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Gary B. Glass, State Geologist

REPORT OF INVESTIGATIONS No. 30

TRAPPER CANYON TAR SAND DEPOSIT, BIG HORN COUNTY, WYOMING: AN EXHUMED STRATIGRAPHIC OIL TRAP

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Alan J. Ver Ploeg and Rodney H. De Bruin

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Front cover. Tensleep Sandstone outcrop exhibiting large-scale wedge planar cross-bedding in the upper middle portion of the outcrop. See Section 3, Figure 6. This outcrop is located one mile east of the Trapper Canyon deposit and represents the most complete exposure of Tensleep Sandstone in the vicinity of the Trapper Canyon deposit.

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INTRODUCTION

The Trapper Canyon Tar Sand Deposit is located in the eastern Bighorn Basin, approximately 25 miles east of Greybull, Wyoming (Figure 1). This tar sand occurrence was first reported in the literature by N.H. Darton in U.S. Geological Survey Professional Paper 51, published in 1906; however, local ranchers were probably aware of the occurrence long before that date. N.H. Darton also conducted the earliest geologic mapping of the area and includes a general geologic map in his Professional Paper. More recently, B.T. Vietti (1977) examined and described the geohydrology of an area that included the Trapper Canyon Deposit. Vietti's description also contained a generalized geologic map. Prior to this present report, no detailed mapping of the Bush Butte Quadrangle or examination of the Trapper Canyon Tar Sand Deposit has been completed and published.

In addition to a detailed geologic map of the Trapper Canyon Tar Sand Deposit, this report provides descriptions of the tar zone and the adjacent barren zones. Samples collected in the field were analyzed for porosity, permeability, oil saturation, and characteristics of the oil. Thin sections of material from both the tar zone and barren zones were examined to determine textural characteristics and kinds of pore-filling cements. Samples were examined using the scanning electron microscope to gain insight into the diagenesis of the reservoir rock and the trapping mechanism.

The Trapper Canyon Tar Sand Deposit was investigated because it was considered potentially commercial and because results of the study might help in forming an economical plan for developing this deposit and similar deposits elsewhere in Wyoming. Also, the area provides an excellent opportunity to examine surface exposures of a tar sand deposit.

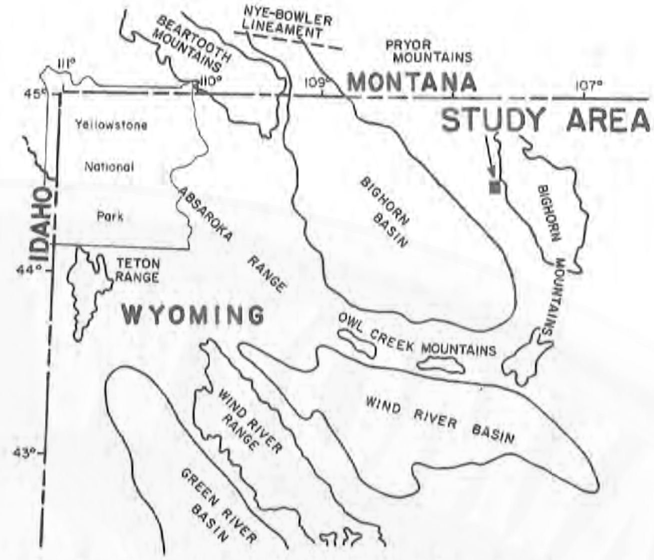

Figure 1. Location of study area.

The final phase of the study involved mapping the Bush Butte Quadrangle and looking for additional tar sand deposits in the mapped area. The search for additional deposits was based on a model developed for the Trapper Canyon Deposit.

TECTONIC AND DEPOSITIONAL HISTORY OF THE BIGHORN BASIN

The Bighorn Basin is an oval-shaped, northwest-trending structural basin, approximately 120 miles long and a maximum of 90 miles wide (Figure 1). The basin is bounded on the north and east by the Nye-Bowler lineament and the Pryor and Bighorn Mountains, and on the south and west by the Owl Creek, Absaroka, and Beartooth Mountains. During the Paleozoic Era and most of the Mesozoic Era, the area was part of the stable shelf region east of the Cordilleran geosyncline. Approximately 2,000-3,500 feet of Paleozoic sediments are preserved in this shelf region, in contrast to over 26,000 feet in the geosyncline in the area west of the Wyoming-Idaho State line (Stone, 1967). Mesozoic rocks in the basin are approximately 10,000-12,000 feet thick (Thomas, 1965). The present structural configuration of the basin is a result of the Late Cretaceous - early Eocene Laramide orogeny (Blackstone, 1963). It was during this orogeny that the peripheral mountain uplifts experienced their major growth. Synorogenic and postorogenic deposition accounted for up to 9,000 feet of Tertiary basin fill (Eardley, 1962).

The Paleozoic rocks in the Bighorn Basin (Figure 2) represent transgressive and regressive cycles of deposition on a stable shelf. Isopach maps constructed by Thomas (1965) show a northward tilting in the Bighorn Basin region and a resulting truncation of the Ordovician, Devonian, and Mississippian sediments in the south. No Silurian rocks are preserved in the basin; the Bighorn Basin may have been a positive area in Silurian time. The Cambrian through Mississippian rocks include shallow-water shelf carbonates and some interspersed shales and transgressive sands. Late Mississippian uplift of the Madison carbonates led to the development of an erosional karst surface, upon which the carbonates and clastics of the Mississippian and Pennsylvanian Amsden Formation and the dominantly eolian sands of the Pennsylvanian Tensleep Sandstone were deposited. Development of a broad, northwest-southeast-trending arch across Wyoming tilted the Tensleep surface to the southwest, which in turn caused truncation and thinning of the Tensleep, especially in the northeast portion of the basin (Blackstone, 1963). Middle Permian transgression then deposited marine Phosphoria rocks unconformably over the partially truncated Tensleep Sandstone. The Phosphoria thins toward the north due to onlap onto the underlying, tilted Tensleep. Sea level fluctuations brought about a north-south-trending facies change in the eastern portion of the basin, with red beds and evaporites of the Goose Egg Formation deposited eastward and carbonates deposited westward (seaward) (Thomas, 1965).

Except for Upper Cretaceous rocks, the majority of the Mesozoic and Paleozoic rocks (Figure 2) are characterized by transgressive and regressive cycles on a stable shelf. A general westerly regression occurred during the Triassic, when Chugwater red beds and evaporites were deposited on the shelf area which later became the Bighorn Basin. Southerly tilting and truncation near the end of the Triassic produced a thinning of sediments to the north (Thomas 1965). The Triassic deposits are unconformably overlain by Jurassic sediments ranging from Gypsum Spring red-bed facies and evaporites to Sundance shallow-marine sandstones, limestones, and shales, capped by varicolored nonmarine Morrison clastics (Stone, 1967). Thinning of Late Jurassic deposits along a northwest-southeast trend in the center of the basin indicates development of a subtle, northwest-plunging arch extending the entire length of the basin, probably the northwest projection of the present Casper Arch (Thomas, 1965). Uplift and tilting of these Jurassic sediments again resulted in thinning toward the south. In the Early Cretaceous, marine deposition was dominant again, with Cloverly, Thermopolis, and Mowry marine shales and sands unconformably deposited on the nonmarine deposits of the Upper Jurassic. The arching which had occurred during the Late Jurassic apparently continued into the Early Cretaceous, with some bifurcation indicated by the thinning of units (depicted on isopach maps compiled by Thomas, 1965). Once again, units thin from north to south. Continuous deposition occurred into the Late Cretaceous. A series of rapid transgressions and regressions which resulted in the deposition of several Frontier sandstone wedges also probably indicates the initiation of the Laramide orogeny and the beginning of the basin as we see it today. The eastward withdrawal of the Cretaceous sea is recorded by the deposition of a dominantly regressive Mesaverde clastic wedge (Stone, 1967). This was followed by the deposition of marine

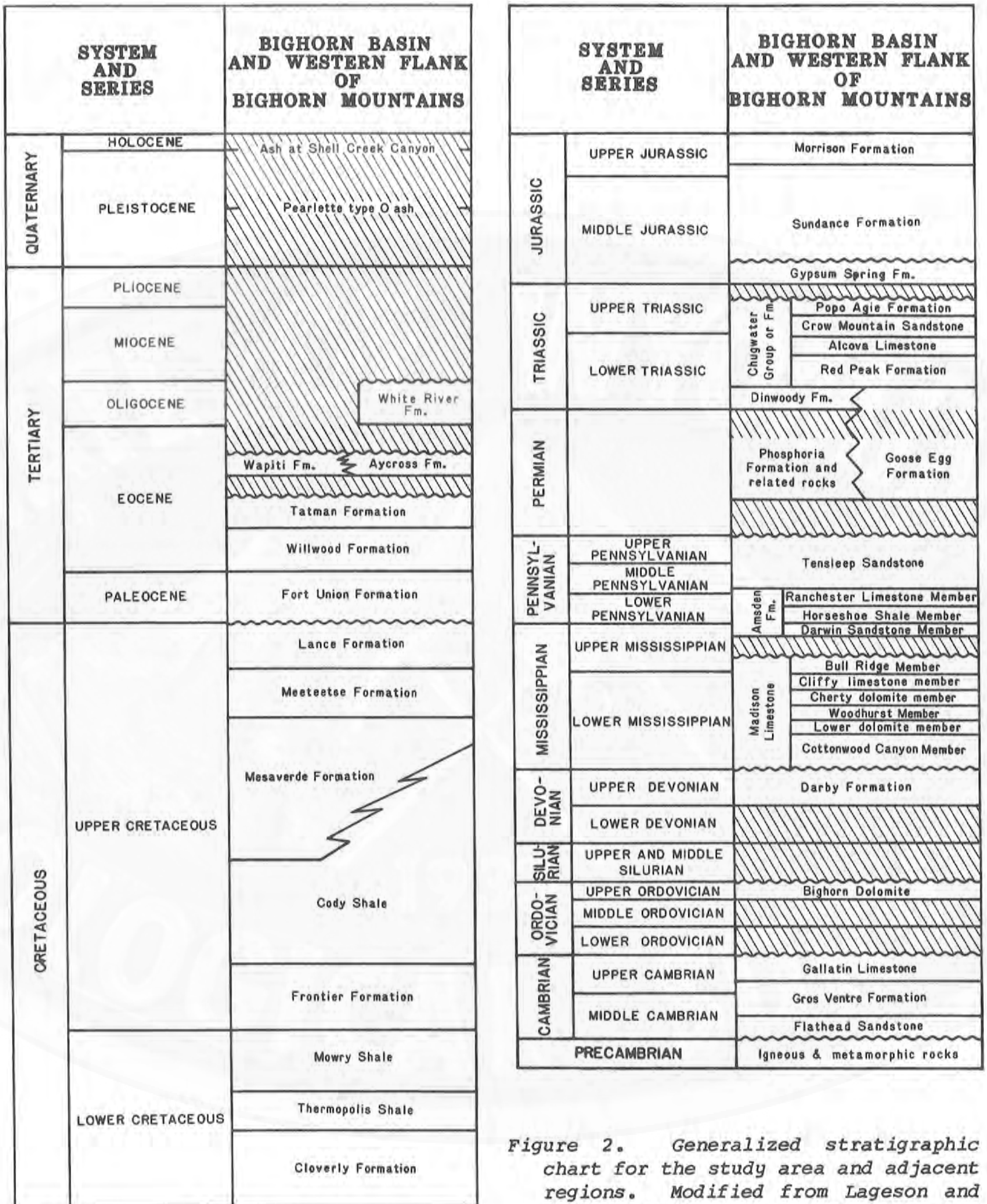

Figure 2. Generalized stratigraphic chart for the study area and adjacent regions. Modified from Lageson and others, 1979; Love and Christiansen, 1980; Sando and others, 1975; and the Wyoming Geological Association, 1969.

shale in the eastern portion of the basin and Meeteetse nonmarine sandstone, claystone, and coal to the west. Nonmarine deposition of the Lance Formation at the end of the Cretaceous indicates a quiet tectonic period.

With the beginning of the Cenozoic (see Figure 2), Laramide orogenesis intensified. Paleocene Fort Union conglomerate and fluvial deposits derived from debris from the marginal uplifts were laid down unconformably on older basin-margin deposits which dipped steeply toward the basin center. However, Paleocene deposits in the center of the basin were laid down nearly conformably with the underlying Mesozoic deposits (Thomas, 1965). Older, preexisting anticlines and folds were intensified at this time, and numerous new folds, especially on the basin margin parallel to the northeastern and southwestern flanks, were initiated. These folds were mostly asymmetrical with the steep limb on the mountainward side. Some of the folds were thrust-faulted on their steep limb in response to compressional forces. Cross faults, perpendicular to fold axes, were also common. Uplift and folding continued into the Eocene. Debris from the marginal uplifts (Willwood Formation) was deposited unconformably on the upturned Paleocene deposits on the basin margin. Toward the basin center, the Willwood rests disconformably on older rocks. Middle Eocene Tatman deposition, mainly lacustrine, was followed by deposition of debris from volcanic activity in northwestern Wyoming, through the Tertiary. This volcanism supplied sediments which helped fill the basin in late Tertiary time, but these sediments were mostly removed by the subsequent erosion that created the present topography (Thomas, 1965).

OIL AND GAS IN THE BIGHORN BASIN

The Bighorn Basin is primarily an oil-producing basin, where over 150 fields produce from 23 different formations ranging in age from Cambrian to Paleocene (Stephenson and others, 1984). Cumulative oil production is just over two billion barrels, the majority of which came from structural traps on the basin's flanks. Paleozoic rocks are the most important reservoirs; the Tensleep Sandstone, Phosphoria Formation, and Madison Limestone, in that order, are the most prolific reservoir rocks in the basin (Figure 2).

On the basis of an extensive study of oil and gas accumulations in the Bighorn Basin, Stone (1967) concluded that the source of essentially all the oil and gas found in Paleozoic reservoirs in the basin is the dark, phosphatic, fine-grained, marine facies of the Phosphoria Formation. Primary migration began immediately after deposition of Triassic sediments and was completed by Early Jurassic time. Hydrocarbons accumulated in regional stratigraphic traps created by (1) updip facies change, pinchout, and truncation of the reservoir rocks in the Phosphoria and (2) irregular truncation of thick Tensleep Sandstone beds prior to the deposition of the impervious Phosphoria / Goose Egg Formations (especially prevalent east of the area covered by marine carbonate facies of the Phosphoria) (Stone, 1967). Oil and gas in some of these stratigraphic traps were later released by fracturing and faulting associated with Laramide folding. These hydrocarbons moved into older Paleozoic reservoir rocks within Laramide and older structures where they were trapped in common pools. The occurrence of a common oil/water contact, in many cases, is attributed to fractures joining the reservoirs. Also, the oil/water contact is commonly tilted as a result of hydrodynamic flow (Stone, 1967).

Mesozoic rocks represent a much lower percentage of the basin's production and reserves. The Upper Cretaceous Frontier Formation (Figure 2) accounts for the majority of the production from the Mesozoic rocks. Source rocks include the Cody, Frontier, Mowry, and Thermopolis black shale units (Stone, 1967).

Although the majority of the basin's production comes from anticlinal or other structural traps, many important stratigraphic traps occur. The largest of these is Cottonwood Creek Field in the southeast corner of the basin. The trap is the result of an eastward, updip facies change from Phosphoria carbonate into impermeable red shale and anhydrite facies of the Goose Egg Formation. The Bonanza-Nowood area, also in the southeast corner of the basin, is another example of a stratigraphic trap. In this case, a thick erosional remnant of Tensleep has been preserved beneath the Goose Egg - Tensleep unconformity, forming a truncational trap in the Tensleep (Stone, 1967).

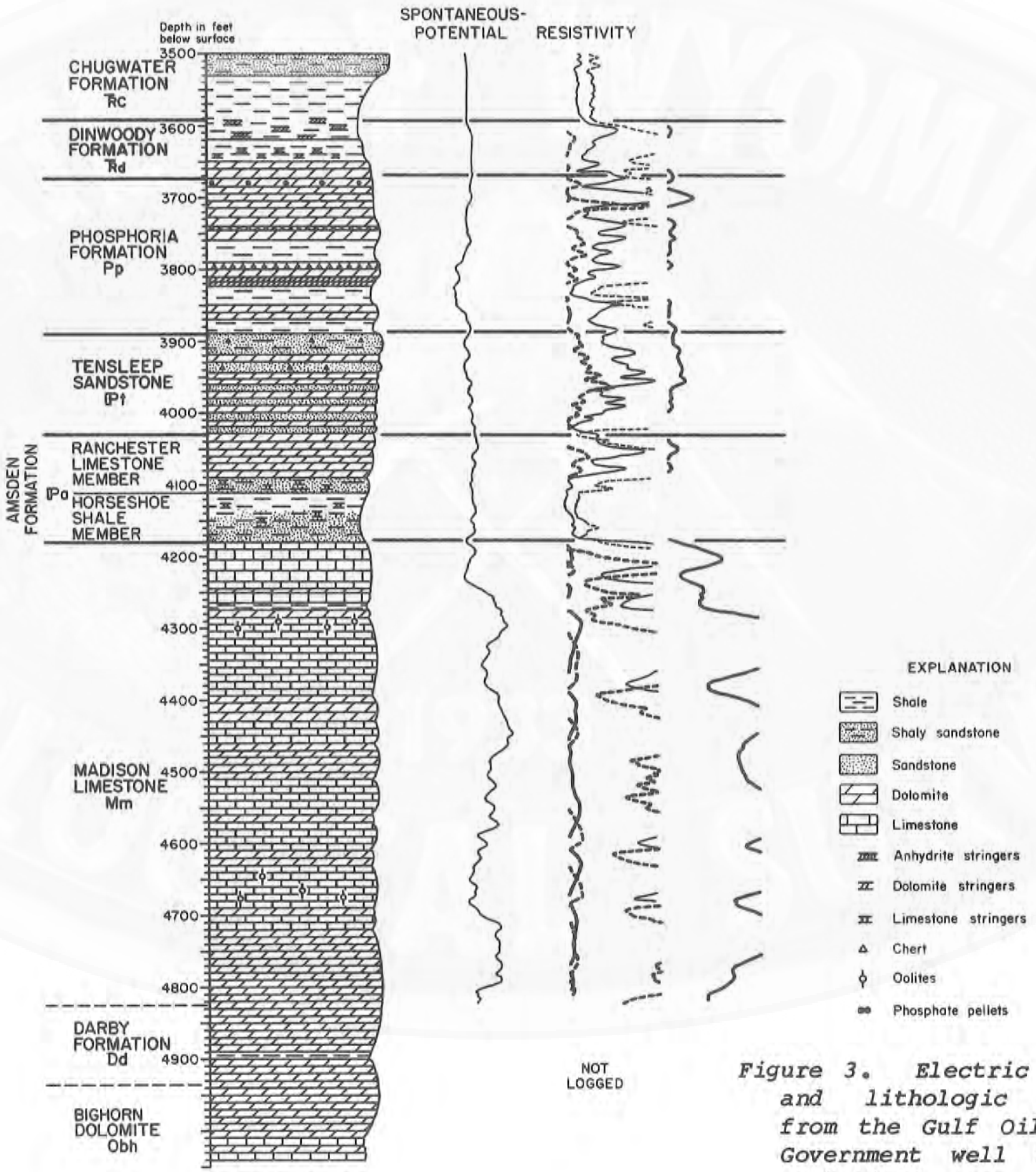

Figure 3. Electric log and lithologic log from the Gulf Oil #1 Government well near Lamb Field.

Lawson and Smith (1966) feel that many of the structurally controlled traps are influenced by stratigraphic effects, including intraformational variations in permeability, and (as was the case with Bonanza-Nowood) incised channels in the Tensleep surface which were later filled with impervious Goose Egg sediments. Later Laramide folding may have been superimposed on or near these primary traps.

GEOLOGIC SETTING OF THE BUSH BUTTE QUADRANGLE

Stratigraphy

The rocks exposed in the Bush Butte Quadrangle range in age from the Ordovician Bighorn Dolomite to the Permian and Triassic Goose Egg Formation. Although seven mappable formations crop out in the area, detailed stratigraphic sections are presented only for the Tensleep Sandstone. Recorded thicknesses of all these units are based on outcrop observations. Figure 2 shows the formations which crop out in the Bighorn Basin and on the western flank of the Bighorn Mountains, and Plate I shows their distribution in the Bush Butte Quadrangle.

The nearest oil and gas well which has penetrated the formations exposed in the Bush Butte Quadrangle is near the north end of East Lamb Anticline (see page 27) in sec. 31, T.52N., R.92W. Figure 3 shows how the formation boundaries are picked on an electric log and how the formations are described in the subsurface.

ORDOVICIAN BIGHORN DOLOMITE

The oldest formation that crops out in the study area is the Bighorn Dolomite. This dolomite was first described from surface exposures on the eastern slope of the Bighorn Mountains by Darton (1904). Because the basal 150 to 200 feet of the formation is not exposed in the quadrangle, its maximum exposed thickness is 200 feet. This upper sequence typically consists of white to cream and light brown to dark brown, finely crystalline to sucrosic dolomite, with some chert. The weathered surface has deep pits, and the formation is thin-bedded at the top (as shown in Figure 4), with a more massive unit extending to the base of its exposure. There is a southward thinning of the Bighorn Dolomite from about 500 feet in the northeastern portion of the Bighorn Basin to less than 200 feet in the southern part of the basin (Thomas, 1965). The lithology suggests an aerated shelf environment of deposition. There is some controversy as to whether the Bighorn is entirely Upper Ordovician

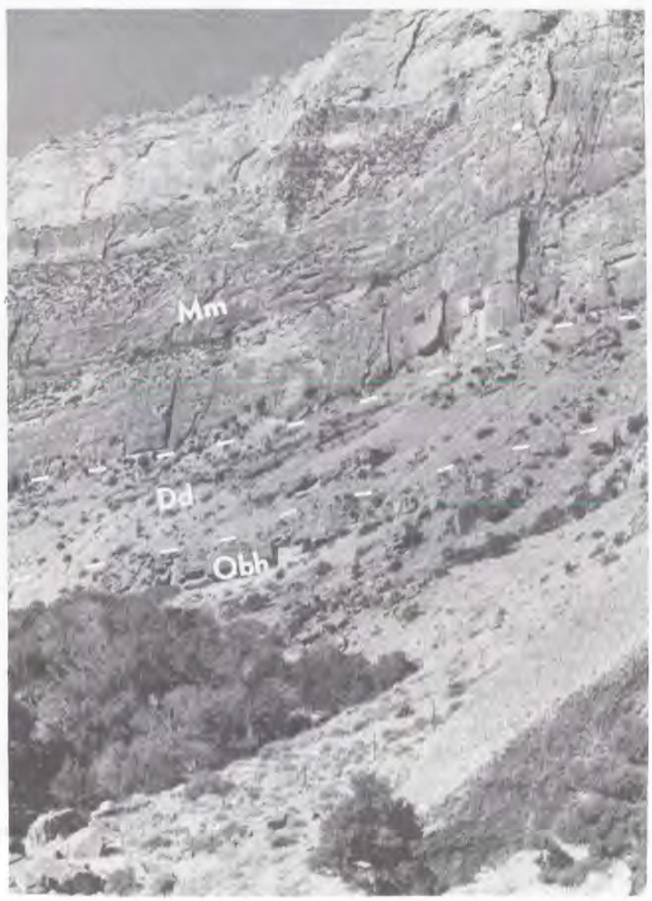

*Figure 4. Outcrop of the Madison Limestone (*Mm*), Darby Formation (*Dd*), and the Bighorn Dolomite (*Obh*).*

or both Upper and Middle Ordovician in the Bighorn Basin (Mills, 1956). Love and Christiansen (1980) have assigned it an Upper Ordovician designation which is reflected in Figure 2. A lithologic log from the Lamb Field area (Figure 3) shows lithologies consistent with the rocks exposed in the Bush Butte quadrangle.

DEVONIAN DARBY FORMATION

Blackwelder (1918) named the Darby Formation for exposures in the canyon of Darby Creek on the west slope of the Teton Range. The Darby in the Bush Butte Quadrangle is extremely difficult to view closely since it crops out only in the shear walls of Trapper and Medicine Lodge Canyons (Plate I). The Darby rests unconformably on the Bighorn Dolomite and is separated from the overlying Madison Limestone by an erosion surface (Figure 2). (Sandberg (1967) has described a section, of what he calls Jefferson Formation, in Shell Canyon approximately 10 miles northwest of the Bush Butte Quadrangle. What we call the Darby in the study area seems equivalent to Sandberg's Jefferson.) The Darby is mainly finely crystalline to microcrystalline, grayish, yellowish, and greenish dolomite, silty dolomite, and sparse interbedded dolomitic shale and siltstone. Practically the whole formation is weakly to moderately resistant, and it usually forms a gently dipping, covered slope, in contrast to the shear walls of the Bighorn Dolomite below and the Madison Limestone above (Figure 4). The lithologic log of the Darby from near Lamb Field (Figure 3) shows lithologies similar to those in the Bush Butte Quadrangle. The Devonian section in the Bighorn Basin thins from 300 feet on the northwest flank to zero on the southeast flank (Benson, 1966), with approximately 100 feet exposed in the Bush Butte area (Plate I). The Darby is Upper Devonian (Figure 2), and Stone (1967) believes that it was deposited in an aerated shelf environment in most of the Bighorn Basin.

MISSISSIPPIAN MADISON LIMESTONE

The Madison Limestone was named by Peale (1893) for beds found in the Madison Range of southern Montana. The Madison thins from about 800 feet near Sage Creek in the northern part of the Bighorn Basin to less than 500 feet in the southern part (Mills, 1956). The thinning is due to onlap at the base and erosion at the top (Stone, 1967). In the Bush Butte Quadrangle, the Madison is approximately 600 feet thick (Plate I).

Lageson, Maughan, and Sando (1979) divide the Madison Limestone into several members in the Bighorn Mountains area (Figure 2). The basal Cottonwood Canyon Member is mainly conodont-bearing shale, siltstone, and silty dolomite. The lower dolomite member conformably overlies the Cottonwood Canyon Member and is thick-bedded, crinoidal dolomite and dolomitic limestone. The Woodhurst Member conformably overlies the lower dolomite member and consists of a lower cross-bedded, crinoidal dolomite or thick-bedded, oolitic limestone and an upper silty, thin-bedded, cyclically interbedded, fine-grained limestone and bioclastic crinoidal limestone. The Woodhurst Member is conformably overlain by the cherty dolomite member: shattered and brecciated, thin-bedded, fine-grained cherty dolomite and dolomitic limestone. The cherty dolomite member is conformably overlain by the cliffy limestone member which is cherty, fine-grained to coarse-grained, mostly thick-bedded, bioclastic crinoidal limestone and dolomite. The top member is the Bull Ridge Member, which conformably overlies the cliffy limestone member.

The Bull Ridge Member has a lower unit of yellow and red shale and siltstone with minor thin carbonate beds and an upper unit of thin-bedded to medium-bedded, fine-grained to medium-grained, stromatolitic limestone or dolomite with some chert (Lageson, Maughan, and Sando, 1979). The Bull Ridge Member of the Madison in the Bush Butte Quadrangle

Figure 5. Outcrops of the Goose Egg Formation (TRPge), Tensleep Sandstone (IPt), the Ranchester Limestone Member of the Amsden Formation (IPar), and the Horseshoe Shale Member of the Amsden (IPah) in the southern part of the Bush Butte Quadrangle.

(Figure 4) commonly has sinkholes and solution cavities filled with Amsden sediments; the Horseshoe Shale Member of the Amsden commonly stains the Bull Ridge Member red.

MISSISSIPPIAN AND PENNSYLVANIAN AMSDEN FORMATION

The lowest member of the Amsden Formation along the western flank of the Bighorn Mountains is the Darwin Sandstone (Figure 2). The Darwin was deposited in irregularities and solution cavities in the karst topography developed on the Madison Limestone surface. Sando, Gordon, and Dutro (1975) show a small amount of Darwin deposited in sinkholes in the upper Madison at Shell Creek about 10 miles northwest of the study area. At Paintrock Creek, about 6 miles south of the Bush Butte Quadrangle, they show 20 feet of Darwin; and at Tensleep Canyon, still farther south, the Darwin thickens to about 100 feet.

No Darwin was seen in the Bush Butte Quadrangle, but the contact between the Madison and Amsden was often covered. At every outcrop where the contact was not covered, the Horseshoe Shale Member of the Amsden, which conformably overlies the Darwin elsewhere in the Bighorn Basin, was lying directly on the Madison Limestone. The Darwin is considered Mississippian (Sando, Gordon, and Dutro, 1975), and was named by Blackwelder (1918) for exposures near Darwin Peak in the Gros Ventre Range, Wyoming.

The type section of the Horseshoe Shale Member of the Amsden is on Amsden Creek in Sheridan County, Wyoming, and was described by Mallory (1967). In the Bush Butte area the Horseshoe Shale is principally shale, siltstone, and mudstone, and usually weathers red or purple. It is poorly exposed in the study area. It forms red soil slopes that are often covered by talus and chert from the overlying Ranchester Limestone (Figure 5). The Horseshoe

Shale represents an offshore facies of the transgressing Amsden sea (Sando, Gordon, and Dutro, 1975) deposited under stable tectonic conditions in quiet, moderately deep water (Mallory).

The type section of the Ranchester Limestone Member (described by Mallory, 1967), which conformably overlies the Horseshoe Shale, is also on Amsden Creek. In the study area it is a

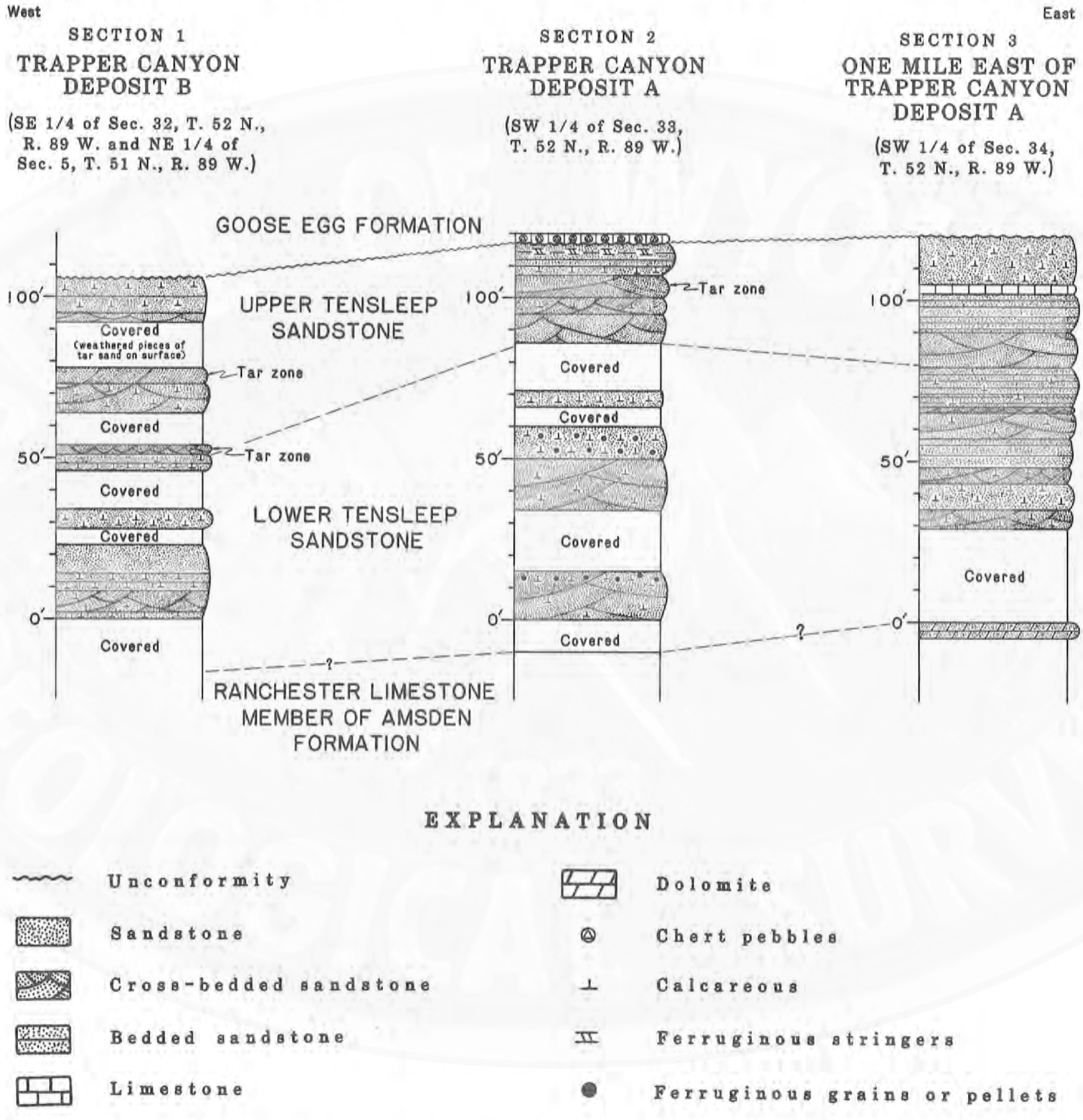

Figure 6. Measured sections of the Tensleep Sandstone at and adjacent to the Trapper Canyon Deposit. See Appendix A for descriptions of the measured section, and Plate I for their locations.

sequence of sandstone, shale, and interbedded cherty limestone and dolomite. Carbonates predominate, and most are thin-bedded to thick-bedded, fine-grained to coarsely crystalline, yellow-gray-weathering dolomite and dolomitic limestone. There is also some thin-bedded, fine-grained to medium-grained, gray- to purple-weathering limestone. Many of the carbonate beds contain red or brown chert in nodules, lenses, or veins. There are also a few thin beds of red shale in the upper half of the member. Sando, Gordon, and Dutro (1975) believe that the Ranchester Limestone is a marine deposit that signals the end of the Amsden transgression. The total thickness of the Amsden in the Bush Butte Quadrangle approaches 200 feet, and the thicknesses of the Horseshoe Shale and the Ranchester Limestone Members are nearly equal (100 feet). Figure 3 shows these two members on both the lithologic log and the electric log from the Lamb Field area.

PENNSYLVANIAN TENSLEEP SANDSTONE

The Tensleep Sandstone was named by Darton (1904) from outcrops just east of Ten Sleep, Wyoming. In general, the Tensleep thickens from around 60 feet in the northern Bighorn Basin to about 200 feet in the southern part of the basin.

In the present report, we describe three sections of the Tensleep from outcrops at or near the Trapper Canyon Tar Sand Deposit (Figure 6; also see Plate I and Appendix A). (These sections were used to document the presence of tar in a particular portion of the upper Tensleep.) The thinnest of these was 105.5 feet thick and the thickest was 120 feet thick; the average thickness for the Tensleep Sandstone in the Bush Butte Quadrangle is about 115 feet (Plate I). Mankiewicz and Steidtmann (1979) measured a section that is well over 200 feet thick at Alkali Creek, only two miles south of the Bush Butte Quadrangle; Figure 7 shows the Tensleep very near their section. It appears that the upper Tensleep eolian sequence, which is about 150 feet thick and less eroded at Alkali Creek, accounts for the thickening of Tensleep in that area.

Large portions of the lower Tensleep were covered where the sections were measured (Figure 6); however, these covered intervals were observable elsewhere. Although the lower Tensleep is

Figure 7. Outcrop of very thick Tensleep Sandstone sequence just south of the Bush Butte Quadrangle. The upper Tensleep eolian sequence is nearly 150 feet thick in this area.

mainly supratidal to subtidal and lagoonal deposits (Mankiewicz and Steidtmann, 1979), there are a few eolian sands and associated sabkha deposits (Figure 6). The lower Tensleep consists of thin interbeds of yellow to pinkish-gray and light gray, fine to medium crystalline dolomite; red and green mudstone; and white to gray sandstone with some detrital carbonate -- it appears that most of the carbonate and mudstone units were covered where the sections for this study were measured. The scale of cross-bedding is much smaller in the lower than in the upper Tensleep; sets in the lower Tensleep seldom exceed five feet in thickness. The Tensleep Sandstone conformably overlies the Ranchester Limestone Member of the Amsden Formation in the study area.

The upper Tensleep in the Bush Butte Quadrangle is mostly sandstone (Figure 6). The sandstone is very-fine-grained to fine-grained, well-sorted, subrounded quartz sand which is cemented by silica or (dominantly) carbonate material. It was deposited in an eolian and related sabkha environment. The eolian sands are thick bedded and finely laminated, with large-scale, wedge-planar cross-bedding in sets up to 25 feet thick. The orientation of cross-bedding indicates a southwest sediment transport direction; the Canadian Shield to the northeast was probably the source for these sediments. The tar in this area always occurs in these cross-bedded sands, and the tar deposits are somewhat discontinuous.

In contrast, the sabkha and interdunal deposits in the Tensleep are usually less than ten feet thick, are seldom continuous for more than a few hundred feet, and are composed of sandy dolomite and dolomitic sandstone which may contain evaporite minerals. These deposits form the cap rock for the tar (Figure 6) and usually show some faint traces of bedding. X-ray analysis shows that dolomite is present; however, in many instances, calcium carbonate has replaced much of the dolomite. Figure 8

Figure 8. View of the Trapper Canyon Deposit B. The Goose Egg Formation (ⱤPge) overlies the Tensleep Sandstone (ⱣPt). Note the eolian sequence in the middle of the photograph and the interdunal sequence in the foreground.

shows an upper Tensleep eolian sequence in the middle of the figure with an interdunal or sabkha deposit in the foreground.

Figure 3 shows the Tensleep in the subsurface near Lamb Field, 20 miles west of the Bush Butte Quadrangle. The thickness there agrees well with thicknesses measured in the Bush Butte Quadrangle, and the lithology is consistent with that described for the study area.

PERMIAN AND TRIASSIC GOOSE EGG FORMATION

The contact between the Tensleep Sandstone and the overlying Goose Egg Formation is often marked by a two- or three-foot-thick chert and limestone pebble conglomerate which is locally known as the "Nowood conglomerate" (Figure 9). The poor sorting and lenticular nature of the Nowood suggest a fluvial origin or the reworked deflation lag of a wadi (Mankiewicz and Steidtmann, 1979).

The Goose Egg Formation crops out in the Bush Butte Quadrangle (Plate I) and also a few miles west in Trone Gulch. It unconformably overlies the Tensleep Sandstone (Figure 2). The Goose Egg was first described by Burk and Thomas (1956) and was named for an exposure near the Goose Egg Post Office about 15 miles southwest of Casper, Wyoming. The Goose Egg in the study area consists of deep red, thin-bedded, sometimes calcareous and somewhat gypsiferous siltstone interbedded with pale-green to purple, thin-bedded, fine-textured dolomite and dolomitic limestone containing some gypsum. Several massive, pale-gray to white gypsum beds that are up to eight feet thick occur throughout the formation. The "Nowood conglomerate" occurs locally at the base of the Goose Egg Formation.

West of the study area, the Goose Egg Formation grades into the Phosphoria Formation and the overlying Dinwoody Formation. The Phosphoria contains the source rocks for most of the oil that has been discovered in the Bighorn Basin. It also contains good reservoir rocks, and much production comes from the Phosphoria. Although the lithologic log from the Lamb Field area (Figure 3) shows Phosphoria and Dinwoody, the pre-

Figure 9. "Nowood Conglomerate" at the contact between the Tensleep Sandstone and the Goose Egg Formation.

sence of red beds and some evaporites indicates that the Goose Egg is not far to the east.

Structure

The major structure in the Bush Butte Quadrangle is an anticline which occurs in the southwest quarter of the Quadrangle and which the authors have named the Black Mountain Anticline. It is interpreted as a continuation of an anticline which occurs in the Black Mountain Quadrangle directly northwest of the Bush Butte Quadrangle (Finley, 1982). Black Mountain Anticline is superimposed on a regional southwest dip of five to eight degrees. It trends northwest-southeast and is asymmetric toward the northeast; the dip of the limbs is shallow (Plate I). There are several small, parallel anticlinal and synclinal structures associated with it (Plate I). Just a few hundred yards south of the quadrangle, there is a major east-west-trending normal fault that has an estimated 50 to 75 feet of displacement with the south side downthrown. There is also a north-south-trending normal fault, which is downthrown to the west, approximately two miles east of the quadrangle.

TRAPPER CANYON TAR SAND DEPOSIT

Location and Exploration History

The Trapper Canyon Tar Sand Deposit is located in sections 32 and 33, Township 52 North, Range 89 West in Big Horn County, Wyoming (Figure 10 and Plate I). The earliest published references to the deposit were made in U.S. Geological

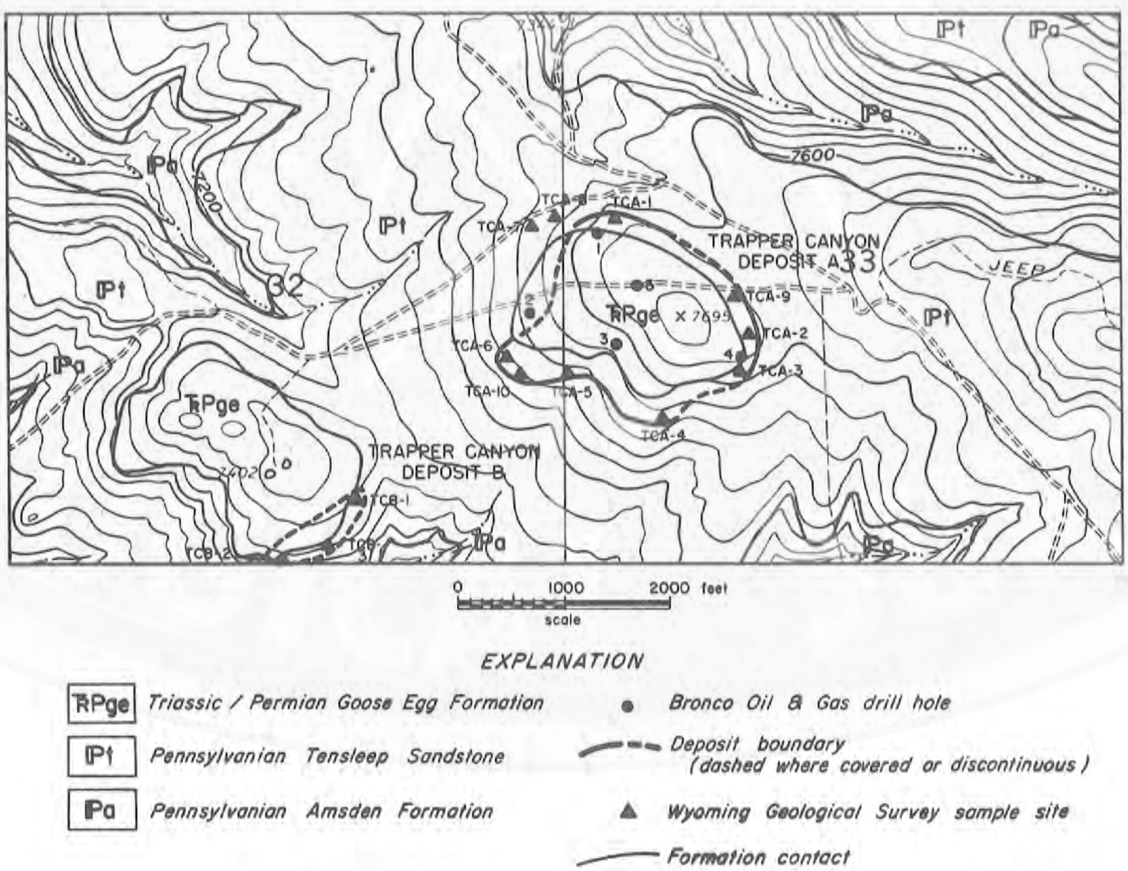

Figure 10. Generalized map of Trapper Canyon Deposits A and B, showing sample sites and drill holes (T.52N., R.89W.). See Appendix B for core analyses.

Survey reports just after the turn of the century. Darton (1906) stated:

A deposit of asphalt occurs in the Tensleep Sandstone on the west slope of the Bighorn Mountains in sections 28, 29, 32, and 33, T.52N., R.89W. The thickness is stated to be 6 feet, but the area has not been ascertained. The material consists largely of asphalt intimately mixed with coarse sand.

The deposit was also referred to by Washburne (1908), who located it one township to the west, by error. He stated:

The asphalt occurs in blanket form, as a bed 10 feet thick, lying on a hilly surface of limestone or sandstone. About half of the bed is reported to be asphalt, and the remainder to be sand and rock which the asphalt binds together in a firm mass. The bed is overlain by 10 feet or more of incoherent rock fragments and soil. Apparently the asphalt exuded from Pennsylvanian rocks at this place and cemented the base of the rock mantle. The occurrence of so large a deposit of asphalt is an excellent argument for the presence of oil in the upper Paleozoic strata.

Washburne's information was obtained through personal communication from a Mr. Peay of Basin, Wyoming.

As we define its location in the present report, the deposit is on Federal land managed by the U.S. Bureau of Land Management (BLM). Some attempts were made in the past to develop the deposit. Due to problems with tar-sand leasing, the rights to the oil were not legally obtained and recent attempts at development were treated as trespass. Bronco Oil and Gas Company, of Denver, Colorado, currently holds a subsurface drilling lease for oil and gas, but this lease does not apply to surface outcrops of tar sand. They are currently assessing whether the tar is producible by conventional drilling techniques. Previously, Big Horn Tar Sands and Oil Company had claimed the deposit for uncommon glass sand and attempted to process some of the outcrop of tar sand on the north end of the deposit. The Bureau of Land Management failed to recognize uncommon glass sand and invalidated the claim, and Big Horn Tar Sands and Oil Company was shown to be in trespass. Their operation was abandoned in November 1981. Older surface disturbances indicate that there were other attempts to mine the deposit prior to the effort by Big Horn Tar Sands and Oil Company, but the authors have no information regarding these earlier efforts.

Description of Deposit

The deposit consists of two tar occurrences, separated by more than one quarter mile. The authors have designated these Trapper Canyon Deposit A and Trapper Canyon Deposit B (Figure 10 and Plate I). Sampled outcrops in Deposits A and B varied in saturation from relatively continuous tar saturation (Figure 11A) to discontinuous saturation (Figure 11B).

The authors examined ten outcrop sites on Deposit A and three on Deposit B. The tar zones and the upper and lower bounding zones were sampled at each outcrop site. The sampling interval was two to four feet. We numbered samples at each site consecutively from the base upward. Whenever possible, we took samples large enough to permit the drilling of cores 1.25 inches in diameter, as required for tar analysis by Core Laboratories, Inc. of Aurora, Colorado. Core Laboratories analyzed each core for (1) permeability before and after tar extraction, (2) porosity before and after tar extraction, (3) tar saturation both as pore percent and as weight percent, (4) water saturation both as pore percent and as weight percent, and (5) grain density, saturated bulk density, and extracted bulk density. Results are tabulated in Appendix B, and results of the analyses for two sample sites are shown in Figure 12: these two sample sites (TCA-5 and TCB-1) are illustrated

Figure 11A. Typical outcrop of relatively continuous, tar saturated reservoir rock on the north side of Deposit A.

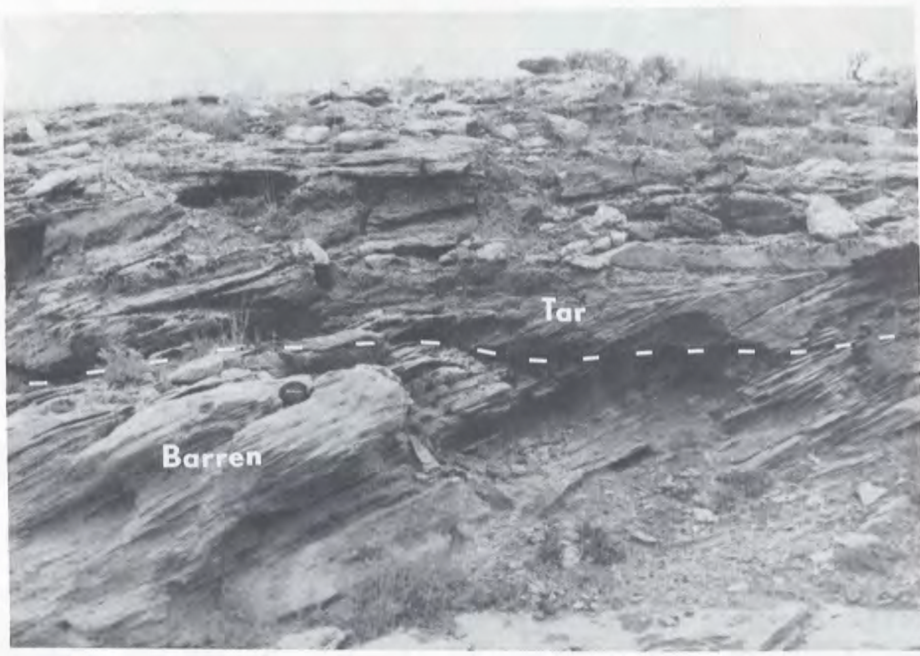

Figure 11B. Discontinuous tar saturation, with tar in dark upper zone underlain by cross-bedded, tight barren zone.

because they represent the thickest sampled zones from each deposit that yielded good permeability, porosity, and tar saturation data. Only the pre-extraction permeability and porosity data are plotted in Figure 12 because obtaining reliable data on the samples after extraction of the tar was difficult. In most cases, the samples were so friable that they broke up entirely after tar removal. Table 1 shows tar saturation for all sample sites. Average tar saturation ranges from 7.9 weight percent (TCA-5) to 15.1 weight percent (TCA-3).

No trends in permeability and porosity were apparent in the data from the tar-zone samples; this absence of trends is consistent with the nature of the reservoir rock. The reservoir rock is interpreted as eolian in origin. There is great variation in permeability and

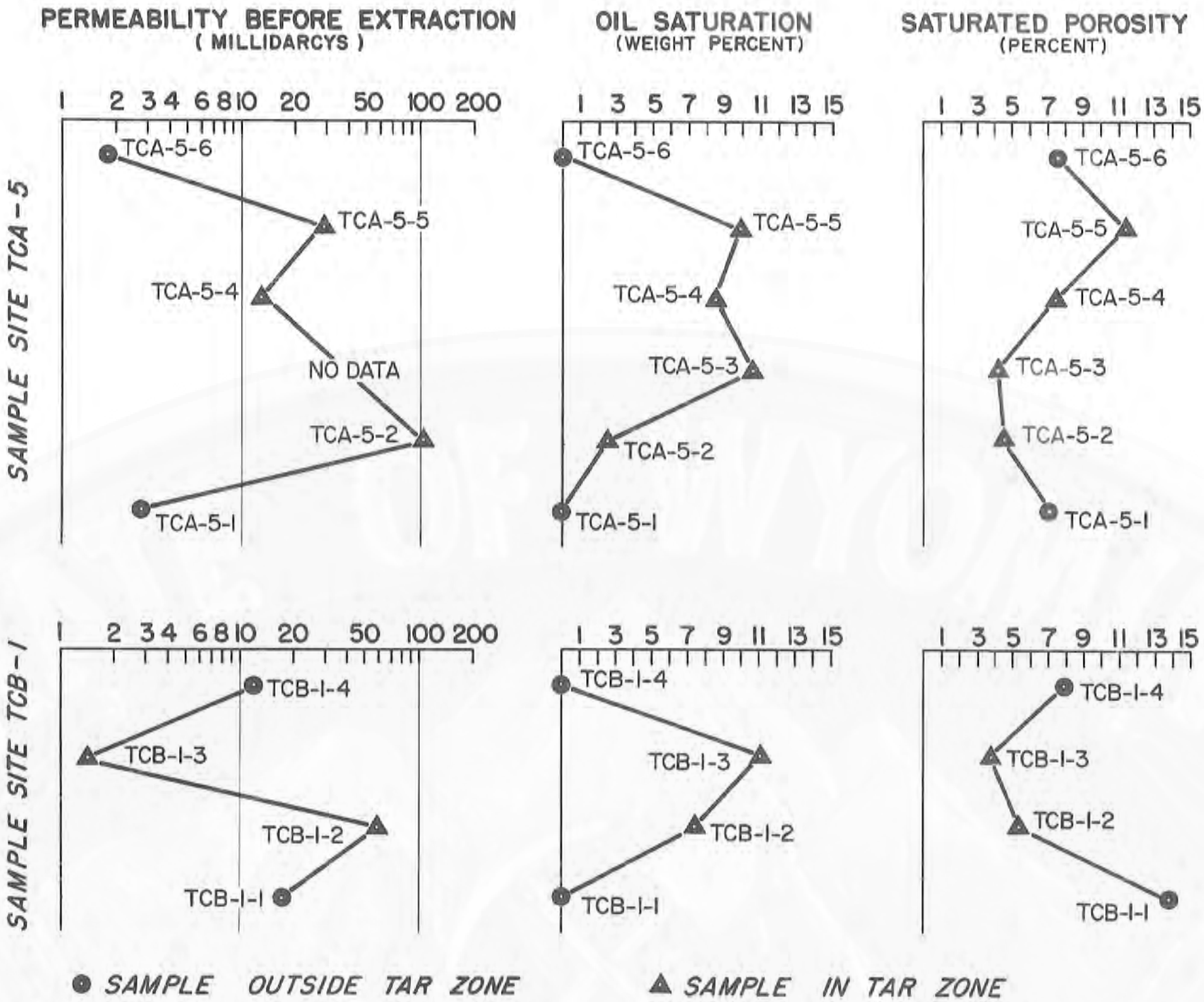

Figure 12. Permeability, tar saturation, and porosity plots for samples from sites TCA-5 (Trapper Canyon Deposit A) and TCB-1 (Trapper Canyon Deposit B). Sampled intervals are numbered from the base upward.

porosity within cross-bedded units, especially across laminae, due to grain-size variation and diagenesis. Complex porosity and permeability variations are documented in Pennsylvanian eolian reservoirs of several fields in Wyoming, including the Little Buffalo Basin, Brady, Lost Soldier, and Wertz fields (Ahlbrandt and Fryberger, 1981). Internal variation in permeability and porosity is the primary basis for discontinuity in the reservoir or tar zone (Figure 13).

The values obtained for permeability and porosity are deceptively low for the tar-saturated samples due to the effects of tar in the pore spaces. Removal of tar caused the friable reservoir rock to disintegrate, allowing no means of determining a true permeability or porosity. The values for the barren zones above and below the tar zone are more accurate measures of the true permeability and porosity for those zones since they are not affected by the presence of tar.

The expected permeability and porosity in the Trapper Canyon eolian reservoir may be estimated on the basis of a study done on Little Buffalo Basin (Emmett, Beaver and McCaleb, 1971), an oil field in the Bighorn Basin which

Table 1. Tar saturation values (in weight percent) for samples collected on Trapper Canyon Deposits A and B. Thickness of sampled tar intervals for Trapper Canyon Deposit A is shown in Figure 15. Thickness of sampled tar intervals for Trapper Canyon Deposit B was not recorded due to their thin, discontinuous nature.

Sample localities

	Deposit A										Deposit B		
Interval*	1	2	3	4	5	6	7	8	9	10	1	2	3
6	0.0				0.0								
5	12.6	0.0			9.9	0.0				0.0			
4	9.0	12.9		0.0	8.5	13.9				11.2	0.0		
3	10.5	13.6	0.0	11.5**	10.6	11.1				12.6	11.1		0.0
2	8.5	15.9	14.5	10.0	2.5	13.4				12.3	7.5	9.3	11.6
1	0.0%	0.0%	15.7%	0.0%	0.0%	0.0%	0.0%	0.0%	13.7%	2.2%	0.0%	11.3%	7.5%
$\overline{X}$†	10.0	14.1	15.1	10.8**	7.9	12.8	-	-	13.7	9.6	9.3	10.3	9.6

*Sampled intervals are numbered from the base upward.

† $\overline{X}$ = average from the sampled portion of the oil zone.

**For example, Sample No. TCA-4-3 shows 11.5% oil saturation. The average oil saturation in the oil zone of sampled outcrop TCA-4, as sampled in sample no. TCA-4-2 and TCA-4-3, is 10.8%.

- = barren

produces from the eolian portion of the Tensleep. The average permeability after extraction for eolian Tensleep Sandstone in this field was 61.3 millidarcys, and the average porosity after extraction was 14 percent. Some low-porosity, low-permeability zones in these cross-bedded sequences had permeabilities of 1 to 5 millidarcys and porosities of 8 percent or less. Emmett, Beaver, and McCaleb also noted that the average permeability parallel to the cross-bedding was four times greater than that across bedding planes. All of these values are probably somewhat lower than would be expected for the Trapper Canyon Deposit, since Little Buffalo Basin production is at an average depth of 4,600 feet and porosity and permeability have been shown to decrease with depth of burial (Fox and others, 1975).

Tar removed from samples was also analyzed for various properties, including elemental and petroleum composition, viscosity, gravity, and vanadium/nickel ratio. Bronco Oil and Gas Company submitted a tar sample from the deposit to

Figure 13. Tar zone, showing discontinuous tar saturation in the reservoir rock. Dark areas represent tar saturated zones. Light areas represent tight barren zones originally cemented with dolomite and in many cases replaced by calcite due to recent groundwater movement.

Rinehart Laboratories, Inc. of Arvada, Colorado for composition and viscosity analysis. Steve Barrell of the Bureau of Land Management at Worland, Wyoming also submitted a sample to the Laramie Energy Technology Center in Laramie, Wyoming for compositional and gravity analysis. Core Laboratories, Inc. of Aurora, Colorado determined nitrogen and sulfur content and gravity (°API) for tar from samples collected for this study. The results show good agreement (Tables 2 and 3). The only viscosity determination is illustrated in Figure 14. The extrapolated viscosity, as shown in Figure 14, is greater than 1,000,000 centipoise at a reservoir temperature of 60°F. On the basis of this analysis, the deposit is a tar sand as defined by the American Petroleum Institute; i.e., its viscosity is greater than 10,000 centipoise at original reservoir temperature. Gravity determinations on our sample (5.5°) and the Bureau of Land Management sample (5.2°), were also well below the 10° API upper limit for a tar sand.

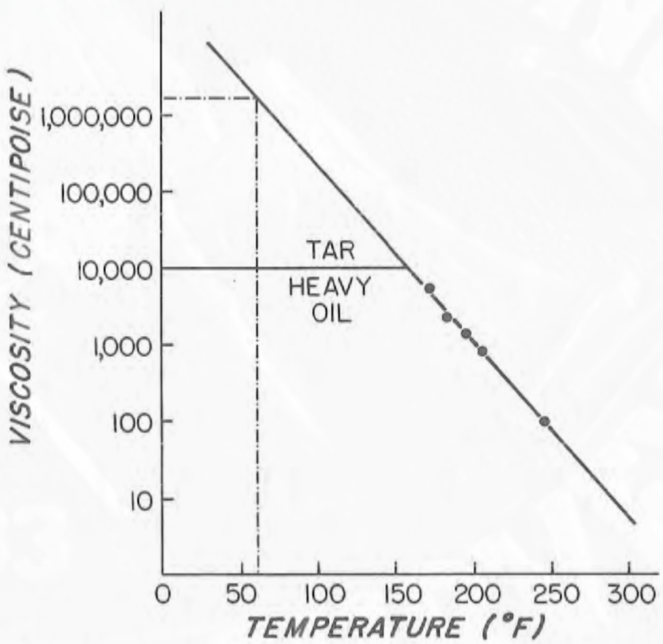

Figure 14. Viscosity determination based on tar sample from Trapper Canyon Deposit A. Plotted points represent measured values. Data courtesy of Bronco Oil and Gas Company.

To substantiate the assumption that the tar in the deposit had the same Phosphoria source as the fields producing from the Tensleep Sandstone in the Bighorn Basin to the west of the Trapper Canyon deposit, tar samples were analyzed for vanadium and nickel content, and a V/Ni ratio was calculated for each. The same was done for a Tensleep oil sample from Lamb Field, located downdip and to the west approxi-

Table 2. Vanadium/nickel ratios from Lamb Field and various samples collected at the Trapper Canyon Deposit.

Sample	Vanadium (mg/kg)	Nickel (mg/kg)	V/Ni
Crude Oil from Lamb Field	1,300	198	6.57
Outcrop (Trapper Canyon, Wyoming Geological Survey)[1]	555	82	6.77
Outcrop (Trapper Canyon, Wyoming Geological Survey)[2]	600	88	6.82
Outcrop sample from upper weathered zoned (Trapper Canyon, Bureau of Land Management)	375	130	2.88
Drill hole sample from upper weathered zone (Trapper Canyon, Bronco Oil and Gas)[3]	160	44	3.64
Drill hole sample from unweathered zone (Trapper Canyon, Bronco Oil and Gas)[3]	830	116	7.16

[1] Sample taken at sample site TCA-1

[2] Average of several sample sites

[3] Sample taken from Bronco Oil and Gas drill hole near sample site TCA-1

mately 20 miles from the Trapper Canyon Deposit. Generally, crude oils in Wyoming from Paleozoic sources exhibit V/Ni ratios greater than 4, while those from a Cretaceous source exhibit V/Ni ratios between 1.5 and 2 (Stone, 1967). The resulting ratios are shown in Table 2, with some samples indicating very close agreement between the deposit and Lamb Field. The Bureau of Land Management sample and the first Bronco Oil and Gas drill hole sample were taken from the uppermost part of the tar zone, and the ratios are lower than those of the other samples. This part of the zone is severely weathered, and the vanadium may have been selectively leached at these sites. The high sulfur content indicated for the tar samples (Table 3) is also characteristic of oil from the Phosphoria Formation (Stone, 1967).

Trapper Canyon Deposits A and B are stratigraphically equivalent, and are contained in the upper, eolian sequence of the Pennsylvanian Tensleep Sandstone. However, Trapper Canyon Deposit B is very discontinuous and thin, probably representing the northwest edge of the overall pre-erosional deposit (Figure 10). For that reason the present study emphasizes Trapper Canyon Deposit A.

Only Deposit A has a potential for economic development. The deposit covers an area of approximately 67 acres. Exposed thicknesses, measured at the ten sample sites shown in Figure 15, were

Table 3. Tar analyses for Trapper Canyon Deposit A samples showing elemental composition, petroleum composition, and gravity.

Elemental composition (in weight percent)

Element	Bureau of Land Management sample	Bronco Oil and Gas sample[1]	Wyoming Geological Survey samples[2]
C	82.25%	75.46%	-
H	10.19	9.06	-
N	.49	.45	.49%
S	5.32	4.46	4.6
O	1.43	7.56	-

Petroleum composition (in weight percent)

Component	Bureau of Land Management sample	Bronco Oil and Gas sample[1]
Asphaltenes	25.00%	23.20%
Saturates	-	15.80
Aromatics	-	43.23
Resins	-	17.17

Gravity (in degrees API)

Bureau of Land Management sample	Wyoming Geological Survey samples[2]
5.2°	5.5°

[1] Drill hole near sample site TCA-1

[2] Average of several samples

0-23 feet. In addition, Bronco Oil and Gas drilled through the overlying Goose Egg Formation and through the tar zone in the five locations shown on Figure 15. The tar zones encountered in these tests were 0-36 feet thick. The overburden was 9-77 feet thick (Figure 15).

As shown in Figure 15, the deposit is variable in thickness, as expected in

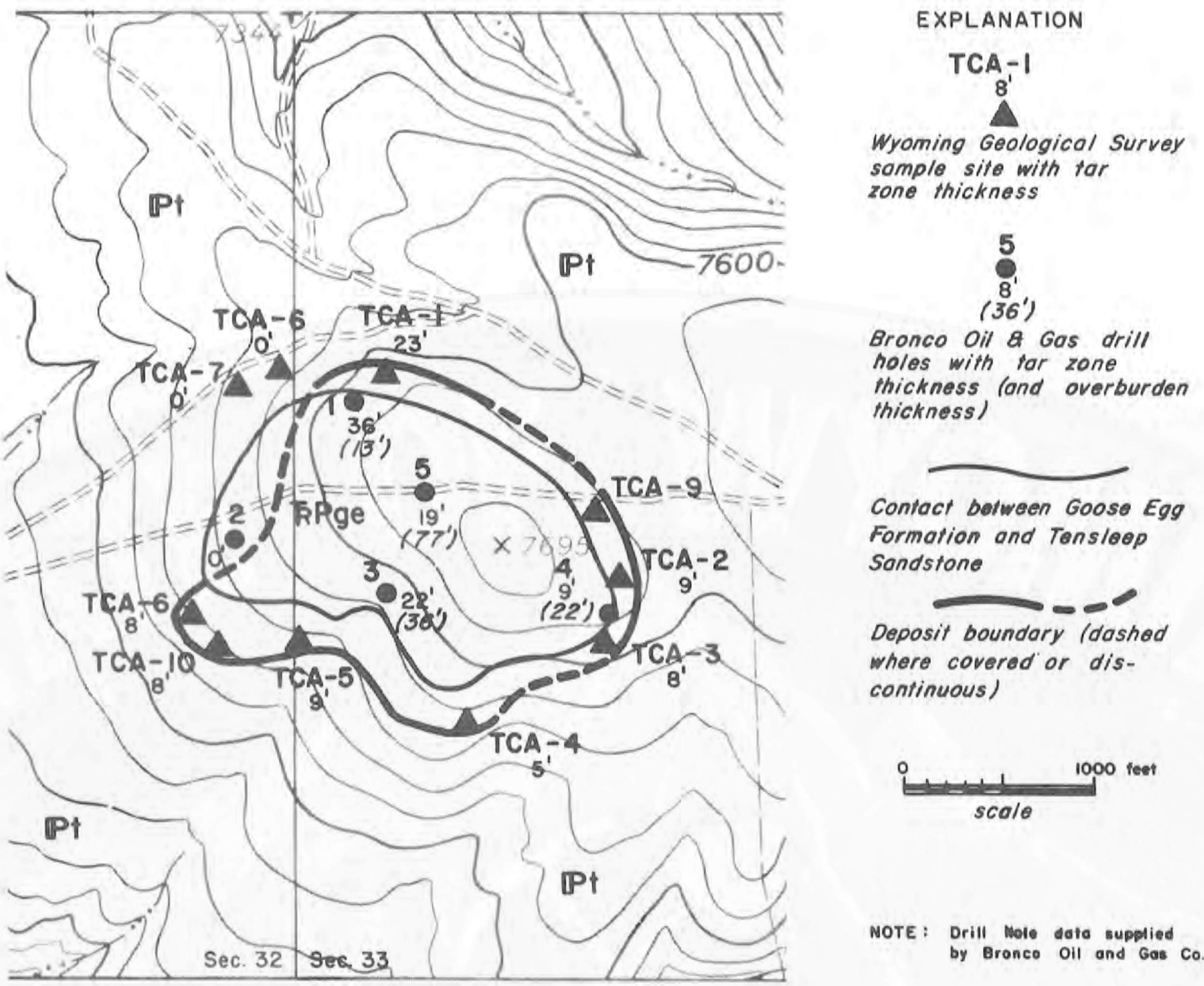

Figure 15. Map of Trapper Canyon Deposit A (T.52N., R.89W.), showing data for sample sites and drill holes. Drill hole data supplied by Bronco Oil and Gas Company.

eolian reservoir rock. It does, however, exhibit an overall thinning toward the south. Drill hole number 2 and sample sites TCA-7 and TCA-8, all lacking tar sand zones, represent the original northwest boundary of the deposit (Figures 10 and 15), where a tight zone in the reservoir rock prevented further petroleum migration. This is the only portion of the original boundary remaining, as the rest has been eroded in recent times, leaving no evidence of the original size of the deposit.

Discontinuity within the reservoir is evidenced by a tight barren zone that crops out on the southeast side of the deposit. In that area, there is no indication of tar impregnation in most of the laterally equivalent eolian sequence between sample sites TCA-3 and TCA-4 (Figures 15 and 16). Also, there may be a tight barren zone on the northeast side of the deposit between sample sites TCA-1 and TCA-9 (Figure 15), but soil cover and vegetation have made verification of this barren zone tentative.

Bronco Oil and Gas Company (written communication, 1982) has estimated 1.9 million barrels of oil in place on the 67-acre deposit. Due to the discontinuous nature of the eolian reservoir

Figure 16. Barren zone on southeast corner of Trapper Canyon Tar Sand Deposit A between sample sites TCA-3 and TCA-4 (see Figure 15). This zone was tightly cemented with dolomite at the time of oil migration.

as seen in the outcrop, no estimate of the resource was made for this report. However, we believe that the oil in place is probably only 50 to 75 percent of Bronco's estimate.

We believe that the most economic way to recover this tar resource is to mine the tar sand and separate the tar with a solvent extraction technique. We anticipate that *in situ* tar recovery methods would have to overcome problems of permeability and porosity variations in the reservoir, as well as the lateral movement of injected fluids. Also, the most effective spacing of injection wells would be hard to predict.

Trapping Mechanism

This study indicates that the Trapper Canyon Tar Sand Deposit is a diagenetically controlled, stratigraphic trap. The tar-impregnated zone occurs in the upper 10 to 40 feet of the Tensleep Sandstone, which is an eolian portion of the sandstone. In all cases, this tar zone is capped by 5 to 10 feet of barren dolomitic sandstone which is thin bedded, probably representing an interdunal or sabkha/wind-flat type deposit. This capping sequence is a very tight zone and is the top of the hydrocarbon trap. In some places, the dolomitic cement has been replaced by calcite (Figure 17A) as ground water supersaturated with calcite has moved through these sands. In other places, the cementing material was later removed by surface water or ground water, leaving a porous zone (Figure 18A). These capping sands, however, were already tightly cemented with dolomite at the time of petroleum migration. A basal tight barren zone was also present at almost all of the sample sites. In most cases, the cementing material was dolomite (Figure 17B and 17C) that shows some calcite replacement (Figure 18B).

The only definable lateral boundary on the trap is on the northwest side of the deposit (Figure 19). Sample sites TCA-7 and TCA-8 are in a barren eolian sequence, the lateral equivalent of the tar-impregnated eolian sequence found in the deposit. X-ray analysis of samples from this sequence indicates a dolomitic cement. However, it appears that recent ground-water movement has dissolved a large part of the original cement. This is indicated by the high permeability and porosity noted for the samples from

Figure 17A. Scanning electron micrograph of sample TCA-5-6, showing calcite cement (C) around quartz grains (Q). Sample taken from capping barren zone. Data readout gives accelerating voltage (25KV), magnification (200 times), sequence number, bar scale equivalent to 100.0 microns, and place and date of micrograph (University of Wyoming, 1983).

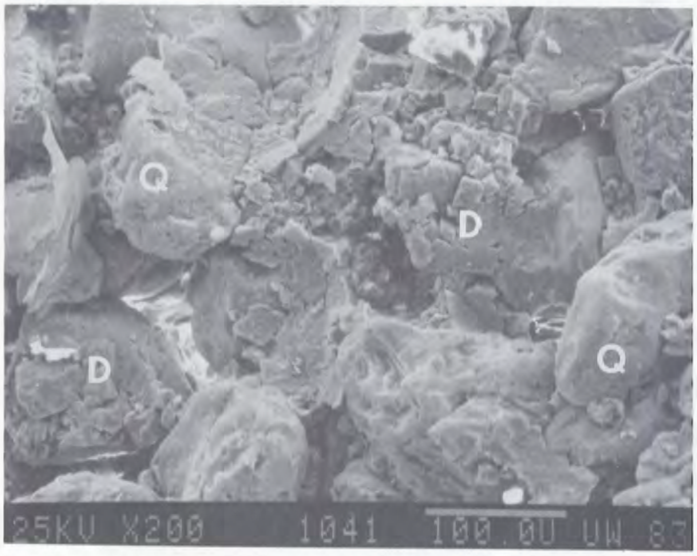

Figure 17B. Scanning electron micrograph of sample TCA-4-1, showing dolomite cement (D) and quartz grains (Q). Sample collected from basal barren zone. Magnification is 200X, and bar scale represents 100 microns.

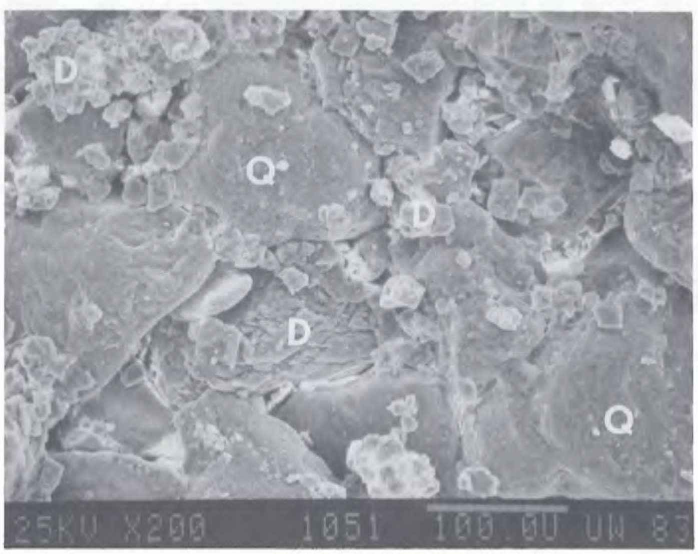

Figure 17C. Scanning electron micrograph of sample TCA-5-1, showing dolomite cement (D) and quartz grains (Q). Sample taken from basal barren zone. Magnification is 200X, and bar scale represents 100 microns.

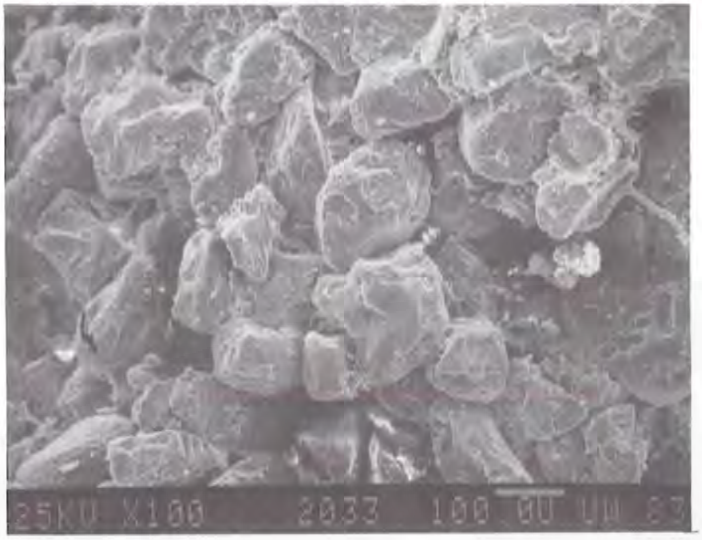

Figure 18A. Scanning electron micrograph of sample TCB-3-3, showing porous zone. Original cement was removed by recent ground-water movement. Data readout gives accelerating voltage (25KV) magnification (100 times), sequence number, bar scale equivalent to 100.0 microns, and place and date of micrograph (University of Wyoming, 1983).

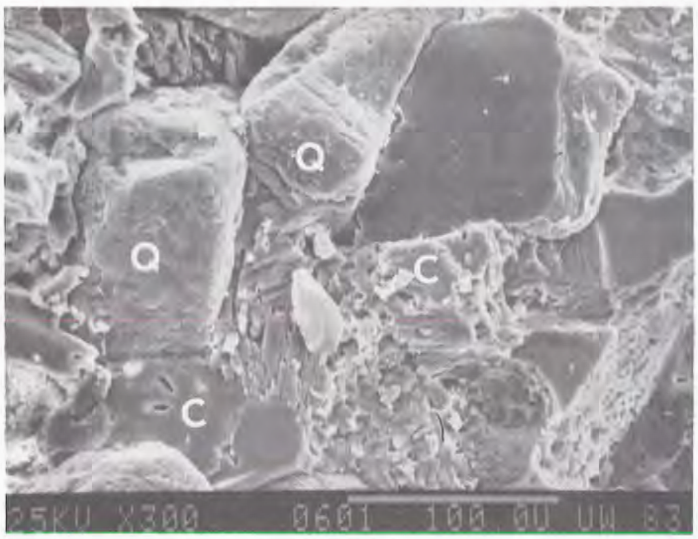

Figure 18B. Scanning electron micrograph of sample TCA-6-1, showing quartz grains (Q) cemented with calcite (C). This sample was collected from the basal barren zone. Magnification is 300X, and bar scale represents 100 microns.

TCA-7 and TCA-8 (Appendix B). If the barren eolian sequence had been as porous and permeable at the time of oil migration as it is now, it would be oil saturated. Therefore, we conclude that at the time of oil migration, this sequence was cemented and formed the northwest boundary of the deposit. Whether or not this diagenetic control was responsible for the other lateral boundaries of the deposit cannot be substantiated because the remainder of the boundaries have been removed by erosion. Since there is no evidence for structural control of the trap (anticlinal or fault control or any indication of a Bonanza-type trap, a channeling in the Tensleep updip from the tar deposit with Goose Egg channel fill forming the updip permeability barrier), we favor diagenetic control for the entire lateral boundary of the trap. Lawson and Smith (1966) list some examples of stratigraphic traps controlled by lateral and updip decreases in permeability. We cannot, however, rule out the possibility of an updip barrier due to Bonanza-type channeling, since all evidence in that direction has been removed by erosion.

Mankiewicz and Steidtmann (1979) have examined the depositional environments and the diagenesis of the Tensleep Sand-

Figure 19. Barren, tight eolian sequence cropping out on the northwest corner of the Trapper Canyon Deposit. This sequence is the lateral equivalent of the tar-bearing zone in the deposit.

stone in the eastern Bighorn Basin. The Tensleep diagenetic chronology as interpreted by Todd (1963), Fox and others (1975), and Mankiewicz and Steidtmann (1979) is a sequence of events conducive to the formation of the type of stratigraphic trap that we suggest. The diagenetic sequence proposed by Mankiewicz and Steidtmann is shown in relation to tectonic events and the timing of hydrocarbon migration and accumulation in Figure 20. The key events, so far as this study is concerned, are the two dolomite cementing events in the Late Pennsylvanian and the Triassic prior to migration and accumulation of oil from a Phosphoria source. The earlier cementing event occurred soon after the deposition of the Tensleep (Mankiewicz and Steidtmann, 1979). Dolomite-saturated recharge water from the interdunal and sabkha subsurface moved into the eolian portion of the Tensleep, creating tight zones with dolomite cementation. Mankiewicz and Steidtmann interpret the Triassic pre-oil precipitation of rhombic dolomite to be related to changes in basin hydrology due to tectonic events at that time. We suggest that these cementing events created the stratigraphic trap proposed for the Trapper Canyon Deposit.

Summary

In summary, the evidence from this study and the work of previous investigators indicate the following sequence of events leading to the Trapper Canyon Deposit as it appears today. Initially, a trap was formed as a result of Pennsylvanian and Triassic cementing events which laterally altered permeability and porosity in the upper eolian portion of the Tensleep in the area. The upper or capping portion of the trap resulted from deposition of an interdunal sequence. Oil from a Phosphoria Formation source migrated during Early Jurassic time, moving updip through the porous sequences in the upper Tensleep, which had been slightly tilted toward the west. The oil had accumulated in this diagenetically controlled trap, probably, by the end of Early Jurassic time. Deposition of the overlying sediments began concurrent with the Laramide orogeny, and continued into Recent time. In Recent time, the deposit was breached and partially eroded. Once the deposit was breached and eroded, the oil in the deposit was exposed to interaction with the atmosphere, ground water, and bacteria, and that interaction resulted in degradation and loss of the light frac-

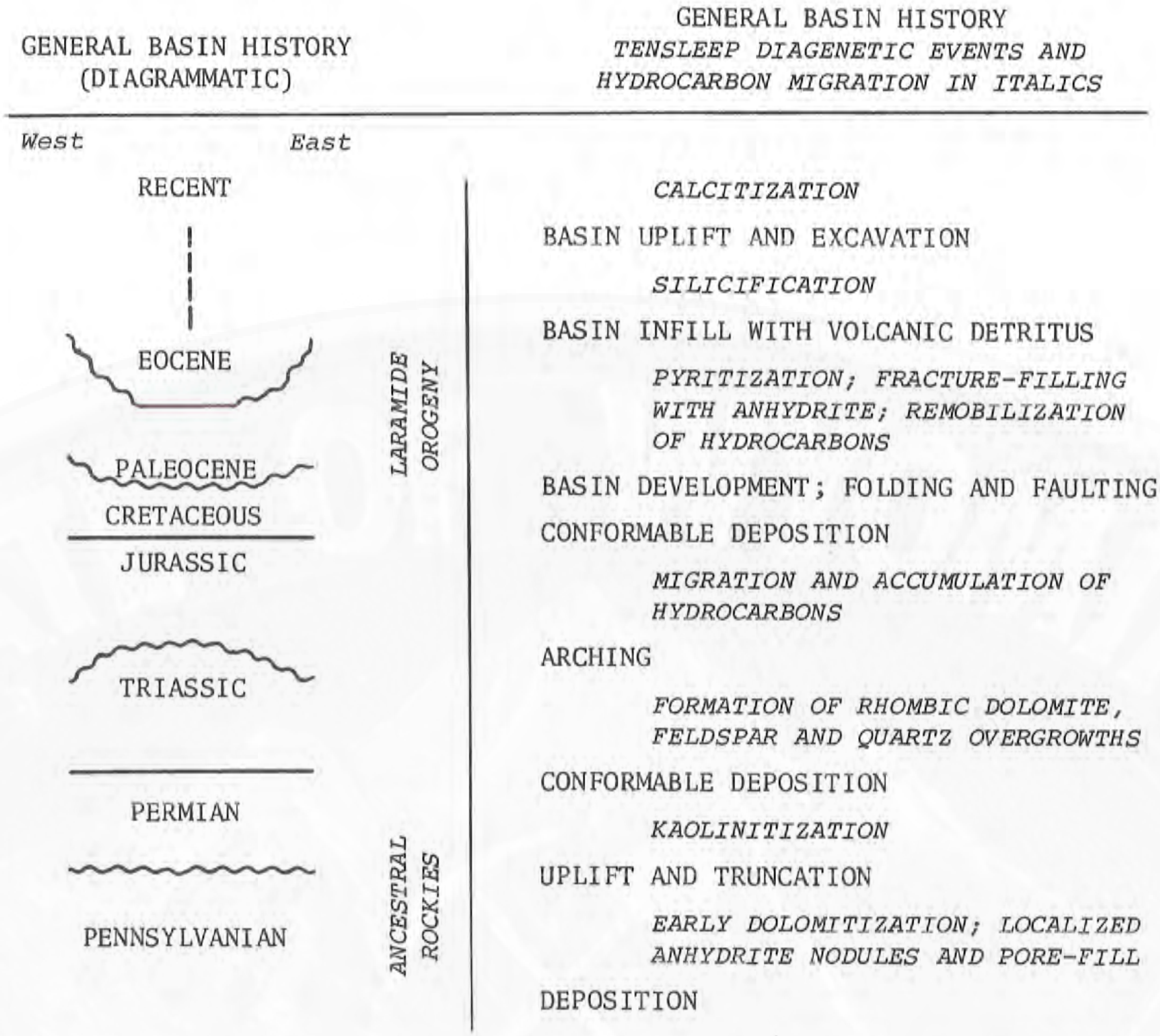

Figure 20. Diagenetic sequence for the Tensleep Sandstone, shown in relationship to major tectonic events and the timing of hydrocarbon migration and accumulation. Taken from Mankiewicz and Steidtmann, 1979.

tions of the oil, leaving the tar sand deposit as it is today.

SEARCH FOR ADDITIONAL DEPOSITS

During geological mapping of the Bush Butte quadrangle, outcrops were examined for evidence of additional tar sand accumulations or paths of oil migration. Special effort was made to examine all outcrops of the porous upper eolian sequence of the Tensleep, as it has been shown to be the oil reservoir and probable carrier bed. As seen in outcrop, the lower portion of the Tensleep contains tight dolomitic sand, dolomite, and limestone, and apparently has no reservoir potential.

The outcrops which retained the upper eolian sequence are concentrated in the southwest corner of the quadrangle and in erosional outliers capped with the Goose Egg Formation near the Trapper Canyon Deposit (Plate I). Over the majority of the quadrangle, the upper eolian sequence has been removed by erosion and only the resistant, impermeable lower sequence remains. Cross section

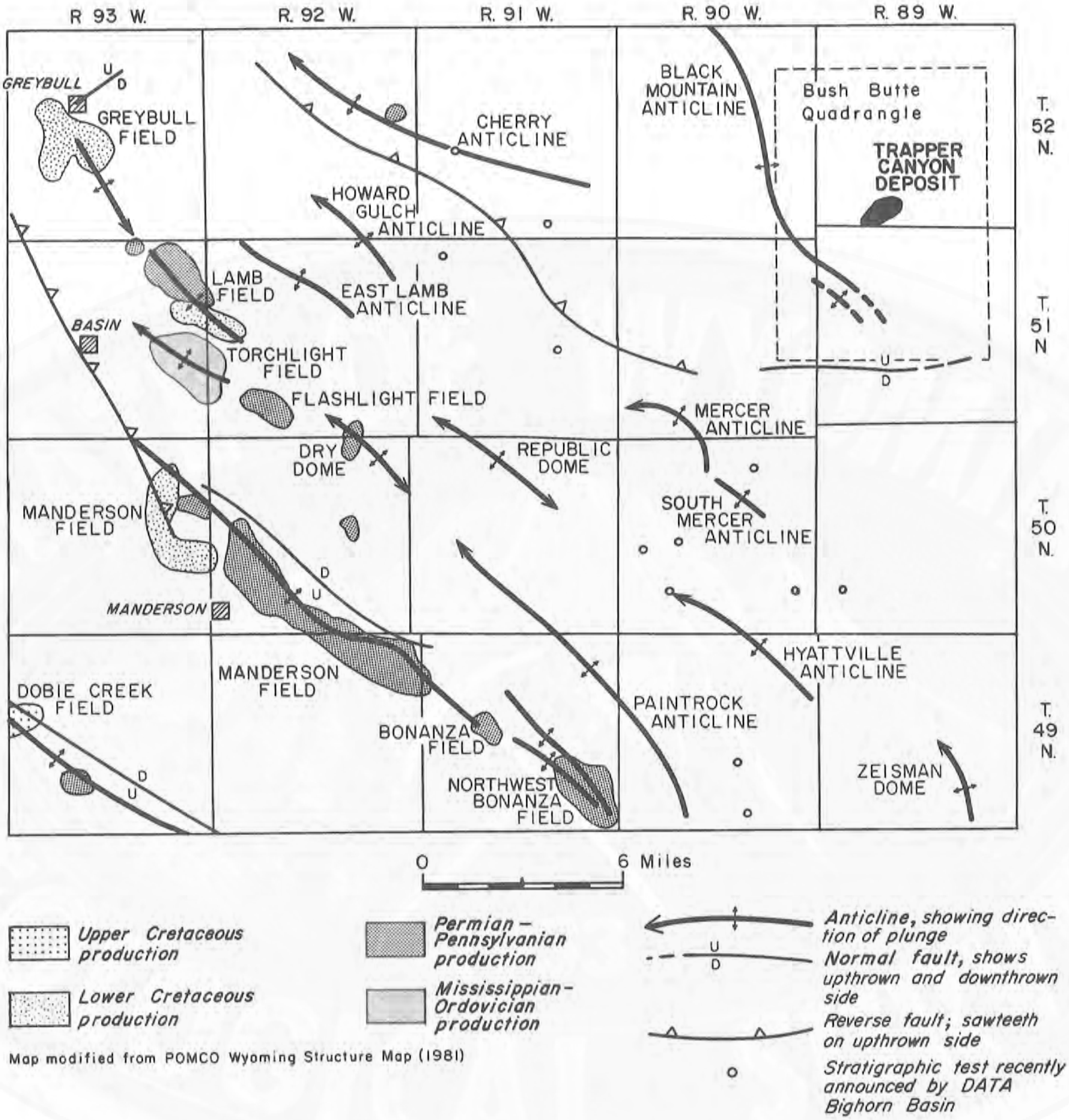

Figure 21. Generalized structure map showing the Trapper Canyon Deposit and producing and nonproducing Laramide structures to the southwest. Map modified from Petroleum Ownership Map Company (POMCO), 1981.

A-A' on Plate I illustrates this situation and depicts the erosional outliers, including the Trapper Canyon Deposit.

Examination of the various Tensleep outcrops and other units cropping out in the quadrangle yielded no indication of additional tar sand or heavy oil accumulation. There was no evidence of a migration path from the west for the tar in the Trapper Canyon Deposit. However, since the majority of the upper eolian Tensleep to the west of the deposit has been eroded, the chance of finding evidence of carrier beds or a migration path is slim. In addition, ground-water movement could have removed visible evidence of carrier beds.

IMPLICATIONS FOR FUTURE EXPLORATION

Although no additional accumulations were found within the Bush Butte Quadrangle, the potential for traps similar to the Trapper Canyon Deposit is excellent farther to the west and southwest, between the Bonanza-Manderson area and this study area. The Laramide structures in that region (Figure 21) have been tested unsuccessfully, but no drilling has been done in the areas between these structures. The key for future exploration is to look for stratigraphic traps similar to the Trapper Canyon Deposit or erosional traps similar to the Bonanza trap, where a channel in the Tensleep is filled by Goose Egg rocks which form an updip permeability barrier. Both traps would be pre-Laramide in all probability, and therefore not necessarily related to existing Laramide structures. Potential traps would be expected in the 1,000-to-3,000-foot depth range, as the Tensleep is covered by Permian and Triassic rocks in this region. The traps will likely contain heavy oil rather than tar sand because they will not have been breached and degraded.

Evidently, there is some interest in these types of deposits. DATA Bighorn Basin of Lakewood, Colorado has staked twelve stratigraphic tests which will penetrate the Tensleep between some of the structures southwest of the study area (Figure 21). These locations were announced in October and November 1983. Several of the locations were drilled in late 1983 and during the spring and summer of 1984. Although none of the tests were successful, oil shows were found in at least one of the wells, and further tests are planned.

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APPENDIX A:

MEASURED TENSLEEP SANDSTONE SECTIONS IN BUSH BUTTE QUADRANGLE

Section 1

Trapper Canyon Deposit B, SE1/4 sec. 32, T.52N., R.89W., and NE1/4 sec. 5, T.51N., R.89W.

	Thickness (feet)
Goose Egg Formation--	80+
Tensleep Sandstone:	
Sandstone; fine-grained; lower part cross-bedded, poorly bedded toward top; very light gray to light gray, weathers light gray with some white mottling; extremely calcareous with pitted surface--	14.0
Covered interval with pieces of tar sand on surface-------------	14.5
Sandstone; very fine-grained to fine-grained; cross-bedded; tar concentrated in upper five feet; very discontinuous; light gray to pale yellowish-orange--	13.5
Covered interval--	9.5
Sandstone; tar impregnated; cross-bedded; tar zone appears to pinch out in both directions------------------------------------	3.0
Sandstone; very fine-grained to fine-grained; horizontal bedding; white to very light gray, upper 1.5 feet is pale yellowish-orange to grayish-orange; very calcareous---------------------	5.0
Covered interval--	12.0
Sandstone; fine-grained; thick bedded; weathers light gray to medium gray, otherwise white to very light gray; very calcareous--	5.5
Covered interval--	5.0
Sandstone; fine-grained; massive unit on top, thinly-bedded unit, cross-bedded unit, and thinly-bedded unit; very pale orange; lower units are calcareous--	23.5
Tensleep Sandstone total--	105.5

Section 2

Trapper Canyon Deposit A, $SW^{1}/_{4}$ sec. 33, T.52N., R.89W.

	Thickness (feet)
Goose Egg Formation (including "Nowood Conglomerate" locally: pebbly; mainly chert and limestone, 2.0 feet)----------------------	50+
Tensleep Sandstone:	
Sandstone; very-fine-grained to fine-grained; light gray; poorly bedded throughout; pockets of limonite in upper zone-----------	10.0
Sandstone; tar-impregnated; cross-bedded; bands of calcite following foresets and alternating with tar -------------------	7.0
Sandstone; fine-grained; cross-bedded; light gray to grayish-orange; moderately calcareous-----------------------------------	5.0
Sandstone; very fine-grained; cross-bedded; grayish-orange weathers medium gray; poorly indurated, noncalcareous----------	9.0
Covered interval--	15.0
Sandstone; very-fine-grained to fine-grained; massive; light gray; moderately indurated; very calcareous--------------------	5.0
Covered interval--	6.0
Sandstone; very fine-grained to fine-grained; massive; white to very light gray; calcareous to very calcareous; contains grains and bands of iron minerals------------------------------------	10.0
Sandstone; very-fine-grained to fine-grained; cross-bedded; very light gray, weathers light gray; moderately calcareous---------	15.5
Covered interval--	18.0
Sandstone; very-fine-grained to fine-grained; cross-bedded; white to very light gray, weathers light gray; hematite grains in the upper two feet--	15.0
Tensleep Sandstone total--	115.5

Section 3

Section measured about one mile east of Trapper Canyon Deposit A in SW1/4 sec. 34, T.52N., R.89W.

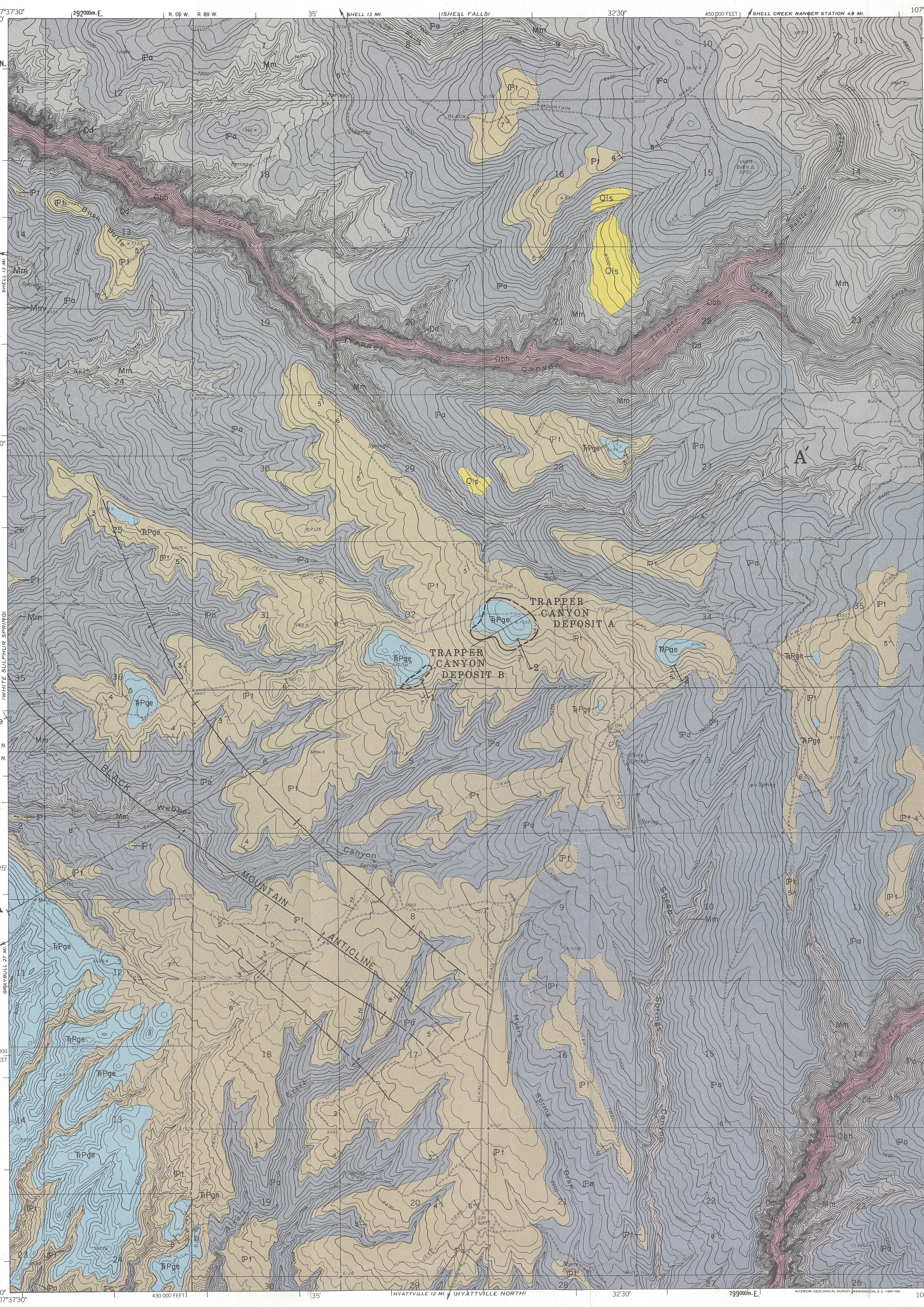
	Thickness (feet)
Goose Egg Formation	60+
Tensleep Sandstone:	
Sandstone; very fine-grained to fine-grained; very light gray to light gray, outside stained pale reddish-brown; very calcareous; zones of coarsely crystalline calcite	15.0
Limestone; coarsely crystalline; interbedded pale red purple and very light gray; well developed bedding two to three inches thick	3.5
Sandstone; fine-grained; grayish orange to pale yellowish-orange; fairly thin-bedded with horizontal bands of white calcite and calcite nodules weathering out	12.5
Sandstone; very fine-grained; cross-bedded with long foresets; very light gray; calcareous nodules weathering out, otherwise not calcareous; a few small limonite streaks	10.5
Sandstone; very fine-grained to fine-grained; very light gray; horizontally bedded; slightly calcareous	12.5
Sandstone; fine-grained; light gray to pale yellowish-orange; cross-bedded; some calcareous nodules weathering out	1.5
Sandstone; very fine-grained to fine-grained; cross-bedded with long foresets; light gray	7.5
Sandstone; very fine-grained; alternating cross-bedded and horizontal bedded, cross-bedded units contain calcareous nodules; pale yellowish-orange; calcareous cement	28.0
Covered interval	29.0
Tensleep Sandstone total	120.0

APPENDIX B: CORE ANALYSES

Sample Number	Permeability (millidarcys) Before extraction	Permeability (millidarcys) After extraction	Porosity percent Before extraction	Porosity percent After extraction	Residual saturation Oil % pore	Residual saturation Weight % Oil	Residual saturation Weight % Water	Residual saturation Total water % pore	Density Grain	Density Saturated	Density Extracted
TCA-1-1	1350	-	13.8	28.9	0.0	0.0	-	50.9	2.61	2.02	1.85
TCA-1-2	-	-	5.5	-	-	8.5	4.0	-	-	2.15	-
TCA-1-3	-	-	2.6	-	-	10.0	3.6	-	-	2.13	-
TCA-1-4	17	-	11.5	-	-	9.0	5.0	-	-	1.91	-
TCA-1-5	-	-	0.6	-	-	12.6	3.5	-	-	2.14	-
TCA-1-6	540	690	11.8	21.0	0.0	0.0	-	43.8	2.64	2.18	2.09
TCA-2-1	-	-	27.3	33.9	0.0	0.0	-	19.5	2.68	1.84	1.78
TCA-2-2	-	-	6.1	-	-	15.9	1.7	-	-	1.97	-
TCA-2-3	247	-	10.0	-	-	13.6	2.6	-	-	1.90	-
TCA-2-4	-	-	4.2	-	-	12.9	1.2	-	-	2.10	-
TCA-2-5	-	-	19.9	27.0	0.0	0.0	-	26.3	2.66	2.01	1.94
TCA-3-1	-	-	1.6	-	-	15.7	2.9	-	-	2.07	-
TCA-3-2	3.3	-	9.9	-	-	14.5	1.1	-	-	1.97	-
TCA-3-3	610	590	14.2	23.3	0.0	0.0	-	39.1	2.66	2.14	2.04
TCA-4-1	108	108	13.5	14.3	0.0	0.0	-	5.6	2.69	2.31	2.30
TCA-4-2	8.7	-	7.5	-	-	10.0	1.8	-	-	2.08	-
TCA-4-3	215	-	11.1	-	-	11.5	2.1	-	-	1.96	-
TCA-4-4	0.11	0.10	4.4	4.9	0.0	0.0	-	10.2	2.64	2.51	2.50
TCA-5-1	2.8	2.8	7.6	8.6	0.0	0.0	-	11.6	2.68	2.46	2.45
TCA-5-2	104	-	11.4	20.4	26.0	2.5	-	18.1	2.64	2.24	2.12
TCA-5-3	-	-	7.5	-	-	10.6	1.1	-	-	2.07	-
TCA-5-4	13	-	4.2	-	-	8.5	0.8	-	-	2.17	-
TCA-5-5	29	-	4.5	-	-	9.9	2.3	-	-	2.10	-
TCA-5-6	1.8	11	7.1	9.8	0.0	0.0	-	27.6	2.65	2.42	2.39
TCA-6-1	4.2	4.4	5.6	6.3	0.0	0.0	-	11.1	2.66	2.50	2.49
TCA-6-2	0.01	-	3.1	-	-	13.4	2.6	-	-	2.13	-
TCA-6-3	0.02	-	8.4	-	-	11.1	2.2	-	-	2.04	-
TCA-6-4	0.02	-	0.8	-	-	13.9	1.0	-	-	2.15	-
TCA-6-5	5.3	5.4	12.4	12.9	0.0	0.0	-	3.9	2.64	2.31	2.30
TCA-7-1	1330	1470	17.2	27.9	0.0	0.0	-	38.4	2.64	2.02	1.90
TCA-8-1	-	-	16.6	31.7	0.0	0.0	-	47.6	2.65	1.99	1.81
TCA-9-1	12	-	25.7	-	-	13.7	2.1	-	-	1.86	-
TCA-10-1	-	-	20.2	28.2	16.7	2.2	-	11.7	2.64	2.00	1.89
TCA-10-2	25	-	6.5	-	-	12.3	1.4	-	-	2.07	-
TCA-10-3	0.04	-	6.9	-	-	12.6	2.5	-	-	2.06	-
TCA-10-4	11	-	7.2	-	-	11.2	2.0	-	-	2.09	-
TCA-10-5	35	35	15.0	15.9	0.0	0.0	-	5.7	2.66	2.25	2.24
TCB-1-1	17	17	13.9	14.7	0.0	0.0	-	5.4	2.68	2.29	2.28
TCB-1-2	58	-	5.4	-	-	7.4	1.5	-	-	2.20	-
TCB-1-3	1.4	-	3.8	-	-	11.1	2.0	-	-	2.04	-
TCB-1-4	12	14	7.9	8.7	0.0	0.0	-	9.2	2.63	2.41	2.40
TCB-2-1	2.6	-	10.7	-	-	11.3	1.6	-	-	1.93	-
TCB-2-2	25	-	9.1	-	-	9.3	1.3	-	-	2.05	-
TCB-3-1	27	-	9.1	-	-	7.5	1.2	-	-	2.07	-
TCB-3-2	0.05	-	10.9	-	-	11.6	1.5	-	-	1.97	-
TCB-3-3	192	520F	13.3	14.4	0.0	0.0	-	7.6	2.65	2.29	2.28

-Sample Unsuitable for Measurement
F = Fractured Permeability Plug

THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist



Base by U.S. Geological Survey, 1957.

Geology mapped in 1982.

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

APPROXIMATE MEAN DECLINATION, 1960

QUADRANGLE LOCATION.

EXPLANATION

QUATERNARY

Qls **Landslide material**
Rock debris; some identifiable bedrock. Mapped occurrences are in the Amsden Formation.

TRIASSIC AND PERMIAN

TRPge **Goose Egg Formation**
Deep red, calcareous and gypsiferous siltstone interbedded with pale green to purple dolomite and dolomitic limestone containing gypsum. Several massive, pale gray to white gypsum beds. Ranges from 250 to 300 feet thick.

PENNSYLVANIAN

IPt **Tensleep Sandstone**
White to light gray, very-fine-grained to fine-grained sandstone which is often very calcareous. Thick-bedded, finely laminated with cross-bedding; some units thin-bedded. Sandy dolomite with small lateral extent. Contact with Goose Egg sometimes marked by chert and limestone pebble conglomerate. Approximately 120 feet thick.

IPa **Amsden Formation**
Lower Horseshoe Shale Member is principally shale, siltstone, and mudstone that weathers red or purple. Upper Ranchester Limestone Member is mainly yellow-gray weathering dolomite and dolomitic limestone. Some sandstone, shale, and gray to purple weathering limestone. From 150 to 200 feet thick.

MISSISSIPPIAN

Mm **Madison Limestone**
Light gray to light brown, mainly limestone and dolomite with abundant crinoid fragments and other bioclastic material. Bull Ridge Member, the uppermost member, is often stained red by Amsden sediments and contains sinkholes and solution cavities. Approximately 600 feet thick.

DEVONIAN

Dd **Darby Formation**
Grayish, yellowish, and greenish dolomite, finely crystalline to microcrystalline. Interbedded with sparse dolomitic shale and siltstone. Approximately 100 feet thick.

ORDOVICIAN

Obh **Bighorn Dolomite**
White to cream and light brown to dark brown, finely crystalline to sucrosic dolomite with some chert. Deeply pitted on surface. Thin-bedded at top, then massive unit to base of exposure. Ranges from 450 to 500 feet thick; only upper 200 feet exposed in quadrangle.

CAMBRIAN

Єu **Cambrian undivided**
Includes the Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone. Does not crop out in quadrangle, but is shown on cross section.

Formation contact
Dashed where approximately located

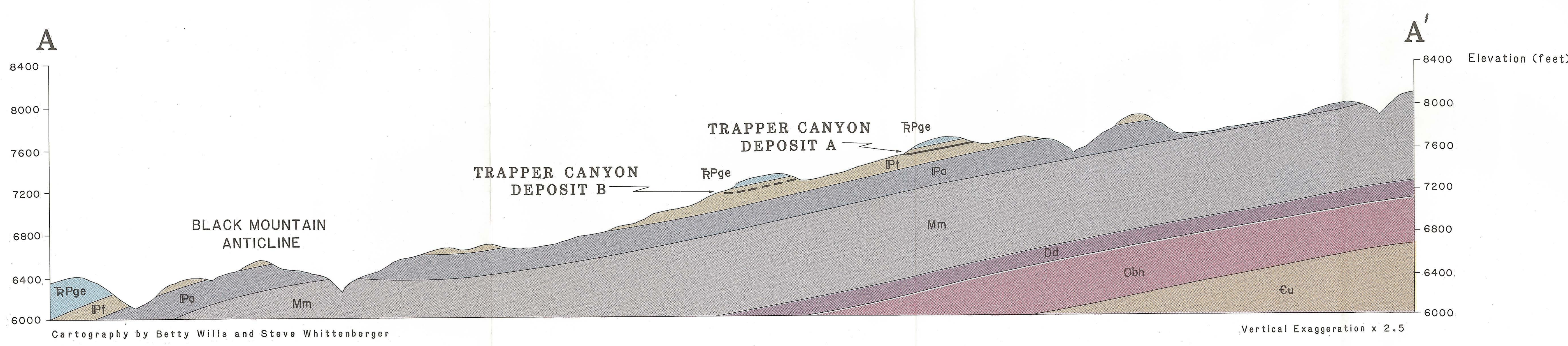
Tar sand deposit boundary
Dashed where covered or discontinuous

Anticline

Syncline

Strike and dip of beds

Measured sections in Tensleep Sandstone
Sections are diagrammed in Figure 6 of text.



Cartography by Betty Wills and Steve Whittenberger

GEOLOGIC MAP OF BUSH BUTTE QUADRANGLE, WYOMING

by

Alan J. Ver Ploeg and Rodney H. De Bruin

1985