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Geologic Insights into Flood Hazards in Piedmont Areas of Arizona

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Proper management of flood hazards in piedmont areas of Arizona is becoming increasingly important as the State's population grows and urban areas expand. In the Basin and Range Province of the western United States, **piedmonts** (literally, "the foot of the mountains") are the low-relief, gently sloping plains between the mountain ranges and the streams or playas that occupy the lowest portions of the valleys. Much of southern, central, and western Arizona is composed of piedmonts, and they comprise most of the developable land near the rapidly expanding population centers of the State.

Viewed from above, piedmonts of Arizona are complex mosaics composed of alluvial fans and stream terraces of different ages that record the recent geologic history of an area. **Alluvial fans** are generally cone-shaped depositional landforms that emanate from a discrete source and increase in width downslope; adjacent fan surfaces may merge downslope to form a continuous **alluvial apron**. Alluvial fans represent periods of net aggradation, when large amounts of sediment were removed from mountain areas and deposited on adjacent piedmonts. The Quaternary Period (roughly the past 2 million years) has been characterized by repeated changes in global climate. Periods of alluvial-fan deposition in Arizona were probably due to climate changes that increased the amount of sediment supplied to streams from mountain slopes and possibly decreased the capacity of streams to transport sediment across piedmonts (Bull, 1991). **Stream terraces** are steplike landforms that are typically inset below adjacent fan surfaces. They represent former floors of stream valleys that were abandoned as the streams downcut even further. Terraces thus exist in areas where the long-term trend has been for streams to entrench themselves into older deposits.

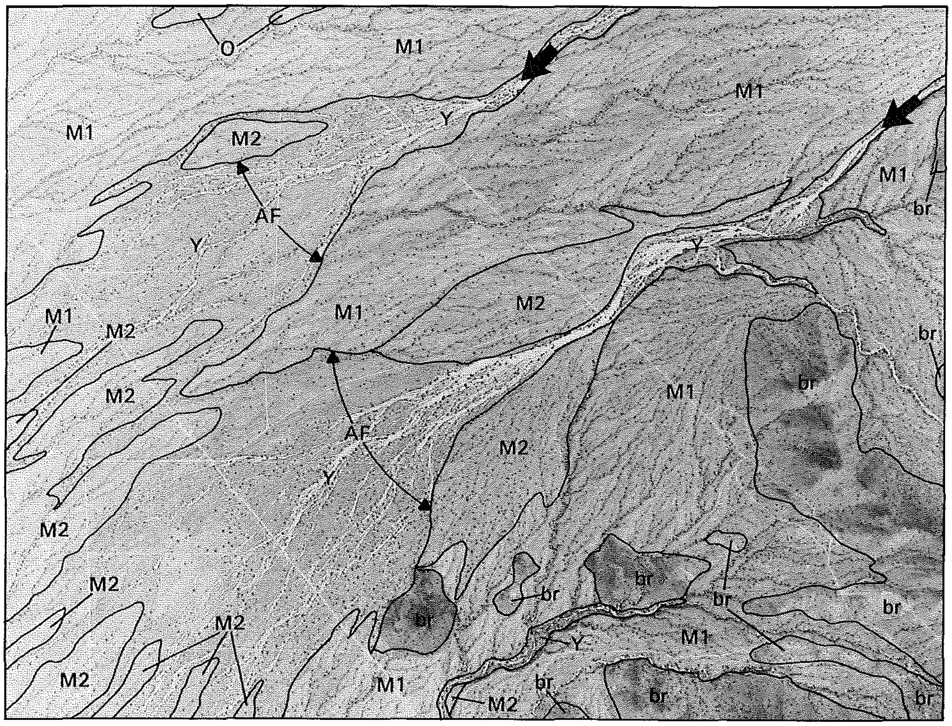

Figure 1. Aerial photograph of the western piedmont of the White Tank Mountains, which shows alluvial surfaces of different ages. The approximate ages of the deposits in thousands of years (ka) are as follows: Y, younger than 10 ka; M2, 10 to 150 ka; M1, 150 to 800 ka; O, older than 800 ka (br = bedrock). The arrows point to relatively large drainages that head in the mountains and flow from right to left across the piedmont. The areas of recent alluvial-fan activity (labeled AF) along these drainages are identified by extensive young deposits (Y) and ***distributary channel patterns****, which consist of streams that branch and flow out of a larger stream. Old, inactive alluvial fans (units M1, M2, and O) are characterized by a lighter color and* ***tributary drainage patterns****, which consist of streams that flow into a larger stream. These old fans compose much of the piedmont and have been isolated from floods associated with the larger drainages for more than 10,000 years.*

Piedmont areas subject to active alluvial-fan flooding are of particular concern from a floodplain-management perspective. Piedmonts in Arizona are typically drained by a few relatively large streams that head in adjacent mountains and many smaller streams that head on the piedmont (Figure 1). Active alluvial fans along the larger streams may be subject to widespread inundation, local high-velocity flow, and drastic changes in channel positions during floods because there is little topographic relief to confine the floodwaters. If development on piedmonts occurs without regard to the distribution of active alluvial fans, lives and

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property may be put at risk. It is preferable and less expensive to mitigate these flood hazards before an area is developed than to deal with them afterwards, when floodwaters are lapping at doorsteps.

The long history of stream behavior and flooding recorded in the geology and geomorphology of piedmonts provides an invaluable perspective on floodplain-management issues. Floods leave physical evidence of their occurrence in the form of alluvial deposits. Characteristics of large floods that have occurred during the past few years may be reconstructed in some detail because evidence of their impact on the landscape is fresh. Over hundreds or thousands of years, the impact of individual floods is more difficult to resolve, but the cumulative effects of many floods are recorded in the geology and geomorphology of a piedmont. Geological studies can address several key issues: (1) How large are the extreme floods on particular drainages?; (2) Which portions of piedmonts are prone to flooding, especially alluvial-fan flooding?; (3) Do the positions of channels on alluvial fans typically change during floods?; and (4) What are the depths and velocities of floodwaters during alluvial-fan floods?

The Arizona Geological Survey (AZGS) is engaged in cooperative efforts with local floodplain-management agencies, the University of Arizona, and the Arizona Department of Water Resources. These studies combine geologic investigations with more traditional hydrologic analyses to delineate flood-prone areas more accurately and to understand better the flooding processes on piedmonts in Arizona.

FLOODPLAIN-MANAGEMENT ISSUES

The principal objective of floodplain-management agencies is to prevent humans and their property from being exposed to undue risks from flooding. These agencies must also maintain credibility with the persons whom they regulate and include in their purview only the areas that are truly at risk of being flooded. Concepts of floodplain management are firmly rooted in the disciplines of hydrology and civil engineering; geologic information typically has not been used in flood-hazard evaluations. Because flooding in piedmont areas may be quite complex, however, standard hydrologic or engineering methods for accurately assessing and managing flood hazards are of questionable value. Critical technical issues, such as determining the extent and character of flooding on piedmonts, cannot be adequately addressed without integrating hydrologic methods and geologic investigations.

Streams that cross piedmont areas in Arizona have several characteristics that make them particularly hazardous to life and property. As is typical in the desert, piedmont streams flow infrequently, lending a false sense of security to persons who live near washes or on active alluvial fans. Large piedmont floods are usually generated by intense precipitation in adjacent mountains. Piedmont dwellings may thus become flooded even if it has rained very little in those areas. During alluvial-fan flooding, floodwaters are free to spread out and inundate wide areas, and drastic changes in channel patterns may occur. If waters take a new path during a flood, a channel that seemed insignificant can grow in size and capacity. Human alterations to natural stream systems on piedmonts may have a profound impact on the course of floodwaters; ill-advised obstruction or diversion of natural channels may cause adjacent areas to receive the brunt of floodwaters. For all of these reasons, local, State, and Federal floodplain-management officials in the United States have come to realize the importance of adequately defining and managing flood hazards in piedmont areas.

Traditional methods of defining regulatory floodplains typically involve four steps: (1) making the assumption that channel beds and banks are fairly stable; (2) estimating the size of the flood that has a 0.01 probability of occurring in any given year on a particular stream (the **100-year flood**); (3) routing the 100-year flood downstream using some preferred hydrologic model; and (4) determining the area that will be flooded and how deep the floodwaters will be at any flooded locality. These procedures, however, are inappropriate for defining areas that are prone to alluvial-fan flooding. As outlined above, channels on alluvial fans may or may not be stable during large floods. In addition, floodwaters may spread so widely that accurate modeling of their extent and depth is difficult. Furthermore, the available data for estimating the sizes of 100-year floods on drainages in Arizona are modest at best; different methods yield dramatically different sizes (e.g., House, 1991).

Hydrologists and engineers have proposed several models to simulate alluvial-fan flooding. The most widely used model is one that is mandated by the Federal Emergency Management Agency (FEMA) to set flood-insurance rates. This FEMA alluvial-fan methodology (AFM) is based on several simplifying assumptions about flow behavior during alluvial-fan floods: (1) floodwaters affect only part of an alluvial fan during any one flood; (2) floodwaters are conveyed in one or more channels of a specific and predictable depth and width; and (3) these channels can form anywhere on the alluvial fan at the beginning of or during a flood (Dawdy, 1979; FEMA, 1985). The AFM uses the width of the channels that are supposed to form during a flood and the total width of the alluvial fan to determine 100-

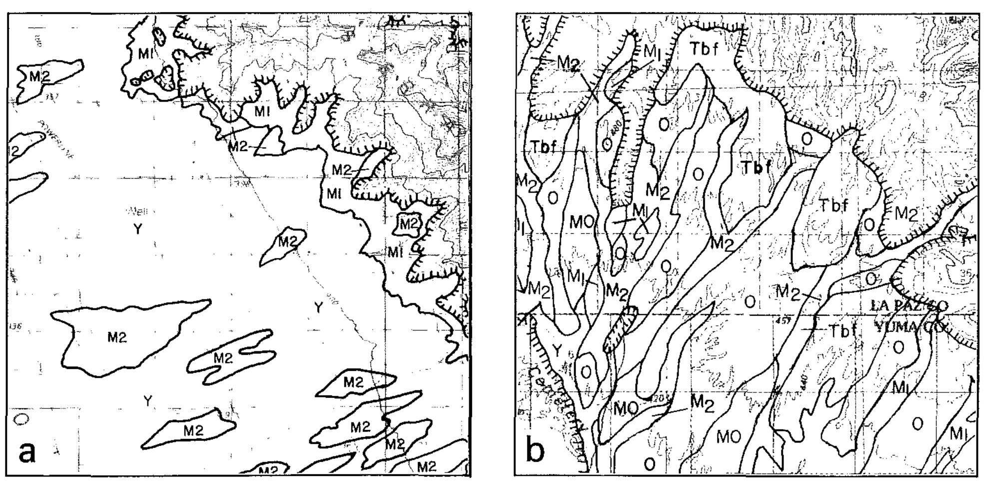

Figure 2. Surficial geologic maps that illustrate differences in the extent of young deposits and alluvial-fan flooding hazards on two piedmonts in Arizona. The map-unit designations are the same as those used in Figure 1; additional map units are as follows: MO, 500 to 1,000 ka alluvial fans; and Tbf, dissected basin-fill deposits older than 1,000 ka. (a) The southwestern piedmont of the Sierra Estrella Mountains in central Arizona is mostly covered with young alluvial deposits less than 10,000 years old (map unit Y), which indicates that alluvial-fan flooding is an important process on this piedmont (from Demsey, 1989). (b) The southwestern piedmont of the Eagle Tail Mountains in southwestern Arizona is almost entirely composed of alluvial fans and terraces more than 10,000 years old (map units M2, M1, O, and Tbf). No active alluvial fans exist on this piedmont (from Demsey, 1990).

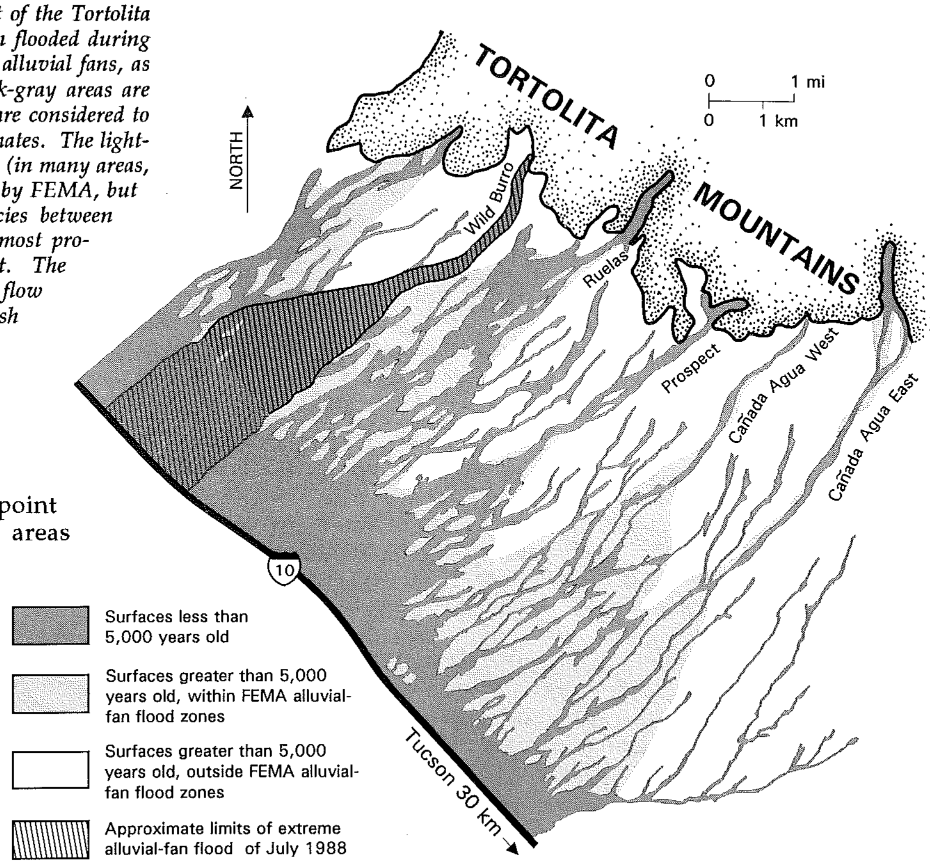

Figure 3. *Generalized map of the southern piedmont of the Tortolita Mountains. This map contrasts areas that have been flooded during the past few thousand years with the limits of active alluvial fans, as defined by the AFM mandated by FEMA. The dark-gray areas are surfaces that are younger than 5,000 years and that are considered to be flood prone based on geologic data and FEMA estimates. The light-gray areas are surfaces that are older than 5,000 years (in many areas, much older) and that are considered to be flood prone by FEMA, but have not been flooded for a long time. Discrepancies between geologic data and the FEMA alluvial-fan areas are most pronounced in the southeastern portion of the piedmont. The approximate area between the outermost threads of flow during the 1988 alluvial-fan flood on Wild Burro Wash is shown by the hachured pattern. The lighter hachures indicate areas that were probably affected by the flood but were not mapped in detail. The area that was affected by this flood coincides very closely with the flood-prone areas determined from geologic data.*

year flood-flow depths and velocities at any point on the fan. FEMA regulations include all areas subject to inundation of 6 inches or more during the 100-year flood in the 100-year floodplain. On piedmonts in Arizona, the extent of the 100-year floodplain has been defined using the assumptions of the AFM and topographic information (Fuller, 1990).

Application of the AFM in Arizona has generated a storm of controversy, however, because it has designated broad portions of piedmonts as potential sites of inundation by the 100-year flood. Three questions highlight the technical aspects of this controversy: (1) Has the AFM been applied to areas that are actually subject to alluvial-fan flooding?; (2) Are the fundamental assumptions of the AFM concerning the behavior of floodwaters on alluvial fans realistic?; and (3) Are the sizes of the 100-year floods used in the AFM realistic? Geologic investigations of piedmont areas can provide an independent assessment of each of these questions.

GEOLOGY AND GEOMORPHOLOGY OF PIEDMONTS IN ARIZONA

The physical characteristics of alluvial surfaces (alluvial fans and stream terraces) on piedmonts may be used to differentiate them by age. Alluvial surfaces are typically deposited by the larger drainages that cross a piedmont; thus, the initial surface features are shaped by large-scale depositional processes. When surfaces are isolated from further deposition or reworking by large streams, they are gradually modified over thousands of years by other processes, which operate very slowly and on a smaller scale. These modifying processes include (1) small-scale erosion and deposition that smooth the original surface topography; (2) **bioturbation**, the churning of sediments by organisms, which obliterates depositional structures; (3) development of soils, primarily through accumulation of silt, clay, and calcium carbonate; (4) development of surficial gravel pavements (desert pavements) above zones of accumulated silt and clay; (5) accumulation of rock varnish on surface gravel; (6) development of tributary **dendritic** (treelike) stream networks on surfaces; and (7) entrenchment of these stream networks below original depositional surfaces and subsequent surface dissection.

Alluvial surfaces of similar age have a characteristic appearance because they have undergone similar postdepositional modifications, and they are distinctly different from both younger and older surfaces. Young (less than a few thousand years old) alluvial-fan surfaces, for example, still retain clear evidence of the original depositional topography, such as **bars** (ridges) of coarse deposits, **swales** (troughlike depressions) where low flows passed between bars, and **distributary channel networks** (networks that branch downstream), which are characteristic of active alluvial fans (Figure 1). Young fan surfaces also show minimal development of soil, desert pavement, and rock varnish and are basically undissected. Very old alluvial-fan surfaces, on the other hand, have not been subject to large-scale flooding for hundreds of thousands of years. These surfaces are characterized by well-developed soils with clay- and calcium-carbonate-rich horizons, well-developed dendritic stream networks that are entrenched several meters below the fan surface, and strongly developed varnish on surface rocks. Old alluvial-fan surfaces may also have smooth, closely packed desert pavements between the entrenched drainages. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

The distribution, character, and relative abundance of surfaces of different ages clarify the long-term history of stream behavior on piedmonts, which, in turn, illuminates the nature and distribution of potential flood hazards. The broad spectrum of stream behavior on the piedmonts of Arizona is illustrated by variations in the areal extent of young deposits. Some piedmonts have extensive deposits of Holocene age (less than 10,000 years old), which indicates that the alluvial fans have been recently active; other piedmonts have few Holocene deposits (Figure 2). The extent of active alluvial fans depends on the rock types in the adjacent mountains and on the stability of base-level at the lower end of the piedmont. Many piedmonts in Arizona, however, show similar patterns of long-term erosion and deposition. The upper piedmont areas near the mountain ranges are dominated by abandoned alluvial fans of Pleistocene age (greater than 10,000 years old); active stream systems are

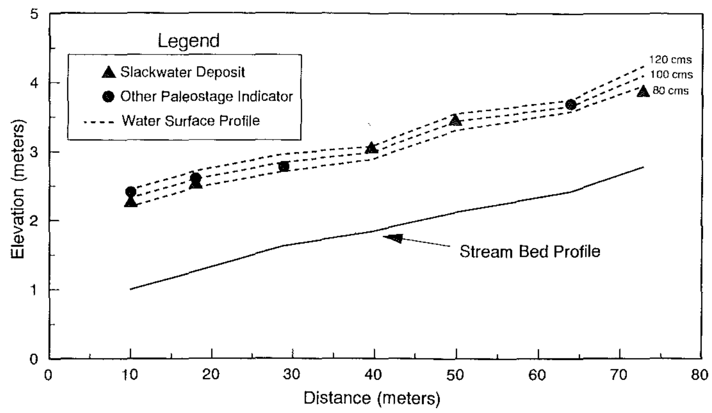

Figure 4. Illustration of the integration of geologic data with the HEC-2 hydrologic model to estimate the size of a paleoflood. Physical evidence of flooding is used to estimate the highest level of the flood. Water-surface profiles generated by the HEC-2 model using different discharge rates (in cubic meters per second, or cms) are compared with the high-water marks to estimate paleoflood discharges (from House, 1991).

entrenched well below these fans, and young deposits are restricted to channels and low terraces. Young deposits are commonly more extensive in the middle and lower portions of the piedmonts, which indicates that these are areas of unconfined distributary flow and alluvial-fan activity. The areas in Arizona that are subject to alluvial-fan flooding, therefore, are typically located in the middle and lower piedmont areas.

GEOLOGIC STUDIES OF PIEDMONT FLOOD HAZARDS IN ARIZONA

Geologic studies of piedmonts in southern and central Arizona have provided a variety of useful information on the character and extent of flood hazards. AZGS geologists have mapped piedmonts in detail to define flood-prone areas. Financial support for these efforts came from the Pima County Flood Control District, Flood Control District of Maricopa County, Arizona Department of Water Resources, and U.S. Geological Survey COGEOMAP program. Other investigations of the size and character of piedmont flooding have been undertaken cooperatively by the AZGS and University of Arizona Department of Geosciences, with financial support from the Pima County Flood Control District and National Science Foundation. The following paragraphs summarize the results of these investigations.

As discussed above, surficial geologic mapping delineates the extent of geologically young deposits, thus revealing the areas that have been subject to alluvial-fan flooding in the recent geologic past (during the past few thousand years). AZGS geologists have mapped in detail the surficial deposits in several areas of southern and central Arizona (McKittrick, 1988; Jackson, 1989, 1990a,b; Field and Pearthree, 1991b). They have also conducted specific mapping projects to evaluate flood hazards on the Tortolita piedmont north of Tucson (Pearthree and others, 1991) and on the piedmonts around the White Tank Mountains west of Phoenix (Field and Pearthree, 1991a).

The geologic assessment of flood-prone areas on the Tortolita piedmont is particularly interesting because this is one of the few areas in Arizona where the AFM has been used to generate flood-insurance-rate maps (FEMA, 1989). The implications of geologic investigations, therefore, may be directly compared with the alluvial-fan boundaries determined through the AFM. The geologic data and the alluvial fans depicted on the flood-insurance-rate maps, however, are substantially different. The flood-insurance-rate maps identify broad areas as being flood prone that have not been flooded for 5,000 years or more (Figure 3). The most serious discrepancies are in the southeastern portion of the piedmont, where young deposits associated with the larger drainages are very limited. The results of the AZGS geologic-mapping effort clearly imply that there are substantive problems with the AFM itself or with the manner in which it was applied to the Tortolita piedmont. Because of these problems, large portions of the piedmont were included in the 100-year floodplain that are not flood prone.

By integrating geologic evidence with hydrologic flow models, geologists can estimate the sizes of the largest floods that have occurred along streams during the past tens, hundreds, or thousands of years. Large floods leave behind evidence that may be used to estimate the height of the water during the flood. This evidence includes fine-grained sediment and floated debris deposited in areas of slow water flow, as well as scour lines where floodwaters eroded older sediments (Baker, 1987). **Paleofloods** are commonly reconstructed in bedrock canyons and upper piedmont areas, where the floods were confined by stable valley sides and the channel beds were relatively unscoured. To reconstruct these floods, researchers use the HEC-2 hydrologic flow model (Hydrologic Engineering Center, 1982) to generate water-surface profiles of different discharges. They then compare these profiles with the geologic evidence of the water-surface elevation above the channel bed (Figure 4). The most reasonable estimates of the maximum paleoflood discharge are those that best fit the geologic evidence.

House (1991) reconstructed paleoflood discharges on the five largest streams that cross the southern portion of the Tortolita piedmont. The purpose of these studies was to evaluate the validity of the 100-year discharges that were used in the AFM to determine flood hazards on the piedmont. The AFM 100-year discharges were determined through the use of a rainfall-runoff model based on idealized, intense rainfall events and estimates of water runoff in stream channels (Zeller, 1979). The results of this model, however, are suspect because of uncertainties in the size, duration, and intensity of rainfall events that generate large floods in these drainages, as well as uncertainties in the parameters used to obtain the runoff estimates. The geologic record of flooding in each of the Tortolita drainages is at least several hundred years long, yet the largest reconstructed paleofloods are substantially smaller than the 100-year-flood estimates obtained from the rainfall-runoff model. This discrepancy suggests that the 100-year discharges used in the flood-hazard assessment of the Tortolita piedmont are unrealistically large.

To realistically assess the hazards of alluvial-fan flooding, researchers must understand the character of water flow during these floods. Flood-hazard assessments must include answers to the following questions: (1) How deep and fast are water flows during floods on alluvial fans?; (2) Do channel patterns commonly change during fan floods or are they relatively stable?; (3) How much of the fan area is affected by relatively deep, high-velocity channelized flow?; and (4) How important is shallower, less hazardous sheet flooding? Researchers have used several hydrologic models of alluvial-fan flooding to assess flood hazards (e.g., the AFM mandated by FEMA). It is difficult to determine how closely these models approximate reality, however, because information on alluvial-fan floods is scant. AZGS geologists made a detailed reconstruction of flow patterns during a very recent, extreme alluvial-fan flood, which affected part of the southern piedmont of the Tortolita Mountains. This study provides a real data set that may be used to test the models' predictions.

AZGS geologists discovered fresh evidence (channel scour and deposition, damaged vegetation, plant flotsam, and fine-

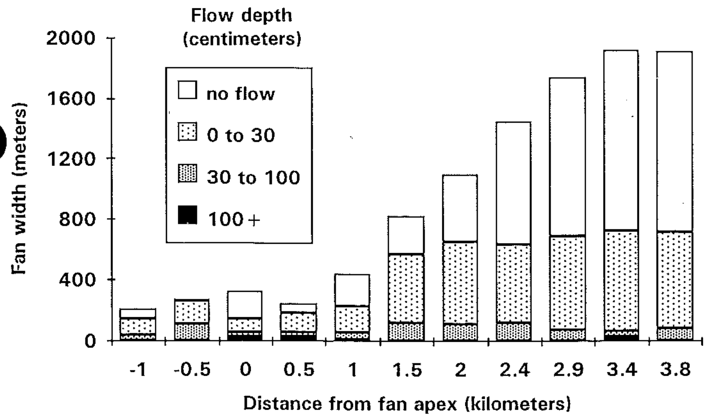

Figure 5. Histogram that shows the distribution of flood-flow depths during the 1988 Wild Burro flood on the southern piedmont of the Tortolita Mountains. The areas that were covered by three depths of flow were determined from 11 transects made across the flood zone, starting above the fan apex. The area of relatively deep flow (greater than 30 centimeters, or 1 foot) remained fairly constant downfan. The flow diverged rapidly below the fan apex, however; the number of distinct flow paths separated by dry areas increased, as did the total flooded area (from Pearthree and others, in prep.).

grained slackwater deposits) of a very large flood that affected much of the active alluvial fan of Wild Burro Wash (Figure 3; Pearthree and others, in prep.). Datable material in the flood deposits, reports of flood damage at the lower end of the piedmont, and weather radar records were used to determine that the flood occurred in July 1988. The maximum discharge at the apex of the alluvial fan, which was estimated through the use of paleoflood techniques (see above), is the largest flood recorded for a drainage of this size in southern Arizona. AZGS geologists mapped flow paths and depths on the alluvial fan in the field, using large-scale aerial photographs with detailed topographic contours that were constructed before the flood. Flow depths and velocities in channels were reconstructed at about 20 locations on the fan.

The results of this study have several ramifications for flood-hazard analysis on alluvial fans. The portion of the piedmont that was flooded closely coincides with deposits that are less than 5,000 years old and associated with Wild Burro Wash. The detailed surficial geologic mapping, therefore, accurately delimited flood-prone areas (Figure 3). Flood flow on the alluvial fan was very complex. From relatively few paths at the fan apex, the flow quickly became more complicated downfan and eventually split into 42 paths separated by dry areas (Figure 5). Although deep channelized flow and shallow sheet flow were both important, flow that was less than 30 centimeters (1 foot) deep was much more widespread. Areas that were not inundated between the outermost flow paths became larger downfan, composing more than half of the fan area at the lowermost limit of mapping. Local flow within channels was much deeper and faster than the AFM predicted. Channels that existed before the flood conveyed most of the floodwaters, and very little change in preflood channel patterns occurred during the flood. This clearly implies that areas in or adjacent to existing channels on alluvial fans have much higher flood potential than areas away from channels.

CONCLUSIONS

Geologic analyses of piedmonts in Arizona can supply unique and invaluable insights into the character and extent of piedmont flooding. A long history of stream behavior and flooding is preserved in the geology and geomorphology of a piedmont. By deciphering this history, geologists can help identify flood-prone areas, estimate the sizes of the largest floods that are likely to occur, and illuminate the nature of flood flow on piedmonts.

By integrating geologic data with hydrologic models, researchers can improve these models and make more accurate, realistic assessments of flood hazards on piedmonts. AZGS geologists have outlined the areas that are potentially subject to alluvial-fan flooding by mapping in detail young sediments deposited by streams on several piedmonts in Arizona. Alluvial-fan areas determined by these geologic studies differ significantly from those determined by the model that FEMA mandates for establishing flood-insurance rates. This suggests that either the model or the manner in which it has been applied in Arizona is incorrect. Geologists can also estimate the sizes of the largest floods during the past few hundred years by integrating physical evidence left by the floods with hydrologic models. These paleoflood investigations may be used to check the validity of hydrologic models that rely solely on idealized rainfall and runoff parameters. AZGS geologists reconstructed in detail the flow during a recent, extreme alluvial-fan flood. The information on flow paths, depths, and velocities should be used to evaluate how closely the models represent conditions during a real flood.

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REGULATION OF OIL AND GAS IN ARIZONA

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In July 1991, the Arizona Geological Survey (AZGS) was assigned statutory responsibility for carrying out the provisions of the Oil and Gas Conservation Act, under the oversight of the Arizona Oil and Gas Conservation Commission. The Commission, which consists of five appointed officials, was established in 1959 by Governor Fannin. The first organizational meeting of the Commission was held on July 8, 1959. Before the Commission was established, the State Land Commissioner was responsible for administering and enforcing the provisions of the act.

Subsequent amendments to the act of 1951 broadened the statutory authority of the Commission to include the regulation of the following: (1) all drilling, development, and production of oil, gas, helium, and geothermal resources; and (2) all underground storage of oil, liquified petroleum gas (LPG), and natural gas. The Commission also has statutory authority to hold public hearings, approve rules, set policy, and promote oil and gas activity in Arizona.

Under the enabling statute, commissioners are appointed to a 5-year term by the Governor with the advice of and confirmation by the Senate. Current members include Jan C. Wilt of Tucson, Chairperson; James E. Warne, Jr. of Phoenix, Vice-Chairperson; Archie Roy Bennett of Prescott; Barbara H. Murphy of Glendale; and Dr. J. Dale Nations of Flagstaff (Figure 1). The State Land Commissioner serves as ex officio member and, thus, has no voting privileges. Since 1959, 32 individuals have served the citizens of Arizona by accepting appointment to the Commission.

Figure 1. *Members of the Oil and Gas Conservation Commission and AZGS support staff review the oil and gas rules and budget and discuss idle wells at their September meeting. Front row, left to right: Barbara H. Murphy (Commissioner), Jan C. Wilt (Commission Chairperson), and Katherine L. Mead (Assistant Attorney General). Back row, left to right: Pamela J. Lott (Secretary), Larry D. Fellows (Director of the AZGS and State Geologist), J. Dale Nations (Commissioner), James E. Warne (Commission Vice-Chairperson), and Steven L. Rauzi (Oil and Gas Program Administrator).*

Since it was established in 1959, the Commission has maintained a staff and office in Phoenix. In July 1991, that office was merged into the AZGS and moved to Tucson. The six-member Commission retains the same powers and duties to hold hearings, approve rules, and set policy, but staff support is now provided by the AZGS.

The Oil and Gas Program Administrator handles the day-to-day administrative and regulatory functions required in the drilling, production, and underground storage of oil, gas, helium, and geothermal resources. Specific activities include collecting compliance bonds; issuing permits; maintaining well logs, files, and samples; maintaining production, injection, and underground-storage records; reviewing, revising, and adopting rules; taking minutes of all meetings and hearings; and answering correspondence on oil and gas matters. The Program Administrator also provides expertise on the petroleum geology of Arizona, in accordance with the statutory provision to encourage and promote the oil and gas industry in Arizona.

Promoting the oil and gas potential of Arizona dates back to 1970, when the Commission started to conduct fundamental geologic studies related to oil, gas, and helium. The Commission expanded its staff of geologists and began compiling regional information on oil and gas geology in the State. Subsequent field reconnaissance resulted in the publication of a series of regional and local maps. These include geothermal gradient, structural, geologic, and geophysical maps. Many of the maps are accompanied by well descriptions and reports on the petroleum geology of a region, county, or producing field.

Current oil and gas publications include the informative *Arizona Well Location Map and Report*. This report is a 28-page tabulation of all wells drilled for oil, gas, helium, or geothermal resources in Arizona. The wells are plotted on two accompanying maps, a 1:667,000-scale map of the entire State and a 1:127,000-scale map of producing oil and gas fields in Arizona. The helium fields east of Holbrook are also included on the latter map. The most recent oil and gas publication is *Proterozoic Hydrocarbon Source Rock in Northern Arizona and Southern Utah*, which describes the distribution of the recently recognized, late Precambrian source rock in northern Arizona and southern Utah. A chart titled *Oil and Natural Gas Occurrence in Arizona* concisely summarizes the petroleum geology of Arizona.

For more information on oil and gas regulations, publications, and related activities, contact Steven L. Rauzi, Oil and Gas Program Administrator, Arizona Geological Survey, 845 N. Park Ave., Suite 100, Tucson, AZ 85719; tel: (602) 882-4795.

OIL AND GAS NOTES

A permit to drill was issued in September to United Gas Search of Tulsa, Oklahoma. The company plans to drill the well, the Mohave County No. 1, about 15 miles south of St. George, Utah, in T. 41 N., R. 11 W., sec. 10. The proposed total depth is 6,500 feet.

Dry Mesa Corporation of Farmington, New Mexico, recompleted an oil well in the Dry Mesa field as a gas producer in the Pennsylvanian Paradox Formation. Merrion Oil and Gas Corporation, also of Farmington, recompleted a gas well in the East Boundary Butte field as an oil producer in the Mississippian Leadville Limestone.

About 258,000 acres in Arizona are currently leased for oil and gas exploration; 198,000 of these are Federal leases and 60,000 are State leases. Recent leasing activity in northern Arizona is partly driven by a growing interest in the oil potential of Precambrian rocks. United Gas Search picked up the parcels for its Mohave County No. 1 well at the Bureau of Land Management (BLM) lease sale in June 1991. Premco Western, Inc. of Dallas, Texas, successfully bid on two parcels near the Mohave County No. 1 well at the BLM lease sale in December 1991.

Arizonans Support National Geologic-Mapping Program

"To stimulate the production of geologic map information in the United States through the cooperation of Federal, State, and academic participants," members of the 102d Congress introduced two bills, S. 1179 and H.R. 2763, in 1991. The bills establish a national geologic-mapping program, which includes a State geologic-mapping component. The U.S. Geological Survey (USGS) would be the lead Federal agency. At the National Governors Conference held in Seattle in August 1991, governors unanimously passed a resolution that strongly supported national legislation to build the Nation's geologic-map database. S. 1179, H.R. 2763, and the governors' resolution emphasize the importance of geologic mapping to modern society and the need for more extensive and detailed map coverage of the Nation. If S. 1179 and H.R. 2763 are both passed and funded, the rate at which geologic maps are completed will be significantly increased. Excerpts from the bills and the full text of the resolution are reprinted below.

SENATOR DECONCINI COSPONSORS S. 1179

S. 1179, the Geologic Mapping Act of 1991, was introduced on May 23 by Senator Bennett Johnston (D-LA) and originally cosponsored by Senators Jeff Bingaman (D-NM) and Larry Craig (R-ID). Additional cosponsors included Senator Dennis DeConcini (D-AZ). The bill was referred to the Committee on Energy and Natural Resources. S. 1179 was passed by the committee in early November, but did not reach the full Senate before the December recess.

Findings

The Congress finds and declares the following:

(1) Geologic maps are the primary data base for virtually all applied and basic Earth-science investigations, including exploration for and development of mineral, energy, and water resources; land-use evaluation and planning for environmental protection; recognition and mitigation of geologic hazards; design and construction of infrastructure requirements such as utility lines, transportation corridors, and surface-water impoundments; and basic research into the composition, structure, and history of Earth materials and formation processes.

(2) All 50 States require basic geologic-map information to plan and execute decisions that affect the social and economic welfare of the public and private sectors.

(3) Despite the pivotal role that geologic maps play in the portrayal and dissemination of geologic information, the Nation has never committed itself to a sustained, systematic effort to build a comprehensive national geologic-map data base; instead, scientific effort has been directed away from the acquisition of long-term baseline information and toward the solution of short-term single-issue problems.

(4) A comprehensive, nationwide program of geologic mapping based on Federal, State, and private efforts is essential to systematically build the Nation's geologic-map data base at a pace that responds to increasing demand for data necessary for the long-term needs of the Nation.

Purpose

The purpose of this Act is to expedite the production of a geologic-map information base for the Nation which can be applied to resolution of issues related to land-use management, assessment, utilization and conservation of natural resources, ground-water management, and environmental protection.

Program Objectives

The objectives of the geologic mapping program shall include

(1) Determination of the Nation's geologic framework through systematic development of geologic maps, to be contributed to a national geologic-map data base, at scales appropriate to the geologic setting and the perceived application, for the purpose of resolving issues related to land-use management, assessment, utilization and conservation of natural resources, ground-water management, and environmental protection;

(2) Establishment of a geologic mapping association whose cooperating partners coordinate to identify national priorities and to develop the national geologic-map data base;

(3) Development of complementary geophysical, geochemical, geochronologic, and paleontologic data bases that provide value-added descriptive and interpretive information to the geologic-map data base;

(4) Application of cost-effective mapping techniques that assemble, produce, translate, and disseminate geologic-map information and that render such information of greater application and benefit to the public; [and]

(5) Development of public awareness for the role and application of geologic-map information to the resolution of national issues of land-use management.

CONGRESSMEN STUMP AND KOLBE COSPONSOR H.R. 2763

H.R. 2763, the National Geologic Mapping Act of 1991, was introduced on June 25 by Congressman Nick Rahall (D-WV) and originally cosponsored by Congressmen Barbara Vucanovich (R-NV), Bill Brewster (D-OK), and Dave McCurdy (D-OK). More than 30 additional cosponsors included Congressmen Bob Stump (R-AZ) and Jim Kolbe (R-AZ). The bill was referred to the Committee on Interior and Insular Affairs. H.R. 2763 passed the House by a voice vote on November 19.

Findings

The Congress finds and declares that

(1) During the past 2 decades, the production of geologic maps has been drastically curtailed.

(2) Geologic maps are the primary data base for virtually all applied and basic earth-science investigations, including
  - (a) exploration for and development of mineral, energy, and water resources;
  - (b) screening and characterizing sites for toxic and nuclear waste disposal;
  - (c) land-use evaluation and planning for environmental development, preservation, and quality;
  - (d) earthquake hazards reduction;
  - (e) predicting volcanic hazards;
  - (f) design and construction of infrastructure requirements such as utility lifelines, transportation corridors, and surface-water impoundments;
  - (g) reducing losses from landslides and other ground failures;
  - (h) mitigating effects of coastal and stream erosion;
  - (i) siting of critical facilities; and
  - (j) basic earth-science research.

(3) Federal agencies, State and local governments, private industry, and the general public depend on the information provided by geologic maps to determine the extent of potential environmental damage before embarking on proj-

ects that could lead to preventable, costly environmental problems or litigation.

(4) The combined capabilities of State, Federal, and academic groups to provide geologic mapping are not sufficient to meet the present and future needs of the United States for national security, environmental protection, and energy self-sufficiency of the Nation.
(5) States are willing to contribute 50 percent of the funding necessary to complete the mapping of the geology within the State.
(6) The lack of proper geologic maps has led to the poor design of such structures as dams and waste-disposal facilities.
(7) Geologic maps have proven indispensable in the search for needed fossil-fuel and mineral resources.
(8) A comprehensive nationwide program of geologic mapping is required in order to systematically build the Nation's geologic-map data base at a pace that responds to increasing demand.

Purpose

The purpose of this Act is to expedite the production of a geologic-map data base for the Nation, to be located within the United States Geological Survey, which can be applied to land-use management, assessment, and utilization, conservation of natural resources, groundwater management, and environmental protection.

Program Objectives

The objectives of the geologic mapping program shall include

(1) Determining the Nation's geologic framework through systematic development of geologic maps, to be contributed to the national geologic-map data base, at a scale of 1:100,000, with supplemental maps at scales appropriate to the geologic setting and the perceived applications;
(2) Development of a complementary national geophysical-map data base, geochemical-map data base, and a geochronologic and paleontologic data base that provide value-added descriptive and interpretive information to the geologic-map data base;
(3) Application of cost-effective mapping techniques that assemble, produce, translate, and disseminate geologic-map information and that render such information of greater application and benefit to the public; and
(4) Development of public awareness for the role and application of geologic-map information to the resolution of national issues of land-use management.

GOVERNOR SYMINGTON SUPPORTS RESOLUTION

The following resolution was supported by Governor Fife Symington and other governors at the National Governors Conference in August 1991.

Geologic maps are a principal source of critical earth-related information required by Federal, State, and local government agencies and the private sector. They are essential for numerous assessments, evaluations, and decisions related to the economic development and maintenance of the environment of the Nation. These maps provide vital information needed for land-use planning. In particular, they are indispensable for locating disposal sites for municipal, hazardous, and radioactive wastes; locating and protecting surface-water and groundwater resources; locating and developing mineral and energy resources; reducing the risks from earthquakes, landslides, and ground-failure hazards; predicting hazards from volcanoes and from stream and shoreline erosion; siting critical emergency facilities; routing highways and public-utility lines; and investigating basic earth-science matters.

Geologic-map coverage of the Nation, however, is critically insufficient and out of date to meet the demands of private, industrial, and government-agency users. The Nation's governors express their strong support for national legislation to build the Nation's geologic-map database through a program to be implemented in equity partnership between the States (through their geological surveys or other designated agencies) and the Federal government (through the U.S. Geological Survey). The program must be sufficiently funded at both the Federal and State levels to permit achieving complete geologic-map coverage for the Nation at an appropriate level of detail within a reasonably short period of time.

PROFESSIONAL MEETINGS

Tucson Gem & Mineral Show. Annual exhibit, February 12-16, Tucson, AZ. Contact Tucson Gem & Mineral Show Committee, P.O. Box 42543, Tucson, AZ 85733; tel: (602) 322-5773.

Mineral Resources. Annual meeting, February 24-27, Phoenix, AZ. Contact Meetings Dept., Society for Mining, Metallurgy, and Exploration, Inc., P.O. Box 625002, Littleton, CO 80162; tel: (303) 973-9550.

Arizona-Nevada Academy of Science and the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science. Joint meeting, May 17-21, Tucson, AZ. Special session on May 19: "Air, Land, and Water in the Canyons of the Colorado: Values, Conflicts, and Resolution." Special evening program features Carl Sagan. Contact Sandra Brazel, Office of Climatology, Arizona State University, Tempe, AZ 85287-1508; tel: (602) 965-6265.

Sunset Review of AZGS Completed

The Joint Natural Resources and Agriculture Committee of Reference held a Sunset Review of the Arizona Geological Survey (AZGS) on October 8, 1991 and recommended that the AZGS be continued for another 10 years. The review covered the period from July 1, 1977 to June 30, 1991. Senator Gus Arzberger and Representative Susan Gerard co-chaired the committee. Other members were Senators Ann Day, John E. Dougherty, Nancy L. Hill, and James J. Sossamon, and Representatives Henry Evans, Kyle W. Hindman, Richard "Dick" Pacheco, and Greg Patterson. Those who testified in behalf of the AZGS were Larry D. Fellows, AZGS Director and State Geologist; James A. Briscoe, President, JABA Inc.; Charles P. Miller, President, Miller Resources, Inc.; and James D. Sell, Manager, Southwestern Exploration Dept., ASARCO, Inc.

SPEAKERS WANTED

Professionals who wish to share their knowledge of how mineral and energy resources are formed, how and where they are located, and why they are important to modern society may contact the Southern Arizona Earth Science Education Coalition (SAESEC). SAESEC is composed of professionals from the Tucson Section of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME), Arizona Geological Society, American Institute of Professional Geologists, Southwest Minerals Exploration Association, Tucson/San Manuel Women's Auxiliary of AIME, and Mining Club of the Southwest. SAESEC receives requests for free speakers from local student, civic, social, and senior citizen groups. Any geologist or related professional who is interested in donating time and talent to this speakers' bureau should contact Claire E. Roscoe, Manager, Mining Club of the Southwest, P.O. Box 27225, Tucson, AZ 85726; tel: (602) 622-6257.

CORRECTION -- On page 2 in the last issue of *Arizona Geology* (vol. 21, no. 3), the credit line for Figure 2 (S P Crater and basalt flow) should read "Photo by Karl Zeller and J.F. McCauley, U.S. Geological Survey."

Pinatubo Generates More Brilliant Sunrises and Sunsets – May Cause Cooler Global Temperatures and Higher Skin-Cancer Risks

by Evelyn M. VandenDolder
Arizona Geological Survey

Although more than 10,000 kilometers (6,200 miles) separate the United States from the Philippines, the eruption of Mount Pinatubo in June 1991 may affect both the climate and the skin-cancer risk in Arizona (Monastersky, 1991). The ash cloud that now circles the globe has already created the most brilliant sunrises and sunsets in the State in recent years.

After more than 2 months of intensified seismicity, deformation, and discharge of small smoky plumes, Mount Pinatubo began to erupt on June 9. The largest explosions occurred on June 14 and 15, creating an ash and gas cloud as high as 20 miles into the stratosphere (Geotimes, 1991; Global Volcanism Network, 1991). By July 7, the cloud had circled the globe (Figure 1). By mid-August, as shown on satellite images, the thickest cloud layer extended to 20° north and south of the Equator, or near the latitudes of Mexico City and Rio de Janeiro. A thinner layer extended to 35° north latitude, or almost as far north as Flagstaff (Associated Press, 1991). Based on satellite and aircraft measurements, Mount Pinatubo was probably the largest volcanic eruption of the century, spewing more than twice the amount of ash and gas as the 1982 eruption of El Chichón in Mexico. Mount Pinatubo could continue to erupt intermittently for several years (Associated Press, 1991).

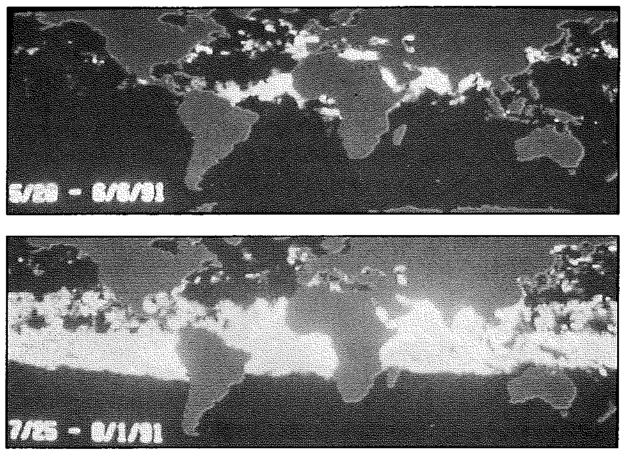


Figure 1. Images from a polar-orbiting satellite of the U.S. National Oceanic and Atmospheric Administration (NOAA). This satellite includes a high-resolution radiometer, which can measure the reflected sunlight from dust and haze in the atmosphere. Such measurements, however, can be obtained only for areas above the ocean on cloudless days. The top image was compiled from May 28 through June 6, before the eruption of Mount Pinatubo. Most of the reflectivity in this image is due to airborne dust from the Saharan and Arabian Deserts. The bottom image was compiled from July 25 through August 1, weeks after the aerosol cloud from Mount Pinatubo had circled the globe. Images courtesy of NOAA.

The haze that encircles the Earth includes both volcanic ash and sulfur dioxide aerosols. These aerosols formed when millions of tons of sulfur dioxide gas from the eruption reacted with water vapor in the stratosphere and created tiny drops (aerosols) of sulfuric acid, which are also contained in acid rain caused by air pollution. Scientists estimate that the aerosols will stay in the stratosphere for 2 to 3 years before they fall to the Earth's surface (Monastersky, 1991).

The haze filters sunlight, creating magnificent sunrises and sunsets. It also absorbs sunlight and reflects it back into space, which could cool the Earth's climate. In 1992 and 1993, after the haze disperses and becomes more evenly distributed around the Earth, mean global temperatures could decline by 0.5° C (about 1° F; Aldhous, 1991; Luhr, 1991). The eruption of El Chichón lowered global temperatures by a few tenths of a degree for 2 to 3 years (Associated Press, 1991). Although the temperature decrease due to Mount Pinatubo could last for 2 to 4 years, the decline may not be noticeable because normal climatic fluctuations are so much larger in any given area, such as Arizona, and because the mean global temperature naturally varies by 0.2° C (Luhr, 1991). In addition, an El Niño, a periodic warming of ocean waters, is developing in the Pacific Ocean. This event will warm the Earth for about a year, further masking the climatic effects of the volcanic haze (Monastersky, 1991). One scientist believes that the eruption of Mount Pinatubo and resultant reflection of sunlight are actually inducing the El Niño event and will shift the jet stream over the north Pacific farther south this winter, increasing precipitation and ending the 5-year drought in California (Geotimes, 1991). Despite the natural variation in global temperatures and the surface heating of the El Niño event, other scientists still believe that the global-scale cooling of 0.5° C will be large enough to be noticeable (Luhr, 1991).

The sulfur dioxide aerosols may also alter the chemistry of the stratosphere, thinning the protective ozone layer that surrounds the globe and allowing more ultraviolet radiation to reach the Earth's surface. This could increase the risk of skin cancer, especially in the mid- and high latitudes (Monastersky, 1991). Some scientists estimate that the aerosols could cause a 15-percent reduction in ozone values during the winter and a 6- to 8-percent reduction during the summer in the mid-latitudes, which include Arizona. This increased radiation would increase the skin-cancer risk and may cause several thousand more cases of melanoma in the United States during the next few decades (Monastersky, 1991). The effect of the eruption on the ozone layer, however, is debatable. Some scientists believe that the data and computer models used to determine the level of ozone depletion are insufficient to make such predictions.

Whatever the effects of the Mount Pinatubo eruption, all scientists studying this event agree that it has provided, and will continue to offer during the next few years, a wealth of information on volcanic processes.

REFERENCES

Aldhous, Peter, 1991, Before and after: Nature, v. 352, p. 651.

Associated Press, 1991, Mount Pinatubo's haze girdles globe; volcanic ash, gas may cool the Earth: The Arizona Republic, August 14, p. A4.

Geotimes, 1991, Could Pinatubo abate drought, cause El Niño?: v. 36, no. 9, p. 11.

Global Volcanism Network, 1991, Geologic phenomena; June 12: Geotimes, v. 36, no. 9, p. 25.

Luhr, J.F., 1991, Volcanic shade causes cooling: Nature, v. 354, p. 104-105.

Monastersky, Richard, 1991, Pinatubo's impact spreads around the globe: Science News, v. 140, no. 9, p. 132-133.

For the Classroom

Calculating the Height of the Pinatubo Global Ash Cloud

by Jon E. Spencer
Arizona Geological Survey

The ash cloud produced by the Pinatubo volcanic eruption spread quickly around the Earth and, by mid-August 1991, was responsible for brilliant sunrises and sunsets in Arizona. At 30 minutes after sunset, a brilliant orange to red glow dominated the western sky. The glow had a fairly distinct, horizontal top, above which was significantly darker sky. This boundary descended to the horizon; **glowset** occurred 40 minutes after sunset. **Glowrise** occurred 40 minutes before sunrise. Although the distinctive boundary at the top of the orange glow had become more diffuse by November, it will probably still be visible well into 1992. A similar brilliant glow was also seen after the eruption of Krakatau in 1883. This article describes a method to calculate the height of the top of the ash cloud from one simple measurement: the time between sunset and glowset (or glowrise and sunrise).

The glow is caused by sunlight striking the airborne ash. The Earth's shadow falls on the ash, and the edge of the shadow travels around the Earth as the Earth turns. An observer sees the sun set when sunlight travels along a line that is tangent to the Earth at the point of the observer (if there are no large mountains obscuring the distant horizon). As shown in Figure 1, glowset for the observer at point A occurs at a later time, when the edge of the Earth's shadow crosses the airborne ash at point B. Note that at glowset at point A, an observer at point D would see sunset. Thus, during the time between sunset and glowset (here designated *m*, as measured in minutes), the Earth has rotated an amount equal to angle DCA, which is here designated α_1 (alpha 1). Given that the Earth rotates 360° every 24 hours and that there are 1,440 minutes per 24-hour day, the angle α_1 may be calculated as follows:

$$\alpha_1 = \frac{m \times 360}{1{,}440}$$

The angle α_2 is equal to α_1 divided by 2.

To calculate ash-cloud height (designated h_1 in Figure 1) using trigonometry, we must know two variables that define triangle ABC in Figure 1. One is angle α_2, which we calculated above; the other is the length of line AC (designated *r* in Figure 1), which is the radius of the Earth (6,370 kilometers). We must also use in our calculations the three properties of triangles outlined in Figure 2. First we determine angle θ (theta). Because the triangle is a right triangle, angle θ is equal to 90° minus α_2. Next, we calculate the length of line AB (designated *x* in Figure 1). According to the law of sines,

$$\frac{x}{\sin\alpha_2} = \frac{r}{\sin\theta}$$

therefore,

$$x = \frac{r \times \sin\alpha_2}{\sin\theta}$$

Next, from the Pythagorean theorem, we calculate the length of line BC, as follows:

$$BC = \sqrt{x^2 \times r^2}$$

Figure 1.

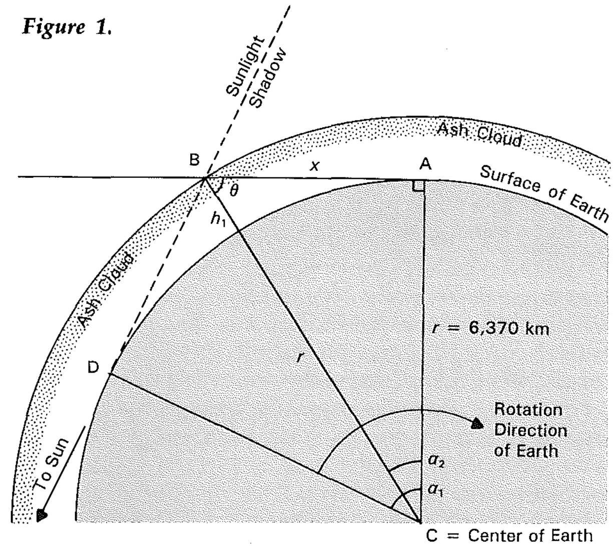
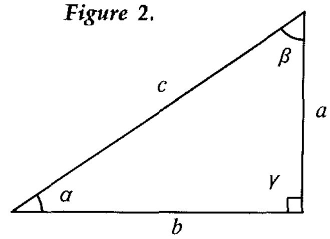


Figure 2.



(1) $\alpha + \beta + \gamma = 180°$
As shown here,
$\gamma = 90°$ (right triangle),

therefore, $\alpha + \beta = 90°$

(2) Law of sines:

$$\frac{a}{\sin\alpha} = \frac{b}{\sin\beta} = \frac{c}{\sin\gamma}$$

(3) Pythagorean theorem (right triangles only):

$$c^2 = a^2 + b^2$$

therefore, $c = \sqrt{a^2 + b^2}$

Ash-cloud height h_1, in kilometers, is then equal to BC - *r*.

This calculated ash-cloud height is accurate for an observer at the Earth's equator, but increasingly larger adjustments must be made as one approaches the poles. This is because at sunset at higher latitudes, the sun does not descend vertically to the horizon but at an angle. Near the poles, the sun does not set at all during spring and summer months, but travels essentially horizontally around the sky near the horizon. The ash-cloud height corrected for latitude (h_2) is determined simply by multiplying the calculated ash-cloud height (h_1) by the cosine of the latitude, as follows:

$$h_2 = h_1 \times \cos(latitude)$$

This is a fairly accurate determination of the height of the top of the ash cloud. In September 1991, glowset occurred 40 minutes after sunset in Tucson, which is at latitude 33° north. Applying the above equations revealed that the height of the top of the ash cloud was 24.3 kilometers, or about 80,000 feet. This calculation is accurate at times near the spring and fall equinoxes, but is slightly inaccurate at times near the winter and summer solstices. A calculation to correct for the time of year, however, is beyond the scope of this article.

New AZGS Publications

The following publications may be purchased from the Arizona Geological Survey (AZGS), 845 N. Park Ave., #100, Tucson, AZ 85719. Orders are shipped by UPS; a street address is required for delivery. All orders must be prepaid by check or money order payable in U.S. dollars to the Arizona Geological Survey. Add shipping and handling charges, listed below, to your total order:

In the United States:	20.01 - 30.00, add 5.75	50.01 - 100.00, add 10.25
$1.01 - $5.00, add $2.00	30.01 - 40.00, add 6.50	Over 100.00, add 12%
5.01 - 10.00, add 2.50	40.01 - 50.00, add 8.00	Other countries: Request price quotation
10.01 - 20.00, add 4.50		

Slaff, Steven, 1991, Earth-fissure activity near Brady and Picacho pumping plants, Tucson aqueduct, Central Arizona Project, Pinal County, Arizona: Open-File Report 91-1, 43 p., scale 1:24,000, 2 sheets. $10.50

Earth fissures are surface and subsurface tension cracks that develop in unconsolidated and semiconsolidated sediments. Hundreds of fissures exist west of the Picacho Mountains in Picacho basin. This report focuses on the portion of the basin that includes the Brady and Picacho pumping plants and parts of the Tucson aqueduct, Santa Rosa canal, and Central Arizona Irrigation and Drainage District (CAIDD) canal. The author identified and mapped earth fissures in the study area and evaluated the potential for future fissure development to damage the Central Arizona Project (CAP). Changes in the local water-table elevation were examined to see whether they provide a qualitative indication of present and future fissure-activity rates, and large-format photographs were tested as a fissure-identification tool. The project was primarily funded by the U.S. Bureau of Reclamation.

Schmidt, Nancy, Reynolds, S.J., and Horstman, K.C., 1991, AZGEOBIB: A preliminary list of references on the geology of Arizona: Open-File Report 91-4, 302 p. $27.00

The largest bibliography on Arizona geology, AZGEOBIB contains approximately 11,600 references pertinent to the geology of Arizona. Although the references are primarily geological in focus, the bibliography is a useful source of information not only for geologists, but also for educators, librarians, hydrologists, archaeologists, and environmental and land-use planners. In its preliminary form, AZGEOBIB is released both as a text file (MS-DOS disk) and as a hard-copy printout.

Gilbert, W.G., 1991, Bedrock geology of the eastern Gila Bend Mountains, Maricopa County, Arizona: Open-File Report 91-5, 13 p., scale 1:24,000. $5.00

The eastern Gila Bend Mountains are composed of Early Proterozoic crystalline rocks and overlying, mid-Tertiary, continental clastic and volcanic rocks of the Sil Murk Formation. Slightly more than half of the bedrock in the eastern part of the range is composed of granitic rocks. Except for a few scattered exposures, the mid-Tertiary rocks crop out in the southwestern part of the map area. Earlier studies suggest that the area has low potential for mining barite, copper, molybdenum, lead, zinc, silver, gold, uranium, thorium, and rare-earth elements. The project was supported by the Cooperative Geologic Mapping Program (COGEOMAP) between the AZGS and U.S. Geological Survey.

House, P.K., 1991, Paleoflood hydrology of the principal canyons of the southern Tortolita Mountains, southeastern Arizona: Open-File Report 91-6, 31 p. $5.00

To derive 100-year discharge estimates for developing flood-insurance-rate maps, agencies such as the Federal Emergency Management Agency (FEMA) have traditionally used standard theoretical rainfall-runoff models. This study, however, suggests that such models do not represent the natural processes in smaller watersheds, such as the Tortolita Mountains. Using the slackwater-deposit/paleostage-indicator (SWD-PSI) technique, the author reconstructed the paleoflood history of three canyons in the Tortolita Mountains and found major discrepancies between his results and those obtained by FEMA. The report describes paleoflood hydrology and its use in the current study and recommends that it be used to check the validity of theoretically derived, regulatory flood-magnitude estimates used in engineering design and floodplain management.

The following 10 Contributed Maps were donated by Karl E. Karlstrom, formerly of the Department of Geology at Northern Arizona University. The areas were mapped by geology graduate students as part of their master's theses. The AZGS seeks high-quality mylars of geologic maps of areas within Arizona, compiled from original research. Please contact the AZGS if you wish to donate items to its Contributed Map series.

Puls, D.D., 1985, Geologic map and balanced cross-section of the northern Mazatzal Mountains, central Arizona: Contributed Map CM-91-B, scale 1:10,000, 2 sheets. $5.50

Sherlock, S.M., 1986, Geologic map and cross-section of Early Proterozoic rocks of McDonald Mountain - Breadpan Mountain area, northern Sierra Anchas, Gila County, Arizona: Contributed Map CM-91-C, scale 1:10,000, 2 sheets. $5.00

Argenbright, D.N., 1985, Geologic map and Proterozoic structure of Crazy Basin area, Yavapai County, Arizona: Contributed Map CM-91-D, scale 1:10,000. $4.00

Brady, T.B., 1987, Geologic map of the Sheep Basin Mountain area, northern Sierra Anchas, Gila County, Arizona: Contributed Map CM-91-E, scale 1:10,000. $5.00

Roller, J.A., 1986, Geologic map and cross-section of the central Mazatzal Mountains, central Arizona: Contributed Map CM-91-F, scale 1:10,000, 2 sheets. $6.00

Darrach, Mark, 1987, Geologic map and Proterozoic structure of the Cleator shear zone, Yavapai County, Arizona: Contributed Map CM-91-G, scale 1:3,000. $4.50

Labrenz, M.L., 1988, Geologic map of the western half of the Young quadrangle, northern Sierra Anchas, and geologic map of the Marsh Creek area, Diamond Butte and Young quadrangles, Gila County, Arizona: Contributed Map CM-91-H, scale 1:24,000 and 1:10,000, 2 sheets. $4.00

Wessels, R.L., 1990, Geologic map of the Jakes Corner area and geologic cross-section of Early Proterozoic rocks of the Jakes Corner area, northern Sierra Anchas, Gila County, Arizona: Contributed Map CM-91-I, scale 1:10,000, 2 sheets. $8.50

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Albin, A.L., 1991, Geologic map of the Peacock Mountains and southern Grand Wash Cliffs, including Peacock Peak, Antares, Hackberry, Valentine, and the southern half of the Music Mountain SE and Milkweed Canyon SW 7.5-minute quadrangles, northwestern Arizona: Contributed Map CM-91-K, scale 1:24,000. $5.25

STAFF NOTES

New Employees

Emily Creigh DiSante has been hired as Administrative Assistant I at the Arizona Geological Survey (AZGS) and serves as Editorial Assistant. She brings to the job more than 11 years of experience in writing and technical editing, as well as 4 years of experience managing her own desktop-publishing business. Emily has a B.A. degree in international studies and an M.A. degree in teaching English as a second language. She speaks Spanish fluently.

Pamela J. Lott is the new Secretary for the AZGS Oil and Gas Program. Her 12 years of work experience include general office work, bookkeeping, paralegal duties, secretarial duties for an oil and gas company, and managing her own business. Pam has a B.S. degree in social science and has been approved by the American Bar Association as a paralegal professional.

Richard A. Trapp, Geologist II, is the new AZGS database manager and backup geologist for the Oil and Gas Program. He has been a computer specialist and systems analyst for 9 years and has experience in computerizing geologic databases. Rick has B.S. and M.S. degrees in geology and has coauthored 11 publications.

Recent Activities

Larry D. Fellows represented the AZGS at the annual meeting of the directors of State geological surveys in western states and at the midyear business meeting of the Association of American State Geologists. He testified at the Sunset Review hearing of the AZGS conducted by the Arizona Legislature. Larry met with the AZGS advisory committees for environmental and engineering geology, mineral resources, and earth science education, as well as geologists in Yavapai County. He participated in the Minerals and Mining Cluster of the Arizona Strategic Planning for Economic Development Committee. He participated in seismic safety meetings sponsored by the Arizona Division of Emergency Services and was a panelist at a meeting on environmental stewardship sponsored by the HAZWaste Society. Larry also participated in meetings of the Environmental Education Task Force and the Interagency Committee on Environmental Education and helped organize the Southern Arizona Earth Science Education Coalition. He gave two presentations on the geology of the Verde basin and led a field trip as part of the third annual Verde River Days held at Dead Horse Ranch State Park in Cottonwood. Larry received the 1991 Distinguished Community Service Award at the fall conference of the Arizona Science Teachers Association (ASTA).

Thomas G. McGarvin led several workshops and field trips during the fall. He presented a workshop titled "The Logic in Geologic Processes" to educators at the fall conferences of ASTA and the Arizona Association for Learning in and About the Environment, secondary school teachers in the Marana school district, and members of the Tucson Estates' Nature Club. He held two additional workshops for Marana-district teachers: "No Rocks, No Ice Cream" and classroom methods for presenting geologic concepts to students in grades K-6. Tom taught docents at Tohono Chul Park in Tucson about basic geologic concepts and the geologic setting of the Tucson area. He led two field trips for teachers that focused on the geology of the Tucson, Santa Catalina, and Rincon Mountains and the Tucson basin. Tom received the 1991 Distinguished Community Service Award at the ASTA fall conference.

During the fall, **Philip A. Pearthree** gave several presentations on geologic hazards in Arizona. He co-led a field trip (with **Kirk R. Vincent** and **P. Kyle House**) for the Arizona Hydrological Society to examine evidence of piedmont flooding. He lectured on seismic hazards in the Basin and Range Province at Arizona State University and the University of Arizona. Phil also gave a geologic perspective on seismic hazards to the Arizona Seismic Safety Council and to planners and emergency-response personnel in Pima County.

At the annual meeting of the Geological Society of America and associated societies in October, **Jon E. Spencer** gave an oral presentation titled "Miocene Base- and Precious-Metal Mineralization Associated with Basin Brines and Detachment Faults, West-Central Arizona," which was coauthored by **John T. Duncan** and Stephen J. Reynolds. Jon also served as cochairman of a full-day symposium titled "Cenozoic Extension in the Cordillera: Geometry, Timing, Mechanisms, and Regional Controls." In December, he gave a talk titled "Mineral Deposits Associated with Detachment Faults in West-Central Arizona" at the Arizona Conference of the American Institute of Mining, Metallurgical, and Petroleum Engineers.

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