Arizona Geological Survey

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Figure 1. Governor Rose Mofford (seated) signs into law House bill 2675, establishing an environmental education program in Arizona schools. Proponents of the bill are, from left to right, Thomas Woods, Arizona Game and Fish Commission; Tony Gabaldon, State Senator from Flagstaff; Kerry Baldwin, Arizona Game and Fish Dept.; Richard Foreman, Southwest Gas Corp.; John Parsons, Arizona State Parks; Marcia Dillman, Commission on the Arizona Environment; Lauri Clements, Arizona Dept. of Commerce, Energy Office; Trish Jahnke, Northern Arizona University; Donald Netko, Motorola Communications and Electronics, Inc.; and Karan English, State Representative from Flagstaff and sponsor of the bill.

Governor Mofford Signs Environmental Education Bill

In June Governor Rose Mofford signed House bill (HB) 2675 (Figure 1), which mandates that each school district in Arizona develop and implement an environmental education program as part of its curriculum. Governor Mofford summarized her support of the bill in the following statement:

"Arizona is an exceptionally beautiful, mineral-rich State that has been experiencing tremendous population growth since 1945. New residents and industries require more and more of the State's land, water, mineral, and energy resources. Increased risk of degrading these resources, unfortunately, always accompanies population growth. It is essential that we do not pollute our precious water resources, foul our air, or reduce the quality of our unparalleled scenic attractions.

"In order to manage our land and natural resources wisely, it is now more important than ever that we understand what and where our resources are, how they relate to every-day activities, and what potential development-related problems exist. This environmental education bill, when fully implemented, will give Arizonans an opportunity to become more knowledgeable, and thus, better stewards of our resources.

"Program activities and planning must begin soon. In the next few weeks, the members of the environmental education task force will be appointed to advise me of the various aspects of environmental education. In addition, an open competition will be announced to design an environmental number license plate. The anticipated proceeds from this special plate will serve as one source of funding for the environmental education program.

"Arizona residents are very concerned about environmental issues. The members of the Arizona Legislature, specifically bill sponsor Karan English, deserve our appreciation for passage of this milestone legislation."

Environmental Education Bill Becomes Law

Figure 1. State Representative Karan English, Flagstaff, sponsor of HB 2675.

House bill (HB) 2675, which creates a multifaceted environmental education program, was passed by the Arizona Legislature and signed by Governor Rose Mofford in June. The bill will impact many groups of Arizonans, including local school districts, community colleges, universities, the Arizona Department of Education, the Arizona Geological Survey (AZGS), and other State agencies. Major provisions of the bill are summarized below through an interview between its primary sponsor, Representative Karan English from Flagstaff (Figure 1), and the AZGS director, Dr. Larry D. Fellows.

The intent of the legislature in passing HB 2675 is stated in section 1 of the bill as follows:

> The legislature recognizes that the education of the people in this State is critical to maintaining the delicate balance among all forms of life and their environments. It is the intent of the legislature that the public schools, community colleges, State universities, and State agencies provide a continuing awareness of the essential mission to preserve the Earth's capacity to sustain life in the most healthful, enjoyable, and productive environment possible. It is the further intent of the legislature that the public schools, community colleges, State universities, and State agencies integrate environmental education throughout the educational system so that awareness of students and the general public is thorough, continuous, and meaningful.

An important statutory mandate of the AZGS is to inform the public about the geologic environment and the origin and character of mineral resources in Arizona. The AZGS fulfills this mandate by conducting investigations about the distribution and character of rocks, earth materials, geologic processes, and mineral resources and providing this information to the public. Information is distributed by publishing and selling reports and maps; by giving talks and displaying exhibits for the general public; and by conducting workshops and preparing aids, pamphlets, and study guides for earth science teachers. A major part of the AZGS mission, therefore, may be described as "environmental education"; this explains the AZGS interest in HB 2675.

Representative English, why did you sponsor this bill?

English: A couple of years ago several people, including John Parsons, one of my constituents from Flagstaff who is a member of the Outdoor Recreation Coordinating Commission, told me that the recently completed State Comprehensive Outdoor Recreation Plan (SCORP) strongly recommended environmental education and asked if I would introduce a bill to develop such a program. I introduced a bill in 1989, and it failed miserably.

It is my belief that an environmental education program is badly needed in Arizona primarily because of the demands being placed on our land and resources by the rapid population growth we have been experiencing for the last 40 years. Regrettably, many people in this State have either an antibusiness or antienvironment bias. It seemed to me that the best way to help change this polarization and to inform our citizens of the importance of both business and environmental concerns is through an education program that involves all aspects of society, not just special interest groups.

In late 1989, I set up a committee to discuss how to structure an environmental education program. I also contacted many groups and tried to emphasize the importance of working together to understand better our land and its resources for wiser management decisions. HB 2675 was prepared with the help of many individuals and groups, was introduced in January, and was passed by the legislature and signed into law by Governor Mofford in June.

How do you define "environmental education"?

English: Section 2 of the bill defines "environmental education" as the educational process dealing with the relationships between people and their natural and manmade surroundings. This includes the interrelationships among population, pollution, resource allocation, resource depletion, conservation, transportation, technology, and urban and rural planning and their effect on the total human environment. This definition is intended to be very general to give direction to the program, but you can see that the emphasis is on people and the wise use of natural resources. Your agency deals with a major part of this subject: rocks and the resources they contain. Other agencies and groups have responsibility for the use and management of these resources.

What are the major provisions of the bill?

English: The bill has five major components. Very briefly, they are as follows:

1. K-12 education, through the Arizona Department of Education and local school districts, will work together to incorporate environmental education into existing curricula or to expand the curricula if practical.
2. The bill will create opportunities for certified teachers, as well as for students preparing for certification, to take classes on various aspects of the environment. Few, if any, of these classes are now available at our three universities.
3. An interagency committee on environmental education will be formed. Members are from agencies that have statutory authority and expertise to educate the public on environmental issues. Through committee activities, agencies will be encouraged to expand or broaden their activities in education for public awareness. I believe that if this committee had been in existence 10 years ago, we would not have had the misinformation and lack of environmental knowledge that has led to the current problem over disposal of hazardous waste at the Mobile site.
4. An environmental education task force, to be appointed by the Governor, has a broad mandate to ensure that environmental education is made available to all Arizonans. The committee will develop guidelines and make recommendations about the structure and funding of the entire program. Long-range guidance and direction will be needed to preserve and protect our resources and environment for future generations of Arizonans.
5. Fund-raising mechanisms, one of which is an environmental number license plate, are prescribed. Governor Mofford will appoint a committee to prepare plans for an open competition to design the plate and will make the final plate selection. Revenues from the sale of these plates will be used as partial funding for the program.

What other funding sources, besides the environmental number license plates, are identified in the bill?

English: The bill I introduced in January included $100,000 for the Arizona Department of Education to start the program. That sum was not included in the bill that was passed. Other funding will, therefore, be needed. Several industries have already pledged to donate money to help fund the task force. I'm optimistic that others will also come forward because the bill had strong support from the business sector. Responsible companies realize that protecting the environment is good business. I'm hoping the Arizona Department of Education will also find funding for the program. They, too, strongly supported the concept and the bill.

What role do universities and community colleges have in environmental education?

English: They have a critical role in providing the needed classes. The Nation is now experiencing a severe shortage of scientists and engineers. That makes it even more important that those who do graduate in science and engineering have a good understanding of how their disciplines relate to the environment. Universities will also provide environmental courses that students will need to become certified teachers or well-informed members of the business community. In short, universities and community colleges will provide students in all disciplines with a working knowledge of the environment and how their particular discipline relates to the environment.

How will State agencies be involved in environmental education?

English: I mentioned earlier that an interagency committee on environmental education is a major provision of the bill. Several State agencies are very interested in accelerating their activities in public education. They already have the expertise and resources. This bill will enhance opportunities for these agencies to work together cooperatively. They will be expected to make the most out of limited tax dollars and other resources. The Arizona Geological Survey, for example, has an important educational responsibility that should be enhanced through participation in the interagency committee.

Do you have any other comments about environmental education or the bill?

English: I'm firmly committed to the need for environmental education. I hope this bill is not "too little, too late." Environmental education is a very serious subject that needs immediate attention and must be a long-term effort. The public is keenly aware of environmental concerns. It's really a pleasure to demonstrate good government by offering this kind of law. An effective environmental education program will give our children some of the tools they will need in the future. Because the world's population is increasing so rapidly, our children's survival will depend on a very fine balance between resource management and environmental protection.

Finally, I express my sincere appreciation to all those in the educational, environmental, and business communities who worked with me to build this piece of legislation that will work for all of us.

How can *Arizona Geology* readers obtain a copy of HB 2675?

English: Write to the Secretary of State, State Capitol-West Wing, 1700 W. Washington Ave., Phoenix, AZ 85007 and ask for a copy of the final adopted version of House bill 2675.

Photo at right: Because earth science directly applies to the students' experience and environment, it fosters student participation. Drawing on examples from the students' natural surroundings or from news coverage of current events, a teacher can illustrate the link between human activities and the Earth.

The Importance of Earth Science Education in Arizona's Public Schools

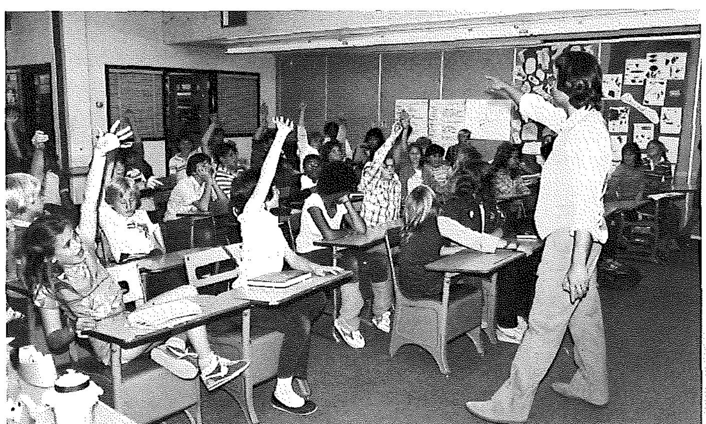
Why teach earth science? A knowledge of earth science is vitally important because most human activities are related to interaction with our planet. An integrated study of Earth's history; its atmosphere, oceans, and crust; its materials and valuable resources; and the geologic processes that shape its surface are all basic knowledge that is key to the development of an informed citizenry.

More specific reasons for teaching earth science in Arizona's public schools include the following: (1) It is a rigorous science that offers exposure to a diverse range of interrelated disciplines; (2) It is closely related to the students' rich natural surroundings; and (3) It offers students subject matter that has direct application to their lives and the world around them. Students only need to step outdoors and observe or listen to news coverage of environmental problems, natural resources, and natural disasters to find relevance in concepts learned in the earth science classroom. Because it offers many opportunities to collect data, experiment, and draw conclusions both in the lab and in the field, earth science is an activity-oriented science course that fosters student participation and critical thinking. It incorporates concepts often not emphasized in other science courses, such as geologic time, the vastness of space, rates of natural processes, and the concept of global systems. As a basic field and laboratory science, earth science provides a rich opportunity for students to explore the interdisciplinary application of all natural and physical sciences to the study of our planet.

The teaching of earth science allows all students to have a better science background with pertinent information about their surroundings. Society is faced daily with environmental and economic concerns such as waste disposal, acid rain, water supplies, and the greenhouse effect. We are absolutely dependent upon the wise use of the Earth's energy, mineral, and human resources. Awareness of the hazards associated with natural phenomena, such as floods, tornadoes, hurricanes, volcanoes, and earthquakes, also requires a knowledge of earth science.

Students who study earth science are better prepared to discuss issues and make informed, responsible decisions. The interdisciplinary approach of earth science develops and builds on skills learned in earlier grades and closely relates to the students' everyday experiences. It develops attitudes, problem-solving skills, and critical thinking that will be useful throughout life, regardless of whether one works in the sciences, business, engineering, or public service. If tomorrow's adults must make wise decisions about the Earth's resources and environmental issues, it is vital that today's students have the opportunity to study earth science at all levels as an integral part of their education.

--Adapted by Peter L. Kresan, Department of Geosciences, University of Arizona, from a statement on earth science education approved and endorsed by the American Geological Institute, American Geophysical Union, Council for Elementary Science Education, National Association of Geology Teachers, National Earth Science Teachers Association, and National Science Teachers Association.



Earth Science Education in Arizona's High Schools

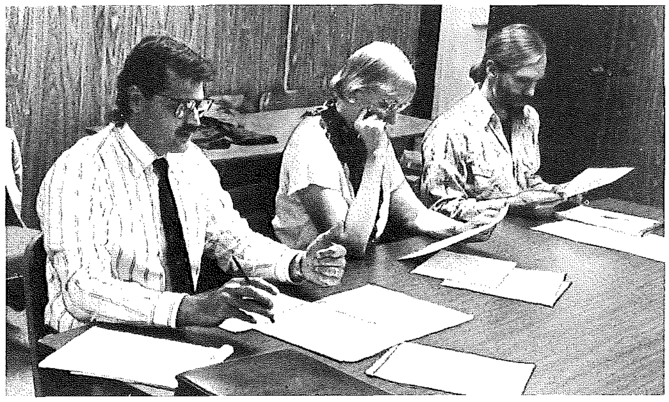


Figure 1. Members of the AZGS advisory committee on earth science education discuss plans: Mike Lang, School Improvement Unit, Arizona Dept. of Education (left); Suzanne Cash, Cortez High School, Phoenix (center); and Edmund Stump, Dept. of Geology, Arizona State University (right).

by Larry D. Fellows
Arizona Geological Survey

Advisory Committee

"Earth science" is defined as the study of (1) the Earth as a planet; (2) the atmosphere, oceans, and solid earth; and (3) the processes that form landscapes and soil. The discipline includes geology, hydrology, meteorology, oceanography, astronomy, and related sciences.

The Arizona Geological Survey (AZGS) is charged by statute to provide lectures and exhibits for the general public and workshops, pamphlets, and study guides for earth science teachers, in addition to conducting a variety of scientific investigations and providing other information. In 1989 an earth-science-education advisory committee was established to ensure that the projects and activities undertaken by the AZGS meet the needs of earth science educators, to determine ways in which cooperation between the AZGS and earth science teachers may be enhanced, and to provide comments and advice about the AZGS program in general. The committee, which will be featured in a future issue of *Arizona Geology*, is composed of high-school earth-science teachers; geology faculty from community colleges, Arizona State University (ASU), Northern Arizona University (NAU), and the University of Arizona (UA); and a representative from the Arizona Department of Education.

At the first meeting of the advisory committee, objectives were discussed (Figure 1). One of the first steps the advisors recommended was to survey high-school earth-science teachers and inquire about the status of earth science education in Arizona. The advisors expressed concern that earth science education may be in decline because of the 1985 decision of the Arizona Board of Regents to deny credit for earth science as a laboratory science course for freshmen enrolling at ASU, NAU, and UA.

Teacher Survey

A questionnaire was sent to the science department coordinator in each Arizona high school to request the names of those teaching earth science during the 1989-90 school year, as well as the total number of earth science sections taught in 1989-90 and 1985, before the regents' decision. The names and addresses of 176 high-school earth-science teachers were compiled and a second questionnaire was prepared, in cooperation with the advisory committee and Arizona Department of Education, and mailed to the teachers. The total number of earth science teachers in the State probably exceeds 200 because 24 schools did not respond to the first questionnaire. The names of these schools are listed elsewhere in this article, along with a plea to *Arizona Geology* readers to identify earth science teachers employed at their high schools.

The response rate (111/176 teachers, or 63 percent) to the second questionnaire indicates a high level of interest in the survey. Many teachers provided additional information about the current situation in their schools. Selected comments are excerpted in following paragraphs.

Trends Since 1985

Preliminary results of the survey have, indeed, confirmed the initial concerns of the advisory committee. Since 1985, 55 of the respondent high schools have dropped a total of 188 sections of earth science courses, 16 have added a total of 65 sections, and 18 have neither dropped nor added sections. This represents a *net decline* of 123 sections, or approximately 19 percent. In 1989-90, 517 sections of earth science were taught in respondent high schools (16 high schools do not teach earth science, 5 opened after 1985, and 1 didn't have adequate information). Several respondents said they no longer offer earth science because of the 1985 decision. Others considered offering it, but decided against it because college-bound students would not receive laboratory science credit for the course if they enrolled in the State's major universities.

A Laboratory Science?

Is earth science, as currently being taught, a laboratory science? Teachers were asked to estimate the percentage of class time devoted to laboratory activities. A "laboratory activity" was defined as one that "stresses *experience-centered* exercises in observation, interpretation, and evaluation, such as specimen identification, field trips, map interpretation, model building, experimentation, and other *hands-on* exercises," in contrast to "*teacher-centered* activities, such as lectures, films, or textbook worksheets." The average portion of time per section that respondents devoted to laboratory activities was 23 percent, which was also the median. (Half the respondents spent more than 23 percent of class time on lab activities and half spent less.) Teachers of 75 of the 517 sections (14.5 percent) spent less than 10 percent of class time on lab activities. Students in 32 sections (6 percent) received no lab experience at all. In 8 percent of the sections, more that 40 percent of class time was spent on lab activities (Table 1).

Earth Science Teacher Qualifications

What were the qualifications of responding earth science teachers in 1989-90? Two out of 5 (43 percent) with more than 10 university credits in earth science courses have a predominantly geological background. One out of six (17 percent) have specialized in other earth science courses, and about the same number (14 percent) have taken an equal number of geology and other earth science courses. One out of four (26 percent) have taken fewer than 10 credits of any earth science course (Table 2).

Table 1. Percentage of time devoted to laboratory activities in high-school earth-science sections. Reported by 95 Arizona earth science teachers in grades 9-12 in 1989-90.

Percentage of Time in Lab	Number of Sections
0-9	75 (15%)
10-40	399 (77%)
41-80	43 (8%)
TOTAL	517 (100%)

Teachers' Comments

Many earth science teachers who responded to the questionnaire eloquently expressed their concerns about recent events and trends. Some of their comments are excerpted below because they give insights into changes that have occurred in earth science education in Arizona since 1985.

"The Board of Regents decision to drop earth science as a lab science was expected. As educators, we are used to having decisions made from the top down. As teachers, we are closest to the learner, yet we are not empowered. It is inconceivable that earth science gets so little support in a State of geologic wonders and commerce. I lament the situation is getting worse with so many master teachers leaving the profession or near retirement. We simply do not have the qualified teachers to replace them.... I worry that our parents and students don't know how great Arizona science education could be if we had authentic and capable leadership that would simply empower teachers. I think our leaders have limited their thinking, or else how could they live with the [unwise] decisions they make about Arizona education?"

"We need to recognize the difference between general science and earth science. It's about time this issue was addressed."

"At an extremely critical time in the history of Arizona and our entire planet, our ... leadership has decided that knowledge of our planet is an unnecessary science. We need the leaders of tomorrow (and today), as well as our gifted, our best and brightest, to be knowledgeable in our planet functions. They need an understanding of the interrelationships between the Earth and the biosphere. They don't get this knowledge in most biology classes because the section on ecology is in the last few chapters of most texts and most teachers generally don't get to it. They study cells and classification systems without learning any application of their knowledge. In chemistry and physics, they learn the laws of science with very little application toward the problems we've created on our planet with toxins and manipulation of the environment."

"The future of Arizona looks bleak if current trends (i.e., rapid uncontrolled growth, overgrazing, wasting water supplies, etc.) continue. Lack of knowledge of the Earth is blatantly visible at every level of leadership and decision making within our wonderfully beautiful, unique State."

"Not including this course as a lab course is certainly an arbitrary decision. This course is becoming more important to the welfare of a voting, informed, educated Republic."

"Earth science is as much a lab class as biology, chemistry, or physics if it is taught by a qualified earth science teacher, which often isn't the case. Because most high school science departments are chaired by biologists, biology teachers are generally the ones placed in a position of teaching earth science.... I began teaching in 1985. I have had to scale down my classes every year since then as earth science has become a "dumping ground" for unmotivated, lower achieving, non-college-bound students."

"Ecology, conservation, and environmental questions are foremost in priority *right now.* Our earth science department is dedicated to maintaining and preserving this planet and the life it supports. These classes are specifically structured to inform, motivate, and prepare these students to protect and wisely use their resources. Survival depends on a well-informed public and that begins (and often ends) in the classroom.... *This is a lab science* class and should be treated as such."

"Nothing has hurt my teaching career (17 yr.) more than the 1985 decision not to allow geological courses to count toward college entrance. Before the regents' decision, we had three teachers teaching earth science and geology. (We had at our max 11 sections of earth science and 4 sections of geology. There were 275 students in earth science and 110 students in geology.) Since 1985, I am constantly told 'I want geology or earth science, but I want to go to college, so I have to take biology or chemistry.' As of this year, we have only six sections of earth science and one very small section of geology.... These courses are not just average or below average courses. Our earth science is on the same level as biology and physical science. Geology is on the same level as chemistry or advanced biology.... I just can't believe that a State where sunshine prevails will not allow geological courses to count. Many of my former students are now in geological or energy fields. But no more!... We as a Nation need people working in energy fields to make sure that we have energy in the future."

"Earth science has become a dumping ground for non-college-bound students since the Board of Regents decision. More lab activity takes place in my earth science class than in many of the biology classes on campus.... Counselors need to be bombarded with information on the importance and need for earth science. I would like to have seen the ESCP text and materials improved. Almost all of my labs come from the old ESCP."

"The lab manual geared for geology/astronomy includes a total of 36 labs, which allows for at least one lab a week. This does not include other labs that are incorporated into the class. It is a miscarriage that this class is not accepted by universities, especially when other classes at this school that require fewer skills and less understanding *are* accepted."

"Our courses have more lab work, environmental concern, and critical thinking than many of the 'selected' courses."

"My students are involved in the subjects of chemistry, physics, volcanology, seismology, and the regular geology incorporated in a survey course, such as earth science. We don't have lab every week, but there are labs relevant to the topics taught. I am quite bothered that earth science has been excluded from science courses approved by our State universities for entering freshmen. Evidently nobody came to my classes to see any of our activities."

"Earth science gets taught by the newest teacher in the science department. Nearly all of the students are at risk. The only labs we do are with rocks and maps. I did lots of 20-minute field trips when I taught 8th grade earth science because of the area. Around the high school, there's nothing much to see. This could be a great class for non-college-bound students to learn about the environment."

"I would like to increase lab time, but our course outline limits time for labs. We are, however, beginning to return to more time for hands-on activities, and I am glad that is happening. If it would be considered a laboratory science for entering college, I would definitely have more labs."

"Six earth science sections have been deleted since 1985. Please note that these

Table 2. University credits in earth science courses taken by high-school earth-science teachers. Reported by 88 Arizona earth science teachers in grades 9-12 in 1989-90.

Type of Credits	Number of Respondents	Number of Geology Credits
More than 10 earth science credits; geology courses predominant	38 (43%)	38
More than 10 earth science credits; number of geology and other earth science credits about equal	12 (14%)	15
More than 10 earth science credits; nongeology courses predominant	15 (17%)	8
Fewer than 10 earth science credits	23 (26%)	

decreases are in the face of *increasing* enrollment during 1985-90."

"There were 20 sections of earth science at my high school. This number has decreased every year. There are five for the 1989-90 calendar year and five scheduled for 1990-91. At this rate, the 1991-92 calendar year will probably offer no sections."

"When I first started teaching an advanced geology class, it was offered for lab credit. The strongly recommended prerequisite was earth science. Both classes were valuable and exciting. During the past 2 years, the geology classes have been cancelled and earth science has been reduced to a low level."

"Earth science is a beginning, catch-all course at my school. It is designed to give students the second [science] credit needed for high school graduation and generally attracts low-ability, low-motivated students."

"Thanks for the chance to be heard. Since 1985, my class has been the dumping ground for students needing science credits for graduation. It used to be the first step in a 4-year science program that many of our students followed. I have been teaching earth science since 1967."

"Removing earth science from the college-bound-student track (for all practical purposes) has resulted in it becoming the dumping ground for students who just hope to graduate from high school and don't want to compete with college-bound students. They generally have no interest in earth science per se. The scholarship level has declined remarkably."

"I have been at this for 13 years. Since the Board's decision, my classes have been at a much lower level."

"Since earth science became a nonlab science, it has become a dumping ground for non-academically-inclined students (noncollege), making it less and less desirable. Somehow we must give it back the esteem it deserves: an ever-developing and changing area of science that affects us all."

"We teach earth science as a decelerated course, in part because it is not accepted by the universities, yet it meets a science need for slower or nonmotivated students for a graduation credit. The subject matter covered in earth science is ... every bit as important as biology, chemistry, or physics in understanding the world in which we live. The material could be every bit as challenging as biology, although it would require less math than either chemistry or physics."

"No earth science has ever been offered at my high school. (In recent years it was considered, but was dropped due to the 1985 Board of Regents decision.)"

"If we could be assured that earth science would be acceptable as a lab science (when taught at regular or accelerated levels), we would strongly consider it as a full-year offering (and I would eagerly teach it!). Our problem is that we have few science teachers and hesitate to teach earth science to regular and accelerated students if they can't use it toward their college-entrance qualifications. Earth science needs to be given the emphasis and status it deserves in the science curriculum, rather than be offered only at lower levels."

"I am currently teaching environmental science. I taught earth science for several years, but the course was eliminated 2 years ago as a result of the 1985 Board of Regents decision."

"Earth science at my school is a junior/senior-level course designed for average or above average students. Because it is not accepted by the universities, it is perceived by college-bound kids as a dummy class. They think (from a recent survey I gave) that they might take geology and astronomy classes as electives because they sound like harder classes."

"Many top students are now steering clear of our earth science program. Their indicated majors, however, will require course work in the field when they work towards a degree. They are illiterate concerning the subject matter."

"I have given up on promoting earth science. Too many students view it as the same course they took for one semester in 7th grade. Rather, I am planning to offer a course called geology/astronomy.... The curriculum will be changed very little, but the name seems to have a greater attraction for interested students. Lots of students would like to study geology and astronomy, but won't sign up for earth science."

"What can we do to get earth science accepted again? Teach it as an upper-division science, like physics? We do more hands-on activities than many biology-chemistry-physics classes! Also many 'paper' labs: interpreting maps, measuring, graphing, etc. Don't these count?"

"I would love to see ESCP be given lab credit. In its 'heyday,' I believe it was the best science course at the freshman level."

Is Anybody There?

Since January 1990, staff members of the Arizona Geological Survey (AZGS) have been trying to compile a complete list of high-school earth-science teachers in Arizona. The list now includes 176 names, but the total number of teachers in the State probably exceeds 200. At the time of this writing, no responses to the AZGS questionnaires have been received from high schools in these towns: Benson; Douglas; Flagstaff (Coconino, Flagstaff, and Sinagua High Schools); Florence; Fredonia (Moccasin High School); Glendale (Apollo and Cactus High Schools); Goodyear (Estrella Mountain High School); Maricopa; Mesa (Mountain View High School); Phoenix (Desert Valley, Phoenix Christian, Polaris, Saguaro, Sunnyslope, Washington, and Westview High Schools); Queen Creek; Tolleson (Union High School); Tombstone; Willcox; and Williams. If you teach earth science in one of these schools, if you know of someone who does, or if you know which of these high schools do *not* offer earth science classes, please inform the AZGS. If you can suggest activities or teaching aids that would be helpful in your earth science classes, also contact the AZGS. Write to or call Larry D. Fellows, Director and State Geologist, Arizona Geological Survey, 845 N. Park Ave., Suite 100, Tucson, AZ 85719; telephone: (602) 882-4795. Teachers' names will be added to the *Arizona Geology* mailing list. Future issues of this free quarterly newsletter will include useful information for earth science teachers.

Future Plans

The status of earth science education in Arizona's high schools will be discussed at the next earth-science-education advisory-committee meeting, which, at the time of this writing, has not been scheduled. In the future, consideration will be given to surveying earth science teachers at the junior-high and elementary-school levels. The committee will identify cooperative projects and other activities that could be undertaken by the AZGS to benefit teachers and students. If you have any suggestions or comments, please send them to Larry D. Fellows, Arizona Geological Survey, 845 N. Park Ave., #100, Tucson, AZ 85719.

Acknowledgments

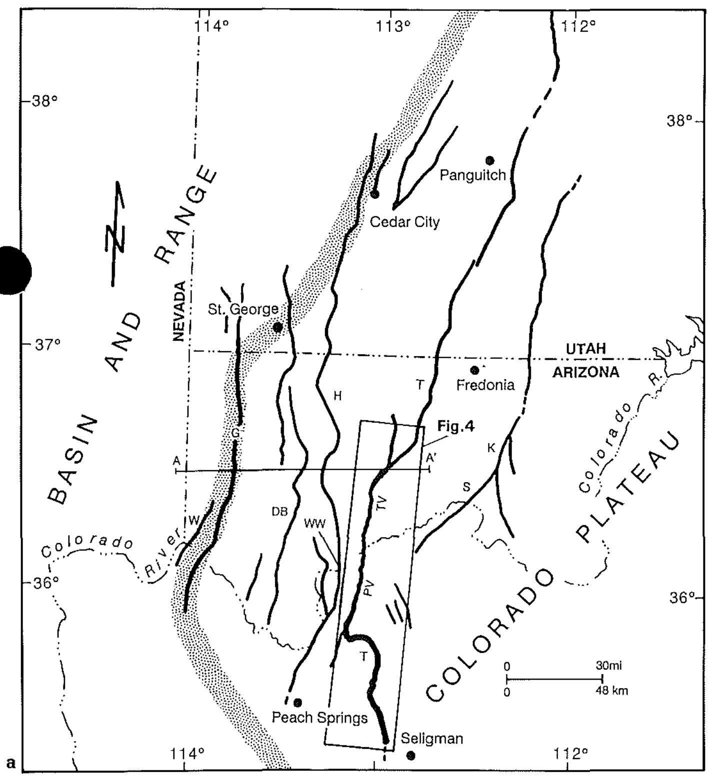
I express my sincere appreciation to members of my advisory committee, high-school science-department chairpersons, earth science teachers who took time from their busy schedules to answer the questionnaire, and AZGS staff members who helped mail the survey and compile the results.

The Toroweap Fault:
One of the Most Active Faults in Arizona

*by Garrett W. Jackson**
Arizona Geological Survey

Striking cliffs slice across northwestern Arizona. These fault-generated escarpments define the transition between two physiographic zones, the Basin and Range Province to the west and the Colorado Plateau to the east (Figure 1). Geophysical evidence suggests that the margins of the Colorado Plateau are foundering as the main body of the plateau is uplifted (Morgan and Swanberg, 1985) and that the Basin and Range Province may be expanding at the expense of the plateau (Keller and others, 1979).

The behavior of the faults that formed the escarpments is enigmatic because datable, displaced surficial materials are commonly absent. Displaced Quaternary alluvium, basalt flows, and cinder cones, however, are evident along the Hurricane and Toroweap faults on the North and South Rims of the Grand Canyon. Documentation of displacement rates, prehistoric earthquake (paleoearthquake) magnitudes, and fault segmentation is, therefore, possible. A section of the Toroweap fault near the Grand Canyon is particularly useful in determining the behavior of active faults in northwestern Arizona. Recent analysis of the faulted materials (Jackson, 1990) has shed some light on how tectonically active this area may be.



GEOLOGIC SETTING

The Toroweap fault, which extends more than 480 kilometers (km), is a plateau-bounding, high-angle normal fault with up to 560 meters (m) of vertical displacement in northwestern Arizona. It was first recognized by Powell (1875) and has been studied by such famous geologists as Dutton (1882) and Davis (1901, 1903). Based on studies of displaced basalt flows, Koons (1945) inferred that movement had occurred along the fault during the Quaternary period, less than 1.6 million years (m.y.) ago. Huntoon (1977) suggested that movement had occurred less than 10,000 years ago (during the Holocene) along the fault in Prospect Valley.

The most recent study of the Toroweap fault (Jackson, 1990), summarized herein, covers a section between Seligman and Pipe Springs, Arizona. Stratigraphic displacement varies significantly along this length, ranging from 250 m on the South Rim to a few tens of meters at the northernmost end of Toroweap Valley. The earliest movement on the fault occurred during the Precambrian, or more than 570 m.y. ago, when it was a normal fault. Compression during the Laramide orogeny (80 to 40 m.y. ago) reactivated the fault in the opposite sense, displacing Precambrian rocks but folding Paleozoic (245- to 570-m.y.-old) rocks. Compression ceased in the early Tertiary and was replaced in the late Tertiary (about 20 m.y. ago) by extension (Wenrich and others, 1986).

QUATERNARY GEOLOGY AND GEOMORPHOLOGY

The evolution of Toroweap and Prospect Valleys, the valleys that drain to the Colorado River along the Toroweap fault, has been strongly influenced by Quaternary tectonic activity.

Toroweap Valley on the north side of the Grand Canyon is a gentle, broad valley with steep alluvial fans derived from cinder

* Current address: B & V Waste Science & Technology, 3600 Port of Tacoma Rd., Suite 304, Tacoma, WA 98424-1046.

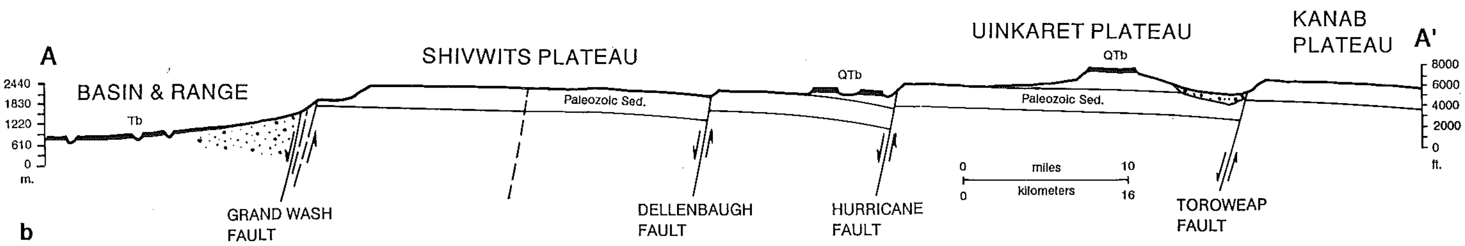


Figure 1. (a) Location map with selected normal faults. Stipple pattern shows the approximate physiographic boundary between the Colorado Plateau and Basin and Range Provinces. W = Wheeler fault; G = Grand Wash fault; DB = Dellenbaugh fault; H = Hurricane fault; WW = Whitmore Wash area; T = Toroweap fault; TV = Toroweap Valley; PV = Prospect Valley; K = Kaibab fault; S = Sinyala fault. Scale = 1:1,900,800. After Best and Hamblin (1978) and Reynolds (1988). (b) Cross section of the western Colorado Plateau (after Best and Hamblin, 1978). QTb = Quaternary and Tertiary basalts; Tb = Tertiary basalts. Each fault has an associated escarpment.

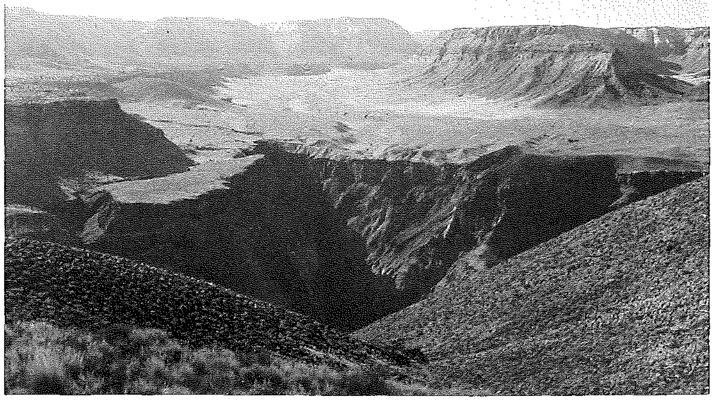


Figure 2. View of Prospect Valley toward south from North Rim of Grand Canyon. Inner Gorge of Grand Canyon is in foreground. Prospect Canyon (center), which is part of the Inner Gorge, has eroded along the Toroweap fault, cutting through Quaternary basalts and cinder cones that filled a previous canyon. The Toroweap-Aubrey Cliffs (left and on horizon) consist of two escarpments. The upper snow-covered cliffs are capped by the Kaibab Limestone. The lower cliffs are capped by the Esplanade Sandstone. The fault is at the base of the lower cliffs. The presence of two escarpments is unique to the northern 10 km of Prospect Valley and is probably related to pre-lava-flow canyon incision.

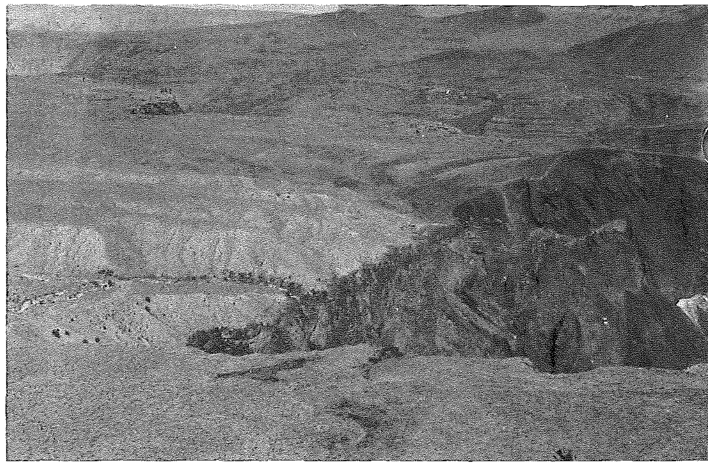


Figure 3. View toward west from top of Esplanade escarpment. Prospect Canyon (center) has eroded past Prospect Wash, creating a 400-m knickpoint. The cinder cone (right) is cut by this incision. The cinder cone once obstructed stream flow, impounding alluvium. Subsequent erosion of the cinder cone allowed Prospect Wash to incise. The wash now flows on canyon-filling basalt.

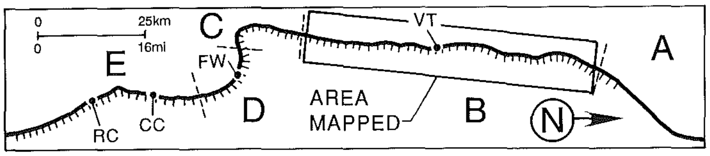


Figure 4. Map of study area. Large letters are segments of the fault; dashed lines separate segments. RC = Rhodes Canyon; CC = Crater Canyon; FW = Frazier's Well; VT = Vulcan's Throne. Box encloses the mapped area. Hachures indicate part of fault for which escarpment sinuosity indices were calculated.

cones and lava flows on the west. Sinuous, vertical cliffs form the escarpment on the eastern side of the valley. In the southern part of the valley, the cliffs are deeply embayed, and alluvial fans emanating from them are broad and gently sloping.

Toroweap Valley probably was once similar to the many adjacent side canyons of the Colorado River. These tributary canyons are steep, narrow, and very deep. Sinuosity of escarpments is usually an indicator of tectonic activity; lower sinuosities indicate higher displacement rates. It is likely, however, that most of the sinuosity of the cliffs is an artifact of earlier canyon cutting. The valley is broad and flat today because it was filled with a succession of lava flows from the Uinkaret volcanic field, starting about 1.2 m.y. ago (McKee and others, 1967). The lavas filled the ancestral valley to a level below the top of the Esplanade Sandstone and dammed the Colorado River several times (McKee and Schenk, 1942). Since the time of lava extrusion, the river has cut completely through several hundred meters of lava dams, plus an additional 15.2 m through Paleozoic rocks.

The latest stage of volcanism is marked by the emplacement of cinder cones near the river. Most notable is Vulcan's Throne, which lies perched near the Inner Gorge. The emplacement of these cinder cones, along with late-stage lava flows and faulting, blocked drainage of Toroweap Valley into the Inner Gorge. Some incision of the valley-filling basalts has occurred, but the Quaternary sediments of the valley remain undissected. Very low stream gradients suggest that the drainage is in equilibrium or is slightly aggradational.

Prospect Valley's present form is quite different from that of Toroweap Valley (Figure 2). Lava also filled the ancestral valley, presumably at about the same time it filled Toroweap Valley, to a level about 150 m below the latter. A wedge of alluvium about 30 m thick was deposited on top of the basalts. These sediments overlap the remnant of a cinder cone at the head of the modern Prospect Canyon (Figure 2), indicating that Prospect Valley was at least partially blocked by cinder cones, as Toroweap Valley is today. Sediments are much thicker on the downthrown side of the fault, indicating syndepositional faulting. Since then a new canyon has eroded through the cinder cone 1.5 km from the Colorado River (Figure 3). The axial drainage, Prospect Wash, has cut completely through the alluvium and now flows on the basalts. This wash does not coincide with the head of Prospect Canyon. The head of the canyon has eroded to the south, beyond the outlet of Prospect Wash. Erosion along the fault plane and canyon walls appears to affect canyon evolution more than fluvial erosion caused by streams such as Prospect Wash.

BEHAVIOR OF THE TOROWEAP FAULT

Segmentation

Variation in stratigraphic displacement along the fault indicates varying rates of displacement. The fault may be divided into five segments based on total displacement, escarpment sinuosity, and Quaternary displacements (Figure 4). Segment A is relatively inactive. No recent displacements are present; escarpment sinuosity is relatively high, and total displacement is only about 76 m. Segment B is the most active segment. It is about 45 km in length and has total displacements of 150 to 265 m. Sinuosity is very low. In addition, at least three surface-rupturing earthquakes have occurred during the late Quaternary; the most recent event occurred about 3,000 years ago (Jackson, 1990). Segment C is a short segment characterized by low sinuosity and high total displacement (up to 280 m), but it lacks evidence of Quaternary displacement. Segment D is bounded by two bends in the fault and is highly sinuous. Total stratigraphic displacement ranges from about 54 m to about 122 m. Many stream terraces and alluvial fans cross the trace of the fault, but no evidence of Quaternary displacement exists. To the south is segment E. Total displacement is moderate, at about 137 m, and the sinuosity of the escarpment is very low. Quaternary alluvium has been displaced; the last surface-rupturing event occurred about 5,000 years ago (Jackson, 1990). Segment E appears to be very similar to segment B.

Temporal Variations in Displacement Rates

Jackson (1990) estimated vertical displacement rates on segment B using estimated ages of faulted basalt flows and geomorphic surfaces. These rates seem to have increased during the Quaternary

(Figure 5). The displacement rate from 3,000 to 40,000 years ago is estimated at 110 m/m.y. This rate is based on soil age estimates derived from measured carbonate content and an assumed carbonate accumulation rate (Jackson, 1990). A basalt flow in northern Toroweap Valley is displaced 36 m. An age estimate of about 635,000 years was obtained on the flow by K/Ar analysis, yielding an average displacement rate of about 56 m/m.y. since the middle Pleistocene. Near Vulcan's Throne, a 203,000-year-old basalt displaced 15 m (Anderson and Christensen, 1989) yields an average displacement rate of 74 m/m.y., which is intermediate between the other two rates. The apparent recent increase in displacement rate suggests that the Toroweap fault is accommodating more extension and that earthquakes are occurring more frequently.

Longer term displacement rates are probably even lower. The timing of initial normal faulting in this part of the Colorado Plateau is uncertain. Normal faulting in southwestern Utah began about 8 to 10 m.y. ago (Anderson and Mehnert, 1979), whereas the main phase of faulting in the Lake Mead area occurred 6 to 10 m.y. ago (Hamblin and Best, 1970; Lucchitta, 1979). In the area southwest of segment E, the main phase of Basin-and-Range-style faulting did not begin until the Miocene (less than 24 m.y. ago). Total displacement of Paleozoic rocks at the Grand Canyon is about 193 m. If one assumes that movement began on the Toroweap fault 8 to 10 m.y. ago, the average displacement rate is 16 to 24 m/m.y. Recent displacement rates thus seem to be significantly higher.

Paleoearthquakes on the Toroweap Fault

Displacement rates represent the cumulative effect of discrete surface-rupturing earthquakes. The magnitudes of paleoearthquakes can be estimated by measuring

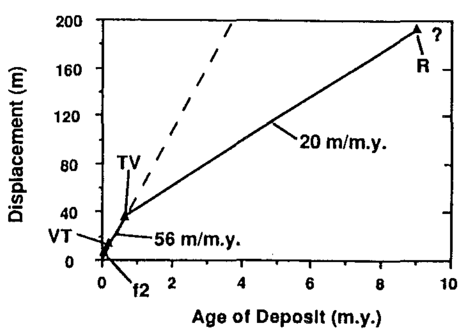


Figure 5. Variation in displacement rates with time. Dashed line shows extrapolated late Quaternary displacement rate (see text). The two lines suggest that either the rate has dramatically increased during the Quaternary or faulting began much more recently than previously thought. Either conclusion suggests that Basin-and-Range-style tectonism encroached onto the plateau during the latest Cenozoic. TV = Toroweap Valley basalt; VT = Vulcan's Throne basalt; f2 = late Pleistocene alluvial surface; R = regional inception of faulting and displacement at the Colorado River.

surface-rupture parameters and comparing them to the parameters of earthquakes with known magnitudes (Hanks sand Kanamori, 1979).

Jackson (1990) calculated the magnitude of the most recent paleoearthquake on segment B of the Toroweap fault. Using the seismic source-moment method, an average displacement of 2.2 m, a segment length of 53 to 62 km, and a depth of faulting of 15 km, Jackson (1990) estimated that the magnitude was between 7.1 and 7.2. This magnitude is equal to or slightly higher than that of the 1989 Loma Prieta earthquake in the San Francisco Bay area (Wallace and Pearthree, 1989).

An earthquake of magnitude 7.1 could seriously damage manmade structures and trigger rockfalls and landslides. The potential of a similarly sized earthquake occurring on segment B in the near future is probably low, however. The most recent earthquake occurred approximately 3,000 years ago, based on Jackson's (1990) scarp slope analysis. The relatively low displacement rate along the fault suggests that the interval between large earthquakes is long. The next earthquake along segment B, therefore, will probably not occur for several thousand years. The threat to human life and property is also relatively low because the region is sparsely inhabited. Residents in areas as far away as Hoover Dam and Las Vegas might feel an earthquake generated along the Toroweap fault, but the extent of potential damage is unknown.

The potential for earthquakes along other segments of the Toroweap fault and along other faults in northwestern Arizona remains a matter of speculation. This area, however, probably has the highest potential of any area in Arizona (Menges and Pearthree, 1983).

Regional Faulting Migration

Increasing displacement rates on the Toroweap fault may indicate a progressive breakup of the Colorado Plateau, as hypothesized earlier (Morgan and Swanberg, 1985; Wong and Humphrey, 1986). Migration of faulting has been documented in other areas along the margins of the plateau. In south-central Utah, faulting shifted uniformly from the Basin and Range Province (9 m.y. ago) to the Sevier fault (7.6 to 5.4 m.y. ago) to the Paunsagaunt fault (less than 5 m.y. ago; Rowley and others, 1981). In southwestern Utah, the rate of displacement during the Pliocene and Quaternary along major normal faults increased from west to east across the Colorado Plateau margin (Hamblin and others, 1981).

In the western Grand Canyon area, faulting seems to be migrating diffusely to the east as western faults become less active. In addition to increases in displacement rate on the Toroweap fault, escarpment sinuosities along major normal faults generally decrease from west to east. The age of the youngest faulted unit generally decreases from west to east as well.

A young fault-bounded depression lies east of the Aubrey Cliffs (segment E; Billingsley and others, 1986). This feature, along with low to moderate seismic activity in the eastern Grand Canyon area (Bausch, 1989; Brumbaugh, 1989), may represent continued migration of faulting to the east.

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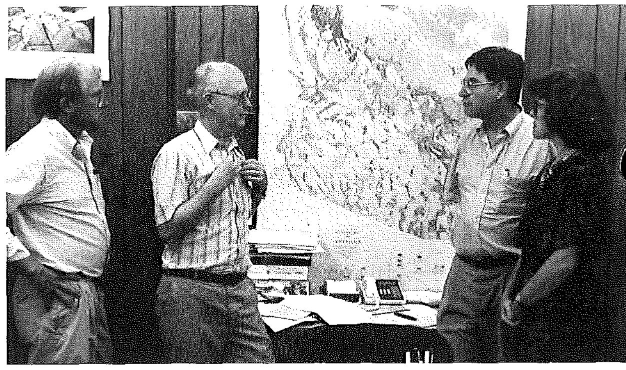
New Publication Describes the Geologic Evolution of Arizona

A landmark publication about the geology of Arizona has recently been published as Arizona Geological Society Digest 17. *Geologic Evolution of Arizona*, edited by J.P. Jenney and S.J. Reynolds, is the first comprehensive book on Arizona geology. This 866-page hardbound volume contains 35 chapters that summarize the stratigraphic, structural, and tectonic evolution of Arizona from Precambrian through Quaternary time. The book also contains chapters on mineral and energy resources, geophysics, landscape development, environmental geology, and hydrogeology, as well as a colored, 1:1,000,000-scale geologic map of Arizona. The articles summarize previously published information and present important new data and interpretations. Copies of Digest 17 may be purchased by mail from the Arizona Geological Society, P.O. Box 40952, Tucson, AZ 85717. Single copies are $60.00, including UPS shipping and handling charges; add $14.00 per book for air mail delivery in the United States, Canada, and Mexico; add $40.00 per book for air mail delivery to other countries. Copies may also be purchased in person from the Arizona Geological Survey office at 845 N. Park Ave., Suite 100, in Tucson.

Director of Geological Survey of Bolivia Visits the AZGS



Dr. Marcelo Claure Zapata (second from right), Executive Director of the Geological Survey of Bolivia, visited the Arizona Geological Survey (AZGS) in July. One discussion topic was the Cooperative Geologic Mapping Program (COGEOMAP) between the U.S. Geological Survey (USGS) and the AZGS. Dr. Claure was in Tucson to plan a major cooperative project between his agency and the USGS to assess the mineral resource potential of Bolivia. The project will be funded by the World Bank. Others in the photograph are Dr. Stephen D. Ludington (left), Assistant Chief of the USGS Branch of Resource Analysis in Menlo Park, Calif.; Ms. Frances W. Pierce (right), geologist in charge of the USGS Mineral Information Office in Tucson; and Dr. Larry D. Fellows (second from left), Arizona State Geologist and Director of the AZGS.

Why Do Able Students Abandon Science?

A recent book published by Research Corporation, a Tucson-based science foundation, explores why many intelligent, high school science students choose to major in nonscience subjects when they enter college. *They're Not Dumb, They're Different: Stalking the Second Tier*, written by Sheila Tobias (who also wrote *Overcoming Math Anxiety*), describes the results of an innovative research project. Seven bright graduate students, who had studied high school science and college calculus, but not college science, were asked to audit introductory physics and chemistry classes at a university. Each student kept a journal that included observations and feelings about why science courses were difficult or distasteful. Two of the seven students tied for highest grades in their classes, proving they were not dumb; their journals, however, revealed that they were, indeed, different from those who typically choose college science. This 94-page book on a neglected problem in science education is being distributed by Science News Books, 1719 N St., N.W., Washington, DC 20036; send $2.00 for the first copy and 50¢ for each additional copy.

University of California Toughens Science Requirements

The University of California Board of Regents has toughened freshman admission standards, requiring a second year of a laboratory science. Lab sciences include biology, chemistry, physics, and earth science. The higher standards will become effective with the entering class of 1994, but are not expected to have a major impact on enrollment because almost 90 percent of current applicants already meet the increased requirements.

New Appointees to Geologic Posts

Barbara Harrington Murphy has been appointed by Governor Mofford to serve a 5-year term on the Oil and Gas Conservation Commission in Phoenix. Ms. Murphy has worked as an assistant geologist for Dames & Moore since 1977, providing geology and soil evaluations for environmental analyses as well as assistance on dam, highway, and landfill design studies. She received a B.A. degree in geology, worked as a geologist for the U.S. Bureau of Land Management in Phoenix, and is an Advisory Board Member for the Arizona Geological Survey.

Charles G. Groat has been named Executive Director of the American Geological Institute (AGI), based in Alexandria, Va. Dr. Groat has served as State Geologist and Director of the Louisiana Geological Survey since 1978. As Executive Director of AGI, he will work at the national level on activities that are significant to the geoscience profession, especially education.

Arizona Geographic Information Council Established

Governor Rose Mofford, by Executive Order 89-24, abolished the Arizona Mapping Advisory Committee and reestablished it as the Arizona Geographic Information Council (AGIC). AGIC will coordinate the management of statewide geographic information and serve as an advisory council to the Arizona State Land Department on managing the State Geographic Information System.

New AZGS Publications

The following publications may be purchased from the Arizona Geological Survey, 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:

$1.01 - $5.00, add $1.75	40.01 - 50.00, add 7.75
5.01 - 10.00, add 2.25	50.01 - 100.00, add 10.00
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20.01 - 30.00, add 5.50	Other countries, request price quotation.
30.01 - 40.00, add 6.25	

O'Hara, P.F., 1990, Geology of the Big Bug metallic mineral district, Arizona: Contributed Map CM-90-A, scale 1:12,000, 2 sheets. $3.00

The Big Bug mineral district encompasses an area of Early Proterozoic, stratabound massive-sulfide mineralization. Deposits of this district have yielded approximately 462,000 ounces of gold, as well as significant amounts of copper, lead, zinc, and silver. These two geologic maps cover several square miles of complexly deformed Proterozoic rocks within and around the Big Bug mineral district.

Toro, J., Gehrels, G.E., Johnson, R.A., Biggs, T.H., Centeno-Garcia, E., Colburn, N.I., Jackson, L., Kruger, J.M., Meader, N.M., Pitts, G.S., Restrepo, P.A., and Skirvin, S.M., 1990, Geological map of the Black Rock detachment, Santa Teresa Mountains, SE Arizona: Contributed Map CM-90-B, scale 1:12,000. $4.00

This new geologic map of the Black Rock Wash area on the east side of the Santa Teresa Mountains in Graham County covers a region of complex Tertiary normal faulting. Two imbricate detachment faults juxtapose a variety of Proterozoic and Tertiary rocks over Proterozoic crystalline rocks and Tertiary granite.

Moyer, T.C., 1990, Generalized geologic map of the Kaiser Spring volcanic field, Mohave County, Arizona: Contributed Map CM-90-C, 17 p., scale 1:50,000. $5.00

This map and the accompanying text, compiled and written as part of a Ph.D. dissertation, describe the geology of the Kaiser Spring volcanic field along the Basin and Range–Transition Zone boundary in west-central Arizona. This field is one of four Miocene-Pliocene bimodal volcanic fields aligned along the projected strike of the Bright Angel fault system. The basaltic and rhyolitic lavas of this field form a classic bimodal suite. Twenty-five known or inferred rhyolite vents are aligned in two subparallel, north-trending zones known as the eastern and western volcanic belts. Most basalts probably erupted from the range-bounding fault of the Poachie Range immediately south of the volcanic field.

Chenoweth, W.L., 1990, The geology and production history of the uranium deposits in the Toreva Formation, Black Mesa, Apache County, Arizona: Contributed Report CR-90-A, 19 p., scale 1:63,360. $4.25

Black Mesa is a 60-mile-diameter southwest-dipping cuesta capped with sedimentary rocks of the Upper Cretaceous Mesaverde Group. All of the uranium-vanadium deposits are in the fluvial upper sandstone member of the Toreva Formation. From 1954 to 1968, 13 properties produced 16,780 tons of ore averaging 0.17 percent U_3O_8 and containing 55,739 pounds of U_3O_8. Black Mesa is one of only two known areas in the Nation with significant uranium production from Upper Cretaceous rocks. The potential for additional discoveries in the area is excellent. The low grade of known deposits, however, precludes exploration unless the price of uranium greatly increases.

The information in this report was obtained in the 1950's while the author was employed by the U.S. Atomic Energy Commission (AEC).

Chenoweth, W.L., 1990, Uranium occurrences on the Zhealy Tso mining permit near Chinle, Apache County, Arizona: Contributed Report CR-90-B, 7 p. $1.25

Exploration for uranium in 1955 resulted in the discovery of several occurrences on the west flank of the Defiance Uplift northeast of Chinle, Arizona. The principal occurrence was found near the junction of Slim and Cottonwood Canyons. Host rocks for the uranium are carbonaceous sandstones in the Shinarump Member of the Triassic Chinle Formation and sandstone in the basal part of the overlying Monitor Butte Member. Exploration drilling, rim stripping, and test pitting indicated that the uranium mineralization was very spotty and too low grade to be mined economically. There has been no recorded production from this area. Most of the information in this report is from the AEC archives.

Chenoweth, W.L., 1990, The Zona No. 1 uranium-vanadium mine, northeastern Carrizo Mountains, Apache County, Arizona: Contributed Report CR-90-C, 10 p. $1.75

The Zona No. 1 uranium-vanadium deposit is similar to other ore deposits in the Salt Wash Member of the Upper Jurassic Morrison Formation. What makes this deposit unusual is that it shows evidence of deformation and metamorphism due to the emplacement of the 68 Ma Carrizo laccolith.

During its 2-year operation from 1953 to 1955, the Zona No. 1 mine produced 2,116 tons of ore averaging 0.19 percent U_3O_8 and 2.91 percent V_2O_5 and containing 8,224 and 123,092 pounds of uranium and vanadium oxides, respectively. This production ranks the Zona No. 1 mine among the top three mines developed in the Carrizo Mountains during the 1950's. Production data are from the AEC archives.

Chenoweth, W.L., 1990, The geology and production history of the Morale uranium mine, Hopi Buttes area, Navajo County, Arizona: Contributed Report CR-90-D, 11 p. $2.00

The Hopi Buttes rise to heights of 600 feet above the surrounding countryside. Most are individual diatremes, but some are complexes of diatremes. Several sediment-filled maars also form inconspicuous low hills. The diatremes and maars erupted into the late Miocene-early Pliocene Hopi Lake. No region in the world is known to contain a greater density of such structures than the Hopi Buttes, where more than 300 diatremes have been discovered within a 1,000-square-mile area.

The diatremes themselves are not mineralized; however, most of the overlying maar-lake sediments that contain travertine deposits also contain anomalous uranium concentrations. During the uranium boom of the mid-1950's, 192 tons of low-grade ore averaging 0.15 percent U_3O_8 and 0.04 percent V_2O_5 were produced at the Morale mine. The host rocks were lacustrine sediments in the Seth-La-Kai maar. Production data are from the AEC archives.

Slaff, Steven, Jackson, G.W., and Pearthree, P.A., 1989, Development of earth fissures in Picacho basin, Pinal County, Arizona, from 1959 to 1989: Open-File Report 89-10, 38 p., scale 1:24,000, 6 sheets. $18.25

In the sediment-filled basins of southern Arizona, water-table declines resulting from the withdrawal of large quantities of ground water cause compaction of aquifer sediments. This compaction leads to differential subsidence of the land surface, which produces stresses in the sediments. Earth fissures, or surficial cracks, may develop where the horizontal stresses are large.

Earth fissures have damaged various facilities in southern Arizona during the past 60 years, such as roads, buildings, and utility systems. This study, which was funded by the U.S. Bureau of Reclamation and conducted by AZGS geologists, focuses on Picacho basin, an area of abundant fissures that threaten the Central Arizona Project (CAP) aqueduct and other man-made structures. Interpretations of aerial photographs taken between 1959 and 1989 and recent field studies were used to detail both rates and patterns of earth fissure development during the past 30 years.

Jackson, G.W., 1990, Quaternary geologic map of the Corona de Tucson 7.5' quadrangle, Arizona: Open-File Report 90-3, 6 p., scale 1:24,000. $2.50

The Corona de Tucson quadrangle 15 miles southeast of Tucson includes the northern Santa Rita Mountains and part of an extensive piedmont flanking the northwest side of the range. Alluvial fans of various ages and discontinuous ephemeral streams compose the surface of the piedmont. This map and the accompanying text describe the surficial geology of this area, including the potential geologic hazards associated with debris flows and earthquakes.

Jackson, G.W., 1990, Tectonic geomorphology of the Toroweap fault, western Grand Canyon, Arizona: Implications for transgression of faulting on the Colorado Plateau: Open-File Report 90-4, 67 p., scale 1:24,000, 2 sheets. $15.50

Linear fault-generated escarpments in northwestern Arizona define the transition between the Basin and Range Province and the Colorado Plateau. Geophysical evidence suggests that the margins of the plateau are foundering as the main body is uplifted. In this report, the author documents displacement rates for the Toroweap fault, a major normal fault near the Grand Canyon. Through geomorphic mapping, soil carbonate analysis, diffusion modeling of fault scarps, and measurement of escarpment sinuosity, he estimates the timing and magnitude of the most recent surface rupture and reconstructs the Quaternary tectonic and geomorphic history of the area. The article that begins on page 7 in this issue is based on this report.

Spencer, J.E., Shenk, J.D., and Duncan, J.T., 1990, Map showing areas in Arizona with elevated concentrations of uranium: Open-File Report 90-5, scale 1:1,000,000. $3.00

Radioactive radon gas is produced by naturally occurring uranium in soil and rock and can seep into homes and other buildings in concentrations that pose a significant health hazard. Buildings in areas where soil and rock contain high concentrations of uranium are therefore more likely to contain hazardous concentrations of radon. This map, compiled to help assess the potential for high radon levels in Arizona, shows the following features: (1) uranium mineral districts, (2) other mineral districts with byproduct uranium production, (3) granitic rocks with unusually high uranium concentrations, (4) localities with anomalous radioactivity, and (5) areas with greater than 5 ppm uranium based on U.S. Department of Energy airborne gamma-ray spectrometer surveys. This map supersedes an earlier AZGS map (Open-File Report 86-11) that did not include the airborne-survey data.

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CORRECTION

In the previous issue of *Arizona Geology* (vol. 20, no. 2; Summer 1990), two errors were inadvertently printed in the lead article, "Plate Tectonics and the Gulf of California Region." Figure 1 on page 1 incorrectly identified the Salton Sea. The Salton Sea is not actually shown in the photograph, but is north of the body of water labeled "S." The third paragraph on page 1 of this same article mentions surface water temperatures in the northern gulf; these measurements are given in degrees centigrade (°C).

REQUEST FOR BIBLIOGRAPHIES

The Arizona Geological Survey is compiling a computerized database of references on the geology, hydrology, and mineral resources of Arizona, to be released as a formal publication. The file already contains more than 5,000 citations. To assure that the database is as complete as possible, we ask that you send us any lists that you have compiled of your own or other authors' publications on Arizona geology. Because we have an Optical Character Recognition (OCR) device, you may send the bibliography as a photocopy or on a floppy disk (IBM-PC or Mac compatible) to Nancy Schmidt, Arizona Geological Survey, 845 N. Park Ave., #100, Tucson, AZ 85719. Thank you for your help.

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