Central Utah Thrust Belt:

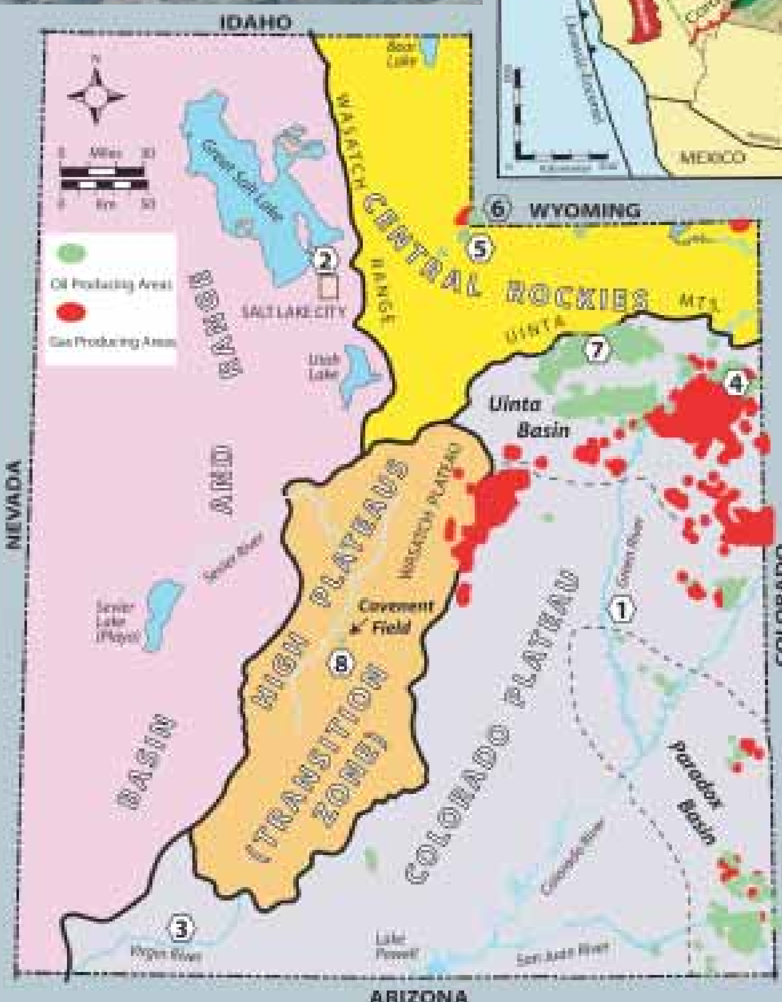
Tectonics of a New Exploration Province

The Middle-Jurassic Arapien Shale in central Utah as major cap rock for petroleum traps.

The recent discovery and development of the Covenant oil field by Wolverine Oil & Gas Corporation in the Central Utah fold-and-thrust belt opens a new exploration province in North America, and gives new impetus for research on the geologic structure and evolution of the area.

Photo: Halfdan Carstens

The Sevier orogenic belt formed as a retro-arc, fold-and-thrust belt from Late Jurassic-Eocene. The basins in Alberta (Northern Rockies, Canada) and western Wyoming (Middle Rockies, USA) are classic petroleum provinces. Central Utah has recently joined its petroliferous sister basins.



Geologic divisions of Utah showing the distribution of producing oil and gas fields, and the location of the recently discovered Covenant field in central Utah. Numbers 1 through 8 are described in the table. The majority of Utah's oil and gas field are concentrated in two large basins – the Uinta basin in northeast, and the Paradox Basin in southeast.

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Utah is divided into four geologic regions:

Central (Middle) Rocky Mountains in northeast which includes a fold-and-thrust belt extended from western Wyoming as well as two mountain ranges – the north-south running Wasatch Range and the east-west running Uinta Mountains.

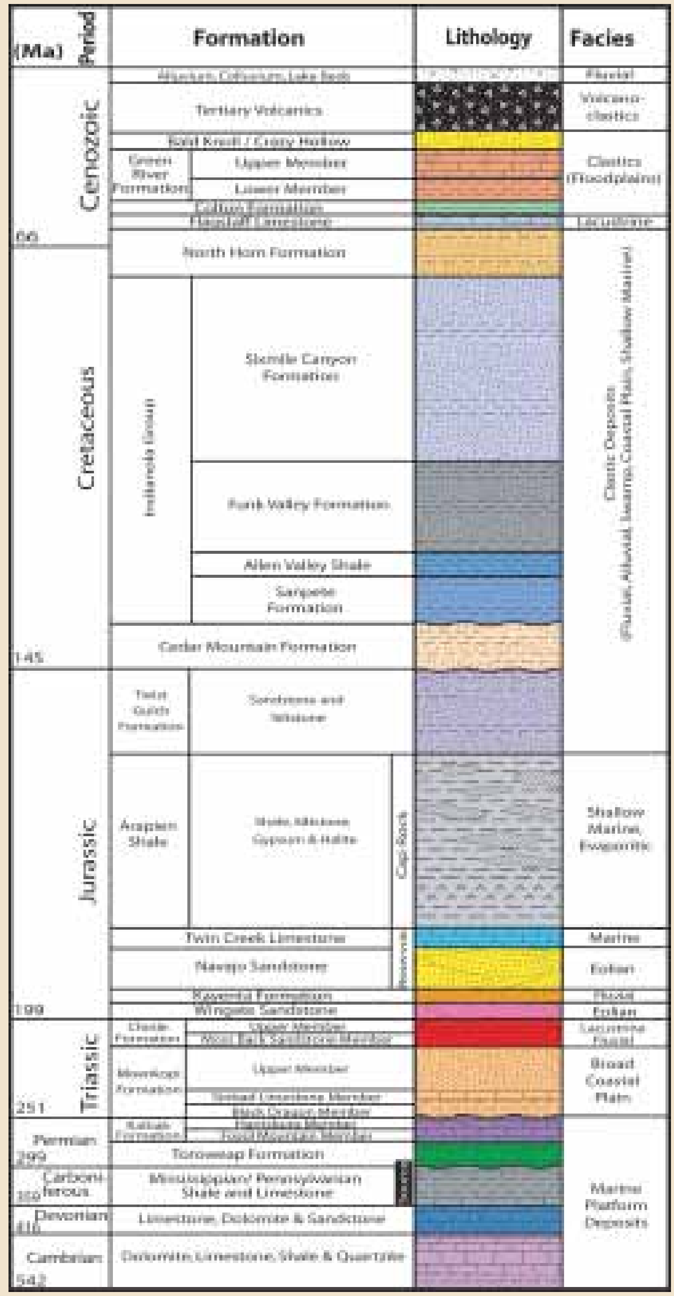
The Colorado Plateau in eastern Utah which also includes parts of Colorado, New Mexico, and Arizona. Several major rivers notably the Green, Colorado, San Juan, and Virgin Rivers have carved out deep and vast canyons on the Colorado Plateau in southeast Utah. This river incision coupled with the arid climate has created a colorful and unique landscape on Earth - the Red Rock Country dominated by red and white sandstones and shales of Mesozoic age. These canyons provide a valuable opportunity for geologists to examine sedimentary formations which are largely buried in central Utah.

The Basin-and-Range which is a vast region of stretched and thinned crust, normal faults, half-grabens, igneous intrusions, and deserts occupying western Utah as well as parts of California, Arizona, Nevada, Oregon, and Idaho. The Basin-and-Range province formed by the extensional tectonic activities during Oligocene to Recent times.

The High Plateaus of Utah which topographically separates the lower Canyonlands on the Colorado Plateau on the east from the Basin-and-Range on the west. Structurally, the High Plateaus are a transition zone from the compressional tectonics of Colorado Plateau to the extensional tectonics of the Basin-and-Range. This Transition Zone includes the Central Utah fold-and-thrust belt which is part of the Cordilleran-Sevier orogenic belt.

The Orogenic Belts

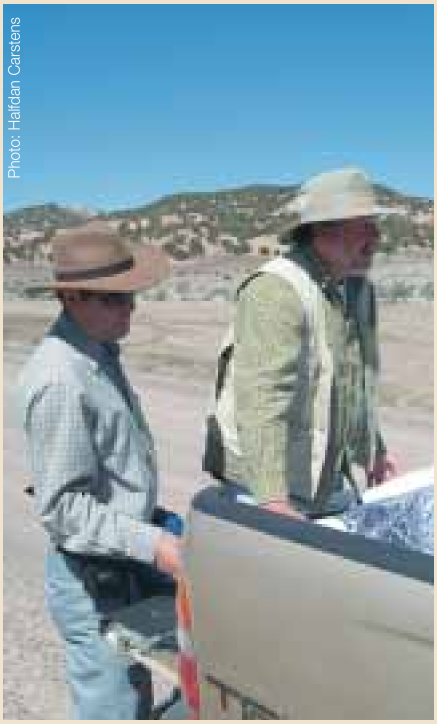
The Cordilleran-Sevier orogenic belt runs from 6,000 kilometers from Canada through western USA (Montana, Wyoming, Utah, and Nevada) down to Mexico. It formed as a result of the subduction of the ancient (now consumed) Kula and Farallon oceanic plates of Pacific side underneath the North American continental plate from the Late Jurassic through the Eocene. Large batholiths (Coast Mountain Batholith, Idaho Batholith, and Sierra Batholith) are



Stratigraphic column for central Utah (modified after Hintze, 1988, Geologic History of Utah).

An outcrop Jurassic Navajo Sandstone displaying cross-bedding structure in Zion National Park, southwest Utah (photo by authors).

An outcrop of fractured Twin Creek limestone (Lower-Middle Jurassic) within a major fold structure (Pigeon Creek, central Utah) (Photo by Authors).



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products of this subduction history and mark the extent of the Cordilleran-Sevier orogenic belt.

The Sevier orogeny should not be confused with the Laramide orogeny which also affected parts of the western U.S.A. The former was older (Late Jurassic-Eocene) thin-skin tectonics; the latter was younger (latest Cretaceous-Eocene) thick-skinned tectonics. Basement uplifts such as the Uinta Mountains and Colorado Plateau are largely products of the Laramide orogeny. Although both Sevier and Laramide orogenies are probably related to the compressional forces of ocean plate subductions, the exact mechanism and timing differentiating these two events has long been a matter of debate among geologists.

The Central Utah fold-and-thrust belt is largely included in the High Plateaus of Utah but also extends to the west comprising both exposed and concealed folds and thrust faults. This overthrust belt is tectonically an extension of the fold-thrust belt in western Wyoming and northeast Utah. Indeed, there are similarities between the Covenant field in central Utah and the Pineview and the Anshutz oil fields in northeast Utah; both produce from the Navajo sandstone and are trapped in thrust folds.

Stratigraphy

A thick succession of sedimentary rocks spanning late Proterozoic to Recent times and of various depositional environments are found in central Utah. Of particular importance for petroleum generation is the Mississippian formations. These sediments were deposited in seas that covered most of Utah at that time, and reached a maximum thickness in the subsiding Oquirrh Basin in northwestern Utah. They primarily consist of organic rich carbonates interbedded with shale layers.

Three significant organic rich Mississippian (Lower Carboniferous) shale beds, which crop out, include the Chiulos Shale Member of the Great Blue Limestone (with a maximum thickness of ~550 m), the Manning Canyon Shale (~600 m) and the Delle Phosphatic Member.

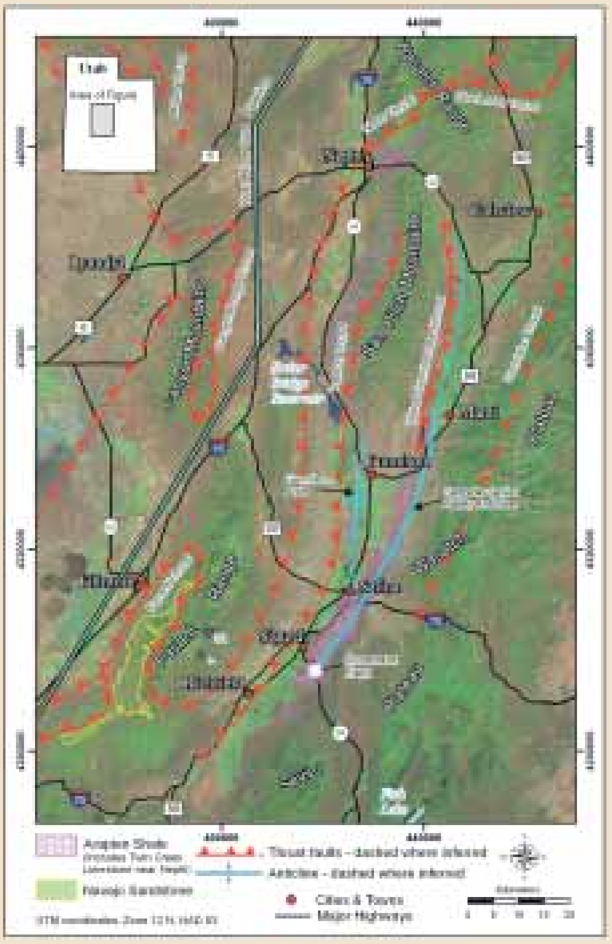
The Colorado Plateau has an abundance of Mesozoic sandstone units that can and sometimes do act as petroleum reservoir rock. Some of these extend westward into the Basin and Range and the Transition Zone, most notably Lower Jurassic Navajo Sandstone, which is desert eolian deposit forming major petroleum reservoirs in Wyoming, and outcropping in the famous natural reserves in southern Utah. This unit is overlain unconformably by Jurassic Twin Creek Limestone, which exhibits strong tectonic fracturing in folded and faulted outcrops. Together, these two units form an excellent column of reservoir rock which may reach a maximum thickness of 800 m in the area.

The Twin Creek Limestone is overlain with Middle-Jurassic Arapien Shale, a marine-evaporitic facies consisting of calcareous shale, with minor calcareous sandstones being found locally (especially at the distal margins), abundant gypsum at shallow levels, and halite (salt rock) at the base.

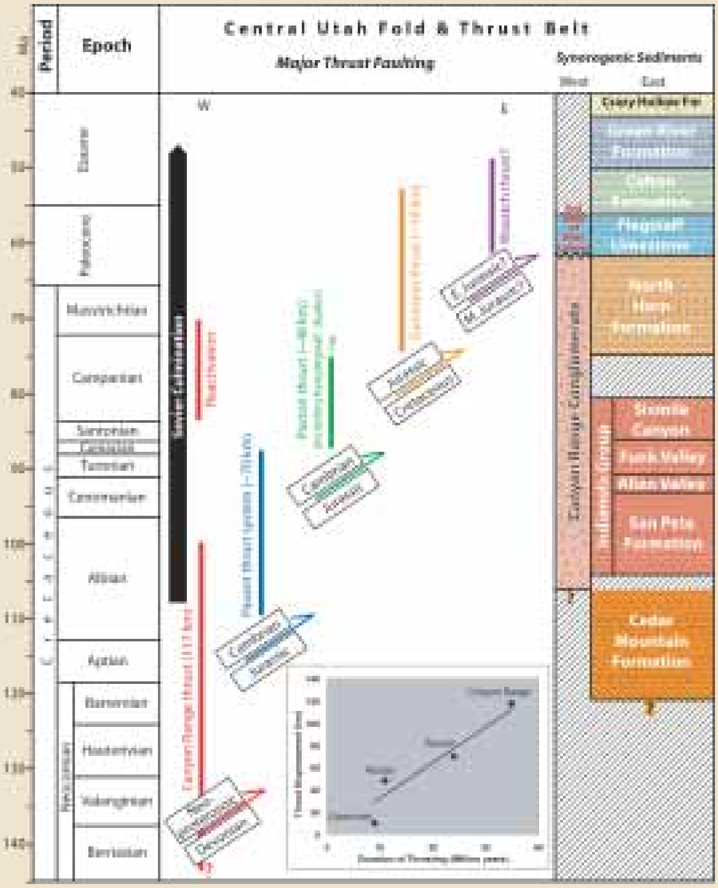
Utah's petroleum exploration and production date back to the late nineteenth century.

No.	Year	Drilling or Discovery
1	1891	First oil well in Utah (Bamberger and Millis Well #1), south of Green River town, ~300 m deep, dry hole
2	1892	Utah's first gas field (Farmington field) discovered
3	1907	First oil field (Virgin field), abandoned in 1970s
4	1948	First commercial production (Equity #1 Well) from an oil field in Uinta Basin
5	1975	Pineview oil field by Amoco Production Co. from Jurassic sandstone reservoir, Absaroka thrust sheet
6	1983	Anshutz Ranch East field by Amoco Utah's most prolific oil and gas field
7	1983	Deepest producing payzone (Brotherson 2-14B4 Well) Altamont field, ~6,242 m feet deep
8	2003	Covenant oil field in the central Utah overthrust belt (17-1 Kings Meadow Ranches Well, ~3,258 m deep)

Numbers refer to locations on the map on page 51.



Thrust faults, major towns, highways, gas pipeline, Covenant field, and outcrops of Navajo and Arapien formations.



A chart for the structural evolution of thrust faults in central Utah including synorogenic clastic deposits shed from the thrust uplifts (data sources: P. DeCelles, 2006, GSA Bulletin, v. 118, pp. 841-846; A. Villien and R.M. Kligford, 1986, AAPG Memoir 64, pp. 281-307.; G. Willis, 1999, Utah Geological Association Publication 27, pp. 1-9.)

Salt diapirism has deformed the Arapien Shale; moreover, salt has also moved along faults and fractures formed during the Sevier orogeny, which were reactivated by mid- to upper-Cenozoic extensional tectonics. The composition of evaporitic minerals and fine-grained mud, coupled with considerable thickness, makes the Arapien Shale an efficient cap rock for petroleum accumulation.

In Central Utah, Arapien Shale crops out along two major linear strips, while the reservoir rocks are buried except for the outcrop of Navaho sandstone in the Pavant Range.

Structural Evolution

The Central Utah fold-and-thrust belt consists of a series of thrust faults which become younger from west to east as deformation migrated in that direction. These thrust faults are described below:

(1) The Canyon Range Thrust (formed during Nocombain-late Albian, ca. 145-110 Ma) is exposed as a klippe (a thrust sheet isolated from the root thrust zone) in the Canyon Range. About 4 km thick rocks of Neoproterozoic-Cambrian lies on the hangingwall while the footwall consist of over 3.5 km thick Neoproterozoic to Devonian rocks. Some authors consider that the Canyon Range Thrust was reactivated during Campanian-Maestrichtian epochs.

(2) The Pavant Thrust system (Late Albian-Coniacian, ca. 110-86 Ma), best exposed in the Pavant Range, displays structural complexity with both hangingwall duplex and footwall imbricate thrust faults. Overall, the Pavant thrust system brings the Cambrian quartzites (Tintic Formation) atop Lower Jurassic Navajo sandstone.

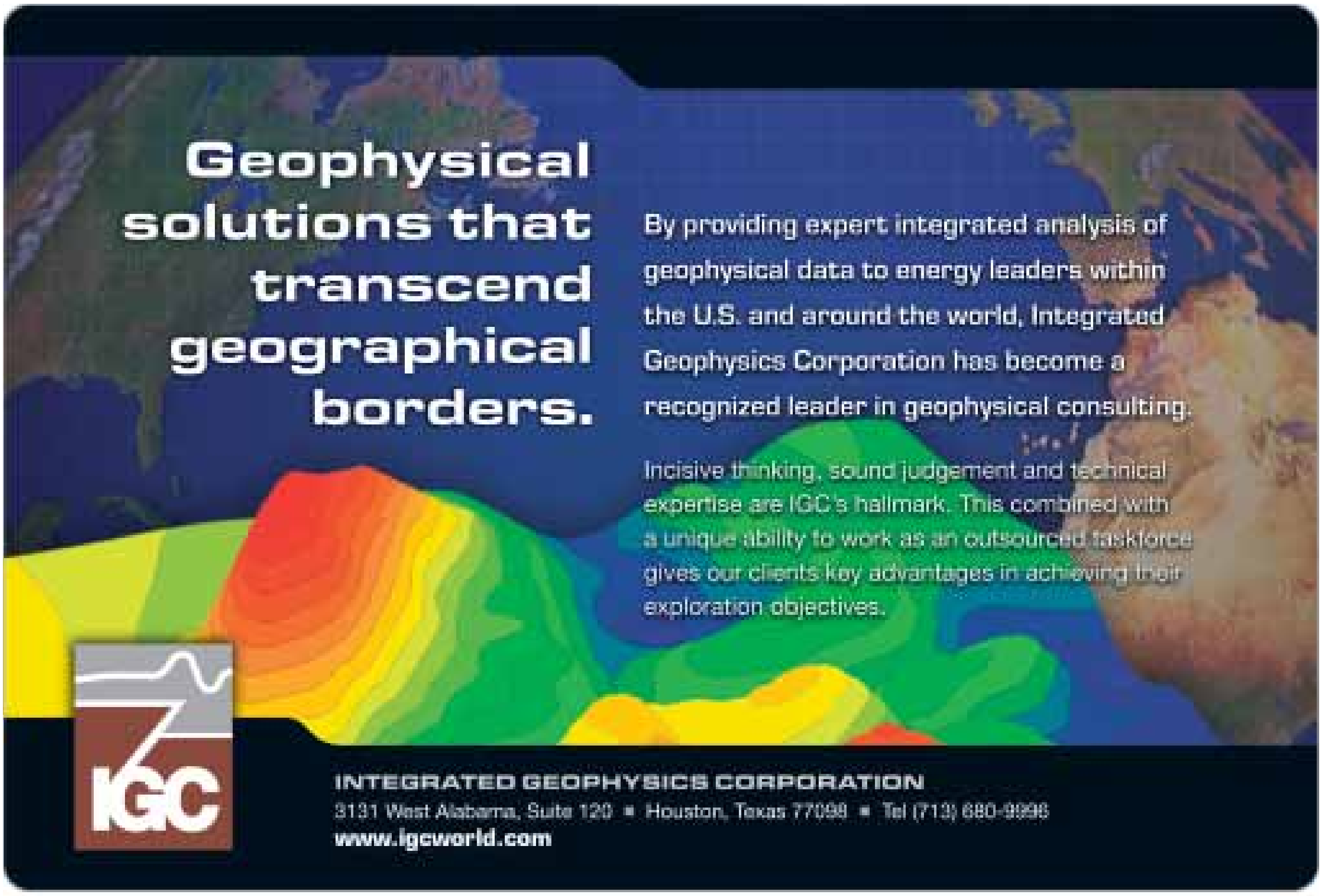
(3) The Paxton Thrust system (Santonian-Early Campanian, ca. 86-75 Ma) is mainly defined from subsurface (seismic and well) data; it is therefore a less known fault. One well (Placid Paxton #1, 1982) penetrating the Paxton thrust found Cambrian rocks faulted over Jurassic formations. Another well (the Amaco Sevier Bridge Well, 1981) discovered hangingwall duplex thrusts with displacements at the Triassic-Middle Jurassic levels.

(4) The Gunnison Thrust (Late Campanian-Maastrichtian, ca. 75-65 Ma) brings Jurassic rocks atop Cretaceous formations. The Covenant field was discovered on the hangingwall of the Gunnison Thrust. Wolverine drilling showed that the Gunnison is a duplex thrust consisting of the main thrust plane and a "back-limb thrust" on the hangingwall so that the Lower Jurassic reservoir rocks (Navajo Sandstone and Twin Creek Limestone) are repeated.

(5) The Wasatch Thrust is not exposed but is hypothesized by some geologists as the easternmost thrust fault in central Utah and beneath the Wasatch Plateau. This thrust possibly formed at 60-50 Ma and has displaced Jurassic formations.

The development of these thrust faults have been constrained from the juxtaposed sedimentary formations on the fault hangingwall and footwall as well as the age of clastic sediments shed from the thrust uplift onto the foreland basin. The stratigraphic data for thrust dating comes from outcrops as well as drilled wells.

Summarizing the thrust evolution of



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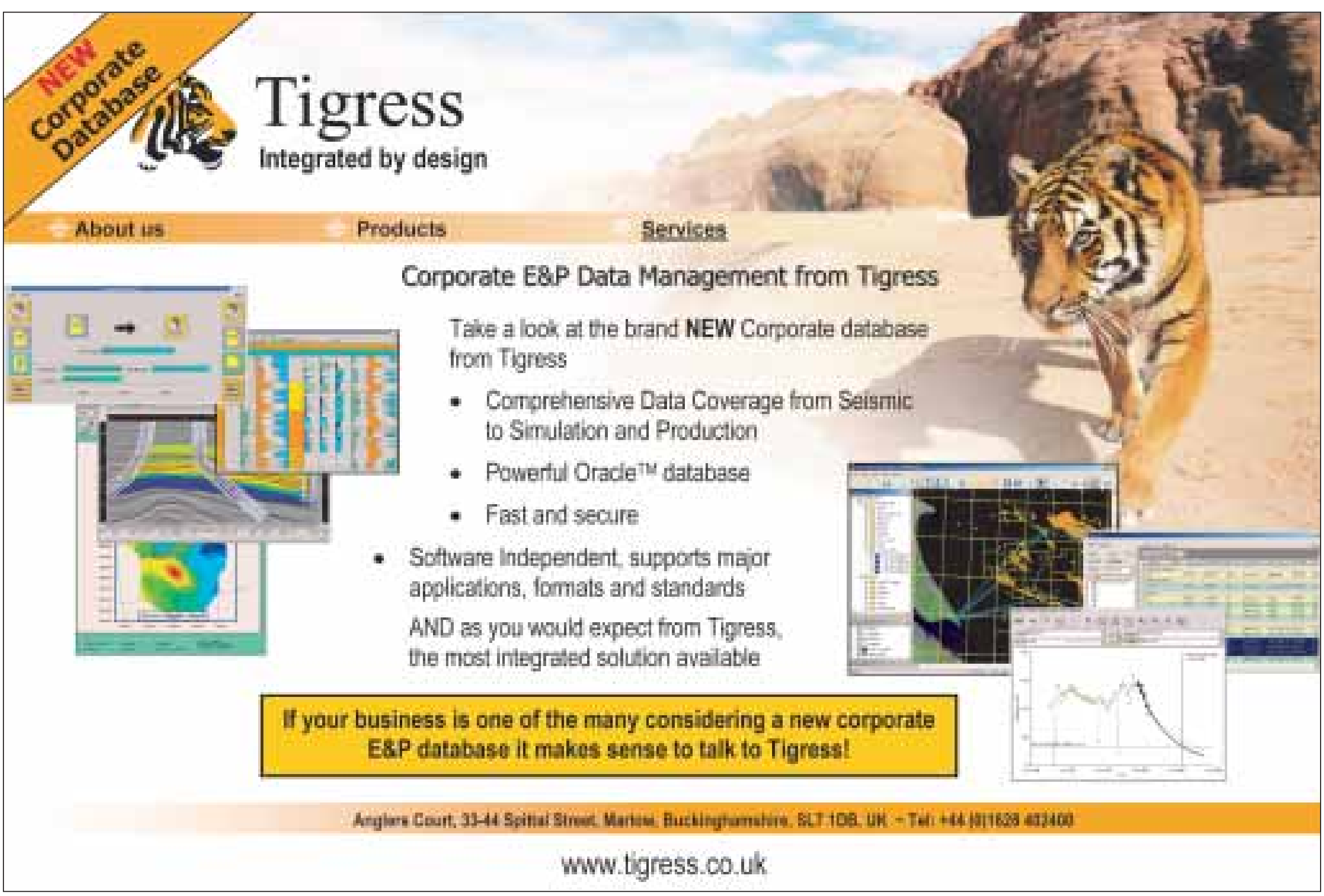

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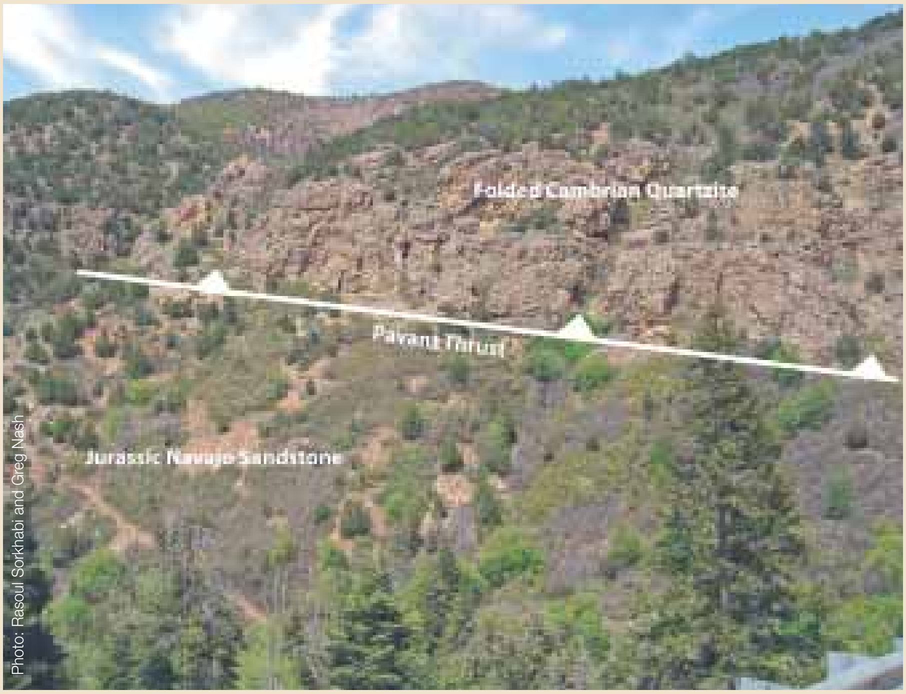

A view of the Pavant thrust fault near the town of Fillmore, central Utah, one of the earliest thrust faults developed during the Sevier orogeny in Utah. The Pavant thrust strikes north-south and dips gently (about 10°) eastward (photo by authors).

central Utah, it seems that as the thrust faults have become younger from west to east, both duration of thrusting and the amount of fault displacement has decreased. Older thrusts have displaced deeper rocks, and as younger thrust developed eastwardly, they displaced younger formations. The Central fold-and-thrust belt is also affected by normal faults during the Basin-and-Range extension.

A New Exploration Focus

According to the U.S. Energy Information Administration, Utah with crude oil proven reserves of 215 million barrels, and with oil production of 40,000 barrels a day, ranked 12th and 13th, respectively, in the United States for onshore production in 2004. In the aftermath of the Covenant field discovery in central Utah, these statistics are already changing. Some geologists estimate that there are one billion barrels of oil hidden in central Utah. Land leasing prices have hiked from $10 an acre a few years ago to over $1000 an acre in the area presently. The central Utah fold-and-thrust belt has become a scene of oil rush with more than twelve companies already present. Almost all of these companies are independent oil firms. Only time and other oil field discoveries will tell whether and when major petroleum companies will move in (come back to) central Utah fold-and-thrust belt.

The Sevier Orogenic Belt

The Sevier belt is mainly a thin-skinned tectonic regime, meaning that the Precambrian basement has been detached from the Phanerozoic sedimentary cover along a deep decollement (detachment) fault. Moreover, this orogenic belt formed as a retro-arc ("behind arc") fold-and-thrust belt with thrust faults generally dipping west in contrast to the eastward subduction of the oceanic plates. Field observations and sandbox analog experiments have shown that a region undergoing plate-scale compressional stress often produces a doubly-verging wedge bounded by thrust belts in opposing directions. In the case of the Sevier belt, this structural setup may be explained by accounts of the juxtaposition of hot-young batholith (on the west) against the old, cold, and dense Precambrian basement of North America on the east. As a result, the Precambrian crust was detached along the soft layers at the basement-cover interface and underthrust the sedimentary cover. As compressional stress as well as fluid overpressure accumulated at particular horizons within the sedimentary cover, thrust planes were generated and thrust sheets were pushed for tens of kilometers, piling older sedimentary rock on top of the younger ones.

The various processes involved for the development of the Sevier fold-and-thrust belt.