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Tucson Mountain Storms Cause Damage and Change

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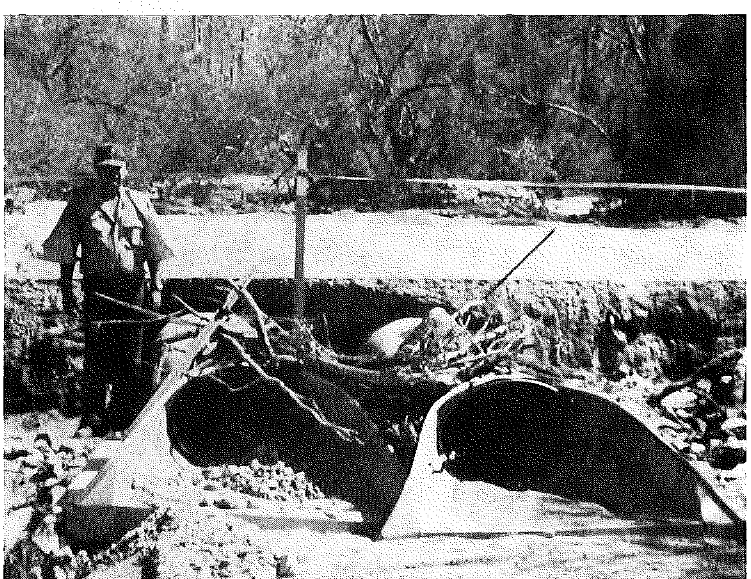
Natural occurrences, such as rainstorms, affect desert terrain in a variety of ways. Rainstorms may cause visible changes to the land surface or even damage to vegetation or man-made structures. In a twenty-four-hour period of September 10-11, 1982, the Tucson Mountain Unit of Saguaro National Monument experienced both change and damage. A series of five highly localized storms swept across Avra Valley, leaving almost half the expected annual rainfall. Nearly five inches of moisture were recorded at the Red Hills Information Center. However, this area was not in the direct path of most of the storms, which left a great deal more rain at other locations.

The first rain saturated the ground and caused some damage to roads. With the ground soaked to capacity, the stage was set for smaller storms to later change the desert terrain considerably. Although the subsequent rains tended to carry less moisture than the first, all the storms resulted in more runoff. The water could not be contained in existing washes, and new runoff routes were created. Large plants such as prickly pear and full-grown trees like the Palo Verde were uprooted and swept away. Rangers, patrolling the roads, observed a number of rattlesnakes that had been washed from their dens and were protesting angrily. Small rodents must have suffered quite heavily because their predators, coyotes and roadrunners, were especially active the next morning.

The runoff moved through the desert creating change. Only when the water encountered a road did structural damage occur. Most of the damage happened when culverts, unable to handle the sand-laden water, were soon buried, allowing the surface of paved roads to be undermined and washed away. Water flowed down dirt roads creating havoc and leaving a deep layer of loose sand. Some park visitors were surprised by the storm, which resulted in the near burial of several vehicles. Because the occupants had abandoned their cars, no one was injured.

Park Rangers estimate that the storm caused almost $100,000 in damages to property in Saguaro National Monument. Fortunately, in this incident, the mass of water moved through one of the few sparsely populated areas of Avra Valley and caused more change than damage.



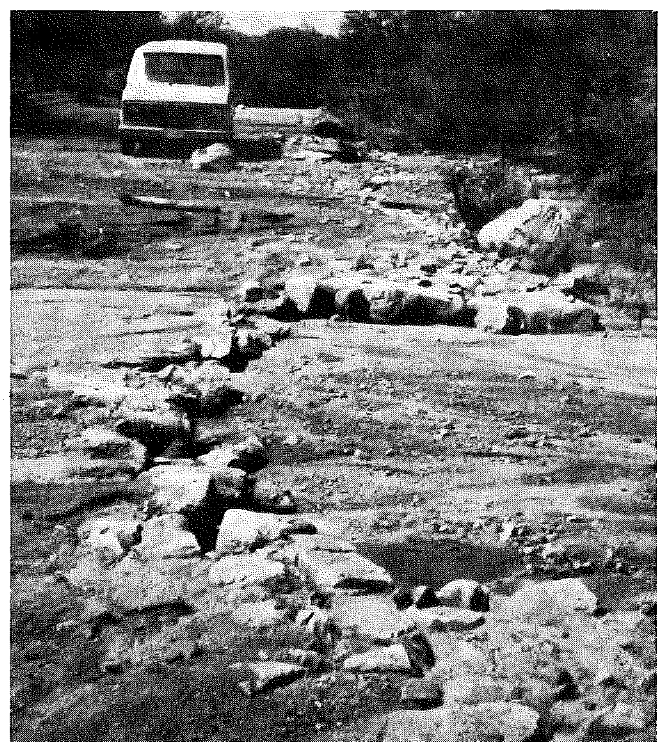


Photo on right: Erosion that occurred where roads crossed washes. A rock foundation, probably built by W.P.A. crews during the depression of the 1930s, was exposed and partially removed by the runoff. Photo on left: Debris-laden water, flowing toward the foreground, plugged upstream end of corrugated pipes. Water then flowed across road, undermined the pavement, and washed away fill material at the downstream end.

Photos: P. Guraedy

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...ial of Peraluminous Granitoids

few sweeping generalizations can be made regarding typical contents of Al, K, Na or Ca. Instead, there are significant regional variations in geochemistry of peraluminous granites (Table 1). In order to more fully understand these geochemical differences, we have explored various criteria for classifying peraluminous granitoids because the granitoids have too limited a compositional range to use traditional classification techniques (i.e., Peacock, 1931). Accordingly, we have developed a classification system that does not require a broad compositional spread for a single peraluminous granitic suite. To arrive at this classification system, we have compiled an extensive geochemical data base on metaluminous igneous suites of known alkalinity (e.g., calcic, calc-alkalic, alkalic-calcic, and alkalic). We have

Table 1. Representative chemical analyses of peraluminous granites.*

Location	Al_2O_3	CaO	Na_2O	K_2O
Santa Catalina Mts., Arizona	14.6	1.6	4.1	3.7
Whipple Mts., California	15.0	2.2	4.1	3.4
Ruby Mts., Nevada	13.8	1.1	3.4	4.5
Northeastern Washington	14.5	1.4	3.2	4.7
Southern Nova Scotia	15.4	0.8	3.6	4.0
Central Portugal (Hercynian)	15.3	0.8	3.5	5.4
Armorican Massif, France (Hercynian)	14.6	0.6	3.7	4.8
Schwarzwald, West Germany (Hercynian)	15.1	0.4	3.1	5.2
Higher Himalaya, Nepal	14.7	0.5	4.1	4.5
Ku Long, Thailand	13.9	1.0	2.7	5.1
Hub Kapong, Thailand	13.3	1.4	2.4	5.3
Kosciusko Batholith, Australia	13.2	1.8	2.6	3.8

*All analyses contain approximately 72 to 73 percent silica. Note that granites from Arizona and California have more calcium and less potassium than granites from Thailand or Europe that are famous for their associated mineral deposits.

found that a subalkaline-alkaline boundary, which approximately coincides with the calc-alkalic-alkali-calcic boundary of Peacock (1931), can be tightly constrained on variation diagrams that plot SiO_2 versus CaO or SiO_2 versus K_2O–CaO (Figures 1 and 2). Such diagrams can be used to evaluate the alkalinity of even the most compositionally restricted peraluminous suites (Figures 3 and 4). Based on these diagrams, peraluminous granitoids can be subdivided into three general catagories: alkaline, marginally alkaline, and subalkaline. Granitoids that plot within the alkaline field on the diagrams are rich in K_2O, poor in CaO or both. They also have relatively low contents of FeO, MgO, and TiO_2. In contrast, subalkaline peraluminous granitoids have less K_2O and more CaO, FeO, MgO, and TiO_2. Marginally alkaline granitoids plot along the subalkaline-alkaline boundary and have intermediate contents of K_2O and CaO.

This subalkaline-alkaline distinction has important applications for the exploration of mineral deposits in both peraluminous and metaluminous granitoids. In general, granitoids that plot within the alkaline field have higher contents of lithophile elements (K, Rb, Li, Be, Mo, Sn, U, and Th) than granitoids that plot within

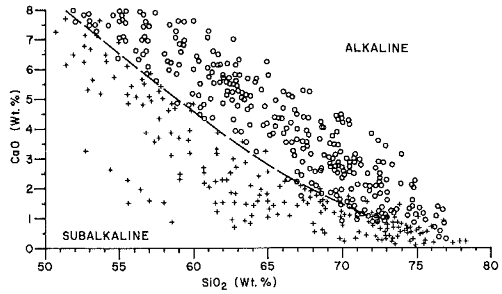

Figure 1. SiO_2 versus CaO variation diagram for metaluminous-suite igneous rocks of known alkalinity. Dots represent calc-alkalic and calcic rocks; crosses indicate alkali-calcic and alkalic rocks (classifications according to Peacock, 1931).

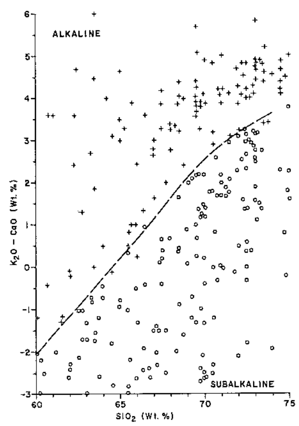

Figure 2. SiO_2 versus K_2O minus CaO variation diagram for metaluminous-suite igneous rocks of known alkalinity. Symbols same as Figure 1.

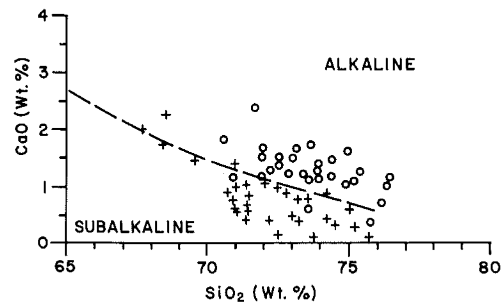

Figure 3. SiO_2 versus CaO variation diagram for peraluminous granitoids of Arizona (o) and the Hercynian belt of Europe (+).

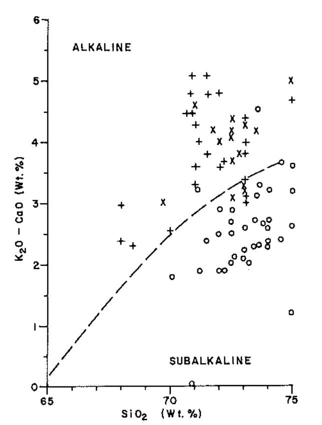

Figure 4. SiO_2 versus K_2O minus CaO variation diagram for peraluminous granitoids of Arizona (o), Europe (+), and Thailand (x).

Technical report continued

the subalkaline field. Alkaline peraluminous granitoids are also more commonly associated with significant lithophile-element mineralization. Notable examples of mineralized alkaline peraluminous granitoids include those of the Hercynian belt of Europe and the tin belt of Thailand. By comparison, many subalkaline peraluminous granitoids, including some in Arizona, are not associated with any type of significant mineralization. Some of these subalkaline rocks are remarkably depleted in lithophile elements (Keith and Reynolds, 1980; Reynolds and others, 1982). In all, the trace element content and mineral potential of peraluminous *and* metaluminous granitoids is strongly dependent on the alkalinity of the parent magma (see also Westra and Keith, 1981 and 1982). Evaluating the specifics of this concept should be of paramount importance to economic geologists.

ORIGIN OF PERALUMINOUS GRANITOIDS

The origin of granitic magmas has been a controversial issue since the inception of geology as a science. The origin of peraluminous granites is no exception. In a milestone paper, Chappell and White (1974) proposed that granitic rocks of eastern Australia could be subdivided into I-type and S-type granites that are interpreted to have been derived from the partial melting of igneous and sedimentary sources, respectively. Because the original S-type granites of Australia are strongly peraluminous, some geologists have implied that all strongly peraluminous granitoids are of S-type, that is, derived from the melting of sedimentary rocks. While there seems to be good evidence that most strongly peraluminous granitoids are derived from the partial melting of crustal rocks, a sedimentary source within the crust cannot be assumed. For example, if enough water is fluxed through anhydrous granulitic orthogneisses, these rocks could partially melt to produce a strongly peraluminous granitic magma.

It seems logical to conclude that the chemical composition of the crustal source should be somehow reflected in the geochemistry of the resulting granitoid. If this conclusion is valid, then alkaline peraluminous granitoids, such as those of the Hercynian belt, must have been formed by the partial melting of continental crust that was enriched in lithophile elements. In contrast, the lithophile-poor, subalkaline granitoids (i.e., Arizona) were probably derived from the melting of a crustal source that was depleted in lithophile elements. We have suggested elsewhere that the depleted character of the lower crust beneath Arizona was caused by an episode of granulite-facies metamorphism and extensive partial melting that culminated in formation of the widespread 1.4 b.y.-old granites (Keith and Reynolds, 1981; Reynolds and others, 1982). These depleted lower crustal rocks, along with Franciscan-type sediments that were underthrust beneath western North America during late Cretaceous-early Tertiary low-angle subduction, could provide an excellent source for the lithophile-depleted peraluminous granitoids of Arizona.

Another interesting possibility is that lithophile-rich and lithophile-poor peraluminous granitoids are produced in different tectonic settings. During a continental collision, such as that which probably formed the Hercynian granites, the lithophile-rich *upper crust* of the *subducted* continent would probably be the main locus of partial melting. Thus, peraluminous granites produced by continental collisions might be expected to be enriched in lithophile elements. In contrast, the lithophile-depleted peraluminous granitoids of Arizona were probably generated during an episode of low-angle subduction of an oceanic plate beneath the North American continent. Partial melting in this tectonic setting would likely take place within the lithophile-depleted *lower crust* of the *overriding* continent or could involve any underthrust oceanic sediments. This distinction in tectonic setting might explain why the Hercynian granites of Europe are enriched in lithophile elements and are consistently associated with lithophile-element mineralization, whereas the peraluminous granites of Arizona are not.

REFERENCES CITED

Chappell, B.W., and White, A.J.R., 1974, Two contrasting granite types: Pacific Geology, v. 8, p. 173-74.

Keith, S.B., and Reynolds, S.J., 1980, Geochemistry of Cordilleran metamorphic core complexes, *in* Coney, P.J., and Reynolds, S.J., Cordilleran Metamorphic Core Complexes and Their Uranium Favorability: U.S. Department of Energy Open-File Report GJBX-258 (80), p. 247-310.

____________________, 1981, Low-angle subduction origin for paired peraluminous-metaluminous belts of mid-Cretaceous to early Tertiary Cordilleran granitoids (abs.): Geological Society of America Abstracts with Programs, v. 13, p. 63.

Miller, C.F., and Bradfish, L.J., 1980, An inner Cordilleran belt of muscovite-bearing plutons: Geology, v. 8, p. 412-16.

Miller, F.K., and Engels, J.C., 1975, Distribution and trends of discordant ages of the plutonic rocks of northeastern Washington and northern Idaho: Geological Society of America Bulletin, v. 86, p. 517-28.

Peacock, M.A., 1931, Classification of igneous rock series: Journal of Geology, v. 39, p. 54-67.

Pitcher, W.S., 1979, The nature, ascent and emplacement of granitic magmas: Journal of the Geological Society of London, v. 136, p. 627-62.

Reynolds, S.J., Keith, S.B., and DeWitt, Ed, 1982, Late Cretaceous-early Tertiary peraluminous granitoids of Arizona-California and their related mineral deposits (abs.): Geological Society of America Abstracts with Programs, v. 14, p. 227.

Shand, S.J., 1927, The Eruptive Rocks: John Wiley, New York, 488 p.

Westra, Gerhard, and Keith, S.B., 1981, Classification and genesis of stockwork molybdenum deposits: Economic Geology, v. 76, p. 844-73.

____________________, 1982, Classification and genesis of stockwork molybdenum deposits — a reply: Economic Geology, v. 77, p. 1252-63.

NEW BUREAU PUBLICATIONS

ARIZONA EARTHQUAKES

Arizona Earthquakes, 1776-1980, Bulletin 193, by Susan M. DuBois, Ann W. Smith, Nan K. Nye, and Thaddeus A. Nowak, Jr.; 456 p., with map (**Historical Epicenters in Arizona: 1830-1980**, scale 1:1,000,000), 1982; research funded by U.S. Geological Survey, U.S. Nuclear Regulatory Commission, Arizona Division of Emergency Services, and Arizona Bureau of Geology and Mineral Technology.

Bulletin 193 includes a re-evaluation of intensities and locations of earthquakes in Arizona; revisions of previously published epicenter maps; the composition of isoseismal maps (12 maps for in-state seismic events, 29 maps for out-of-state earthquakes); disclosure of unpublished earthquake data; and detailed interpretation of the most damaging historical earthquake of 1887 (see also **The 1887 Earthquake in San Bernardino Valley, Sonora: Historic accounts and intensity patterns in Arizona**, Special Paper 3, by S.M. DuBois and A.W. Smith, 1980, $6.).

Arizona Earthquakes and accompanying epicenter map is available for $20; the map alone for $3. Twenty percent handling is required on all mail orders within the U.S.

GEOLOGIC MAP INDEX

Index of Published Geologic Maps of Arizona, 1903-1982, compiled by Robert B. Scarborough and Michel L. Coney; six plates at scale 1:1,000,000, November 1982.

This map series consists of six sheets displaying areas covered by all known published geologic maps of Arizona (preliminary maps, maps compiled from multiple sources, regional maps generalized from older maps — those with new information, outcrop maps with new data on age or rock type, and structural maps displaying geologic contacts). Each area is numbered and corresponds to a reference of the cited area at the bottom of the sheet. Nearly 500 map references are included in this index.

The map set may be obtained from Arizona Bureau of Geology and Mineral Technology, 845 N. Park Ave., Tucson, 85719 for $5.00 (plus $1.50 handling charge if by mail).

"Cluster" Meetings

Each year the Geologic Division and the National Mapping Division of the U.S. Geological Survey hold "cluster" meetings with representatives of the western states to discuss state and federal activities of mutual interest. In 1982 the meetings, sponsored by the U.S. Geological Survey (USGS) and hosted by the Arizona Bureau of Geology and Mineral Technology, were both held in Tucson at the Wild Horse Ranch Resort in October. USGS staff from Menlo Park, Denver, and Reston were present, as were state geologists or their representatives from nine western states.

Discussions were held with the Geologic Division on USGS budget outlook for FY 1982-83, geologic mapping activities, contractual arrangements with states, geologic hazards, strategic and critical minerals, radioactive waste disposal, digital mapping, and the COSUNA project (Correlation of Stratigraphic Units of North America). The Association of American State Geologists and the USGS have been working together to complete an Implementation Plan for Cooperation. This effort, in general, will involve program planning, identification of projects of mutual interest and responsibility, determination of ways to work together on specific projects, and publication of the results.

Discussions with the National Mapping Division focused on topographic mapping progress and plans. Most of the states have formal cost-sharing agreements with the USGS for completion of topographic and other maps in their respective states.

A field trip was taken to the Tucson Mountains vicinity to give participants an overview of the geologic framework and related phenomena in the Tucson Basin. Stephen Reynolds led the trip and was assisted by H. Wesley Peirce (both of the Arizona Bureau of Geology and Mineral Technology) and Roger Ashley (USGS). The trip also included a stop at the Arizona-Sonora Desert Museum.

State Geologic Map

A limited quantity of the **Geologic Map of Arizona** (scale 1:500,000) is again available. This map, originally published in 1969, had been out of stock for more than a year before it was reprinted. The map may be obtained from the Arizona Bureau of Geology and Mineral Technology for $6 over-the-counter, with an additional 20 percent handling cost for mail orders.

Bureau geologist Stephen Reynolds, in the September 1981 *Fieldnotes*, (v.11, no. 3) described the historic development of the state map from the 1800s. Work on the 1969 *Geologic Map of Arizona* began during the 1950s as a cooperative project between the U.S. Geological Survey (USGS) and the Arizona Bureau of Mines (which became known as the Arizona Bureau of Geology and Mineral Technology in 1977). John R. Cooper of the USGS and Richard T. Moore with the Bureau, collaborated as project coordinators.

The Arizona Bureau of Mines compiled and published county geologic maps at a scale of 1:375,000, using existing geologic maps (published and unpublished). Reconnaissance mapping by Arizona Bureau of Mines geologists, Eldred Wilson, Richard T. Moore, and H. Wesley Peirce, and by USGS geologists, filled in gaps where there were no maps or where existing maps were inadequate. Robert O'Haire, Bureau mineralogist, compiled virtually all the county maps.

Since the late 1950s, much detailed mapping has been done and many new age determinations have been made. Consequently, the ages of some rock units are now known to be considerably different than shown on the 1969 map. The Bureau and USGS are cooperating to prepare more detailed geologic maps of Arizona. The Phoenix 1° × 2° sheet (scale 1:250,000) is being mapped by Bureau geologists.

County maps (scale 1:375,000) are also available for purchase at the Bureau, except for Pima, Santa Cruz, and Maricopa Counties, which have gone out of print.

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