Arizona Bureau of Geology and Mineral Technology

FIELDNOTES

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MAPS: the Earth on Canvas

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Amelia Earhart, the plucky aviator whose 1937 round-the-world flight attempt ended in disaster, may have been the victim of a mapmaker's mistake. Earhart's flight plan gave the wrong coordinates for Howland Island, the 2-mile-long sandbar in the South Pacific that she and navigator Fred Noonan were trying to reach when they vanished. The faulty flight plan, which was based on inaccurate government charts, put Howland Island 7 miles to the northwest of its actual location. Earhart's flight plan listed the coordinates for the tiny island as latitude (lat) 0°49′ N., longitude (long) 176°43′ W., whereas the actual coordinates are lat 0°48′ N., long 176°38′ W. (Barker, 1986). Some investigators who researched the possible causes for Earhart's disappearance believed that she and Noonan were on course and would have reached Howland Island if they had been given the correct coordinates. The first chart to list accurate coordinates was published 4 to 5 months after they vanished. It is therefore likely that the mapping mistake was discovered during the search for Earhart.

Earhart's story illustrates the importance of accuracy in maps and translates a seemingly inconsequential error on paper into the language of human tragedy. Accurate, detailed maps have enabled humans to chart not only their courses across vast oceans, but also the progress of their civilizations. The following article gives an abbreviated history of cartography, the art and science of mapmaking; explains scale, coordinate systems, and projections; illustrates how remote-sensing techniques aid mapmaking; describes various specialized maps and how they are used; and lists several sources of maps of Arizona.

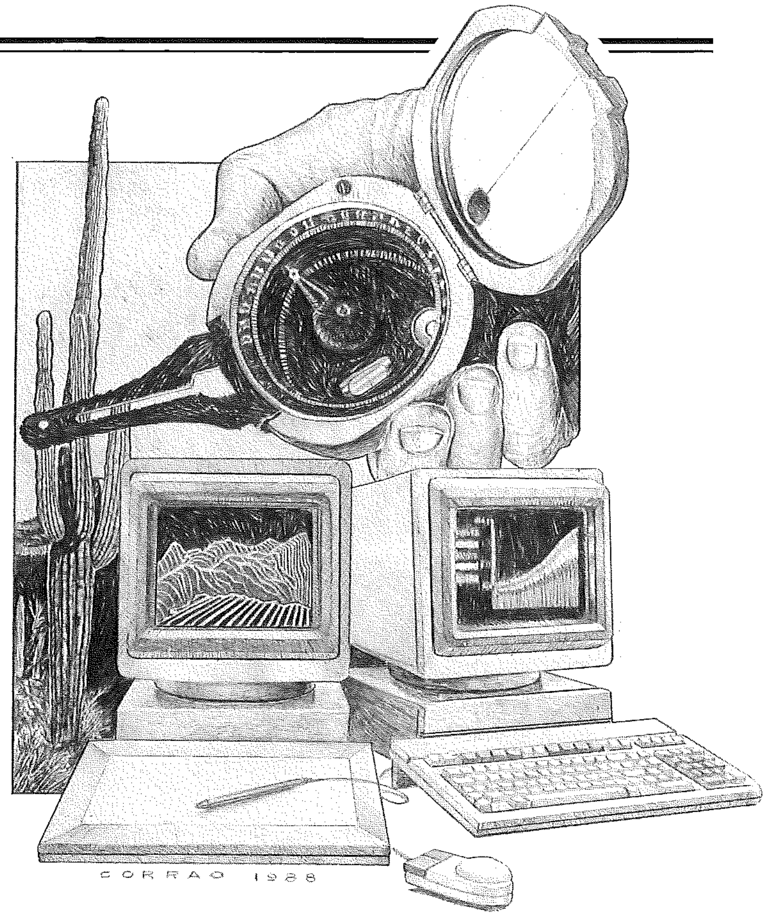

Figure 1. *Today's cartographic instruments range from the compass, which was invented during the 11th or 12th century, to sophisticated computer systems that increase the speed, accuracy, and quality of mapmaking efforts.*

HISTORY OF MAPMAKING

Maps are as old as human culture. The detail and accuracy of mapmaking efforts have, in turn, both reflected and enhanced the advancement of civilization. From prehistoric hunters, who probably drew crude maps in the dirt, to Renaissance navigators, who explored and mapped the oceans and continents, to today's cartographers, who use satellite images, mapmaking has had a long and exciting history.

As human culture evolved from a nomadic, hunting existence to a more settled, agrarian lifestyle, land ownership and determination of property lines became more important. The oldest known map, dated about 2500 B.C., is a small clay tablet that shows a man's estate nestled amid mountains and rivers in Mesopotamia (Chamberlin, 1950; Raisz, 1962). The Egyptians measured and mapped their countryside for property taxes to fuel their thriving civilization. These early peoples believed that Earth was flat; their maps reflected this concept.

Ancient Greek culture emphasized logic, reason, and scientific thought, nurturing interest in the world as well as the mind. The Greeks conceived the idea of a spherical Earth. About 400 B.C., Aristotle offered evidence as proof: the shape of Earth's shadow on the Moon during an eclipse (Chamberlin, 1950). Eratosthenes (276-194 B.C.), mathematician and philosopher, estimated the size of Earth based on observations of shadows and a knowledge of geometry. Despite his crude methods (by modern standards), his estimate of Earth's circumference (28,000 miles) was only 12 percent larger than its actual size (about 24,900 miles; Chamberlin, 1950). His map, which showed parts of Europe, Africa, and Asia, was the first to include parallels and meridians. The early Greeks also defined the poles, Equator, and tropics and developed several projections that are still used today.

Medieval cartographers, seeking a more simplistic view of the world to mirror their religious beliefs, chose more symmetrical, "divinely perfect" outlines for Europe, Africa, and Asia rather than the more accurate irregular coastlines of earlier maps. In the late 13th century, however, the use of the compass burgeoned, as did the production of highly accurate maps known as portolan charts, which were used with minor modifications for more than three centuries. Portolan charts were based on systematic compass surveys. Most charts included 16 or 32 compass roses with radiating rhumb lines (lines that show compass direction), a design sometimes used on current maps as decoration (Raisz, 1962).

The discovery of the Americas effected a renaissance in cartography. As the number of trade routes increased, so did the need for more detailed maps. New discoveries from explorations modified humans' view of the world. The first map to include America, published in 1500, showed it as part of Asia (Raisz, 1962). It was not until after Magellan's voyage from 1519 to 1522 that maps accurately depicted the immensity of the Pacific Ocean. The invention of the engraving and printing processes during this period enabled wider and more timely distribution of new maps. The highest quality maps produced during the late 16th and 17th centuries were compiled by Dutch and Flemish mapmaking masters, such as Mercator, Ortelius, and Janszoon (Raisz, 1962).

The 18th century, known as the Age of Reason, brought a concomitant age of map accuracy. Instruments to measure latitude and longitude became more sophisticated. Triangulation and topographic mapping of France during this time, sponsored by the Cassini family, spurred interest in similar national surveys during the following century (Raisz, 1962). Cartographers of the 19th century also diversified and specialized their products, creating geologic, economic, and transportation maps, among others. With the founding of the U.S. Geological Survey (USGS) in 1879, systematic mapping of the United States became an organized effort.

In our own century, the advent of remote-sensing techniques, such as aerial photography and satellite imagery, has enabled cartographers to create a "bird's-eye" view of the world and its features. Digital scanning systems and laser plotters have dramatically increased the accuracy and detail of modern maps (Figure 1). Technological advances and increasingly sophisticated instruments continue to enhance the quality and accuracy of human attempts at sketching the face of Earth.

SCALE

Scale defines the relationship between a distance shown on a map and the corresponding actual distance on the ground. Scale may be expressed in three ways (Zumberge and Rutford, 1983):

(1) As a graph, line, or bar divided into units that represent ground distances.

(2) In words that state the relationship between map distance and ground distance; for example, "one inch equals one mile" means that 1 inch on the map corresponds to 1 mile on the ground.

(3) As a fraction or fixed ratio between linear measurements on the map (the numerator) and corresponding distances on the ground (the denominator). For example, a scale of $\frac{1}{63,360}$ or 1:63,360 means that 1 unit of measurement on the map (1 inch, 1 centimeter, etc.) represents 63,360 of the *same* units on the ground. In this example, 1 inch on the map corresponds to 1 mile on the ground [1 inch (map) = 63,360 inches (ground) = 5,280 feet (ground) = 1 mile (ground)]. The first number (map distance) given in the ratio is always 1; the second number (ground distance) varies, but the *larger* the second number, the *smaller* the scale.

Many areas have been mapped several times, but at different scales. One should choose a map with a scale specific to its intended use. For instance, a large-scale map shows more detail, but less area; therefore, an urban planner might choose a 1:600-scale map that

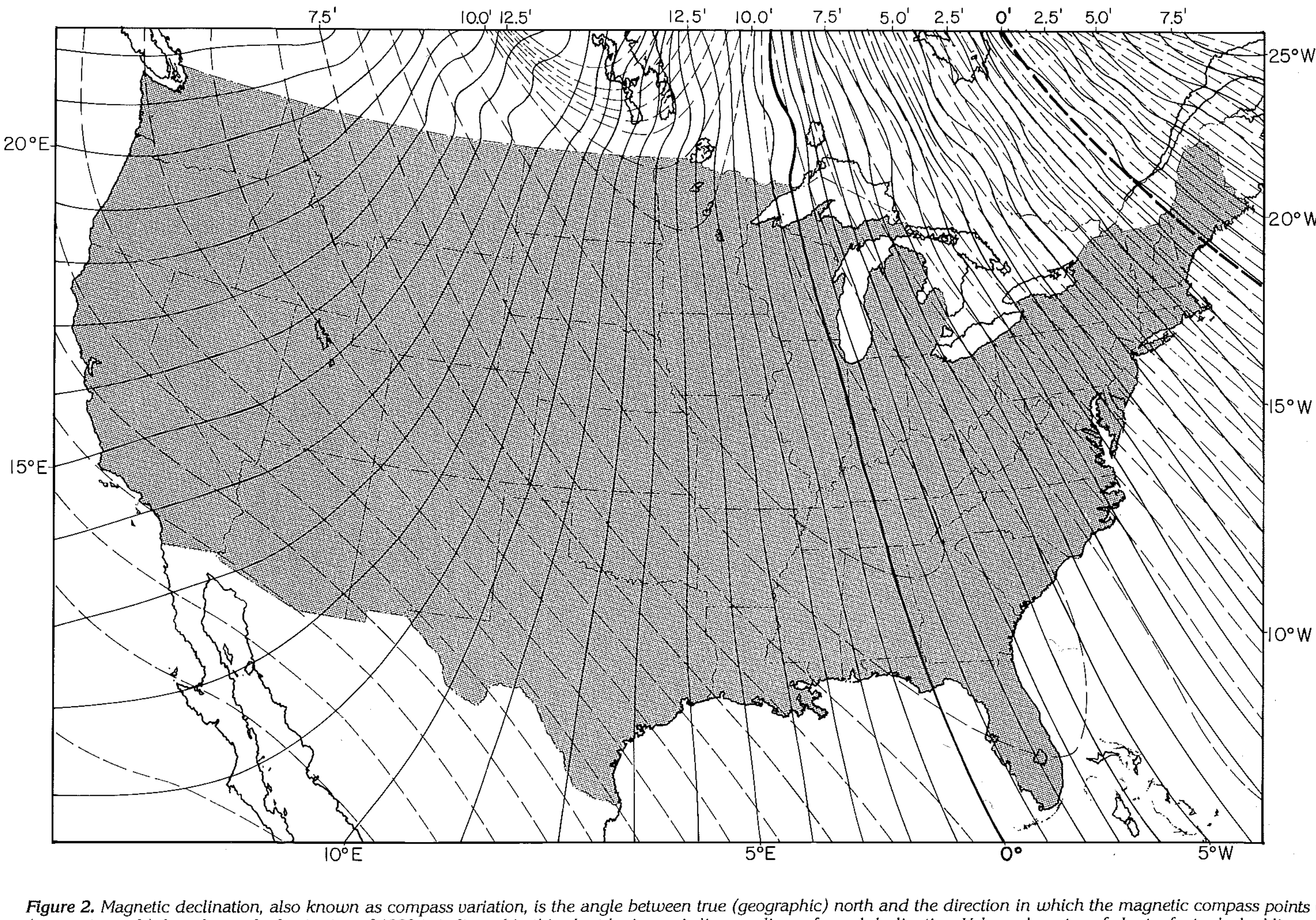

Figure 2. Magnetic declination, also known as compass variation, is the angle between true (geographic) north and the direction in which the magnetic compass points (magnetic north). Its value at the beginning of 1980 is indicated in this chart by isogonic lines, or lines of equal declination. Values along top of chart refer to dashed lines. Values along sides and bottom of chart refer to solid lines. Solid lines indicate number of degrees between magnetic north and true north, with magnetic north east of true north west of 0° line (labeled on bottom of chart), and west of true north east of 0° line. Dashed lines indicate change, in minutes per year, in direction of magnetic north, with change to more eastward direction east of 0° line (labeled on top of chart), and change to more westward direction west of 0° line. From Fabiano and Peddie, 1980.

shows power and water lines, house lots, streets, etc. A small-scale map shows less detail, but encompasses a wider area. A geologist interested in the general geologic history of Arizona might choose a 1:500,000-scale geologic map of the State that shows major rock formations and geologic features.

Large-scale topographic maps (see section titled "Types of Maps") of 1:24,000 show natural and manmade features, such as important buildings, campgrounds, caves, ski lifts, watermills, bridges, and private roads. Intermediate-scale topographic maps of 1:50,000 and 1:100,000 usually omit these features. Small-scale topographic maps of 1:250,000 and smaller (i.e., scales with a larger denominator) show only major features such as national and State parks, Indian reservations, airports, major roads, and railroads (U.S. Geological Survey, 1981b).

COORDINATE SYSTEMS

"Finding oneself" is not easy in this world, whether it be in the psychological or the geographical sphere. Ever since the first map was compiled, cartographers have searched for an accurate system to locate points on the globe. Some map users, such as navigators, need a means to track their progress across oceans; others, such as land owners and government officials, need a method to establish property lines; still others, such as geologists, need a way to identify localities of outcrops, minerals, etc., so that future researchers can find and study them.

In the United States, three coordinate systems are generally used: (1) geographic coordinates (latitude and longitude); (2) Public Land Survey (PLS), also called the "Land Office Grid" or "township and range"; and (3) Universal Transverse Mercator (UTM) grid. Each of these systems is explained in sections that follow.

Latitude and Longitude

Cartographers have arbitrarily divided Earth's surface into a system of reference coordinates termed latitude and longitude based on a series of imaginary lines, called parallels and meridians, respectively, drawn on the surface.

If one imagines Earth as a globe with an axis through the North and South Poles, meridians of longitude would be circles around the globe that pass through both poles. A meridian is labeled according to its distance, measured in degrees, east or west of the zero meridian, which was established in 1884 by international agreement as the meridian that passes through Greenwich, England, near London. Before this time, many countries used meridians that passed through their own capital cities as the 0° meridian for their own maps (Chamberlin, 1950). The zero meridian is also called the Greenwich or prime meridian. Because the globe encompasses 360°, the 180° west meridian (long 180° W.) and the 180° east meridian (long 180° E.) represent the same imaginary line known as the International Date Line. Although this line mostly follows the 180° meridian, there is some variation to prevent separating land masses, such as the Aleutian Islands, into two time zones.

Midway between the North and South Poles, an imaginary line called the Equator circles Earth and cuts it in half into the Northern and Southern Hemispheres. Imaginary lines drawn concentrically around the poles and parallel to the Equator are called parallels of latitude. They are labeled according to their distances, measured in degrees, north or south of the Equator. The Equator is 0° latitude (lat 0°), the North Pole is 90° north latitude (lat 90° N.), and the South Pole is 90° south latitude (lat 90° S.). Parallels of latitude, as their name states, always parallel each other; meridians of longitude, however, converge at the poles.

Each degree used to measure latitude and longitude may be divided for more precise location into 60 minutes, represented by the symbol ′. Each minute, in turn, may be subdivided into 60 seconds, identified by the symbol ″. For example, coordinates of the office of the Arizona Geological Survey are about lat 32°13′57″ N., long 110°57′22″ W. (U.S. Geological Survey, 1983c).

Because the circumference of Earth is about 24,900 statute (land) miles (21,600 nautical miles), each degree of latitude measures about

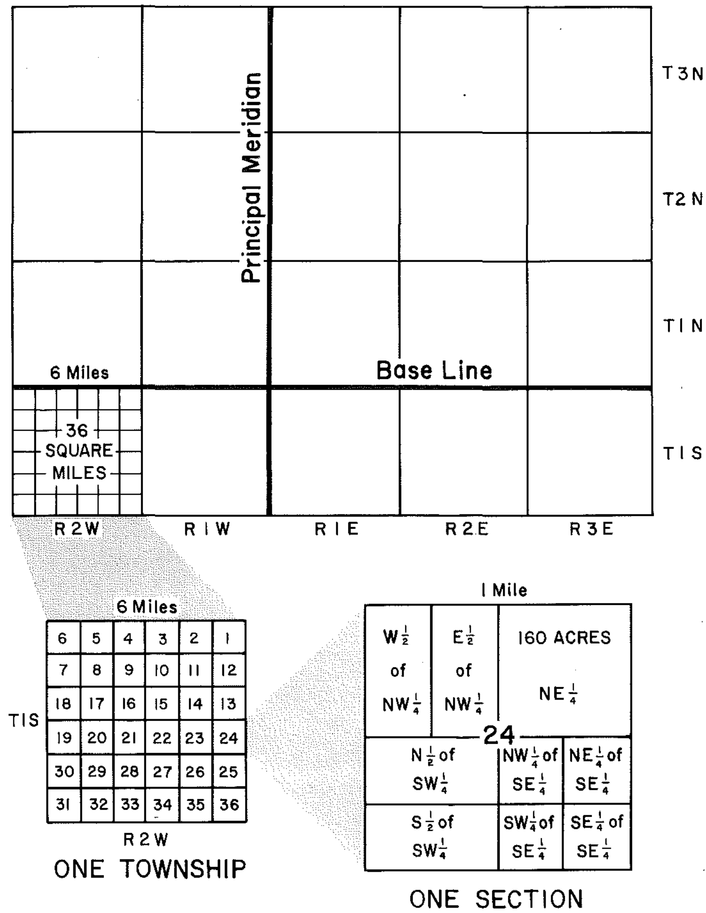

Figure 3. Township-and-range land divisions used in the United States and some parts of Canada. From Zumberge and Rutford, 1983.

69.2 statute miles (60 nautical miles), each minute measures about 1.15 statute miles (1 nautical mile), and each second measures about 101 feet (Chamberlin, 1950). Distances represented by degrees of longitude vary depending on the latitude. At the North and South Poles, for example, one could walk through 360° of longitude by walking in a circle around the pole. At the Equator, such a walk would be a considerable undertaking indeed!

Time zones are related to meridians because of Earth's rotation. A full rotation of Earth on its axis (360° of longitude) takes 24 hours, 15° of longitude takes 1 hour, and 1° takes 4 minutes.

The latitude-and-longitude coordinate system is used worldwide. Similar systems have been extrapolated for use in space. Of the three systems discussed in this article, this is the only one that can be determined astronomically without a map (Merrill, 1986a).

Meridians always run in a true north-south direction. True north, however, is not the same as magnetic north (the direction that the needle in a magnetic compass points), except on the meridian that passes through the magnetic North Pole (Zumberge and Rutford, 1983). This is because of polar wandering; the geomagnetic axis does not coincide with Earth's axis of rotation. The magnetic North Pole is actually at about lat 70° N., which is about 1,250 miles (2,000 kilometers) from the geographic (true) North Pole (Strahler, 1981).

The angle in any given location between true north and magnetic north is called the magnetic or compass declination. Declination records have been kept in Paris and London since about 1600 (Strahler, 1981). Local declination and its annual variation are usually shown in the lower margin of most maps published by the USGS. The correction for annual change, however, will be only approximate if the map is more than 20 years old (Compton, 1962). Declination can also be determined from an isogonic chart (Figure 2) or by setting a

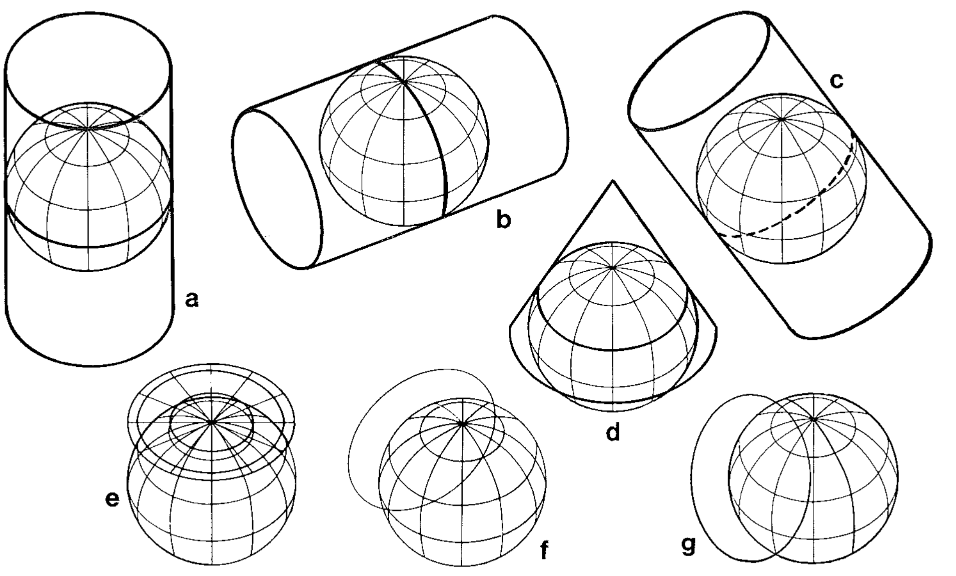

Figure 4. *Projection of the globe onto three surfaces: (a) regular cylindrical (surfaces touch along Equator); (b) transverse cylindrical (surfaces touch along meridian); (c) oblique cylindrical (surfaces touch along circle path); (d) regular conic (surfaces touch along parallel); (e) planar or azimuthal, polar aspect (surfaces touch at pole); (f) planar or azimuthal, oblique aspect (surfaces touch at point between pole and Equator); and (g) planar or azimuthal, equatorial aspect (surfaces touch at Equator). From Snyder, 1987.*

compass on a level surface and sighting on Polaris, the North Star (Compton, 1962). In Phoenix, Arizona, magnetic declination is 13° E., in Tucson it is 12.5° E., and in Flagstaff it is 13.5° E. (U.S. Geological Survey, 1982b, 1983a,c).

Township and Range

Township and range designations are used to locate property boundaries. Although this system of land division is linked to the coordinate system of latitude and longitude, it works independently of it. The basic unit, called a section, is a square-shaped area 1 mile long and 1 mile wide. One section contains 640 acres. A township contains 36 sections, or 23,040 acres. When this system was designed, each section was intended to encompass an exact square mile of land. Surveying errors, however, created irregularities in the shapes of many sections and townships in the United States (Zumberge and Rutford, 1983).

Township-range divisions are based on a grid of perpendicular lines. Boundary lines that run east to west are called township lines; those that run north to south are called range lines. Instead of the Equator and zero meridian, reference lines for township designations are specific latitudinal and longitudinal lines called the base line and principal meridian, respectively (Zumberge and Rutford, 1983). A township is located by giving its position north or south of the base line and east or west of the principal meridian. The notation "T. 4 S., R. 2 W." indicates township four south, range two west. Many base lines and principal meridians are used in the United States, so township and range coordinates are never very large. In Arizona, most townships are measured from the Gila and Salt River Base Line (about lat 33°22′38″ N.) and Meridian (about long 112°18′20″ W.), which intersect on Monument Hill near the confluence of the Gila and Salt Rivers just west of Phoenix (U.S. Geological Survey, 1971). Baseline Road in Phoenix follows the Gila and Salt River Base Line. The other reference point used to measure townships in the State is the intersection of the Navajo Base Line (about lat 35°45′04″ N.) and the 1st Guide Meridian (about long 109°23′01″ W.) on the Navajo Indian Reservation in northeastern Arizona (U.S. Geological Survey, 1955).

As with degrees of latitude and longitude, sections may be further divided to locate features more precisely: into halves [e.g., the north half (N½) or east half (E½)] or into quarters [e.g., the northwest one-quarter (NW¼) or southeast one-quarter (SE¼)]. Quarter sections, in turn, may be subdivided into halves or quarters. In Figure 3, the 40 acres shown in the extreme southeast corner of section 24 are designated by this notation: SE¼SE¼ sec. 24, T. 1 S., R. 2 W.

UTM Grid

The Universal Transverse Mercator (UTM) grid was adopted by the U.S. Army in 1947 to assign rectangular coordinates on military maps of the world (Snyder, 1987). Although the original UTM grid used only numerals as coordinates, the U.S. Army simplified it by substituting letters for several numbers. In military parlance, the UTM is called the Military Grid Reference System; in scientific jargon, it is simply called the UTM (U.S. Department of the Army, 1969, 1983; Hines, 1986; Merrill, 1986b).

The UTM divides Earth from west to east into 60 numbered zones, each of which encompasses 6° of longitude. Beginning at the 180° meridian (the International Date Line), zones are numbered 1 to 60 consecutively from west to east (Merrill, 1986a). For example, zone 1 extends from long 180° W. to long 174° W. From south to north, the UTM divides Earth into 20 lettered subzones, each of which encompasses 8° of latitude, except for zone X, which extends 12° (Merrill, 1986a; Snyder, 1987). These zones are lettered C to X consecutively from south to north. (The letters I and O are not used to avoid confusing them with numbers.) Numbered and lettered grid zones extend only from lat 80° S. to lat 84° N. The polar regions beyond these parallels are assigned coordinates on the Universal Polar Stereographic (UPS) grid, which will not be discussed in this article (Snyder, 1987). Most of the State of Arizona lies in grid zone 12S, which covers a rectangular area from long 114° W. to 108° W. and from lat 32° N. to 40° N.

Each grid zone may be further divided into grid squares that measure 100,000 meters (109,361 yards) on a side; these are given double-letter designations. In turn, grid squares may be subdivided with finer numerical grids that enable one to locate an area 10 meters by 10 meters (11 yards by 11 yards) on most current maps (Merrill, 1986a).

The USGS began adding UTM grid lines to its 7½-minute quadrangle maps in 1957. Most 15-minute quads do not include them. State base maps, new maps, and reprinted quadrangle maps, however, include UTM grid lines or tick marks (Merrill, 1986a).

In an unending quest for perfect accuracy, scientists continue to develop new location systems or modify old ones and debate the usefulness, precision, and accuracy of each (Hines, 1986; Merrill, 1986a,b, 1987; Nelson, 1987).

MAP PROJECTIONS

Earth is a sphere, actually a spheroid because it bulges slightly at the Equator and flattens at the poles. The most accurate map of Earth is a globe because scale is constant and geographical relationships are true. Because a globe is cumbersome and impractical on a large scale, cartographers have developed ways to convert the three-dimensional spherical image to a two-dimensional flat image. A map projection is a systematic method of transferring the grid system of parallels and meridians from globe to paper using mathematical calculations to alleviate distortion (Chamberlin, 1950).

As the word "projection" implies, areas of the globe are projected onto another surface and then transferred to paper. This intermediate surface can be a cylinder, cone, or plane. The shape of this surface, the line of contact or point of tangency between this surface and the globe, and the point on Earth chosen as the center or starting point determine the type of projection (Figures 4 and 5).

There is no best projection to portray the world. A cartographer determines which projection to use based on the characteristics deemed most important, such as area, shape, scale, or direction. Hundreds of projections have been developed throughout the history of cartography, but only a few dozen are used to produce most of today's maps. Some of the more common or useful projections are briefly described below. Snyder (1987) has written an excellent book on projections that includes both historical and descriptive text for the layperson and mathematical calculations for the professional cartographer.

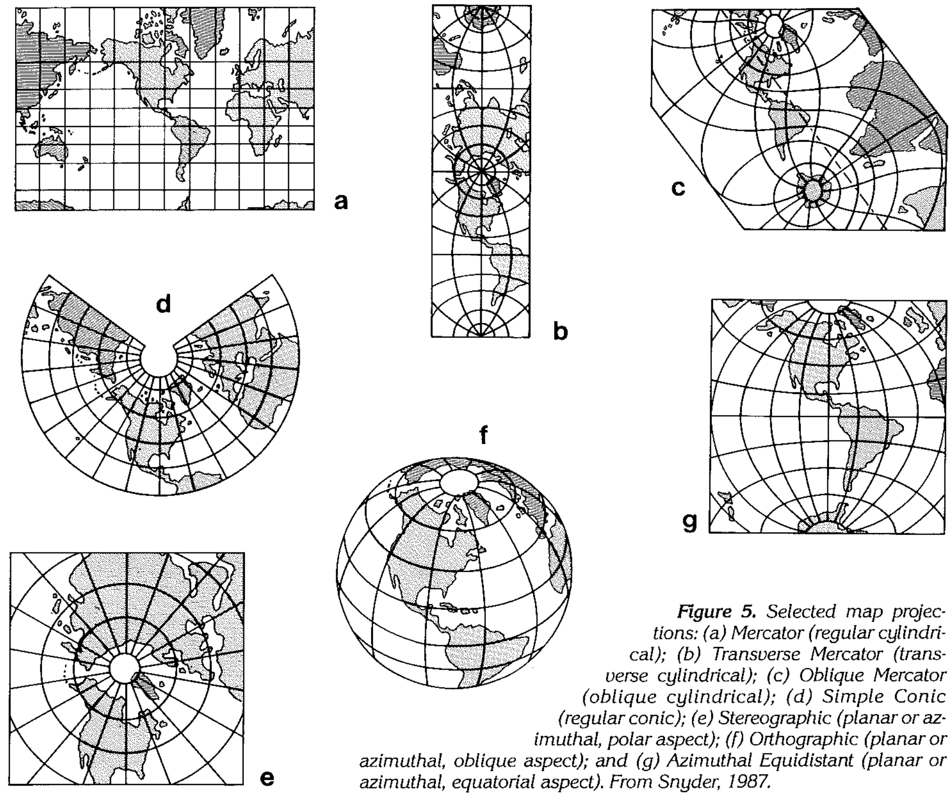

Figure 5. Selected map projections: (a) Mercator (regular cylindrical); (b) Transverse Mercator (transverse cylindrical); (c) Oblique Mercator (oblique cylindrical); (d) Simple Conic (regular conic); (e) Stereographic (planar or azimuthal, polar aspect); (f) Orthographic (planar or azimuthal, oblique aspect); and (g) Azimuthal Equidistant (planar or azimuthal, equatorial aspect). From Snyder, 1987.

Cylinders

Perhaps the most well-known and most easily drawn projection was developed by the Flemish cartographer Gerardus Mercator (1512-94). The Mercator projection is drawn by wrapping a cylinder around the globe, with both surfaces touching along the Equator; meridians are then projected from the center of the globe (Snyder, 1987; Figures 4a and 5a). Mercator developed this projection to aid navigation. This is the only projection on which all points are shown at their true compass courses from one another; if a ship's direction remains constant with respect to north, the sailing route between two points is a straight line. Since 1910 this has been the standard projection used on nautical charts of the U.S. Coast and Geodetic Survey, now called the National Ocean Service (Snyder, 1987). Areas in the polar regions, however, are greatly distorted with this projection. Greenland appears to be larger than South America, yet it is only ⅛ the size of the continent (Snyder, 1987; Figure 5a). Because most world maps in elementary and high school textbooks are drawn with the Mercator projection, students could be confused about relative sizes of land masses. This projection is best used on maps of equatorial regions and has been used to map those areas on Earth, Mars, Mercury, Venus, the Moon, and the satellites of Jupiter and Saturn (Snyder, 1987).

Variations of the Mercator projection have been developed to handle special cartographic needs. In the Transverse Mercator projection, the cylinder and globe touch along a meridian instead of along the Equator (Figures 4b and 5b). Areas along the central meridian remain true to scale, no matter how far north or south of the Equator they are. This projection is used for areas in which the north-south dimension is greater than the east-west dimension. It is also the base for the USGS's 1:250,000-scale maps (1° x 2° quadrangles) and some 7½- and 15-minute quadrangles (Snyder, 1987). In the Oblique Mercator projection, the cylinder touches the globe along a circle path specifically chosen to alleviate distortion in the mapped area (Figures 4c and 5c). The USGS has further modified this to obtain the Space Oblique Mercator projection, which is used for continuous mapping of Landsat satellite images (Snyder, 1987).

Cones

Cylindrical projections are used mostly for maps of the world or narrow areas along the Equator, a meridian, or an oblique circle. Conic projections, on the other hand, are used to map areas in the middle latitudes that extend in mostly an east-west direction.

A regular conic projection is drawn by setting a cone on top of the globe, with the cone apex and globe axis aligned. The cone and globe touch along a specific latitude (standard parallel). Meridians are drawn from the apex to points at which corresponding meridians on the globe intersect the standard parallel (Figure 4d). The cone is then cut along one meridian and unrolled (Snyder, 1987).

The simplest conic projection is the Equidistant or Simple Conic, which shows true scale along all meridians and one or two standard parallels (Figure 5d). It is the basic form developed about 150 A.D. by the Greek astronomer and geographer Claudius Ptolemy. This projection is the one most often used in atlases for maps of small countries (Snyder, 1987).

Variations of the simple conic projection include the Polyconic, which is mathematically based on an infinite number of cones tangent to an infinite number of parallels (Snyder, 1987). This projection was developed by Swiss-born Ferdinand Rudolph Hassler (1770-1843), who became the first superintendent of the U.S. Coast Survey, precursor of the U.S. Coast and Geodetic Survey. Because of Hassler's promotion, the Polyconic projection was used on large-scale maps of the United States, such as USGS 7½- and 15-minute topographic quadrangles, until the 1950's. Quadrangle maps drawn with the Polyconic projection at the same scale and based on the same central meridian will fit exactly from north to south or east to west; however, they cannot be mosaicked in both directions without distortion (Snyder, 1987).

The Lambert Conformal Conic projection was developed by the Alsatian mathematician and cartographer, Johann Heinrich Lambert (1728-77). On this projection, local shapes, scale, and angles remain accurate, but area does not. It is used for mapping large countries and smaller regions with an east-west orientation such as the United States, North Carolina, and Long Island (Snyder, 1987). It is also the projection used for the USGS 1:500,000-scale State base-map series; the Arizona base map was used to compile the 1969 version of the State geologic map (Wilson and others, 1969).

Planes

Azimuthal (or zenithal) projections are drawn on a plane that touches the globe at one of the poles, the Equator, or some point between these. The center of the projection determines its aspect: polar, equatorial, or oblique (Figures 4e, f, g; 5e, f, g). The direction or azimuth from the center to every other point on the map is shown accurately. Because this projection has one standard point or center, it is used mostly to portray circular regions such as Antarctica, rather than areas that extend mostly in one direction (Snyder, 1987). On polar aspects, meridians are shown as straight lines that radiate at true angles from the center (pole), like the spokes on a wheel; latitude lines appear as concentric circles around the pole (Figure 5e).

Except for the polar aspect, azimuthal projections are more difficult to draw than the cylindrical or conic versions. Azimuthal projections, however, portray Earth's roundness and unity, features that are less apparent in the other two projections.

The Stereographic projection is the most widely used azimuthal projection. Hipparchus, the Greek astronomer and father of trigonometry (2nd century B.C.), is credited with its invention, although it was probably known to the Egyptians. The Stereographic projection was used only for maps of the heavens until the early 1500's (Snyder, 1987). This projection can depict only one hemisphere at a time. Its polar aspect is used extensively for maps of Antarctica and the polar regions of other planets and satellites (Figure 5e).

The Orthographic projection is probably the most well known of the azimuthal projections. Because the perspective is from an infinite distance, maps drawn with this projection appear as they would from outer space, with a three-dimensional effect (Figure 5f). Its development is also credited to Hipparchus, who used it for astronomical calculations. The Orthographic projection became popular during World War II as world leaders tried to emphasize the global aspects of the conflict (Snyder, 1987). It is seldom used in atlases today, except for pictorial views of the globe, because only one hemisphere can be shown at a time and distortion near the outer edges is severe.

The Azimuthal Equidistant projection shows distances and directions correctly from one point (point of tangency) on Earth's surface and any other point on the map (Figure 5g). Maps based on this projection usually show less than one hemisphere. The Egyptians probably used the polar aspect for star charts. Navigators have used it to chart coastlines based on distances and directions obtained at sea. This projection is used today in maps of the polar regions and continents and in world maps for radio and seismic use. The polar aspect is also used as the emblem of the United Nations.

REMOTE SENSING

Before the invention of the airplane, mapmaking was a down-to-earth profession based on observations made on land or sea. With the advent of aviation, cameras could record what only birds and balloonists had seen previously. Remote-sensing techniques, such as aerial photography and satellite imagery, are used by scientists, engineers, and cartographers to determine land features, study seasonal changes in vegetation and wildlife habitats, and evaluate damage caused by geologic hazards such as floods, landslides, and active volcanoes.

Vegetational differences are reflected in the shades and patterns that appear in black-and-white aerial photographs. Heavy vegetation such as forests are medium to dark gray in color, whereas grasslands are light gray. Cultivated fields are usually rectangular in shape. Shades also give clues to soil and rock type. Clays that retain moisture, for example, appear darker than dry sand. Because the type of vegetation commonly reflects the bedrock on which it grows, vegetational variations can also be used to determine rock type (Zumberge and Rutford, 1983).

Photointerpretation can be enhanced by viewing aerial photos stereoscopically. Two photos of the same area taken from slightly different positions can be overlapped through the use of a stereoscope to show the relief of the land. Each eye sees only one of the photos, but the brain combines the two images to produce a three-dimensional view (Zumberge and Rutford, 1983).

False-color images are created by satellites that record infrared radiation from Earth. The measured differences are computer-enhanced to produce a picture in which the colors are not true to life; for example, green vegetation may show as red and water may appear black (Zumberge and Rutford, 1983). Color variations result from differences in vegetation, soil, moisture, and rock types. False-color images created by Earth Resource Technology Satellites (Landsat) are byproducts of the U.S. space program. Each Landsat satellite circles the globe 14 times a day, scans a particular area of Earth more than 40 times a year, and creates images, each of which covers 115 square miles (U.S. Geological Survey, 1981a). The frequency and amount of coverage make satellite imagery especially useful in studying Earth's surface. Satellite images, however, cannot show the detail that aerial photographs can because they are taken farther from Earth's surface and thus, at a smaller scale.

TYPES OF MAPS

A map is a graphic representation of part of Earth's surface. Some types, such as road maps, show the distribution of features and manmade structures in two-dimensional form. Other types, such as topographic maps, illustrate the three-dimensional nature of Earth's features on a two-dimensional surface. Because geologic structures are three-dimensional, the latter type of map is more useful to geologists.

There are basically four types of maps: planimetric, topographic, photoimage, and thematic [U.S. Geological Survey, undated(b)]. Planimetric maps show natural and manmade features, such as rivers, lakes, roads, railroads, towns, and land boundaries, but do not show relief features, such as hills or valleys. The latter may be labeled, however. A road map is a planimetric map. Topographic maps show both features and land elevations. Photoimage maps, such as orthophotoquads and orthophotomaps, are derived from aerial photographs that have been corrected to eliminate distortions due to perspective or camera tilt. These maps are related to standard coordinate systems but show details that do not usually appear on conventional maps. Thematic maps show information about a specific topic such as geology, rainfall, population, soil (pedology), or vegetation. Thematic maps include geologic maps, which show the position, structure, and composition of rock units and surficial materials and the nature of boundaries between rock types, such as faults and depositional contacts; geophysical maps, which show variations in geophysical properties, such as gravity or magnetism (Figure 2); hydrologic maps, which show information about water resources; pedologic maps, which show distribution and character of soils; and land-use maps, which indicate the areas that are being used for agricultural, recreational, wilderness, urban, or other purposes [U.S. Geological Survey, undated(b)].

Because of their usefulness to the professional geologist and because they are often confused by the layperson, topographic and geologic maps are described in further detail in following sections.

Topographic Maps

Every geologic process leaves a mark on Earth's surface. Wind and water erosion, glaciation, and volcanism leave their respective signatures as characteristic landforms. Unlike other maps, a topographic map shows these three-dimensional imprints, as well as manmade features. Relief (mountains, hills, valleys, and plains), bodies of water (lakes, ponds, rivers, canals, and swamps), and cultural features (roads, railroads, towns, land boundaries, etc.) are depicted on topographic maps.

On a contour map, relief is shown through the use of contour lines, imaginary lines on Earth's surface that connect points of equal elevation above or below sea level (Figure 6a). A contour interval, the elevation difference between two adjacent contour lines, is generally a constant value chosen according to the ground slope and map scale; it may vary, however, on a single map to show relief features more precisely. Contour intervals range from 5 to 1,000 feet (Zumberge and Rutford, 1983). Widely spaced contours indicate flat areas or areas with a gentle slope, whereas closely spaced contours indicate steep terrain such as mountains or cliffs. Index contours, which are usually every fifth contour line and are drawn with heavier lines than other contours, list elevations. Spot elevations may be given for certain locations, such as mountain summits, road intersections, or lakes. Bench marks indicate points at which the land elevation has been precisely determined by surveying techniques and are marked on land by brass plates that are permanently fixed on the ground. These can be found on the tops of remote mountains as well as on the sidewalks of major cities. Each bench mark is shown on a topographic map by the letters "BM," followed by a cross and the measured elevation. When contour lines cross stream-filled valleys or canyons shown on a map, they bend upstream; the contour resembles the letter "V" with the apex pointing upstream (Zumberge and Rutford, 1983).

On a shaded-relief map, the land is shaded to simulate the effect that sunlight would have on the terrain. The pattern of light and dark accentuates the shape of physical features and creates a three-dimensional effect. Slope maps create this same effect through the use of different colors and shades to indicate steepness and slope [U.S. Geological Survey, undated(b)].

A topographic map covers a specific quadrangle, an area that is outlined by parallels of latitude (the northern and southern boundaries of the map) and meridians of longitude (the eastern and western boundaries of the map). Standard quadrangle maps are bounded by 7½ minutes each of latitude and longitude (7½-minute quad), by 15 minutes each of latitude and longitude (15-minute quad), or by 1° of latitude and 2° of longitude (1° x 2° quad; Table 1). The USGS has been producing standard topographic maps for 7½- and 15-minute quadrangles in the United States since the 1880's. Although the actual area shown on a quad map is not a true rectangle, the map appears to be rectangular because it is drawn at such a large scale.

Government agencies and private industries use topographic maps as bases for more specialized maps, such as geologic, land-use, soil, and road maps. Specialized data are superimposed directly on the topographic base sheet. Topographic maps are also used by planning agencies to aid in selecting sites for highways, airports, industrial plants, pipelines, powerlines, communication facilities, and recreational areas (U.S. Geological Survey, 1983b). These maps are especially important in assessing and managing natural resources. They also serve as practical guides for any camping, hiking, fishing, or hunting trip.

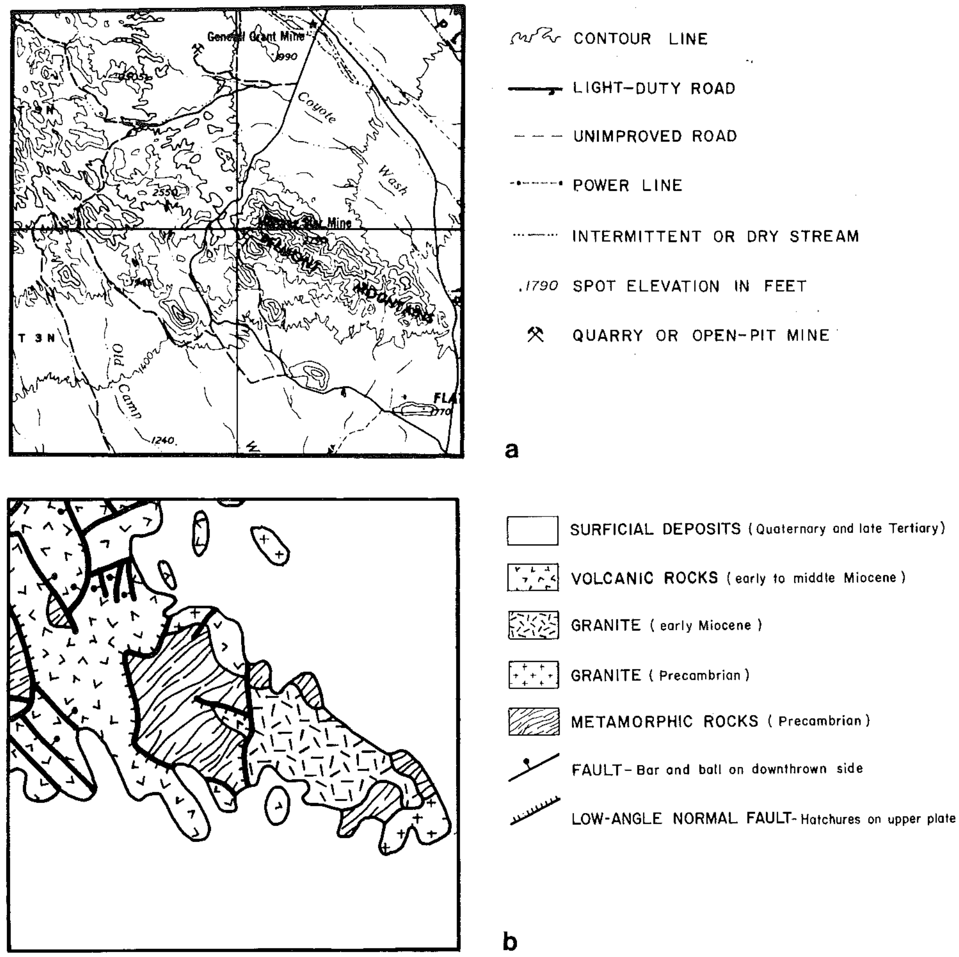

Figure 6. *Comparison of topographic (a) and geologic (b) maps drawn at the same scale for the same region, the southeastern Big Horn and Belmont Mountains of west-central Arizona, an area within townships T. 3 and 4 N., R. 6 and 7 W. Note the contour lines in (a) that indicate relief and the patterns in (b) that symbolize rock types.*

Geologic Maps

Just as a person's face may reflect his or her character, the face of Earth may reveal what lies beneath its surface. A geologic map shows how Earth would appear if materials, such as vegetation, were stripped away (U.S. Geological Survey, 1982a). These maps use standard symbols, patterns, and colors to depict the types and relative ages of rocks and surficial materials, and the surface and subsurface associations of rock units (Figure 6b).

A geologic map is not easy to compile. It requires countless hours of fieldwork, keen observation skills, an ability to think three-dimensionally, and at times, X-ray vision. The first step includes studying areas where the rocks are visible and can be identified in outcrops (ledges, fault scarps, streambanks, etc.) or in manmade excavations (roadcuts, mines, wells, etc.). In areas where the bedrock is covered, geologists may be able to infer the underlying rocks by studying surficial materials, vegetation, landforms, and regional structure. Age-dating techniques are unique to each rock type. The age of each rock or surficial unit is identified from fossils or bits of other rocks included within it, from radiometric dating, or from its position relative to other units. (Barring an episode of geologic upheaval, a sedimentary or volcanic rock unit is always younger than the one below it, a natural law that geologists call the law of superposition.) Geologists also study aerial photographs and preexisting maps to fill in missing data and to corroborate field observations (U.S. Geological Survey, 1982a).

The geologist records the locations, types, and ages of the rock units and surficial materials by using various colors or patterns on a topographic base map. Standard patterns have been adopted to distinguish among rock types. The basic rock units shown on a geologic map are called formations. A formation is usually named after a geographic feature (mountain, canyon, town, etc.) near the area where the unit was first identified. Using special symbols, the geologist records other significant observations on the map such as faults, folds, contacts between rock units, and the strike and dip of formations (respectively, the direction of a horizontal line within a unit and the angle that the unit slopes in outcrop).

The reliability of a geologic map depends on the number of observations made in the field and the competence of the geologist. If there are few outcrops, little contrast between rock types, and a history of complicated geologic events, geologists can make many plausible interpretations and several credible geologic maps of the same area (U.S. Geological Survey, 1982a).

Geologic maps can be used to locate mineral or energy deposits because specific rock types or structures (e.g., faults) are often associated with specific deposits. They can also be used to locate sources of ground water or construction materials (sand and gravel, flagstone, etc.), to determine the suitability of areas for agriculture or urban development, or to identify potential geologic hazards. Geologic maps provide an enormous amount of information needed for

Table 1. Map scales and corresponding areas on the ground. From U.S. Geological Survey, 1981b.

Scale	1 Inch on Map Represents	1 Centimeter on Map Represents	Standard Quadrangle Size (Lat x Long)	Quadrangle Area (Square Miles)
1:24,000	2,000 feet	240 meters	7½ x 7½ minute	49 to 70
1:62,500	nearly 1 mile	625 meters	15 x 15 minute	197 to 282
1:250,000	nearly 4 miles	2½ kilometers	1° x 2° or 1° x 3°*	4,580 to 8,669
1:1,000,000	nearly 16 miles	10 kilometers	4° x 6°	73,734 to 102,759

* 1° x 3° is the standard size for quadrangle maps of Alaska.

deciphering Earth's long and complex geologic history.

WHERE TO OBTAIN MAPS

The National Cartographic Information Center (NCIC) of the USGS provides a nationwide information service for U.S. cartographic data, including maps, charts, aerial photographs, satellite images, and map data in digital form obtained by more than 30 Federal agencies. For information on Arizona, contact either the headquarters (National Cartographic Information Center, U.S. Geological Survey, 507 National Center, Reston, VA 22092; tel: 703-860-6045) or the western branch office (Western Mapping Center-NCIC, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025; tel: 415-329-4309).

The USGS has placed on microfilm virtually all the topographic maps of the United States that it has published since 1884. These are available from the NCIC offices. Printed versions of USGS maps of Arizona (topographic, geologic, land-use, etc.) may be obtained from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Bldg. 41, Denver, CO 80225; tel: 303-236-7477.

Aerial photographs and Landsat images may be obtained from the USGS Earth Resources Observation System (EROS) Data Center. Contact User Services Section, EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198; tel: 605-594-6151.

Another source of aerial photos is the U.S. Department of Agriculture (USDA). The Agricultural Stabilization and Conservation Service (ASCS) maintains an extensive file of aerial photographs. The U.S. Forest Service distributes maps and survey data as well as aerial photos. The Soil Conservation Service produces pedologic maps and soil-survey reports, which include aerial photos and describe the geology, properties, and management of soils within the survey area. Contact the Aerial Photography Office, ASCS-USDA, 2222 West 2300 South, P.O. Box 30010, Salt Lake City, UT 84130; tel: 801-524-5856; U.S. Forest Service-USDA, Region 3, 517 Gold Ave., S.W., Albuquerque, NM 87102; tel: 505-842-3292; or Soil Conservation Service-USDA, 201 E. Indianola Ave., Suite 200, Phoenix, AZ 85012; tel: 602-241-2247.

The U.S. Bureau of Land Management (BLM) compiles and distributes maps that show land ownership: National and State Parks, other State lands, National Forests, BLM lands, Indian Reservations, and private properties. BLM also maintains land records and provides aerial photographs. For information, contact the Arizona State Office, U.S. Bureau of Land Management, 3707 N. 7th St., P.O. Box 16563, Phoenix, AZ 85011; tel: 602-241-5547.

The Arizona State Land Department also supplies land-ownership maps. Its Resource Analysis Division, an NCIC-affiliate office, provides aerial photographs and other remote-sensing data. Contact the Arizona State Land Department, 233 N. Main Ave., Tucson, AZ 85701; tel: 602-628-5480; or the Resource Analysis Division, Arizona State Land Department, 1616 W. Adams, Phoenix, AZ 85007; tel: 602-255-4061.

The Arizona Department of Transportation produces planimetric maps that outline roads, distinguish road surfaces (e.g., paved vs. dirt), and show other cultural features. Contact the Highways Division, Arizona Department of Transportation, 206 S. 17th Ave., Phoenix, AZ 85007; tel: 602-255-7011; or Engineering Records, Arizona Department of Transportation, Rm. 112-F, 1655 W. Jackson, Phoenix, AZ 85007; tel: 602-255-7498.

The Arizona Geological Survey, which is the Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology, produces various maps as a result of its own research efforts. Among these are maps that show geology, mineral occurrences, geothermal resources, historical epicenters, areas of land subsidence, and earth fissures. Contact the Arizona Geological Survey, 845 N. Park Ave., Tucson, AZ 85719; tel: 602-621-7906.

Planning offices for each county produce and distribute planning and zoning maps. For maps of the two most populous counties, contact the Cartographic Section, Maricopa County Department of Planning and Development, 111 S. 3rd Ave., Rm. 300, Phoenix, AZ 85003; tel: 602-262-3569; or the Pima County Planning and Development Services Department, 130 W. Congress St., Tucson, AZ 85701; tel: 602-792-8361.

Old maps may be examined in public, university, or historical-society libraries. They may also be obtained from the National Archives (Publication Sales Branch, National Archives, 8th and Pennsylvania Ave., N.W., Washington, DC 20408); or from the Library of Congress (Geography and Map Division, Library of Congress, Washington, DC 20540).

Maps produced by the National Geographic Society may be obtained by contacting the society at P.O. Box 2806, Washington, DC 20013.

Some private companies distribute maps produced by government agencies or commercial cartographic firms. These are listed in the Yellow Pages of telephone directories under the heading "Maps."

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——— 1979, Topographic maps; silent guides for outdoorsmen: pamphlet.

——— 1981a, How to order Landsat images: pamphlet.

——— 1981b, Map scales: pamphlet.

——— 1982a, Geologic maps; portraits of the Earth: brochure, 19 p.

——— 1982b, Phoenix quadrangle, Arizona-Maricopa Co., 7.5-minute series (topographic): scale 1:24,000.

_____ 1983a, Flagstaff west quadrangle, Arizona-Coconino Co., 7.5-minute series (topographic): scale 1:24,000.
_____ 1983b, Topographic maps; tools for planning: pamphlet.
_____ 1983c, Tucson quadrangle, Arizona-Pima Co., 7.5-minute series (topographic): scale 1:24,000.
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Arizona Is Among Finalists for SSC

Arizona is one of eight finalists for the $4.4-billion Superconducting Super Collider (SSC), a prestigious scientific laboratory that will enable physicists to study the ultimate structure of matter. Proposals for two sites in Arizona were sent to the National Academies of Science and Engineering (NAS/NAE) for consideration: the Sierrita site about 30 miles southwest of Tucson and the Maricopa site about 35 miles southwest of Phoenix. The Maricopa site made the Academies' unranked list of "best qualified" sites for the SSC; the Sierrita site was rejected.

Other finalists are Colorado, Illinois, Michigan (Stockbridge site), New York (Rochester site), North Carolina, Tennessee, and Texas (Dallas-Ft. Worth site).

Last September the U.S. Department of Energy (DOE) asked the NAS/NAE to evaluate 36 site proposals in 25 States using DOE's prescribed cost considerations and technical criteria, such as geologic stability and tunneling ease. The NAS/NAE delivered its report and recommendations to DOE on December 24. DOE expects to identify a preferred site in July and announce a final decision on January 19, 1989, the Reagan administration's last day in office.

Secretary of Energy John S. Herrington predicts that the SSC could spur a revolution in science, education, technology, and commerce similar to that created by the invention of the cyclotron 57 years ago, which led to advances in lasers, microcircuits, and medical treatments. The SSC could provide as many as 4,500 construction jobs, 3,000 permanent jobs, and an annual operating budget of $270 million.

The Arizona Geological Survey (AGS) has printed or filed several publications concerning the SSC. A nontechnical description and summary of the two proposed sites appeared in the Spring 1987 issue of *Fieldnotes.* Geologists from the SSC project, the AGS, and the U.S. Geological Survey compiled a reconnaissance geologic map of the Maricopa Mountains, which has been released as AGS Open-File Report 87-4. The original geotechnical investigations conducted by the Arizona SSC committee are available as Open-File Report 87-7. (See descriptions under "New Publications from the Arizona Geological Survey" on page 11.) The final proposals for the two sites, consisting of 8 volumes each, have been placed in the Survey's library and may be examined during regular working hours (8:00 a.m. to 5:00 p.m., Monday through Friday). These volumes are titled Executive Summary, Offer and Incentives, Geology and Tunneling, Regional Resources, Environment, Setting, and Utilities.

CUSMAP Meeting to be Held in Tucson

On February 26 and 27, 1988 a meeting will be held in Tucson, Arizona to discuss results of the Ajo-Lukeville 1° x 2° Conterminous United States Mineral Assessment Program (CUSMAP). The purpose of the meeting is to describe the CUSMAP project in the Ajo-Lukeville, Arizona area, review the results obtained thus far, and seek advice on further program development to fit the needs of the public and Federal and State agencies. On the 26th, invited talks and a poster session will be presented, which will include a discussion of mineral-resource potential within the quadrangle and an overview of the geologic, geochemical, and geophysical maps and reports developed during the study. An all-day field trip to the New Cornelia porphyry copper-gold deposit will be conducted on the 27th. Registration is $5.00; an additional transportation fee may be required for the field trip. For more information, contact Floyd Gray, U.S. Geological Survey, 345 Middlefield Rd., MS 901, Menlo Park, CA 94025; tel: (415) 329-5410.

The U.S. Geological Survey started the CUSMAP program in 1978 to provide information for long-range national policy and for Federal, State, and industry decisions concerning the land and its resources. The program will provide mineral assessments on approximately 1 million square miles of land, composing more than one-fourth of the area of the United States. Projects involve study of 1:250,000-scale, 1° x 2° quadrangles; 22 are completed or scheduled for completion in 1988; 7 others are in progress.

Results of each CUSMAP project are published as maps and reports that describe the geology and include an assessment of the mineral resources. A list of publications prepared under the CUSMAP program is available from the Office of Mineral Resources, U.S. Geological Survey, National Center, MS 913, Reston, VA 22092; tel: (703) 648-6112.

New Report Examines U.S. Mineral Industry

In his annual report to Congress, Secretary of the Interior Donald P. Hodel describes the U.S. mineral industry's efforts to improve its competitive position. The report, required under the 1970 Mining and Minerals Policy Act, examines issues and policy actions that will affect the industry's revitalization and discusses the Federal government's role in ensuring the Nation an adequate and dependable supply of minerals. The report also documents the industry's 1986 performance.

During recent years, the domestic mineral industry has lost market shares to foreign producers. Labor costs, regulatory constraints, and declining ore grades kept production costs up while excess world production kept prices down. The industry retreated: U.S. companies cut production, canceled expansion plans, closed mines, laid off workers, and reduced investment. In many cases, however, they continued to lose money.

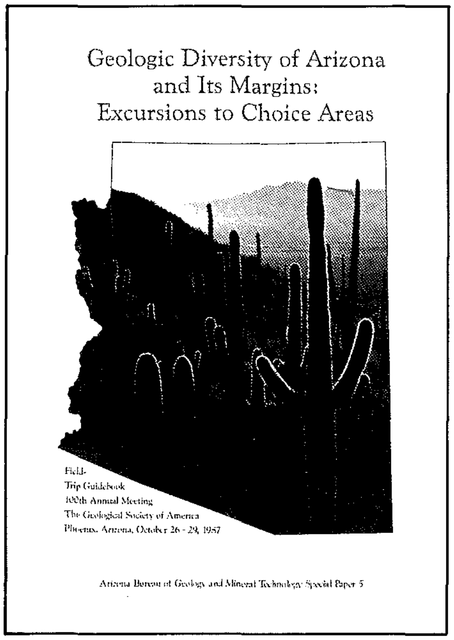
U.S. firms are now turning to technology to improve productivity and cut costs. Small firms are becoming more common in an industry traditionally dominated by large companies. Local investor groups and foreign investors have increased their stake in the industry. Some companies are opting to specialize in fewer phases of mineral production. Others have chosen to diversify by entering new, mostly "high-tech" lines of business.

Prices stabilized or improved in 1986 and the value of U.S. mineral production rose slightly, even though output fell from 1985 levels. Mines and plants reopened and some companies began to make money. Environmental regulations could impose new costs on mineral producers, however. U.S. trade policy will also affect the mineral industry; nonfuel-mineral products account for more than 10 percent of the Nation's trade deficit.

A copy of the Secretary's report, *The Mineral Position of the United States—1987,* may be obtained from the Office of Public Information, U.S. Bureau of Mines, 2401 E St., N.W., Washington, DC 20241; tel: (202) 634-1004.

100th Annual GSA Meeting: Arizona Geological Survey Participation

The 100th annual meeting of The Geological Society of America (GSA) was held in Phoenix, Arizona October 26-29, 1987. The meeting was one of the most successful GSA has ever held. About 5,200 earth scientists gathered to hear more than 1,800 scientific presentations on current research in 35 geology-related fields, including environmental, engineering, and economic geology, as well as more traditional areas such as stratigraphy and hydrogeology. In addition to 93 sessions describing original research, 27 special symposia were held to discuss critical geologic issues. These ranged from hard-rock geology to paleoanthropology, from coal supplies in the United States to assuring the archival collections of geologic data. A 200-booth technical geoscience exhibit featured the newest and most sophisticated equipment, as well as countless publications. To illustrate the unique geology of the Southwest, 15 premeeting and 14 postmeeting field trips were led.



Staff members of the Arizona Geological Survey (AGS), participated in planning the GSA meeting, producing the field-trip guidebook, and presenting original research results through talks, field trips, and publication displays.

Jon Spencer, Research Geologist, served as Field-Trip Cochairman. His duties included preparing budgets for 34 field trips, which required numerous phone calls to each trip leader. As an associate editor of the field-trip guidebook, Jon reviewed manuscripts on the geology of western Arizona. Jon, together with Steve Reynolds, Research Geologist, and geologists from other agencies, led a field trip to examine Mesozoic thrust faults, Tertiary detachment faults, and associated mineralization in the Harquahala, Granite Wash, Whipple, and Buckskin Mountains of western Arizona and southeastern California.

Steve Reynolds led another trip to study ductile to brittle evolution of the South Mountains metamorphic core complex near Phoenix, and was a coleader of a third trip to examine the structural geology of the Rincon and Pinaleño metamorphic core complexes in southeastern Arizona. Steve also presided over the symposium, "Tertiary Extensional Tectonics of the Lower Colorado River Region."

Wes Peirce, Principal Geologist Emeritus, was a coleader of a field trip to central Arizona to study the geomorphology and structure of the Colorado Plateau-Basin and Range Transition Zone.

Tom McGarvin, Research Assistant, helped arrange the video entertainment offered by the Science Theater and served on the committee that selected the program of short films on geologic topics. Tom also managed the AGS exhibit booth, which was shared with the Arizona Geological Society.

In her role as coeditor of the field-trip guidebook, *Geologic Diversity of Arizona and Its Margins: Excursions to Choice Areas,* Evelyn VandenDolder, Associate Editor, edited manuscripts, designed the cover and final layout, and supervised the preparation and printing. The guidebook was published by the Arizona Geological Survey as Special Paper 5. (See "New Publications from the Arizona Geological Survey" on page 11.) Evelyn also managed the AGS booth.

Larry Fellows, State Geologist and Assistant Director, served as representative of the Association of American State Geologists at the member society council meeting of the American Geological Institute. Larry managed the AGS booth when not attending technical sessions.

AGS participation in talks given at the meeting included the following:

(1) "Reduction of crustal flexural rigidity during folding of crystalline rocks in the Harcuvar and Whipple metamorphic core complexes, west-central Arizona and southeastern California" (written and presented by Jon Spencer);

(2) "Interaction between Mesozoic and Cenozoic tectonic features in the Buckskin Mountains and adjacent areas, west-central Arizona and southeastern California" (written and presented by Jon Spencer; coauthored by Steve Reynolds);

(3) "Mesozoic structural evolution of the Maria fold and thrust belt, west-central Arizona and southeastern California" (coauthored by Steve Reynolds and Jon Spencer);

(4) "K-metasomatism of mid-Tertiary rocks in the upper plate of the Bullard detachment fault, west-central Arizona" (written and presented by Mike Roddy, Student Assistant; coauthored by Steve Reynolds);

(5) "Superimposed domino-style normal faults in a Tertiary bimodal volcanic complex, Wickenburg Mountains and vicinity, central Arizona" (coauthored by Steve Reynolds); and

(6) "Major early Miocene extensional deformation in southwestern Arizona and southeastern California" (coauthored by Mike Grubensky, Research Assistant).

PROFESSIONAL MEETINGS

Cordilleran Section, Geological Society of America. March 28-30, 1988, Las Vegas, Nev. Contact Edna Collis, Geological Society of America, 3300 Penrose Pl., Box 9140, Boulder, CO 80301; tel: (303) 447-2020.

Precious and Rare Metals. April 6-8, 1988, Socorro, N. Mex. Contact Arpad Torma, New Mexico Institute of Mining and Technology, Socorro, NM 87801.

Far West Section, National Association of Geology Teachers. April 15-16, 1988, Barstow, Calif. Contact Lori Gaskin, Geology Dept., Barstow College, 2700 Barstow Rd., Barstow, CA 92311; tel: (619) 252-2411.

Palo Verde Dedication

The Palo Verde Nuclear Generating Station at Wintersburg, Arizona, was dedicated in December 1987. It is the largest nuclear-power complex in the Western Hemisphere, with a generating capacity of 3,810 megawatts.

CORRECTION

In the Fall 1987 issue of *Fieldnotes* (vol. 17, no. 3), Figure 15 on page 7 was incorrectly identified. The photo shows the Twin Buttes open-pit copper mine, rather than the Pima-Mission complex. Both mines are near the community of Green Valley, south of Tucson.

New Publications from the Arizona Geological Survey

The following publications may be purchased over the counter or by mail from the Arizona Geological Survey, 845 N. Park Ave., Tucson, AZ 85719. For price information on these and other Survey publications, contact the Survey offices.

Brumbaugh, D. S., Davis, John, and Roberts, L., 1987, A report on earthquake activity recorded at station Flagstaff in 1984: Open-File Report 87-12, 40 p.

This report is the first of an annual series that will provide information on earthquake recording in Arizona. The report describes equipment and recording sites and includes a discussion of activity in Arizona and other western States.

Cunningham, Dickson, DeWitt, Ed, Haxel, Gordon, Reynolds, S. J., and Spencer, J. E., 1987, A geologic map of the Maricopa Mountains, central Arizona: Open-File Report 87-4, scale 1:62,500.

The Maricopa Mountains and surrounding areas compose Arizona's proposed site for the Superconducting Super Collider (SSC), a multibillion-dollar scientific laboratory for particle physics. The Maricopa Mountains consist of Proterozoic crystalline rocks with Tertiary volcanic and sedimentary rocks exposed at the south end of the range. The structural simplicity of the granitic rocks that make up most of the range, plus the great depth to the ground-water table, make this area attractive as an SSC site. This map was prepared as part of Arizona's SSC site proposal.

Davis, G. H., and VandenDolder, E. M., eds., 1987, Geologic diversity of Arizona and its margins; excursions to choice areas [field-trip guidebook for the 100th annual meeting of The Geological Society of America]: Special Paper 5, 422 p.

This field-trip guidebook was published by the Arizona Geological Survey in conjunction with the 100th annual meeting of The Geological Society of America, which was held in Phoenix, Arizona in October 1987. The guidebook contains 33 field guides for trips that provide a comprehensive exposé of the geology of Arizona. An entire spectrum of topics is covered: from the oldest and "hardest" of Precambrian crystalline rocks to megafaunal dung deposits barely 15,000 years old; from modern shoreline ecosystems in the Gulf of California to the messiest of sheared metasediments in western Arizona; from earth fissures formed through aggressive withdrawal of ground water to crossbedding in a dry Mesozoic environment, now represented by the Navajo Sandstone; from disseminated gold to disseminated copper to massive sulfide. The trips are organized in the guidebook according to region: northern Arizona, central Arizona, southeastern Arizona, and western Arizona.

DeNatale, J. S., Nowatzki, E. A., and Welty, J. W., 1987, Geotechnical engineering investigations for Arizona's SSC sites: Open-File Report 87-7, 338 p.

In order for a site to be suitable for a movement-sensitive facility such as the Superconducting Super Collider (SSC), it must possess the appropriate geotechnical environment. Geotechnical data were compiled to aid in engineering analyses of the SSC facilities at the proposed Maricopa and Sierrita sites. This report outlines the materials-testing program and presents the results of the individual laboratory and field studies. The engineering analyses for slope stability, bearing capacity, and foundation settlement are also described. The original field boring logs, laboratory data sheets, and engineering design calculations are included as appendices.

Grubensky, M. J., and Reynolds S. J., 1987, Index of unpublished (pre-1969) geologic maps in Arizona done by the Arizona Bureau of Mines and the U.S. Geological Survey: Open-File Report 87-5, scale 1:250,000, 14 sheets.

This report contains an index of unpublished quadrangle-scale (1:24,000 and 1:62,500) and intermediate-scale (1:125,000 and 1:250,000) mapping in Arizona completed prior to 1969 and compiled for the 1969 Geologic Map of Arizona. Individual index maps, at a scale of 1:250,000, are included for each 1° x 2° quadrangle. Most maps listed in the index are in quadrangle form and are field sheets.

Grubensky, M. J., Stimac, J. A., Reynolds, S. J., and Richard, S. M., 1987, Geologic map of the northeastern Vulture Mountains and vicinity, central Arizona: Open-File Report 87-10, 7 p., scale 1:24,000.

The Vulture Mountains are within the Basin and Range Province in central Arizona, adjacent to the Transition Zone. This area was mapped because it was previously unmapped in detail and was suspected to contain a highly faulted and potentially mineralized assemblage of Proterozoic crystalline rocks, Cretaceous granite, and middle Tertiary volcanic and sedimentary rocks. Geologic mapping was conducted as part of the COGEOMAP program.

Jagiello, K. J., 1987, Bedrock geology from New River Mesa to the northern Phoenix basin, Arizona: Miscellaneous Map MM-87-D, scale 1:24,000.

This geologic map covers a transect across the boundary between the Transition Zone and Basin and Range Province in the area north of Phoenix. The geology is characterized by several gently tilted fault blocks, which are mostly composed of basaltic rocks that rest on Proterozoic crystalline basement.

Marshak, Stephen, Vander Meulen, Marc, and Bhagat, Snehal, 1987, Geology of the Battleship Peak Area, Buckskin Mountains, La Paz County, Arizona: Miscellaneous Map MM-87-B, scale 1:8,000.

This detailed map of the southwestern end of the Buckskin Mountains shows the diverse lithologies of metasedimentary and metaigneous rocks, which overlie the granitic and gneissic rocks that compose most of the range. The metamorphic rocks have been affected by multiple deformations, and their original stratigraphic sequence is unclear.

Peirce, H. W., ed., 1987, Proceedings of the 21st Forum on the Geology of Industrial Minerals: Special Paper 4, 134 p.

This proceedings volume contains 22 items (16 full papers and 6 informative abstracts) presented in Tucson, Arizona in April 1985 during the 21st annual Forum on the Geology of Industrial Minerals. The theme of the meeting, "Aggregates to Zeolites in Arizona and the Southwest," was designed to help fill an informational void on the subject of industrial (nonmetallic) rocks and minerals. Included in this volume are overviews of Arizona, Nevada, and Utah, as well as topical studies on the geology and nonmetallic minerals of Arizona and the Southwest.

Péwé, T. L., Wellendorf, C. S., and Bales, J. T., 1986, Environmental geology of the Tempe quadrangle, Maricopa County, Arizona: Folio Series GI-2, scale 1:24,000, 8 sheets.

Several maps are included in this geologic investigations series: A-B-C (sold as a set), geologic maps; D, landforms; E, flooding; F, ground water; G, caliche; and H, depth to river gravel.

Proctor, P. D., Fleck, K. S., and Shahin, A. N., 1987, Radiometric and petrochemical characteristics of the Dells Granite, Yavapai County, Arizona: Open-File Report 87-8, 67 p.

In igneous rocks, uranium and thorium are found in highest concentrations in granites. This report identifies the distribution patterns of U, Th, and K within an abnormally radioactive granitic pluton. Distribution patterns are related to major-element petrochemistry, mineralogy, and physical characteristics of the rock. The report also discusses the possibility that uranium dissolved and migrated downward into the granite and surrounding sediments and was deposited and enriched in these geologic environments.

Reynolds, S. J., Florence, F. P., Welty, J. W., Roddy M. S., Currier, D. A., Anderson, A. V., and Keith, S. B., 1986, Compilation of radiometric age determinations in Arizona: Bulletin 197, 258 p., scale 1:1,000,000, 2 sheets.

This compilation provides information on 1,688 radiometric age determinations in Arizona. Dating methods used were K-Ar, Ar-Ar, Rb-Sr, fission-track, isotopic-lead, and lead-alpha. The determinations are indexed by age, geographic location, and rock unit. The location for each determination is plotted on the accompanying maps.

Reynolds, S. J., Florence, F. P., Roddy, M. S., Welty, J. W., and Trapp, R. A., 1986, Map of the K-Ar and Ar-Ar age determinations in Arizona: Map 24, scale 1:1,000,000.

This map is included in Bulletin 197, but may be purchased separately.

Reynolds, S. J., Florence, F. P., Roddy, M. S., Welty, J. W., and Trapp, R. A., 1986, Map of fission-track, Rb-Sr, and U-Pb age determinations in Arizona: Map 25, scale 1:1,000,000.

This map is included in Bulletin 197, but may be purchased separately.

Stimac, J. A., Fryxell, J. E., Reynolds, S. J., Richard, S. M., Grubensky, M. J., and Scott, E. A., 1987, Geologic map of the Wickenburg, southern Buckhorn, and northwestern Hieroglyphic Mountains, central Arizona: Open-File Report 87-9, 13 p., scale 1:24,000, 2 sheets.

This report describes the geology of the Red Picacho quadrangle and parts of the Wickenburg, Garfias Mountain, and Wittman quadrangles. The map area includes the Wickenburg Mountains and contiguous parts of the Buckhorn and Hieroglyphic Mountains. Geologic mapping was conducted as part of the COGEOMAP program.

Theobald, P. K., Billone, M. A., Detra, P. S., and Vassalluzzo, C. A., eds., 1987, Summary of a workshop on the search for unconventional ore deposits in Arizona: Open-File Report 87-11, 16 p.

A workshop on future mineral-resource research in Arizona was held on January 12 and 13, 1987, in Tucson. The objective was to exchange information on the geology of metallic-mineral resources. The emphasis was on the potential for discovery of new ore deposits and on the type of research required to fulfill that potential. The term "unconventional" used in the workshop title refers to nonporphyry copper deposits. The workshop was organized by the Arizona Geological Survey, the University of Arizona Department of Geosciences, and the U.S. Geological Survey Office of Mineral Resources. This report has also been released by the U.S. Geological Survey as Open-File Report 87-498.

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Fieldnotes

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