[PS]Tar Sand Triangle Bitumen Deposit, Garfield and Wayne Counties, Utah*

Steven Schamel[1]

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Abstract

The bitumen in the Tar Sand Triangle deposit is reservoired in a several-hundred-foot-thick eolian sandstone, the White Rim Sandstone (Lower Permian). Across an area of 84 square miles, the thickness of the bitumen-impregnated sandstone exceeds 100 ft. The strata are gently dipping and otherwise unstructured. Average porosity and permeability of the sandstone reservoir are in the range 15-20 % and 200-500 md, respectively. The oil saturation is consistently low, averaging 30-35%. The bitumen has an API gravity less than 8º at the surface and just over 10º in core. It has a high asphaltene and sulfur content, and it is saturate-poor. Although very viscous at reservoir temperatures, the bitumen is a few orders of magnitude less viscous than the Uinta Basin heavy oils. This study estimates a total in-place bitumen resource between 4.25 to 5.15 billion barrels in a deposit less than 200 square miles in size. However, at a commercially viable resource minimal threshold equal and greater than 60 MBO/ac, the in-place bitumen resource is estimated to range between 1.30 and 2.46 billion barrels in an area of 30 to 52 square miles, respectively. The Tar Sand Triangle deposit has several drawbacks that will make commercial bitumen recovery operations difficult and expensive, but not impossible. These include the relatively low grade of the resource and the apparent low oil saturations; the generally poor quality of the oil due to high sulfur content and high viscosity at reservoir temperatures; the difficult access by existing unimproved roads, all of which pass through the Glen Canyon NRA; potentially complicated and/or expensive process water access; the lack of petroleum service vendors and other support services in southeast Utah; and the proximity to environmentally-protected and visually stunning public lands.

Tar Sand Triangle Bitumen Deposit, Garfield and Wayne Counties, Utah

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Summary

The bitumen in the Tar Sand Triangle deposit is reservoired in a several-hundred-foot-thick eolian sandstone, the White Rim Sandstone (Lower Permian). Across an area of 84 square miles, the thickness of the bitumen-impregnated sandstone exceeds 100 ft. The strata are gently dipping and otherwise unstructured. Average porosity and permeability of the sandstone reservoir are in the range 15-20 % and 200-500 md, respectively. The oil saturation is consistently low, averaging 30-35%. The bitumen has an API gravity less than 8° at the surface and just over 10° in core. It has a high asphaltene and sulfur content, and it is saturate-poor. Although very viscous at reservoir temperatures, the bitumen is a few orders of magnitude less viscous than the Uinta Basin heavy oils. This study estimates a total in-place bitumen resource between 4.25 to 5.15 billion barrels in a deposit less than 200 square miles in size. However, at a commercially viable resource minimal threshold equal and greater than 60 MBO/ac, the in-place bitumen resource is estimated to range between 1.30 and 2.46 billion barrels in an area of 30 to 52 square miles, respectively.

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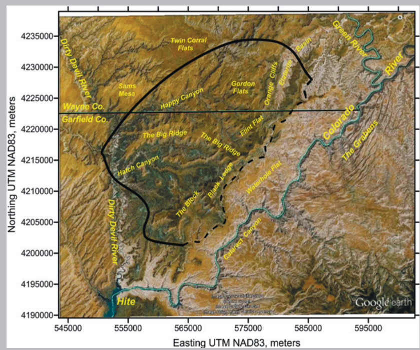
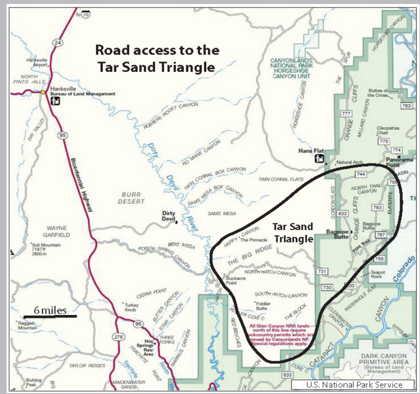
Location and Extent of the Deposit



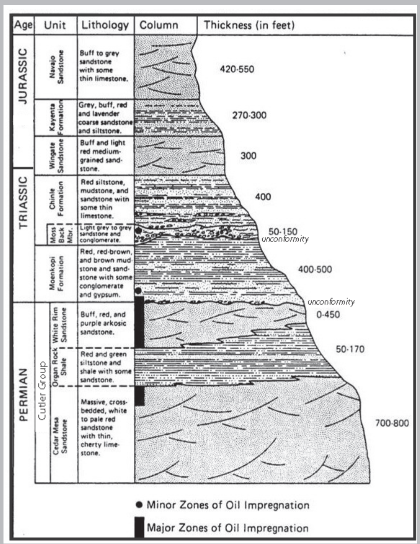
The Tar Sand Triangle bitumen deposit, with a previously estimated 2.5 to 12 billion barrels of resources in-place, is located on the Colorado Plateau in Garfield and Wayne Counties, southeast Utah. It lies beneath a deeply dissected plateau bounded on three sides by deep canyons: the Green River to the northeast, the Colorado River to the southeast, and the Dirty Devil River to the west. The highest surface, supported by the Navajo Sandstone (Jurassic) and having an elevation of about 7000 ft, is preserved along a long, sinuous ridge west of the Orange Cliffs. Below this surface are several benches, principally supported by the Moenkopi Formation (Triassic) and the Cedar Mesa Sandstone (Permian). The encircling rivers are at elevations of 3700-4000 ft.



The deposit covers an area of over 200 square miles (126,000 acres). About 40% of the deposit is within the Glen Canyon National Recreation Area (NRA). The remaining part of the deposit is on public lands administered by the U.S. Bureau of Land Management (BLM) and the Utah State and Institutional Trust Lands Administration (SITLA). No part of the deposit is on fee land.

Despite the remoteness of this rugged terrain, many parts of the deposit can be reached by unpaved county roads. The principal road (#633) follows along the ridge above the Orange Cliffs from the Hans Flat ranger station on the north to the center of The Big Ridge on the south. This road traverses the central portion of the deposit, providing access to much of the potentially prime operational areas in the deposit.

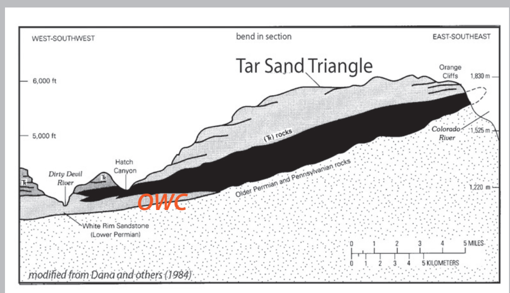
Geologic Setting of the Deposit



Bitumen is found principally in the White Rim Sandstone, the uppermost formation of the Cutler Group. However at a few locations, the upper Cedar Mesa Sandstone and the sandy basal part of the Moenkopi Formation, the Hoskinni Member, are also bitumen-impregnated (Fig. 4). The Cedar Mesa Sandstone and White Rim Sandstone are similar eolian deposits separated in the Tar Sand Triangle deposit by the Organ Rock Shale Tongue projecting southwestward out of the Paradox basin. The White Rim Sandstone is encased in less permeable strata, the Moenkopi Formation red mudstones above and the Organ Rock Shale below.

This reservoir is a white, subrounded to well-rounded, fine- to very fine-grained quartz arenite in thick to massive beds dominated by large-scale, high-angle cross-stratification. The White Rim Sandstone is mainly eolian in origin, but portions of the unit were modified by marine processes as the sea transgressed across the coastal dune fields

The bitumen in the White Rim Sandstone occupies a conventional stratigraphic trap in which the up-dip edge is truncated by the base-Triassic unconformity. Within this trap an inclined oil-water contact at elevations of 4200 to 4650 ft relative to mean sea level (msl) is recognized in wells. The oil-water contact (OWC) establishes the western and northwestern down-dip tapered edge of the deposit. The eastern up-dip edge is defined either by the basal Triassic unconformity cutoff or by the modern land surface in the canyon of the Colorado River. At the location of the deposit, stratification is nearly flat-lying, dipping to the northwest at just 120 ft per mile.



The combination of erosional beveling and stratigraphic position above the westward thinning tongue of the Organ Rock Shale has resulted in the thinning of the White Rim Sandstone towards the southeast and east. In the area of the Tar Sand Triangle deposit, the White Rim Sandstone is less than 350 ft thick. The source of the oil and the direction of charge are unknown.

The Tar Sand Triangle deposit is thought to be part of a much larger oil accumulation on the Colorado Plateau in the tectonic position of either the southwest rim of the Paradox Basin (Pennsylvanian) or the up dip edge of the Sevier foredeep basin (Cretaceous), or both. It may be a remnant of a 30-40 billion barrel oil (BBO) field in which the original oil evolved into a bitumen within the reservoir after emplacement by a combination of biodegradation, water washing and near-surface oxidation. The degradation of the oil probably occurred as the Colorado Plateau uplifted in the late Cenozoic and the oil pool was exhumed.

Figures after Dana and others (1984)

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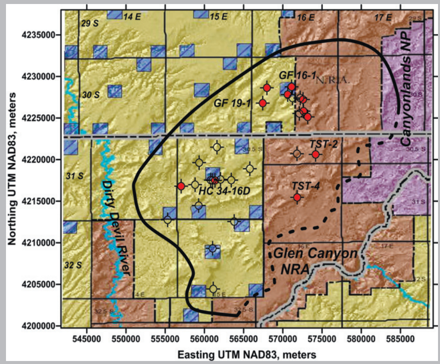
Tar Sand Triangle Bitumen Deposit, Garfield and Wayne Counties, Utah -- Panel 2

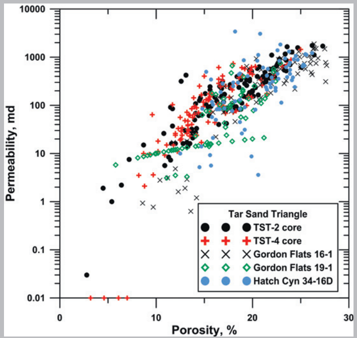
Character of the Sandstone Resevoir and Bitumen

Twenty-eight wells provide control on the thickness of the White Rim Sandstone in the Tar Sand Triangle deposit and the thickness of the reservoir interval that is bitumen-impregnated (see map and table on the right). The average reservoir thickness is 236.8 ft (median = 232.5 ft), which is consistent with the regional isopach map in Dana and others (1984) showing the unit thinning southeastward toward the Colorado River. The elevation of the top of the White Rim Sandstone in the set of wells ranges from a high of 5464 ft in 31S-16E-16 to a low of 4601 ft in 31S-15E-8. Across the deposit, the average bitumen-impregnated interval constitutes only about half of total unit thickness, 124.9 ft (median = 124.5 ft). The range of thicknesses of the bitumen-impregnated interval encountered in the wells is 14 to 249 ft. The spatial distribution of bitumen-impregnated thicknesses defines a central core of the deposit with bitumen-impregnated interval thickness in excess of 150 ft passing outward in all directions to a bitumen zero-edge within the White Rim reservoir.

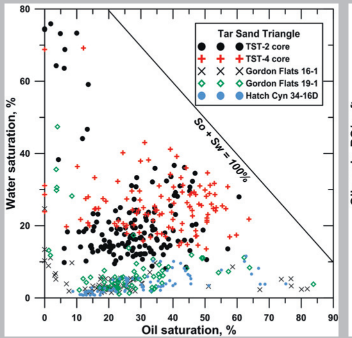
Petrophysical data for the White Rime Sandstone, as measured in cores, is displayed in cross-plots and logs below.



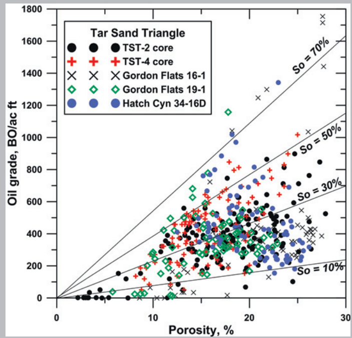
Well API #	Well	T	R	Sec.	loc.	Elev (ft)	Top WRSs	Thick ft	Impr. ft	MBO/ac
4305530008	Saga.-Skyline State 1	30S	16E	16	SE NE	6362	4892	240	50	29.00
4305530015	Gordon Flats 16-1	30S	16E	16	SW SE	6298	4878	230	72	29.85
4305530016	Gordon Flats 19-1	30S	16E	19	NE NE SE	6231	4701	210	98	33.94
4305530003	Skyline State 2	30S	16E	22	NE NW	6381	5037	240	89	
4305530017	Gordon Flats Fed Unit 1	30S	16E	22	NW SW NE	6542	5150	264	200	113.42
4305510924	French Seep 1	30S	16E	27	SE NW	6465	5075	228	115	
4301710738	Robbers Roost 41-33	30.5S	16E	33	NE NE	6604	5179	185	185	
4301730163	TST-2	30.5S	16E	35	SE NW NW	6812	5400	168	165	59.42
4301730085	Technology 14-36	31S	14E	36	NE SE SW	4823	4623	235	14	
4301730091	White Rim 44-4	31S	15E	4	SE NE SE	6034	4634	na	156	
4301730089	Magnum 23-8	31S	15E	8	SE NW SE	5084	4601	371	57	
4301730092	Garfield 44-15	31S	15E	15	SW SE SE	5321	4814	303	124	
4301730087	Winfield 21-15	31S	15E	15	NE NE NW	6127	4703	na	186	
4301730086	Remington 14-15	31S	15E	15	NW SW SW	5307	4778	301	169	
4301730096	State 34-16	31S	15E	16	SW SE	5058	4733	295	175	
4301711186	Utah S-Govt 22-19	31S	15E	19	SE NW	4850	4606	333	190	103.55
4301730088	Monroe 22-20	31S	15E	20	NE SE NW	4988	4681	336	86	
4301730090	Cromwell 33-29	31S	15E	29	NW SW SE	5060	4832	259	60	
4301730144	TST-4	31S	16E	16	NE SE NE	6895	5464	130	125	53.53
4301730097	State 11-2	32S	15E	2	NW NW NW	5320	5180	180	84	
4301730095	State 31-16	32S	15E	16	NE NW NE	5535	5138	188	26	
4301711276	USA Federal A-1	32S	15E	33	C NW NE	5400	5270	160	80	
4301730107	Hatch Cyn U 34-16B	31S	15E	16	SW SE	5058	4771	na	178	
4305530046	Shell 7	30S	16E	17	SW NW	6163	4682	167	77	33.21
4305530045	Shell 1 Sentinel	30S	16E	21	NE NE NE	6333	4958	197	161	
na	Gordon Flats 27-1	30S	16E	27	NE SE	6567	5135	213	196	244.00
4305530041	Shell 9	30S	16E	27	NW NE	6540	5112	249	249	85.83
4301730109	Hatch Canyon 34-16D	31S	15E	16	SW SE	5088	4769	na	130	59.11
							Median:	*232.5*	*124.5*	*59.11*
							Average:	*236.8*	*124.9*	*76.80*



As might be expected of eolian sandstone, the porosity and permeability of the White Rim Sandstone, as measured in the cores below, are good for a conventional oil reservoir. Average porosity is in the range 15.3% to 20.2% and permeability is between about 100 and 500 md. In the cores, there is substantial vertical variability in porosity, which likely would be detrimental to the overall effectiveness of in situ oil recovery processes. For all cores, a good correlation exists between porosity and permeability. Note that the majority of core samples have porosity in excess of 15% and permeability greater than 100 md.



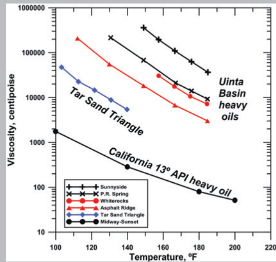
Average oil saturation, So, is in the range 24 to 36 vol%; the average water saturation, Sw, is somewhat lower between 4.0 and 26 vol%. The sum of So + Sw is less than the expected 100% indicating that the reservoir is deficient in fluids. Either (a) the reservoir is situated above the local water table, within the vadose zone, and air is also present in the pore space, or (b) the handling of the cores was such that fluid loss occurred before the cores were analyzed. It is most likely that the water drained from the core preferentially to the highly viscous, virtually immobile bitumen. This would mean that the values of So reported closely reflect the actual oil saturations in the reservoir --- 50 vol% or less. Successful in situ oil recovery processes, whether thermal, chemical or electrical, normally require oil saturations greater than 60%, preferably in the 70 to 90% range (Schamel, 2009).



The richness of bitumen in the reservoir or "oil grade" is calculated from the values of porosity and oil saturation. The oil grade (in units of barrels of oil per acre foot) is 7758 BO/ac ft, the volume in barrels of an acre foot, multiplied by the product of porosity times So, both expressed as decimal fractions. The logs below show the large vertical variability of bitumen richness in the White Rim Sandstone reservoir. The oil grade is considerably more variable than porosity, reflecting the important role of oil saturation (see figure above). In the five cores, the average oil grade varies from a low of 360.1 BO/ac ft to a high of 454.7 BO/ac ft. The actual bitumen resource-in-place represented by the core is the average grade in BO/ac ft times the net thickness of the bitumen-impregnated interval in feet. The values range from a low of 29.85 MBO/ac (thousand barrels/acre) in the Gordon Flats 16-1 core to 59.42 MBO/ac in the TST-2 core. Where the actual oil or bitumen content is reported as weight percent of total rock, the oil grade is a function of rock and oil densities: BO/ac ft = 169.4 x oil wt%.

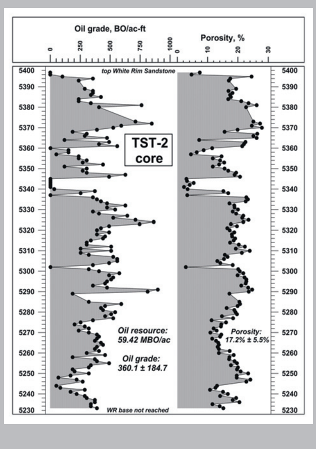
Comparison of bitumen properties:
Tar Sand Triangle, Asphalt Ridge, Utah, and Athabasca, Alberta.

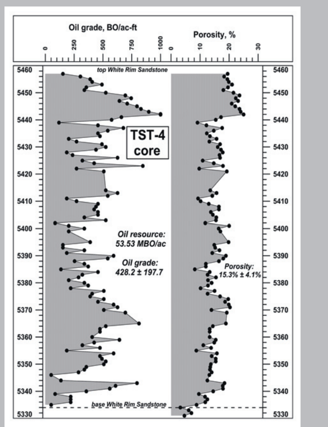
Property	*TST*	*AR NW*	*Athabasca*
API gravity	11.1	14.4	11.6
H/C atomic ratio	1.44	1.64	1.48
Saturated HC (wt %)	25.7	21.6	27.8
Aromatic HC (wt %)	31.9	38.1	26.9
Asphaltines (wt %)	26.0	6.3	16.4
Carbon residue (wt %)	21.6	3.5	16.1
Sulfur (wt %)	4.38	1.02	4.85
Nitrogen (wt %)	0.46	0.59	0.47
Va + Ni (ppm)	161	145	292
Dyn. viscosity (poise)	12,990	29,500	6,380
Heating value (Btu/lb)	17,900	18,800	17,700

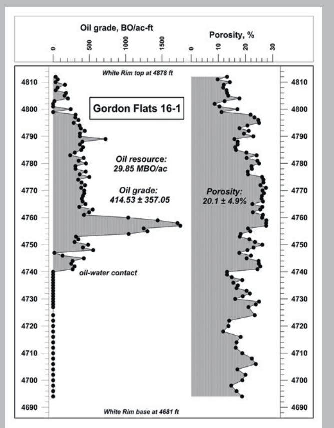


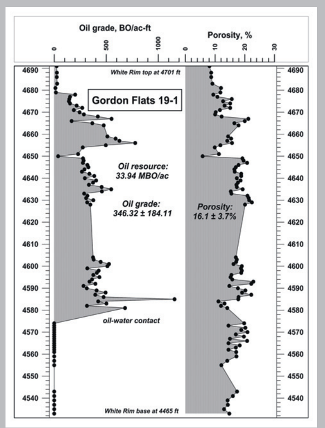
Surface bitumen samples are much heavier and more degraded than the 11.1° API oil from core that was analyzed by Bunger and others (1979; see table). The Tar Sand Triangle bitumen is very close in composition and physical properties to the well-known Athabasca bitumen, but it differs substantially from the more saturate-rich heavy oil from Utah's northwest Asphalt Ridge. It has a relatively low (1.44) H/C ratio and high asphaltine (26.0%) and sulfur (4.38%) content, as well as a very high carbon residue. All of these factors will make upgrading the bitumen/heavy oil difficult and expensive. However, the oil does have a favorable nitrogen and metals content. Bitumen extracted from Sagadahoc-Skyline State 1 core has an API gravity of 8.5º and a total sulfur content of 5.47 wt%. Bitumens from this deposit are not well characterized.

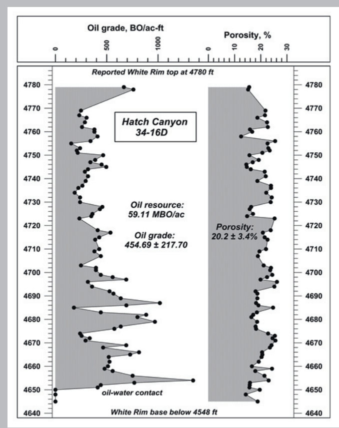
The viscosity of the Tar Sand Triangle bitumen is the lowest of any heavy oils and bitumen in Utah, but it is slightly more viscous than the Athabasca oil. At a reservoir temperature of 100°F, the viscosity of the oil is about 50,000 centipoise (cp). By conventional Andrade extrapolation, a viscosity of 100 cp would be reached in this heavy oil at 230°F and 10 cp would be reached at 290°F. These temperatures are within the range of thermal recovery processes, such as steam stimulation. TheTar Sand Triangle bitumen is considerably more viscous than the typical 13º heavy oil of the Midway-Sunset field, southern San Joaquin basin, California, that requires thermal stimulation to be produced commercially.











Core data from Utah Division of Oil, Gas and Mining public files and/or Dana and others (1984)

Tar Sand Triangle Bitumen Deposit, Garfield and Wayne Counties, Utah -- Panel 3

Calculation of Bitumen Resource-in-Place

To date, the most rigorous estimate of the bitumen resource is a study conducted by the Laramie Energy Technology Center in the early 1980s (Dana and others, 1984). Using public domain and proprietary well data, the thickness of the bitumen-impregnated White Rim Sandstone reservoir was compiled for 28 wells penetrating the full resource interval. For eight of the wells there was adequate oil grade data from core samples to calculate a bitumen resource value for the well. These values ranged from a high of 244.0 MBO/ac for Gordon Flats 27-1 (30S-16E-27) to a low of 29.0 MBO/ac in Saga.-Skyline State 1 (30S-16E-16). Using the 28 bitumen-impregnated thickness values, a "resource-thickness" isopleth map was constructed. The eight bitumen resource values then were used to sketch out four concentric zones having the general shape of the isopleths map. The zones having areas of 26, 61, 55, and 56 square miles (sections) size are assigned average bitumen resource values of 110, 75, 35, and 10 MBO/ac, respectively. The total in-place bitumen resource for the deposit is calculated as 6.3 billion barrels (BBO). Although substantially less than the 12.5 to 16.0 BBO reported by Ritzma (1979), the 6.3 BBO estimated by Dana and others (1984) still is based on optimistic projection of just a few wells with unusually large values of bitumen resource.

The approach taken in this study expands on the database and methodology of Dana and others (1984) adding and revising the control wells and adopting a more rigorous analysis of the data. Three additional bitumen resource control wells were added to the original set of eight: Gordon Flat 16-1, Gordon Flat 19-1, and Hatch Canyon 34-16D.

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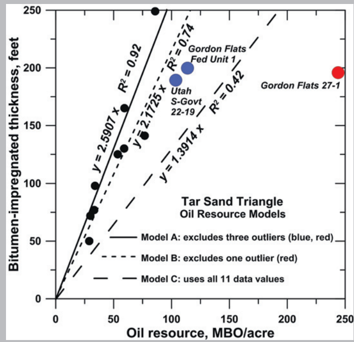
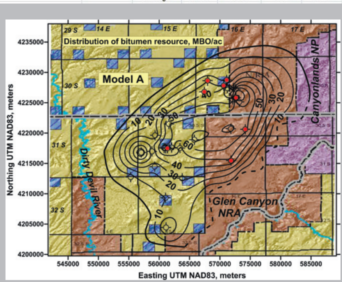
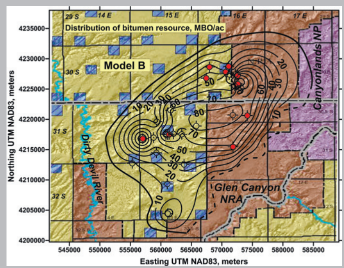
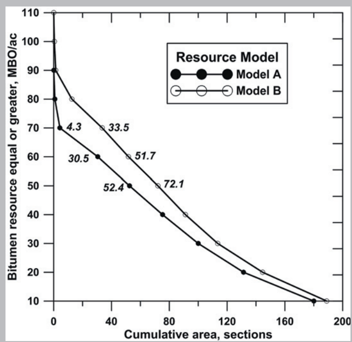
A large area in which the bitumen-impregnated interval is in excess of 100 ft thick, an apparently homogeneous, relatively porous reservoir, and relatively low viscosity of the oil all would suggest that steam-based thermal in situ recovery methods could be successful in the Tar Sand Triangle (Schamel, 2009). However, the close proximity to a national park and a national recreation area, as well as limited access to water resources, would favor a recovery process that has little water demand, has a very small surface footprint, and generates minimal air pollutants. THAI™ (toe-to-heel air injection) in situ combustion might be applied very effectively in this deposit, particularly as the deposit has generally low oil saturation. Solvent extraction is an alternative technology, and electrical heating might prove effective on the intermediate benches where the deposit is relatively close to the surface.

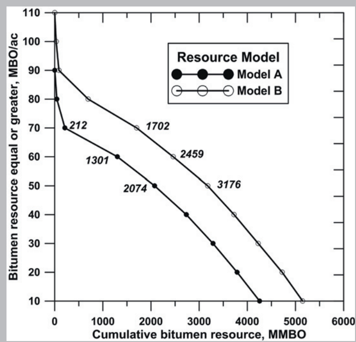
Well	E-NAD83	N-NAD83	Impr. ft	MBO/ac	Model A	Model B	Model C
Saga.-Skyline State 1	571119	4228821	50	29.00	19.30	23.01	35.94
Gordon Flats 16-1	570615	4227888	72	29.85	27.79	33.14	51.75
Gordon Flats 19-1	567444	4226851	98	33.94	37.83	45.11	70.43
Skyline State 2	572215	4227473	89		34.35	40.97	63.96
Gordon Flats Fed Unit 1	572571	4227291	200	113.42	77.20	92.06	143.74
French Seep 1	572097	4225606	115		44.39	52.93	82.65
Robbers Roost 41-33	571800	4220756	185		71.41	85.16	132.96
TST-2	574171	4220679	165	59.42	63.69	75.95	118.59
Technology 14-36	555324	4212821	14		5.40	6.44	10.06
White Rim 44-4	561606	4221560	156		60.22	71.81	112.12
Magnum 23-8	559325	4219693	57		22.00	26.24	40.97
Garfield 44-15	563414	4217593	124		47.86	57.08	89.12
Winfield 21-15	565795	4218967	186		71.80	85.62	133.68
Remington 14-15	562051	4217670	169		65.23	77.79	121.46
State 34-16	561043	4217567	175		67.55	80.55	125.77
Utah S-Govt 22-19	557043	4216866	190	103.55	73.34	87.46	136.55
Monroe 22-20	558821	4217048	86		33.20	39.59	61.81
Cromwell 33-29	559265	4214533	60		23.16	27.62	43.12
TST-4	571830	4215518	125	53.53	48.25	57.54	89.84
State 11-2	563799	4212614	84		32.42	38.67	60.37
State 31-16	561043	4209398	26		10.04	11.97	18.69
USA Federal A-1	561132	4204497	80		30.88	36.82	57.50
Hatch Cyn U 34-16B	560806	4217593	178		68.71	81.93	127.93
Shell 7	567978	4228692	77	33.21	29.72	35.44	55.34
Shell 1 Sentinel	571237	4227473	161		62.15	74.11	115.71
Gordon Flats 27-1	573134	4225243	196	244.00	75.66	90.22	140.87
Shell 9	572630	4225891	249	85.83	96.11	114.61	178.96
Hatch Canyon 34-16D	561340	4217567	130	59.11	50.18	59.84	93.43
		Median:	*125*	*59.11*	*48.06*	*57.31*	*89.48*
		Average	*124.9*	*76.80*	*48.21*	*57.49*	*89.76*











The oil resource values are plotted against the resource-thickness for the 11 control wells in the table to the left. While most data points cluster, one well stands far apart from the others. Excluding this clear outlier, Gordon Flats 27-1, the linear regression for the remaining 10 wells has an average oil grade equivalence of 460.3 BO/ac ft, a value exceeding the upper range for all but a few of the control wells. The R2 for this regression is 0.74. By excluding two additional wells, Gordon Flats Fed Unit 1 and Utah S-Govt 22-19, the linear regression for the remaining eight wells has an average oil grade equivalence of 386.0 BO/ac ft and an R2 of 0.92. The linear regressions serve as the basis for two alternative bitumen resource models. Model A, the more conservative, is based on eight wells and has a very good correlation. Model B, a plausible alternative, is based on 10 wells.

The model values of bitumen resource are the products of the resource-thickness times the average oil grade equivalence associated with each model. This yields 28 values for each model. These values are gridded by Kriging on a 100 x 100 node array and contoured in Surfer 11™ (see maps to the left). The band of highest values trends northeast-southwest across the deposit as would be expected from the northwest dip of the White Rim Sandstone reservoir and its thinning to the southeast. However, the richest portions of the deposit lie within the Glen Canyon NRA.

An alternative way of viewing the models is to compare the cumulative planar areas represented by successively lower bitumen resource thresholds. The area of the deposit having a bitumen resource equal or greater than 10 MBO/ac is 180 sections (square miles) in size in Model A and 189 sections in Model B. The areas having bitumen resource equal or greater than 60 MBO/ac are 30.5 and 51.7 sections in Model A and B, respectively. The total in-place bitumen resource for the deposit in areas modeled as greater than 10 MBO/ac is 4255 MMBO in Model A and 5149MMBO in Model B.

The total in-place bitumen resource estimate may attract the attention of speculators, but is in most respects a meaningless number for an operator. If the resource is too lean for commercial exploitation, it can never become booked reserves and future produced hydrocarbons. With no experience actually producing the Tar Sand Triangle bitumen, it is not presently prudent to speculate on the level of reservoir richness where commercially-viable production is possible. Consequently, the in-place bitumen resource is plotted for specific MBO/ac thresholds. For instance, at the 60 MBO/ac richness threshold, the in-place resource is 1301 MMBO in Model A and 2459 MMBO in Model B. Note that for threshold values greater than 70 to 80 MBO/ac, the total bitumen resource diminishes rapidly, reflecting the contraction of the area having these larger bitumen grades.

Although the bitumen resource estimates are developed by a rigorous, established analytical procedure, the limited number of control wells diminishes their level of confidence. Twenty-eight wells across an area of approximately 200 square miles is a data density of just one well per 7.2 square miles. Additionally, the majority of the control wells are clustered on the Gordon Flats, the southeast The Big Ridge, and in North Hatch Canyon, reducing the effective data density.

Prospects for Exploitation

The Tar Sand Triangle deposit has several drawbacks that will make commercial bitumen recovery operations difficult and expensive, but not impossible. These include:

1) the relatively low grade of the resource and the apparent low oil saturations.
2) the generally poor quality of the oil due to high sulfur content and high viscosity at reservoir temperatures.
3) the difficult access to the deposit by existing unimproved roads, all of which pass through the Glen Canyon National Recreation Area.
4) potentially complicated and/or expensive process water access.
5) the lack of petroleum service vendors and other support services in southeast Utah.
6) the proximity to environmentally-protected and visually stunning public lands.

Acknowledgements and References

This paper greatly expands on a chapter describing the Tar Sands Triangle bitumen deposit in the Utah Geological Survey Open-File Report 551, Strategies for in situ recovery of Utah's heavy oil and bitumen resources (Schamel, 2009). That report was prepared, in part, with a UGS research contract managed by Craig Morgan. Wally Gwynn and Gene Van Dyke provided valuable assistance to earlier investigations of the Tar Sand Triangle bitumen deposit enabling the open-file report and this paper.

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