

OIL AND GAS IN NORTHEASTERN COLORADO

Prospects of Developing New Fields

by

U. S. G. S.

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Report by: Courtesy of United States Geological Survey

OIL AND GAS IN NORTHEASTERN COLORADO  
Prospects of Developing New Fields

The Department of the Interior announces that new oil and gas fields may be discovered in northeastern Colorado far east of the proved fields of the Fort Collins-Wellington district, according to geologists of the Geological Survey, who have been examining that part of the State during the last few months. No anticlines comparable in steepness of flanks to those that contain oil and gas in the eastern part of Larimer County were found east of Larimer and Boulder counties, but the exploration disclosed a broad, low anticlinal fold that extends southward from the eastern part of Weld County across Morgan County into the southwestern part of Washington County. The beds along this line are very gently flexed, the dip being much less than that in most of the producing fields of the Rocky Mountain region, though similar to that in the Mid-Continent oil fields of Oklahoma and Kansas. Whether or not folds so gentle favor the accumulation of oil in Colorado can be determined only by drilling several properly located test wells. The exact depth to the reservoir beds that are believed to lie beneath the surface in Morgan and adjacent counties can not be foretold, but the Federal geologists have concluded that at favorable localities the depths are not so great as to discourage drilling.

Geologic Work Done in 1924.

The rocks underlying that part of Colorado that lies east of the Rocky Mountains and north of the latitude of Denver are not unfavorable to the occurrence of petroleum, and sporadic attempts to find it have been made during a period covering many years. Interest in this region was neither general nor intense, however, until after November, 1923, when a well that produced daily 80,000,000 feet of wet gas was completed near Wellington. Since then drilling activity has steadily increased, and interest has extended from the region near the mountains, where the geology is well known, to the larger region on the east, where the geology is little known because the rocks are very poorly exposed. To meet the demand for information concerning that region, field studies were made by the United States Geological Survey from May to September, 1924. The work was begun by Julian D. Sears, who was assisted by James Gilluly and later by Ralph G. Lusk. Mr. Sears returned to Washington in June and thereafter the work was directed by Kirtley F. Mather. A detailed report is now being prepared by Messrs. Mather, Gilluly, and Lusk and will be published as soon as possible.

Rocks Exposed in the Region.

Northeastern Colorado is underlain by sedimentary rocks of Cretaceous and Tertiary age. The Cretaceous beds, which consist largely of shale and sandstone but include some limy beds and coal, were deposited before the upheaval of the Rocky Mountains. Most of the lower beds of the Cretaceous were laid down on the floor of a vast shallow sea, which covered all this part of North America. Near the end of the Cretaceous period the sea dwindled in size and became shallow until it finally disappeared from Colorado, leaving only fresh or brackish water lagoons, lakes, and marshes. In these bodies of water, and on the flood plains of rivers, where part of the vegetation was buried and changed to coal, the uppermost Cretaceous beds were formed. The lower beds of the Cretaceous are the sources and the reservoirs of the oil and gas. The Tertiary beds were deposited after the Rocky Mountains had been upheaved and consist chiefly of debris washed out by streams from the mountains and spread far over the lowlands. To-day they cover the Cretaceous rocks over large areas in Colorado and prevent the surface determination of the structure of the possible oil-bearing beds. Considerable areas, especially along South Platte River, are covered with sand dunes, river alluvium, and stream gravel, which were laid down still later, in Quaternary time, and these also obscure the geology of the underlying strata. The succession of rocks in the region is shown in the following table:

Geologic formations in northeastern Colorado.

	<u>Feet.</u>	
Quaternary . . . . . Gravel, sand, and alluvium . . . . .	0-100	
Unconformity.		
Tertiary . . . . . Gravel, sand, and clay . . . . .	10-300	
Unconformity.		
Cretaceous:		
Laramie formation . . . . Sandstone, shale, and coal.	200-800	
Fox Hills formation . . . Sandstone, and shale . . . . .	400-1,800	
Pierre shale:		
Dark shale with some beds of sandstone . . . . .	1,500-6,000	} 4,500-10,000
Shale with many sandstone lenses . . . . .	1,275+	
Richard sandstone member . . . . .	0-70	
Sandy shale . . . . .	100-200	
Larimer sandstone member . . . . .	0-150	
Sandy shale . . . . .	0-170	
Rocky Ridge sandstone member . . . . .	0-165	
Sandy shale . . . . .	300-600	
Terry sandstone member . . . . .	0-20	
Sandy shale . . . . .	200-400	
Hygiene sandstone member . . . . .	0-100	
Dark shale and sandy shale . . . . .	2,400-3,100	
Niobrara formation:		
Limestone and limy shale . . . . .	330-410	} 590-640
Benton shale:		
Upper sandstone member (the so-called "Niobrara" Benton" of some geologists) . . . . .	10-20	
Dark shale, limestone, and bentonite . . . . .	580-620	
Dakota formation:		
Upper sandstone member (Muddy sand of drillers)	30-80	} 315-425
Dark shale . . . . .	110-240	
Middle sandstone member . . . . .	10-15	
Sandy shale . . . . .	25-65	
Lower sandstone member . . . . .	35-75	

Structure near the Mountains.

Where exposed in the hogbacks near LaPorte and elsewhere along the front of the Colorado Rockies, the Dakota, Benton, and Niobrara formations dip eastward at angles of 20° to 40°. If this steep inclination continued it would carry these beds far below sea level a few miles east of their outcrops. Toward the east, however, the inclination gradually becomes less. The Hygiene sandstone member in general dips eastward at an angle between 15° and 25°, and the higher sandstone beds, such as the Rocky Ridge and the Richard, show dips of 8° to 14°. Still farther east, near the boundary line between Larimer and Weld counties, the Fox Hills beds dip at angles of 4° to 8°, and a few miles farther east the Laramie lies nearly horizontal. This prevailing eastward dip, which decreases with increase of distance from the mountains is the characteristic structural feature of the country within 30 miles of the mountain front.

There are, however, several very significant local reversals of the regional dip, which have determined the location of the known oil and gas fields in this part of Colorado. A well-defined, slightly sinuous anticlinal fold extends from a point about 2 miles northeast of Fort Collins in a general northerly direction for about 14 miles. The beds on the west side of this fold dip westward at angles of 10° to 15°; those on the east side dip eastward at angles of 5° to 10°. A little south of west from Wellington a saddle on the anticlinal crest divides it into two parts, known as the Wellington and Fort Collins anticlines. The "closed" portion of each is between 4½ and 5 miles long and is nearly 1½ miles wide. The Discovery, Mitchell, and Scott wells of the Union Oil Co. of California are drilled near the top of the Wellington anticline. The Whitaker well was drilled by the same company on the top of the Fort Collins anticline.

Two miles west of the saddle between the Wellington and Fort Collins anticlines there is a smaller fold, known as the Douglas Lake anticline, which has a similar trend. Its "closed" portion is about 2 miles long from north to south and half a mile wide from east to west. About 19 miles south of Fort Collins and 2 miles west of Berthoud is a fourth fold, somewhat similar, known as the Berthoud anticline. It is about 3 miles long from north to south and about 1½ miles wide from east to west. The flanks of these two anticlines dip at angles ranging from 4° to 12°.

The rocks exposed at the surface on these four anticlines belong in the upper part of the middle third of the Pierre formation. The Rocky Ridge sandstone member and the shale just below it appear at the surface along the crests of the Wellington, Douglas Lake, and Berthoud anticlines, and the shale beneath the Larimer sandstone member is exposed along the crest of the Fort Collins fold. Starting at these horizons the Discovery and Mitchell wells, drilled on the Wellington anticline, tapped the pay sand at depths of 4,285 feet and 4,216 feet, respectively, and the Whitaker well, on the Fort Collins anticline, came in at a depth of 4,475 feet.

After the Discovery well had struck gas, before the other two had been drilled, no one could tell which of two sandstones was yielding the gas -- the so-called "Nio-Benton," a sandy member 18 to 20 feet thick, at the top of the Benton formation, or the upper sandstone (Muddy sand of the drillers), 30 to 40 feet thick, at the top of the Dakota formation about 600 feet below the "Nio-Benton." Several geologists working independently had calculated from the surface data that the "Nio-Benton" sand should lie at depths between 4,100 and 4,500 feet at the site of the Discovery well. Measurements made by Messrs. Sears and Gilluly indicated a depth of 4,470 feet for the "Nio-Benton" and consequently of more than 5,000 feet for the upper sandstone of the Dakota formation, yet the character of the sand struck at 4,285 feet led them to decide that this was the upper sand of the Dakota. This decision has now been amply verified by the records of the Mitchell and Whitaker wells which prove that the gas and oil struck in the Wellington and Fort Collins fields is obtained from the uppermost member of the Dakota formation and not from the top of the Benton shale. It may here be noted that the "Nio-Benton" sand is not the equivalent of the Wall Creek sand of Wyoming, as had been supposed. With the assistance of J. B. Reeside, jr., the geologists were able to correlate this sand with the Carlile shale, which lies well above the Wall Creek sand in Wyoming, and to decide that the Wall Creek sand is not present in the foothill region of northern Colorado.

The fact that the upper sandstone of the Dakota has been reached in all three wells at depths 500 to 700 feet less than those indicated by the surface geology demands explanation. So many geologists working at different localities have reached the same conclusion that the discrepancy can hardly be due to an error in measurement. Nor is it likely that hidden faults have caused a duplication of outcrops so nicely balanced that sections measured at several different places between the wells and the mountains should give nearly identical thicknesses for the strata. The conclusion seems inevitable that the formations involved are thinner in the Fort Collins-Wellington field than at the places where they crop out, a few miles farther west. This thinning does not seem to be due to differences in the thickness of the beds as originally deposited, which would indicate an abrupt decrease in the thickness of the mid-Cretaceous strata eastward from the mountain front. On the contrary, according to Mr. Mather's interpretation, most if not all of the apparent thinning is due to the stretching of beds on the crest of the Fort Collins-Wellington fold by the bending of the strata that form the fold.

#### Structure away from the Mountains.

East of the four anticlines named, wherever the conditions are known in Rs. 67, 66, and 65 E. north of the fortieth parallel, the Cretaceous beds dip toward the east without reversal. The inclination decreases more or less regularly until, in the eastern half of this strip, the beds are nearly horizontal. Nevertheless the dip is sufficient to carry the Dakota formation far below sea level unless there is a much more abrupt thinning of the formations between the Dakota and the Fox Hills than the known facts would indicate. Because of this dip the beds that crop out near the producing wells north of Fort Collins lie 4,000 to 6,000 feet below the surface in the vicinity of Nunn, Eaton, Greeley, and Hudson. The upper sand of the Dakota in the Fort Collins and Wellington fields can scarcely be less than 8,000 feet below the surface in this part of Weld County.

After making all possible allowance for the convergence of the Dakota and Laramie strata because of the eastward thinning of the intervening Pierre and Fox Hills formations, a geologist would not hold out much hope that the upper sand of the Dakota could be reached at any practicable drilling depth in northeastern Colorado unless the regional eastward inclination of the beds were reversed so that strata far below the Laramie again came to the surface. Fortunately, abundant evidence of such reversal has been found in the study of the areal distribution of the Cretaceous formations. Between Hardin and Masters Fox Hills beds appear at several places on the south side of South Platte River. About 3 miles east and southeast of Osgood the Fox Hills formation is exposed in a region that is nearly or quite surrounded by Laramie beds. All of Morgan County except the extreme northwest and southwest corners is occupied by Fox Hills and Pierre beds, which are covered at several places by Tertiary gravels, sand, and clay. Extending southward from Fort Morgan at least as far as the southwest corner of Washington County there is a belt of Pierre shale, 5 to 15 miles wide, bordered on both sides by Fox Hills sandstone and shale; and

north of Stoneham, in easternmost Weld County, and in adjacent parts of Logan County the two main heads of Pawnee Creek have cut their valleys through the cover of Tertiary sediments and have exposed Pierre shale, again nearly or quite surrounded by Fox Hills beds. East of Sterling the eastward-dipping Fox Hills beds disappear beneath Laramie strata that underlie the Platte River bottoms in the east half of Logan County, but south of T. 4 N., Rs. 52, 53, and 54 W., the edge of the Tertiary cover extends over the Fox Hills formation, so that the presence or absence of Laramie beds under the Tertiary beds in this vicinity can not be determined.

In all this region in Morgan and adjacent counties the beds lie very nearly flat. Dips of one-half to three-fourths of a degree are the rule; a dip of  $1\frac{1}{2}^{\circ}$  or  $2^{\circ}$  is exceptional; at no place is the dip so much as  $3^{\circ}$ . The exposures are in general far apart, and the individual outcrops are small. Under such conditions the true bedding and dip of the strata are difficult to determine with certainty; the slight dips observed at the surface may not represent truly the dip a few thousand feet down. Such a formation as the Pierre shale must have been compacted differently in different areas under its varying overburden of sediments, and the structure of its uppermost beds or of the overlying Fox Hills beds, in which the dips are so gentle, is probably quite different in detail from that of the underlying Niobrara, Benton, and Dakota beds.

The best clue to the presence of anticlinal folds in the Dakota formation beneath northeastern Colorado is therefore the areal distribution of the overlying Pierre, Fox Hills, and Laramie beds. Outcrops of Pierre shale east of the Greeley syncline can occur only at places where upward flexures of the beds have lifted them a thousand feet or so above their altitudes beneath Greeley. The summits or higher flanks of such regional anticlines are the only places where prospecting for oil is justified by the known geology of this part of the State.

The localities where anticlinal folds may be inferred from the areal geology are indicated on the accompanying map. The most notable of these folds is the Fort Morgan anticline, which apparently extends in general southward from the southwest quarter of T. 5 N., R. 57 W., across T. 4 N., R. 57 W., and the east half of T. 3 N., R. 57 W., and continues southward close to the boundary between Rs. 56 and 57 W. at least as far as T. 2 S., and probably several miles farther. Next in importance is the Pawnee Creek anticline, which brings the Pierre to the surface in Tps. 8 and 9 N., R. 56 W., in the southwest quarter of T. 9 N., R. 57 W., and the northwest quarter of T. 8 N., R. 57 W. A third flexure, the Greasewood Lakes anticline, curves southeastward from the southwest corner of T. 7 N., R. 61 W., into the southwest quarter of T. 6 N., R. 60 W., and beyond that is lost among the sand hills north of Goodrich.

#### Areas Worth Prospecting for Oil and Gas.

Apparently none of these three anticlines is comparable in sharpness of folding to those near the mountain front from which oil and gas are now being produced; they are very much broader folds with much lower dips. In fact, very few of the known oil-bearing anticlines in the Rocky Mountain field are as gently arched as these, the sides of which dip only a degree or two. It might be logical, therefore, to doubt whether these low anticlines could cause oil to accumulate in large pools along their crests. But it is in just such anticlines as these that the oil pools of the Mid-Continent field are found, and it is therefore believed that they should not be passed by without thorough tests.

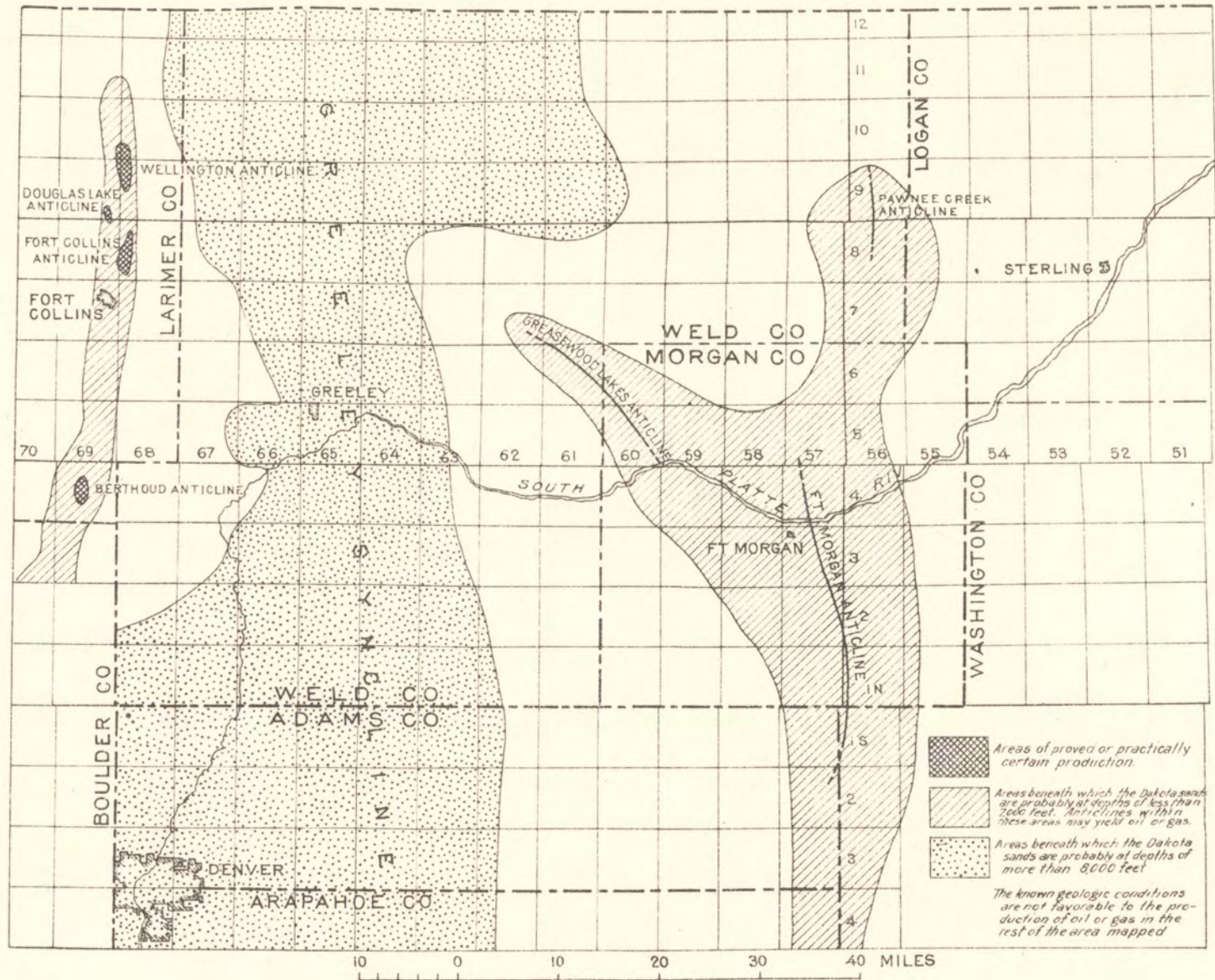
The geologist may confidently predict that sandy beds well fitted to serve as reservoirs for oil and gas lie beneath the surface in northeastern Colorado, but, unfortunately, he can not yet state precisely the depth to such sands at any specified locality. As yet only one sand, the upper sand of the Dakota formation, is abundantly productive in the adjacent oil and gas fields near Fort Collins. Nevertheless the possibility of obtaining oil from other sandy beds should not be overlooked. Probably the Hygiene and other sandstone members of the Pierre formation become thinner and finally disappear at greater or less distances east of their outcrops near the mountains. None of these beds have been recognized in the areas of Pierre outcrop, either in the vicinity of Morgan County or close to the eastern boundary of Colorado. About 10 miles due south of Fort Morgan a sandy zone has been encountered in water wells at depths of 500 to 600 feet, but the sandstone there is probably not the eastward extension of any one of the sandstone members near Fort Collins. In view of the occurrence of oil near Boulder and Florence, it seems possible that oil may be found in commercial quantities in one or more of these sandstone lenses in the Pierre. If so, the pools would be found near the upper edges of the lenses, where the porous sandstone pinches out. Probably there are sandstone lenses which thus




pinch out on the west flank of the Fort Morgan anticline and which lie at depths of 500 to 5,000 feet, but the surface geology gives no clue to their location. Drilling for them would be the wildest of wildcat ventures.

The upper sand or some other of the closely associated sandstones of the Dakota formation offers by far the best chance for oil in northeastern Colorado. The depth to this upper sand of the Dakota depends upon the amount and place of the thinning of the Pierre and Fox Hills formations. Only in the Denver Basin do these formations display the great combined thickness of 7,000 to 10,000 feet. Elsewhere, as in Kansas and the Black Hills region, their total thickness is only 2,000 to 4,000 feet. In the northwest corner of Morgan County the Fox Hills formation is only about 400 feet thick, whereas 50 miles to the west, near the Larimer-Weld county line, its total thickness is 1,800 feet. Presumably the Pierre thins eastward somewhat less abruptly, but its thickness in northeastern Colorado can not be determined, because, unfortunately, those wells in this area that start in recognizable beds near the top of the Pierre have not penetrated the Dakota, and those near Wray that have reached the Dakota start at an unknown position in the Pierre. The Padroni well, north of Sterling, which starts approximately at the base of the Laramie, may have reached the Carlile or top member of the Benton at a depth of 4,484 feet, but the record of this well is indefinite and unreliable. The best that the geologist can do now is to state that the upper sand of the Dakota formation may be reached at depths between 4,000 and 6,000 feet below the surface along the crest of the Fort Morgan anticline near the southern boundary of Morgan County.

With this information at hand the value of the various parts of northeastern Colorado for prospecting have been indicated on the accompanying map. The most favorable areas are shown by crossed lines. Those areas in which the Dakota probably lies at depths of less than 7,000 feet beneath the surface are shown by a single line pattern; within these areas only the higher parts of the anticlines should be tested. In the unshaded areas and especially in the Greeley syncline the known geologic conditions are unfavorable for the production of oil or gas and drilling is not justified.

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 Areas of proved or practically certain production.  
 Areas beneath which the Dakota sands are probably at depths of less than 2000 feet. Anticlines within these areas may yield oil or gas.  
 Areas beneath which the Dakota sands are probably at depths of more than 8000 feet.  
*The known geologic conditions are not favorable to the production of oil or gas in the rest of the area mapped.*

DEPARTMENT OF THE INTERIOR  
 U. S. GEOLOGICAL SURVEY  
**MAP OF NORTHEASTERN COLORADO**  
 Showing areas favorable or unfavorable for the occurrence of oil or gas