OIL PROSPECTS IN WASHINGTON COUNTY, UTAH.

By Harvey Bassler and John B. Reeside, Jr.

INTRODUCTION.

Washington County is the extreme southwestern county of Utah. It is reached most easily by autostage from stations on the Los Angeles & Salt Lake Railroad. Most of the traffic of the county passes through Lund by way of Cedar City, a distance of 90 miles from St. George, the county seat; part of it passes through Modena by way of Enterprise, a distance of 60 miles but at present a more difficult route. An automobile route, the Arrowhead Trail, connecting Salt Lake City and Los Angeles, crosses the central part of the county. From this route spur highways reach the main towns and Zion Canyon National Park, in the eastern part of the county. Except on these main roads automobile traffic is somewhat hazardous—indeed, for the greater part impracticable. (See fig. 9.)

The region is drained by Virgin River, one of the larger tributaries of the Colorado, and might be considered the northern extension of the Grand Canyon district. Erosion has produced a topography of marked relief, and over much of the area rock exposures, which are common in the steep slopes and canyon walls and along the ridges, make it relatively easy to observe stratigraphic and structural details.

The climate is arid, and farming, except on the upland plateaus, is practicable only where streams supply water for irrigation. Such streams are absent south of Virgin River and are not numerous north of it, there being only five of six of any importance. The climate makes it possible in these favored localities to produce many varieties of fruit and other products, some of them semitropical, upon which the population of the region now depends largely for its support. Sheep and cattle raising is an important industry, the high plateaus and mountain pastures being occupied for this purpose in the summer and the lowlands in the winter.

St. George is the chief town and county seat. It has a population of 2,215 (1920), with the usual complement of stores, banks, and other enterprises necessary for the trading center of an agricultural region. Other towns are scattered along Virgin River and its principal tributaries. Leeds, 15 miles east of St. George, was formerly the center of a prosperous silver-mining district, but the industry has been idle since the late nineties.

Exploratory drilling for oil has not been extensive in Washington County. Drilling near Virgin City resulted in several small wells as early as 1907. About 15 test wells were then sunk, most of them

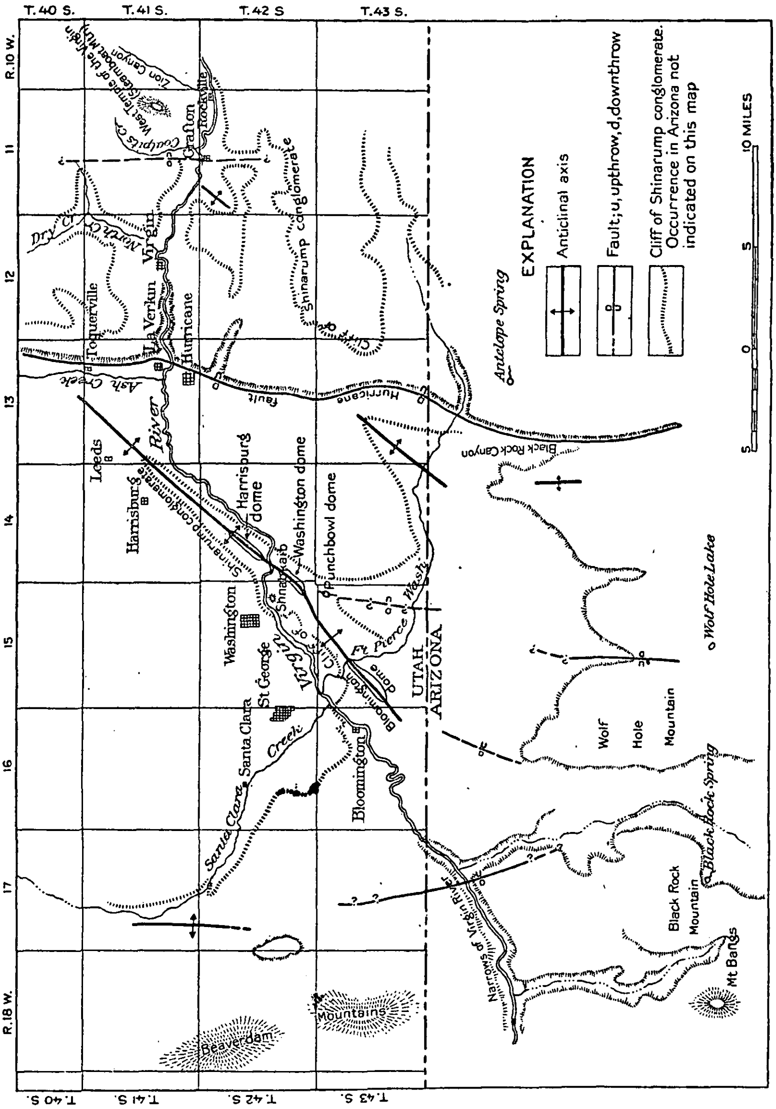

FIGURE 9.—Map of parts of Washington County, Utah, and Mohave County, Ariz.

grouped near Virgin City but some a considerable distance away. No further exploration was made for 10 years, when some of the old wells near Virgin City were cleaned out and several new wells were drilled. In 1919 a well was started on the Harrisburg dome and has reached a depth of 2,200 feet (September, 1920).

The writers spent part of the autumn of 1919 examining the region in reconnaissance. Some detailed work was done near Virgin City and on the three domes of the Virgin anticline, but much of the work was rapid, without a satisfactory base map, and accordingly lacks detail. Much assistance was given by several residents, for which the writers take this opportunity of expressing their thanks.

GEOLOGY.

STRATIGRAPHY.

The rocks of the region range in age from Mississippian to Tertiary, but those of greatest importance as possible sources of oil are the older rocks, beneath what is known as the Shinarump conglomerate—the relatively thin but resistant and sharply marked brown sandstone, bearing pebbles and many petrified logs, that forms an easily recognized and persistent cliff-making stratum over a large stretch of country. These older rocks are included in the Moenkopi formation, the Kaibab limestone, and a sandstone formation which represents the Coconino sandstone and Supai formation of the Grand Canyon area. The Moenkopi formation, of red sandstone, shale, and gypsum, with yellow earthy limestone in the lower part and a discontinuous conglomeratic limestone member at the base, was long believed to be of Permian age but is now considered Lower Triassic. It is from 1,800 to 2,000 feet thick in this region. The Kaibab limestone is at most points not a pure limestone formation but consists of two layers of very hard cherty gray limestone separated by softer shale, gypsum, and thin dark limestone. At many points the lower hard limestone is underlain by soft material similar to that above, and locally there is above the upper hard limestone a variable series of limestone, gypsum, and shale. The divisions vary much in thickness at different localities and may include beds at somewhat different horizons in the formation at different places. The entire formation ranges from 950 to 1,100 feet in thickness. In the past it has been considered of Pennsylvanian age, but it is now believed by many geologists to be Permian and is so classified by the United States Geological Survey.

Beneath the Kaibab limestone is a massive yellow and red sandstone containing, in the St. George district, very few soft or shaly layers and attaining 1,500 feet in thickness. Farther east it contains a larger proportion of shaly layers. In the Grand Canyon the Kaibab limestone is underlain by the Coconino sandstone, a light-colored massive formation 300 feet thick, of Permian (?) age, which rests on the Supai formation, a succession of red sandstone and shale about 1,200 feet thick, of Pennsylvanian (?) age. In the general region of St. George the rocks underlying the Kaibab do not possess the precise characteristic features of the Coconino and Supai of the Grand Canyon, but examination of a series of stratigraphic sections at intervals between these regions has revealed a gradual northwestward thinning of the typical Coconino until its identity is finally lost in the top of the sandstone beneath the Kaibab limestone. This sandstone in the same direction becomes increasingly more sandy and less red until in the Beaver Dam Mountains, west of St. George, there is no longer any really red material nor any shale throughout its thickness of more than 1,400 feet. In Virgin Canyon a dense gray siliceous limestone lies beneath the sandstone and is probably equivalent to the Redwall limestone of the Grand Canyon, which is in part Pennsylvanian and in part Mississippian.

Composite section for the region east of the Hurricane fault scarp.

Smith's Mesa, 3 miles north of Virgin City, Utah.

		Feet.
Shinarump conglomerate (Triassic):		
Sandstone, gray, platy, with a few pebbles		20
Shale, gray to green, with some fossil wood		20
Sandstone, coarse, gray-white on fresh surface, limonitic brown on weathered surface; locally filled with small black blobs of wad in appearance suggestive of specks of petroleum; contains lenses of pebbles of chert, variously colored, quartz, silicified wood, and igneous rock. Base is irregular. Unit contains abundance of fossil logs, mostly silicified though in part replaced by copper minerals and rarely by pockets of lignite		75
		115
Unconformity.		
Moenkopi formation (Lower Triassic):		
Sandstone, soft, and shale, brick-red to very deep red, with gypsum and a little lighter-colored shale		405
Shnabkaib shale member:[1] Shale, sandy, and sandstone, soft, fine grained, creamy white, with some pinkish layers and gypsum		360
Sandstone and shale, brick-red, with some reddish gypsum and light bluish-gray gypsum; lighter colored than the upper red beds		400
Virgin limestone member:[2]		
Limestone, yellow, earthy, fossiliferous	5	
Shale, yellow and red	25	

[1] Named for the striking isolated mesa 2 miles southeast of the town of Washington, on the northwest flank of the Washington dome. This member is more fully described in a forthcoming report on the stratigraphy of the region, by the authors of this report, which will form one of the chapters of Professional Paper 129.

[2] The Virgin limestone member, Rock Canyon conglomeratic member, and Harrisburg gypsiferous member are new names, used for the first time in this report, but the members are more fully described in a forthcoming report on the stratigraphy of the region, by the authors of this report, which will form one of the chapters of Professional Paper 129. The Virgin limestone member is named for Virgin City, where the limestone is well exposed; the Rock Canyon member is named for Rock Canyon, 5 miles north of Antelope Spring, Ariz.; and the Harrisburg member is named for its occurrence in the Harrisburg dome, 8 miles east of St. George.

		Feet.
Moenkopi formation (Lower Triassic)—Continued.		
Virginia limestone member—Continued.		
Limestone, yellow, earthy, fossiliferous	5	
Shale, yellow, calcareous	25	
Limestone, fairly massive, yellow, earthy, fossiliferous	20	
		80
Sandstone and shale, brick-red, with gypsum		360
Rock Canyon conglomeratic member:[2] Irregular complex of limestone, limestone and chert conglomerate, shale, and gypsum. Absent locally		170
		1,775
Unconformity.		

Hurricane fault scarp, 6 miles south of Hurricane, Utah.

Kaibab limestone (Permian):	
Harrisburg gypsiferous member[2] (may include some beds of basal part of Moenkopi formation): Limestone, gray, thin bedded, some of it containing many small angular fragments of chert; and shale, gray or yellow	160
Limestone, massive, gray, with much brown chert; fossils abundant in chert; forms upper cliff	260
Shale, soft sandstone, and gypsum, the whole forming a gray slope	200
Limestone, gray, massive, with much brown chert; light colored on fresh surface; contains softer shaly layers near middle of unit; forms lower cliff	230
Limestone, sandy, cream-colored, and also thin bedded, dark drab; gypsum, white to gray; forms slope	80
	930

Black Rock Canyon, Ariz., 18 miles south of Hurricane, Utah.

Coconino sandstone (Permian?) and Supai formation (Pennsylvanian?):	
Sandstone, medium grained, gray-white on fresh surface, yellow-brown on weathered surface, medium-bedded, cross-bedded	200
Sandstone, like unit above but in thinner beds separated by softer brick-red sandstone	490
Sandstone, medium grained, cross-bedded, gray-white on fresh surface, yellow-brown on weathered surface, relatively thin bedded and forming a bench	155
Sandstone, like the unit next above but practically in one bed and forming a sheer wall; exposed	380
	1,225

[2] See footnote 2 on page 90.

Composite section for the region near St. George, Utah.

Harrisburg dome, 8 miles east of St. George.

	Feet.
Shinarump conglomerate (Triassic)	100±
Unconformity.	
Moenkopi formation (Lower Triassic):	
Shale and sandstone, brick-red; upper part very dark	320
Sandstone, yellow, medium grained; massive in upper part	75
Shale, red, with some sandstone and gypsum	80
Shnabkaib shale member: Shale, sandy, white to light gray, with gypsum and some pink shale	630
Shale, red, sandy, with gypsum	435
Virgin limestone member: Limestone, earthy, greenish yellow, in three thin bands separated by greenish-yellow and reddish-brown shale	160
Shale, red, some of it sandy, with gypsum and a little bluish gypsiferous shale	275
Shale, yellow, gypsiferous	60
Rock Canyon conglomeratic member absent at this locality, though present elsewhere in the region.	
	2,035
Unconformity.	
Kaibab limestone (Permian):	
Harrisburg gypsiferous member: Limestone, light gray, blue-gray, yellow, and reddish, some of it with very characteristic white chert with platy fracture; shale, red and yellow, gypsiferous; gypsum	137

Narrows of Virgin River, below Bloomington, Utah.

Limestone, thin bedded, gray, with some small chert fragments; may duplicate some of Harrisburg member described above	70
Limestone, massive, uniform, fine grained, gray on fresh surface, brownish on weathered surface; filled with layers and nodules of brown chert	275
Breccia of limestone and chert in a limy matrix; whole mass weathers to a yellow-brown color. This unit with unit above forms a cliff	110
Gypsum, red shale, breccia of limestone and chert, and gray shale, forming a slope	80
Limestone, very massive, gray to light gray on weathered surface, cherty; forms cliff	220
Soft sandstone, yellow, gypsiferous; limestone, thin bedded and arenaceous; forms slope	65
	957

	Feet.
Coconino sandstone (Permian?) and Supai formation (Pennsylvanian):	
Coconino sandstone(?): Sandstone, cross-bedded, buff, coarse, above; sandstone, white on fresh surface, dark gray on weathered surface, cross-bedded, in middle; sandstone, white to cream-colored, earthy, below	45
Supai formation(?): Sandstone, medium-grained, cross-bedded, exceedingly massive. Lower part yellow and brown with a little irregular red staining; middle part similar but with much red staining and a few thin soft red sandstones; upper part at some places a uniform red but usually a clean yellow-brown. The unit is practically one continuous bed and can not be divided into definite subunits	1,490
Redwall limestone (Pennsylvanian and Mississippian):	
Limestone, siliceous, with some sandstone; mostly heavy bedded; light gray on fresh surface, red-brown to dark gray on weathered surface; exposed	500

STRUCTURE.

The region may be considered structurally as two districts separated by the Hurricane fault, which runs north and south on a line 15 miles east of St. George. East of the fault the rocks are relatively little disturbed. Some smaller faults and some low anticlines are present, but as a whole the district is one of low monoclinal dips without any large modifications. This structure is expressed topographically by flat-topped mesas and level benches of hard strata with intervening slopes of soft materials. West of the Hurricane fault folds and smaller faults of various sizes have so greatly changed the original attitude of the rocks that the district is structurally complex in comparison with that east of the fault. A north-south fault of considerable size lies along the east side of Heber Valley, 10 miles west of St. George. Another 10 to 20 miles south of St. George, east of Wolf Hole Mountain, may be a northward extension of the Grand Wash fault of the earlier geologists, but it has not yet been traced more than a short distance.

OIL PROSPECTS IN THE DISTRICT EAST OF THE HURRICANE FAULT.

FIELD NEAR VIRGIN CITY.

Oil was discovered in 1907 at a point 2 miles northeast of Virgin City, in sec. 13, T. 41 S., R. 12 W., and for a short time exploration was very active. About 15 wells were drilled, most of them grouped around Virgin City but a few at some distance from it. According to the best information now available most of these wells were failures, making only small or no showings of oil and gas; one in

Virgin City is said to have produced enough gas to make a flame several feet long from a 2-inch pipe; one well (No. 9, fig. 10) produced some oil; and three wells, which still produce, came in with production stated variously as high as 36 barrels a day, but probably in reality not more than half that.

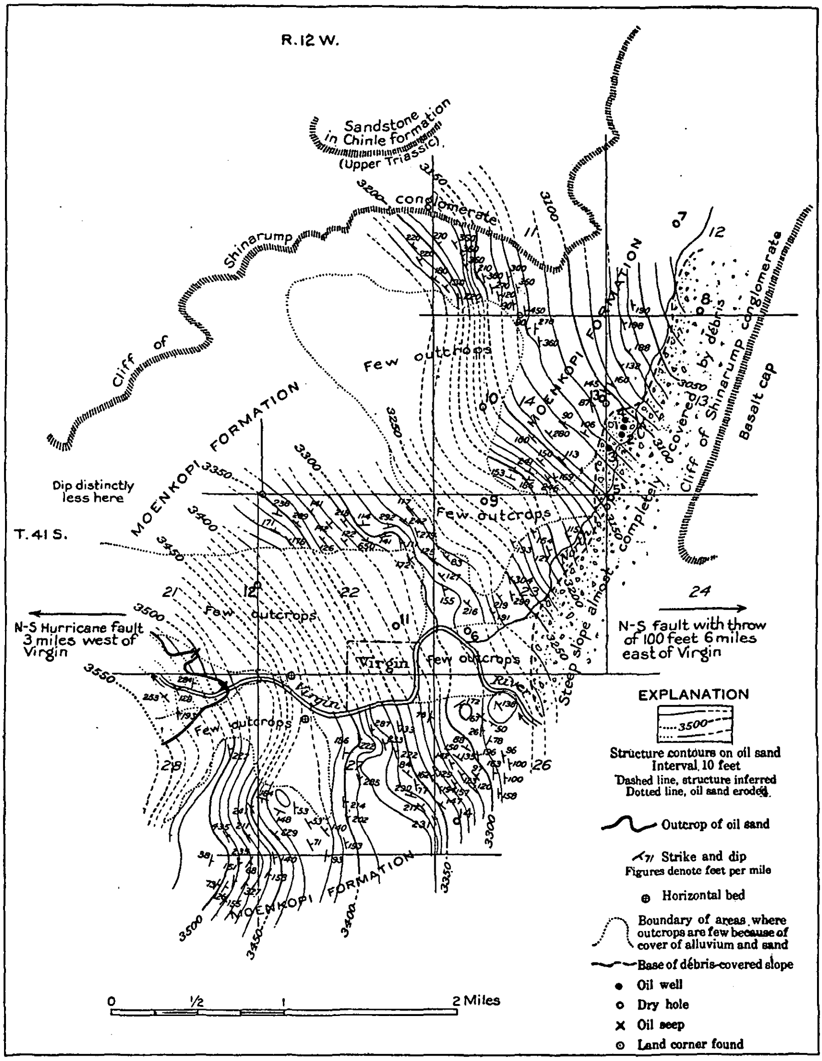

FIGURE 10.—Map of the oil field near Virgin City, Utah.

There was no market for the oil at the time of discovery except as fuel for further drilling, and as the financial panic of 1907 cut down the capital necessary for such exploratory work all activity ceased abruptly.

Nothing more was done in the field until 1918, when the three producing wells were cleaned out and shot, pumping was started, and a small local refinery was built. A new well was drilled near the old wells and has a production of 4 or 5 barrels a day; a second hole put down on the north bank of Virgin River, about a mile south of the first one, proved to be dry. The total production from the four wells, which are uncased holes 550 to 600 feet deep, is about 20 barrels a day (September, 1920). The bulk of this amount is coming from one well, the other wells pumping much more water than oil. The refinery will handle 800 gallons of crude oil per 8-hour shift, and the products find a ready local market.

The oil is reported to range in gravity from 25° to 35° Baumé, to have a paraffin base that includes some asphalt, and to contain some sulphur. It is dark brown and very fluid. There has been little gas in the wells, but the amount is increasing as pumping continues.

The oil comes from a 1-foot bed of limestone which is at the top of the basal Rock Canyon conglomeratic member of the Moenkopi. The wells appear to have met no oil until they pierced this layer and to have obtained no increase from lower beds. This bed is easily found on the outcrop west of Virgin City, and at some points oil and sulphur water are seeping from it, notably at one locality a mile west of Virgin City. The associated limestone contains many cavities, due to the removal of fossils by solution, which are filled with a very fluid oil, though none is apparent in the mass of the rock. Likewise certain sandstone layers in the red beds of the Moenkopi above the limestone contain enough oil to form when fragments are heated in a glass tube a brown ring of oil on the cold part of the tube.

The original source of the oil has not been determined. No carbonaceous matter is apparent anywhere near the oil sand, either in the red beds above it or in the limestone beneath. Over a distance of perhaps 25 miles there is evidence locally of oil in the basal Moenkopi without any apparent carbonaceous matter in either the overlying or underlying rock. At this horizon some miles northeast of Toquerville there are in the limestone many fossil cavities filled with oil. This is true also at the places west of Virgin City mentioned above and at other localities 5 or 6 miles south of Virgin City. At the localities on Rock Canyon and 2 miles southwest of Black Rock Canyon, described on pages 104–105, the basal Moenkopi contains much asphaltic material. In the absence of any other probable source of the oil, the layers of abundantly fossiliferous limestone seem to be the most probable place of origin. However, the higher oil-bearing layer described on page 98 is separated by thick intervals of rock from any known fossiliferous beds.

The accumulation of oil may be due to various causes. In many fields an anticlinal fold is the governing factor, the oil accumulating in the higher parts of the fold if water is abundant in the sands, on the flanks if water is not abundant, and in the intervening synclines if the rocks are dry. In other fields the oil accumulates in a rock terrace formed by a steplike wrinkle in an inclined layer. The dip is low on the terrace but steeper toward the terrace on the high side and away from it on the lower side. In some fields an inclined oil-bearing layer is sealed by faulting or by overlap at its upper end by impervious rocks, so that oil can accumulate just beneath the seal. Some oil reservoirs are merely porous pockets in rock that is elsewhere relatively impervious, as, for example, sandstone lenses in a shale. Or the rock may be more porous at some places than at others, permitting a greater oil content locally because there is more space for it. In some regions oil accumulates in the favorable places which are nearer the source of the oil and is absent from places that are equally favorable except that they are farther away. For example, in some large structural basins that contain folds at different distances from the basin rim oil moving up from the central part of the basin accumulates in the folds that lie nearer the center of the basin rather than in those that lie farther out.

The accumulation of oil in the field near Virgin City has been attributed previously either to the probable presence of permeable sandstone lenses in impervious shale or to chance variations in the porosity of a sandstone layer—causes neither of which is determinable from the surface. However, there is a much more probable cause of accumulation in the structure of the field. The rocks of this field dip to the northeast at an average angle of not more than 2°, though the dip is not uniform but is modified by steepenings where it may rise to 5° or 6° and by flattenings where the rocks are nearly level. The contour lines on figure 10 show the form of the surface of the oil sand, as nearly as it may be determined from the surface. Contour lines that are close together indicate that this surface is relatively steep; lines that are widely separated indicate that it is relatively flat. The producing wells, Nos. 1 to 4 of the map, in the SW. ¼ sec. 13, are clearly situated on a flat area. Well No. 5, in the NW. ¼ sec. 24, known to have been a failure, lies at the foot of an area of relatively high dip. Well No. 6, in the SW. ¼ sec. 23, known to have been a failure, seems to lie on a flat area, though near the higher edge. Well No. 9, in the NW. ¼ sec. 23, reported to have been a small producer, lies apparently on a flat. Well No. 11, in the SE. ¼ sec. 22, a gas well in Virgin City, may lie on a flat, though the contour lines for the area near it are based on insufficient data. The information now available, though it is not very reliable, seems to indicate that wells Nos. 7 and 8, in sec. 12; No. 10, in the NW. ¼ sec. 14; No. 12, near the west quarter corner of sec. 22; No. 13, near the west quarter corner of sec. 13; and No. 14, in the SW. ¼ sec. 26, were all failures. It seems most probable on the evidence here presented that terraces, or areas of low dip, are favorable to the accumulation of oil in this field and that the steep slopes are unfavorable. To what extent, in addition, variations in porosity of the sand are a factor it is difficult to say, though they are probably of minor importance. There are no anticlines, faults, or other features closely enough associated with the producing field to offer an explanation for the accumulation of oil, so that the only likely factor left is that of accumulation on a terrace.

OTHER FAVORABLE LOCALITIES.

If the view above set forth is correct, there are several untested localities near Virgin City that are structurally as favorable at least as the small area from which oil is now obtained, and the producing wells are sufficiently close to these terraces to justify the recommendation that other localities where the structure is similar be tested. Approximate locations for such tests are the northwest corner of the NW. ¼ SW. ¼ sec. 23, T. 41 S., R. 12 W; the center of the NW. ¼ SW. ¼ sec. 23, T. 41 S., R. 12 W.; the center of the NE. ¼ NW. ¼ sec. 26, T. 41 S., R. 12 W.; the center of the SE. ¼ NW. ¼ sec. 26, T. 41 S., R. 12 W.; and the SE. ¼ SE. ¼ sec. 27, T. 41 S., R. 12 W.

If drilling at these places gives favorable results, a still more pronounced flattening in the W. ½ sec. 27, T. 41 S., R. 12 W., should be tested, though it lies so close to the outcrop of the oil-bearing beds that seepage at the outcrop may have allowed any oil present to escape, and it may not prove any better than the other locations. On the other hand, several fields lately brought in, such as the Upton-Thornton and Osage fields of Wyoming, produce from sands whose outcrop lies very close to the wells, and it is possible that a similar condition exists here.

A relatively pronounced structural terrace is visible on Virgin River 1 mile west of Grafton and 6 miles east of Virgin City, in secs. 5, 6, and 7, T. 42 S., R. 11 W. Old Grafton Wash cuts through it. The surface rock is the middle red-bed member of the Moenkopi formation. The fold trends northeast and southwest from the river. The dip on the southeast side is 6° to 8° SE., and the northwest side is flat or even slightly reversed. Farther northwest the low regional dip of about 2° SE. again prevails. This terrace is a duplicate on a somewhat larger scale and with more pronounced features of those near Virgin City. Under it the horizon of the producing sand at Virgin City lies at a depth of 800 to 900 feet. The locality where this terrace crosses San Juan River is only a mile west of the fault that passes in a north-south direction through Grafton. (See fig. 9.) Though toward the south the terrace diverges from the fault, the effect of the fault would be to cut down the area of rock that might contribute to a possible accumulation of oil on the terrace. A short distance north of San Juan River the fold passes under basalt and can not be traced farther, though it can not extend far before meeting the fault. South of the river its full extent is not known, but it can be seen for several miles at least. The large size and apparent great extent of this fold in comparison with that producing at Virgin City make it worth a test.

Several miles east of Antelope Spring, Ariz., and about 20 miles south of Virgin City, where the general dip is 1°–2° NE., a reversed dip of 1°–3° W. in the Virgin limestone member of the Moenkopi formation betrays the presence of a low anticline whose axis extends apparently in a north-south direction. A reversed dip of 3° observed about 7 miles southeast of Antelope Spring probably indicates a southward extension of the axis to that locality. Little is known of the extent and character of this fold, as no study was made to determine its possibilities or select drill sites, but it is believed that its axis passes approximately through what would be sec. 19, T. 44 S., R. 12 W., if the Utah land subdivisions were extended into Arizona. The depth on this fold to the horizon of the sand that is productive at Virgin City should be 300 to 400 feet. A well drilled in 1907 about 4 miles east of Antelope Spring does not lie near enough to test this anticline, though it is said that gas was struck in the well.

HIGHER OIL SAND.

Another possible oil-bearing bed is in the upper part of the Moenkopi formation, in the midst of red beds, about 1,000 feet above the oil-yielding bed of the Virgin River field. This oil-bearing zone was noted on Dry Creek, 3 miles north of the Dixie Co.'s wells, where a 6-foot layer of brown sandy shale that smells strongly of oil when broken is overlain by 4 feet of contorted oil-stained shale containing nodules of gypsum. About 2 feet higher a 6-inch layer of shale and gypsum is crossed by stringers of pure black asphalt a quarter of an inch to an inch thick. Nothing was observed that would suggest the source of this oil and asphaltic matter. No carbonaceous material or fossils were seen in any of the beds above it up to the Shinarump conglomerate, and no carbonaceous matter or fossils occur between it and the Virgin limestone member. The containing beds themselves seem to include nothing that could have furnished oil. Where the structure is favorable and these beds lie 200 feet or more below the surface, they may be of greater value than the lower producing beds of the Virgin River field. Furthermore, wells sunk in such locations may reach down to the lower beds. No search was made by the writers to locate folds in the beds above this higher zone of oil-bearing rock, nor was it traced farther than the canyon of Dry Creek.

PROSPECTS FOR FUTURE PRODUCTION.

The present Virgin City field appears to be of value for supplying local demand. The thinness of the oil "sand" seems to preclude the possibility of production adequate to repay the expenses of distributing the oil to refineries outside the field. However, at some distance from Virgin City the oil-bearing beds may thicken so much that they will furnish an adequate reservoir for greater accumulations of oil. Therefore any pronounced anticlinal fold that may be detected in the beds of the Moenkopi formation in this general region should be prospected to test this possibility.

OIL PROSPECTS IN THE DISTRICT WEST OF THE HURRICANE FAULT.

The most prominent structural feature of the district west of the Hurricane fault is the Virgin anticline, with its three superimposed domes—the Harrisburg dome, the Washington dome, and the Bloomington dome. Minor anticlines were noted at several localities.

VIRGIN ANTICLINE.

The axis of the Virgin anticline trends southwestward through Tps. 41 and 42 S., R. 14 W., and T. 43 S., R. 15 W. Over most of its length this anticline exposes the red rocks of the Moenkopi formation, but at three places, where it has been affected by cross folds, it brings up the Kaibab limestone. These cross folds form well-defined domes, called the Harrisburg, Washington, and Bloomington domes. The Harrisburg dome lies in secs. 8, 9, 16, and 17, T. 42 S., R. 14 W., about 3 miles east of the town of Washington. The Washington dome lies in secs. 30 and 31, T. 42 S., R. 14 W., and secs. 25 and 26, T. 42 S., R. 15 W., several miles southwest of the Harrisburg dome and southeast of the town of Washington. The Bloomington dome lies in secs. 8, 9, 17, 18, and 19, T. 43 S., R. 15 W., 6 miles southwest of the Washington dome and 5 miles south of the town of St. George. These three domes offer the most promising locations for the accumulation of oil if any is present in the anticline, and more time was spent in studying them. They are therefore described in some detail below, and the maps (figs. 11 and 12) show more detail than was procured regarding the other folds of the region.

Harrisburg dome.—The Harrisburg dome lies in secs. 8, 9, 16, and 17, T. 42 S., R. 14 W., just north of the place where Virgin River crosses the anticline, about 8 miles northeast of St. George and 3 miles east of Washington. An almost completely encircling outcrop of the Virgin limestone low in the Moenkopi formation and the high core of Kaibab limestone rising out of the red shales and sandstones mark it off, even to the layman's eye. The oil-bearing zone of Virgin City is not present over the crest of the dome and appears to be lacking also on the flanks. The dips are high, from 40° to 65°, and the folding is close—so close, in fact, that on the southeast flank a hinge fault has been formed on a line running 500 to 800 feet from the axis and parallel to it. (A hinge fault is a fault or crack starting in unbroken rock and gradually separating the broken ends of a given stratum farther and farther as it recedes

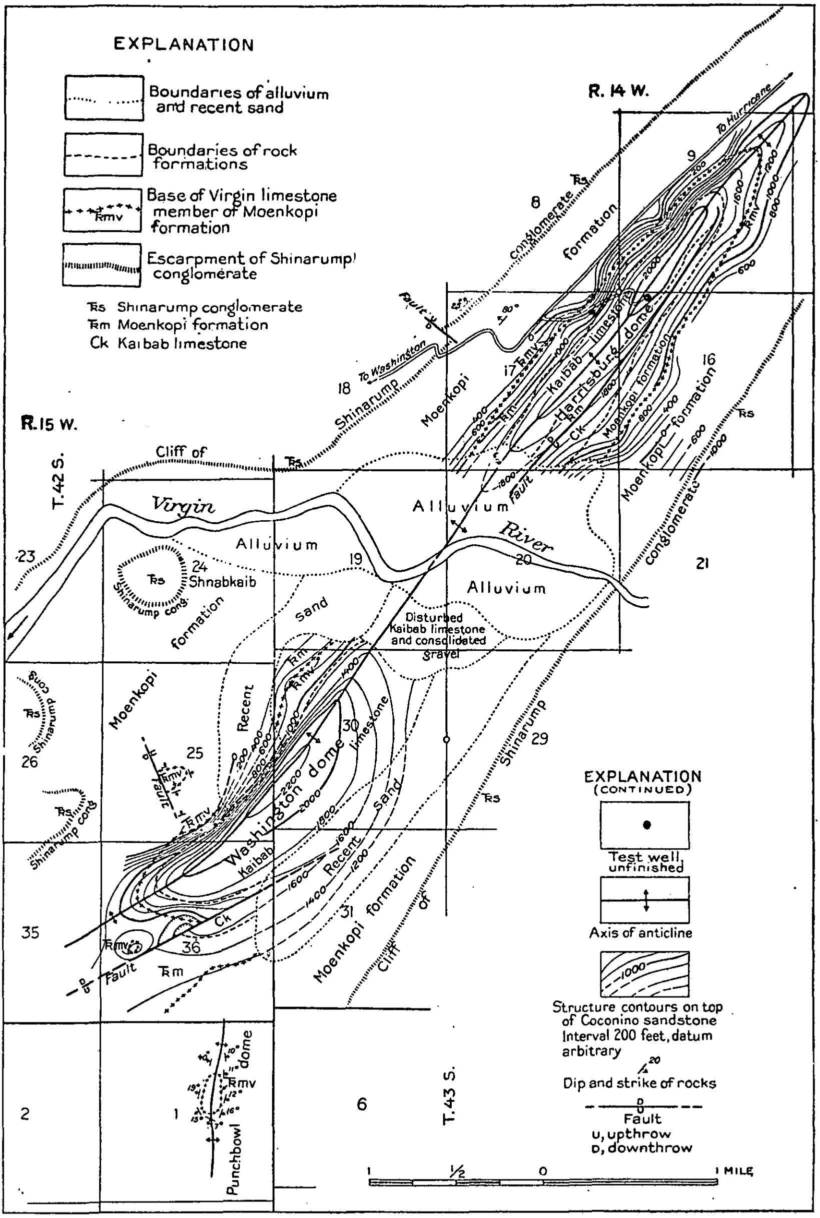

FIGURE 11.—Map of part of the Virgin anticline, Washington County, Utah, showing the Harrisburg and Washington domes.

from the unbroken part, somewhat as the two blades of an open pair of shears separate progressively outward from the pivot.) This fault begins near the north end of the dome, and the displacement increases southward until the rocks on the east are raised a distance of perhaps 500 feet at the southernmost exposure. The Kaibab limestone is only slightly eroded at the top of the dome, and practically its entire thickness must be pierced to reach the sandstone. As the thickness is over 900 feet in the Hurricane cliff, to the east, and in Virgin Canyon, to the west, it is likely that 950 feet is not an excessive estimate of the thickness under the dome. Reports of the rocks passed through in drilling the well on this dome seem to indicate that they included a little more than 1,000 feet of Kaibab strata. This larger figure may be due to a thickening along the crest of the fold produced during the folding.

This well, the only well now being drilled in the region, is near the northwest corner of sec. 16 and is close to the highest point structurally on the Harrisburg dome. It lies practically on the axis and is an adequate test of the upper part of the dome. At present (September, 1920) the well is reported to have reached a depth of 2,200 feet and therefore to have pierced the Kaibab limestone and most of the underlying sandstone. It is proposed to continue the well to a greater depth, but the prospect of success at lower horizons is very small. A light showing of oil was reported at approximately the horizon of the top of the sandstone, and water was found at several other horizons.

Washington dome.—The Washington dome lies across Virgin River from the Harrisburg dome, in secs. 30 and 31, T. 42 S., R. 14 W., and secs. 25 and 26, T. 42 S., R. 15 W. It is separated from the Harrisburg dome by an area where bedrock is concealed by river silt, gravels, and blown sand, but there is ample field evidence that the two domes are distinct. South of the river some evidence of faulting is shown by small outcrops of much disturbed Kaibab and Moenkopi rocks piercing this mantle, but this faulting is on a small scale and does not affect the dome itself. The dome shows topographically in the high core of Kaibab limestone rising from the softer and more eroded red rocks of the Moenkopi formation. The Virgin limestone member of the Moenkopi formation is exposed locally but is mostly buried under blown sand. The oil-bearing bed of the Virgin City field is not present over the crest of the dome and where present on the flanks shows no indication of oil. The best chance of finding oil in this dome is in the sandstone that represents the Coconino and Supai formations. The Kaibab limestone is not deeply eroded on the crest of the fold, and any well would have to pierce most of that formation to reach the sandstone beneath, the thickness being the same as under the Harrisburg dome—that is, 900 to 1,000 feet of Kaibab limestone must be penetrated. The Washington dome is unsymmetrical. The dips on the west side are from 40° to 60° or more, and those on the east side are commonly around 20°; the axis therefore lies much closer to the west side. Near the south end of the dome a fault of the same type as that in the Harrisburg dome cuts the southeast flank, but it seems to be of lesser extent, though the displacement reaches 700 or 800 feet at its visible maximum. This fault is exposed for a distance of three-quarters of a mile and passes under cover at each end of the exposure. The structurally highest part of the dome lies at the surface in the NW. ¼ SW. ¼ sec. 30, T. 42 S., R. 14 W., and the SE. ¼ SE. ¼ sec. 25, T. 42 S., R. 15 W., but owing to the unsymmetrical form any drilling to test the crest should be shifted 300 to 400 feet to the east, as in such folds the axis does not lie in depth immediately beneath its position at the surface.

Several minor domes occur near the Washington dome. One of them lies north of the south end, near the center of sec. 25, T. 42 S., R. 15 W., and is cut by a small fault on the west side. Another lies south of the south end of the Washington dome, near the west side of sec. 36, T. 42 S., R. 15 W. A more pronounced minor dome is that in sec. 1, T. 43 S., R. 15 W., known locally as the Punchbowl dome. It is a true dome, though much smaller than the three main domes. These minor domes are all in the Moenkopi formation and are shown clearly by the attitude of the light-colored Virgin limestone member in the midst of the darker-colored red beds. In all these smaller domes the horizon of the oil sand of the Virgin City field, judged by the outcrops on the main dome, is either absent or is barren of oil if present. The depth to the Coconino-Supai sandstone is about 1,400 feet in each of the domes. These smaller domes are less favorable locations for drilling than the larger ones, which should be tested first.

Bloomington dome.—The Bloomington dome, which is larger than the other two chief domes, extends through secs. 8, 9, 17, 18, and 19, T. 43 S., R. 15 W., about 5 miles south of St. George. (See fig. 12.) It is clearly defined by the encircling Virgin limestone member of the Moenkopi and the high core of Kaibab limestone. The oil-bearing bed of the Virgin City field is not present over the crest of the dome and contains no oil where present on the flanks. The best chance of finding oil is in the Coconino-Supai sandstone. Like the Washington dome, this dome is unsymmetrical, the western flank dipping 40° to 70° and the eastern flank less than 20°. On it are imposed several distinct high areas, so that it is really a close group of domes. The largest, areally, of these subordinate domes is at the south end of the main dome, its crest lying in the NE. ¼ NW. ¼ and NW. ¼ NE. ¼ sec. 19. It is broader and more nearly symmetrical than the others. The oldest rock exposed is practically the top of the Kaibab limestone, and 900 to 1,000 feet of rock must be penetrated to reach the sandstone. The next largest crest is that in the SE. ¼

SE. ¼ sec. 8. It brings to the surface the top of the upper hard limestone of the Kaibab, and therefore a shallower well, about 800 feet deep, would reach the sandstone. It is smaller than the southern minor dome. Between these two is a smaller and lower high area, on the line between the NE. ¼ and the NW. ¼ sec. 17.

On the flank of the Bloomington dome in the SE. ¼ sec. 17 a minor dome has been formed. The surface rock is the Moenkopi formation beneath the Virgin limestone member. Another minor fold is present in the SW. ¼ sec. 19, on the east flank of the main dome.

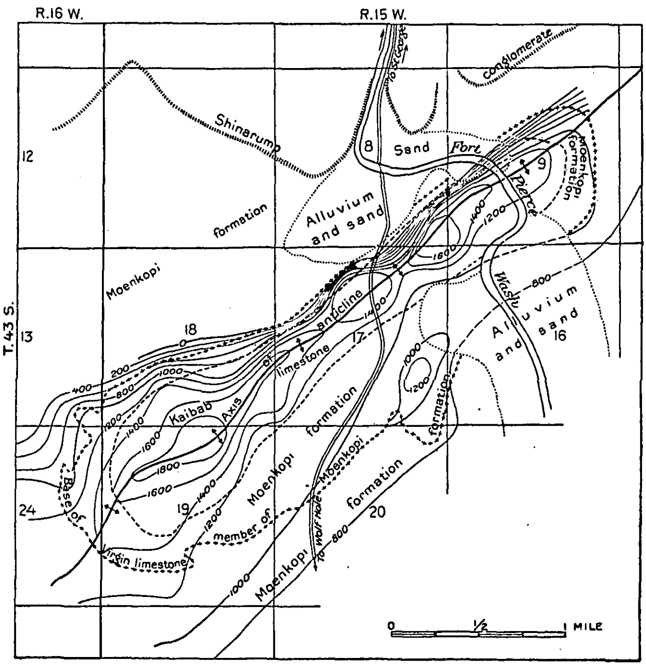

FIGURE 12.—Map of the Bloomington dome, Washington County, Utah.

Fictitious "Kingman dome."—South and southwest of the Bloomington dome a very large, relatively flat area is reported locally to be occupied by what is termed the "Kingman dome." There is no such dome, however, but in the area it is supposed to cover there are merely several very small domes.

OTHER ANTICLINES.

Smaller anticlines are present at several other places in this field. One of these extends through the eastern part of T. 41 S., R. 17 W., and is plainly shown where the Arrowhead Trail, the tourist route from St. George, Utah, to St. Thomas, Nev., crosses it, about 15 miles from St. George. The rocks exposed here are in the upper part of the Moenkopi formation. The axis of the fold trends nearly north and south and plunges to the north, and the dip of the flanks is gentle. No study was made of this fold to determine its size or the presence of closed structure, but its axis extends 4 or 5 miles at least and is probably much longer. The oil-bearing zone of Virgin City may be present beneath it, and the Coconino-Supai sandstone is certainly there. At the locality where the Arrowhead Trail crosses the axis the former should lie about 1,500 feet beneath the surface and the latter about 2,500 feet. In the western part of T. 43 S., R. 13 W., about 15 miles south of east of St. George, another anticline, in rocks of the Moenkopi formation, extends in a northeasterly direction, the north end abutting against the Hurricane fault and the southern part passing over into Arizona. The axis of this fold plunges northeastward. The southeast limb dips steeply and is cut off obliquely by the fault. No detailed study was made of this fold, and its full extent and character are not known, but the axis extends at least 5 miles and is probably much longer. The Virgin City oil sand may be present beneath it, and the Coconino-Supai sandstone certainly is. The depth to these beds varies because of the plunging of the axis.

Farther south, in Arizona, at a place about 18 miles south of the town of Hurricane, Utah, and the same distance southeast of St. George, a small, low anticline with its axis trending north a mile west of the Hurricane fault is seen in rocks of the upper part of the Moenkopi formation. This fold is several miles in length and apparently closed. Its east limb is cut off by the Hurricane fault, but the west limb is not faulted so far as known. The Virgin City oil sand may be present beneath it, and the Coconino-Supai sandstone certainly is. Near Black Rock Spring, Ariz., 25 miles south of St. George, the valley between Black Rock Mountain and Wolf Hole Mountain contains a large number of small domes, the largest of them perhaps 3,000 feet across. These are in the lower part of the Moenkopi and the upper part of the Kaibab formation, but they are so numerous and so closely crowded together that their value is likely to be small. No detailed study was made of this area.

EVIDENCES OF OIL.

Evidence of oil in the rocks of this region is meager. The bed that furnishes the oil found at Virgin City is missing at the crests of the larger uplifts and if present elsewhere does not offer any indication of containing petroleum. The extreme top of the sandstone formation, where exposed in the Hurricane fault scarp 5 to 7 miles south of Hurricane, is stained along the face with oil, and the rock yields oil when heated in a glass tube. At a point 6 miles south of Hurricane this zone includes the upper 20 feet of the sandstone. Near Black Rock Canyon, Ariz., which lies 18 miles south of Hurricane, Utah, and is a distinct locality from Black Rock Spring, mentioned above, thin zones at several horizons are stained by oil. However, the sandstone as exposed in the canyon of the Virgin below St. George shows no sign whatever of oil. In Rock Canyon, which cuts the Hurricane fault scarp about 15 miles south of Hurricane, a deep, wide gash was eroded into the upper part of the Kaibab limestone and filled with gypsum, shale, and limestone of the basal part of the Moenkopi formation. This filling is very irregular in composition and contains many thin veins of asphaltite and zones impregnated with bituminous matter. The material is more abundant in the lower part of the exposure and seems to have come up from below. About 2 miles west of the south end of Black Rock Canyon, in Arizona, a crushed zone, 100 feet wide, cutting through the lower part of the Moenkopi formation is filled with bituminous material in the form of veins and impregnations. This material likewise seems to have come up from below. These occurrences are favorable to the presence of oil in the suitable structural forms of the region in that they show at near-by points oily materials in rocks whose continuation underlies the folds, though they are by no means a proof that oil occurs in the folds.

GROUND WATER.

The water conditions in the older rocks of the region are but poorly known. Springs are rare, and as far as surface indications are valid the rocks seem to be dry. However, Virgin River crosses the outcrops of all the formations, and some water from this stream may seep into the rocks. Besides this the region has some rainfall, though small, and some of it must enter the rocks. In the well on the Harrisburg dome water was struck between 1,000 and 1,100 feet beneath the surface. It will probably be found at most points that the rocks below the surface contain water, a factor of great importance in the development of an oil field, for if water is present in abundance the highest parts of the anticlines and domes will usually contain any oil that may have accumulated.

PROSPECTS OF COMMERCIAL PRODUCTION.

The value of this region as a possible producer of oil it is impossible, of course, to gage in advance of drilling. The region contains favorable structural features, and there are rocks in them capable of serving as reservoirs for oil. At certain places, as described above, there is evidence favorable to the assumption that these rocks carry some oil. Whether oil is actually present in these rocks in the anticlines and domes remains for the drill to determine. The well drilled on the Harrisburg dome is a fair test of a part of that fold. The fault on the east side, however, reduces the value of this test as a criterion for the region. However, no seepage along the fault is evident, and its largest effect is probably that of cutting off part of the area of rock which might have contributed to any oil content of the dome. According to reports the drill penetrated 1,050 feet of limestone and about 1,200 feet of the Coconino-Supai sandstone without finding more than a light showing of oil. Failure of the well on this dome should not be taken as an absolute condemnation of the whole area, for the fault may have affected the dome adversely, whereas the other domes are still intact. Besides, if the rocks are only partly saturated with water oil may be absent on the crest and still be present down the dip. Nevertheless the crests of the domes should be tested first to determine the presence or absence of oil or water, before other locations are tried.

DIFFICULTIES OF EXPLORATION.

Drilling operations in Washington County, Utah, and the part of Arizona adjacent to it are in general carried on under some handicaps. No part of the region is less than 70 miles from a railroad by any practicable route, and much of it is 90 or 100 miles from a railroad. Much of the material for drilling must be brought from Los Angeles, Calif., or other distant center of supply. Away from a few main routes, such as that between Lund and St. George or that through Virgin City up the Virgin to Zion Canyon, the roads are mostly unkept trails. Fuel and water are expensive and hard to obtain at many localities. Electric power was used at the well on the Harrisburg dome but probably could not be supplied to many rigs at one time nor at places far from the transmission lines. The rocks of the Moenkopi formation are relatively soft and easy to drill, but those of the Kaibab limestone offer difficulties because of the abundance of chert, and drilling in them is slow and expensive.

RECOMMENDATIONS FOR DRILLING.

The localities near Virgin City suggested on page 97 as favorable places for drilling test wells lie near good roads and are easily accessible. Water in abundance may be obtained from ditches, from North Creek, or from Virgin River. Fuel is scarce, however, as the easily accessible timber has already been cut off, and coal, if used, must be hauled from Colob Plateau, some 30 miles to the north. Electric power is not now available in this district. The rocks to be drilled are relatively soft and offer little difficulty. Wells less than 600 feet deep should be sufficient.

Any test hole on the terrace near Grafton, described on page 97, should be located some distance south of Virgin River, perhaps in sec. 7, T. 42 S., R. 11 W., to get as far from the Grafton fault as possible. This locality would not be as easy of access as those near Virgin City, as the river would have to be forded and a road made to the south. Water could be piped or hauled from the river, but fuel would have to be hauled a long distance. The rocks to be penetrated are relatively soft and easily drilled, and a 900-foot well should reach the horizon of the Virgin City oil sand.

The anticline east of Antelope Spring is not well enough known to justify the recommendation of localities for drilling. The rocks to be pierced are relatively soft and easy to drill, and water can be obtained from Antelope Spring, but the region is remote from the settlements and sources of supply, and fuel is scarce and must be hauled some distance.

The writers believe no further test should be made on the Harrisburg dome at present, at least not until showings elsewhere on the Virgin anticline justify it.

The first test on the Washington dome should be made near the northwest corner of the SW. ¼ SW. ¼ sec. 30, T. 42 S., R. 14 W. This locality is not easily accessible because of its high elevation and the rough topography, but a short road can be built to it from existing trails. Water can be obtained by piping or hauling from Virgin River. Fuel is very scarce and would have to be hauled a long distance unless electricity could be obtained to replace it. The use of electricity would entail the building of several miles of power line. The depth to the sandstone beneath the Kaibab limestone is 900 to 1,000 feet, and much of the rock is very cherty, tough material that is difficult to penetrate.

The first test on the Bloomington dome should be made near the center of the NW. ¼ NE. ¼ sec. 19, T. 43 S., R. 15 W. Conditions are much the same here as on the Washington dome except that the locality is more accessible. Water can be procured from ditches or from Fort Pierce Wash, but fuel is lacking. The depth to the sandstone is 900 to 1,000 feet, and the intervening rock is in large part tough and cherty. The second best locality on the Bloomington dome is in the southeastern part of the SE. ¼ SE. ¼ sec. 8, T. 43 S., R. 15 W. Here the depth to the sandstone is about 800 feet.

The minor domes near the Washington and Bloomington domes should not be tested unless the larger domes show good results or give some indication that there is oil down on the flanks which might be present in the smaller domes.

The anticlines described briefly on pages 103–104 need further examination. The present data are insufficient to determine the presence or absence of closure, and without this knowledge recommendations are unwarranted.