around 5,800 feet (1,768 m). Elevations of the southern outcrops range from 5,600 to about 6,300 feet (1,707-1,920 m), since the exposure wraps around an unnamed mountain that has a peak elevation of 6,614 feet (2,016 m).

Along the northern outcrops, land ownership is a combination of private lands and federal lands managed by the USDA Forest Service, Uinta National Forest. In the southern outcrop area, the surface ownership is mostly private, but the Federal Government has reserved a patchwork of mineral ownership. The boundary of the Manti-La Sal National Forest lies 1 to 2 miles (1.6-3.2 km) southeast of the southern outcrop area (figure 54). Private land in the area is used for summer home sites and grazing. National Forest lands are typically used for summer-range grazing and for harvesting wood products.

Geologic Setting

Pinnell (1972) mapped the surface geology in the area surrounding the deposits and described the geologic units. Peterson and Ritzma (1972) studied the deposit(s) and reported some analytical results. The deposit is located in complex geologic terrain on the east (leading) edge of the Sevier orogenic belt where Mesozoic and older formations were thrust upon younger rocks along the southwest margin of the Uinta Basin during the Cretaceous Period. The North Horn, and Flagstaff Formations (latest Cretaceous-Paleocene), rest unconformably on the Price River Formation, which in-turn rests unconformably on highly folded and faulted Cretaceous and Jurassic rocks. The post-Sevier formations (North Horn and Flagstaff Formations), which were deposited against and across rocks of the overthrust complex, are much less deformed.

The northern area tar-sand deposit (figure 55) is in a group of fairly continuous lacustrine, sandstone lenses within the Flagstaff Formation that extend along a sinuous outcrop for 1.8 miles (2.9 km). Bitumen also occurs in interbedded oolitic limestone that grades laterally and vertically into sandstone. High-angle faults truncate this deposit on both east and west sides, although some bitumen persists across the west bounding fault into section 28. The bitumen-saturated zone is about 70 feet thick (21 m) on the west side, and 50 feet (15 m) thick on the east side. Four small-displacement faults cut the bitumen-saturated beds (Peterson and Ritzma, 1972).

In the southern part of the deposit (Asphaltum mine), the bitumen-saturated zone crops out for a distance of about 2 miles (3.2 km), curving from east to west around the flanks of a mountain and following a dip-slope within the Flagstaff Formation. The saturated zone is about 20 feet (6.1 m) thick on the northern tip of the mountain and thins to a feather edge about 1 mile (1.6 km) south in Wildcat Canyon. The lithology of the bitumen-saturated zone in the lower part of the Flagstaff Formation is similar to that of the northern area. The outcrops are mostly concealed beneath vegetation; only a few good exposures are observed in and near old adits. Pinnell (1972) mapped

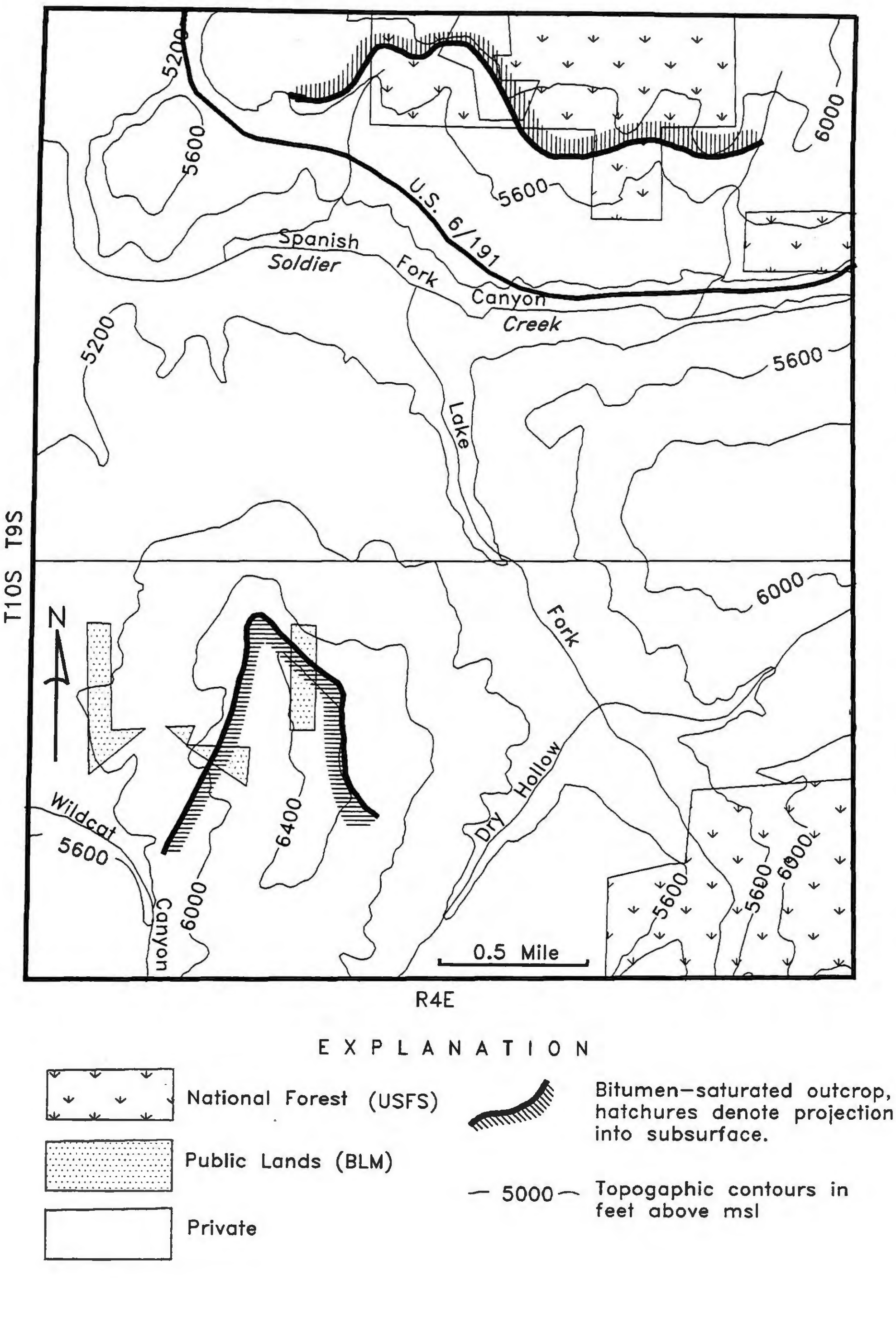
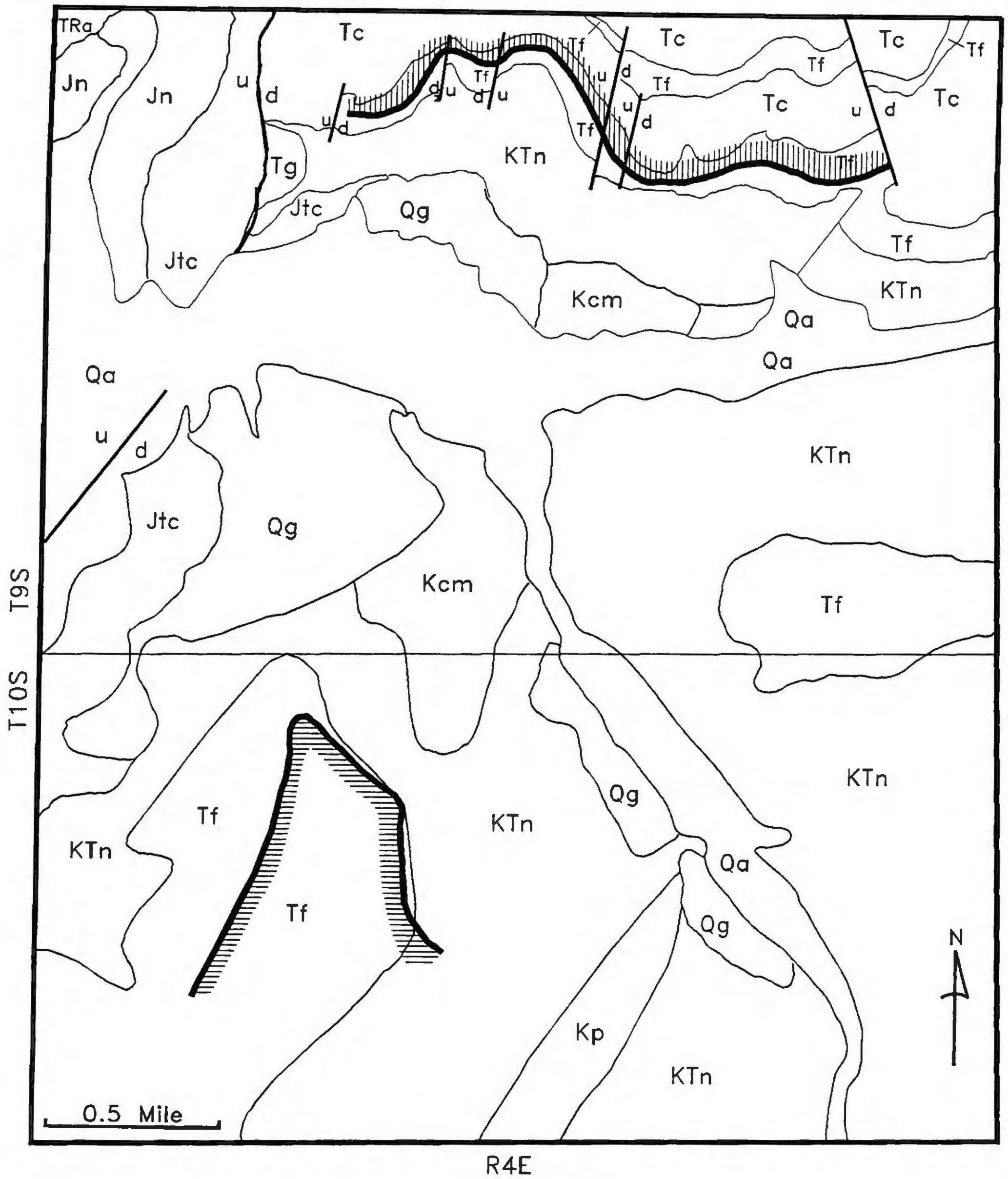


Figure 54. Land-ownership map of the Thistle tar-sand deposit area.



EXPLANATION

Qa	Alluvium	Kp	Price River Formation
Qg	Terrace gravel	Ki	Indianola Group
Tg	Green River Formation	Kcm	Cedar Mountain Formation
Tc	Colton Formation	Jtc	Twin Creek Limestone
Tf	Flagstaff Formation	Jn	Nugget Sandstone
KTn	North Horn Formation	TRa	Ankareh Shale

Bitumen-saturated outcrop, hatchures denote projection into subsurface.

Geologic contact

Fault

Figure 55. *General geology of the Thistle tar-sand area (after Pinnell, 1972; and Young, 1976; tar-sand outcrops after Peterson and Ritzma, 1972).*

the area surrounding the Oil Hollow occurrences as Green River Formation (Eocene) within the footwall of the Martin Mountain Fault.

The most common reservoir rock is calcareous sandstone which tends to be medium to coarse grained, well sorted, and porous. Interbedded with the sandstone is oolitic coquina containing fossil snails and clams, and oolitic, sandy limestone.

Ritzma (1979) estimated the resource for both northern and southern deposits between 2.2 and 2.5 million barrels, and included Oil Hollow in this estimate.

Bitumen Analyses

Peterson and Ritzma (1972) reported the results of analyses of a bitumen sample collected from the Asphaltum mine (table 2). The material yielded nearly 15 percent bitumen by weight, with sulfur content of 1.07 percent.

Development History

Peterson and Ritzma (1972) describe prospect pits, adits, haulage roads, and loading facilities at the Asphaltum mine. They also reported that the material was used extensively for paving streets in Utah towns, but cited no reference for this information. More recent reconnaissance, however, shows little evidence today of past tar-sand mining, possibly due to considerably more vegetative cover (C. Bishop, UGS, verbal communication, January 1996). At Oil Hollow, they reported an obscured bulldozer cut and remnants of a simple retorting operation (circa 1950).

Upper Kane Hollow

Location and Access

The Upper Kane Hollow tar-sand deposit consists of two small areas of bitumen-saturated rocks exposed about 2.5 miles (4 km) south of U.S. 40 in the area known as "The Rim Rock." This area is between Asphalt Ridge and Raven Ridge in the SW¼SW¼SW¼ section 13; and the NE¼NE¼NE¼ section 24, T.6S., R.23E. (SLM), northeastern Uintah County (figure 25). U.S. Highway 40 provides access to the area, which lies about 20 miles (36 km) southeast of Vernal. The outcrops can be approached by 4-wheel-drive vehicle, but are accessible only on foot over rough terrain.

Physiography and Land-Use

The deposit lies along the west side of a number of low-lying, west-northwest-trending hogbacks, collectively called the Rim Rock, that extend from Powder Springs Wash northwestward to upper Kane Hollow. The area is hilly, cut by deep gullies and washes. The Rim Rock, Cow Wash, and Upper Kane Hollow tar-sand deposits occur along this trend. The bitumen-saturated outcrops on the west side of the Upper Kane Hollow deposit are located along the steep sides of Kane Hollow at an elevation of about 5,050 feet (1,539 m). Tar-sands on the east side of the deposit crop out along the west bank of a small, unnamed tributary of upper Kane Hollow at an elevation of about 5,150 feet (1,570 m). Surface ownership in the area is mainly Public Land (BLM administered) with several scattered state school sections (SITLA administered). A contiguous tract of 640 acres of private land is situated within 2 miles (3.2 km) northeast of the deposit. Land is used mainly for stock grazing and oil and gas development.

Geologic Setting

The Upper Kane Hollow tar-sand deposit is one of many similar occurrences situated along the north flank of the Uinta Basin. The deposit is in sandstone beds in the Parachute Creek Member of the Green River Formation (Eocene), which dip south-southwest from 25 to 30 degrees (figure 56). In this area the Green River Formation overlies the Wasatch Formation (Eocene-Paleocene) and Mesaverde Group (Upper Cretaceous) with angular discordance. The Green River rests unconformably on Mesaverde beds that dip from 60 to 65 degrees south-southwest (Doelling and Graham, 1972).

The east side of the deposit is in an area of tightly compressed folds and small-displacement faults. Bitumen saturation is heaviest close to the faults, suggesting a genetic relationship.

Tar sands occur in discontinuous sandstone lenses which are medium to coarse grained and locally conglomeratic. Most are friable and soft, but some resistant ledges are calcareous and well-cemented. Bitumen is localized and varies in degree of saturation from very weak to moderate. Much of the bitumen is dry and disintegrates to powder when struck with a pick. Maximum thickness of impregnated sandstone in the eastern outcrop area is 15 feet (4.6 m). Maximum thickness of the western outcrops is about 23 feet (7 m). Total area of the deposit is estimated to be about five acres.

Bitumen Analyses

Wood and Ritzma (1972) extracted and analyzed one sample of bitumen from this deposit (table 2). The sample yielded an API gravity of 7.6 with a sulfur content of 0.32 percent, very close to the average of analyses from other Uinta Basin tar-sand deposits.

Development History

Discovery of this and other tar-sand occurrences in the Asphalt Ridge-Raven Ridge trend is thought to have helped promote exploration that led to the discovery of petroleum in the Green River Formation in the Red Wash Field situated 4 to 5 miles (6.4 to 8 km) to the south.

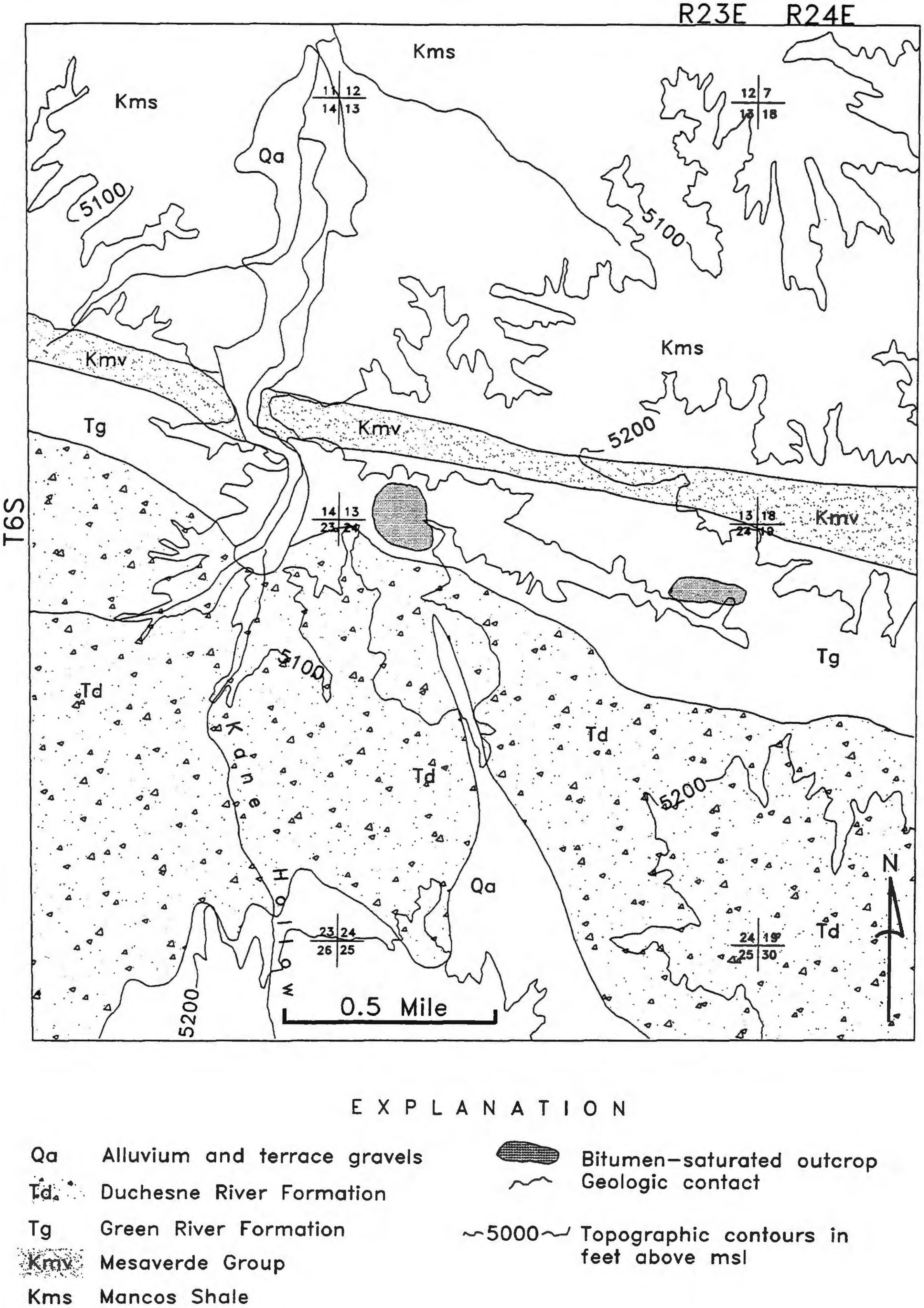


Figure 56. *General geology of the Upper Kane Hollow tar-sand area (after Doelling and Graham, 1972; tar-sand outcrops from K. Clem, unpublished data).*

Whiterocks

Location and Access

The Whiterocks deposit lies on the northern flank of the Uinta Basin, 27 miles (43.5 km) north of Roosevelt, Duchesne County, and 30 miles (48 km) northwest of Vernal, Uintah County (figure 25). The deposit is located near the mouth of Whiterocks Canyon, and is directly northwest of the Littlewater Hills deposit. The deposit is in sections 17-19, T.2N., R.1E., and section 24, T.2N., R.1W. (USM), Uintah County, and covers an area of about 400 acres. The deposit is found on the USGS Ice Cave Peak 7.5-minute quadrangle.

Access to the deposit is via various county roads either west from Vernal or north from Roosevelt toward the town of White Rocks. From White Rocks, there is a graded road which parallels the east side of Whiterocks River, crossing the deposit.

Physiography and Land-Use

The deposit is found within the marginal benches subsection of the Uinta Mountains physiographic province. Bitumen-saturated sandstone crops out on the east and west sides of Whiterocks Canyon and is probably continuous beneath valley alluvium (figure 57). The main part of the deposit lies at an elevation of 7,200 feet (2,195 m). The valley area is mostly private land surrounded on three sides by the Ashley National Forest.· To the south lies the Uinta and Ouray Reservation. The Whiterocks River has eroded through the deposit, forming a flood-plain as wide as 3,500 feet (1,158 m). The Whiterocks River is a major tributary to the Duchesne and Green Rivers. The bitumen-saturated and other formations form steep cliffs at the mouth of Whiterocks Canyon. The west wall rises about 300 feet (91 m) and the east wall rises about 500 feet (152 m) above the valley (Peterson, 1985).

Geologic Setting

Exposed strata consists primarily of steep, southeast-dipping Triassic and Jurassic rocks (figure 58). At the mouth of Whiterocks Canyon, the Wasatch Formation (Paleocene-Eocene) lies unconformably upon south-dipping rocks of the Mancos Shale and Mesaverde Group (Cretaceous). The Navajo Sandstone (Jurassic) lies unconformably above the Chinle Formation (Triassic) and unconformably below the Carmel Formation (Jurassic). Other formations exposed in Whiterocks Canyon include Precambrian, Cambrian, Mississippian, Pennsylvanian, Permian, Triassic, and Jurassic age rocks.

The Navajo Sandstone, which is also called the Nugget Sandstone in northeastern Utah, is bitumen-saturated in and around Whiterocks Canyon (figure 58). The Navajo is divided into two units; a thin-bedded lower unit, and a highly cross-stratified upper unit (Uyger and Picard, 1985). The Navajo is mostly of eolian origin, deposited in dune fields and interdune environments (Picard, 1975; Uygur, 1983). The enclosing Chinle and the Carmel Formations are comprised mainly of impervious shales that may have acted to seal in oil migrating into the Navajo.

The deposit is associated with the crest of a steep, south-plunging anticlinal nose (Whiterocks anticline) that subparallels the Whiterocks River. The influence of this structure on bitumen saturation is unknown.

Covington (1963) suggested several theories about the origin of the oil. He favored a Pennsylvanian age for the oil migrating from the Weber Sandstone. He also suggested the Green River Formation (Eocene) as a possible source due to similarities in chemical analyses. Sulfur isotopes (Mauger and others, 1973) support this theory.

The bitumen-saturated zone occurs almost entirely within the Navajo Sandstone, and is about 900 feet (274 m) thick. The deposit strikes N65°E for about 1.5 miles (2.4 km). The outcrop is covered on both sides by the Duchesne River Formation (Eocene-Oligocene).

The Navajo is a consolidated, fine-grained, and well-sorted subarkose. Poorly sorted zones of sandstone with a bimodal grain-size distribution are also present. Mineralogically, the Navajo Sandstone is mature and relatively uniform, with varying amounts of clays, iron oxides, and carbonate cements. Shale, siltstone, and calcareous zones are uncommon. Fracturing is common, although orientation is variable. The degree of bitumen saturation is dependent on permeability and is, therefore, not uniform; barren zones are adjacent to rich zones.

Numerous resource estimates have been calculated for the Whiterocks deposit. Severy (1943) estimated resources of 9.52 million barrels based on outcrop mapping. Based upon the results of 11 core-holes, Shirley (1961)

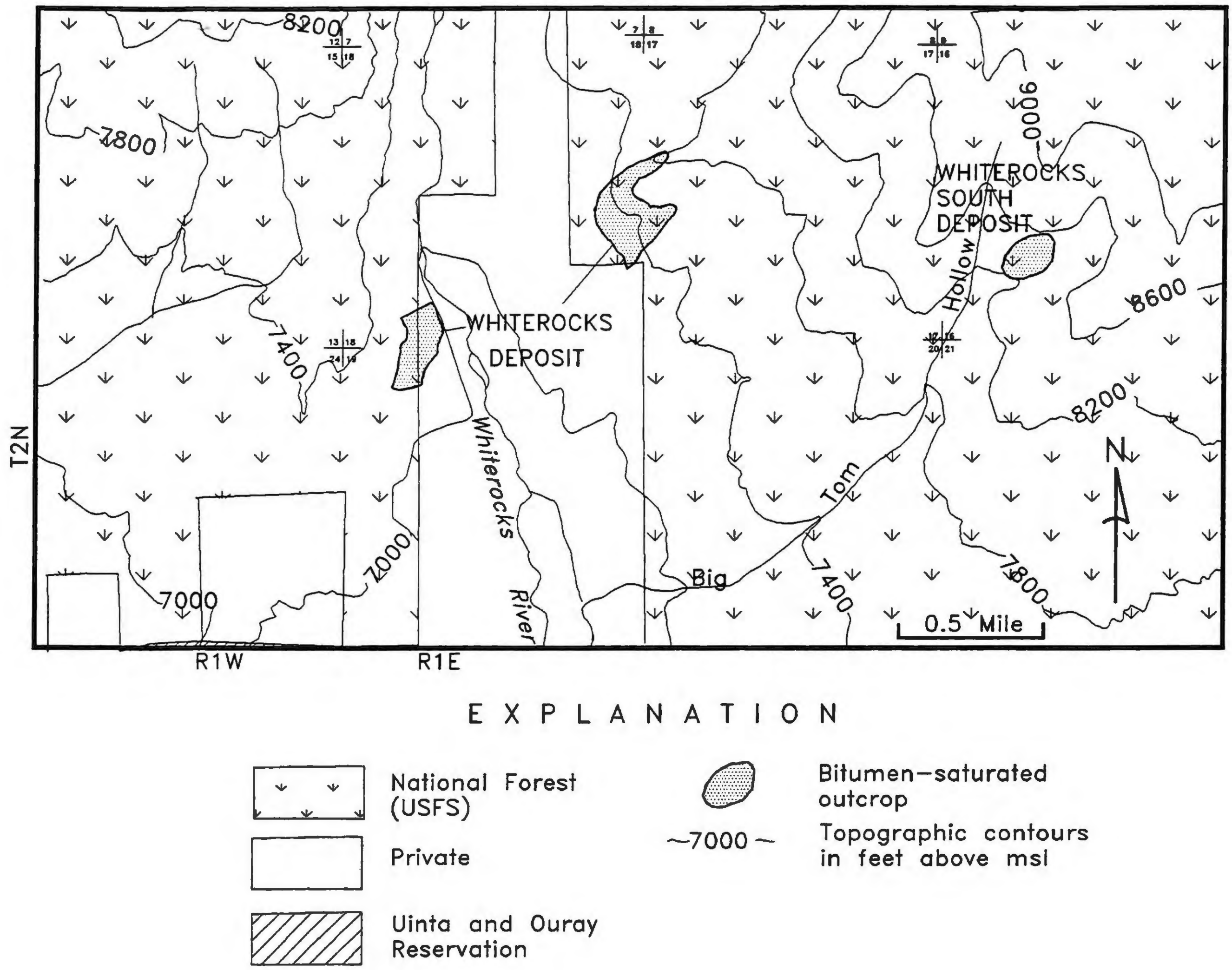


Figure 57. Land-ownership map of the Whiterocks and Whiterocks South tar-sand area.

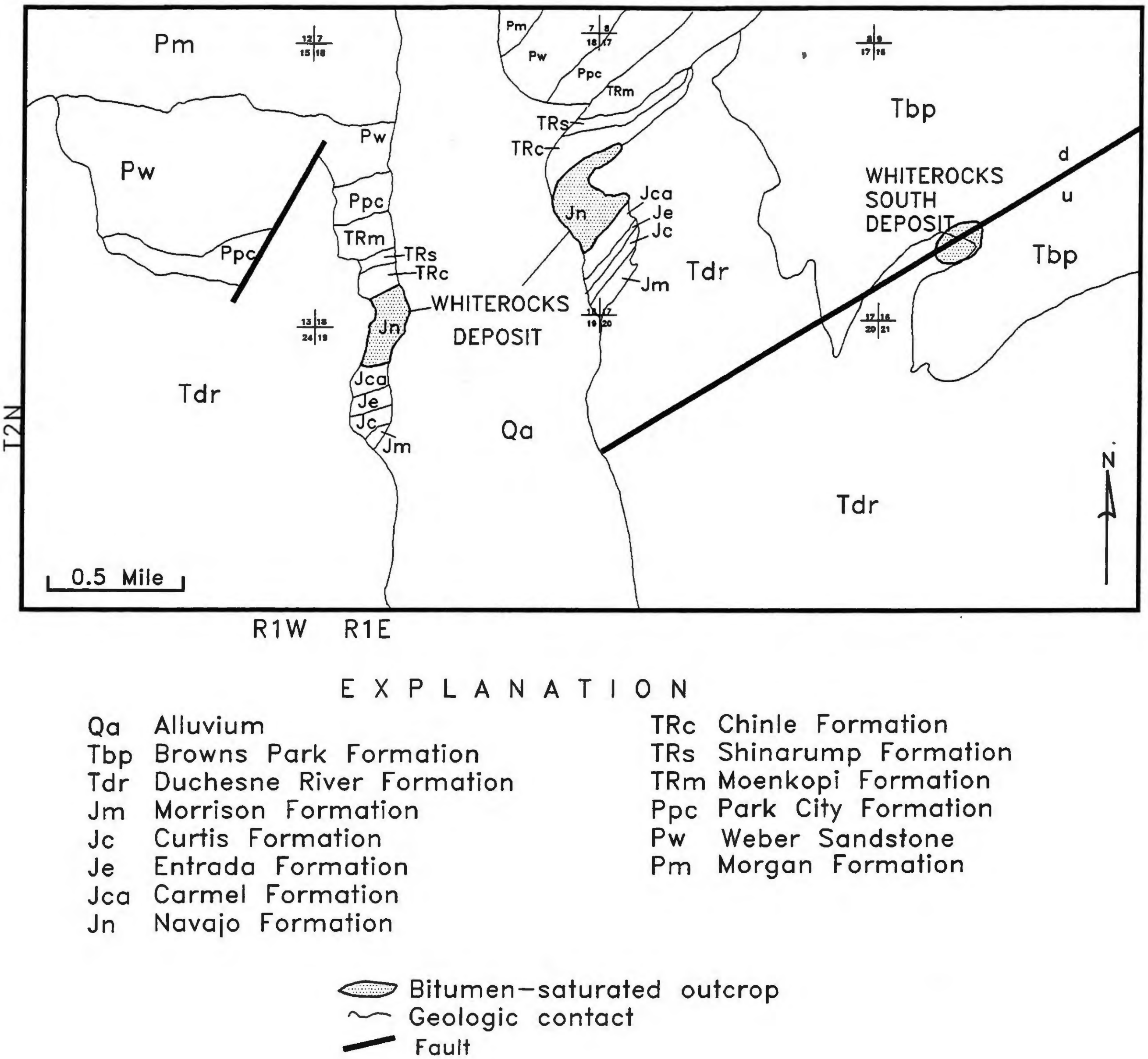


Figure 58. *General geology of the Whiterocks and Whiterocks South tar-sand areas (after Covington, 1964; tar-sand outcrops from K. Clem, unpublished data).*

calculated total resources of 105 million barrels. Of this total, Shirley classified 57 million barrels as proven reserves and 27 million barrels as probable resources. Covington (1963), using existing core-hole data and results of surface mapping, estimated approximately 50 million barrels. Lewin and Associates (1984) reported a measured resource of 60 million barrels in-place for 200 acres, with speculative resources of another 60 million barrels on 200 acres, calculating 600 feet (183 m) of saturation. Peterson (1985) suggested that the deposit contains more than 100 million barrels of oil in-place. Campbell (1975a) calculated 37.3 million barrels of oil-in-place, assuming 182 acres with 500 vertical feet (152 m) of saturation. Ritzma (1979) classified the deposit as "very large," with 65 to 125 million barrels of oil in-place. From this he categorized 50 million barrels as measured, 15 million barrels as indicated, and the remainder inferred.

It is interesting to note that the lower portion of the Duchesne River Formation, which overlies the eastern extent of the deposit, contains saturated pebbles of Navajo Sandstone. Bitumen occurs in the Duchesne River Formation, however, only along the contact with the Navajo Sandstone. This might indicate that oil migration was prior to deposition of the Duchesne River Formation.

Bitumen Analyses

Wood and Ritzma (1972) reported standard analyses of bitumen samples from the deposit, and Mauger and others (1973) presented data for sulfur isotopes (table 2). Sample 68-10E was collected from the Navajo Sandstone prospect pit, located in the SW¼NE¼SE¼ section 18, T.2N., R.2E. The WR-1, WR-2, and WR-3 samples are from the Navajo, located at T.2N., R.1E.

Development History

Peterson (1985) reported the results of exploratory drilling and presented a brief synopsis of development activities. Tar-sand exploration and development at Whiterocks until the 1940s was limited to small mining operations in pits and adits. In 1957 and 1958, three exploratory wells were drilled along the trend of the deposit in an effort to find liquid crude-oil. Two extraction plants were constructed in the early 1960s and used hot water and solvents in their processes. Also in the early 1960s, White Rocks Oil Properties of Salt Lake City drilled 11 core holes in the deposit; nine of these drill holes reportedly penetrated the entire bitumen-saturated interval. Western Industries of Las Vegas, Nevada, opened a strip-mine and built a pilot plant along the east side of the Whiterocks River apparently in the late 1960s. Major Oil Company, in the early 1970s, opened a strip-mine and built a pilot plant on the west side of the Whiterocks River (Peterson, 1985). Although other companies conducted exploratory work in the early 1980s, no other processing facilities were constructed. The quarry on the west side of the Whiterocks River is now being mined by Duchesne county for highway paving use.

Whiterocks South

Location and Access

The Whiterocks South deposit lies on the northern flank of the Uinta Basin in the SW¼ section 16, T.2N., R.1E. (USM), Uintah County (figure 25). Access to the deposit is by various county roads either west from Vernal or north from Roosevelt to the town of Whiterocks. From Whiterocks, a graded road parallels the mountain front, on the east side of Whiterocks Canyon. Located about one mile (1.6 km) east of the Whiterocks deposit, the Whiterocks South deposit can only be reached by fire-control roads and hiking trails.

To date, no analytical data are available and no exploratory work has been done for the Whiterocks South tar-sand occurrence.

Physiography and Land-Use

The Whiterocks South deposits consists of one small, bitumen-saturated outcrop near the head of a small side-canyon (Big Tom Hollow) of Whiterocks Canyon, and lies entirely within Ashley National Forest. The occurrence is located in mountainous terrain at an elevation of about 8,500 feet (2,591 m), is mostly obscured by brush, and occupies an area of less than one square mile (figure 57).

Geologic Setting

The Whiterocks South deposit (figure 58) is geologically similar to the Littlewater Hills deposit located about three miles (4.8 km) to the southeast. The deposit is located on the north flank of the Uinta Basin in the belt of south-dipping beds that marks the basin margin in this area. One mile (1.6 km) east of this deposit, the Navajo Sandstone (Jurassic) dips 65 degrees south.

The Duchesne River Formation (Eocene-Oligocene) rests unconformable upon the buried Mesozoic section and is overlain by the Browns Park Formation (Miocene). The Duchesne River Formation is composed of diverse fluvial sedimentary rocks. These fluvial deposits consist of heterogeneous, laterally discontinuous sandstone lenses with varying amounts of conglomerate and poorly stratified, fine-grained rocks (Anderson and Picard, 1972). Along south-facing slopes, dense brush obscures exposures of the upper Duchesne River contact.

Bitumen saturates less than 15 feet (5 m) of the basal part of the Duchesne River Formation (Ball Associates, Ltd, 1964). A small northeast-trending fault in the area suggests a possible relationship to the bitumen occurrence. Ball Associates, Ltd. (1964) classified this deposit as a "minor" occurrence with no economic significance.

Willow Creek

Location and Access

The Willow Creek deposit is located on the southwest flank of the Uinta Basin, about 15 miles (24 km) north-northeast of Price in T.6-7S., R.8-9W. (USM), and T.11S., R.9-10E. (SLM), Duchesne, Utah, and Wasatch Counties (figure 25). Bitumen-saturated outcrops extend eastward from near the Utah-Duchesne County line to Willow Creek, a distance of about 4 miles (6.4 km). The elevation of bitumen-saturated outcrops range between 7,600 and 9,400 feet (2,317-2,865 m).

Vehicle access is gained by driving north from Price via U.S. Highway 6 for about 10 miles (16 km), then turning east onto State Highway 33. The Avintaquin Campground Road, located about 14 miles (23 km) from the Highway 6 turnoff, provides access to the northern outcrops. The Willow Creek Road, located about 10 miles (16 km) from the Highway 6 turnoff, provides access to the southern outcrops.

Physiography and Land-Use

The Willow Creek deposit is located on the western part of the southern limb of the Uinta Basin. The Roan Cliffs extend into the deposit area from the southeast, arbitrarily ending at Willow Creek. Willow Creek, a perennial stream, is the main drainage of the area, and flows southwest into the Price River. The surrounding area is characterized as high plateaus dissected by streams that form deep, steep-walled canyons. Emma Park, a homoclinal valley, lies less than 3 miles (5 km) south of the deposit area, and trends southeast to Whitmore Park along the base of the Roan Cliffs.

The southern boundary of the Ashley National Forest lies less than 1 mile (1.6 km) north of the outcrops. The main deposit area consists of a patchwork of private and state lands, and small tracts of Public Land (BLM administered) are scattered throughout the deposit area (figure 59). The Federal Government has reserved mineral rights on most of the private land in the area, and, as of 1980, had established protective withdrawals, presumably for solid hydrocarbons (U.S. Bureau of Land Management, 1980).

Geologic Setting

Strata exposed in Willow Creek are the upper part of the Garden Gulch Member and the basal part of the Parachute Creek Member of the Green River Formation (figure 60). The Garden Gulch Member consists of alternating thin sandstone, siltstone, shale, and limestone beds. The Parachute Creek Member consists of massive beds that become thin upward and consist of fine-grained sandstone, interbedded with siltstone and shale. The sandstone beds are fluvial-deltaic and exhibit channeling characteristics. Regional dip is northward from 4 to 6 degrees toward the center of the Uinta Basin.

Channel sandstones are commonly the bitumen-saturated units. Although extensive ground cover masks the surface expression of the deposit, Tripp (1986a) estimated total thickness of the saturated zone at about 80 feet (24 m). Surface evidence for much of the deposit is limited to bitumen-saturated "float," stones that have eroded from the deposit. Degree of saturation varies both vertically and horizontally. Ritzma (1979) classified the deposit as "large," and estimated that the Willow Creek deposit contains between 10 and 15 million barrels of oil in-place.

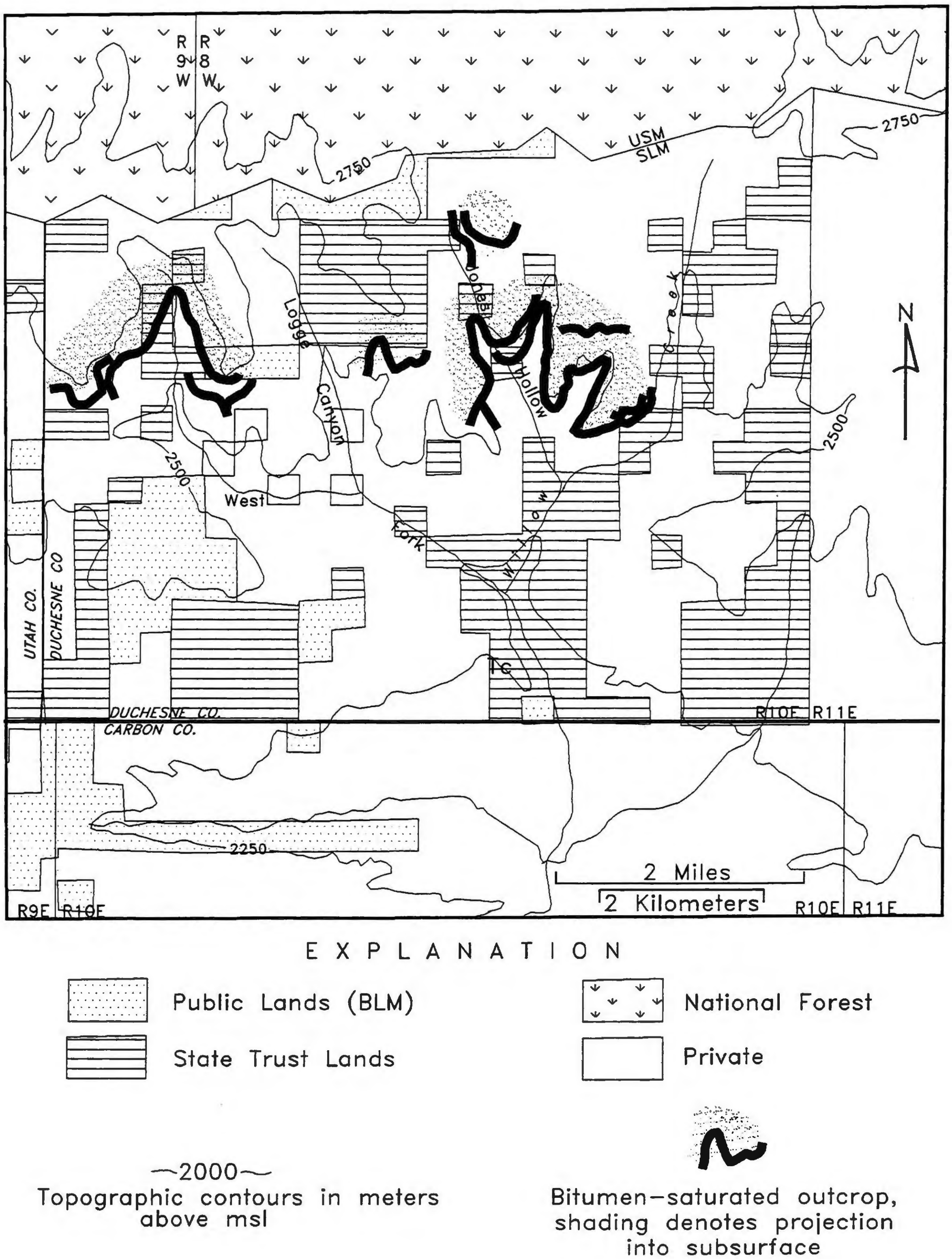


Figure 59. Land-ownership map of the Willow Creek tar-sand area.

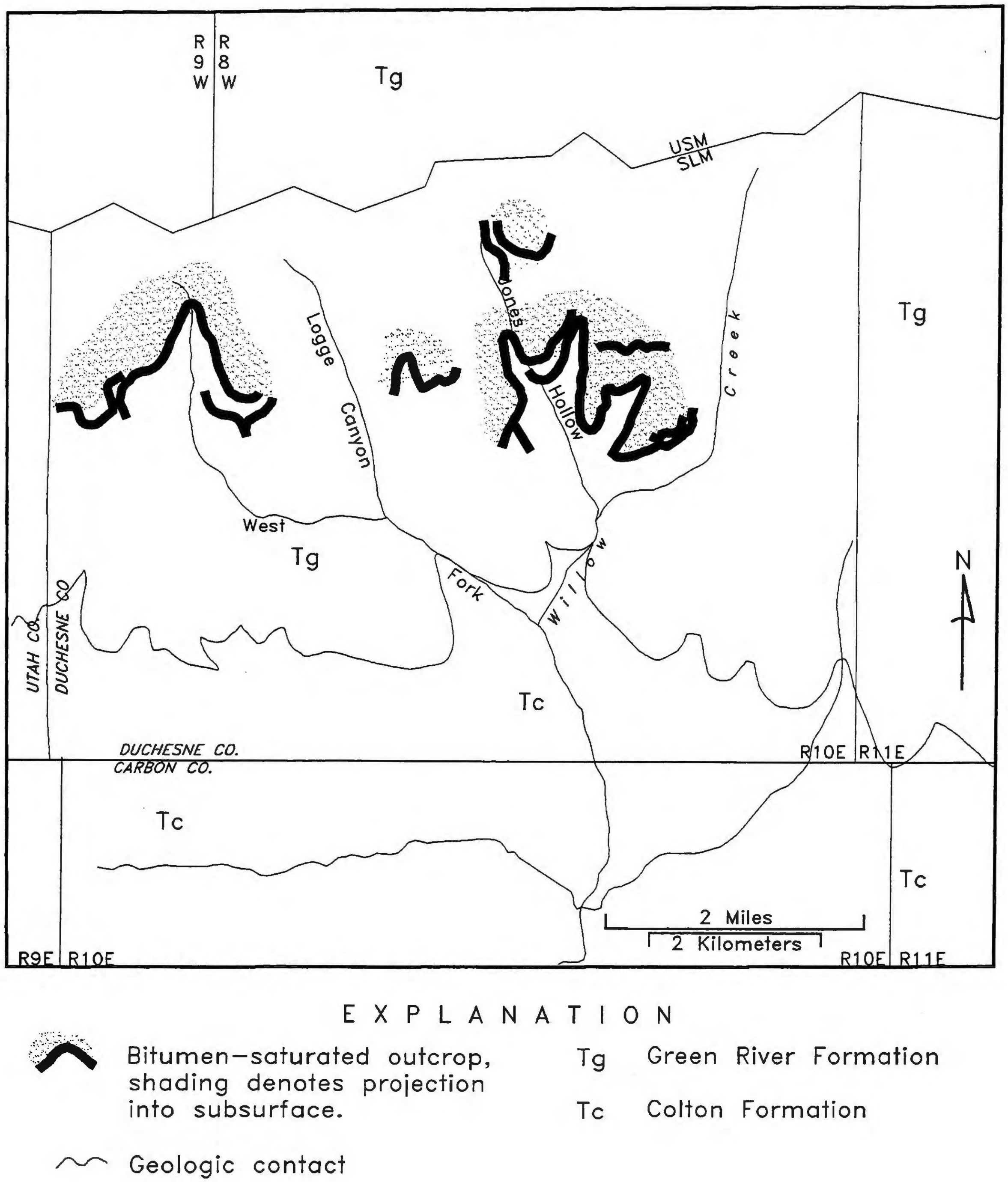


Figure 60. General geology of the Willow Creek tar-sand area (after Witkind and others, 1978; tar-sand outcrops from K. Clem, unpublished data).

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REFERENCES

Anderson, D.W., and Picard, M.D., 1972, Stratigraphy of the Duchesne River Formation (Eocene-Oligocene?), northern Uinta Basin, northeastern Utah: Salt Lake City, Utah Geological and Mineral Survey Bulletin 97, 25 p.

Anonymous, 1974, Fairbrim & Arizona Fuels to begin oil sands recovery tests on Sohio property in Utah: Synthetic Fuels, September 1974.

---, 1981, Western Tar Sands, Incorporated: Oil and Gas Journal, June 29.

Ball Associates Ltd., 1964, compilers, Surface and shallow oil-impregnated rocks and shallow oil fields in the United States: U.S. Bureau of Mines Monograph 12, 375 p. [Oklahoma City, Interstate Oil Compact Commission]

Banks, E.Y., 1981, Petrographic characteristics and provenance of fluvial sandstone, Sunnyside oil-impregnated sandstone deposits, Carbon County, Utah: University of Utah unpublished master thesis, p. 112.

Barb, C.F., 1944, Hydrocarbons of the Uinta Basin of Utah and Colorado: Quarterly of the Colorado School of Mines, vol. 39, no. 1, 65 p.

Bass, N.W., 1964, Relationship of crude oils to depositional environment of source rocks in the Uinta Basin, *in* Sabatka, E.F., editor, Guidebook to the Geology and Mineral Resources of the Uinta Basin, Utah's hydrocarbon storehouse: Salt Lake City, Intermountain Association of Petroleum Geologists, Thirteenth Annual Field Conference, p. 201-206.

Bradley, W.H., 1931, Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah: U.S. Geological Survey Professional Paper 168, 58 p.

Bruhn, R.L., Picard, M.D., and Beck, S.L., 1983, Mesozoic and Early Tertiary structure and sedimentology of the central Wasatch Mountains, Uinta Mountains, and Uintah Basin, *in* Gurgel, K.D., editor, Geologic Excursions in the Overthrust Belt and Metamorphic Core Complexes of the Intermountain Region - Guidebook - Part I: Salt Lake City, Utah Geological and Mineral Survey Special Studies 59, p. 63-106.

Bruhn, R.L., Picard, M.D., and Isby, J.S., 1986, Tectonics and sedimentology of Uinta arch, western Uinta Mountains and Uinta Basin: American Association of Petroleum Geologists Memoir 41, p. 333-352.

Bryant, Bruce, 1992, Geologic and structure maps of the Salt Lake City 1°x 2° quadrangle, Utah and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1997, scale 1:125,000.

Byrd, W.D., II, 1970, P.R. Spring oil-impregnated sandstone deposit, Uintah and Grand Counties, Utah: Salt Lake City, Utah Geological and Mineral Survey Special Studies 31, 34 p.

Campbell, J.A., 1975a, Oil-impregnated sandstone deposits of Utah: Mining Engineering, v. 27, no. 5, p. 47-53.

---, 1975b, Structural geology and petroleum potential of the south flank of the Uinta Mountain uplift, northeastern Utah: Utah Geology, v. 2, p. 129-132.

Campbell, J.A., and Ritzma, H.R., 1979, Geology and petroleum resources of the major oil-impregnated sandstone deposits of Utah: Salt Lake City, Utah Geological and Mineral Survey, Special Studies 50, 24 p.

Cashion, W.B., 1967, Geology and fuel resources of the Green River Formation, southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey, Professional Paper 548, 48 p., 5 pt.

Cashion, W.B., 1973, Geologic and structure map of the Grand Junction 1° by 2° quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-736, scale 1:250000.

Cashion, W.B., and Donnell, J.R., 1974, Revision of nomenclature of the upper part of the Green River Formation of the Piceance Creek Basin, Colorado and the eastern Uinta Basin, Utah: U.S. Geological Survey Bulletin 1394-G, 9 p.

Chatfield, John, 1965, Petroleum geology of the Greater Red Wash area, Uintah County, Utah: Mountain Geologist, v. 2, no. 3, p. 115-121.

Clark, D.L., 1957, Marine Triassic stratigraphy in eastern Great Basin: American Association of Petroleum Geologists Bulletin, v. 41, p. 2,192-2,222.

Clem, K.M., 1984, Economic potential of the P.R. Spring oil-impregnated deposit, Uinta Basin, Utah: Salt Lake City, Utah Geological Survey Special Studies 65, 35 p.

---, 1985, Economic potential of state-owned lands in the Sunnyside special tar sand area: Salt Lake City, Utah Geological and Mineral Survey, Report of Investigation 196, 29 p.

Covington, R.E., 1963, Bituminous sandstone and limestone deposits of Utah, *in* Crawford, A.L., editor, Oil and gas possibilities of Utah, re-evaluated: Utah Geological and Mineralogical Survey, Bulletin 54, p. 225-248.

---, 1964, Bituminous sandstones in the Uinta Basin, *in* Sabatka, E.F., editor, Guidebook to the Geology and Mineral Resources of the Uinta Basin, Utah's hydrocarbon storehouse: Salt Lake City, Intermountain Association of Petroleum Geologists, 13th Annual Field Conference, p. 227-242.

---, 1976, Oil-impregnated rocks of Utah: Distribution, geology and reserves: Provo, Utah, Brigham Young University Geology Studies, v. 22, p. 2, p. 143-150.

Covington, R.E., and Young, K.J., 1985, Brief history and recent developments in tar sand deposits of Uinta Basin, *in* Picard, M.D., editor, Geology and Energy Resources, Uinta Basin of Utah: Utah Geological Association Publication 12, p. 227-241.

Crawford, A.L., 1949, Gilsonite and related hydrocarbons of the Uinta Basin -- oil and gas possibilities of Utah: Utah Geological and Mineralogical Survey, p. 235-260.

Dana, G.F., 1983, Oil shale? Tar sand? There's a definite difference indeed!, *in* Tarman, P.B., Mattews, R.D., editors, Synthetic fuels from oil shale and tar sands: Chicago, Institute of Gas Technology, p. 11-37.

Dane, C.H., 1954, Stratigraphic and facies relationships of upper part of Green River Formation and lower part of Uinta Formation in Duchesne, Uintah, and Wasatch Counties, Utah: American Association of Petroleum Geologists Bulletin, v. 38, p. 405-425.

---, 1955, Stratigraphic and facies relationships of upper part of Green River Formation and lower part of Uinta Formation in Duchesne, Uintah, and Wasatch Counties, Utah: U.S. Geological Survey Oil and Gas Investigation Chart 52 (2 sheets)

Demaison, G.J., 1977, Tar sands and supergiant oil fields, *in* Redford, D.A., and Winestock, A.G., editors, The oil sands of Canada-Venezuela: Montreal, Quebec, Canadian Institute of Mining and Metallurgy Special Volume 17, p. 9-16.

Doelling, H.H., and Graham, R.L., 1972, Eastern and northern Utah coal fields -- Vernal, Henry Mountains, Sego, La Sal-San Juan, Tabby Mountain, Henry's Fork, Goose Creek, and Lost Creek: Utah Geological and Mineral Survey, Monograph 2, 409 p.

Dyni, J.R., Milton, C. Jr., and Cashion, W.B. Jr., 1985, The saline facies of the upper part of the Green River Formation near Duchesne, Utah, *in* Picard, M.D., editor, Geology and Energy Resources, Uinta Basin of Utah: Salt Lake City, Utah Geological Association Publication 12, p. 51-60.

Fouch, T.D., 1975, Lithofacies and related hydrocarbon accumulations in Tertiary strata of the western and central Uinta Basin, Utah: Denver, Rocky Mountain Association of Geologists.

Fouch, T.D., Nuccio, V.F., Osmond J.C., MacMillan, Logan, Cashion, W.B., and Wandrey, C.J., 1992, Oil and gas *in* Uppermost Cretaceous and Tertiary rock, Uinta Basin, Utah, in Fouch, T.D., Nuccio, V.F., Chidsey, T.C., Jr., editors, Hydrocarbon and Mineral Resources of the Uinta Basin, Utah and Colorado: Salt Lake City, Utah Geological Association Guidebook 20, p. 9-47.

Franczyk, K.J., Fouch, T.D., Johnson, R.C., Molenaar, C.M., and Cobban, W.A., 1992, Cretaceous and Tertiary paleogeographic reconstruction for the Uinta-Piceance Basin study area, Colorado and Utah: U.S. Geological Survey Bulletin 1787-Q, 37 p.

Gable, D.J., and Hatton, Tom, 1983, Maps of vertical crustal movements in the conterminous U.S. over the last 10 million years: U.S. Geological Survey Map I-1315, scale 1:5,000,000 1:10,000,000.

Garvin, R.F., 1969, Stratigraphy and economic significance, Currant Creek Formation, northwest Uinta Basin, Utah: Utah Geological and Mineral Survey Special Studies 27, 53 p.

Glassett, J.M., and Glassett, J.A., 1976, The production of oil from intermountain west tar sands deposits, final report to the U.S. Bureau of Mines (contract no. S-0241129): Provo, Utah, Brigham Young University, Eyring Research Institute, 91 p.

Gurgel, K.D., editor, 1983, Energy resources map of Utah: Utah Geological and Mineral Survey Map 68, scale 1:500,000.

Gwynn, J.W., 1971, Instrumental analysis of tars and their correlations in oil-impregnated sandstone beds, Uinta and Grand Counties, Utah: Utah Geological and Mineral Survey Special Studies 37, 64 p.

---, 1985, The Hill Creek oil-impregnated sandstone deposit: Utah Geological and Mineral Survey Report of Investigation 201, 40 p.

---, 1986, Overburden map and thickness determinations, Sunnyside oil-impregnated sandstone deposit, Carbon and Duchesne Counties, Utah: Utah Geological and Mineral Survey Report of Investigation 210, scale 1:50,000.

Hansen, A.R., 1963, The Uinta Basin - structure, stratigraphy and tectonic setting, *in* Crawford, A.L., editor, Oil and gas possibilities of Utah, re-evaluated: Utah Geological and Mineralogical Survey Bulletin 54 p. 175-176.

Hintze, L.F., 1980, compiler, Geologic map of Utah: Salt Lake City, Utah Geological and Mineral Survey Map A-1, scale 1:500,000.

---, 1988, Geologic history of Utah: Provo, Brigham Young University Geology Studies Special Publication 7, 202 p.

Holmes, C.N., and Page, B.M., 1956, Geology of the bituminous sandstone deposits near Sunnyside, Carbon County, Utah, *in*, Peterson, J.A., editor, Geology and economic deposits of east-central Utah: Intermountain Association of Petroleum Geologists, Seventh Annual Field Conference Guidebook, p. 171-177.

Holmes, C.N., Page B.M., and Averitt, Paul, 1948, Geology of the bituminous sandstone deposits near Sunnyside, Carbon County, Utah: U.S. Geological Survey, Oil and Gas Investigations Preliminary Map 86 (2 maps), scale 1:6,000, 1:24,000.

Hunt, J.M., 1979, Petroleum geochemistry and geology: San Francisco, W.H. Freeman & Company, 617 p.

Isby, J.S., and Picard, M.D., 1985, Depositional setting of Upper Cretaceous-Lower Tertiary Current Creek Formation, north-central Utah: Utah Geological Association Publication 12, p. 39-49.

Jacob, A.F., 1969, Delta facies of the Green River Formation (Eocene), Carbon and Duchesne Counties, Utah: Boulder, University of Colorado, Ph.D. dissertation, 182 p.

Johnson, L.A., Marchant, L.C., and Cupps, C.Q., 1975a, Properties of Utah tar sands--South Seep Ridge area, P.R. Spring deposit: U.S. Bureau of Mines Report of Investigation 8003, 14 p.

---, 1975b, Properties of Utah tar sands--North Seep Ridge area, P.R. Spring deposit: Laramie, Energy Research and Development Administration, Laramie Energy Research Center Report of Investigation LERC/RI 75/6, 17 p.

---, 1976, Properties of Utah tar sands -- Flat Rock Mesa area, Hill Creek Deposit: Laramie, Wyoming, Laramie Energy Research Center, Report of Investigation LERC/RI-76/5, 18 p.

Johnson, S.Y., 1992, Phanerozoic evolution of sedimentary basins in the Uinta-Piceance basin region, northwestern Colorado and northeastern Utah: U.S. Geological Survey Bulletin 1787-FF, 38 p.

Kayser, R.B., 1966, Bituminous sandstone deposits, Asphalt Ridge, Uintah County, Utah: Salt Lake City, Utah Geological and Mineralogical Survey, Special Studies 19, 62 p.

Kerns, Ray, 1984, Utah tar sands: Salt Lake City, Utah Geological Survey *Survey Notes*, p. 1-9.

Kinney, D.M., 1955, Geology of the Uinta River-Brush Creek area, Duchesne and Uintah Counties, Utah: U.S. Geological Survey Bulletin 1007, 185 p., pl. 1, scale 1:63360.

Kinney, D.M., and Rominger, J.F., 1947, Geology of the Whiterocks River-Ashley Creek area, Uintah County, Utah: U.S. Geological Survey Oil and Gas Investigations Preliminary Map OM-82, scale 1:404,500.

Koesoemadinata, R.P., 1970, Stratigraphy and petroleum occurrence, Green River Formation, Red Wash field, Utah: Golden, Quarterly of the Colorado School of Mines, v. 65, no. 1, p. 1-77.

Kuuskraa, V.A., Hammershaimb, E.C., and Paque, M., 1984, Major tar sand and heavy-oil deposits of the United States; in Meter, R.F, editor, Exploration for heavy crude oil and natural bitumen: American Association of Petroleum Geologists Studies in Geology no. 25, p, 123-135

Lewin and Associates, 1984, Major tar sand and heavy oil deposits of the United States: Oklahoma City, Interstate Oil Compact Commission [Library of Congress Catalog Card No. 84-80053], 271 p.

Lindsay, J.B., editor, 1969, Geologic map of the Uinta Mountains uplift and surrounding transition area, in Geologic guidebook of the Uinta Mountains, Utah's maverick range: Intermountain Association of Petroleum Geologists Guidebook, 16th annual field conference, scale 1:250,000.

Marchant, L.C., Johnson, L.A., and Cupps, C.Q., 1974, Properties of Utah tar sands -- Threemile Canyon, P.R. Spring deposit: U.S. Bureau of Mines Report of Investigation 7923, 14 p.

Marsell, R.E., 1964, Geomorphology of the Uinta Basin - A brief sketch, in Sabatka, E.F., editor, Guidebook to the Geology and Mineral Resources of the Uinta Basin, Utah's Hydrocarbon Storehouse: Salt Lake City, Intermountain Association of Petroleum Geologists Thirteenth Annual Field Conference, p. 29-39.

Mauger, R.L., Kayser, R.B., and Gwynn, J.W., 1973, A sulfur isotopic study of Uinta Basin hydrocarbons: Utah Geological and Mineralogical Survey Special Studies 41, 17 p.

Merriam, N.W., and Fahy, L.J., 1985, LETC Tar Sand Research - North Asphalt Ridge, *in* Picard, M.D., editor, Geology and Energy Resources, Uinta Basin of Utah: Salt Lake City, Utah Geological Association Publication no. 12 p. 253-256.

Meyer, R.F., and DeWitt, Wallace, 1990, Definition and world resources of natural bitumens: U.S. Geological Survey Bulletin 1944, 14 p.

Nelson, A.R., and Weisser, R.R., 1985, Quaternary faulting on Towanta Flat, northwestern Uinta Basin, Utah, *in* Picard, M.D., Geology and energy resources, Uinta Basin of Utah: Salt Lake City, Utah Geological Association Publication 12, p. 147-158.

Osmond, J.C., 1965, Geologic history of site of Uinta Basin, Utah: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1957-1973.

Osmond, J.C., Locke, R., Dille, A.C., Praetorious, W., and Wilkins, J.G., 1968, Natural gas in Uinta Basin, Utah, *in* Beebe, B.W., editor, Natural gases of North America - part 1, Natural gases in rocks of Cenozoic age: American Association of Petroleum Geologists Memoir 9, v. 1, p. 174-198.

Palacas, J.G., Audors, D.E., King, J.D., and Lubeck, C.M., 1988, Use of biological markers in determining thermal maturity of biodegraded heavy oils and solid bitumens, *in* Mayor, R.F., and Wiggins, E.J., editors, Proceedings Fourth UNITAR/UNDP International Conference on Heavy Crude and Tar Sands: Edmonton, Alberta, Canada, Alberta Oil Sands Technology Research Authority v. 2, p. 575-592.

Peterson, P.R., 1975, Lithologic logs and correlations of coreholes, P.R. Spring and Hill Creek oil-impregnated sandstone deposits, Uintah County, Utah: Utah Geological and Mineral Survey Report of Investigations 100, 30 p.

---, 1985, The Whiterocks tar sand deposit, *in* Picard, M.D., editor, Geology and Energy Resources, Uinta Basin of Utah: Utah Geological Association Publication 12, p. 243-252.

Peterson, P.R., and Ritzma, H.R., 1972, Oil-impregnated sandstone, Thistle area, Utah County, Utah, *in* Baer, J.L. and Callaghan, editors, Plateau-Basin and Range Transition Zone, Central Utah: Salt Lake City, Utah Geological Association Publication 2, p. 93-95.

---, 1974, Informational core drilling in Utah's oil-impregnated sandstone deposits, southeast Uinta Basin, Uintah County, Utah: Utah Geological and Mineral Survey Special Studies 36, 24 p.

Picard, M.D., 1955, Subsurface stratigraphy and lithology of Green River Formation in Uinta Basin, Utah: American Association of Petroleum Geologists Bulletin, v. 39, p. 75-102.

---, 1959, Green River and lower Uinta Formation subsurface stratigraphy in western Uinta Basin, Utah, *in* Williams, N.C., editor, Guidebook of the Wasatch and Uintah Mountain Transition Area: Salt Lake City, Intermountain Association of Petroleum Geologists, p. 139-149.

---, 1971, Petrographic criteria for recognition of lacustrine and fluvial sandstone, P.R. Spring oil-impregnated sandstone area, southeast Uinta Basin, Utah: Salt Lake City, Utah Geological Survey Special Studies 36, 24 p.

---, 1975, Facies, petrography and petroleum potential of Nugget Sandstone (Jurassic), southwestern Wyoming and northeastern Utah: Denver, Rocky Mountain Association of Geologists Symposium, p. 109-127.

---, 1985, Stratigraphic sequence, depositional environments, and sandstone types, western Uinta Mountains and Uinta Basin, in Picard, M.D., editor, Geology and energy resources: Salt Lake City, Utah Geological Association Publication 12, p. 19-20.

Picard, M.D., and High, L.R. Jr., 1968, Sedimentary cycles in the Green River Formation (Eocene), Uinta Basin, Utah: Journal of Sedimentary Petrology, v. 38, no. 2, p. 378-383.

---, 1972, Paleoenvironmental reconstructions in an area of rapid facies change, Parachute Creek Member of Green River Formation (Eocene), Uinta Basin, Utah: Geological Society of America Bulletin, v. 83, p. 2689-2708.

Pinnell, M.L., 1972, Geology of the Thistle quadrangle, Utah: Provo, Brigham Young University Geology Studies, v. 19, part 1, p. 89-130.

Porter, Livingstone Jr., 1963, Stratigraphy and oil possibilities of the Green River Formation in the Uinta Basin, Utah, *in* Crawford, A.L., editor, Oil and gas possibilities of Utah, re-evaluated: Salt Lake City, Utah Geological and Mineralogical Survey, Bulletin 54, p. 193-198.

Pruitt, R.G. Jr., 1961, The mineral resources of Uintah County: Salt Lake City, Utah Geological and Mineralogical Survey Bulletin 71, 101 p.

---, 1964, A problem in petroleum leasing - liquid vs. semisolid, *in* Sabatka, E.F., editor, Guidebook to the Geology and Mineral Resources of the Uinta Basin, Utah's Hydrocarbon Storehouse: Intermountain Association of Petroleum Geologists Thirteenth Annual Field Conference, p. 243-246.

Quigley, Sam, 1972, Oil-impregnated sandstones of Raven Ridge, Vernal, Utah: Salt Lake City, Utah Geological and Mineral Survey, unpublished report.

Richardson, E.A., Ashcroft, G.L., and Westbrook, J.K., 1981, Annual normal precipitation, *in* Greer, D.C., Gurgel, K.D., Wahlquist, W.L., Christy, H.A., and Peterson, G.B., editors, Atlas of Utah: Provo, Brigham Young University Press, p. 67-70.

Ritzma, H.R., 1968, Oil-impregnated rock deposits of Utah: Salt Lake City, Utah Geological and Mineral Survey Map 25, scale 1:750,000.

---, 1971, Faulting on the north flank of the Uinta Mountains, Utah and Colorado: Wyoming Geological Association Guidebook 23, p. 145-150.

---, 1972, Exploration and development of oil shale and oil-impregnated rocks, 1970-1975 (abstract): American Association of Petroleum Geologists Bulletin, v. 56, p. 649-650.

---, 1973, Oil-impregnated rock deposits of Utah: Salt Lake City, Utah Geological and Mineral Survey, Map 33, scale 1:750,000.

---, 1975, The Chinese Wax Mine -- a unique oil-impregnated rock deposit: Utah Geology, v. 2, no. 1, p. 79-82.

---, 1979, Oil-impregnated rock deposits of Utah: Salt Lake City, Utah Geological and Mineral Survey Map 47, scale 1:750,000.

---, 1987, Utah tar sands, *in* Hollander, J.M., editor, Annual Review and Energy Annual Reviews Inc., p. 286-355.

Ritzma, H.R., and Campbell, J.A., 1979, Bibliography of oil-impregnated rock deposits of Utah: Utah Geological and Mineral Survey Circular 64, 18 p.

Robinson, H.M., 1916, Ozokerite in central Utah, *in* White, David, Ashley, G.H., and Campbell, M.R., editors, Contributions to Economic Geology (Short Papers and Preliminary Reports), Part II--Mineral Fuels: U. S. Geological Survey Bulletin 641, p. 1-16.

Rowley, P.D., Hansen, W.R., Tweto, Ogden, and Carrara, P.E., 1985, Geologic map of the Vernal 1.5 x 2.5 quadrangle, Colorado, Utah, and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1526, scale 1:250,000.

Ryder, R.T., Fouch, T.D., and Elison, J.H., 1976, Early Tertiary sedimentation in the western Uinta Basin, Utah: Geological Society of American, Bulletin v. 87, p. 496-512.

Sanborn, A.F., 1977, Possible future petroleum of Uinta and Piceance basins and vicinity, northeast Utah and northwest Colorado: Denver, Rocky Mountain Association of Geologists Symposium, p. 151-166.

Schenk, C.J., and Pollastro, R.M., 1987, Preliminary Geologic Analysis of the tar sands near Sunnyside, Utah; in Meyer, R.F., (editor), Exploration for Heavy Crude Oil and Natural Bitumen: American Association of Petroleum Geologists Studies in Geology no. 25, p. 584-599.

Severy, C.L., 1943, Whiterock River bituminous sandstone deposit, Uintah County, Utah: U.S. Bureau of Mines unpublished War Minerals Report, dated December, 1943, 15 p.

Shea, G.D., and Higgins, R.V., 1952, Separation and utilization studies of bitumens from bituminous sandstones of the Vernal and Sunnyside, Utah deposits, Part 1- Laboratory hot-water separation tests: U.S. Bureau of Mines, Report of Investigations 4871 p. 1-10.

Shirley, H.B., 1961, Whiterock River bituminous sandstone deposit, Uintah County, Utah: U.S. Bureau of Mines War Minerals Report 15 p.

Sinks, D.J., 1985, Geologic evaluation and reservoir properties of the P.R. Spring tar sand deposit, Uintah and Grand Counties, Utah: U.S. Department of Energy, Western Research Institute, Laramie, Wyoming, DOE/FE/60177-1883, 190 p.

Spieker, E.M., 1930, Bituminous sandstone near Vernal, Utah, *in* Miser, H.D., Contributions to economic geology (short papers and preliminary reports), part II mineral fuels: U.S. Geological Survey Bulletin 822, p. 77-98.

Stokes, W.L., 1977, Physiographic subdivisions of Utah: Utah Geological and Mineral Survey Map 43, scale approximately 1:2,500,000.

Thurber, J.L., and Welbourn, M.E., 1977, How Shell attempted to unlock Utah tar sands: Petroleum Engineer, v. 49, no. 12, p. 31-42.

Tissot, B.P., Deroo, G. and Hood, A., 1978, Geochemical study of the Uinta Basin; Formation of petroleum from the Green River Formation: Geochimica et Cosmochimica Acta, v. 42, no. 10., p. 1469-1485.

Tissot, B.P., and Welte, D.H., 1984, Petroleum formation and occurrence: Springer-Verlag, New York.

Tripp, B.T., 1986a, Argyle Canyon - Willow Creek tar sand deposit - Isopach Map: Salt Lake City, Utah Geological Survey Open File Report 100, scale 1:50,000.

---, 1986b, Argyle Canyon - Willow Creek tar sand deposit - Overburden Map: Salt Lake City, Utah Geological Survey Open File Report 101, scale 1:50,000.

---, 1986c, Argyle Canyon-Willow Creek tar sand research project: Salt Lake City, Utah Geological and Mineral Survey unpublished file report, 9 p.

U.S. Bureau of Land Management, 1977, Area of responsibility and land status map State of Utah: U.S. Department of Interior, Bureau of Land Management, scale 1:500,000.

---, 1980, Surface management status - mineral management status, Price 30 X 60 Minute Quadrangle: U.S. Department of Interior, Bureau of Land Management, scale 1:100,000.

---, 1984, Utah combined hydrocarbon leasing -- regional final EIS: Salt Lake City, U.S. Department of Interior, Bureau of Land Management, v. 1, 328 p.

---, 1985, P.R. Spring combined hydrocarbon lease conversion, final environmental impact statement: U.S. Department of the Interior, Bureau of Land Management, 122 p.

U.S. Department of Energy, Energy Information Administration, 1993, Largest U. S. Oil and Gas Fields, August 1993: U.S. Government Printing Office, 65 p.

Untermann, G.E., and Untermann, B.R., 1954, Geology of Dinosaur National Monument and vicinity, Colorado-Utah: Salt Lake City, Utah Geological and Mineral Survey Bulletin 42, 221 p.

---, 1964, Geologic map of Duchesne County: Salt Lake City, Utah Geological and Mineralogical Survey Bulletin 72, scale 1:404,800.

Utah Division of Energy, 1991, Utah Energy Statistical Abstract: Utah Division of Energy, Department of Natural Resources.

Utah Division of State Lands and Forestry, 1992, Draft Book Cliffs general management plan: Utah Department of Natural Resources, 51 p., appendices.

Uygur, Kadir, 1983, Diagenesis and reservoir qualities of the Jurassic Navajo (Nugget) Sandstone in Utah and southwestern Wyoming: Salt Lake City, University of Utah unpublished PhD thesis, 320 p.

Uygur, Kadir, and Picard M.D., 1985, Mesozoic stratigraphy of the Uinta Basin, northeast Utah: Salt Lake City, Utah Geological Association Publication 12, p. 21-37.

Weiss, M.P., Witkind, I.J., and Cashion, W.B., 1990, Geologic map of the Price 30' X 60' quadrangle, Carbon, Duchesne, Uintah, and Wasatch counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1981, scale 1:100,000.

Wells, L.F., 1958, Petroleum occurrence in the Uinta Basin, *in* Habitat of oil, a symposium: American Association of Petroleum Geologists, p. 344-365.

Wenger, W.J., Hubbard, R.L., and Whisman, M.L., 1952, Separation and utilization studies of bitumens from bituminous sandstones of the Vernal and Sunnyside, Utah deposits, Part 2 - Analytical data on asphalt properties and cracked products of the separated bitumens: U.S. Bureau of Mines, Report of Investigations 4871, p. 11-28.

Wiley, D.R., 1967, Petrology of bituminous sandstones in the Green River Formation, southeastern Uinta Basin, Utah: Salt Lake City, University of Utah unpublished masters thesis, 94 p.

Witkind, I.J., Lidke, D.J., and McBroome, L.A., 1978, Preliminary geologic map of the Price 1° by 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 78-465, scale 1:250,000.

Wood, R.E., and Ritzma, H.R., 1972, Analysis of oil extracted from oil-impregnated sandstone deposits in Utah: Salt Lake City, Utah Geological and Mineral Survey Special Studies 39, 19 p.

Young, G.E., 1976, Geology of Billies Mountain quadrangle, Utah County, Utah: Provo, Brigham Young University Geology Studies, v. 23, part 1, p. 205-280.

ERRATA

Following are corrections to Utah Geological Survey Open-File Report 335, "*Tar-Sand Resources of the Uinta Basin, Utah*".

- On page 5, the caption for table 1 should read:

  Summary of tar-sand resources of the Uinta Basin (after Ritzma, 1979 and Oblad and others 1987).

- On page 120, the reference for Ritzma, 1987 should be deleted and the following reference should be inserted at its correct alphabetical position on page 118:

  Oblad, A.G., Bunger, J.W., Hanson, F.V., Miller, J.D., Ritzma, H.R., and Seader, J.D., 1987, Tar sand research and development at the University of Utah, *in* Holander, J.M., editor, Annual Review of Energy, Annual Reviews Inc., Palo Alto, California, v. 12, 1987, p 283-356.