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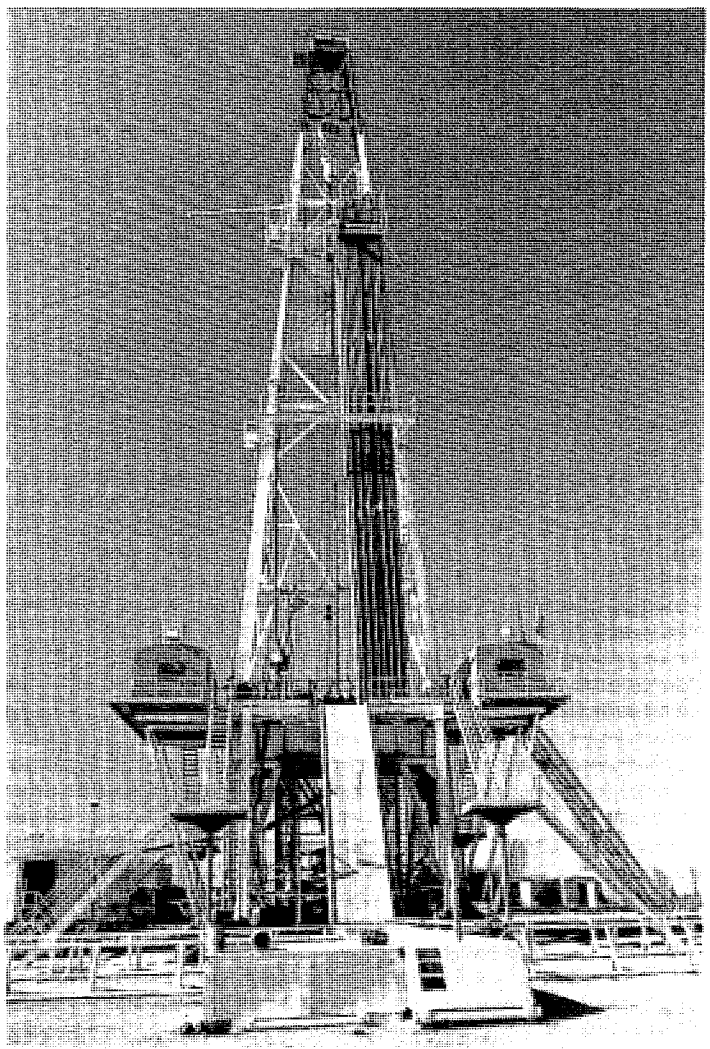
FIELDNOTES
From The State Of Arizona
Bureau Of Geology And Mineral Technology

Vol. 11, No. 1 | Earth Sciences and Mineral Resources in Arizona | March 1981

The Great Southwestern Arizona Overthrust Oil and Gas Play

An Update



Parker Drilling Rig number 166 on location in Pinal County, Arizona in January 1981. Ground-to-crown height is about 140 feet.

by Stanley B. Keith

[February 17, 1981]. Anschutz-Texoma State No. 1-10-2 is history. On February 14, 1981, Phillips Petroleum, operators of the hole and the Anschutz-Texoma overthrust play (see *Fieldnotes*, v. 9, n. 1; v. 10, n. 1), plugged and abandoned the Pinal County test well. Phillips had become one-third owner of the Anschutz-Texoma play in September 1980 for about 60 million in cash and work commitments.

A recent Phillips press release summed up the nine million dollar test as "an unusual frontier effort" that entered granitic rocks at about 4,000 feet and terminated in granitic rocks at 18,013 feet "without encountering any shows of hydrocarbons." The recent drilling established a new Arizona depth record smashing the old record of 12,500 feet set in 1972 by Exxon (formerly, Humble Refining Co.), 15 miles southeast of Tucson. No new statements have been released on the notorious 'sediment' interval from 12,056 to 12,063 feet that created so much speculation in early October of last year. Unfortunately, the reported intention of Phillips to transfer the hole to a joint government-academic consortium for scientific purposes has apparently been frustrated because of blockage by lost equipment stuck in the hole at about 12,000 feet.

Meanwhile, about four miles east-southeast of Tombstone, in Cochise County, Arizona (SW¼, SW¼, Sec. 14, T. 20S, R. 23E) a new test permitted for 20,000 feet is scheduled to begin this spring. This well will be drilled by the same Parker Drilling Co. rig now being disassembled at the Pinal County well location. Given the regional geology around the Tombstone drill site, this writer's prognosis is that the new well will encounter Precambrian rocks (1.7 b.y. Pinal Schist or, more likely, 1.4 b.y. granite) within 10,000 feet. The author also doubts that the hole will reach anything near the permitted depth of 20,000 feet and that significant petroleum shows in this area will be unlikely.

The Pinal County well closes an exciting chapter in the history of Arizona geologic research. While no thrust fault geology consistent with the bold and provocative Anschutz overthrust concept was apparently encountered, this reviewer suspects the well will eventually yield a wealth of scientific data that supports other models of low-angle tectonic phenomena related to crystalline rocks in Arizona. We eagerly await any publication of the Anschutz-Texoma No. 1-10-2 (also known as Phillips Arizona State A-1) well data and post-mortem interpretations.

IN THIS ISSUE

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Selected Flood Summaries and Cost Estimates in Arizona

by Susan M. DuBois and Brian R. Parks

As explained in the previous *Fieldnotes* issue (v. 10, n. 4, p. 6), the term "flood" is often used synonomously with *runoff* and *erosion* as the cause of major damage related to heavy precipitation. Here it has been loosely applied where excerpts of source material have been quoted. However, all of the events in the chart did include periods of overbank flow (flooding) on portions of the floodplains.

Flow rates in the washes or rivers are expressed in cubic feet per second (cfs). A useful analogy for visualizing such quantities of water and rates of flow is a 3 ft wide by 5 ft long by 2 ft deep bathtub, filling to the rim in 30 seconds at 1 cfs; 1 sec at 30 cfs; 1/30 sec at 300 cfs.

Flood events presented below were selected with regard to the following criteria: 1) all resulted in either great monetary or human loss (or both); and 2) the events had a wide geographical and temporal distribution. These 15 events comprise only a small portion of the 103 *documented* floods which occurred between 1872 and 1981. [Other destructive storm runoff (not summarized below) also occurred in the following locations: Yuma—March 1884; Nogales—June 1887; Clifton—December 1906; Upper Gila River—September 1926; Safford—September 1944; statewide—December 1965; Phoenix—June 1972; central and eastern Arizona—October 1972; statewide—February 1978].

DATE	AREA DAMAGED	DRAINAGES	LOSSES *(Millions of $)*†	SOURCES
February 1890*	Statewide	All major	$ 6,636	3, 4, 15, 17
February 1891	Statewide	All major	28,575	2, 4, 5, 6, 15, 26
January—May 1905	Clifton, Upper Gila Valley	Gila River San Francisco River	37,750	5, 9, 13, 16, 20
January 1916	Statewide	Salt River Gila River Colorado River Rillito River	2,382	5, 6, 7, 15, 26
August 1940	Tucson	Santa Cruz River	960	2
July 1954	Globe Miami	Pinal Creek	3,553	10
September 1962	South Central Arizona	Santa Cruz River Santa Rosa Wash	9,310	2, 12, 22
August 1963	Prescott	Granite Creek	1,441	1
September 1964	Tucson	Rillito River Santa Cruz River	6,411	14
December 1966	Grand Canyon	Crystal Creek Chuvar Creek	5,040	8, 19
September 1970	Santa Cruz Basin North Central Arizona	Tonto Creek Santa Cruz Verde River Oak Creek	10,860	18, 21
September 1976	Bullhead City	Silver Creek	7,440	10
October 1977	Santa Cruz Basin	Santa Cruz River	56,160	2, 22, 23
December 1978	Central and Eastern Arizona	Gila River Salt River San Francisco River	85,020	2, 24, 25
February 1980	Phoenix	Salt River	40,607	2, 4, 11

†In this column losses have been adjusted to 1979 dollars using the Gross National Product Implicit Price Deflator.
*See summaries of these events below.

February 1890

Heavy rains caused the Santa Cruz, Salt, Gila and Colorado Rivers to overflow. The Tempe bridge and miles of track between Maricopa and Yuma washed out. Farmland and irrigating systems, mostly in the upper Gila valley, were destroyed. The wood and earthen Walnut Grove Dam (110 ft high, 400 ft wide) 20 mi. S of Prescott on the Hassayampa River overflowed and burst on 2/22/90. Approximately 50,000 acre ft of water were released as a "wave 100 ft high" destroyed everything in its path, including several mining camps and an uncompleted smaller irrigation dam. Between 70 and 100 deaths were reported. The dam failed after its spillway became clogged with vegetation and water overflowed its crest. Damage estimate includes *only* cost of Walnut Grove Dam.

February 1891

Heavy rains starting on 2/15/91 created some of the largest estimated flows on major drainages in Arizona: Bill Williams River

for such instability was presented. This question ignores the evidence to the contrary, namely the observation that bench mark 1283 is part of a 45-km-long segment of the leveling line along which movements were small to negligible from 1905 to 1967 (Holzer, 1979, p. 4693). Any bench mark or an average of several bench marks within this segment could have been used as a reference mark. Bench mark 1283 was selected because of its proximity to the area of uplift. The practical effect of selecting a more distant mark would be to diminish the statistical significance of the measured uplift. Raymond and others (1980) also "suggest that bench 1283 should not be considered absolutely stable as Holzer suggested." According to Holzer (1979, p. 4692), "the absolute elevation of bench mark 1283 is unknown, so that the terms uplift and subsidence are relative to bench 1283. Because a presumably localized crustal phenomenon is being examined, however, conclusions from the present investigation should not be affected by lack of an absolute reference."

SEISMICITY

A potential effect from man-induced changes of stress in the earth's crust is to trigger seismicity (Raleigh and others, 1976; Yerkes and Castle, 1976; and Castle and others, 1980). Mechanisms proposed for this seismicity include changes of surface load and changes of effective stress caused by pore-pressure changes. Particularly relevant to south-central Arizona is an earthquake sequence in New York that was attributed to crustal unloading caused by a quarry operation (Pomeroy and others, 1976). Most examples of man-induced seismicity appear to be triggered phenomena because, in general, the man-induced stress changes are very small relative to the inferred tectonic stress. By analogy to the problem of reservoir-induced seismicity (Castle and others, 1980), evaluation of the potential for man-induced seismicity in south-central Arizona requires consideration of the present stress state and how it is altered by groundwater withdrawal. Because south-central Arizona has been aseismic historically and the magnitude of the man-induced stress change is small, approximately 1 bar, the probability of man-induced seismicity appears small. However, man-induced seismicity has been observed in areas of low natural seismicity (e.g., Lake Mead; see Packer and others, 1977). Hence, the level of natural seismicity is not a completely reliable indication of whether or not man-induced seismicity may occur. In addition, as stated in Holzer (1979, p. 4679), "it may be pertinent that previously unexperienced seismicity may have occurred in south-central Arizona in the 1970s (Peirce, 1975; Yerkes and Castle, 1976). Although the cause of the seismicity is controversial—some have attributed it to sonic booms channeled by the atmosphere (Peirce, 1975)—it may be related to the unloading described here."

Raymond and others (1980) argue that unloading due to groundwater withdrawal is unlikely to induce earthquakes in south-central Arizona. They argue that "if earthquakes may result from unloading ... then earthquakes should have followed loading at Lake Mead and comparable areas" and cite experience at Lakes Powell and Mead. This reasoning is fallacious. If a stress change in one direction tends to promote failure and seismicity, then a stress change in the opposite direction should tend to promote stability. Accordingly, the decrease of local seismicity observed near Lake Powell after impoundment or loading (Mickey, 1973), which Raymond and others (1980) cite as evidence against the possibility of man-induced seismicity following unloading in south-central Arizona, actually supports the possibility of man-induced seismicity in unloading situations. This deduction of course ignores the effects of differences in the state of stress between areas. Loading can increase stability under some stress states and decrease it under others (e.g., see Snow, 1972). Experience at Lake Mead, where seismicity increased after impoundment or loading (Carder, 1970), is opposite to that at Lake Powell. Although Raymond and others (1980) attribute the seismicity to increased pore pressures caused by hydraulic connection between underlying rocks and the reservoir, other investigators have concluded that "the post-impoundment seismicity may be the result of stresses *generated by the weight* of Lake Mead" (Packer and others, 1977, p. 39–40, emphasis added). These two examples cited by Raymond and others (1980) serve only to demonstrate that our understanding of the seismicity related to the impoundments at Lakes Mead and Powell is incomplete and does not provide an adequate basis for rejecting the possibility of man-induced seismicity in south-central Arizona.

CONCLUSIONS

The questions raised by Raymond and others (1980) concerning the validity of the measured uplift from 1948 to 1967 are without support and are based on misunderstandings of how geodetic data are collected and reduced and on a misinterpretation of Holzer (1979). In fact, even by their own analysis the uplift near Casa Grande is a valid observation. Admittedly, the uplift is small relative to potential error. This concern led to the extensive discussion of error by Holzer (1979). By conventional analysis of error, however, the 1948–67 uplift near Casa Grande is statistically significant.

Raymond and others (1980) also have not argued convincingly that man-induced seismicity will not be associated with the unloading in south-central Arizona. Their argument against man-induced seismicity in south-central Arizona, which is based on experience at Lakes Powell and Mead, can be challenged. In fact, the effect observed at Lake Powell argues for potential man-induced seismicity in south-central Arizona. By analogy to the problem of reservoir-induced seismicity, evaluation of the potential for man-induced seismicity in south-central Arizona requires consideration of the present stress state and how it is altered by groundwater withdrawal.

ACKNOWLEDGMENT: The author is grateful for reviews of the original draft by Robert O. Castle, Joseph F. Poland, and Robert F. Yerkes.

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STATE TRUST LANDS — 1979–1980

The State of Arizona, through the Arizona State Land Department, administers the "state trust lands" which amount to 13% of the total lands that make up the state. Income generated by the state trust lands goes to the common schools and 14 other beneficiaries. In fiscal year 1979–1980 (July 1, 1979 to June 30, 1980) $24,549,917 was generated, representing an increase of 25% over the preceding year. Income is produced from state trust lands by leasing, issuing permits and by selling minerals, land and timber, in addition to other activities.

Most of the state lands were under lease during 1979 and 1980. Because the Land Department employs multiple-use practices, some lands were covered by more than one type of lease. In fact, there were 13, 617 active leases in 1979–1980, totaling 17,164,604 acres. The total amount of state trust land is almost 9,582,000 acres. Leases are granted for "minerals," "common mineral materials," oil and gas, geothermal, agriculture, commerce and grazing. Prospecting permits and special use permits are also granted by the Land Department. "Mineral" leases are for metals, such as copper, gold, uranium, etc., whereas "common mineral materials" (also known as industrial minerals) are for sand and gravel, decomposed granite and building stone, etc. "Common mineral materials" are sold by the Land Department at public auction with the highest bidder receiving the right to extract the materials.

Revenues from state trust lands that were generated by mineral resources or related activities made up almost half of the total. Copper contributed the largest amount, as can be seen from the summary below:

MINERAL-RELATED INCOME	
Royalties from copper leases	$7,995,000
Royalties from other mineral leases	111,926
Royalties from common mineral materials	954,893
Oil and gas leases	1,822,144
Mineral leases and prospecting permits	288,597
Geothermal leases	61,567
Rentals on mineral leases	31,892
Total	$11,266,019

OTHER INCOME	
Agriculture leases	$2,664,962
Grazing leases	1,244,578
Rights-of-way	1,100,930
Commercial leases	1,019,330
Land sales (principal)	4,776,553
Land sales (interest)	1,039,899
Other	1,437,646
Total	$13,283,898

STATE TRUST LANDS GRAND TOTAL $24,549,917

The above information was summarized from the State Land Department's 1979–1980 Annual Report. Additional information may be obtained from the Land Department, 1624 West Adams St., Phoenix, AZ 85007.

Geology Along the Lower Salt River

The Bureau has contracted with Water and Power Resources Service (WPRS, formerly the Bureau of Reclamation) to produce a strip geological map at a scale of 1:24,000 along the Salt River from Roosevelt Dam downstream to just below Granite Reef Dam. The project falls under WPRS' safety of dams program, and is designed to provide basic lithologic and structural data for a mile-wide strip on both sides of the river, to assist in first-order planning procedures for WPRS-related projects on the river. The upstream two-thirds of the project is complete with the final report in preparation, while work on the downstream one-third was under way in February 1981.

Fieldnotes

Vol. 11, No. 1 March 1981

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The Overthrust Belt: Will it double U.S. gas reserves?

J. H. C.

MAR 1 1 1980

Philip F. Anschutz, President, The Anschutz Corp., Denver, Colo.

20-second summary

Some 200+ tcf of gas could be proved by the year 2000 if exploration activities are expanded to test the limits of the western U.S. Overthrust Belt, currently the nation's largest onshore gas play. Recent geologic and seismic data indicate the trend may extend from Alaska down into Mexico, far beyond the play's limits to date. This article discusses basis for this optimistic projection and well-by-well events leading up to present Overthrust activity within Wyoming and Utah.

IN RECENT YEARS, a great deal has been said and written about the Overthrust Belt—currently the nation's hottest onshore exploration play. The Overthrust Belt traces a sinuous path from Alaska down into Mexico, and at its maximum reaches a width of about 200 miles (Fig.1). However, not everyone in the industry agrees with the trend and interpretation as presented here, especially the segment south of central Utah. Many geologists feel the play effectively ends there—a conclusion The Anschutz Corp. does not agree with. The concepts and thinking that led Anschutz to project an extension of the Thrust Belt province into Nevada, Arizona and New Mexico will be discussed in detail.

Discovery

Despite active exploration and development in the Alberta foothills dating back to 1924, when an overthrust structure was found productive in Canada's giant Turner Valley field, exploration efforts in the U.S. segment of the trend were essentially unrewarding until the mid-1970s. The area was considered to have too long and complicated a history of deformation, uplift and erosion to harbor major oil and gas reserves, and prediction of subsurface structures was nearly impossible with then-existing seismic techniques. Reflecting these concerns, as late as 1970, an AAPG report on the remaining U.S. resource base for conventional hydrocarbons concluded that the Overthrust Belt had only "fair-to-poor" prospects of becoming a significant petroleum province.

While several thrust-related oil and gas discoveries were made in the 1950s and 1960s along the western edge of the LaBarge Platform in western Wyoming, the event that is generally credited with igniting the U.S. Overthrust Belt play was American Quasar's early 1975 discovery of the Pineview oil field in northeast Utah. A second discovery was reported shortly thereafter (early 1976) by Amoco Production Co. at Ryckman Creek, some 40 miles to the north in southwestern Wyoming. Ryckman Creek established that Pineview was not an isolated occurrence and fueled speculation that similar geologic conditions could extend over a wide area.

Following five years of intensive exploration and drilling activity, the Overthrust Belt has yielded a total

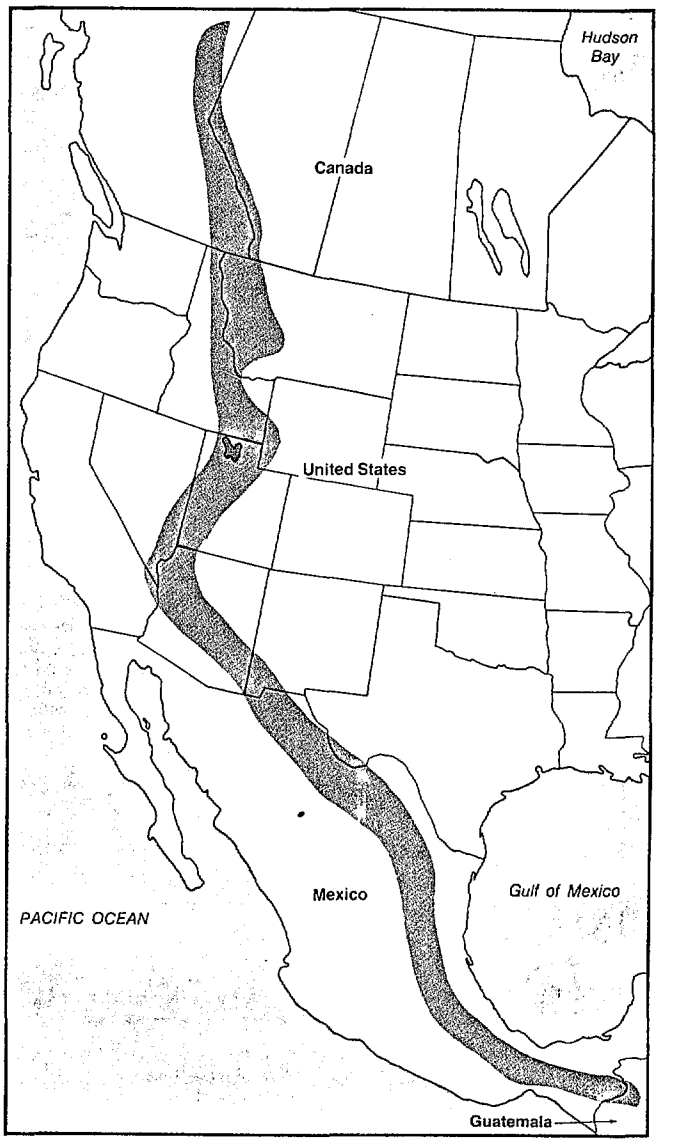

Fig. 1—In recent years, drilling activity has been mainly limited to the southwest Wyoming-northeast Utah portions of the western U.S. Overthrust Belt play; however, geologic and seismic data now indicate the trend may extend some 2,200 miles from Alaska down into Mexico with a maximum width of 200 miles.

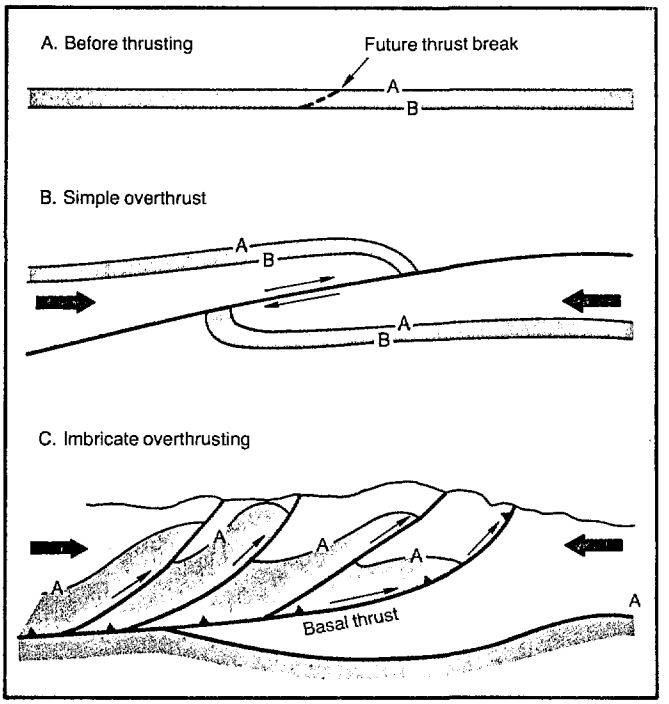

Fig. 2—The theory of plate tectonics is the most common explanation for the sequence of events illustrated here, which in turn depicts the origin of the western U.S. Overthrust Belt. At its maximum about 65 miles of horizontal, sediment shortening occurred in the Wyoming-Utah Thrust Belt segment as a result of the events interpreted in Stage C.

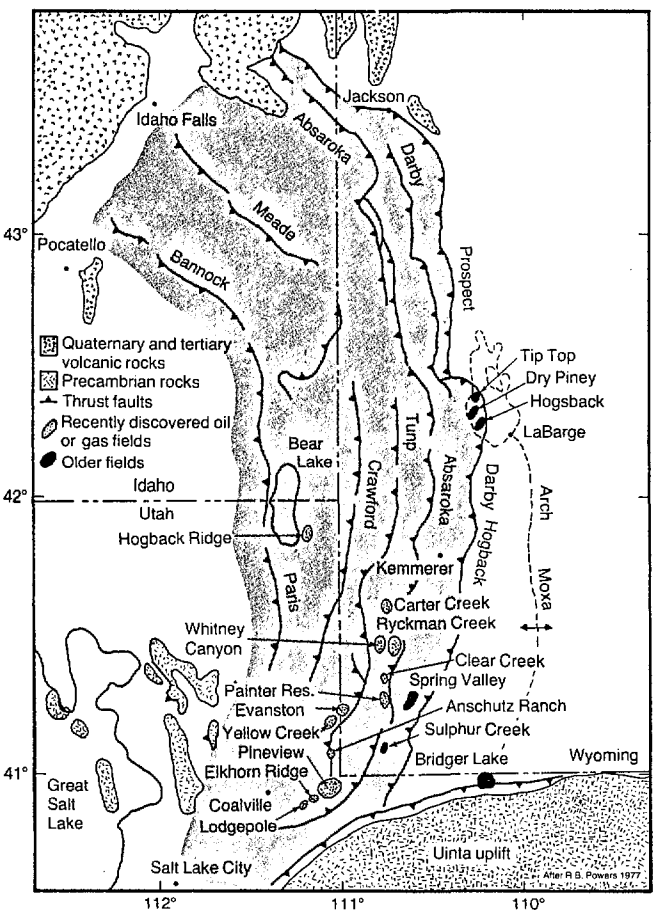

Fig. 3—The major thrust fault systems and major oil and gas discoveries within the currently explored limits of the western U.S. Overthrust Belt are depicted. Complex mechanics of the thrust faulting and consequent sediment deformation are the key to the generation, migration and entrapment of reserves throughout the play.

of 12 commercial fields. Because many of these fields are still in their early stages of evaluation and gas plants and pipe lines are lacking to process and transport the large quantities of natural gas that have been found, Overthrust Belt production is still rather modest; it recently amounted to about 21,000 bpd of oil and 55 MMcfd of gas. Natural gas output will build to a significant level—perhaps 800 MMcfd—by the early 1980s as new gas plant and pipe line capacity becomes available.

Why did it take the Overthrust Belt so long to emerge as a frontier exploration province? Aside from the old axiom that oil and gas must first be found in the minds of men, three reasons can be enumerated:

- Economics—improved oil and gas prices have provided the requisite incentive to explore.
- Improved seismic technology and development of high speed computer data processing capabilities has given the industry a reliable exploration tool.
- Confirmation that large reserves could exist in such a deformed area has fostered new exploration ideas and the allure with which to pursue them.

Geology

The Overthrust Belt is not a new geologic concept; it began 55 years ago in Canada. What is new, however, is the fact that it is productive in the U.S. (revoking a lot of erroneous and pre-conceived notions to the contrary), and capable of trapping major oil and gas fields. The Overthrust Belt is destined to become the nation's most important new gas supply province of the past 20-30 years, especially if the current, rather confined, limits of the play can eventually be extended border-to-border by future drilling.

The Overthrust-Hingeline province is part of a vast system known as the Cordilleran orogenic belt. This complex of mountain ranges and basins extends all the way from Alaska to South America and is bordered by the Pacific Ocean and the Great Plains. Geologists theorize that the Cordillera evolved from thick, mainly marine sediments deposited in an oceanic trough (designated the Cordilleran geosyncline) that persisted during late Precambrian to middle Mesozoic geologic time on the western margin of the ancestral North American continent. Thereafter, a series of orogenic episodes uplifted, compressed, and extensively deformed the rocks along the east edge of the geosyncline, giving the Overthrust-Hingeline province in the continental U.S. its present structural configuration.

The terms Overthrust Belt and Hingeline, though often used interchangeably, actually refer to very different geologic phenomena. The Hingeline represents a former stable shelf or transition zone on the eastern edge of the Cordilleran geosyncline, equivalent to today's continental shelf. The Overthrust Belt, on the other hand, takes its name from the violent stresses in the earth associated with the tectonic movements that formed it.

Although the Overthrust Belt and the Hingeline are actually contiguous in some places, the Wyoming-Utah-Idaho Overthrust Belt is usually defined geographically as the area between the Snake River Plain in north-central Idaho and the Uinta Mountains in northern Utah.

The northern portion of the Thrust Belt re-emerges as the so-called Disturbed Belt (a Canadian term used interchangeably with Overthrust Belt) in southwestern Montana and continues north-northwest up into the Alberta foothills.

South of the Uintas, the Hingeline follows an arcuate path through south-central Utah and back over into the Las Vegas, Nev., area. Thrusting was not as widespread in this part of the trend; consequently, one is more likely to find a near "normal" layered sequence of sediments here.

Plate tectonics (continental separation and movement) is the most common explanation for the occurrence of thrusting. A rift or pull-apart zone began to develop along the western margin of the ancient North American continent in early Jurassic time as the Pacific and North American plates began to separate. This rift and separation, if it had been allowed to continue, would likely have caused the west coast of the current North American continent to become a separate continent. However, the rift turned out to be short-lived as the North American plate began to converge and ultimately collided with the Pacific plate. This tectonic activity resulted in a period of compressional (horizontally directed) deformation in which massive sheets of rock were folded, faulted and transported to the east in an overlapping fashion analogous to the shingles on a house. The total horizontal shortening across the Thrust Belt amounted to about 65 miles, or about 50% of the original sedimentary section. (The sequence of events previously described is illustrated in Fig. 2).

At least six major, west-dipping, low-angle thrust fault systems have been identified in the Overthrust Belt. The mechanics of this process and its attendant deformation have played a key role in hydrocarbon generation, migration and trap formation. The optimum conditions for oil and gas to accumulate in the Overthrust Belt appear to be where Mesozoic and Paleozoic reservoir rocks were folded and thrust and brought into direct communication with in-place organic-rich Cretaceous source beds in the subthrust.

While this is one of the most difficult and costly environments that exists in which to explore for oil and gas, Anschutz Corp. firmly believes that the potential reward offered to the successful explorer warrants such a high risk effort.

Drilling activity

In Fig. 3 the positioning of the major thrust fault systems in Wyoming, Utah and Idaho is depicted. Within this area, more than 40 drilling rigs are currently at work on exploration or development objectives. Note the cluster of oil and gas fields found since 1975 in northeast Utah and the extreme southwest corner of Wyoming. Very large pay intervals are being defined. Discoveries have been made that contain a water-free hydrocarbon column up to 5,000 feet thick—a figure usually reserved for fields in the Middle East.

It is particularly noteworthy that of the 15 giant fields (by AAPG definition, a giant field has recoverable reserves of 300 bcf of gas or 50 million barrels of oil) Anschutz Corp. estimates have been found onshore in the U.S. since 1970, five are located in the Overthrust Belt. These are the kind of discoveries and the large reserve

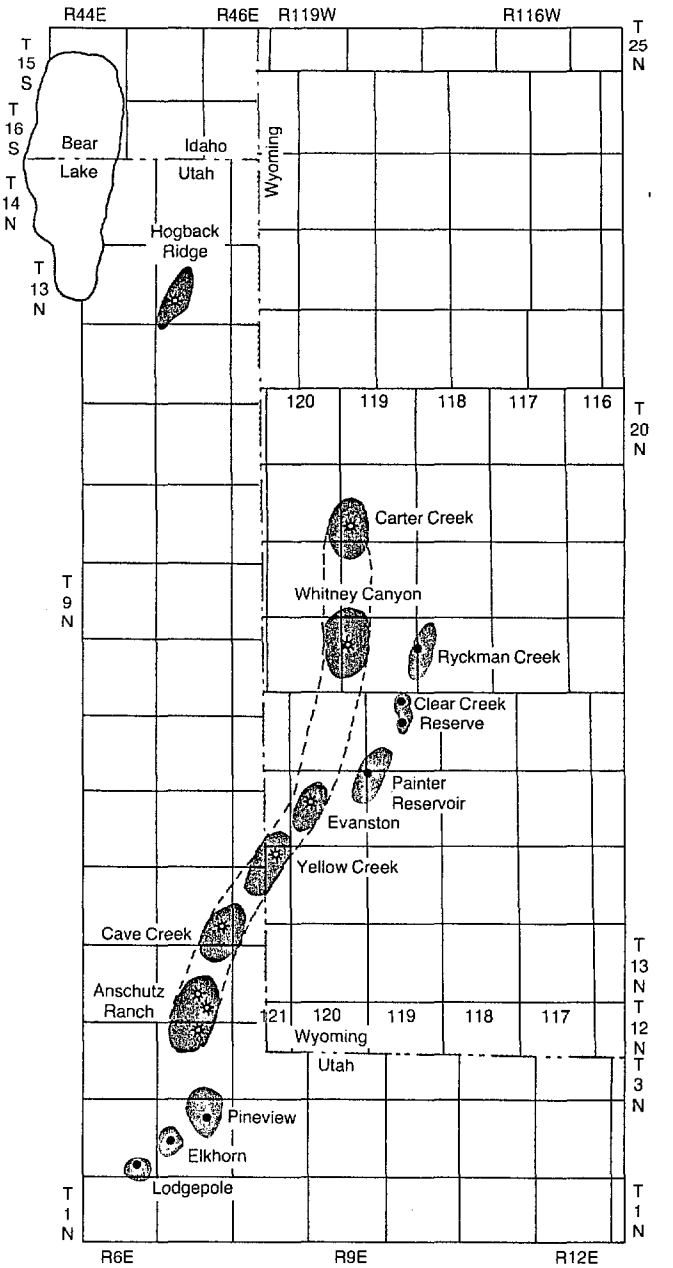

Fig. 4—Current Thrust Belt oil and gas discoveries are illustrated. The tendency for the discoveries to line up along the northeast-southwest strike of the fault planes (depicted in Fig. 3) can be seen. The possibility therefore arises that several of the fields may eventually be found to link up into several massive, producing reservoirs (see "Overthrust Predictions").

potential frontier exploration plays that must be developed in this country if the U.S. is to have any hope of stabilizing its long-term downtrend in oil and gas reserves that commenced in the early 1970s.

Field development

Success to date in the Overthrust has been limited to a small 50-mile portion of the 2,200-mile-long belt that stretches from Canada to Mexico. Fig. 4 locates the current Thrust Belt discoveries. With the exception of the Hogback Ridge field in northern Utah, which produces from the older Crawford thrust, the Overthrust Belt fields occur in anticlinal (hanging wall) closures on the

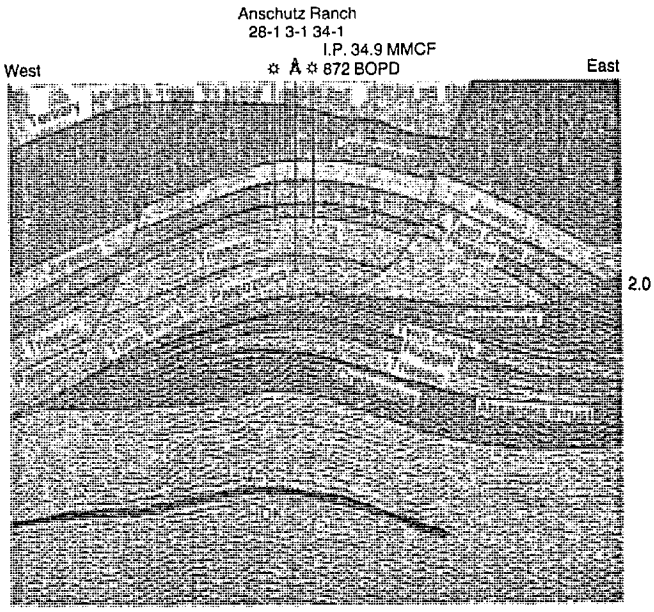

Fig. 5—This seismic time cross-section, taken through the Anschutz Ranch field, North Pineview area, depicts the complex thrust-type geology found along the Overthrust Belt. The Anschutz Ranch play began as a shallow gas find, but tests of the deeper zones are currently underway.

folded leading edges of the Absaroka or Tunp thrusts. Note the tendency of the fields to line up along the regional northeast-southwest axis (strike) of the fault planes. This gives rise to a fairway concept or a situation in which a number of structurally high areas may be located and found productive in the same thrust sheet over a great distance.

The **Pineview** field (Fig. 4) discovery well was completed in January 1975 from the Jurassic Nugget sandstone. In September 1975, a second pay zone, the Jurassic Twin Creek limestone, which overlies the Nugget, was added. The combined gross pay thickness of the Nugget and Twin Creek formations near the crest of the structure approximates 1,600 feet. Subsequent Pineview development also has established shallower pays in the Jurassic Stump and Cretaceous Kelvin formations. The field is still being developed.

The **Ryckman Creek** (Fig. 4) discovery well was completed in September 1976 with 515 net feet of oil and gas pay in the Nugget. This 40-mile stepout to Pineview confirmed that similar geologic conditions existed in the Wyoming Overthrust segment.

The next development of note was the **Yellow Creek** discovery in July 1976. The field pay here is the Twin Creek. Yellow Creek has the largest **confirmed** areal extent of any field thus far.

The important **Whitney Canyon** discovery was first announced in August 1977. Because of mechanical problems, the initial well on the structure was completed in an upper zone for a small quantity of Triassic Thaynes gas. The indicated deeper potential at Whitney Canyon was confirmed in July 1978. Amoco's follow-up well 1/2 mile to the northeast penetrated a 4,500-foot-thick column that was gas effective from the Triassic all the way down through the Cambro-Ordovician (Big Horn) zone.

Chevron's **Carter Creek** discovery, 9-miles north of Whitney Canyon, was another important deep discovery in 1978. In terms of structural size and thickness of pay, however, the Whitney Canyon deep discovery added an entirely new dimension to Overthrust Belt exploration. Most of the early finds such as Pineview and Ryckman Creek were made in Jurassic reservoirs with one or two pays in the contorted upper plate of a Mesozoic fold trend. Though possessing sizeable reserves by U.S standards, the productive area tended to be rather narrow and restricted. Whitney Canyon, on the other hand, confirmed industry thinking that the "mother lode" in the Thrust Belt would be found in the older Paleozoic rocks on the deeper, thicker and broader folds. The ability to stack production from a number of different zones over many thousands of feet on a large structural feature can mean giant reserves.

Another important discovery fairway taking shape in the Paleozoic fold trend is represented by **Anschutz Ranch-Cave Creek-Yellow Creek.** Fig. 5 is a seismic cross-section through the Anschutz Ranch. This 18-mile-long area began as a shallow Twin Creek gas play, but has assumed added importance in the light of events at Whitney Canyon/Carter Creek and Amoco's apparent multi-pay deep gas discovery at Cave Creek. A lot more will be known about the gas reserves present in the deeper horizons following the completion of Amoco's testing program on their Cave Creek well and deep tests at Anschutz Ranch (drilling at presstime) and Yellow Creek (planned to spud by end of 1979). If the Anschutz Ranch 34-2 well reaches its target depth of 19,000 feet, it will rank as the deepest hole drilled to date in the Overthrust Belt.

Moving away from the currently productive part of the trend, drilling activity is picking up as the search for hydrocarbons fans out geographically. As such, it is probably only a matter of time before someone brings in a remote discovery that results in a significant extension to the known limits of the play.

Current programs. Highlighting some of the more notable exploratory programs now underway: Amoco and Rainbow Resources, in separate ventures, are drilling rank wildcats in southwestern Montana's Disturbed Belt; Supron, Ladd, American Quasar, Phillips and Cities Service are active on exploratory locations in central Idaho, hoping to find the state's first commercial field, and several other companies are at work in northern Wyoming.

A sleeper in the Overthrust-Hingeline province is the central Utah area south of the Wasatch and Uinta mountains. All the necessary geologic ingredients exist here for enormous discoveries to be made. Mobil, Amoco, Exxon, Chevron and Placid Oil, the latter running a three-rig program on farm-out acreage, are the only companies currently active, but there are indications that another 10-15 wildcats will be spudded in the area within the next year.

In Clark County, Nevada, northeast of Las Vegas, Mobil is drilling an exploratory test scheduled to go to 17,500 feet. It is a badly needed, deep wildcat in a region that has previously seen nothing comparable in the Thrust Belt.

Anschutz Corp., in partnership with Peoples Gas Co., has projected the Overthrust-Hingeline play into southern Utah, Nevada, Arizona and New Mexico. This area has been traditionally classified as part of the Basin and Range province. However, based on geological studies of the area and an extensive seismic program, evidence

was found of some deep troughs that are locally covered by multiple thrust plates similar to other parts of the trend. As the far-reaching implications of these findings became apparent, the two companies embarked on an aggressive leasing effort.

Detailed seismic shooting on preliminary leads has revealed the presence of some extremely large structures. Barring any unforeseen delays, Anschutz and Peoples had scheduled to spud a 16,000 to 20,000-foot exploratory hole in early 1980.

Under the more broad interpretation, the Arizona Overthrust-Hingeline is basically a continuation of a trend coming up from Mexico. Pemex, the state-owned oil company, has made a number of major, largely unpublicized, finds in Mexico's overthrust trend. Immediately west of the old Veracruz fields, oil has been produced from overthrust structures. Further to the north, near the U.S. border, Pemex admits having proven up 6-10 tcf of gas in the Monclova area of the Sabinas basin. Some 65 undrilled structures remain to be evaluated. According to Pemex, 33 of these prospects are at least 18 miles long with thick sedimentary sections. As to what all this means for Arizona, an appreciation of its reserve potential must perforce take into account developments south of the border, given the strong geologic analog that Mexico represents.

Reserves. Within the area under discussion, Anschutz Corp. estimates industry has found indicated reserves of about 300 million barrels of oil and 6 tcf of gas—all this along a general trend that had 500 dry holes drilled in it between the time of the early Canadian discoveries and Pineview. The primary exploration emphasis today is on the deeper pay horizons.

The real romance in the Overthrust Belt is the number and thickness of possible pay zones. So far, 11 different formations have been established as commercially productive, ranging in depth from 2,800 feet in the Cretaceous at Pineview to below 15,000 feet at Whitney Canyon. Encouraging though non-commercial gas shows have also been recorded at even greater depths in several of the deep tests that have penetrated Cretaceous sands in the subthrust. The presence of so much prospective sediment, amid a multiplicity of trapping mechanisms, is really what differentiates the Thrust Belt from the more traditional onshore plays.

OVERTHRUST PREDICTIONS

► Whitney Canyon and Carter Creek discoveries will eventually linkup, forming a giant gas field about 15 miles long and at least 4 miles wide, with recoverable gas reserves of 5-10 tcf. Whitney Canyon/Carter Creek is easily the largest field uncovered in the Overthrust Belt to date; in fact, it will probably rank as the most significant U.S. discovery since Prudhoe Bay. Likewise, Anschutz Ranch, Cave Creek and Yellow Creek, all of which are prospective in the Paleozoics, will merge into another giant gas accumulation. It is then conceivable that the entire Paleozoic fold trend running from Carter Creek to Anschutz Ranch, a distance of about 40 miles, could be connected into a single super-giant gas field with 20-30 tcf of recoverable gas reserves. Wells along this trend will produce from Jurassic through Paleozoic, but the largest reserves will come from older rocks.

► The Overthrust Belt geologic environment will extend from northeast Utah/southwest Wyoming up into Idaho and Montana, eventually connecting with the foothills trend in Alberta. Many new fields will be uncovered in the northern half of the belt, an area whose ultimate gas reserve potential could exceed 100 tcf.

► Overthrust Belt type exploration opportunities will extend much further to the south than currently believed—probably into the Caribbean Sea somewhere between Mexico, Belize and Guatemala. Further, the overthrust geology that has resulted in Mexican discoveries west of Veracruz and in the Monclova area will trend up into New Mexico and Arizona. Also including parts of Utah and Nevada, this southern extension of the U.S. Overthrust Belt could hold gas reserves rivaling those in the established northern half—about 100 tcf.

► The gas Mexico is developing in their overthrust play, so close to the U.S. southern border, will find markets in the U.S. While it has received almost no publicity outside of selected petroleum publications, it should be kept in mind that the large (6-10 tcf) Monclova gas reserves (and the area's unexplored potential) are only about 325 miles southeast of El Paso, Texas.

► Successful exploration along the full length of the Overthrust Belt will spawn a variety of new pipe line systems. In fact, all of the various Rocky Mountain area pipe line developments could lend impetus to several interesting possibilities involving link-ups with Canadian and Alaskan gas supplies moving into the U.S. And in the southern Overthrust Belt, gas discoveries could use existing pipe line systems in West Texas and New Mexico, these same systems being the logical outlets for Mexican overthrust gas as well.

Development obstacles

Companies operating in the Overthrust Belt are confronted by a seemingly endless list of obstacles, all of which, to the detriment of the final consumer, tend to inhibit the pace of exploration, development and marketing. These restrictions include remote and inaccessible terrain and related seismic data acquisition difficulties; the cost and delays associated with deep drilling in a complex geologic environment; the necessity to conform to numerous, and at times ridiculous, environmental rules and regulations and public land policies, and the lack of readily accessible markets for product.

Seismic. While the single biggest technical breakthrough to aid Overthrust Belt exploration involves seismic technology, in particular the development of more sophisticated data acquisition and computer processing techniques, a primary inhibiting factor has been cost of seismic. In many parts of the U.S., $3,000 per line-mile for seismic is a reasonable figure. In the mountainous areas of the Thrust Belt, a figure of $25,000 per line-mile is not unusual, without counting the formidable winters that can double or triple costs per mile.

Drilling. The Overthrust Belt is a deep drilling frontier (wells have been taken below 18,000 feet); for this reason, highly toxic and corrosive hydrogen sulfide must often be dealt with. The presence of salt and the complex geometry of the rock layers that must be penetrated are other factors that can impede drilling. Sur-

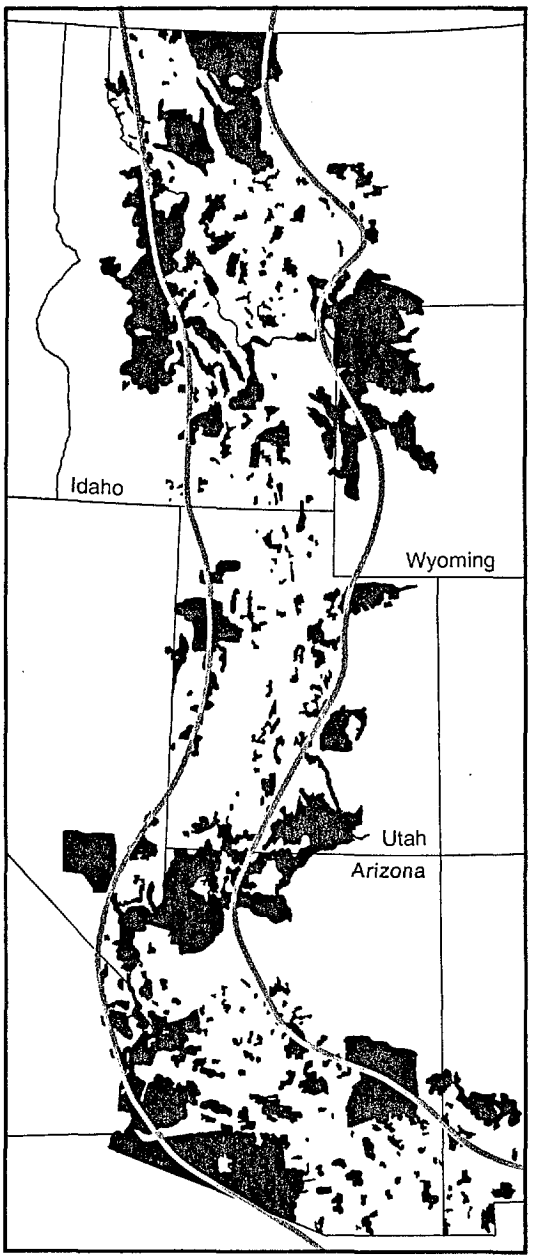

Fig. 6—The various federal and state land withdrawals currently finalized or under study are indicated throughout the U.S. portion of the western Overthrust play. Such actions are critically jeopardizing the U.S. effort to increase domestic exploration and production in order to reduce dependence on foreign oil and gas supplies.

face locations are usually remote and costly to build, and cold weather, ice and snow in the winter frequently cause drilling delays and added expense.

For example, costs to date on a wildcat location south of Jackson Hole, Wyo., include $500,000 for roads and location and $8 million for the well itself. A 16,000-foot subthrust test can easily require 180-270 days to drill and complete.

Environmental. At a time when the country faces a critical need for indigenous forms of energy to reduce our ballooning balance of payments deficit and to lessen our vulnerability to capricious actions by suppliers of imported oil, it is a sad commentary indeed that federal and state land withdrawals and restrictions are severely limiting exploration activity (Fig. 6). Allotted space does not permit a listing of all the environmental laws and regulations operators must contend with, some of which have virtually eliminated vast areas from lease acquisition and exploration. Even where drilling is permitted on federal land, an oil company must struggle through some 132 separate steps and obtain as many as 136 individual permits.

Marketing. A final obstacle that could retard Overthrust Belt development is the lack of pipe lines to move the gas to large consuming areas. The market problem can cause long delays in realizing cash flow, delays which can impact heavily on smaller operators.

In the Overthrust producing area, as now defined, the existing lines and markets are clogged with excess gas. As a result, most of the producing capacity is not as yet hooked up. In the Overthrust, an operator can be half a state away from a connection in some cases.

One step in the right direction, however, is the proposed 842-mile Trailblazer Pipeline sponsored in part by Peoples Gas. This interstate system is designed to initially deliver 350 MMcfgd on its easternmost leg. With timely FERC approval, construction could begin in 1980.

Another major pipe line project involves Pacific Gas Transmission's proposed 800-mile, $500-million system. This line would extend from western Wyoming down through Utah and Arizona to an eventual southern California terminus with an existing Pacific Gas & Electric line. Initial thruput of 300 MMcfgd is planned.

Although much of the Overthrust gas is relatively dry, Mapco is discussing an $80-million natural gas liquids (NGL) line that would connect future Overthrust gas plants to the company's existing Four Corners system.

Other gas companies active in the Overthrust Belt with existing systems include Northwest Pipeline, Mountain Fuel Supply and Colorado Interstate Gas Co. And a number of outside gas companies hold or are presently seeking an Overthrust position, including Columbia Gas System, Northern Natural, Cities Service and El Paso.

What is now taking shape is competition to see who will ultimately succeed in anchoring major new systems out of this highly prospective area, and the markets into which this gas supply will flow. The future of the traditional gas supply business may not be in the East or Gulf Coast; instead, it may be shifting to the West.

A look ahead

The Overthrust Belt play is big. Even if it fails to reach the lofty potential suggested here, it will still be one of the most significant developments affecting the domestic oil and gas industry in several decades. A recent study by the Potential Gas Committee estimated that 100 tcfg could be found by future exploration and drilling in the Wyoming-Utah-Idaho-Montana segment of the Overthrust Belt alone. Extending such projections to include the larger view of the Overthrust Belt, some 200+ tcf of gas could possibly be found by the year 2000 (not a Potential Gas Committee estimate), which is equivalent to total U.S. proven reserves at year-end 1978. However, whether 100 tcf or 200 tcf proves correct, either figure indicates a major U.S. play and new energy supplies that U.S. consumers cannot afford to let slip by. ■