# The Engineering Geologist

THE GEOLOGICAL SOCIETY OF AMERICA

NEWSLETTER OF THE ENGINEERING GEOLOGY DIVISION OF THE GEOLOGICAL SOCIETY OF AMERICA

Volume 14, Number 1 August 1979

## ENGINEERING GEOLOGY DIVISION REPORT TO GSA BOARD, Presented at 1978 Council Meeting

The Engineering Geology Division is pleased to submit this report to the Council concerning its activities for the past year.

**I. Status of the Division.** 1977 saw a resurgence of activity in the Division, after the membership decided the issue of whether to phase out. In the vote, as reported by Chairman Richard W. Galster, in *The Engineering Geologist*, vol. 13, no. 1, April 1978, 58% of the respondents to our questionnaire voted to maintain the Division, 37% voted for phase-out, and 5% went undecided. The Management Board of the Division has taken this as a mandate to progressive activity, and we are steaming on! The membership of the Division, as of 31 August 1978, stands at 950, a 15% increase over 1977.

**II. The Annual Symposium.** The traditional Engineering Geology Division Symposium, held at the annual meeting, will be chaired by Past-President, Dr. Robert F. Legget. This year's topic will be "Geology beneath Cities," probably consisting of eight invited papers.

For 1979, we have selected the topic "Academic Training of the Engineering Geologist," which will be held in cooperation with the National Association of Geology Teachers and the Association of Engineering Geologists. Co-chairmen will be R. H. Jahns (for GSA), James V. O'Connor (for NAGT), and Martin L. Stout (for AEG); all three are teachers of the subject.

**III. Publications.** One issue of *The Engineering Geologist* was released in April (vol. 13, no. 1). A second issue is in Dorothy Palmer's hands, as of about 17 August. We expect this number to be rather meaty. The Secretary has initiated a policy of inviting three to six prominent engineering geologists to provide one- to two-page, double-spaced copy as briefs of activities going on in their organizations or areas. No. 2 will contain summaries by Ellis Krinitsky, of activities in determination of seismic evaluation, at the U.S. Army Waterways Experiment Station, and by Fitzhugh T. Lee, of the U.S. Geological Survey, Denver, dealing with his activities in representing GSA in the U.S. National Committee on Rock Mechanics.

Recent activities in Division publications are

Engineering Geology Review Volume III, *Landslides*, edited by Donald R. Coates; released for sale at the Seattle meeting, November 1977;

Engineering Geology Review Volume IV, *Geology in the Siting of Nuclear Power Plants*, edited by Allen W. Hatheway and Cole R. McClure, Jr.; in editorial processing at Boulder;

Engineering Geology Review Volume V, *Expansive Soils*, edited by Christopher C. Mathewson; final collection of papers underway;

Case Histories Volume 11, *Decay and Preservation of Stone*, edited by Erhard M. Winkler; released for sale in May 1978.

Plans are being considered for publishing a review volume dealing with geology beneath cities, the theme of Dr. Legget's 1978 Annual EGD Symposium.

**IV. Awards.** The Burwell Award Committee has nominated Nicholas R. Barton of the Norwegian Geotechnical Institute, Oslo, as the 1978 recipient. The award recognized Dr. Barton's work in determination of the effect of discontinuities on rock strength, particularly for his paper, "The Shear Strength of Rock and Rock Joints," appearing in the International Journal of Rock Mechanics and Mining Sciences, v. 13, no. 9, 1976. Dr. Barton has acknowledged Dr. Frye's notification and has written that he plans to attend the Toronto meeting and to receive his award.

*Allen W. Hatheway, Secretary*

### ENGINEERING GEOLOGY DIVISION ACTIVITIES AT THE ANNUAL MEETING IN SAN DIEGO NOVEMBER 5-8, 1979

Dinner and Business Meeting, Monday, Nov. 5, 1930–2230 hours, Garden Room North.

E. B. Burwell Award to Evert Hook and John W. Bray, Monday, Nov. 5, 1930-2230 hours, Garden Room North.

Tuesday, Nov. 6—Academic Training for Engineering Geologists, 0800-1200 hours, San Diego Room.

Wednesday, Nov. 7—Engineering and Environmental Geology, 1300-1700 hours, San Diego Room.

Thursday, Nov. 8—Poster Sessions, Council, Chamber, Cabinet Rooms, Booths 9, 10, 11, 12, 13, 14.

## Rockbursts in the Mount Waldo Granite, Maine

*Fitzhugh T. Lee*
Engineering Geology Branch, U.S. Geological Survey

In situ rock conditions favoring rockbursts in the Devonian Mount Waldo Granite (Sweeney, 1976) near Bucksport, Maine, were investigated to assess the suitability of crystalline rocks of coastal Maine as potential sites for underground oil storage chambers. This study followed reconnaissance engineering geology investigations of the bedrock in the Penobscot Bay area that were made to characterize the geotechnical characteristics of the various rock types. Factors investigated included in situ stresses, rock structure, strength, deformability, and deformations produced by bursts or rock creep.

Rockbursts, the sudden failure of highly stressed rock accompanied by the very rapid release of strain energy, can produce violent rock breakage. Destructive rockbursts have been reported in several granite quarries on the mainland and on coastal islands, although no quantitative study has been made of them. Bursts were so numerous and severe in one quarry that it had to be closed after reaching a depth of 50 m. Although the lower part of these workings was below sea level, the quarry remained dry until it was filled by pumping. This indicated that the fractures are tight, a desirable attribute for fluid storage.

The Mount Waldo Granite is a light-gray, medium- to coarse-grained, porphyritic biotite granite. The granite mass is roughly circular in plan, with a diameter of approximately 16 km. Gravity data indicate that the pluton averages less than 7 km thick and is steep walled (Sweeney, 1976). The 390-m.y.-old granite was probably intruded along a structurally weak zone defined by the N60°E-striking Norumbega fault shortly after the culmination of regional Acadian thermal and structural events in Maine. Postemplacement deformation of the granite locally produced several zones of steeply dipply fractures striking N25° to 40°E and N70° to 85°W, the latter attitude being more common. Steeply dipping joints are not abundant and typically contain pyrite and clay coatings. Vertical aplite dikes strike N80°E and N75°W.

The most conspicuous structural feature of the Mount Waldo and other coastal granites is the pervasive sheeting (exfoliation) which has developed parallel to topography in response to erosional unloading. Sheets are 3 to 20 cm thick at the surface, typically increasing to 3 m and greater at depths of 7 to 15 m. At some sites local subhorizontal shear zones are associated with upper levels of sheeting. These zones consist of closely spaced en echelon fractures oblique to the bounding sheets and contain sand- to clay-size gouge material. Such features were probably formed in areas of initial high stress concentrations; they may have been caused by a reduction in vertical stress due to erosion and exfoliation, which led to failure in shear in much the same way failure is produced in cores in the laboratory by reducing lateral confinement while maintaining a high axial load. The sheeting passes through vertical diabase dikes of possible Tertiary age. On the basis of age and topographic relations, it is improbable that the sheeting formed by cooling and shrinkage of the magma.

Horizontal stresses were determined at two sites in the granite. The sites are separated by approximately 3.8 km horizontally and 132 m vertically. Site 1 is on a spur of Mount Waldo and site 2 is in a low-lying stream valley. The sites were selected to examine topographic effects on stresses, the influence of sheeting on stresses, and spalls and popups as indicators of stress conditions.

At both locations stress directions rotated with dep[th]. Changes in stress magnitude and orientation appear to be c[on]trolled by individual sheets and by the distance from a sheet boundary to the point of measurement. The maximum horizontal stress direction at site 1 in the top sheet at a depth of 0.15 m is N19°W; at a depth of 6.5 m (in unsheeted granite), it is N76°E. The latter stress direction is believed to be related to the nearby Norumbega fault, a major right-lateral, strike-slip fault striking N60°E, which controlled the emplacement and possibly later brittle deformation of the granite. The maximum horizontal stress directions in the metamorphic rock at a low-lying location at a third site adjacent to the granite and 0.3 km from the fault range from N45°E to N73°E at depths of from 0.53 to 6.8 m. At site 2 the maximum horizontal stress direction in the top sheet is N17°W, and at 7.8 m, it is N24°E. At this location the rock at 7.8 m contains poorly formed, closely spaced sheeting fractures and widely spaced, high-angle tectonic joints. Both types of fracturing appear to have altered the stress field.

Surprisingly, we found that stress magnitudes were twice as high at the mountain location as in the valley, a result that is contrary to what is expected from conventional analyses. Maximum horizontal compressive stresses at site 1 range from 4.76 MPa at 0.15 m to 13.26 MPa at 6.5 m. At site 2 the range is from 1.45 MPa at 0.23 m to 7.56 MPa at 7.8 m. Lower stress levels at site 2 can be explained by lower elastic moduli and the presence of through-going, tectonic, high-angle fractures at this location. Also, sheeting and incipient sheeting (to a depth of at least 28.19 m) are more prominent at site 2. At site 1, spalls, popups, shallow subhorizontal shear zones, and offset drill ho[les] were common. These features were absent at site 2.

Our measurements suggest pronounced structural control of stresses in the granite as well as in the bordering gneiss. Present-day stresses are largely paleotectonic and were annealed in the rock during its cooling and deformation. The vertical stresses in the granite and gneiss, as determined from hydrofracture measurements, ranged from 1.4 to 2.8 MPa at depths of 4 to 26 m. These magnitudes are too great to be accounted for by present-day gravity or boundary-tectonic loading.

Dale (1907) described a severe rockburst in the main quarry on the northeast spur of Mount Waldo that produced north-northwest–trending fractures extending the entire length (275 m) of the quarry. This fracturing occurred in the summer and was accompanied by loud explosive noises. Part of this old broken zone is still visible in the upper part of the east wall of the quarry—a vertical zone of shearing and crushing as much as 2 m wide, 13 m long, and 3 m deep, striking N28°W with vertical curvilinear fractures extending to the south approximately 100 m. The vertical shear zone terminates downward at a sheet surface. This rockburst evidently was triggered by the removal of a 3-m-deep channel at this location. Results of laboratory experiments and field observations in the Lower Devonian Chelmsford Granite in Massachusetts (Holzhausen, 1977) demonstrate that rockburst fractures can be produced by cutting channels normal to vertical walls which are compressed uniaxially. Failure stresses are produced by concentrating applied stresses at the tips of flaws. The fractures propagate unstably, roughly normal to the channels. Development of through-going fractures in the labo[ra]tory was preceded by localized crushing of the rock, and the result was similar to the features observed at Mount Waldo.

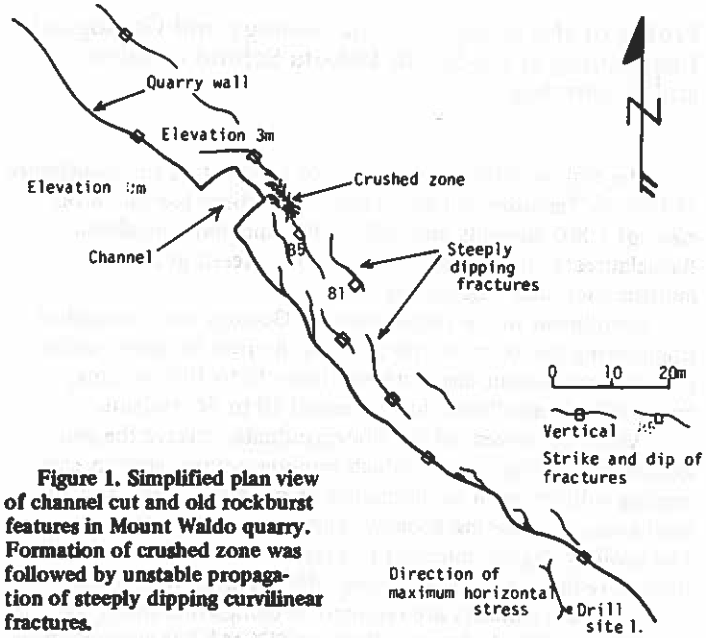


**Figure 1. Simplified plan view of channel cut and old rockburst features in Mount Waldo quarry. Formation of crushed zone was followed by unstable propagation of steeply dipping curvilinear fractures.**

At the Mount Waldo quarry, the maximum horizontal stress direction at the south end of this zone in the uppermost sheet (which is the stratigraphically nearest measurement to the rockburst) is N19°W. The direction of the old channel is N50°E, forming an angle of approximately 70° with the maximum horizontal stress. The sheared and crushed zone direction of N28°W corresponds closely to the fracture directions of Holzhausen (1977). These features are shown in Figure 1.

The following factors are closely related to rockburst potential in shallow openings in granitic rocks.

1. The stresses that were stored in the granite during the rock's cooling and deformational history can be reduced and reoriented in the energy-consuming sheeting process. Stresses are more relieved normal to sheets than parallel to sheet surfaces. The inference that the least principal stress is normal to sheet surfaces was borne out by hydrofracture data.

2. Stresses in the upper sheeted parts of rock masses are extremely variable. This is supported by the frustration expressed by many New England quarry operators who find that stress conditions and rock behavior vary from place to place. However, as suggested by the data from the Mount Waldo Granite and the work of Holzhausen (1977), rockburst occurrence should be less frequent where walls are oriented parallel to the maximum horizontal stress, provided no channels are cut normal to such walls.

3. Popups, spalls, and shallow subhorizontal zones of crushing and shearing are indicators of high local stress concentrations.

4. Well-developed tectonic fracturing and sheeting reduce stresses and lessen rockburst occurrence.

5. Our measurements show that stresses are more consistent in terms of magnitude and direction below the level of sheeting.

## REFERENCES CITED

Dale, T. N., 1907, The granites of Maine, *with an* introduction *by* G. O. Smith: U.S. Geological Survey Bulletin 313, 202 p.

Holzhausen, Gary, 1977, Axial and subaxial fracturing of Chelmsford Granite in uniaxial compression tests, *in* Wang, Fun-Den, and Clark, G. B., eds., Energy resources and excavation technology—U.S. Symposium on Rock Mechanics, 18th, Keystone, Colorado, 1977, Proceedings: Colorado School of Mines Press, p. 3B7-1 to 3B7-7.

Sweeney, J. F., 1976, Surface distribution of granitic rocks, south-central Maine: Geological Society of America Bulletin, v. 87, p. 241–249.

# Applications of Geotechnical Engineering in the Development of Power Plant Projects at PNM

*M. P. Fay and C. E. Anderson*
Public Service Company of New Mexico

The Public Service Company of New Mexico (PNM) is an investor-owned electric and water utility which has its main office in Albuquerque, New Mexico. PNM, like other utilities in the Southwest, is investigating potential sites and planning construction of several power plant facilities. Successful development of these facilities will require extensive application of the principles of geotechnical engineering, from the preliminary exploration phase through construction completion. The primary facilities being investigated include a 600 MW pumped storage hydroelectric generating plant and a 2,000 MW coal-fired generating plant. In addition, potential nuclear power plant sites are being studied.

Both the pumped storage project and nuclear site investigations will require the coordinated efforts of exploration and engineering geologists, seismologists, rock mechanics specialists, hydrologists, and hydrogeologists. For projects such as these, PNM utilizes its own specialists to plan and perform certain investigative segments while engaging the services of private consulting firms capable of providing additional expertise in the more technical areas of geological engineering.

The 600 MW pumped storage plant will provide peaking and intermediate power which will allow the use of off-peak baseload energy during on-peak demand through a hydrostorage/release concept. Geotechnical evaluation of the Pumped Storage Project has developed through two levels of investigation. Initially, a site selection study was performed which delineated progressively smaller areas showing potential for containing a suitable plant location. This evaluation led to identification of a number of candidate sites which were evaluated for geologic, engineering, economic, and environmental characteristics and were ranked accordingly. The study analysis led to selection of a location in the northwest quadrant of New Mexico as a prime candidate site for the proposed facility.

A geotechnical verification program was then initiated to determine whether any conditions exist at the site which could cause economically prohibitive design requirements or unacceptable risks during construction. Exploratory drilling and trenching identified geologic formations occurring at the upper reservoir, lower reservoir, power plant, and waterway (shaft and tunnels) locations. A geologic site description was compiled from literature review, examination of aerial photographs, and field mapping. From these data, a site stratigraphic section and several reservoir cross sections were developed.

The preliminary subsurface exploration program included 2,100 lineal feet of core drilling at 12 locations and 35 test pit excavations. Selected core samples were tested in the laboratory to determine engineering characteristics of the various formations. Test results were used for the conceptual design of the shaft and tunnels. These data and subsequent analyses indicated no geotechnical factors which would prevent site development. Furthermore, all geotechnical information gathered was utilized in preparing a feasibility level engineering analysis for the site.

An exploratory adit and test chamber construction program is tentatively planned to experimentally determine the bedrock stress/strain behavior that will result from excavation of the final tunnel and power plant caverns. An extensive instrumentation program will be initiated during test chamber excavation to monitor bedrock deformation characteristics. Additional laboratory tests will be conducted to determine final engineering design parameters for the power house, shaft, and tunnels.

Investigations are also underway for tentative development of a 2,000 MW coal-fired generating plant in northwestern New Mexico, the first 500 MW of which has been authorized. The current plan is to utilize coal from the Fruitland formation of northwestern New Mexico; however, alternate coal reserves will also be considered for development.

For potential nuclear power plant site investigations, the required geotechnical investigations will include thorough assessment of such factors as seismic risk, subsidence potential, water supply availability, and impact upon ground-water quality. Seismic risk analysis will include investigations to determine approximate dates for most recent movement along any faults occurring in the candidate site area and the potential for future ground motion. This task can be accomplished through field exploration to determine whether displacements occur in existing Quaternary deposits, and also by determining whether faults in the site area are related to geologic structures known to be seismically active.

Portions of New Mexico exhibit surface subsidence features which are believed to be the result of karstification which has occurred at considerable depth. Should the site be located in such an area, the subsidence potential must be evaluated by deep core drilling to determine whether soluble bedrock actually occurs beneath the site, and the extent of any existing solution weathering. Such coring would require special precautions to obtain maximum possible core recovery and detailed geologic and borehole geophysical logging. Studies must also be conducted at candidate coal or nuclear sites to determine the potential for ground-water contamination due to seepage into existing aquifers.

PNM is also making a feasibility comparison between surface water and ground water for power plant cooling purposes. In the case of a nuclear plant, the Nuclear Regulatory Commission requires investigations to establish the legal and physical availability and long-term reliability of the cooling water supply whether a surface or ground-water source is chosen. The criteria developed by various state and federal agencies for coal-fired plants are similar, but not as stringent. Establishing availability and long-term reliability of a ground-water supply will necessitate extensive aquifer testing and hydrogeologic analyses.

Successful completion of the planned power plant facilities will require expertise in many areas of geotechnical engineering. The varied scope of these projects will demand the concerted efforts of specialty consultants, architect/engineering firms, and contractors. In summary, it is apparent that effective management skills and an understanding of the concepts of geotechnical engineering are necessary ingredients for the successful completion of the type of projects contemplated by PNM.

M. P. Fahy is a geological engineer in the Resource Development and Technical Services Department of PNM.

C. E. Anderson is a plant design engineer for the Pumped Storage Project at PNM.

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## Profile of the Department of Geology and Geological Engineering at the South Dakota School of Mines and Technology

The Dakota School of Mines was founded by the Legislature of Dakota Territory in 1885. Today the college has an enrollment of 1,800 students and 250 faculty and staff members. Baccalaureate and graduate degrees are offered in science, mathematics, and engineering.

Enrollment in the Department of Geology and Geological Engineering has risen sharply; during the past 10 years, undergraduate enrollment has increased from 30 to 100 students, and graduate enrollment has increased 10 to 54 students.

About 90 percent of the undergraduates receive the geological engineering degree, which requires course work in engineering subjects such as mechanics of materials, fluid and soil mechanics, engineering geology, and geophysical prospecting. The geology degree, intended to prepare the student for graduate studies, requires a broader course offering in basic sciences.

Graduate students are required to complete a thesis for both the M.S. and Ph.D. degrees. Because SDSM&T is situated in the Black Hills, and the Badlands are 30 miles away, most graduate students engage in field-related theses, taking advantage of the excellent geology and pleasant climate of the area.

Graduates are typically employed by oil, geophysical, or mining companies. In the past several years, employment opportunities have been excellent. In 1978 all graduates found jobs, and the average starting salary for B.S. degrees was about $17,000/year.

There are presently 11 faculty members in the Geology and Geological Engineering Department, with two more members to be added in the coming year.

*Alvis L. Lisenbee* (Head), Ph.D., Pennsylvania State U.; structural geologist specializing in Laramide structure of Black Hills uplift including emplacement mechanism of Tertiary intrusives in the northern Black Hills

*John C. Mickelson*, Ph.D., Iowa State U.; invertebrate paleontologist specializing in northern Great Plains paleogeography

*John P. Gries*, Ph.D. (Professor Emeritus), U. of Chicago; stratigrapher specializing in hydrogeology

*Jack A. Redden*, Ph.D., Harvard; economic geologist specializing in structural geology of Precambrian rocks in the Black Hills

*Philip R. Bjork*, Ph.D., U. of Michigan; vertebrate paleontologist specializing in Badlands fauna

*Perry H. Rahn*, Ph.D., Pennsylvania State U.; engineering geologist specializing in hydrogeology

*James E. Fox*, Ph.D., U. of Wyoming; sedimentologist–invertebrate paleontologist specializing in clastic depositional environments

*William M. Roggenthen*, Ph.D. pending, Princeton U.; geophysicist specializing in paleomagnetism

*Kenneth E. Kolm*, Ph.D., U. of Wyoming; geomorphologist specializing in remote sensing

*James A. Sturdevant*, Ph.D., Pennsylvania State U.; economic geologist specializing in heavy metals

*Willard L. Roberts;* mineralogist specializing in Black Hills pegmatite mineralogy

In addition to the regular faculty members, there are supporting faculty of SDSM&T, such as specialists in rock mechanics in the mining engineering department, soil and fluid mechanics in the civil engineering department, and geochemistry in the chemistry department.

The future of geologic studies at SDSM&T is bright due to the strategic location of Rapid City in an area rich in energy resources, such as coal, oil, and uranium, and the traditional emphasis on geological engineering, which appeals to companies engaged in quantitative assessment and production of geologic resources.

*Perry H. Rahn*
Department of Geology and Geological Engineering
South Dakota School of Mines & Technology
Rapid City, South Dakota 57701

## ANNOUNCEMENTS

- The third Australia–New Zealand Geomechanics Conference will be held at the Victoria University of Wellington, Wellington, New Zealand, from May 12 to May 16, 1980.

  Those interested in attending should contact

  The Organising Secretary
  3rd AUST-NZ Geomechanics Conference
  C/-Barr, Burgess and Stewart
  P.O. Box 243
  Wellington, New Zealand

- The annual meeting of the Association of Engineering Geologists will be held in Chicago, October 2–6, 1979. This is a short course on applications of engineering geology: two days of field trips and two days of technical sessions. Contact Abe Dolgoff, Chairman, c/o Sargent & Lundy Engineers, 55 East Monroe Street, Chicago, Illinois 60603, (312) 269-7142.

### 1979 ENGINEERING GEOLOGY DIVISION

**Officers** (3 Members) (Chairman, 1 year; Chairman-Elect, 1 year; Secretary, 1 year)

| | |
|---|---|
| *Chairman: | Richard H. Jahns<br>School of Earth Sciences<br>Stanford University<br>Stanford, CA 94305<br>(415) 497-2544 |
| *Chairman-Elect: | Allen W. Hatheway<br>Haley & Aldrich, Inc.<br>238 Main Street<br>Cambridge, MA 02142<br>(617) 492-6460 |
| *Secretary: | John S. Scott<br>Director, Terrain Sciences Division<br>Geological Survey of Canada<br>601 Booth Street<br>Ottawa, Ontario K1A 0E8<br>(613) 995-4938 |

**Management Board** (5 Members) (Consists of the Division officers, the Chairman of the preceding year, and one Councilor serving a 2-year term.)

| | |
|---|---|
| Past-Chairman: | Richard W. Galster<br>18233 13th Avenue NW<br>Seattle, WA 98177<br>(Office) (206) 764-3711<br>(Home) (206) 542-2596 |
| **Councilor: | Don U. Deere<br>6834 S.W. 35th Way<br>Gainesville, FL 32601<br>(904) 378-3061 |

* A one-year term of office which shall begin immediately following the annual business meeting at which their election is announced and extend through the next annual business meeting.

** Second year of an initial two-year term.

William J. Mallio, *Editor*

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