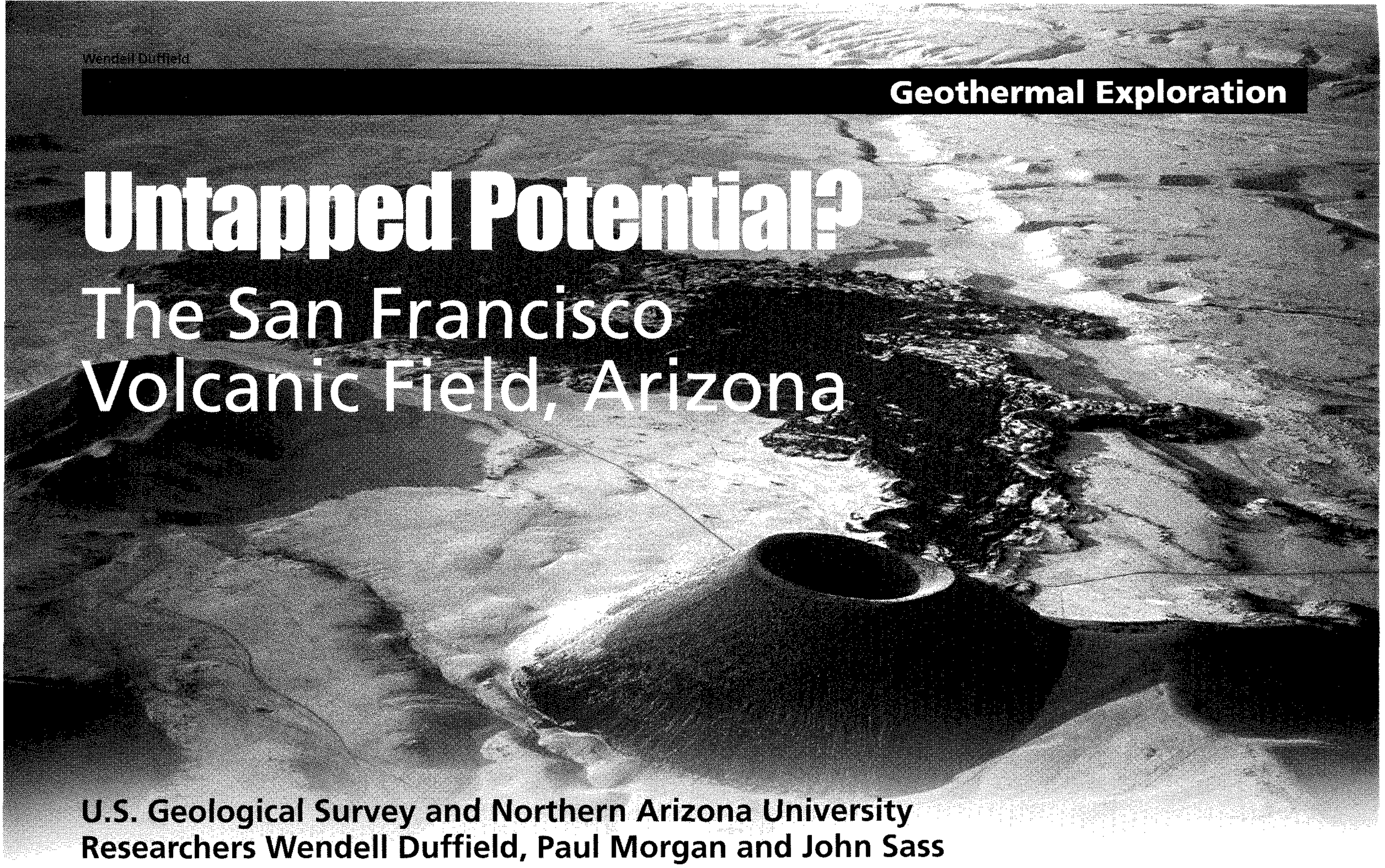

Wendell Duffield

Untapped Potential?

The San Francisco Volcanic Field, Arizona

U.S. Geological Survey and Northern Arizona University Researchers Wendell Duffield, Paul Morgan and John Sass Say Geothermal Exploration Drilling Should Start Now

The San Francisco Volcanic Field (SFVF) of northern Arizona was a focus of reconnaissance studies for geothermal energy potential during the late 1970s and early 1980s. However, lack of surface manifestations and shallow exploration targets as promising as several others elsewhere in the western United States resulted in a waning of interest by geothermal developers. As a consequence, geothermal exploration in the SFVF never advanced to exploratory drilling, even though the youthfulness of volcanism suggested a potent thermal anomaly in the crust (Muffler, 1979).

The U.S Department of Energy (DOE) recently publicized its GeoPowering the West Initiative (GRC *Bulletin*, Jan./Feb. 2000, v. 29, no. 1; also see http://www.eren. doe.gov.geopoweringthewest). One of the announced major goals of the initiative is to double the number of states (from four to eight) having geothermal electric power plants by 2006. This announcement has rekindled interest in discovering a geothermal resource of electrical grade in Arizona.

Areas of heat flow high enough to suggest potential for such resources are known within the Transition Zone and the Basin and Range of Arizona (Sass et al., 1994). However, areas that are more likely to contain high-temperature hydrothermal fluids that could be harnessed to generate electricity are within Arizona's late Cenozoic volcanic fields (Fig. 1), including the SFVF (Moore and Wolfe, 1987), the Springerville Volcanic Field (Condit et al., 1999), and the Pinacate Volcanic Field (Gutmann et al., 2000). In our judgment, the SFVF is the most promising of these three.

Most hydrothermal systems capable of development to generate electricity are directly beneath or closely adjacent to young volcanic fields. With rare exception, these young volcanic areas include a significant presence of silicic (rhyolite and dacite) volcanic rocks, in addition to the more common basalt. Obvious exceptions to this generalization exist at Kilauea Volcano, Hawaii, and in Iceland. But in settings with continental crust, young silicic volcanic rocks and "electrical grade" hydrothermal systems go hand-in-hand.

The silicic rocks are solid evidence that an upper-crustal magma reservoir is (or very recently was) present, and can thus serve to power a high-temperature hydrothermal system. The Springerville area of Arizona lacks silicic volcanism young enough to be a contemporary heat source, and its youngest basalt eruptions are older than those of the SFVF. The Pinacate Volcanic Field lacks silicic rocks, and is mostly in Mexico.

High-temperature hydrothermal systems generally are expressed at the Earth's surface as hot springs, fumaroles and high heat flow. However, in situations where such expressions are lacking, yet the presence of young silicic volcanism argues strongly for a substantial upper-crustal thermal anomaly, the volcanic rocks themselves are by default the principal surface guide to evaluation of the potential for a developable hydrothermal system. The SFVF is a classic example of this situation.

This volcanic field extends 50 miles E-W and is about 15 miles wide N-S. Starting about six million years ago, volcanism has mi-

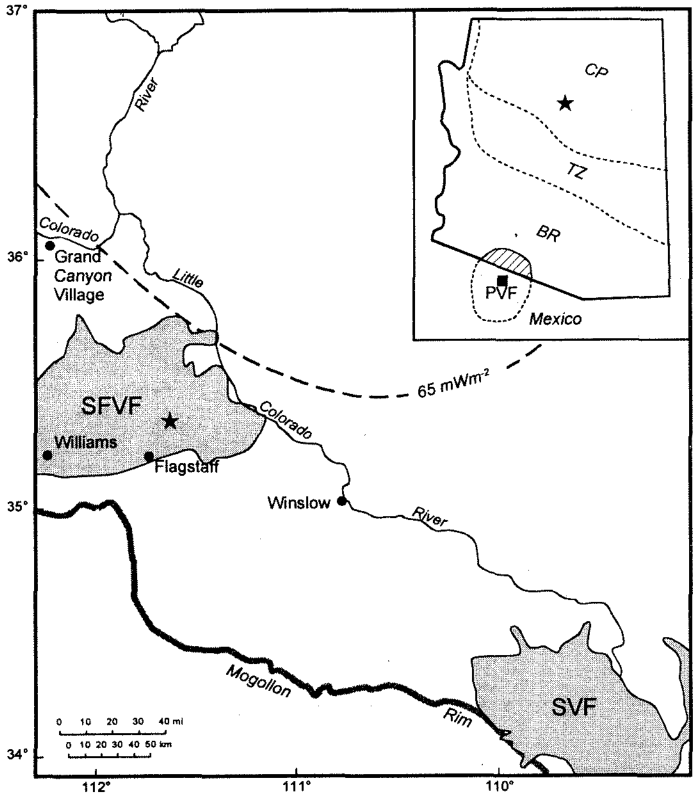

Figure 1. Map showing locations of the San Francisco, Springerville and Pinacate Volcanic Fields (SVFV, SVF, PVF). Inset identifies major physiographic features of Arizona: Colorado Plateau (CP), Transition Zone (TZ), Basin and Range (BR). Star shows location of proposed drill site. Dashed line shows heat flow contour in milliwatts per square meter.

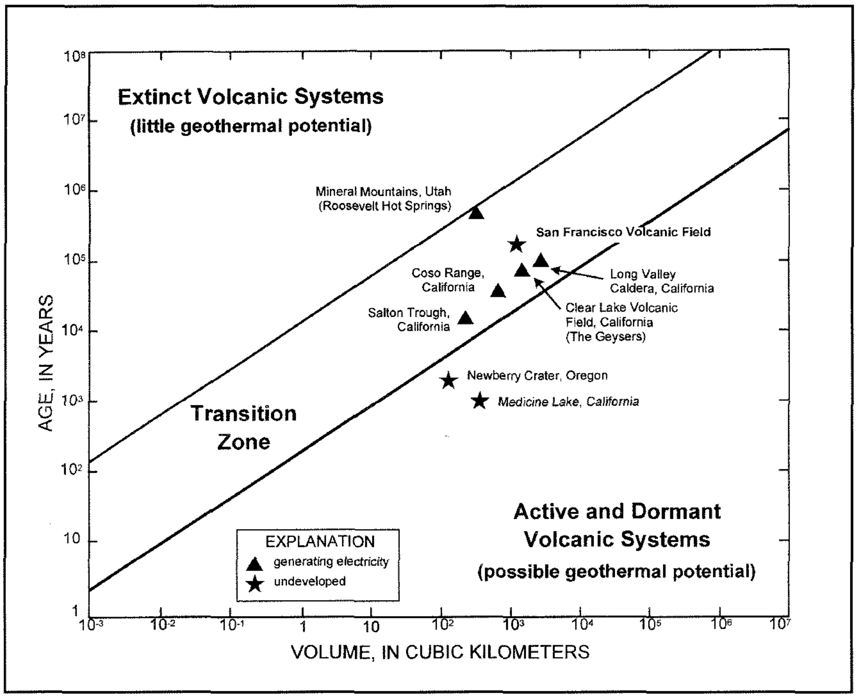

Figure 2. Age of most recent silicic volcanism vs. volume of magma in the crust just after eruption, for selected volcanic fields of the western United States.

grated irregularly eastward with time from the vicinity of Williams to a bit east of Flagstaff (Tanaka et al., 1986). The youngest eruption occurred less than 1,000 years ago (at Sunset Crater) and was basaltic in composition. Adjacent to this very young volcano are rhyolitic and dacitic lava domes and flows (for example, O'Leary Peak and Sugarloaf Mountain), which are only about 200,000 years old (Wolfe et al., 1987; Moore and Wolfe, 1987; Duffield, 1997).

As one method of evaluating the geothermal potential associated with a volcanic field, the U.S. Geological Survey about three decades ago developed a technique to calculate the magnitude of a contemporary upper-crustal heat anomaly, based on the numerical age of the youngest silicic eruption in the field and the estimated volume of magma remaining in the crust immediately after that eruption. The amount of "excess" heat in the upper crust calculated from this age/volume information serves as a guide to the probable presence (or absence) of an electrical-grade hydrothermal system.

The calculation for the youthful silicic part of the SFVF indicates a substantial thermal anomaly, and thus potential for an associated high-temperature hydrothermal system. Results are reported in Muffler (1979) and Duffield et al. (1994), and a table of supporting data appears in Smith et al. (1978).

We illustrate results graphically here (Fig. 2), and point out that the SFVF appears as promising as several other young volcanic fields elsewhere in the western United States that have been developed to generate electricity since resources calculations were made in the 1970s.

For lack of thermal manifestations, the SFVF is not amenable to many of the surface geoscience techniques that have been used to identify, define, and delineate geothermal reservoirs elsewhere. However, in addition to the volcanic analysis described above, studies of how seismic waves from distant earthquakes traverse the crust beneath the SFVF indicate a zone of anomalously slow seismic velocity that extends across most of the eastern half of the field (Stauber, 1982). The core of this anomaly is beneath the vicinity of Sunset Crater-O'Leary Peak–San Francisco Mountain, and suggests the presence of partly molten and/or anomalously hot rock in the mid-to-lower crust (9-35 km depth).

Another seismic study (Durrani et al., 1999), based on wave velocities from nearby dynamite blasts, indicates relatively high velocities in the uppermost (10 km and shallower) crust and is interpreted to result from the presence of dikes and other intrusions from an underlying magma source. This study also identified a localized low-velocity region that is interpreted as "partially melted material related to the Sunset Crater volcanic center," the youngest volcano of the entire field. Thus, seismic evidence and youthful volcanism together point to a promising geothermal prospect in the eastern part of the SFVF.

Silica geothermometry is a common exploration tool in geothermal studies. However, no hot springs exist in the area of interest. Lack of hot springs and fumaroles may simply reflect the fact that the regional water table is more than 1,000 feet deep—heat that might otherwise be expressed as surface manifestations is believed to be swept away laterally by regional subsurface groundwater flow (Sass et al., 1994). Nonetheless, well water may contain a minor component of thermal water mixed with "normal" ground water. For example, silica concentrations in 544 water samples from within and somewhat south of the SFVF suggest silica-equilibrium temperatures of 7.4° to 135.7°C (Taylor, 1997).

Concentrations of various cations typical of thermal, but not normal ground waters, provide additional evidence that waters from deep wells include a component of thermal water. Insufficient data are available to estimate the proportions of thermal and nonthermal waters, but enough information exists to suggest reservoir temperatures systematically greater than 100°C.

Given this geologic and hydrologic information—and encouraged by DOE's desire to discover new electrical-grade geothermal resources in four additional western states—we submit that there is strong justification to drill an exploration well to a depth of between 2.5 and 3.0 km in the area where the youngest silicic rocks, the seismic anomalies, and the silica-groundwater anomaly overlap. An ideal site for such drilling is within a large gravel pit on U.S. Forest Service land (Fig. 3), west and near the base of O'Leary Peak. This gravel pit is scheduled to terminate operation by the end of 2000, and the already disturbed condition of the land there should minimize the potential for environmental concerns.

If drilling identifies a commercial-grade hydrothermal reservoir, there is likely to be interest on the part of industry to define the size of the reservoir, to drill a series of production and injection wells, and to erect a geothermal power plant in or near the already disturbed area. The State of Arizona very recently announced a new tax law favorable to developers of renewable energy sources, including geothermal. The state also recently announced that at least one percent of all electricity generated in Arizona must use alternative energy resources, one of which could be geothermal.

It seems likely that an exploration hole of the sort we propose will be drilled in this area sooner or later, as demand for sources of "clean-and-green" electrical power continues to grow. Let's do so now, rather than wait yet another two decades to test what appears to be a favorable geothermal drilling target. ■

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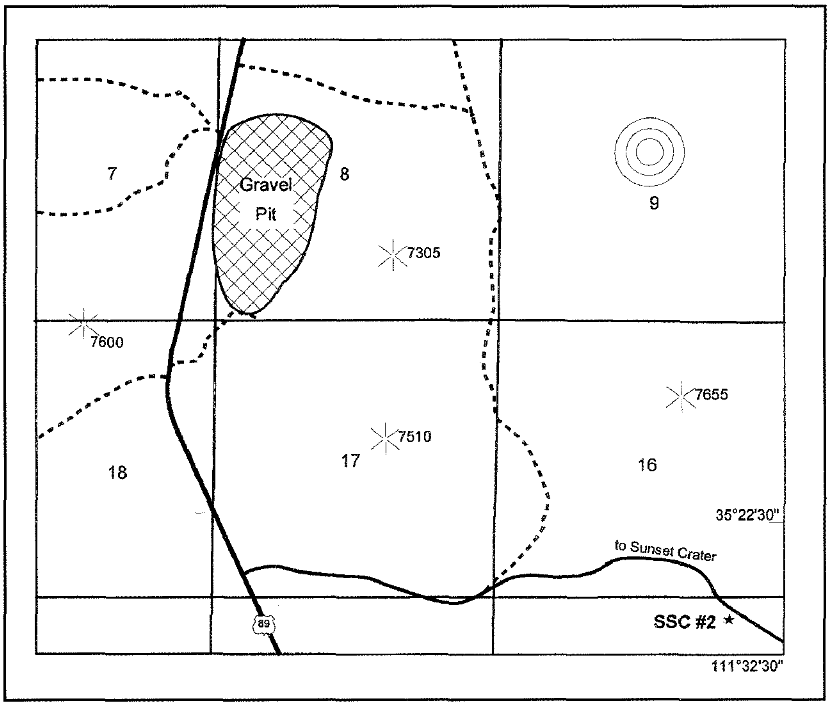

Figure 3. Map showing area for proposed drill site (hatched area). SSC #2 is a water well drilled by the U.S. National Park Service. Quaternary basalt cinder cones are depicted by stars; Quaternary rhyolite dome by concentric rings; U.S. Forest Service roads are depicted by dashed lines.

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