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OIL AND GAS PROSPECTING BENEATH THE PRECAMBRIAN OF FORELAND THRUST PLATES IN THE ROCKY MOUNTAINS

by

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OIL AND GAS PROSPECTING BENEATH THE PRECAMBRIAN OF FORELAND THRUST PLATES IN THE ROCKY MOUNTAINS[1]

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ABSTRACT: Only 15 wells in the Rocky Mountain region have drilled through Precambrian to test the 3-6 million acres of sedimentary rocks that are concealed and virtually unexplored beneath mountain front thrusts. More than half of these wells had oil and gas shows and one was a producing oil well. These wells have not only set up an exciting play for the future, they have also helped define the structural geometry of the mountain front thrusts, including the angle of the thrust and the presence or absence of fault slivers of overturned Mesozoic or Paleozoic rocks. Most important for further geophysical exploration, these wells have provided vital data on seismic velocities in Precambrian rocks. Analysis of these data will stimulate further exploration along the fronts already drilled: the Emigrant Trail Thrust, the Washakie Thrust, the Wind River Thrust, the Uinta Mountain Thrust, and the thrust at the north end of the Laramie Range.

The geologic success of these wells has encouraged leasing and seismic acquisition on every other mountain front thrust in the Rockies. Wells are presently drilling on the Casper Arch and the west flank of the Big Horn Basin adjacent Oregon Basin Field. An unsuccessful attempt to drill through the Arlington Thrust of the Medicine Bow Range will probably only momentarily daunt that play, and the attempted penetration of the Axial Arch in Colorado has not condemned that area. Untested areas that will be explored in the near future are: the south flank of the Owl Creek Range, the northeast flank of the Beartooth Mountains in Montana, the east and west flanks of the Big Horn Mountains, the north flank of the Hanna Basin, the south flank of the Uinta Mountains, the White River Uplift, the north flank of North Park Basin, and the Front Range.

INTRODUCTION

Three to six million prospective acres in the Rocky Mountain region are buried and overlain in thrust contact by Precambrian rocks. This vast subthrust area has been tested by only 15 wells (Fig. 1) which have drilled through Precambrian crystalline and metasedimentary rocks into underlying younger strata. Half of these wells have had hydrocarbon shows, and in conjunction with more sophisticated seismic processing and geologic interpretations, these wells have been the basis for exploration plays beneath all mountain front thrusts throughout the Rocky Mountain region.

Credit for this exciting play must go to the many people who for the last 35 years fought against great managerial prejudices to get wells drilled through Precambrian and probably suffered more than the normal disappointment over a dry hole because of it. Their efforts, however, were not in vain because they gave the industry a solid foundation for exploration beneath these thrust plates and more important, gave the scientific world the much needed third dimension to begin to interpret the structure of the Rocky Mountains, a truly unique structural province of the world.

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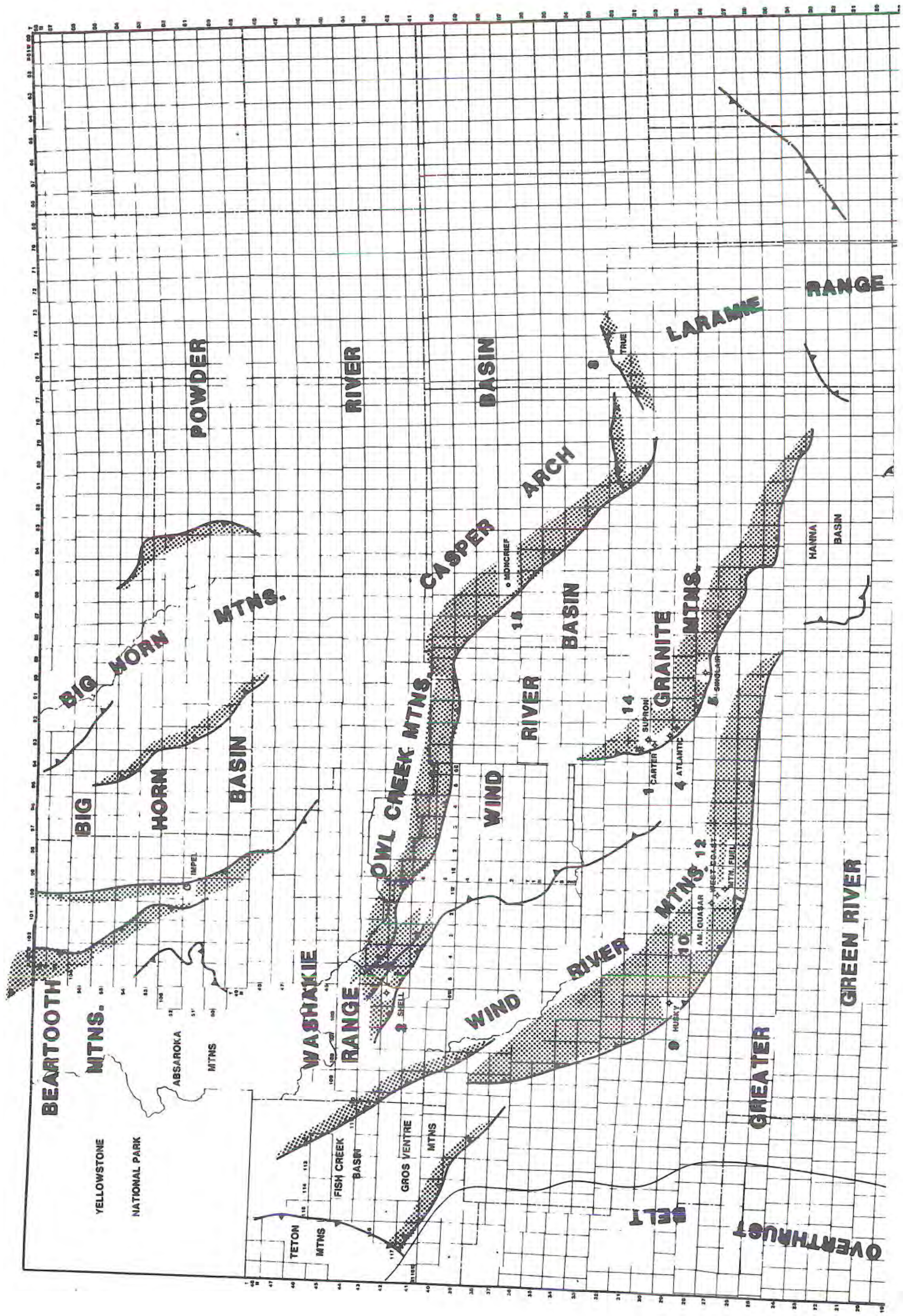
The data presented in this paper (Table 1) are derived from a combination of scout cards, well logs, conversations with geologists and engineers, and from rumors. These sources, while the best available, are naturally subject to error in reporting or interpretation.

EMIGRANT TRAIL THRUST (Granite Mountains)

Carter Oil Co. drilled the first well on a mountain front thrust prospect through the Emigrant Trail Thrust in central Wyoming (Fig. 2) in 1950. Carter drilled 1900 feet of Precambrian granite (Sec. 32, T30N, R93W, Fremont Co., Wyo.) before coming out of the granite into an 880 foot thick fault sliver of overturned Cambrian through Jurassic rocks (Berg, 1961). "Fault sliver" is a term used in this paper to describe the fault bounded sliver of sedimentary rocks frequently found beneath the Precambrian. The fault sliver usually has numerous other thrust faults within it and the sedimentary rocks within the sliver are frequently highly deformed. Carter then drilled a normal subthrust section from the Thermopolis Shale through Tensleep Sandstone. Regional mapping of the area shows that the major syncline of the Long Creek arm of the Wind River Basin slips beneath the Emigrant Trail Thrust about 8 miles north of the well. Both the 13° northeast dip at total depth and the 5925 feet of fresh water recovered on a drill stem test from subthrust Tensleep are indications that there is no stratigraphic or structural barrier in the Tensleep between the well and the outcrop to the southeast. A drill


BEARTOOTH MTNS.
YELLOWSTONE NATIONAL PARK
ABSAROKA MTNS
BIG HORN MTNS.
BIG HORN BASIN
POWDER RIVER BASIN
CASPER ARCH
OWL CREEK MTNS.
WASHAKIE RANGE
WIND RIVER BASIN
WIND RIVER MTNS.
GRANITE MTNS.
LARAMIE RANGE
HANNA BASIN
GREATER GREEN RIVER
OVERTHRUST BELT
TETON MTNS
FISH CREEK BASIN
GROS VENTRE MTNS
IMPEL
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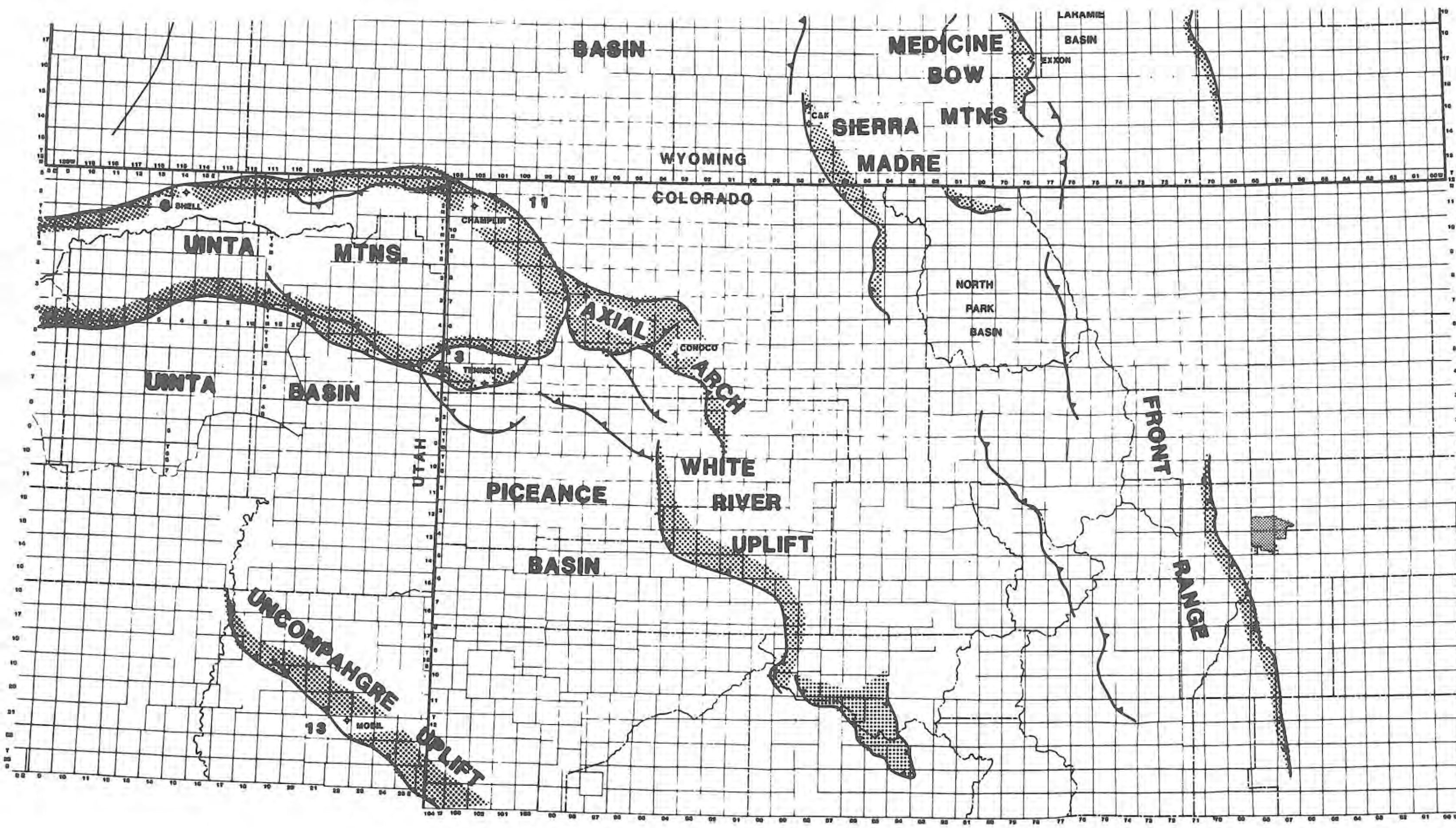

Fig. 1. Location of the 15 wells testing only a very small part of the three to six million acres of sedimentary rocks beneath mountain front thrusts. Stipple indicates approximate overthrows. Numbers correspond to wells listed in Table 1.

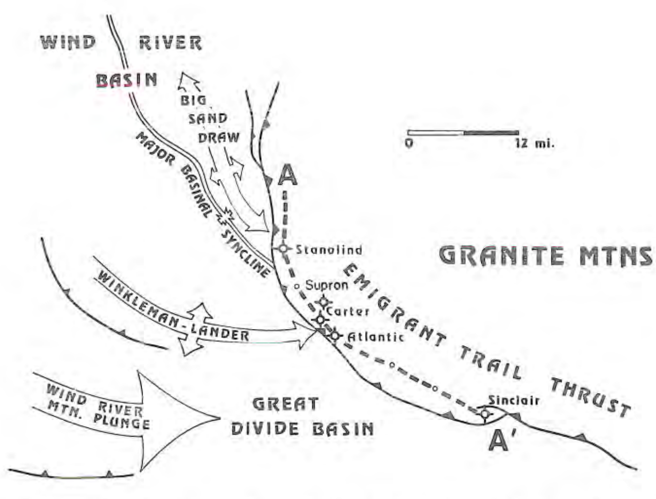

Fig. 2. The Carter, Atlantic Refining, Sinclair and Supron wells drilled through Precambrian granite into the sediments beneath the Emigrant Trail Thrust.

stem test in the lower Sundance also recovered 3160 feet of fresh water. The only shows in the subthrust section in this well were oil cut and stain from cores in the Phosphoria. Oil shows of this type are common in the Phosphoria and are probably not related to structural entrapment.

Stanolind drilled the #1 Scarlett Ranch Unit well (Sec. 22, T31N, R94W, Fremont Co., Wyo.) nine miles to the north of the Carter well in 1956, located slightly northeast of the major synclinal axis. The Stanolind well spudded in Paleozoics instead of Precambrian and was about 5000 feet structurally lower than the Carter well. Because of the greater thickness of Precambrian and younger rocks (Fig. 3), the Stanolind well was still in the Precambrian at total depth (8,000 feet). Another several hundred feet of drilling might have put them into subthrust Paleozoic sediments on trend with the prolific Big Sand Draw-Beaver Creek trend that has produced over 175 MMBO and 1 TCF gas to date. Since the Stanolind well is north of the basinal axis, it could be in an optimum position for significant hydrocarbon accumulation in any existing structural or stratigraphic traps as an extension of the Big Sand Draw trend (Lowell, 1978). Several shallow tests drilled in this area that failed to penetrate the Precambrian are described by Love (1970) in his comprehensive text on the Granite Mountains.

In 1960, Atlantic Refining drilled the #1 Ice Slough well (Sec. 9, T29N, R93W, Fremont Co., Wyo.) two miles south of the 1954 Carter test (Figs. 2 & 3). Their results were essentially the same as the Carter well, drilling 2,056 feet of granite before coming out in a fault sliver of overturned Paleozoics and lower Mesozoics and then into a normal section of Thermopolis through Tensleep. Cores of the Phosphoria contained live and dead oil in vugular porosity. A test in the

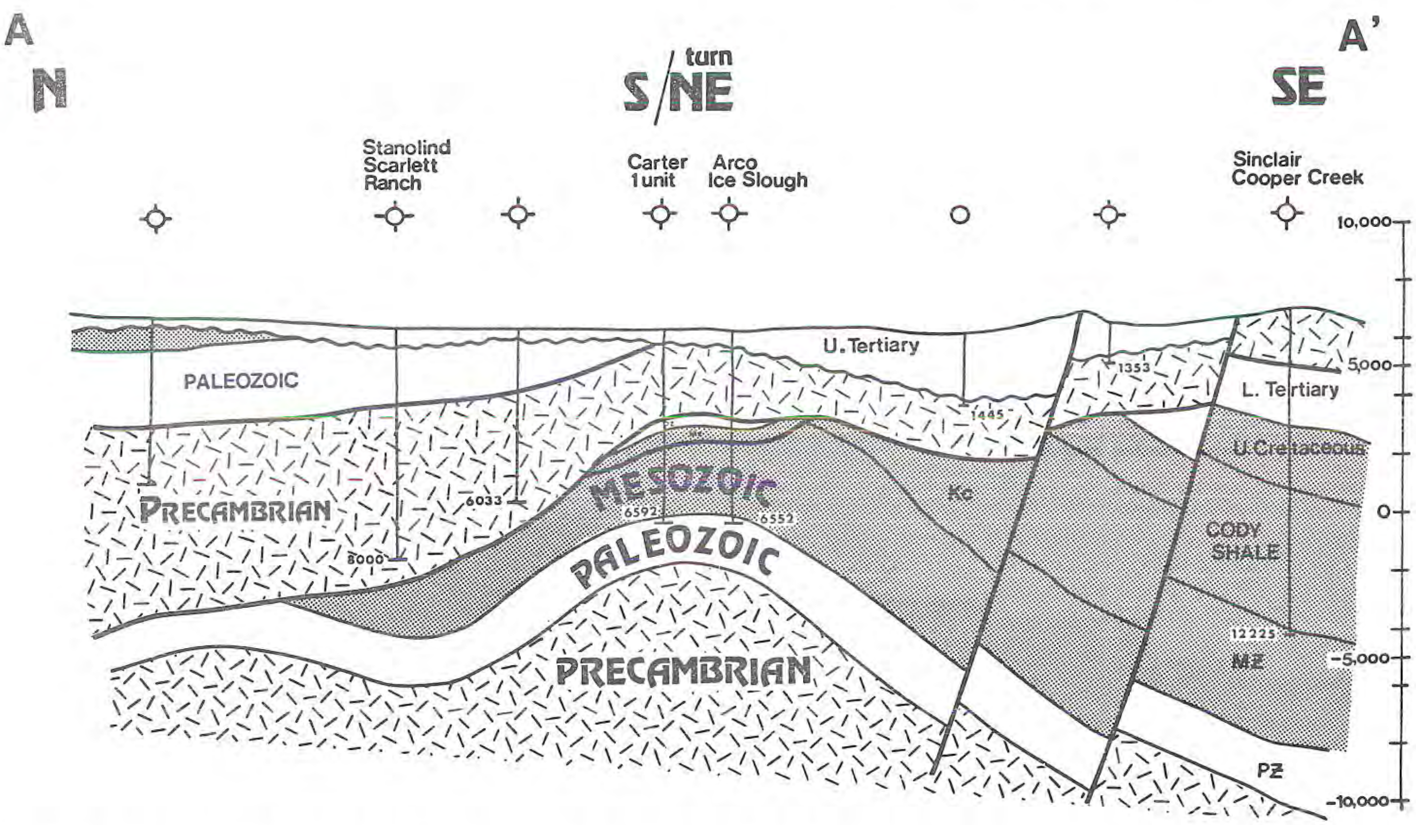

Fig. 3. Cross section A-A' along the leading edge of the Emigrant Trail Thrust, showing structure of overthrust and subthrust. Vertical exaggeration x5. (See Fig. 2 for line of cross section.)

Phosphoria recovered 660 feet of slightly gas and mud cut water with strong sulfur odor, and another test just above the Tensleep recovered 5110 feet of slightly muddy fresh water. The fresh water and the northeast dips in this zone again possibly indicate there was no structural barrier on this synclinal flank between the well and the outcrop. This well was abandoned, and both it and the Carter well were probably located on velocity pullups on the southwest flank of the large basinal syncline.

In 1961, the Sinclair Cooper Creek well (Sec. 19, T28N, R90W, Fremont Co., Wyo.) was drilled through the Precambrian of the Emigrant Trail Thrust about 17 miles southeast of the Carter well (Fig. 2). A 2087 foot section of Precambrian granite was drilled before the well penetrated an undisturbed section of Tertiary Wasatch Formation (Love, 1970). A normal Tertiary and Cretaceous section was drilled to a total depth of 12,224 feet, bottoming in the Frontier Formation that had gentle south dip. Oil shows in samples from the Cody were reported, but one drill stem test in the Cody recovered only 15 feet of mud.

In 1980, Supron drilled one of two locations staked in Sec. 28 T30N, R93W, Fremont Co., Wyo., 6200 feet northeast of the Carter well. They drilled through 5000 feet of Precambrian, or 2000 feet more than the Carter well. This indicates a 25° dip on the thrust plane confirming the angle predicted by Berg (1961) and Love (1970). The Tensleep was about 500 feet low to the Carter well indicating they are probably still in the northeast dipping beds on the southwest flank of the syncline of the Long Creek arm of the Wind River Basin. This well was plugged and abandoned in November, 1980.

The subthrust play of the Emigrant Trail Thrust can be divided into three parts (Fig. 3): 1) the northern end, with the prolific Big Sand Draw trend intersecting the thrust beneath granite 2) the central part characterized by being structurally highest in both the overthrust plate and the subthrust plate, and 3) the southeast flank, with characteristics of the Great Divide Basin to the south including thicker Tertiary and Cretaceous sections. To date, the potential of this play in all three areas remains inadequately tested.

E A THRUST (Washakie Range, northwest flank of the Wind River Basin)

A second mountain flank thrust was tested in 1956 when Shell drilled the #1 Government well (Sec. 9, T42N, R105W, Fremont Co., Wyo.) through Precambrian near Dubois, Wyoming (Fig. 4). They drilled 7,400 feet of granite and schist in the E A Thrust plate and then into a fault sliver of overturned, deformed and sheared Lower Paleozoic through Cretaceous rocks (Fig. 5). At 8,678 feet, they drilled out of the fault sliver and into a normal section of Cretaceous through Jurassic rocks, bottoming in the Sundance at a total depth of 10,689 feet. A drill stem test in the overturned Tensleep and Phosphoria recovered 69 barrels of gas cut muddy water. The probable reason this test failed is that it too was located on the wrong side of the major basinal axis (Fig. 4) with no stratigraphic or structural barriers between the well and the outcrop.

The Wind River Basin synclinal projects beneath the E A Thrust northeast of the well and this is consistant with the 15° northeast dips found in the lower units of the Shell test. The area northeast of the synclinal axis offers good exploration potential. Both seismic and regional geologic studies indicate subthrust sedimentary sections may extend for some distance north-northeast of the Shell well (Fig. 5).

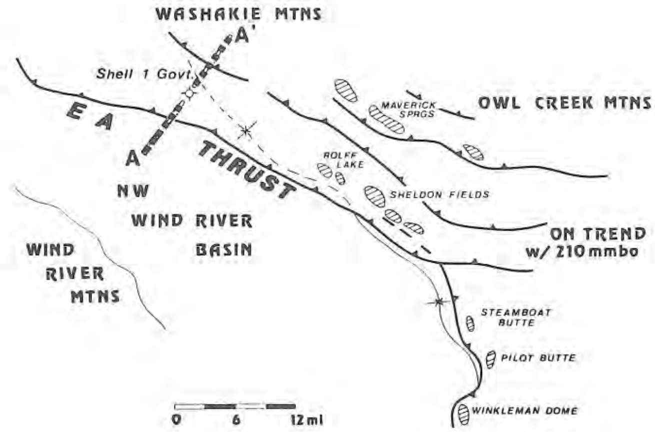

Fig. 4. Shell (Sec. 9, T42N, R105W, Fremont Co., Wyo.) drilled near Dubois, Wyoming, through the E A Thrust of the Washakie Mountain front.

LARAMIE RANGE (South flank, Powder River Basin)

In 1971, a True Oil Company development well in South Glenrock Field (ne ne Sec. 6, T32N, R75W, Converse Co., Wyo.) drilled through 1,125 feet of Precambrian at the north end of the Laramie Range before penetrating a thrust and drilling into Cretaceous rocks. Total depth was 7,898 feet in the Cretaceous Skull Creek Shale. Drill stem tests in the Muddy Sandstone recovered only 60 feet of mud, and the well was abandoned. Later that year, a True offset well (31-6 Hakalo, nw ne, Sec. 6, T32N, R75W) a few hundred feet to the west (Fig. 6) drilled through 288 feet of Precambrian before crossing the thrust and drilling into Cody Shale (Fig. 7). Drilled to the Skull Creek, this well was completed as an oil well in the subthrust Muddy with a potential for 70 barrels of oil per day. This is the first sub-Precambrian production in the Rocky Mountain Region.

WIND RIVER MOUNTAIN FRONT

Four wells have been drilled through Precambrian along the southwest front of the Wind River Mountains (Fig. 8). All were dry holes but because they revealed subthrust structuring, good reservoir and source beds, and shows of gas, exploration is expected to continue along this front in the future.

In 1973, the Husky #2 Federal well (Sec. 2, T29N, R106W, Sublette Co., Wyo.) drilled 4,500 feet of Tertiary, then 6000 feet of Precambrian before entering a fault sliver with an overturned section beginning with an undated black shale overlying Mississippian rocks of probable Osagean through Chesterian ages (Fig. 9). Because their rig did not have the capacity to drill deeper, they quit drilling at 12,944 feet in the Amsden, and plugged and abandoned the well. They never drilled out

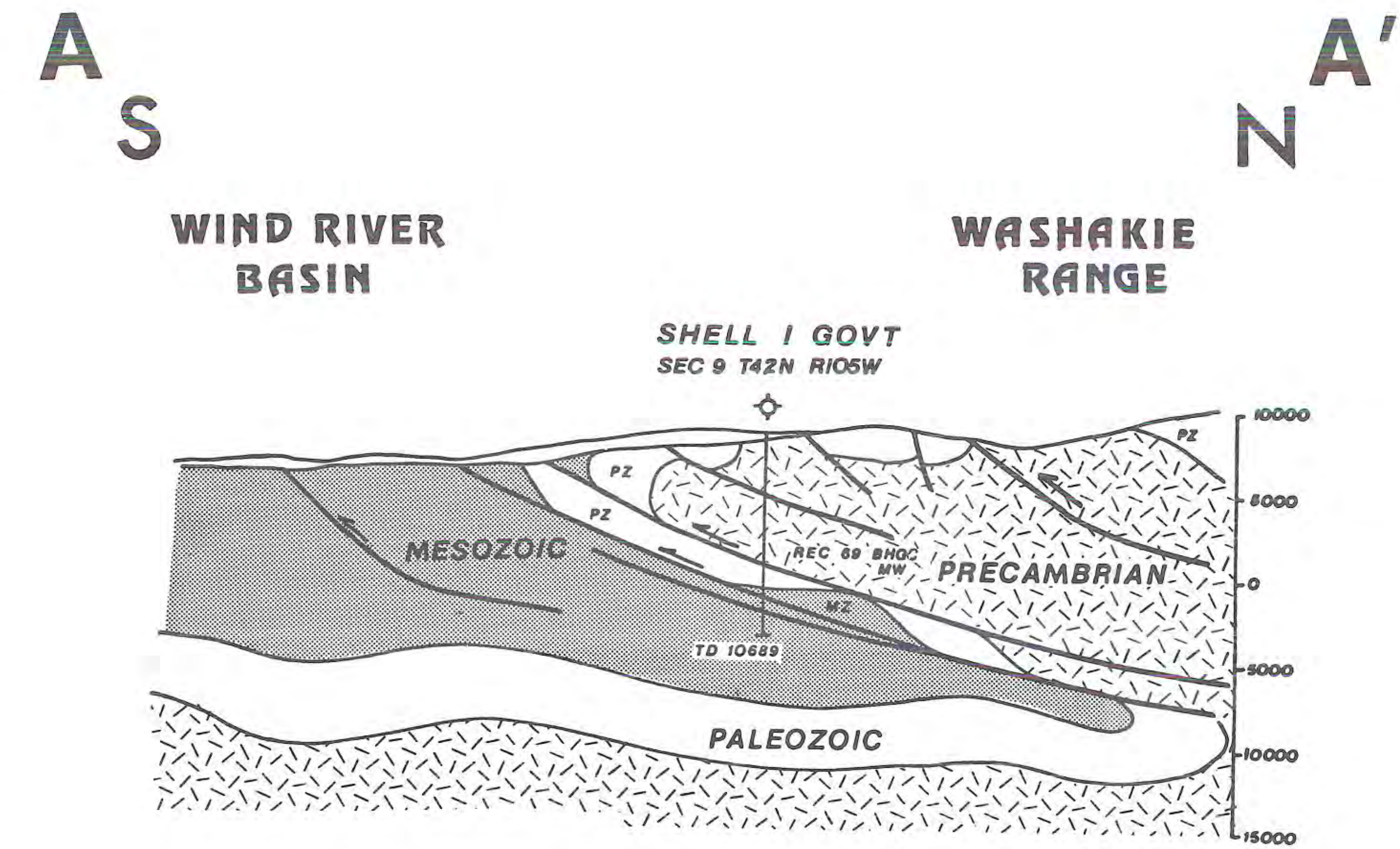

Fig. 5. Shell had shows in the overturned Paleozoics beneath the thrust. Vertical exaggeration x2. (See Fig. 4 for line of cross section.)

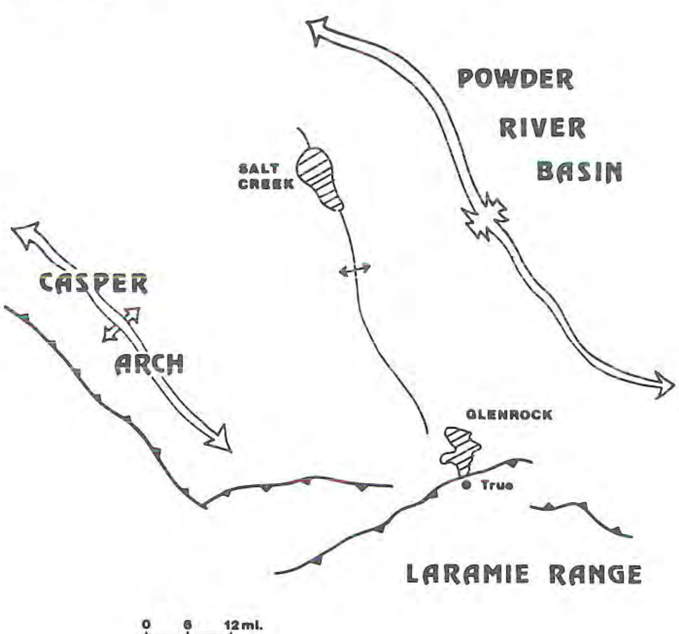

Fig. 6. Precambrian rocks in the thrust on the north flank of the Laramie Range were penetrated by two True wells (Sec. 6, T32N, R75W, Converse Co., Wyo.).

of the fault sliver to test the normal Cretaceous and older section that extends some 20 miles or more back beneath the Wind River Thrust, according to COCORP seismic interpretations (Smithson and others, 1979). There were no oil and gas shows reported in this well.

Three wells drilled through Precambrian on the southern end of the Wind River Thrust (Fig. 8). In 1970, Mountain

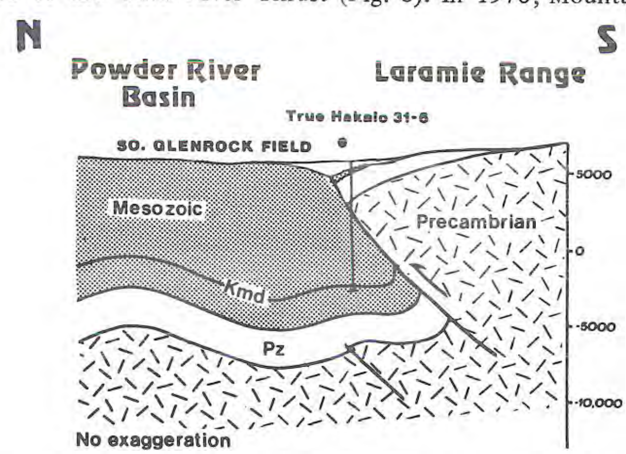

Fig. 7. The first sub-Precambrian production (70 BOPD) in the Rocky Mountains was from a development well drilled by True Oil in South Glenrock field.

Fuel spudded their #1 Dickey Springs well (Sec. 24, T27N, R101W, Fremont Co., Wyo.), and penetrated 4,290 feet of Precambrian before drilling into Tertiary Wasatch (Fig. 10). Subsequent tops included Ft. Union at 5,000 feet, Lance at 7,622 feet and Mesaverde at 10,945 feet. Dips in the subthrust section were 7-10° north-northwest. Three drill stem tests were run in the Mesaverde, and recovered only minor amounts of mud before the well was abandoned.

American Quasar subsequently drilled the #1 Skinner Federal (Sec. 32, T28N, R101W, Fremont Co., Wyo.) seven miles northwest of the Mountain Fuel well and nine miles back from the leading edge of the thrust. In this regard, it is the most adventuresome well drilled on this play to date. After drilling about 10,100 feet of Precambrian, they penetrated what appeared to be Cody Shale based on the presence of *Inoceramus* and glauconite, dipping about 30° north (Fig. 10). At 13,434 feet, they drilled into a sandstone, possibly Frontier, dipping about 50° north. Cutting another thrust fault at 14,000 feet, they drilled into younger Cretaceous Mesaverde sandstones with numerous coal beds. At the total depth of 15,040 feet, dips were 50° north-northwest. Seven DST's were run across the fault at the top of the Mesaverde—five were misruns, one recovered 1,146 feet of mud, and the last one gauged a maximum of 29.4 mcfgd and recovered

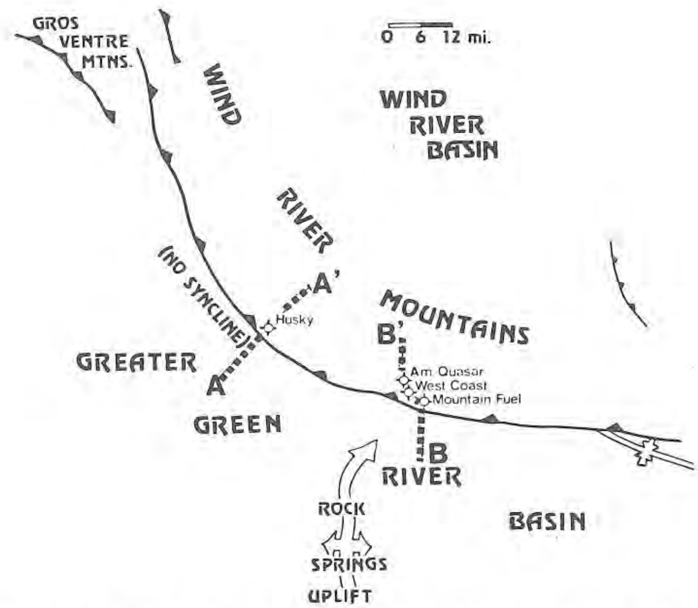

Fig. 8. Four wells drilled through the Precambrian of the Wind River Mountain thrust.

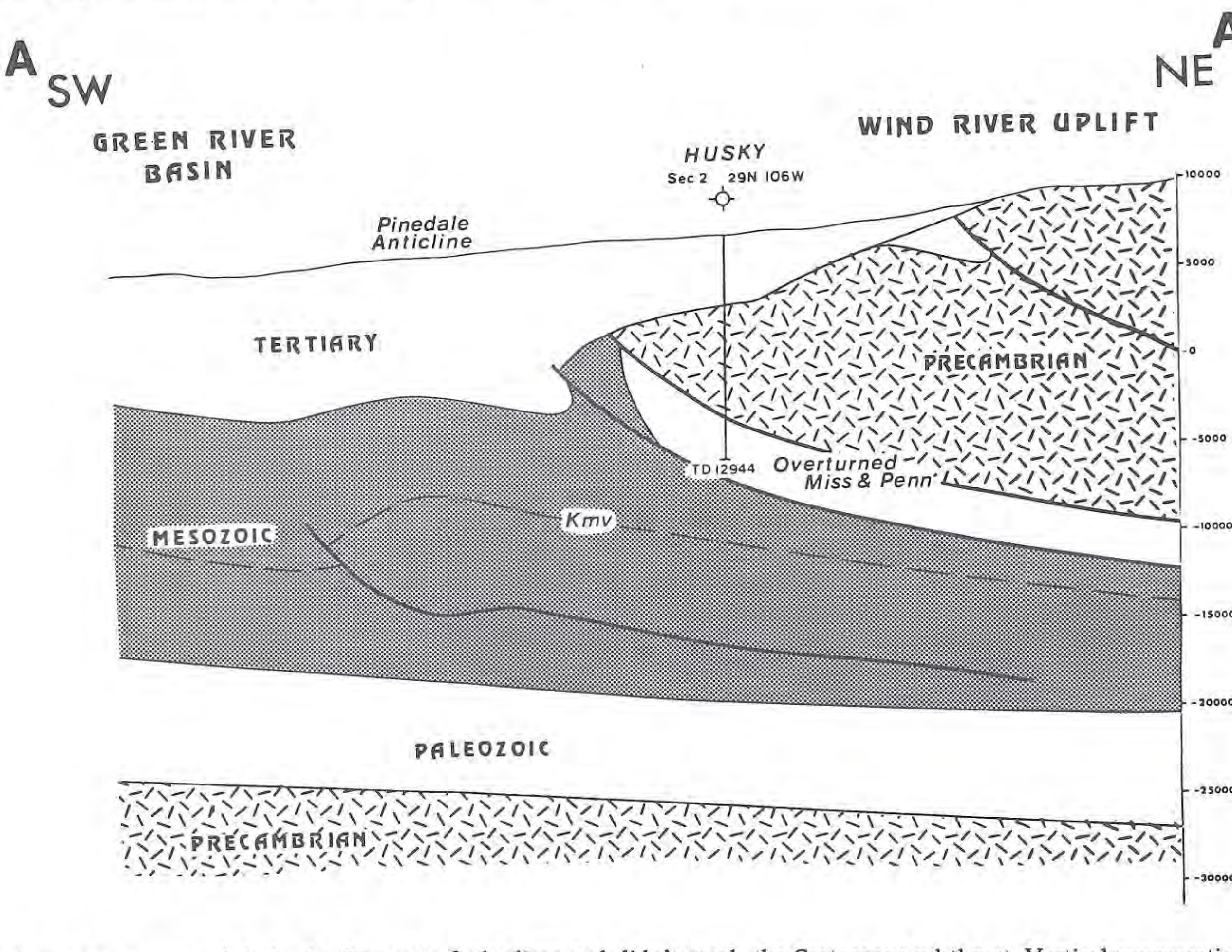

Fig. 9. Husky ran out of rig in the Paleozoic fault sliver and didn't reach the Cretaceous subthrust. Vertical exaggeration x2. (See Fig. 8 for line of cross section.)

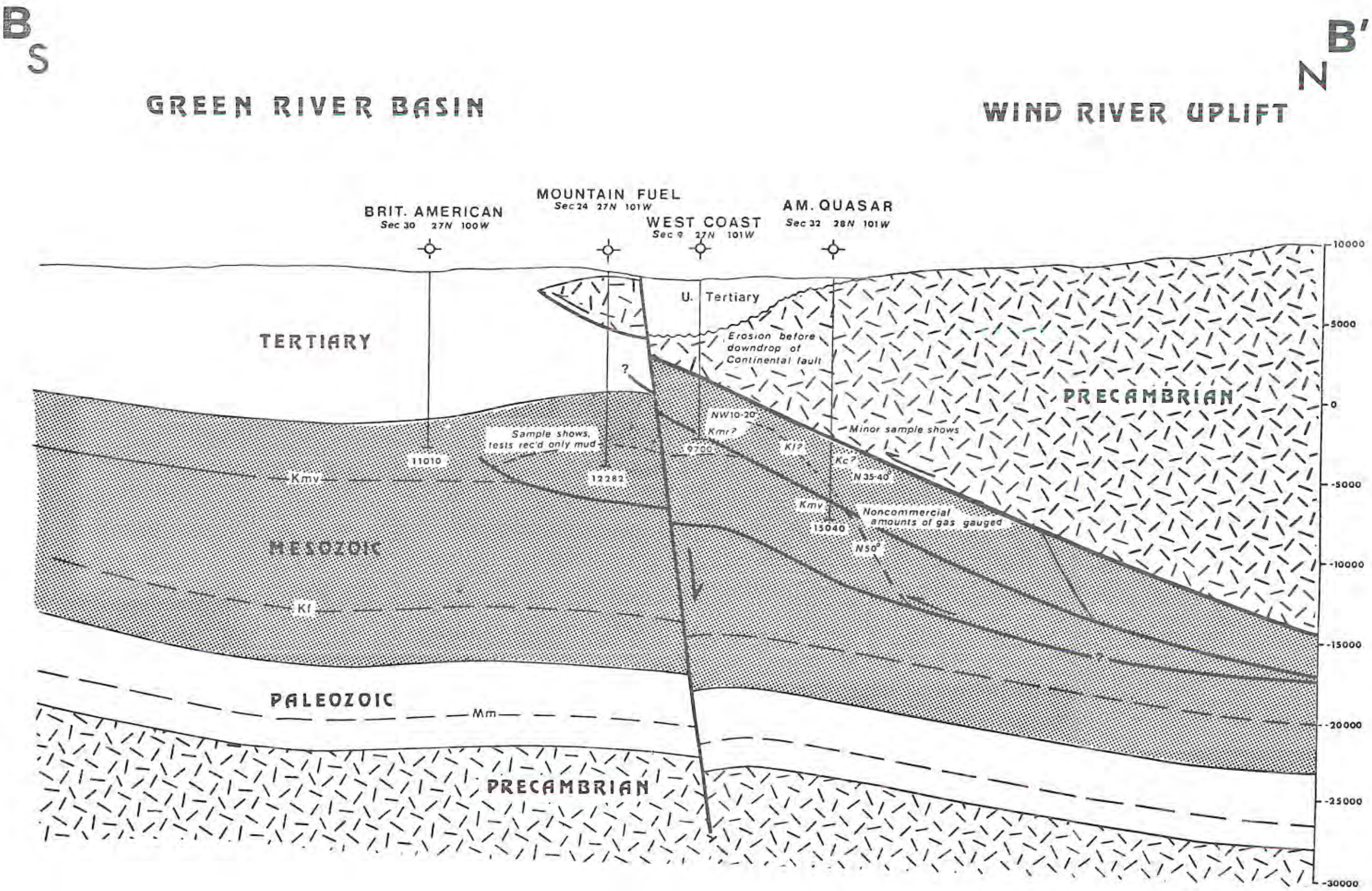

Fig. 10. Three wells tested Cretaceous subthrust structures on the south end of the Wind River Mountain thrust. The American Quasar well was nine miles back from the leading edge of the thrust, setting a record in this regard. Vertical exaggeration x2. (See Fig. 8 for line of cross section.)

2,458 feet of gas and very slightly oil cut mud from the pipe. No attempts were made to complete the well before abandonment.

In 1976-77, West Coast Oil drilled a 9,700 foot test two miles south (updip) of the American Quasar well (Sec. 9, T27N, R101W, Fremont Co., Wyo.). The West Coast well drilled out of the Precambrian at about 5,000 feet and into beds of probable Cretaceous age (Fig. 10). Near the bottom of the hole, Cretaceous shale was identified by J.D. Love (personal communication, 1980). Dips averaged 45° north in the bottom of this well. It is likely that they did not drill through the second thrust fault penetrated in the American Quasar well at 14,000 feet. Because of the steep dips near the bottom of both wells, it is possible that the true subthrust beneath highly disturbed fault slivers has not yet been tested along the Wind River Thrust.

UINTA MOUNTAIN UPLIFT

In 1960, Tennessee Gas and Oil Co. drilled the #1-USA Margie Hicks-A well (Sec. 3, T3N, T103W, Moffat Co., Colo.) north of Rangely Field in northwest Colorado (Fig. 11), which has produced 615 MMBO to date from the Pennsyl-

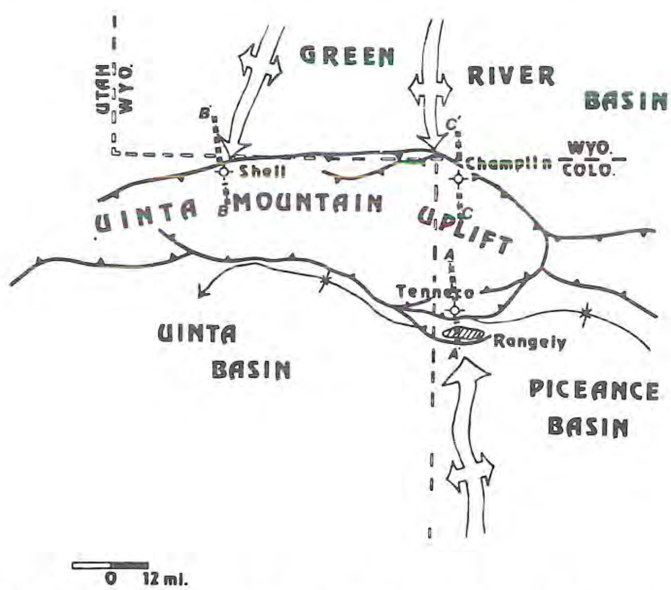

Fig. 11. Three wells have drilled through Precambrian metasediments of the Uinta Mountain Uplift.

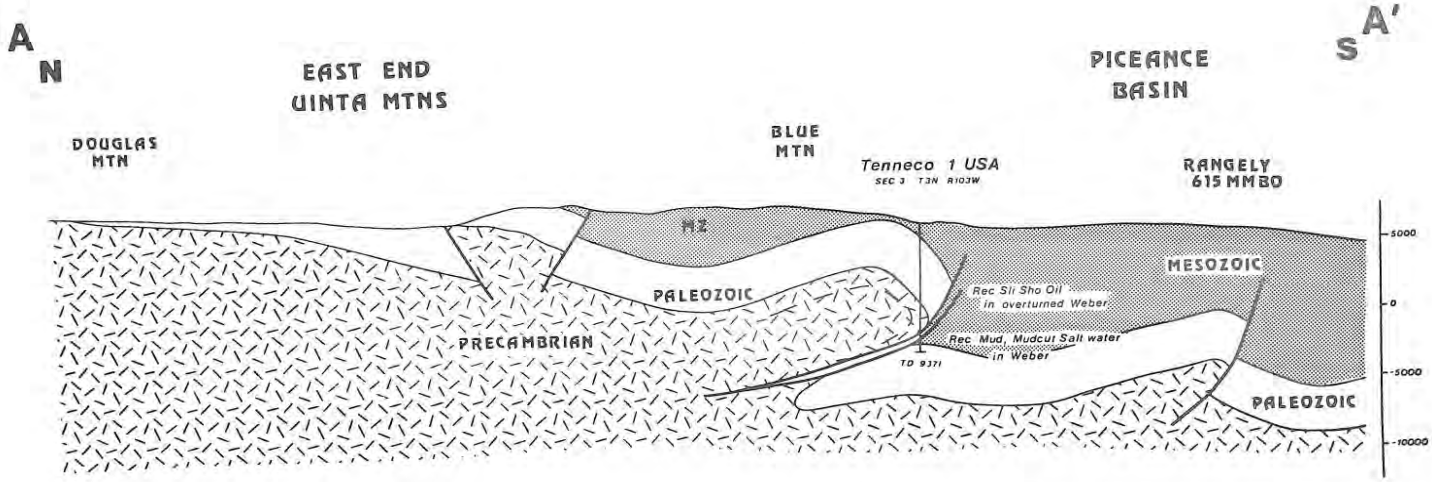

Fig. 12. Tennessee Gas (Tenneco) drilled the southeast end of the Uinta Mountains through Precambrian into tight Weber Sandstone. Vertical exaggeration x2. (See Fig. 11 for line of cross section.)

vanian Weber Sandstone. Tennessee Gas' objective was a seismic structure in the subthrust, hoping for similar potential. Interpretation of this well is primarily from R.B. Powers (oral commun., 1980), one of the geologists responsible for this play. T.G. & O drilled into Precambrian Uinta Mountain Group metasediments at 6,020 feet (Fig. 12) and at 8,050 feet into a fault sliver of overturned Pennsylvanian Weber through Triassic Moenkopi. At 8,470 feet they drilled out of the fault sliver and into a normal south-dipping section of Moenkopi through Weber. Originally scheduled for 8,350 feet, they had to drill 9,371 feet to test the Weber objective, apparently because seismic velocity pullups affected their estimated total depth and structural interpretation. Also, they had moved their initial location 750 feet south primarily to allow the drill bit to drift updip (north) and also to avoid drilling a thicker Precambrian section. They might have topped the Weber higher structurally if the hole had actually drifted north. The bottom hole location was about 1300 feet south of the estimated target spot. Dips in all beds in the fault sliver were approximately 31° north, and were at low angles to the southeast and southwest below the fault sliver. Although an undrilled closure may lie to the north, a more probable interpretation is that the Weber Sandstone will be steeply folded against the thrust fault. Numerous oil shows in samples were noted in this well. A drill stem test of the overturned Weber in the fault sliver, which had scattered brown oil staining in samples and a drilling break, recovered only 590 feet of muddy brackish water. Good oil shows were present in the Park City and Weber below the fault sliver, but no porosity was observed. Three drill stem tests in the Weber at the bottom of the hole recovered only mud or mud cut salt water. Bottom hole dips were generally southeast.

In 1967, Shell drilled the northwest flank of the Uinta Mountain Uplift (Fig. 11) reaching a total depth of 17,100 feet in the 21X-9 Dahlgreen Creek Unit (Sec. 9, T2N, R14E, Summit Co., Utah). They drilled almost 9,200 feet of Precambrian Uinta Mountain Group before drilling into a fault sliver with overturned Permian Park City through Jurassic Nugget (Fig. 13). Another small fault sliver with Triassic Shinarump was drilled before entering a normal Cretaceous Mesaverde through Jurassic Morrison section. Dip was almost flat in the subthrust. Although no drill stem tests were run in the subthrust, numerous sample shows were found in the Phosphoria and Moenkopi of the fault sliver and in the subthrust Dakota, topped at 16,790 feet.

Champlin drilled the Bear Springs #1 Unit well (Sec. 19, T11N, R102W, Moffat Co., Colo.) (Fig. 11) in 1975-76 to a total depth of 13,810 feet. They drilled 7,100 feet of Precambrian Uinta Mountain metasediments that are overturned near the thrust (Fig. 14). At 7,100 feet they drilled into overturned Mancos dipping to the south, and several hundred feet deeper, into Mancos dipping 13° northeast. That dip persisted to total depth in the Pennsylvanian Weber Sandstone. Although oils shows in samples began in the Precambrian fifteen hundred feet above the thrust, beneath the thrust shows were present only in the Moenkopi and Phosphoria. A drill stem test in the Dakota recovered 465 feet of gas cut mud and 6,816 feet of gas cut water. The Weber was porous, but apparently since no shows were seen, it was not tested.

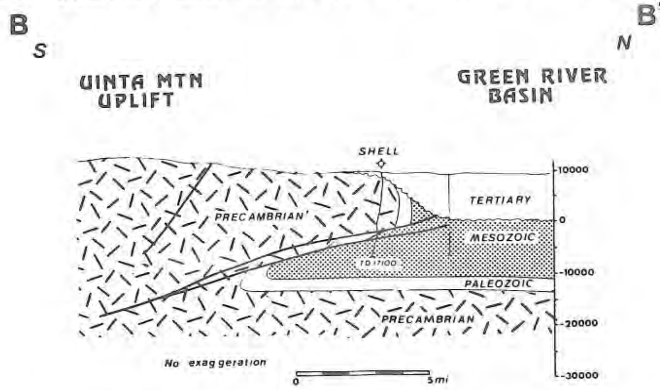

Fig. 13. Shell 21X-9 Dahlgreen Creek Unit well (Sec. 9, T2N, R14E, Summit Co., Utah) had numerous sample shows but ran no drill stem tests. Revised from Clement, 1977. (See Fig. 11 for line of cross section.)

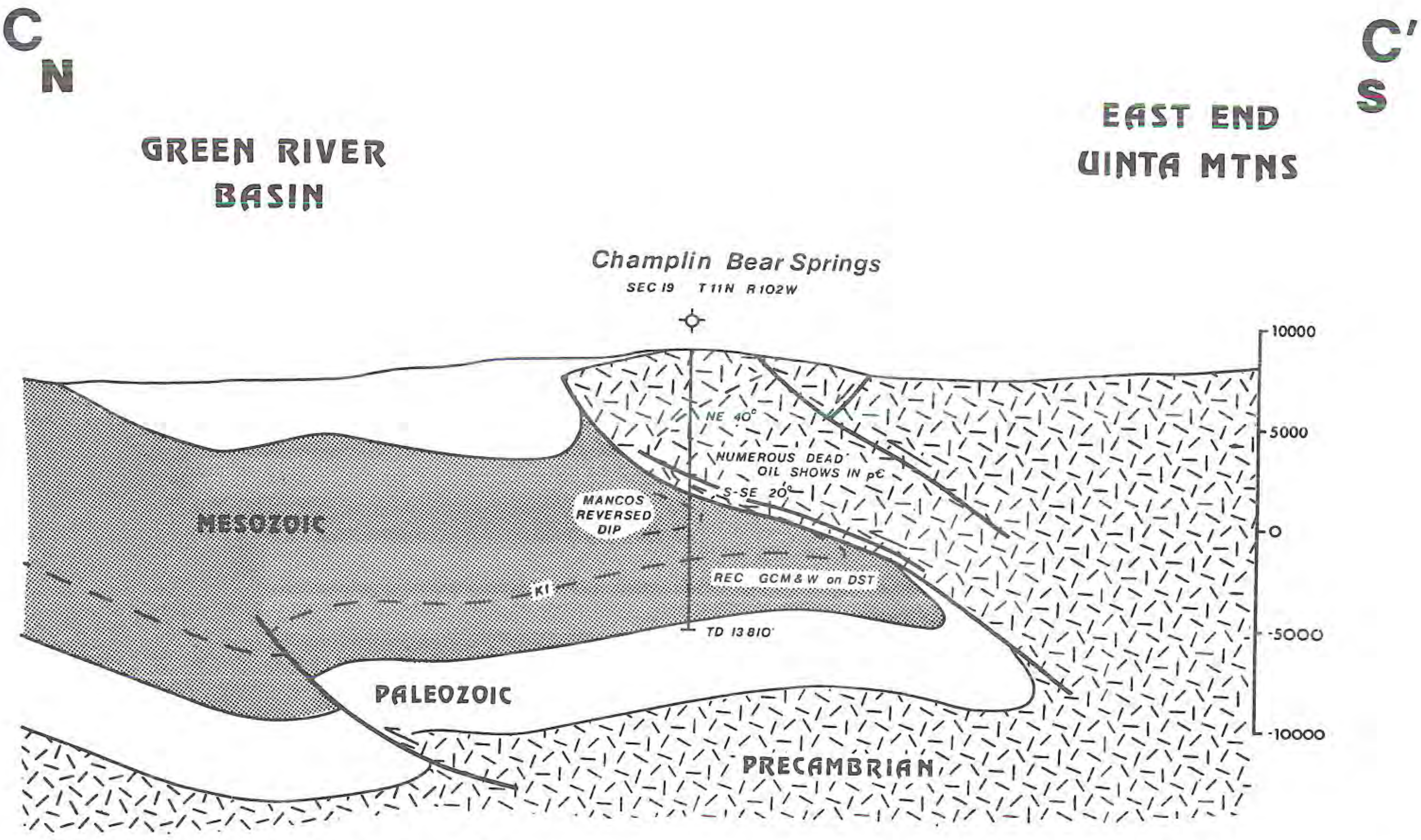

Fig. 14. Champlin drilled through 7100' of Precambrian metasediments into overturned Cretaceous Mancos Shale and eventually into porous, wet Weber dipping northeast 13°. Vertical exaggeration x2. (See Fig. 11 for line of cross section.)

With north-northeast dip in the section, it is possible that a structural closure may exist to the south of this well, where topographic problems prevented seismic confirmation of critical south dip.

UNCOMPAHGRE MOUNTAIN FRONT THRUST

In 1977, Mobil drilled through the southwest flank of the Uncompahgre Uplift. The Mobil C-1 McCormick Federal (Sec. 11, T21S, R22E, Grand Co., Utah) drilled to a total depth of 19,287 feet (Fig. 15), penetrating more Precambrian (14,000 feet) than any other well in the Rockies. At 17,600 feet, they drilled out of Precambrian and into very tight Mississippian or older dolomite, with beds dipping approximately 27° south-southwest at the bottom of the hole. It is possible but not verified that this was part of a fault sliver of overturned Paleozoics. Every other well that drilled through Precambrian into Paleozoics has drilled into a fault sliver. There were no shows reported in the subthrust, and no tests were run. The well took nine months to drill, including three months lost when pipe twisted off twice.

UNSUCCESSFUL ATTEMPTS TO PENETRATE SEDIMENTARY SECTION BENEATH PRECAMBRIAN

Since the Axial Arch, Medicine Bow, and Sierra Madre plays are still active, three recently drilled wells in these areas deserve mention, despite their not drilling through Precambrian.

Axial Arch (Northwest Colorado)

In 1976, Conoco drilled the Axial 1-13 Federal (Sec. 13, T5N, R9W, Moffat Co., Colo.) (Fig. 16) on the Axial Arch of northwest Colorado. After penetrating a normal sedimentary section of Cretaceous and older rocks, they drilled

Fig. 15. Mobil C-1 McCormick Federal (Sec. 11, T21S, R22E, Grand Co., Utah) drilled through a record 14,000' of Precambrian granite. Vertical exaggeration x2.

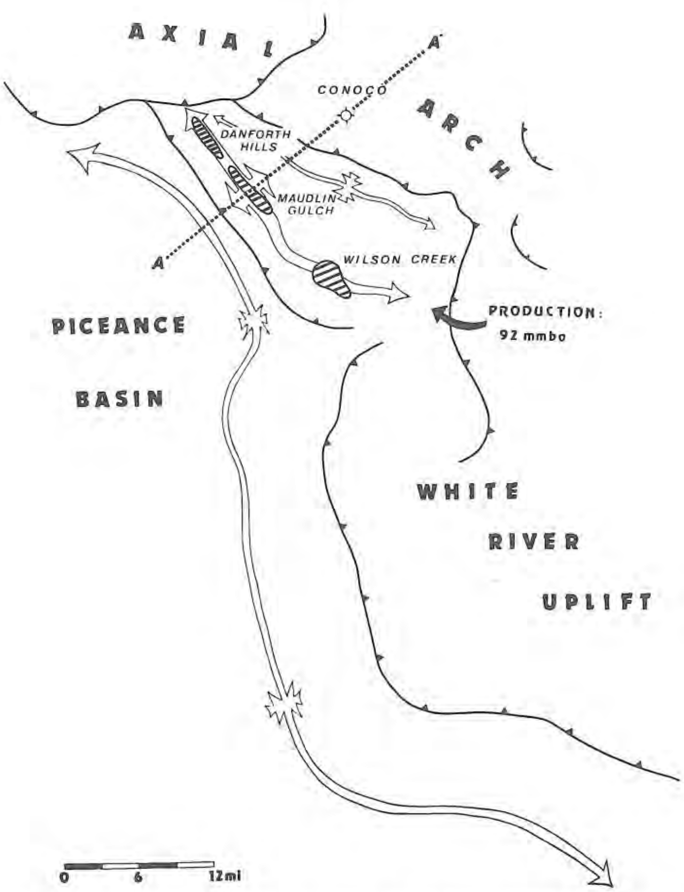

Fig. 16. Numerous seismic crews have been working on the Axial Arch and White River Plateau of northwest Colorado, and future drilling can be expected despite the 1976 failure of Conoco to drill through Precambrian.

Precambrian from 7,600 feet to the total depth of 9,425 feet (Fig. 17). Their goal was a structure with four-way seismic closure located on the same structural block as the Wilson Creek-Danforth Hills trend to the west-southwest that has produced over 92 million barrels of oil. The thrust may be just a few hundred feet deeper, a speculation that still remains to be tested. The increased thickness of high velocity Precambrian found in this well will subtract from the amount of seismically calculated structural closure.

Arlington Fault (East flank, Medicine Bow Range)

In the winter of 1979-80, Exxon spudded the 1 Medicine Bow (Sec. 10, T17N, R78W, Carbon Co., Wyo.) assuming they were east of the Arlington thrust of the Medicine Bow Range (Fig. 18). After drilling an unexpected 4,573 feet of Precambrian (Fig. 19), they plugged their well, leaving untested an interpreted seismic structure at the proposed depth of 8,500 feet. Application of faster velocities in the Precambrian to the seismic data may alter the anticipated structure, but does not alter the seismic evidence for sedimentary section extending some distance beneath the Medicine Bows, adjacent to a good oil-bearing province.

Sierra Madre Fault (East flank, Washakie Basin)

In 1980, C&K Petroleum drilled the #1-36 Hartt Unit well (Sec. 36, T15N, R88W, Carbon Co., Wyo.) to a total depth of 5,856 feet to test an interpreted seismic structure west of the mountain front thrust (Fig. 20). According to R.A. Andersen (oral commun., 1980), they were surprised to drill from Tertiary cover into Precambrian at approximately 300 feet. After drilling 700 feet of Precambrian schist, gneiss and quartz veins, a thrust fault was cut and they penetrated a thin section of lower Triassic redbeds, a thin Permian section and a normal Pennsylvanian, Mississippian and Cambrian section. Precambrian crystalline rocks (phyllite, mica schist, and gabbro) were then penetrated at about 2000 feet. The well was abandoned at 5860 feet in Precambrian, a depth that was determined by the velocity survey to be the top of the deep seismic reflections.

The rig was then moved to the #3-15 Hartt Unit location (Sec. 15, T15N, R88W) which was again interpreted to be in front of the main mountain front thrust. The second well penetrated several hundred feet of Tertiary cover before entering a middle and lower Triassic redbed sequence. The rest of the section was nearly identical to the Permian through Cambrian section identified in the 1-36 well. Precambrian was penetrated at about 2450 feet and the well reached total depth at 4175 feet, still in Precambrian. C&K is currently re-evaluating seismic data with new velocity control and will resume operations in this area in the future.

CURRENT ACTIVITY

Leasing is in progress on every Precambrian-cored uplift in the Rockies, and two wells are presently drilling on the Casper Arch and the west flank of the Big Horn Basin.

Casper Arch

The Moncrief 16-1 Tepee Flats well (Sec. 16, T73N, R86W, Natrona Co., Wyo.) is on the west flank of the Casper Arch (Fig. 21) and is projected to reach Mississippian at 20,000 to 22,000 feet. Although this well is a tight hole, rumors indicate they drilled out of the Precambrian thrust at about 15,000 feet into a possibly overturned Triassic section (Fig. 22). It is also rumored they drilled out of the fault sliver into a Cretaceous section. This prospect is in an exceptionally good area for hydrocarbon potential, being on the same basin margin as the Madden structure to the northwest which has produced over 130 billion cubic feet of gas from Tertiary and Cretaceous reservoirs. A discovery here could be as significant to the mountain front thrust play as Pineview was to the Overthrust Belt.

The Madden structure is an asymmetric faulted fold related to mountain front compression. Monsanto Company's studies (Nels Voldseth, oral commun., 1980) suggest the deep Paleozoic reservoir rocks on the structure could be in fault contact with Cretaceous source rocks. Moncrief's structural objective may be similar as it shares the same structural province. Later this year Monsanto plans a deep test of the Mississippian on the Madden structure; however, this will not require drilling through Precambrian as Moncrief has apparently accomplished.

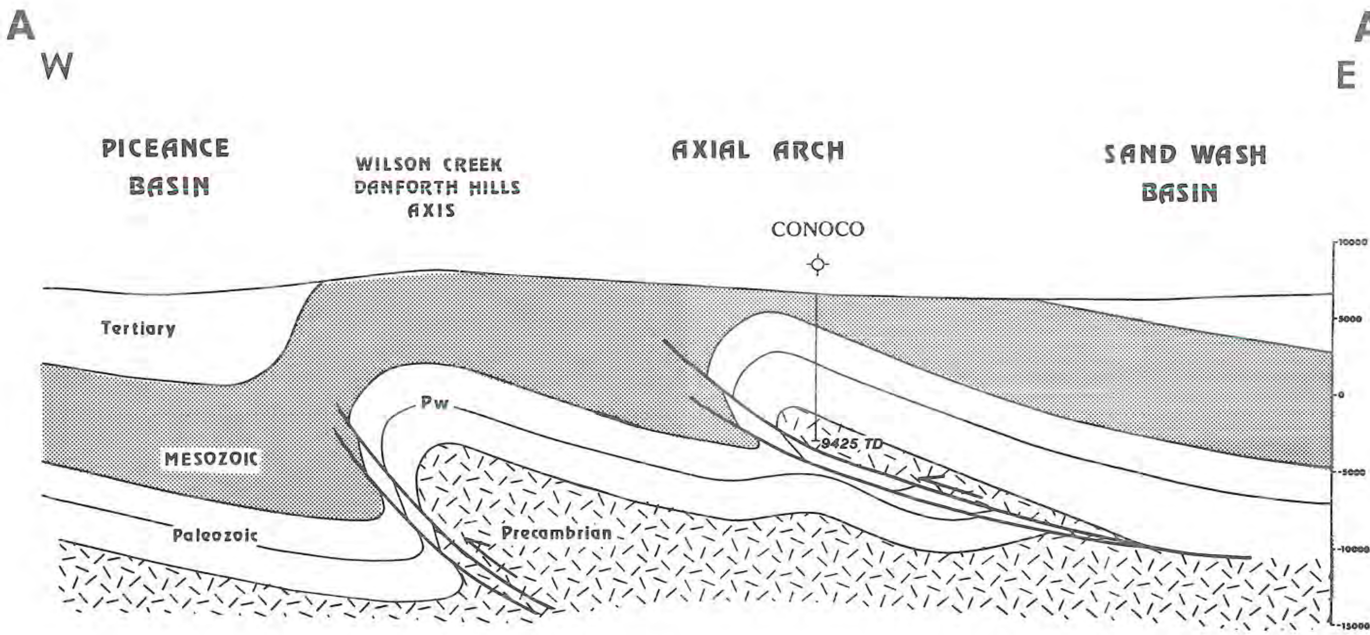

Fig. 17. Conoco's Precambrian test (Sec. 13, T5N, R94W, Moffat Co., Colo.) failed to reach the subthrust objective on the Axial Arch. Vertical exaggeration x2. (See Fig. 16 for line of cross section.)

West flank, Big Horn Basin

Impel is drilling the #1 Loch Katrine Unit well (Sec. 3, T51N, R100W, Park Co., Wyo.) projected to Madison at 21,500 feet, on the east side of Oregon Basin field (Fig. 23). They expect to drill through the thrust (which, like the Owl Creek Thrust of the Wind River Basin, has about 25,000 feet of vertical relief) east of the Precambrian core and to then drill into a normal section of Upper Cretaceous and older sediments. Impel is currently drilling at 5535 feet in Cody shale with 80° dips, and they expect to reach total depth in late fall of 1981.

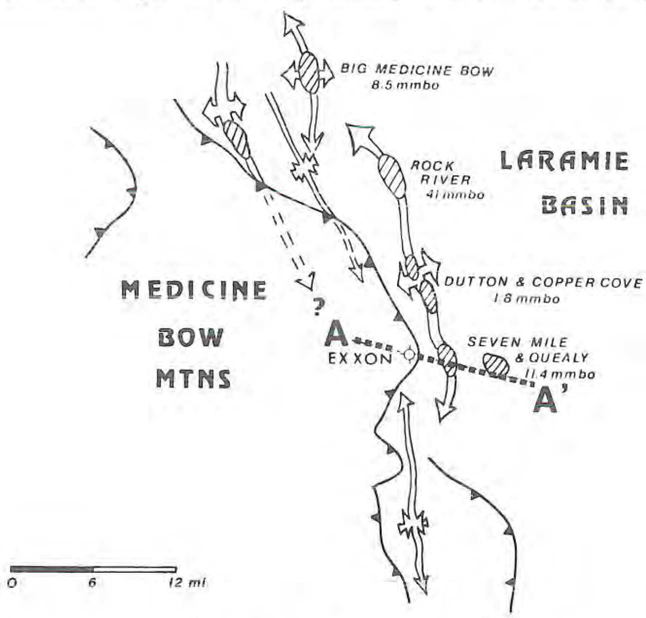

Fig. 18. Exxon drilled 4573' of unexpected Precambrian in their #1 Medicine Bow well.

FUTURE OIL AND GAS EXPLORATION BENEATH MOUNTAIN FRONT THRUSTS

The 15 wells that have drilled through Precambrian to date have refined and revised structural models and seismic interpretations of mountain front thrusts, thereby defining future prospective areas. By applying well data and velocity and dipmeter surveys to existing seismic, better interpretations are being made and new parameters for shooting are being developed to obtain greater resolution of thrust faults and subthrust structures. This has been a critical problem in the mountain front play, as few companies will drill unless a structure is defined by seismic, and seismic records have often been and sometimes still are insufficient for this purpose. There may be some areas in which good seismic records will never be obtained. Future exploration along the mountain flanks of the Rockies will include continued drilling along the thrusts that have already been drilled, with the benefit of the data already acquired.

Additional unexplored areas having subthrust potential for hydrocarbon discoveries include:

1. The Owl Creek Range on the north flank of the Wind River Basin is one of the largest unexplored mountain front thrusts with the most evidence of subthrust hydrocarbons. Oil seeps have been described from Precambrian granite, Paleozoics, Mesozoics and even from Upper Eocene uranium sands (Love, oral commun., 1980) on the southern flank of this range. There has been some debate on the nature of this basin boundary as to whether it has had dominantly strike slip movement or has had a significant element of compressional and overthrusting movement. The presence of the

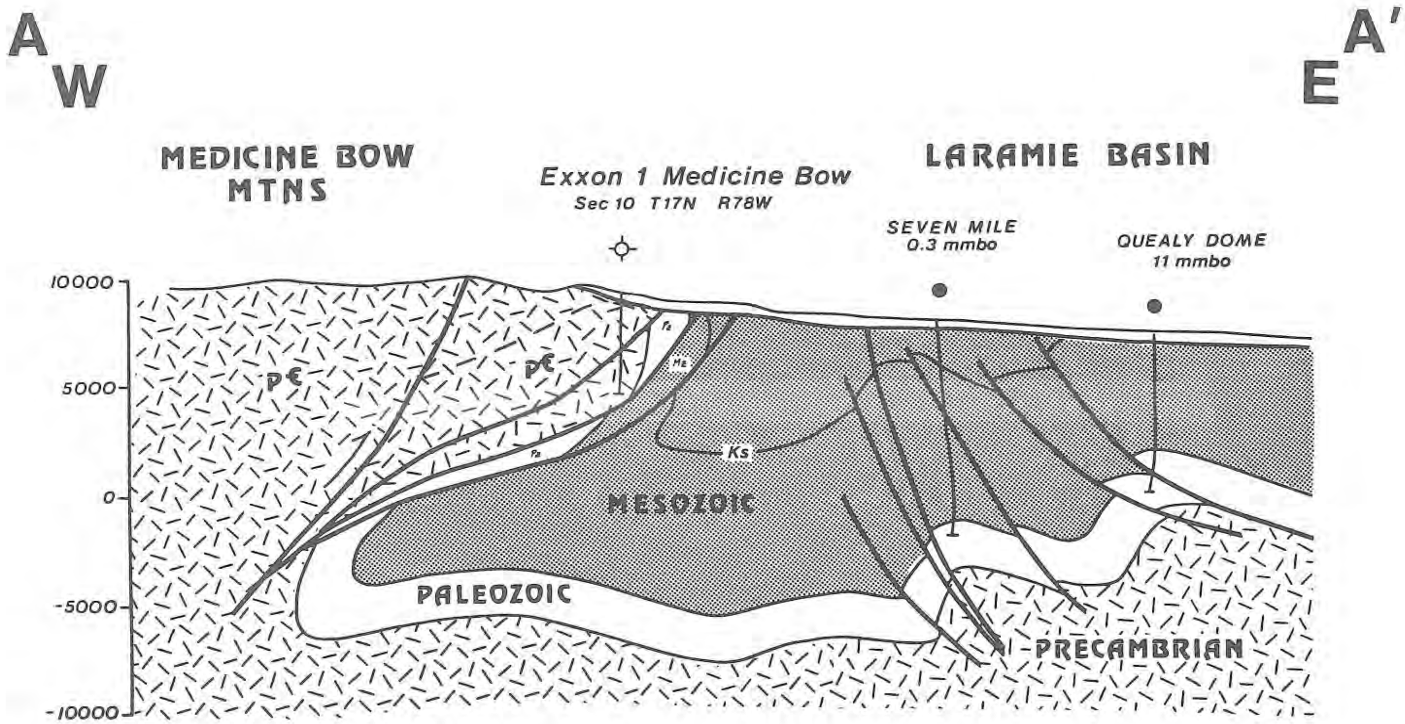

Fig. 19. Exxon's Precambrian test in the Medicine Bow Range was unsuccessful in reaching Mesozoic sediments interpreted from seismic records. Vertical exaggeration x2. (See Fig. 18 for line of cross section.)

Madden structure, the proven thrusting in the Dubois area to the northwest, and the numerous oil seeps from beneath the flank of the mountain range are evidence that a subthrust province of untested sedimentary rocks is buried beneath this

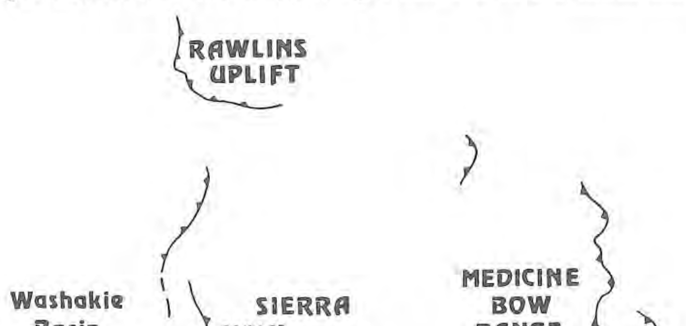

Fig. 20. C&K Petroleum drilled into the complex crystalline and metamorphic rocks of the Sierra Madre front in 1980.

mountain flank, and substantiates the theory of southward overthrusting.

2. The northwest flank of the Beartooth Mountains near the Montana-Wyoming border, where the Big Horn Basin synclinal axis and part of the basin's western flank is overridden by the Beartooths, is an area untested for oil and gas potential. Any structures present would be highly prospective since so few structural closures in the Big Horn Basin are without hydrocarbon production.

3. The east and west flanks of the Big Horn Mountains have seismic evidence for one to three miles of mountain front thrusting over parts of the hydrocarbon rich Big Horn and Powder River Basins. The east flank also has evidence from well data to indicate several miles of overthrust, although the Precambrian has not been drilled through at this time.

4. The north end of the Wind River Mountains adjacent to the Fish Creek Basin remains unexplored. Kansas-Nebraska Natural Gas (Sec. 24, T43N, R110W, Fremont Co., Wyo.) drilled 2,500 feet of Precambrian in this north-south trending thrust before plugging and abandoning their proposed Paleozoic test. Interest in the subthrust potential here should increase with any discoveries in the Fish Creek Basin, currently being explored and drilled for oil and gas.

5. Data from seismic lines on the north flank of the Hanna Basin in central Wyoming indicate several miles of unexplored sedimentary rocks beneath an overthrust block. With accelerated exploration and production in this basin, the subthrust potential of the northern margin will probably be tested soon by drilling.

6. The subthrust of the south side of the Uinta Uplift in Utah has not been drilled, although seismic activity has ex-

WELL NAME & OPERATOR	LOCATION	THRUST	SPUD DATE	COMPL. DATE	DRLG. TIME	TOP p€	p€ Thick.
1. Carter #1 Unit	Sec. 32, 30 N, 93W Fremont Co., Wyo.	Emigrant Trail	1-12-50	6-7-50	6 mo.	1200'	1900'
2. Shell #1 Gov't.	Sec. 9, 42N, 105W Fremont Co., Wyo.	E A Thrust	6-29-56	12-6-56	5 mo.	435'	7418'
3. Tennessee Gas USA Margie Hicks	Sec. 3, 3N, 103W Moffat Co., Colo.	Uinta Mountain	9-22-60	1-28-61	4 mo.	6020'	245'
4. Atlantic Refining #1 Ice Slough	Sec. 9, 29N, 93W Fremont Co., Wyo.	Emigrant Trail	11-3-60	12-18-60	1.5 mo.	1092'	2056'
5. Sinclair #1 Cooper Creek	Sec. 19, 28N, 90E Fremont Co., Wyo.	Emigrant Trail	4-22-61	9-15-61	5 mo.	surf.	2087'
6. Shell Dahlgreen 21X-9	Sec. 9, 2N, 14E Summit Co., Utah	Uinta Mountain	11-17-67	10-8-68	10.3 mo.	2920'	8810'
7. Mountain Fuel #1 Dickey Springs	Sec. 24, 27N, 101W Fremont Co., Wyo.	Wind River	6-14-70	10-3-70	3.5 mo.	surf.	4290'
8. True 36-1 Hakalo	Sec. 6, 32N, 75W Converse Co., Wyo.	Northern Laramie Range	7-8-71	8-17-71	1.3 mo.	1960'	288'
9. Husky 8-2 Federal	Sec. 2, 29N, 106W Sublette Co., Wyo.	Wind River	5-29-73	10-2-73	4 mo.	4525'	6140'
10. Am. Quasar #1 Skinner	Sec. 32, 28N, 101W Fremont Co., Wyo.	Uinta Mountain	9-27-74	11-6-75	7 mo.	surf.	10,100'
11. Champlin Fed. 31-19 (Bear Springs)	Sec. 19, 11N, 102W Moffat Co., Wyo.	Uinta Mountain	8-30-75	4-10-76	6.3 mo.	surf.	7158'
12. West Coast Oil Skinner Fed. 1	Sec. 9, 27N, 101W Fremont Co., Wyo.	Wind River	9-12-76	1-22-77	4.3 mo.	3600'	1400'
13. Mobil C-1 McCormick Fed	Sec. 11, 21S, 22E Grand Co., Utah	Uncompahgre	2-3-77	12-1-77	9.5 mo.	3600'	14,000'
14. Supron Energy 1 F-28-30-93	Sec. 28, 30 N, 93W Fremont Co., Wyo.	Emigrant Trail	9-12-80	11-3-80	2 mo.	424'	5286'
15. Moncrief 16-1 Tepee Flats	Sec. 16, 37 N, 86W Natrona Co., Wyo.	Casper Arch	10-18-79	drlg	drlg		9000'?

TABLE 1.

SUBTHRUST FAULT SLIVER THICKNESS	FORMATION BENEATH PRECAMBRIAN	FORMATION BENEATH FAULT SLIVER	FORMATION AT TD	TD	DIP AT TD	SHOWS
800'	Cambrian	Thermopolis	Tensleep	6591'	13° NE	Oil cut and stain from Phosphoria cores
812'	Ord.? or Dev.	Mowry	Sundance	10,689'	15° NE	Rec. 69 bbls GCMW from the Phosphoria and Tensleep in fault sliver
1100'	Cambrian Ladore	Park City	Weber	9371'	low angle SE-SW	Sample shows in Weber, Moenkopi, Park City in fault sliver. Sample shows in Weber of subthrust
520'	Cambrian?	Thermopolis	Tensleep	6552	NE?	Dead & live oil in subthrust Phosphoria. Rec. 660' sli G&MCW w/strong sul. odor on test
none	Wasatch	------	Frontier	12,224'	20°? S	Oil shows in samples in Cody, DST rec. 15' M.
2065'	Phosphoria	Mesaverde	Morrison	17,100'	0° ?	Sample shows in Phosphoria, Moenkopi, Thaynes, and Shinarump of fault sliver, and in subthrust Dakota, no tests in subthrust
none	Wasatch	------	Mesaverde	12,282'	7-10° N	Trace of fluor. in subthrust shales
none	Cody	------	Skull Creek	7898'	?	Sample shows in Frontier, Mowry, Muddy; completed for 70 BOPD in Muddy
unknown	Ord.? Miss.?	unknown	Amsden	12,944'	?	none reported
3900'	Cody	Mesaverde	Mesaverde	15,040'	50° N	Gas to surf. on Mesaverde test (guageable), rec. 2458' G&VSOCM
none	Mancos	------	Weber	13,810'	15° NE	Sample shows in Precambrian, Moenkopi, & Phosphoria; Rec. 465'GCM, 6816'GCW in Dakota test
unknown	Cretaceous?	------	Mowry?	9700'	10° NW	none reported
unknown	Miss. or Dev.	unknown	Miss. or Dev.	19,302'	27° S-SW	none reported
?	Chugwater?		Amsden?	7769'	?	Sample shows in Phosphoria
2500'?	Triassic?	Cretaceous?				rumored gas from Cretaceous

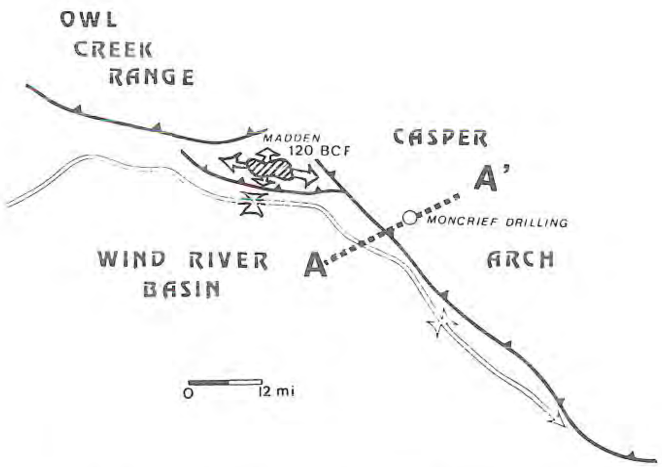

Fig. 21. Moncrief #16-1 Tepee (Sec. 16, T37N, R86W, Natrona Co., Wyo.) is drilling the mountain front thrust of the Casper Arch.

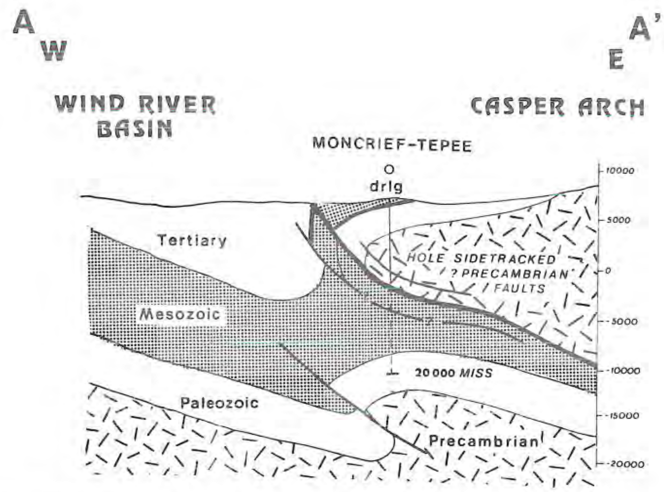

Fig. 22. A structure similar to Madden is expected in the subthrust of the Casper Arch. Vertical exaggeration x2. (See Fig. 21 for line of cross section.)

tended several miles north of the edge of the thrust. The close proximity to the Altamont-Bluebell production makes this area highly prospective.

7. In Colorado, the west side of the White River Uplift (Grand Hogback) has experienced extensive leasing and seismic activity in recent years, and drilling can be expected to commence there in the near future, as well as in several places along the Juniper Mountain-Axial Arch trend. Recently, hundreds of miles of seismic line have been shot across the historic "block uplifts" of the Colorado Plateau region and this has prompted a needed re-evaluation of the previous structural models, applying compressional concepts.

8. Efforts are being made at this time to commence drilling a sub-Precambrian prospect on the north side of North Park Basin, a very complex structural province related to the Sierra Madres and the Medicine Bows.

9. In light of new tectonic concepts of horizontal compression of Colorado mountain ranges and rumors of oil in Precambrian cores, the east flank of the Front Range will probably be more extensively explored and structurally defined through both seismic surveys and wildcat drilling.

OBSERVATIONS FROM EXPLORATION THROUGH 1980

Observations derived from drilling and exploration include:

1. Subthrust structural highs generally are coincident with

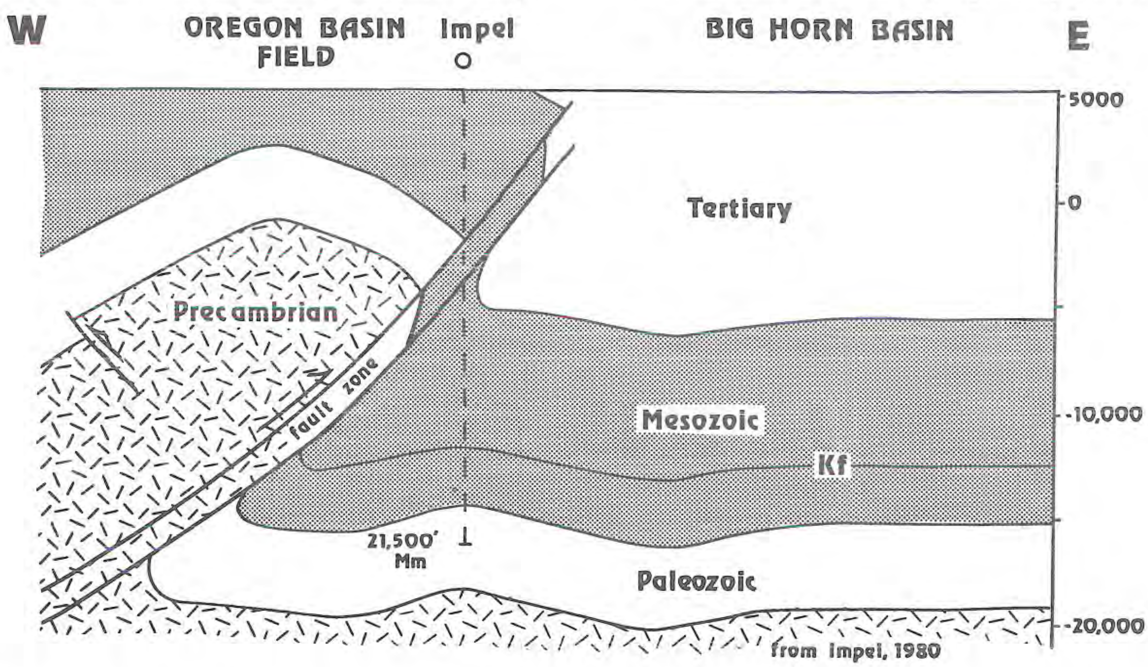

Fig. 23. Impel is drilling a subthrust test just east of Oregon Basin field (Sec. 3, T51N, R100W, Park Co., Wyo.). Vertical exaggeration x2.

structural highs, anticlines, and Precambrian outcrops on the overthrust sheet (Berg, 1962). This does not preclude the presence of hydrocarbons in the deeper subthrust structures or stratigraphic traps. Most subthrust tests to date have been drilled where major anticlinal trends in the basinal block can be projected beneath the overthrust block, i.e., where the Moxa Arch and the Douglas Creek Arch intersect the Uintas, the Rock Springs Uplift intersects both the Uintas and the Wind River Range, and the Winkleman Dome trend intersects the Emigrant Trail Thrust.

2. If Paleozoic rocks are present just beneath the Precambrian, they are usually in a fault sliver of overturned beds resulting from the fold-fault process of mountain front compressional thrusting.

3. The amount of overthrow on the mountain flank thrusts cannot yet be predicted by the position along the structural trend, i.e., northwest-southeast trending flanks of the ranges will not necessarily have more overthrow than an east-west trending mountain flank.

It has been suggested that dip-slip thrust overlap at the ends or on the east-west trending flanks of these ranges was minimal, and strike slip movement was more prevalent. However, the presence of subthrust section 9 plus miles behind the thrust edge in the American Quasar well on the south flank of the Wind River Mountains has caused revision of this hypothesis to include significant thrust overlap on this east-west trending flank. In addition, the evidence for significant thrust overlap on the south flank of the Owl Creek Range indicates probable compressional fold-thrust movement toward the south on this east-west trending mountain flank.

4. The presence of overturned Paleozoic v.s. normal Tertiary or Cretaceous is also not yet predictable based on the part of the mountain flank being drilled. The Wind River and Emigrant Trail Thrusts had overturned Paleozoics beneath the Precambrian on the west flank and normal Tertiary and Cretaceous section beneath the Precambrian on the outer edge of the southern flank. These two cases alone might be used to establish a pattern except that the east-west trending Uintas demonstrate both phenomena. It may be safe to predict that along the long edge of a mountain flank thrust one can expect overturned Paleozoics or older Mesozoics beneath the thrust, and at the ends of the ranges, regardless of the direction of thrusting, one can expect to drill into a normal Tertiary or Cretaceous section.

5. Three mountain fronts have had more than one well drilled through them. The four wells drilled along the Wind Rivers show three very different subthrust structural phenomena: a.) overturned Paleozoic fault sliver, b.) normal Tertiary and older section, and c.) fault slivers of intensely folded Cretaceous rocks. Similar sequences have been found beneath the Emigrant Trail and Uinta Mountain thrusts.

6. Although movement on the mountain front faults was most active during the Laramide orogeny, there also was recurrent movement on some of these uplifts during the Paleozoic and Mesozoic, hence oil and gas prospecting should include analyses of hydrocarbon generation, migration, and entrapment since Paleozoic.

7. Regional geology must be incorporated to avoid drilling the drained or flushed side of a major basinal syncline beneath the edge of the thrust.

8. Geophysical interpreters must include good velocity control and incorporate the limited geologic data for both the prospect area and for entire mountain flank thrusts. Interpreters are beginning to recognize the problems of recording, processing, and interpreting data from areas characterized by steeply dipping to overturned beds, numerous fault slivers, superimposed normal faults, the wide variety of Precambrian reflections, and large imbricated fault zones.

9. Seismic acquisition must include one to three miles of additional data acquisition beyond the expected width of the overthrow to record the deeper data and to acquire the necessary fold for optimum interpretation at the subthrust end of the line.

10. The best interpretations of seismic information should involve extensive geologic extrapolations where data is commonly unreliable, such as the fault sliver zone. In addition, geologic modeling is recommended and is being done by some companies where a model is proposed, known seismic parameters (velocities) are combined with this model to produce a synthetic seismic section in the lab. Comparisons with the real seismic sections are then made and adjustments applied to the geological or geophysical parameters until the synthetic and real sections correspond with each other and the final geologic model is the interpretation (J. Albertus, oral commun., 1980). As stated before, there may be some areas where good data is not attainable.

11. Drilling through Precambrian is not necessarily slower (Fig. 24) or more costly than conventional drilling. In most cases drilling times and costs are comparable to nearby wells drilled to similar depths without any Precambrian. Cretaceous shales are often much slower and are prone to more drilling

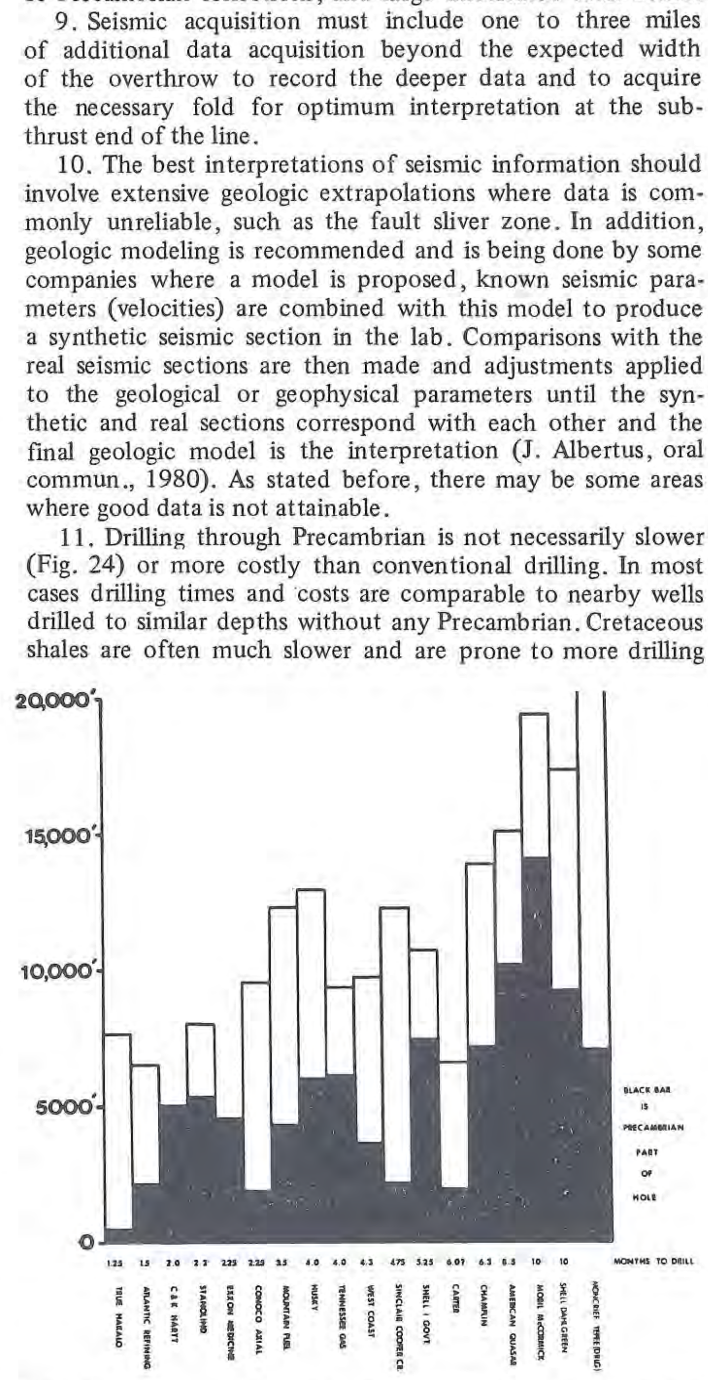

Fig. 24. Bar graph showing depth drilled, thickness of Precambrian rocks drilled, and drilling times for the wells that have drilled through the Precambrian of mountain front thrusts.

problems than granite or metasediments. Future drilling will be faster and less expensive by utilizing the bit information, mud programs, hole deviation information, and other critical drilling records of the 15 existing wells.

CONCLUSIONS

The vast province of virtually unexplored mountain flank acreage throughout the Rocky Mountain region contains enormous potential for undiscovered hydrocarbon reserves. Evolution of structural concepts and improvements in acquisition and interpretation of seismic data combined with well data from the 15 wells that have drilled through Precambrian make this play one of the most daring and promising plays of the region.

ACKNOWLEDGMENTS

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