Geoscience Canada

Flow and Transport in Fractured Rocks

J. E. Gale

Volume 9, Number 1, March 1982

URI: https://id.erudit.org/iderudit/geocan9_1con03

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

Cite this article

Gale, J. E. (1982). Flow and Transport in Fractured Rocks. *Geoscience Canada*, *9*(1), 79–81.

Summary and Conclusions

In order to provide future supplies of raw materials which will enable our descendants to enjoy a standard of living at least equal to our own, an increasing pressure will be exerted on those who are at the leading edge of the search for resources. For mineral deposits researchers, this will require a shift of emphasis towards identifying and elucidating the factors controlling mineralization, and developing a better understanding of those peripheral effects of mineralization which can constitute evidence that ore may be found nearby.

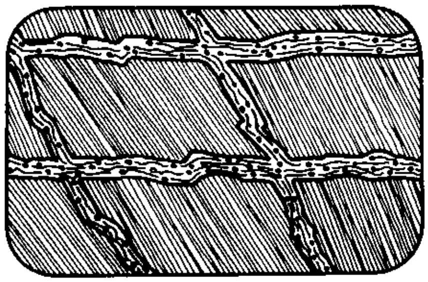
The papers presented in this symposium are clear evidence of a welcome new trend in which mineral deposits research has shifted away from "science for the sake of science" towards "science in the service of mankind." We have been given a veritable feast of exploration guidelines, some proven, others whose validity remains to be confirmed. Equally important is the demonstration of what can be achieved by international collaboration in attacking geological problems. As a member of the exploration industry, I can assure you that these guidelines will be put to good use.

References

Eidel, J.J. and SEG Research Committee, 1980, *Preliminary results of the SEG research questionnaire; What we need the most* (Abst.): Geol. Soc. America, 1980 Ann. Mtg., Atlanta

Hutchinson, R.W., 1981, *Exploration technology: the geological challenge:* Canadian Min. Jour., April, 1981, p. 31-43.

MS received December 7, 1981



Flow and Transport in Fractured Rocks

J.E. Gale
Department of Earth Sciences
University of Waterloo
Waterloo, Ontario N2L 3G1

On April 23, 1981, a one day invitational workshop on "Current Laboratory Studies of Flow and Transport in Fractured Rocks" was held at the University of Waterloo. This workshop was followed, on April 24, 1981, by a one day conference on "Flow and Transport in Fractured Rocks", which was sponsored by the Natural Sciences and Engineering Research Council of Canada. The workshop and conference were organized by W. Brace (Mass. Instit. Technology), J.E. Gale (Chairman of the organizing committee, University of Waterloo) and P.A. Witherspoon (University of California at Berkeley).

The purpose of the workshop was to bring together about 15 laboratory oriented researchers who are currently studying the flow and transport properties of fractures in order that they could compare experimental techniques, discuss their latest experimental results, and share their views on the adequacy, completeness and direction of current research programs. The workshop participants, in addition to the three members of the organizing committee, included T. Engelder (Department of Geological Sciences, Lamont Doherty University, New York) whose work includes studies of the effect of fracture roughness on flow through artificial fractures, H. Heard (Lawrence Livermore Laboratory, Livermore, California) whose work includes the measurement of key geophysical parameters and the permeability of both intact granitic rocks and fractured samples, R. Kry (Esso Research, Calgary) whose detailed field studies of the effects of viscosity changes on flow, around a borehole packer, through a single fracture indicates the importance that the oil and gas industry places on understanding the mechanisms of flow in fractured reservoirs, J. Logan (Center for Tectonophysics, Texas A & M University) whose extensive work on both intact porous sandstones and samples of the same sandstone containing artificial (sawcut) fractures includes permeability testing under both hydrostatic and triaxial test conditions, W. Marine (Savannah River Laboratory, Aiken, South Carolina) who has been involved in an extensive series of field and laboratory studies of the hydrogeologic systems in the coastal plain sediments and underlying crystalline basement rocks and a series of low-permeability Triassic sedimentary rocks, P. Rissler (Ruhrtalsperrenverein, Essen, West Germany) well known for his careful laboratory studies on artificial fractures and detailed discussion of the basic laws governing flow in fractures, D. Snow (Colorado Springs, Colorado) well known to the hydrogeologic community in both North America and Europe for this theoretical contributions on fracture flow, R. Stesky (Erindale College, University of Toronto) whose research focuses on changes in geophysical parameters and the permeability of artificial fractures as a function of changes in confining stress up to 200 MPa, G. Thompson (University of Arizona) who has completed an exhaustive study of the characteristics of a wide range of nonradioactive tracers for solute transport studies, J. Walsh (Mass. Instit. Technology) well known for his theoretical contributions to the field of geophysics, D. Watkins (Lawrence Berkeley Laboratory, University of California) whose recent research deals with the laboratory study of the stress-permeability characteristics of natural fractures in cores ranging up to one meter in diameter, and M. Wigley (Battelle Memorial Institute) whose interest is in the potential of fractures in crystalline and sedimentary rocks to provide pathways for the migration of radionuclides from high level nuclear waste repositories.

Formal presentations at the workshop were kept to a minimum in order to ensure time for a reasonable amount of discussion on each topic. The workshop opened with a presentation by Peter Rissler on basic flow laws governing flow in fractures.

As pointed out by Rissler more care must be taken in conducting both field and laboratory flow tests. Especially important is the need to conduct an initial analysis of the raw data to determine which flow law or model is most applicable in its interpretation. The topic of laboratory testing of single fractures in the low stress regimes, effective normal stresses of 0 to 30 Mpa, was introduced by John Gale and Dai Watkins and included a presentation of results from a series of uniaxial compression tests on granite cores. These cores each contained a single fracture oriented normal to the core axis, and ranged in size from 10 cm to 100 cm in diameter. This work shows that natural fractures tend to show less hysteresis and less of a change in permeability with increase in normal stress than do induced fractures. Also the results presented by Gale and Watkins suggest that fracture permeability decreases with increases in sample size rather than increasing as previously thought.

In the afternoon Paul Witherspoon presented some recent work by his group in which they attempted to fit theoretical curves to the measured experimental data using measured values of the area of contact between both sides of the fracture plane. Joe Walsh followed with a presentation on his recent theoretical study that show that fracture permeability was related to the effective pressure, the latter he showed to be equal to the confining pressure minus the pore pressure corrected for fracture plane topography and rock type. Walsh's work suggests that once this correction is made, the cube root of permeability (k) is related to the natural logarithim of the effective pressure.

The greater part of the afternoon consisted of presentations and discussions by Hugh Heard, Terry Engelder, Bob Stesky and John Logan on the testing of both intact granitic samples, porous sandstones and samples of both rock types containing induced (tension) and sawcut fractures. Heard's group has applied the transient pressure pulse techniques to measure matrix permeabilities of granite as low as $10^{-24}m^2$. Terry Engelder reported on the work by his group using sawcut fractures oriented parallel to the core axis. Each sawcut surface was finished to a different degree of roughness permitting Engelder to show the effects of roughness on deviations from the basic cubic fracture flow law. The work by Bob Stesky and his group at Erindale College on similar samples sizes indicated a similar relationship between confining stress and fracture permeability. John Logan's work on porous sandstones showed that even with intact cores the permeability changes resulting from changes in hydrostatic stress of up to 40 MPa were 78 per cent non recoverable. Under triaxial test conditions the samples showed a significant drop in permeability after brittle failure occurred suggesting that the fractures making up the failure surface are not well interconnected. The workshop closed with a presentation by Wendell Marine in which he compared his field and laboratory studies of the hydrologic characteristics of the bedrock near Aiken, South Carolina. Marine reported that the rock mass permeabilities that were most compatible with the groundwater isotopic and geochemical data were not all that different from the measured laboratory values, suggesting that overall flow through the rock mass must be partly controlled by flow through the rock matrix.

The discussion at the end of the workshop set the stage for the general meeting on Friday, April 24th. Bill Brace started the morning sessions by reviewing the conclusions reached by the workshop participants. There is a need to qualify the effects on experimental results of the disturbances resulting from the sampling and preparation of natural fractures. There was a general concensus that, in terms of understanding flow and transport in fractures, the present laboratory investigations are pointed in the right direction. However, the group concluded that there is a need to determine both the total and effective porosity of fractures, the contact area within the fracture plane (as a function of stress, time and aperture) and whether the observed scale effects in recent studies are real or part of the statistical variation that one would expect to encounter in such experimental programs. In addition more work needs to be done on transient effects in fractures as well as rock-water interaction and the effect of fracture filling (i.e., fracture mineralogy) on time dependent phenemona.

On the question of whether we have a sound theoretical basis for describing flow in a single fracture, it was concluded that several of the existing models show promising results in terms of the fit between observed and theoretical data. The group felt that the necessary measurements that have to be made have now been identified and that the effective stress relationship in fractures needs to be studied closely. A real concern is whether or not the geometric factors on a laboratory scale are related to real world problems. Thus in situ tests, such as those described by Marine, but more detailed, are needed to determine the relationship of laboratory results to actual field results.

In contrast to progress on describing flow in single fractures the workshop participants agreed that an understanding of solute transport in single fractures requires a more detailed description of both the nature and distribution of porosity in the fracture plan. Both flow and solute transport in multiple fracture systems are subjects which require additional work before one can hope for reasonable correlations between measured and predicted results.

P. Rissler developed the theme of his workshop presentation and applied his analysis to borehole injection tests, pointing out the need to first establish the flow regime (laminar or turbulent) before analyzing the field test data. Rissler's work is an important contribution towards bridging the gap between small scale and rock mass studies. P. Montazer and W. Hustrulid described a series of borehole injection tests around a drift in a metamorphic rock mass. The purpose of the tests was to determine the effect of the excavation of the drift on the fracture permeability. Interpretation of the test results was complicated by the lack of background tests before the drift was excavated and the partially saturated nature of the fracture system, but the authors felt that an opening and closing of the relevant fracture sets due to the drift excavation had been observed.

The final paper in the morning session was a four part presentation by J. Gale, A. Rouleau, and P. Fritz (University of Waterloo) and P. Witherspoon. This presentation dealt with the fracture, hydrogeological and geochemical studies at the Stripa test site in Sweden. These studies represent an attempt to determine from detailed measurements the basic fracture statistics of orientation, length and spacing as well as the distribution of fracture permeabilities from a series of borehole packer injection tests. The authors reported on their progress in attempting to combine the fracture and hydrology data to calculate the directional permeabilities of the rock mass (the discrete data approach). The total volume of water flowing into a 30 m section of the test excavations was measured by determining the change in the humidity of the air used to ventilate the test section of the drift. Pore pressures in the rock mass surrounding the drift were measured in a number of packed off intervals in 15 boreholes drilled outwards from the drift. Thus the authors were able to determine a bulk permeability for the rock mass surrounding the test drift. Comparison of the bulk permeability value with the directional permeabilities computed from the discrete data will further our understanding of fluid flow in fractured rock masses.

The isotope and geochemical data from the Stripa test site showed that water at 330 m below the ground surface were different than the surface water systems. Also the water obtained at depths greater than 410 m appeared to be older than those discharging at the 330 m levels.

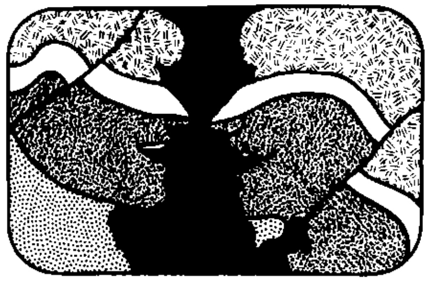
The afternoon session started with a presentation by C. Davison (National Hydrology Research Institute, Ottawa). Davison presented the results of studies, completed as part of the high level nuclear waste disposal program in which different borehole methods of characterizing small scale groundwater movement and solute transport through fractured granitic rocks were evaluated. This paper is further evidence of the expanding data base available to researchers trying to understand problems of fluid flow in fractured rocks.

J. Long and P. Witherspoon (paper presented by Witherspoon) discussed the results of a numerical model study in which the authors attempted to develop an equivalent porous media from a network of discontinuous fractures. D. Trimmer (Lawrence Livermore Laboratory) developed the theoretical basis for the transient pressure pulse technique. Part of his presentation dealt with the criteria for optimizing the experimental configuration in order to minimize measurement and interpretational difficulties.

G. Thompson (University of Arizona) gave a very thorough review of the types and characteristics of nonradioactive tracers for solute transport studies. This paper and related publications by Thompson are required reading for anyone planning to conduct tracer studies in fractured and fractured porous rocks. In the final paper, J. Gale and E. Reardon presented the results of a laboratory study showing the development of flow tubes in a grouted fracture. The authors showed the importance of groundwater chemistry in changing fracture permeability and the different interpretations on the transport characteristics of a single fracture that could be made using the basic flowrate and hydraulic gradient data.

The narrow scope of the workshop and the limited number of participants ensured an in-depth discussion in which everyone had an opportunity to participate. The presence of such a large number of active and well known researchers at the general sessions enriched both the presentations and the discussions. The twin goals of providing a forum for researchers to meet and discuss their work on flow and transport in fractured rocks and communicate their progress to the general hydrogeologic community, were both successfully accomplished by the back to back workshop and the conference sessions.

MS received October 19, 1981



Roles, Images And Geoscientific Debate

Lynn Machan
Institute of Sedimentary and Petroleum Geology
Geological Survey of Canada
3303-33rd Street, N.W.
Calgary, Alberta T2L 2A7

Editorial Roles

During several of the technical sessions of the Association of Earth Science Editors conference held in Denver, October 4-7, 1981, the editorial role was identified as the means by which the information exchange process could be brought into focus with present reality, by which target audiences could be tuned into that reality, and by which the public at large could be drawn into participating more fully in the constant change characteristic of this electronic decade.

The Technological Time Warp

In a keynote address, Jim Davis (State Geologist of California) stated that changing scientific concepts require technological communicators to interface with the general public. Just as paleontology was the geological insight of the 19th century, so, in this century, geodynamics and comparative planetology are changing our philosophical and scientific understanding of the environment. Because earth science information affects our quality of life in very direct ways, an informed public must evaluate the information provided to it in order to come up with appropriate policy decisions.

According to Jack McGuire (Montana College of Mineral Science and Technology) innovative earth science professionals are in the right place at the right time. He spoke of splendid growth opportunities for editors capable of building communication bridges between the users and creators of technology. A slide show presentation of Petroleum Information Corporation (P.I.) served to demonstrate this agency's