Implications of Live Oil Shows in an Eastern Arizona Geothermal Test (1 Alpine-Federal)

by

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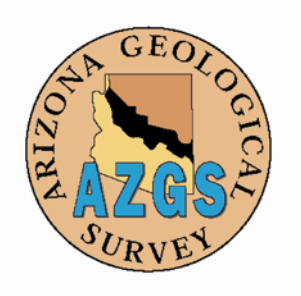

INTRODUCTION

The 1 Alpine-Federal geothermal test, at an elevation of 8,556 feet in eastern Arizona, was drilled by the Arizona Department of Commerce and U.S. Department of Energy to obtain information about the hot-dry-rock potential of Precambrian rocks in the Alpine-Nutrioso area, a region of extensive basaltic volcanism in southern Apache County. The hole reached total depth of 4,505 feet in August 1993. Temperature measurements were taken through October 1993 when final temperature, gamma ray, and neutron logs were run.

The Alpine-Federal hole is located just east of U.S. Highway 180/191 (old 180/666) at the divide between Alpine and Nutrioso, in sec. 23, T. 6 N., R. 30 E., in the Apache-Sitgreaves National Forest (Fig. 1). The town of Alpine is about 6 miles south of the wellsite and the Arizona-New Mexico state line is about 6 miles east. The basaltic Springerville volcanic field is just north of the wellsite (Crumpler, L.S., Aubele, J.C., and Condit, C.D., 1994). Although volcanic rocks of middle Miocene to Oligocene age (Reynolds, 1988) are widespread in the region, erosion has removed them from the main valleys between Alpine and Nutrioso. As a result, the 1 Alpine-Federal was spudded in sedimentary strata of Oligocene to Eocene age (Reynolds, 1988). These sedimentary strata are exposed in road cuts along the highway and consist of light-colored, fine-grained clastics with minor conglomerates. The White Mountains, formed of volcanic rocks, are to the west, Escudilla Mountain (capped by volcanic rocks) is north, the Datil volcanic field is east in west-central New Mexico, and the Mogollon Rim (also capped by volcanic rocks) is to the south.

Tonto Drilling Company of Salt Lake City, Utah, was the drilling contractor in cooperation with the Southwest Technology Development Institute (SWTDI) of New Mexico State University. Wellsite geologists were W.R. Hahman, Sr. and C.A. Swanberg as consultants and J.C. Witcher of SWTDI. Details on the temperature gradients, geothermal potential, and geology encountered in the 1 Alpine-Federal are presented in AZGS Contributed Reports CR-94-D, CR-94-E, and CR-94-F.

SUBSURFACE GEOLOGIC PLATES OF EASTERN ARIZONA AND WESTERN NEW MEXICO

1	Thickness of Baca Formation
2	Structure on base of Cretaceous strata
3	Remnant thickness of Cretaceous strata
4	Structure on top of San Andres Limestone
5	Thickness of San Andres Limestone
6	Structure on top of Glorieta Sandstone
7	Thickness of Glorieta Sandstone
8	Structure on top of Supai Group
9	Thickness of Supai Group
10	Structure on top of Fort Apache Limestone
11	Thickness of Fort Apache Limestone
12	Structure on top of Precambrian rocks

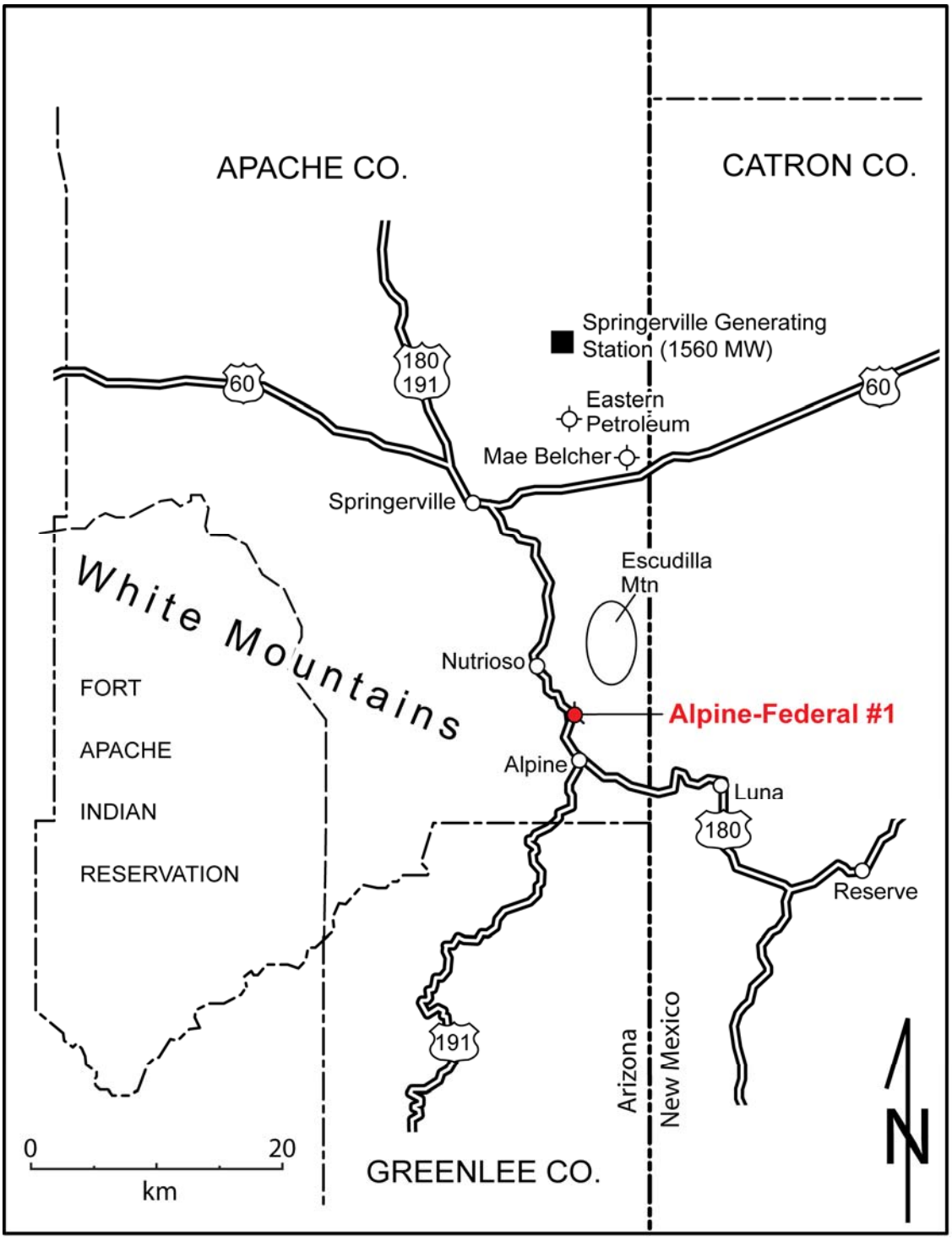

Figure 1. White Mountains area of east-central Arizona

This additional open-file report focuses on important information the 1 Alpine-Federal provides about the petroleum geology, paleogeography, and potential beneath the extensive basaltic volcanism in east-central Arizona. Data from the Alpine hole are integrated with regional well and surface control (Appendix) and presented in a series of 12 subsurface structure and thickness maps (Plates) bounded by Show Low on the west, St. Johns on the north, Datil on the east, and the Alpine hole on the south. Most formation tops for wells in Arizona are taken from Peirce and Scurlock (1972, p. 120-123, 154). Formation tops for wells in New Mexico are taken from Petroleum Information scout cards, Foster (1964, figs. 1, 2, and 3), and estimated from the regional cross section by Wengerd (1962, p. 58). Surface control is taken from McKay (1972) and Potochnik (1989, fig. 3) south of Show Low, Moore (1968, Plate 2) in the Fort Apache Indian Reservation, and Sirrine (1956, p. 201-204) east of Springerville. Regional well and surface control for the geologic plates (Pocket) is listed in the Appendix.

Primary objectives of the 1 Alpine-Federal were the depth, temperature, and nature of underlying Precambrian rocks. Because of the unexpected thickness of Tertiary sedimentary strata, however, depth to Precambrian rock was underestimated in the geothermal test proposal. As a consequence, the Alpine hole was still in Permian strata at the maximum contracted drilling depth of 4,500 feet. This left unresolved the important and critical geologic data pertaining to the nature of pre-Permian Paleozoic strata (Pennsylvanian in particular) and their paleogeographic relationships to the southern extremity of the ancient Defiance Positive region. The 1 Alpine-Federal did, however, reveal potentially important petroleum source rocks in Permian carbonate units and possibly Cretaceous strata at this location (Fig. 2).

Upon its arrival at the core repository of the Arizona Geological Survey, the author examined the core from the 1 Alpine-Federal with long-wave ultraviolet (UV) light, chloroethane, and dilute hydrochloric acid and found good shows of oil in Permian carbonate units. The Fort Apache unit of the Supai Group (Peirce, 1989, fig. 3) has a subtle petroliferous odor that becomes a strong petroliferous odor when acid is applied to the rock. Several yellowish gray to brown limestone units above the Fort Apache have a petroliferous odor and uniform to rhythmic light gold fluorescence in UV light. Some of the brown limestone units have a very faint straw-colored cut and bright yellow to light blue cut fluorescence. The highest petroliferous limestone unit, 196 feet above the Fort Apache, has bleeding oil along vertical fractures across a thin interval (4 inches) of fossil hash. The presence of bleeding (live) oil in Permian units shows that the basaltic volcanism reflected in the Alpine hole has not been totally detrimental to the petroleum potential of the region and may in fact have enhanced the hydrocarbon maturity of Paleozoic rocks. The live oil shows in the Alpine hole indicate that Permian rocks at this location are now in the oil-generating window at a relatively shallow depth.

The 1 Alpine-Federal, drilled with rotary tools to 500 feet, was conventionally cored from 500 feet to the total depth of 4,505 feet. The core is stored and is available for study at the Arizona Geological Survey (AZGS) in Tucson and the New Mexico Bureau of Mines and Mineral Resources (NMBMR) in Socorro. Core through the Tertiary interval of the hole is stored at the NMBMR. Cuttings to 500 feet, a representative sampling of the Tertiary core (approximately 1 ft/10 ft), and all of the core below the Tertiary are stored at the AZGS. Humble Geochemical Services, Humble, Texas, is preparing a geochemical log and report on the core stored at the AZGS.

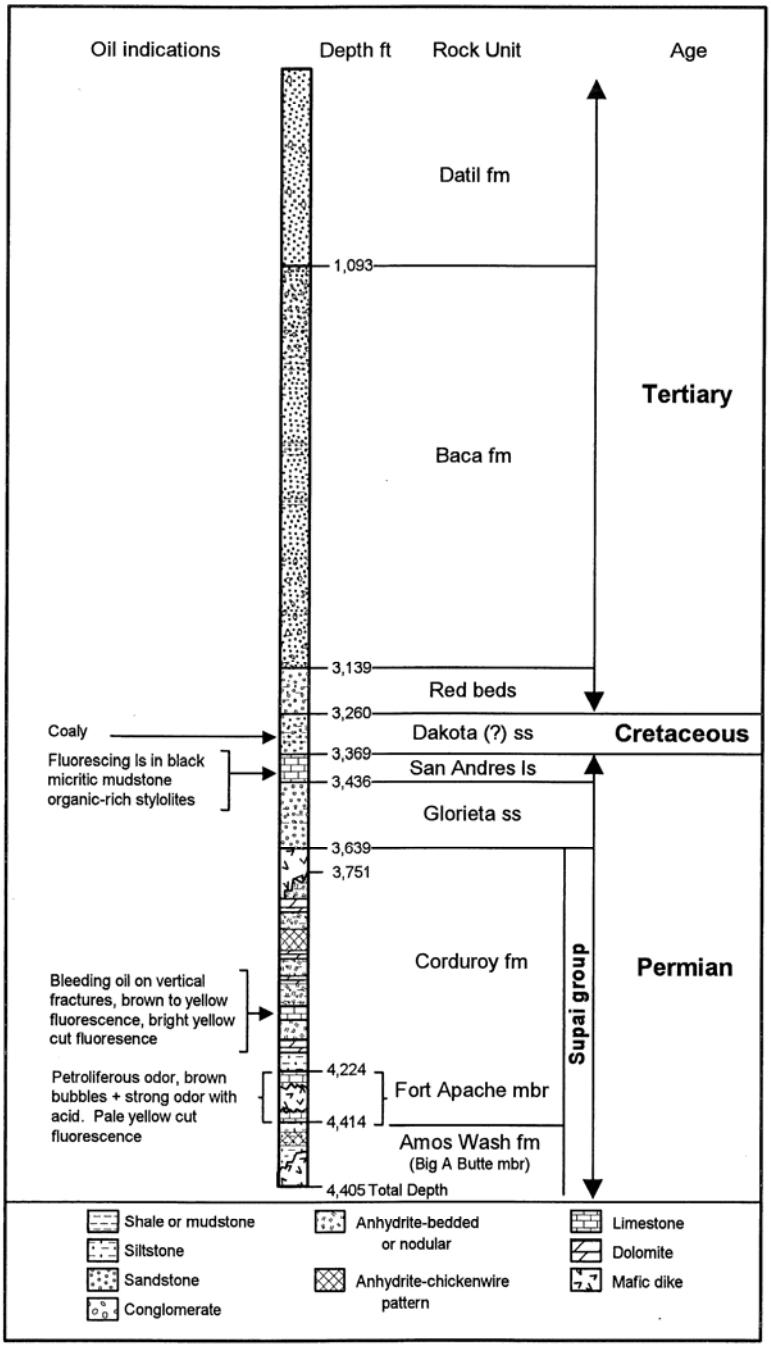

Figure 2. Rock units penetrated in 1 Alpine-Federal

STRATIGRAPHY

The 1 Alpine-Federal penetrated Tertiary, Cretaceous, and Permian rocks. The Permian rocks are cut by three mafic dikes (Fig. 2). Wellsite geologists reported Tertiary Datil Formation from the surface to 1,093 feet, Eocene Baca Formation at 1,093 feet (2,046 feet thick), Tertiary redbeds at

3,139 feet (121 feet thick), Cretaceous strata at 3,260 feet (109 feet thick), Permian San Andres Limestone at 3,369 feet (67 feet thick), Permian Glorieta Sandstone at 3,436 feet (203 feet thick), a mafic dike at 3,639 feet (drilled thickness of 112 feet), and Permian Yeso Formation, which is cut by two mafic dikes, at 3,751 feet (604 feet thick).

H. Wesley Peirce inspected the core with the author. He considered the unit below Glorieta Sandstone to be the Permian Supai Group and identified the Fort Apache Limestone unit of the Supai Group from 4,224 to 4,414 feet. As it is cut by a mafic dike from 4,260 to 4,360 feet, the Fort Apache unit has a net thickness of 90 feet in the Alpine hole. Another dike cuts the Supai Group from 4,455 feet to the total depth of 4,505 feet (Fig. 2). The dikes have increased the drill depth necessary to penetrate Permian units in the Alpine hole but have not altered them to any appreciable extent as evidenced by baked zones ranging from only three inches up to about one foot.

TERTIARY

Tertiary strata in the 1 Alpine-Federal occur from the surface to 3,260 feet. They consist of clastic rocks ranging from mudstone to boulder conglomerate and two minor volcanic units. The volcanic rocks include a green porphyritic andesite breccia from 854 to 942 feet (88 feet thick) and a light-brown poorly welded tuff from 1,018 to 1,038 feet (20 feet thick). Clastic units in the Tertiary strata are mostly brown to red in color.

Wellsite geologists assigned the two volcanic units between 854 and 1,038 feet in the Alpine hole to the Datil Formation. They picked the top of the underlying Baca Formation at the top of a major conglomerate unit (about 200 feet thick) containing clasts of red granite of probable Precambrian age. Base of the Baca was picked at the base of another major conglomerate (about 450 feet thick) resting on 121 feet of early Tertiary redbeds, which in turn rest unconformably on Cretaceous strata.

Total thickness of Tertiary strata in the Alpine hole is 3,260 feet, 2,046 feet of which the wellsite geologists assigned to the Baca Formation. Thickness data for the Baca and related deposits is presented in Plate 1 and suggest a southerly thickening wedge of strata abutting the east-northeast-trending northern boundary of the Morenci high of Cather and Johnson (1984, fig. 2). Baca deposits are thin north of Quemado, where underlying Cretaceous rocks are thick, and thick where underlying Cretaceous rocks are relatively thin (compare Plates 1 and 3). Data for the Baca thickness map (i.e. surface control on Plate 1) includes Mogollon Rim Formation of Potochnik (1989, fig. 3) and Eagar Formation of Sirrine (1956, p. 201-204). As the thickness of these units is taken from incomplete surface sections, their original thickness is unknown. Cather and Johnson (1984, p. 8) considered the Baca Basin to be late Laramide in age and limited to the southwest by the contemporaneous Apache uplift and Mogollon highlands and to the southeast by the Morenci uplift. The northern boundary of the Morenci uplift is used to limit the southern extent of Baca and related deposits on the Baca thickness map (Plate 1).

The Mogollon Rim Formation of Arizona (equivalent of Baca Formation) appears to have accumulated against, and eventually overtopped, an early Tertiary (Oligocene or earlier; see Peirce, Damon, and Shafiqullah, 1979, p. 10) "Mogollon Rim" eroded into softer strata of the Permian Supai Group in the Fort Apache Indian Reservation in eastern Arizona. Similarly, Baca deposits appear to have accumulated against a buried, early Tertiary "Mogollon Rim" eroded into softer Cretaceous

rocks in western Catron County, New Mexico, as suggested by thick Baca over thin Cretaceous and thin Baca over thicker Cretaceous (compare Plates 1 and 3). The Baca Formation, unlike the Mogollon Rim Formation in eastern Arizona, is preserved to its full extent, overtopping the buried "Mogollon Rim," in western Catron County, New Mexico.

No shows of oil or gas were reported in Tertiary strata by the wellsite geologists and none were observed in the representative sampling of core examined by the author.

CRETACEOUS

Cretaceous strata in the 1 Alpine-Federal rest unconformably on Permian San Andres Limestone and consist of 109 feet of white to light gray coarse-grained sandstone and medium to dark gray, dense mudstone. The sandstone contains numerous dark gray to black coal-like laminations with minor shaly coal beds a few inches thick. Wellsite geologists reported possible dead oil at the contact with overlying Tertiary strata. Since the actual core containing the Cretaceous-Tertiary contact is stored at the NMBMR, the author could not confirm this observation, but Richard Chavez of the NMBMR (personal communication, 1993) reported small, grain-sized pieces of coal just below the contact. McKay (1972) reported shaly coal beds a few inches to six feet thick in a zone between 20 and 85 feet above the base of Cretaceous strata in the Show Low area.

The presence of scattered coal grains and laminations in Cretaceous rocks in the Alpine hole and shaly coal beds up to six feet thick in the Show Low area suggest that coalbed methane or natural gas may be trapped in the erosionally thinned Cretaceous rocks between the Alpine hole and Show Low, in the thicker Cretaceous strata near Quemado, or where Cretaceous strata abut the northern boundary of the Morenci high shown on Plate 1.

Cretaceous strata cut across successively older units to the south, overlying Triassic rocks north of Show Low and Permian rocks south of Show Low. These and other stratigraphic relationships indicate pre-Cretaceous uplift to the south. Lindgren (1905, p. 5) reported Cretaceous rocks resting unconformably on Mississippian limestone near Morenci, Arizona, which is 60 miles south of the Alpine hole. Pre-Cretaceous uplift to the south may have allowed coalbed methane or natural gas to be trapped at the basal Cretaceous contact in that direction. This gas may be trapped today against the northern boundary of the Morenci uplift, the east-northeasterly trend of which is shown on Plate 1.

The base of Cretaceous rocks tends to rise in elevation in a southerly direction in eastern Arizona and dips easterly into a structural depression just west of Datil, New Mexico (Plate 2). The difference in elevation of the base of Cretaceous strata in the Alpine hole and the Huckleberry hole, north of Quemado (Plate 2 and Appendix), is about 200 feet whereas this difference between the Alpine hole and the Mae Belcher hole, southeast of St. Johns, is 1,500 feet and between the Huckleberry hole and the Skelly 1 M.N. Teel hole, northeast of the Mae Belcher hole, is 1,400 feet. A northeast-trending, vertical fault is therefore dashed between the structurally lower Cretaceous strata in the Alpine and Huckleberry holes and the structurally higher Cretaceous strata in the Mae Belcher and Skelly holes (Plate 2). This inferred fault has a displacement of 500 to 750 feet (Plate 2) and parallels the northeast trend of the structurally significant Salt River Lineament of Peirce (1986, fig. 1). Coalbed methane or natural gas may be trapped in Cretaceous strata against this inferred

post-Cretaceous fault.

The thickness map of Cretaceous strata (Plate 3) represents remnant (erosional) thickness. Original thickness of Cretaceous rocks in east-central Arizona is not implied. These erosionally thinned rocks are 500 feet thick near Show Low, 109 feet thick in the 1 Alpine-Federal, 175 feet thick in the Shell 1 State, and over 1,750 feet thick near Quemado (Plate 3 and Appendix), suggesting that post-Cretaceous, pre-mid-Tertiary erosion (probably contemporaneous with the Apache and Morenci uplifts) has removed over 1,200 feet of Cretaceous strata in the Show Low and Alpine areas.

Wellsite geologists assigned Cretaceous strata in the 1 Alpine-Federal to the Dakota (?) Formation based on its appearance. Discussion of age assignments is not the focus of the current report, but a review of Cretaceous strata in the Mogollon Rim region by Nations (1989, p. 442-444 and fig. 8) indicates that these rocks are Cenomainian in age, which tends to support the wellsite geologists assignment of Cretaceous strata in the Alpine hole to the Dakota (?) Formation.

PERMIAN

Permian strata penetrated by the 1 Alpine-Federal include San Andres Limestone, Glorieta Sandstone, and the upper part of the Supai Group. The Supai Group of Peirce (1989) is used here. From the top, it consists of the Corduroy, Amos Wash, and Oak Creek Formations. The Corduroy Formation contains the Fort Apache Limestone Member at its base and the much thicker overlying section of clastics, carbonates, and evaporites. In the Fort Apache region the upper part of the Amos Wash Formation contains clastics with a few interbedded units of carbonate and evaporites, all assigned to the Big A Butte Member. This rock grouping contains the Yeso-Abo Formation equivalents in adjoining New Mexico.

SAN ANDRES LIMESTONE

The San Andres Limestone of New Mexico and the Kaibab Formation of Arizona are considered approximately equivalent units. Both units are present in east-central Arizona. Their distribution is based on contrasting paleogeographic position, lithology, and fauna (Akers, 1964, p. 23; also Peirce and Wilt, 1970, p. 71-72; Peirce, 1976, p. 50; and Aldrich et al., 1986, p. 106). The Salt River Lineament of Peirce (1986, fig. 1) appears to have influenced the transition between these two contrasting realms (Peirce, 1989, fig. 1 and p. 363). The Permian carbonate beneath Cretaceous strata in the Alpine hole is within the domain of the San Andres Limestone of New Mexico and eastern Arizona (Plates 4 and 5).

San Andres Limestone in the 1 Alpine-Federal consists of 67 feet of brownish gray to dark gray fossiliferous limestone. The limestone is intermittently interbedded with thin dark gray to black shales and contains numerous stylolites filled with black, earthy organic material, which can be scraped off with the fingers. A collapse breccia of lighter-colored limestone clasts in dark gray to black micritic mudstone is present at the base of the unit. The limestone clasts in the collapse zone have an even, golden-colored fluorescence, no cut, and a weak translucent cut fluorescence.

Bleeding oil shows in Permian units below San Andres Limestone in the Alpine hole suggest that similar organic-rich carbonates deeper in the section may have been matured by volcanism. Consequently, volcanism may have matured organic-rich San Andres Limestone away from the 1

Alpine-Federal where mafic dikes intrude the unit even though no live oil shows were observed in it in the Alpine hole. Intrusion away from the hole may have induced fracture porosity and permeability in these dense carbonate rocks, allowing for mobilization and accumulation of volcanically matured hydrocarbons.

The collapse breccia at the base of San Andres Limestone in the 1 Alpine-Federal is tight. However, breccia zones may provide good reservoir rock in areas away from the hole where leaching took place before oil generation and migration or where the rock was more effectively fractured and matured by volcanism and intrusion.

The top of the San Andres Limestone tends to rise in elevation in a southerly direction in Arizona and dips easterly into a structural depression just west of Datil (Plate 4). Two closures above the 6,000-foot contour interrupt the southerly trend between Show Low and St. Johns. One closure above the 6,500-foot contour interrupts the trend southeast of St. Johns. The structure southeast of St. Johns is disrupted on the south by the inferred northeast-trending, vertical fault between the Alpine and Mae Belcher holes (Plate 4).

San Andres Limestone is 67 feet thick in the 1 Alpine-Federal where it is unconformably overlain by Cretaceous rocks and over 400 feet thick near Quemado where it is unconformably overlain by Triassic rocks (Plate 5). Depositional thickness (and thus paleogeographic information) of San Andres Limestone is more accurately shown in wells where Triassic rocks overlie it. This includes holes in the northern part of the mapped area of southern Apache County, Arizona, and all the holes in the mapped area of west-central Catron County, New Mexico. Thickness of San Andres Limestone where Cretaceous rocks overlie it reflects pre-Cretaceous erosional truncation. This includes the 1 Alpine-Federal hole and outcrops south of Show Low. The stratigraphic relationship between San Andres Limestone and overlying rocks is shown on Plate 5. The pre-Cretaceous erosional strike in the region trends approximately northwest, whereas the depositional strike of San Andres Limestone trends northeast with a zero edge near and parallel to the Salt River Lineament (see Aldrich et al., 1986, fig. 4). Eroding the depositional trend beneath Cretaceous rocks produces a second, erosional wedgeout to the southwest (Plate 5).

GLORIETA SANDSTONE

Glorieta Sandstone in the 1 Alpine-Federal consists of 203 feet of distinctive light gray to white, well-sorted, medium-grained sandstone with minor gray siltstone and small, scattered patches of pyrite. Bedding is wavy with horizontal laminations, typical of water-laid deposits, and is very unlike the eolian style large-scale wedge-trough cross-bedding typical of the classic Coconino Sandstone to the west. Extension of the Salt River Lineament of Peirce (1986, fig. 1) is used to mark the approximate transition between Coconino Sandstone to the west and Glorieta Sandstone to the east (Plates 6 and 7). Glorieta Sandstone in the Alpine hole is porous and permeable and underlies a basal breccia zone of San Andres Limestone.

Like the overlying San Andres Limestone, top of the Glorieta Sandstone rises in elevation in a southerly direction in Arizona and dips easterly into a structural depression just west of Datil (Plate 6). The gentle northerly dip of Coconino Sandstone (equivalent to Glorieta) between Black Mesa Basin to the north and Mogollon Rim to the south averages less than one degree over a distance of

120 miles (Conley, 1979, Map G-10). Structural closure above an elevation of 6,000 feet interrupts this low-gradient, northerly dip between Show Low and St. Johns and southeast of St. Johns. The structure southeast of St. Johns may have closure above 6,500 feet. Reversal of regional northerly dip by the structure southeast of St. Johns has resulted in a broad east-trending syncline south of the structure (Plate 6). The southern flank of this syncline, in which the Alpine hole is situated, appears to abut the east-northeast-trending northern boundary of the Morenci high shown on Plate 1. The inferred northeast-trending vertical fault between the Alpine and Mae Belcher holes separates the structural tendency of Glorieta Sandstone in Arizona from the structural tendency of the unit in New Mexico (Plate 6).

Thickness of the Glorieta Sandstone ranges between 200 and 250 feet over much of the mapped area (Plate 7). It thickens to the west near Show Low in the direction of the eolian Coconino Sandstone in central Arizona.

A fault intruded by a mafic dike appears to separate Glorieta Sandstone from the underlying Supai Group in the 1 Alpine-Federal. The upper contact of the dike with the overlying Glorieta is vague but the lower contact of the dike with a brecciated rubble zone at the top of the underlying Corduroy Formation of the Supai Group is sharp and high angle (80^{o} to 85^{o}). The dike between the Glorieta and the "Supai" has a drilled thickness of about 112 feet but its true thickness, based on the high angle of the lower contact, is about 40 feet. The fault and dike may be related to the northeast-trending faulting mapped on the basis of structural relations at the base of Cretaceous strata (Plate 2).

SUPAI GROUP

Peirce (1989, figs. 3 and 6), following the stratigraphic rationale of Winters (1963, p. 8-11), used the Fort Apache Limestone to separate the Supai Group in central and east-central Arizona into an upper Corduroy Formation, a middle Amos Wash Formation, and a lower Oak Creek Formation. As Winters (1963, p. 10), Gerrard (1966, p. 2,441 and 2,444), and Peirce (1989, p. 366) recognized, the Fort Apache Limestone is a distinctive marker unit that can be regionally traced throughout central and east-central Arizona. It is thus a logical horizon at which to separate the Supai Group in this region. In the subsurface, the base of the Fort Apache is easily picked in well logs because it is characterized by a distinctive gamma ray log curve break. Thus it is an important subsurface correlation horizon.

The Corduroy Formation of the Supai Group in the 1 Alpine-Federal resembles sea-margin sabkha deposits, consisting of reddish brown sandstone, siltstone, and shale interbedded with white to brown anhydrite and solution-brecciated gray to brown dolomite. The sandstone beds are few in number but are relatively thick (up to 10 feet), clean, and well sorted. The numerous interbedded siltstone and mudstone layers typically include rip-up clasts of dolomite and anhydrite suggesting storm-agitated conditions. Beds of nodular anhydrite surrounded with mudstone grade into thick beds of anhydrite having a mushy or chickenwire pattern.

The basal Fort Apache Limestone Member of the Corduroy Formation, in the Alpine hole, occurs at a depth of 4,224 feet, about 470 feet below the top of the Supai Group (which may be incomplete because its upper contact is the lower contact of the mafic dike at 3,751 feet). The Fort Apache is 90 feet thick and consists of rhythmically banded gray to brown fossiliferous limestone containing pin-

point to vuggy (up to one-inch diameter in the core; see Fellows, 1994, fig. 1) porosity and vertical, calcite-filled fractures. Most of the Fort Apache has a faint petroliferous odor and yields brown bubbles and a strong petroliferous odor when acid is applied. When the acid dries, brown rims are left on the rock. Dark brown material, which may be dead oil (based on no fluorescence or cut but faint cut fluorescence), is present in most of the pin-point porosity and along some of the vertical fractures.

Above the Fort Apache unit (within the Corduroy Formation) in the Alpine hole, between drilled depths of 4,028 and 4,140 feet, are several zones of yellowish gray to yellowish brown petroliferous limestone. Stylolites and thin dark shale laminations are common in these petroliferous zones, which yield brown bubbles and a strong petroliferous odor when acid is applied. Samples yield a very faint straw cut and a pale yellow cut fluorescence in chloroethane.

The strongest shows of oil in the 1 Alpine-Federal occur in a 4-foot thick yellowish gray to brown limestone at 4,028 feet (196 feet above the top of the Fort Apache unit) that contains thin intervals of fossil hash and bleeding oil along vertical fractures. The oil has brown to yellowish brown fluorescence and bright yellow cut fluorescence.

Petroliferous rocks in and above the Fort Apache unit of the Supai Group is not entirely unexpected. Gerrard (1966, p. 2,450) reported a strong petroliferous odor on freshly broken pieces of Fort Apache Limestone in outcrops to the west in the Fort Apache Indian Reservation. Amstrat Stratigraphic logs record heavy oil, oil staining, and dead to asphaltic oil in the upper part of the "Supai" in several wells both north and west of the 1 Alpine-Federal (see Peirce and Wilt, 1970, Plate 8). The petroliferous zone in the Corduroy Formation (above the basal Fort Apache Member) in the Alpine hole may be closely related to a petroliferous zone reported in the Corduroy Formation (above the basal Fort Apache Member) in the Eastern Petroleum 1-A Coyote Creek well, which is about 23 miles north of the 1 Alpine-Federal (Fig. 1).

The 1 Alpine-Federal penetrated 41 feet of the Big A Butte Member of the Amos Wash Formation before entering a mafic dike at 4,455 feet. The hole bottomed in this mafic dike at 4,505 feet. That portion of the Big A Butte Member cored in the Alpine hole consists of redbed clastics interbedded with thin limestone and anhydrite beds, the most notable of which is the "Big A Butte anhydrite nick" on the gamma ray curve at 4,424 feet.

Like overlying Permian units, structural tendency of the "Supai" (Plate 8) and the Fort Apache Limestone (Plate 10) is to rise in elevation in a southerly direction in Arizona and dip easterly into a depression just west of Datil, New Mexico. The Alpine hole is situated in a broad syncline south of the structure southeast of St. Johns that interrupts the regional low-gradient northerly-dipping tendency of Permian units in Arizona (Plates 8 and 10). The low-gradient northerly dip of the Fort Apache Member of the Corduroy Formation in east-central Arizona averages less than one degree between the Holbrook "salt" basin to the north and the Mogollon Rim to the south (Conley, 1977, Map G-7) . The southern flank of the gentle syncline south of the structure southeast of St. Johns probably abuts the east-northeast-trending northern boundary of the Morenci high shown on Plate 1. This syncline is displaced by northeast-trending faulting between the Alpine and Mae Belcher holes (Plates 8 and 10).

The Supai Group thins southward from the Holbrook "salt" basin, ranging from 2,500 feet north of Show Low to 1,650 feet southwest of Datil. It is probably just under 1,500 feet thick at the 1 Alpine-Federal location (Plate 9). Most of the thinning takes place in the Corduroy Formation evaporites above the Fort Apache unit. In the New Mexico portion of the mapped area, the Supai Group thickness map (Plate 9) includes the combined thickness of the Yeso and underlying Abo Formations as recorded on Petroleum Information scout cards. The Yeso consists of interbedded redbeds, evaporites, and carbonates and the Abo consists of redbeds (Foster, 1964, p. 20-22). Gerrard (1966, fig. 3) showed that upper "Supai" strata (base of Fort Apache Limestone to base of Coconino Sandstone) in central and east-central Arizona have a prominent east-southeast basin trend and thin markedly to the south.

Thickness of Fort Apache Limestone also reflects an east-west trending basin (Gerrard, 1966, fig. 10). It is 90 feet thick in the 1 Alpine-Federal with a maximum thickness of about 130 feet between the Mae Belcher and Alpine holes (Plate 11).

A mafic dike at the upper contact of the Supai Group, a breccia zone just below this contact, and the unusually short distance between overlying Glorieta Sandstone and underlying evaporites in the upper Supai Group, suggest that the uppermost part of the Corduroy Formation is faulted out in the 1 Alpine-Federal. In the Mae Belcher well, about 18 miles north, the distance between Glorieta Sandstone and Corduroy evaporites includes 100 feet of reddish sandstone. In the Alpine hole this distance is 25 feet (and lacks sandstone) suggesting that 75 feet of upper Corduroy Formation is missing at this location. The 563 feet of Corduroy Formation in the Alpine hole, however, is consistent with the southward thinning of "upper Supai" noted by Gerrard (1966, fig. 3) suggesting that thinning of Supai Group in the 1 Alpine-Federal (compared to its thickness in the Holbrook "salt" basin to the north) is a combination of faulting and stratigraphic thinning.

Only 604 feet of Supai Group was penetrated in the Alpine hole before coring was stopped. Considering that 75 feet of uppermost "Supai" may be faulted out at this location, from 600 to 1,000 feet of Supai Group below the Fort Apache unit (including Amos Wash and Oak Creek Formations of Peirce, 1989, fig. 3) remains untested at this location. Whereas faulting may shorten and decrease the drilled depth necessary to fully penetrate the Supai Group, dikes occupying the faults may increase the depth necessary to fully penetrate the "Supai."

PRE-PERMIAN UNITS

Live oil shows in Permian rocks in the 1 Alpine-Federal suggest that the volcanism as reflected in the hole has not been totally detrimental to the hydrocarbon potential of the region. Volcanism may in fact have enhanced the fracture porosity and hydrocarbon maturity of Paleozoic rocks. Thus pre-Permian strata are of interest in the region even though the 1 Alpine-Federal did not completely penetrate even Permian rocks. Pennsylvanian and older rocks remain untested over a large and interesting region of east-central Arizona.

Lowermost Permian and uppermost Pennsylvanian strata contain carbonized and coalified plant debris to the west along the Mogollon Rim (Peirce, Jones, and Rogers, 1977, p. 19). These units may contain even higher percentages of organic material in the general region of the 1 Alpine-Federal because of its more proximal location to the southwest edge of the ancient Defiance Positive

feature.

PENNSYLVANIAN

Even though the 1 Alpine-Federal was not drilled deep enough to encounter Pennsylvanian strata, mapping by Wrucke (1961, fig. 2) suggests the presence of these rocks beneath "Supai" at this location. He reported two large blocks of probable Pennsylvanian Naco limestone at an elevation of 8,600 feet on the northeast flank of Escudilla Mountain (about 6.5 miles northeast of the 1 Alpine-Federal, see Fig. 1). He surmised that volcanism carried these large blocks of Naco (?) limestone to the surface from their more extensive presence at depth (Wrucke, 1961, p. 24-25).

The northeasterly extent of Pennsylvanian onlap on the southwest edge of the Defiance Positive is limited by two wells drilled north of Escudilla Mountain (Fig. 1 and Appendix). The Eastern Petroleum 1-A Coyote Creek in sec. 27, T. 10 N., R. 30 E., about 23 miles north of the 1 Alpine-Federal, penetrated Permian Supai Group over Precambrian granite at an elevation of 4,628 feet (Plate 12). The Mae Belcher 1 State in sec. 20, T. 9 N., R. 31 E., about 18 miles north of the Alpine hole, penetrated Supai Group over Precambrian granite at an elevation of about 4,422 feet (Plate 12).

Wrucke's (1961) recognition of displaced Naco (?) limestone on Escudilla Mountain suggests that an edgeline of onlapping Pennsylvanian rocks exists between the 1 Alpine-Federal and the Mae Belcher and Eastern Petroleum wells. These rocks may be 750 feet thick at the 1 Alpine-Federal location (Kottlowski, 1959, fig. 1; Kottlowski and Havenor, 1962, p. 78; Kottlowski, 1965, fig. 6).

PRE-PENNSYLVANIAN

Regional isopach mapping suggests that 165 (Armstrong, Mamet, and Repetski, 1980, fig. 1) to 230 (Beus, 1989, fig. 2) feet of Mississippian strata and 150 feet of Devonian strata (Beus, 1980, fig. 2) could be present at the 1 Alpine-Federal location. Precambrian rocks at the 1 Alpine-Federal location may thus be as deep as 6,570 feet at an elevation of 1,985 feet, 2,400 feet structurally lower than the Precambrian surface at the Mae Belcher well (Plate 12). This buried paleogeographic Precambrian surface is the unexplored southwestern edge of the Defiance Positive, which trends southeasterly through this region and extends at least 60 miles in a northwesterly direction (Peirce, 1979, fig. 1). Pre-Permian Paleozoic strata near and along this feature is of much interest to petroleum explorers.

OIL AND GAS POSSIBILITIES

Woodward and Grant (1986, p. 308-310) reported Devonian rocks in west-central New Mexico that contained ideal source beds. They also noted potential source and reservoir rocks in Pennsylvanian units. Conley (1975, p. 7) reported asphalt in fractures of the Devonian Martin Formation near Payson, Arizona, about 120 miles west of the Alpine hole. Devonian strata have produced over 95,000 barrels of oil and Mississippian strata have produced over 800,000 barrels of oil and 386 million cubic feet of helium-bearing gas in northeastern Arizona, about 200 miles north of the Alpine hole (Rauzi, 1993).

Stratigraphic and structural traps in the region would include unconformities, faulting, and folding where lower Permian, Pennsylvanian, Mississippian, and Devonian rocks onlap the unexplored

southwest edge of the Defiance Positive. Peirce (1979, p. 1) noted that faulting probably gave magnified expression to the southwest margin of the Defiance Positive during Pennsylvanian time. Hydrocarbons could have formed in place or migrated from deeper basins or reefs to the west, south, or east of the positive region. Hydrocarbons formed in place may have been sourced by organic-rich reefs or lagoon, swamp, and marsh deposits near and along the margin. Maturation of hydrocarbons may have been enhanced by Tertiary volcanism.

Stratigraphic traps in Paleozoic rocks may involve mafic dikes or sills. These would induce fracture porosity and permeability in Paleozoic carbonates during intrusion and may become reservoir rock themselves after cooling. Although igneous rock does not seem compatible with accumulation of hydrocarbons, more than 17 million barrels of oil have been produced from igneous rock at the Dineh-bi-Keyah Field in northeast Arizona (about 180 miles north of the Alpine hole). This igneous reservoir rock of Tertiary age intruded white to light tan carbonates and black shales of the Pennsylvanian Hermosa Formation and has yielded more oil than any reservoir rock in Arizona. Probable Pennsylvanian petroleum in a Tertiary volcanic reservoir rock raises many interesting questions and implications.

Stratigraphic traps in Paleozoic rocks may include lenticular to tabular clastics interbedded with carbonate strata near and along the margin of the Defiance Positive. Other stratigraphic traps in the region may include reefs, biohermal buildups, and fractured, vuggy, or cavernous carbonate rocks.

Live oil in Permian carbonates in the 1 Alpine-Federal suggests that the hydrocarbon potential of east-central Arizona and west-central New Mexico should not be dismissed because of the extensive surface cover of basaltic volcanic rocks. Live oil in close proximity to mafic dikes in the Alpine hole suggests that volcanism may have enhanced the hydrocarbon maturity of Paleozoic strata and the mobility of petroleum in the region.

Post-Paleozoic, pre-upper Cretaceous uplift of Paleozoic strata may be another factor in trapping hydrocarbons in the region. Depositional dip into deeper basins surrounding the Defiance Positive may have been reversed. Consequently, initial petroleum migration up depositional dip may also have been reversed.

Hydrocarbons may be trapped against the northeast-trending fault north of the Alpine hole (Plates 2-12). Hydrocarbons may be trapped south of the Alpine hole at unconformities beneath upper Cretaceous strata and against faulting that probably defines the northern boundary of the Morenci high (Plate 1). Seismic data may help define the location of these and other important post-Cretaceous faults that may have influenced petroleum movements and collecting points.

CONCLUSIONS

The 1 Alpine-Federal penetrated potentially important hydrocarbon source rocks in east-central Arizona and showed that Precambrian rocks are deeper than projected by the operator at this location. Live oil shows in Permian carbonate units in the Alpine hole and regional studies suggest that petroleum potential exists in Permian and pre-Permian rocks yet to be explored in east-central Arizona and west-central New Mexico.

Hydrocarbon source rocks in the 1 Alpine-Federal include upper Supai Group, San Andres

Limestone, and possibly Cretaceous strata. Bleeding oil in the upper "Supai" in the Alpine hole indicates that these rocks are in the oil-generating window at this location suggesting that the extensive basaltic volcanism in east-central Arizona may have helped mature the Paleozoic units. San Andres Limestone contains organic-rich stylolites and dark gray to black shales and may be an effective hydrocarbon source (and reservoir) rock where matured (and fractured), perhaps, by volcanism. Cretaceous strata contain coaly laminations and grain-sized pieces of coal and may be a source for coalbed methane or natural gas.

The region, therefore, offers opportunities for hydrocarbon accumulations beneath the extensive surface cover of volcanic rock in east-central Arizona. Given that (1) live oil shows are present in close proximity to volcanic rock in the 1 Alpine-Federal, (2) volcanism may have enhanced the hydrocarbon maturity and potential of Paleozoic rocks, (3) favorable Paleozoic paleogeography exists near and along the southwest margin of the Defiance Positive, and (4) interbedded clastic, carbonate, and organic-rich deposits are likely along this margin of Pennsylvanian and earlier onlap, the region deserves further evaluation for oil and gas.

ACKNOWLEDGMENTS

The author thanks Wes Peirce for stimulating and insightful discussions on the geology and paleogeography of Arizona. I also thank Wes for taking time to accompany me while examining core from the Alpine hole, critically reviewing this report, and offering valuable suggestions and criticism. The author thanks Ed Heylmun for his discussions and suggestions, and for examining the core several times with the author. The author takes full responsibility for final conclusions, omissions, and oversights.

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APPENDIX

Regional well and surface control used for geologic plates

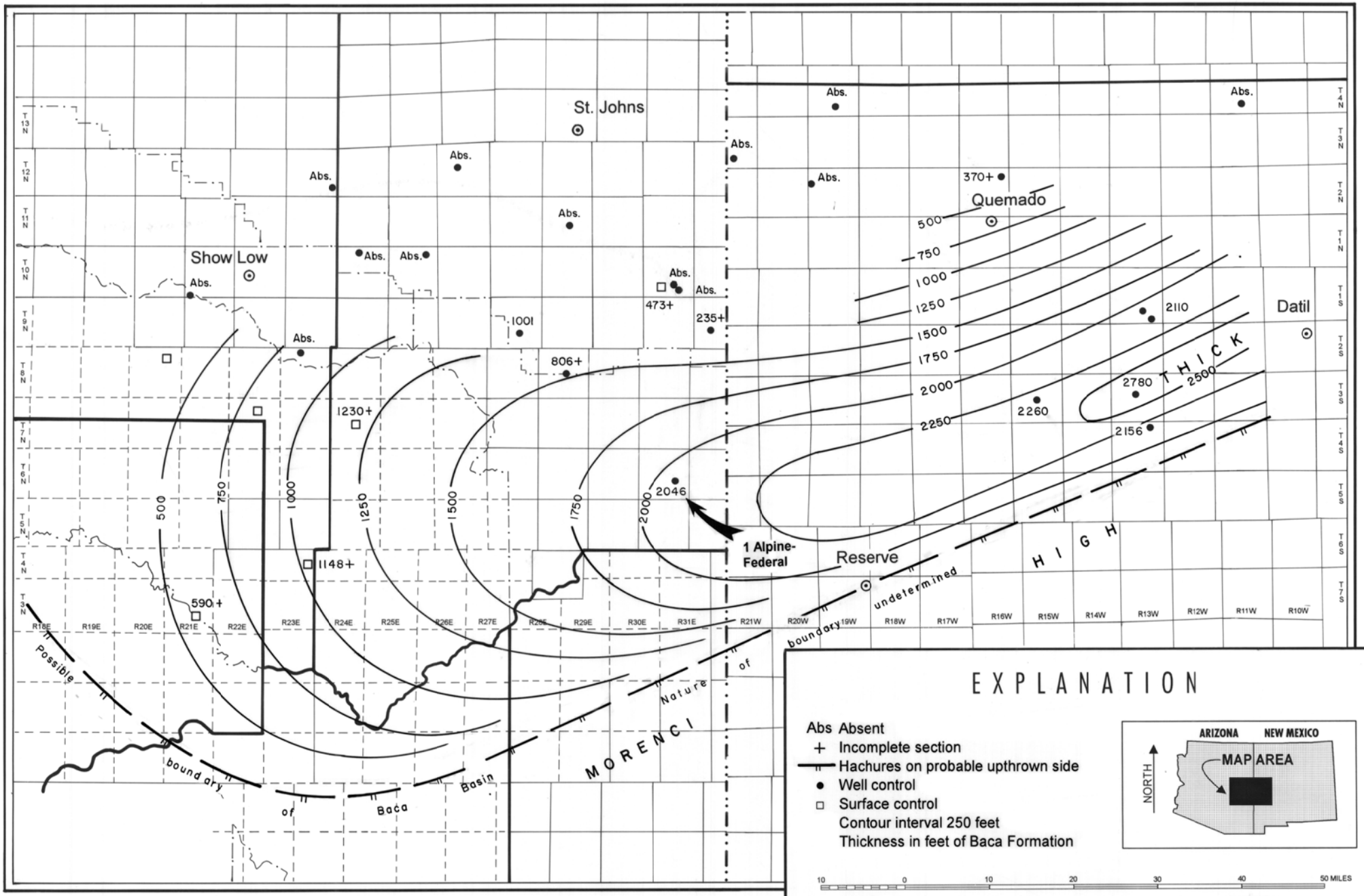
ARIZONA

Location			Name	County
12 N.	23 E.	Sec. 25	Pan American #1-B	Navajo
	26 E.	Sec. 17	Sumatra Energy #1-17	Apache
11 N.	28 E.	Sec. 22	Tenneco #1-C Federal	Apache
10 N.	21 E.	Sec. 31	Tenneco #1-X Fort Apache	Navajo
	24 E.	Sec. 4	Tenneco #1-B Federal	Apache
	25 E.	Sec. 2	Cities Service #204-A State	Apache
	30 E.	Sec. 26	Tenneco #1 Merrill	Apache
	30 E.	Sec. 27	Eastern #1-A Coyote Creek	Apache
	30 E.	Sec. 28	Surface control	Apache
9 N.	27 E.	Sec. 22	Cities Service #201 Colter	Apache
	31 E.	Sec. 20	Mae Belcher #1 State	Apache
8 N.	20 E.		Surface control	Navajo
	23 E.	Sec. 4	Arizona Game & Fish water well	Navajo
	28 E.	Sec. 15	Cities Service #202 Hall	Apache
7 N.	22 E.		Surface control	Navajo
	24 E.		Surface control	Apache
6 N.	**30 E.**	**Sec. 23**	**Tonto #1 Alpine Federal**	**Apache**
4 N.	23 E.		Surface control	Navajo
3 N.	21 E.		Surface control	Gila

NEW MEXICO

Location			Name	County
4 N.	19 W.	Sec. 27	Skelly #1 C.A. Teel	Catron
	11 W.	Sec. 27	Spanel & Heinze #1-9617 Santa Fe	Catron
3 N.	21 W.	Sec. 27	Skelly #1 Goesling	Catron
2 N.	19 W.	Sec. 7	Skelly #1 M.N. Teel	Catron
	16 W.	Sec. 11	Huckleberry #1 Federal	Catron
1 S.	13 W.	Sec. 27	Shell #1 Aspen Federal	Catron
		Sec. 35	Tenneco #1 Federal	Catron
3 S.	15 W.	Sec. 21	Shell Mangus Mtn. Federal	Catron
	13 W.	Sec. 16	Hunt Oil Company #1-16 State	Catron
4 S.	13 W.	Sec. 2	Shell #1 State	Catron

ARIZONA NEW MEXICO



EXPLANATION

Abs Absent
\+ Incomplete section
Hachures on probable upthrown side
Well control
Surface control
Contour interval 250 feet
Thickness in feet of Baca Formation

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

S.L.RAUZI

FEBRUARY 1994

Thickness of Baca Formation

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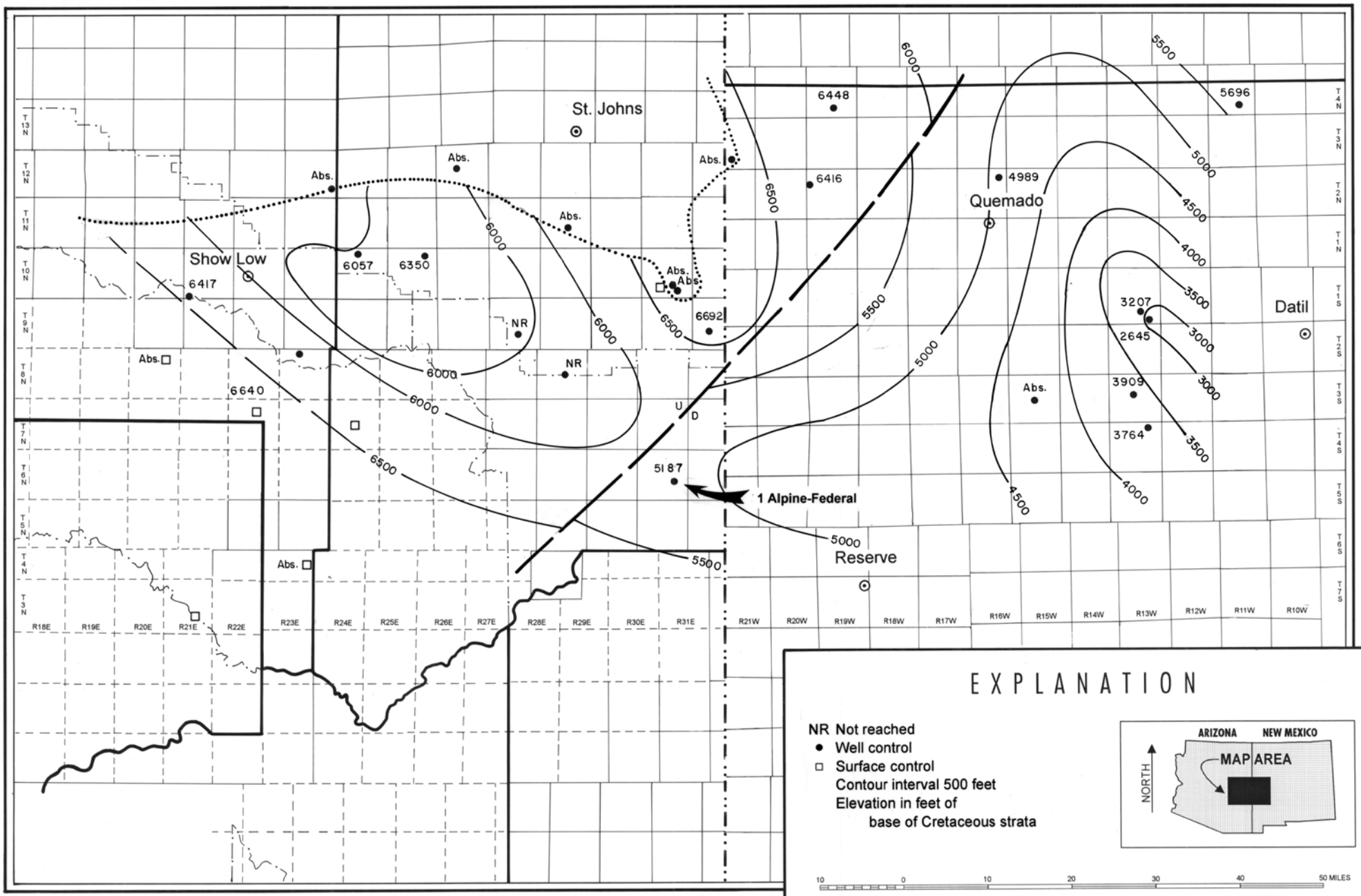
ARIZONA NEW MEXICO

OFR 94-1



EXPLANATION

NR Not reached
● Well control
□ Surface control
Contour interval 500 feet
Elevation in feet of
base of Cretaceous strata

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

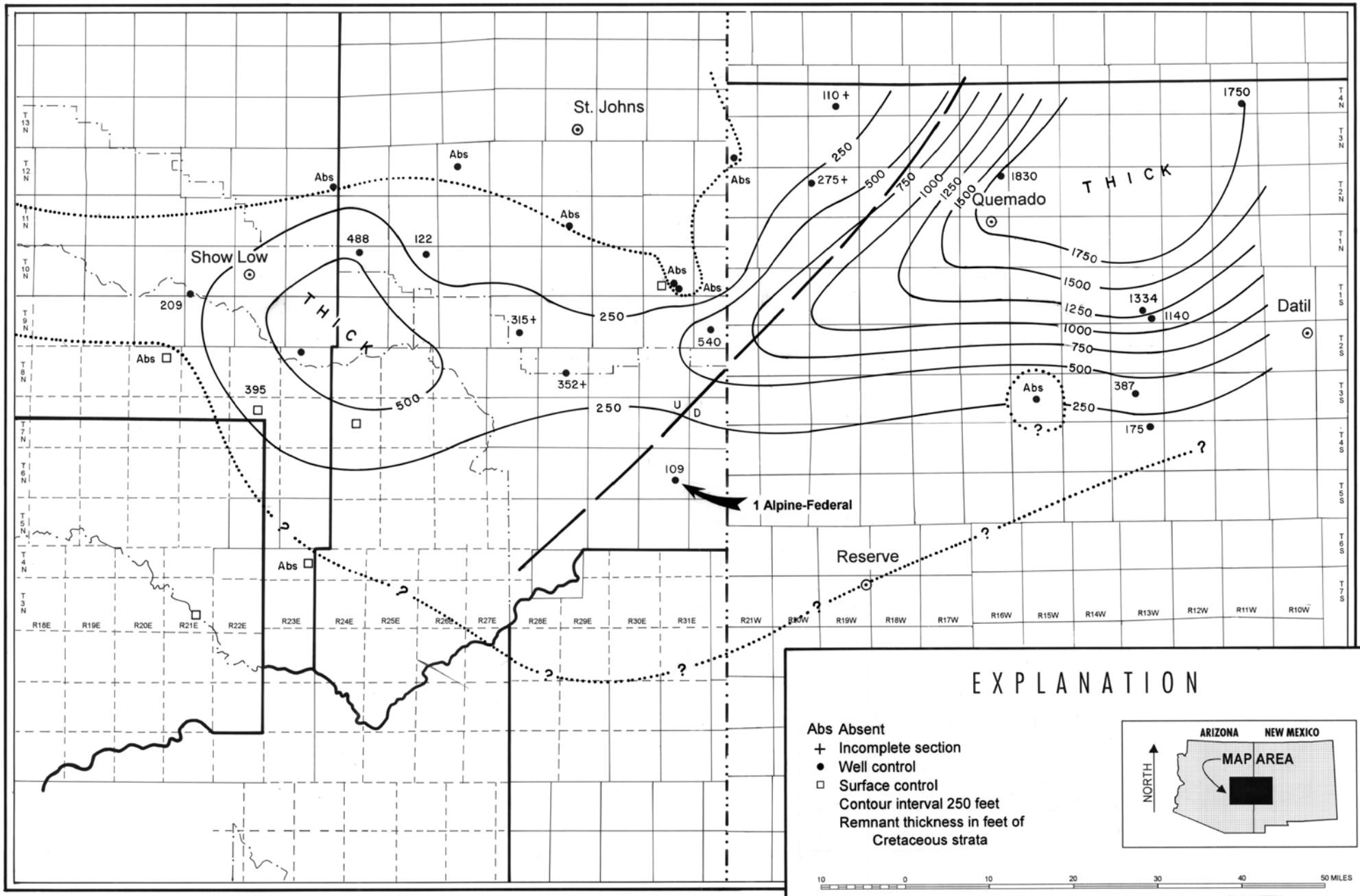
S.L.RAUZI

FEBRUARY 1994

Structure on base of Cretaceous strata

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 2 of 12, with text

ARIZONA NEW MEXICO



EXPLANATION

Abs Absent
\+ Incomplete section
● Well control
□ Surface control
Contour interval 250 feet
Remnant thickness in feet of Cretaceous strata

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

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Remnant thickness of Cretaceous strata

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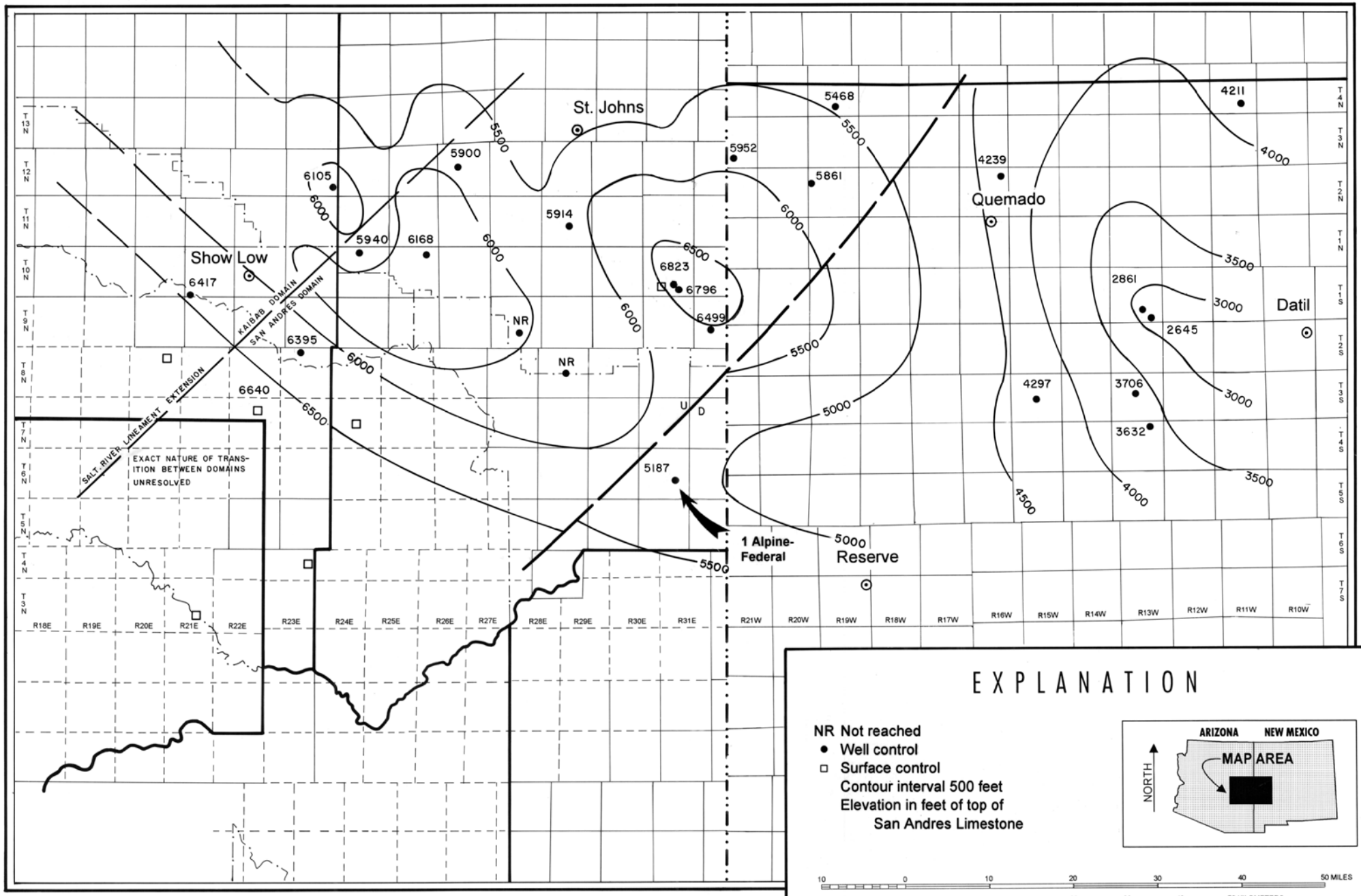


EXPLANATION

NR Not reached
• Well control
□ Surface control
Contour interval 500 feet
Elevation in feet of top of San Andres Limestone

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

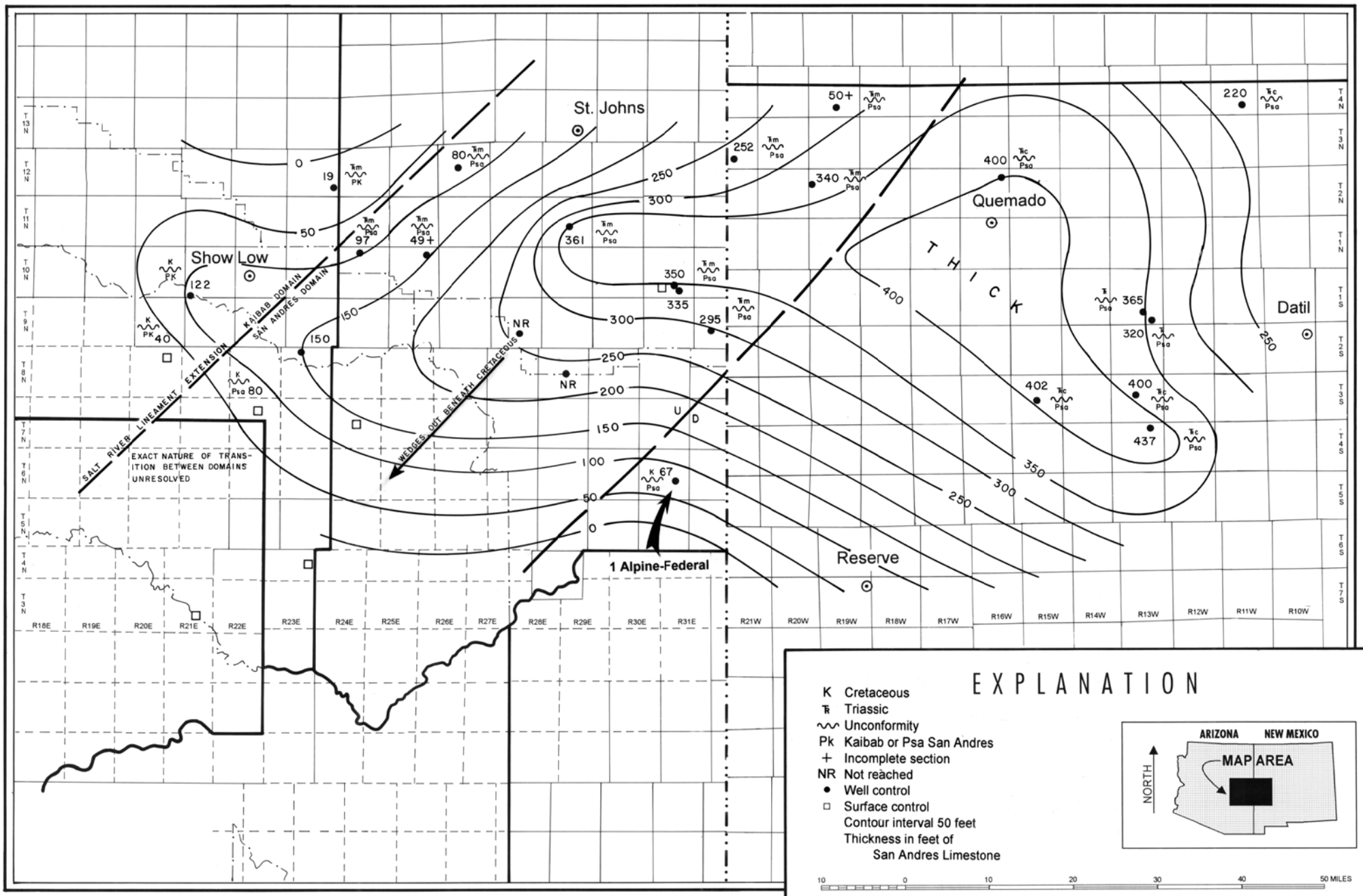
S.L.RAUZI

FEBRUARY 1994

Structure on top of San Andres Limestone

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 4 of 12, with text

ARIZONA NEW MEXICO



EXPLANATION

- K Cretaceous
- Tr Triassic
- Unconformity
- Pk Kaibab or Psa San Andres
- \+ Incomplete section
- NR Not reached
- ● Well control
- □ Surface control
- Contour interval 50 feet
- Thickness in feet of San Andres Limestone

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

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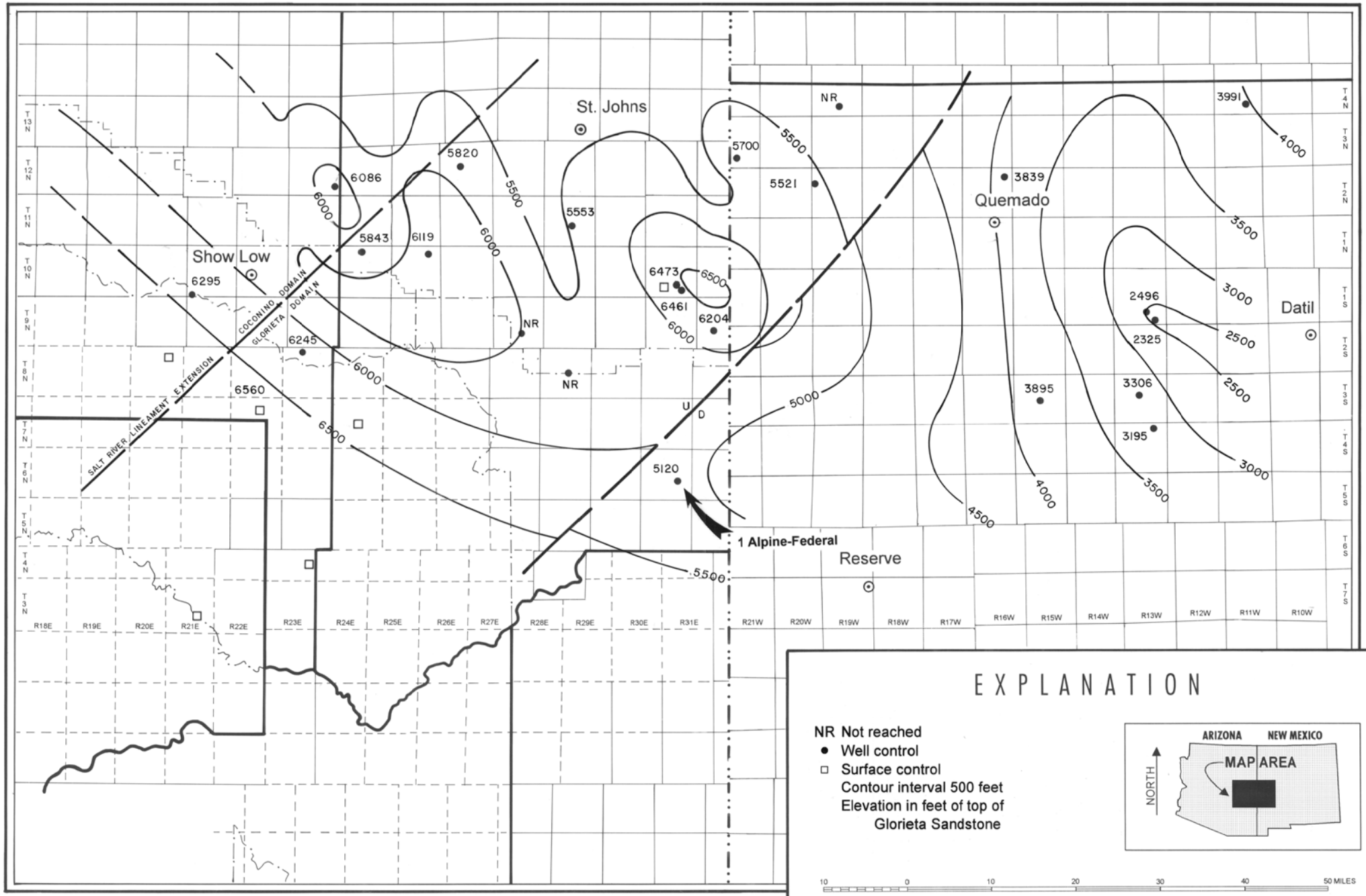
Thickness of San Andres Limestone

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 5 of 12, with text

ARIZONA NEW MEXICO



EXPLANATION

NR Not reached
● Well control
□ Surface control
Contour interval 500 feet
Elevation in feet of top of Glorieta Sandstone

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

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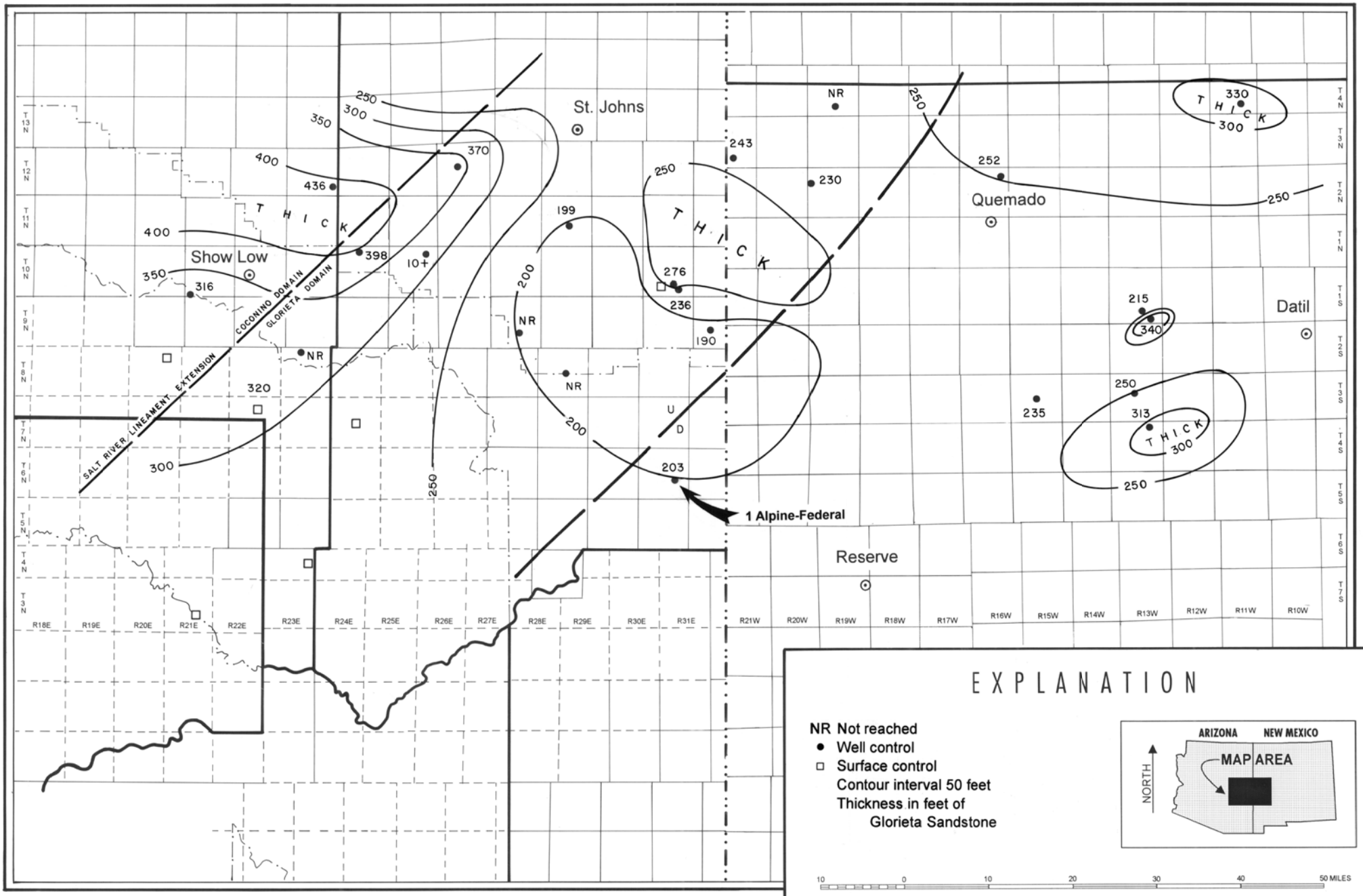
Structure on top of Glorieta Sandstone

ARIZONA NEW MEXICO



EXPLANATION

NR Not reached
● Well control
□ Surface control
Contour interval 50 feet
Thickness in feet of
Glorieta Sandstone

10 0 10 20 30 40 50 MILES
10 0 10 20 30 40 50 KILOMETERS

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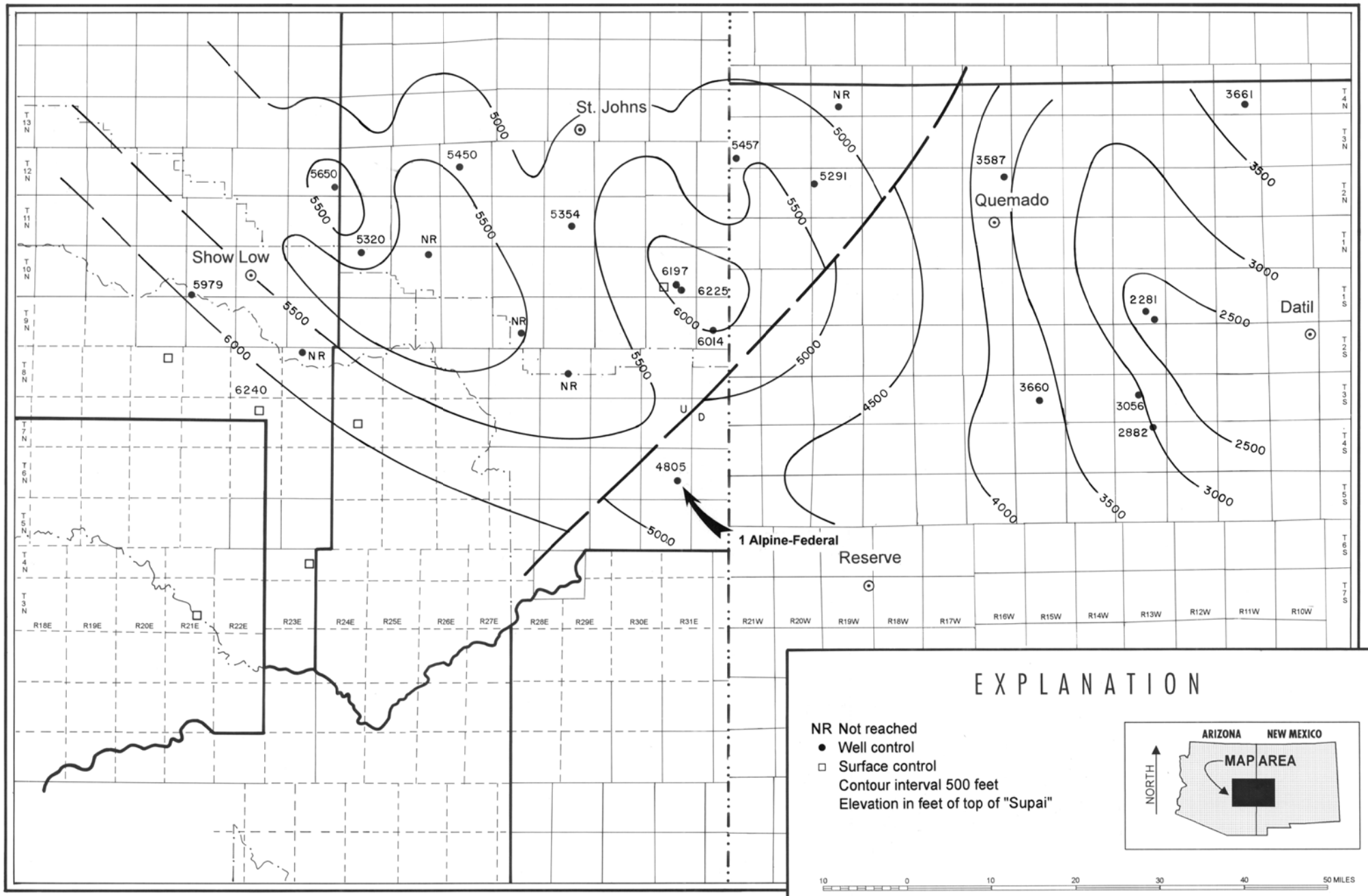
Thickness of Glorieta Sandstone

ARIZONA NEW MEXICO



EXPLANATION

NR Not reached
● Well control
□ Surface control
Contour interval 500 feet
Elevation in feet of top of "Supai"

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

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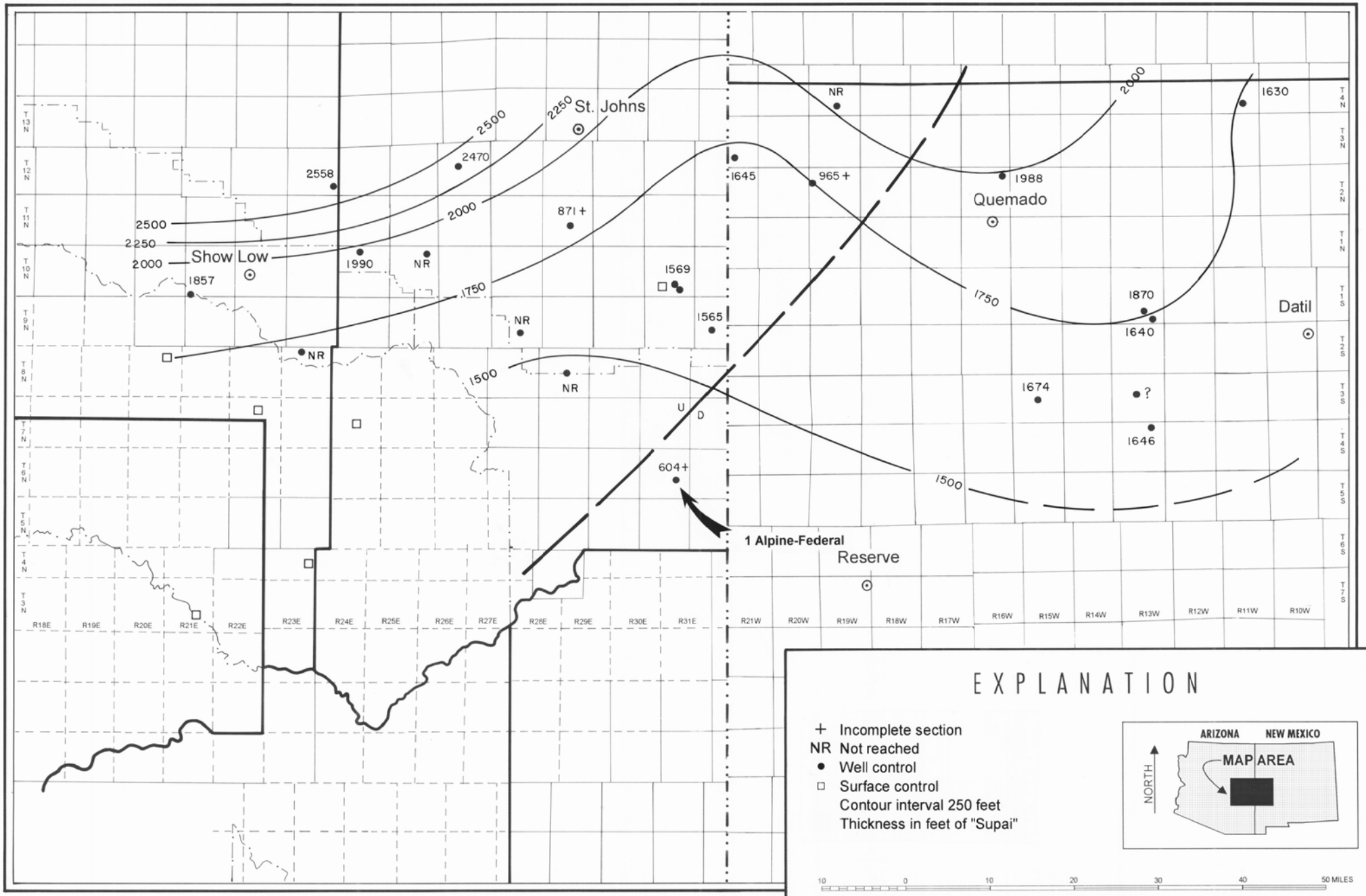
Structure on top of Supai Group (Top Yeso Formation in New Mexico)

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 8 of 12, with text

ARIZONA

NEW MEXICO



EXPLANATION

+ Incomplete section
NR Not reached
• Well control
□ Surface control
Contour interval 250 feet
Thickness in feet of "Supai"

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

S.L.RAUZI

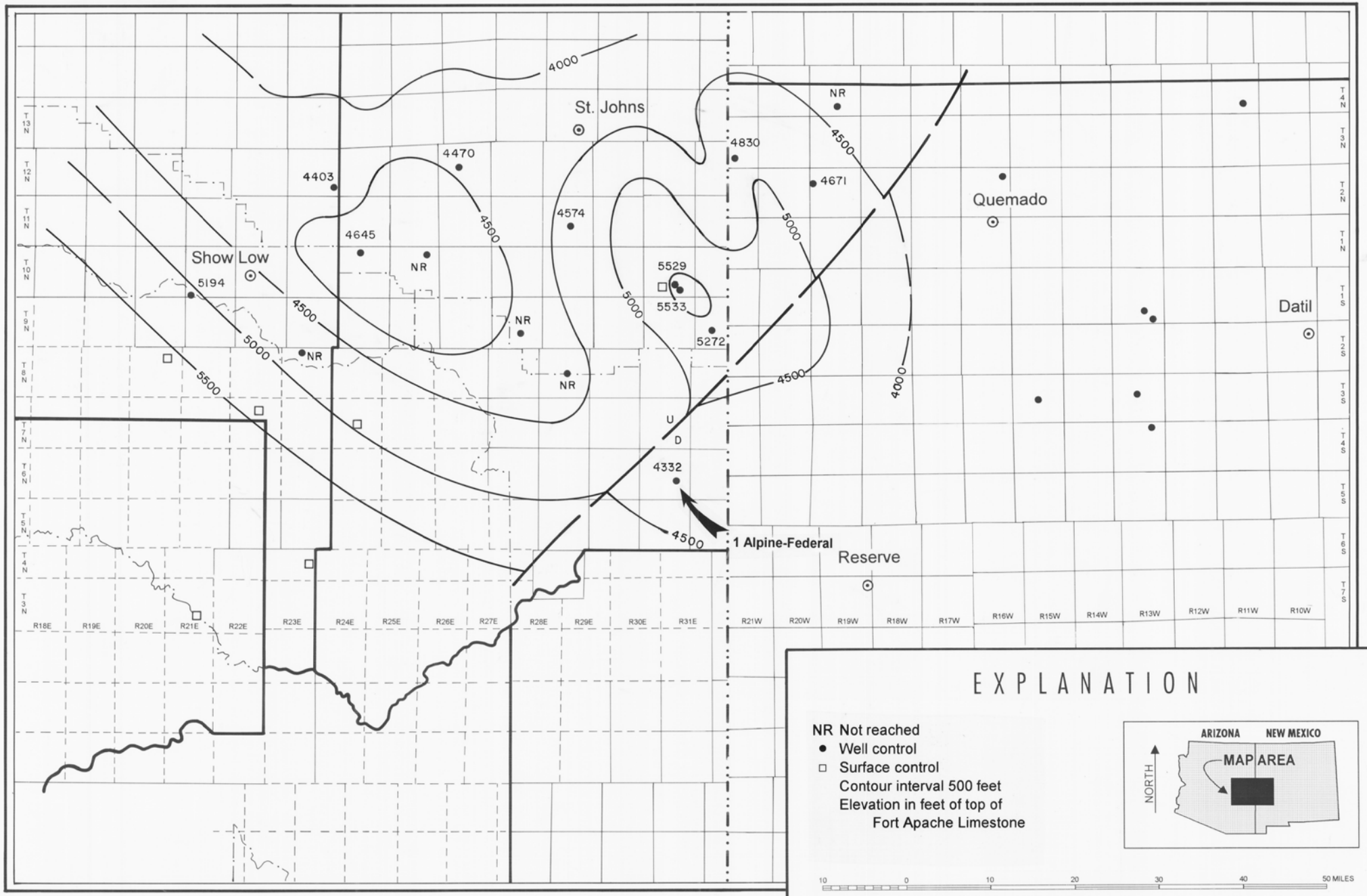
FEBRUARY 1994

Thickness of Supai Group (Includes Yeso and Abo Formations in New Mexico)

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 9 of 12, with text

ARIZONA NEW MEXICO

OFR 94-1



EXPLANATION

NR Not reached
● Well control
□ Surface control
Contour interval 500 feet
Elevation in feet of top of Fort Apache Limestone

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

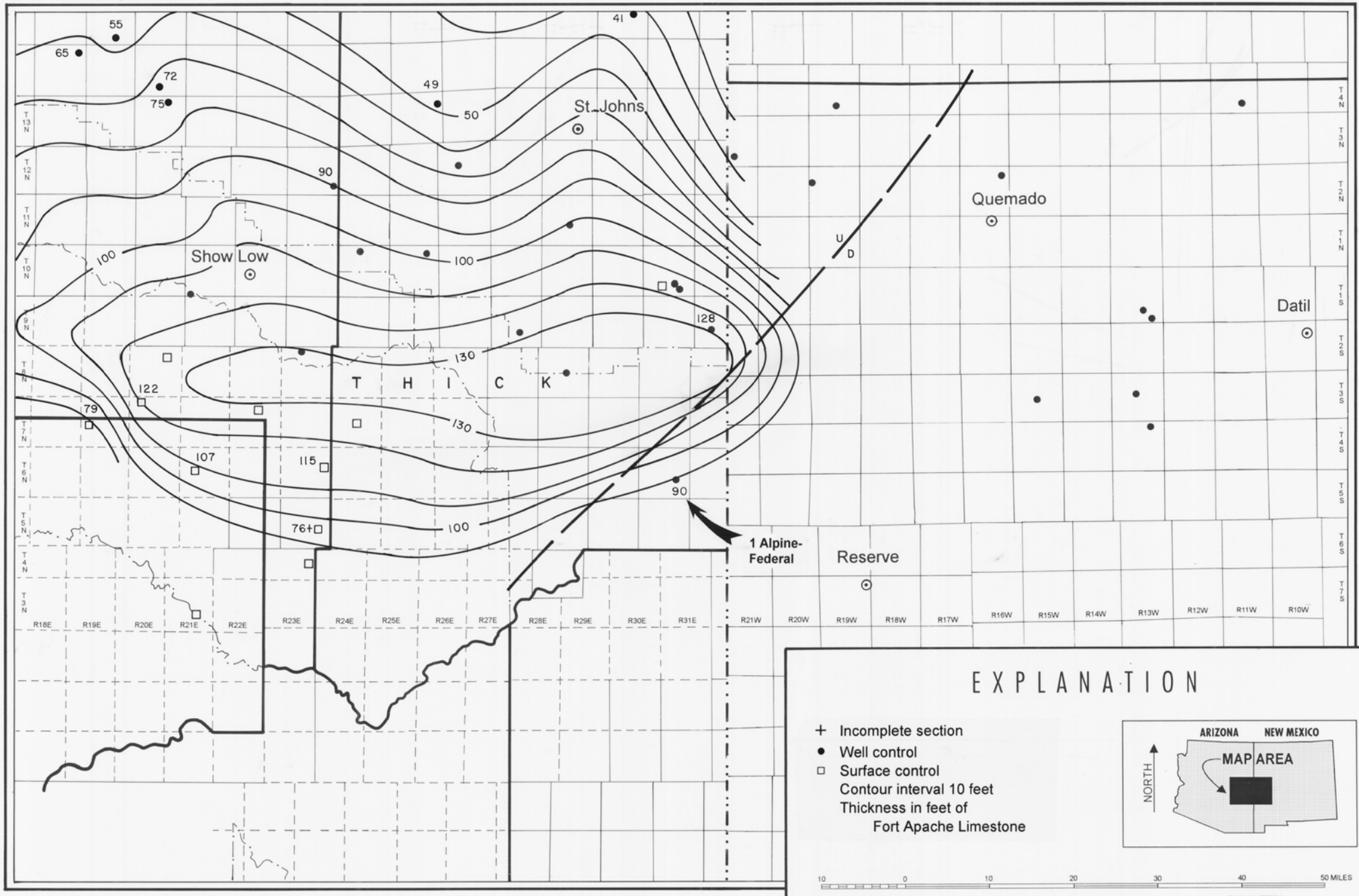
S.L.RAUZI FEBRUARY 1994

Structure on top of Fort Apache Limestone

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 10 of 12, with text

ARIZONA

NEW MEXICO



EXPLANATION

+ Incomplete section
- ● Well control
- □ Surface control

Contour interval 10 feet

Thickness in feet of
Fort Apache Limestone

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

S.L.RAUZI

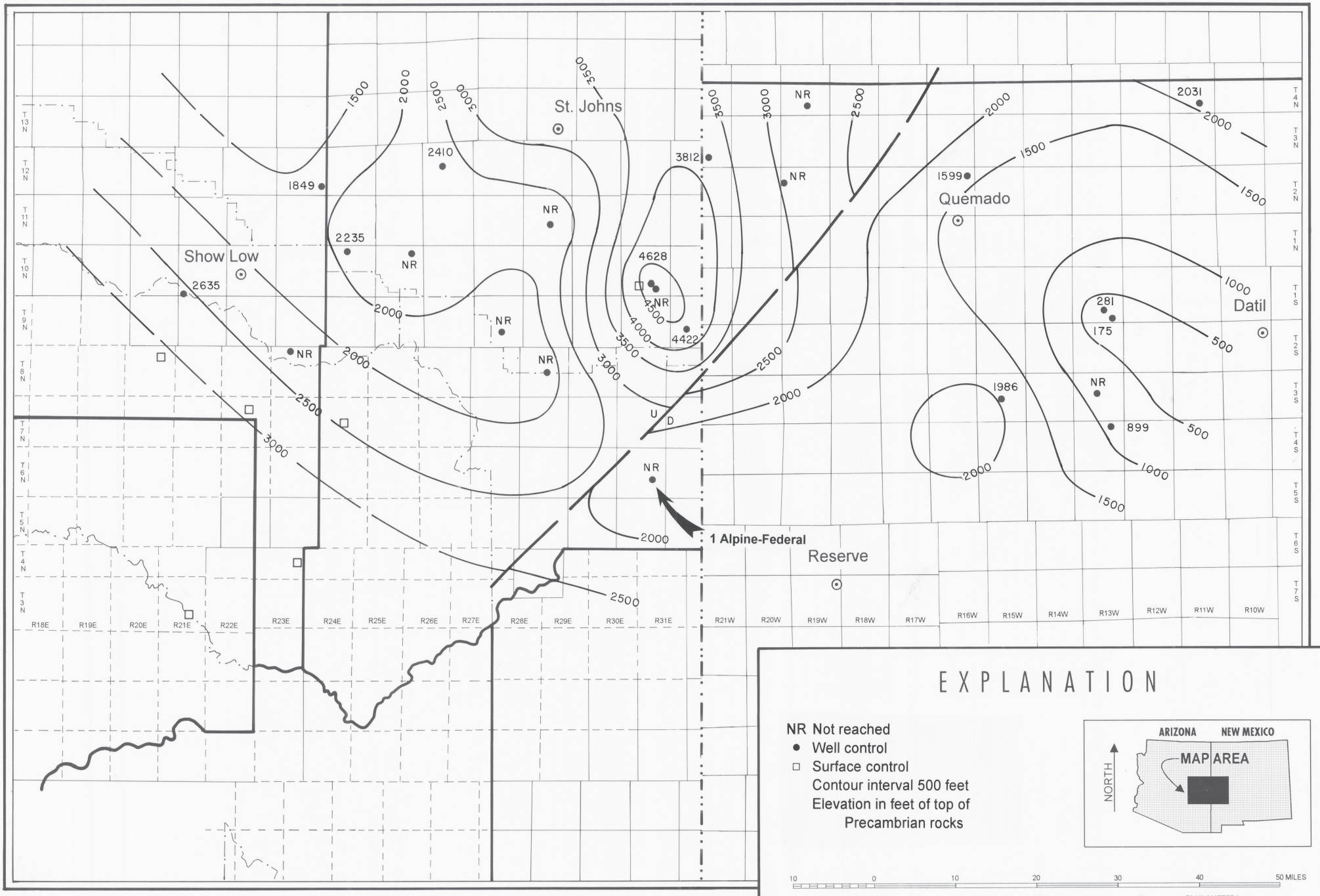
Modified from Gerrard, 1966, Figure 10

FEBRUARY 1994

Thickness of Fort Apache Limestone

Arizona Geological Survey *Open-File Report OFR-94-1*, Plate 11 of 12, with text

ARIZONA NEW MEXICO



EXPLANATION

NR Not reached
● Well control
□ Surface control
Contour interval 500 feet
Elevation in feet of top of Precambrian rocks

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

S.L.RAUZI

FEBRUARY 1994

Structure on top of Precambrian rocks