## Chapter 1 : Fractures, fluid flow and mineralization: an introduction | Ken McCaffrey - calendrierdelascience

*With fracture-controlled flow dominating in magmatic and hydrothermal environments, permeability is a critical parameter. Understanding the causes of it and how it interplays with heat and chemical transfer is fundamental to understanding the behavior of all types of fluid flow in the crust.*

Wilkinson L Lonergan Downloaded from http: This is not surprising given recognized the role of high fluid pressures in that many modern ideas concerning the flow of lowering the shear stress required to move and fluids in fractures stem from observations made emplace large thrust sheets, geologists had as a result of human exploitation of mineral tended to ignore the importance of fluids in resources. Much has The origin of many modern concepts may be changed in the intervening 40 years. The grow- cation and interpretation of mineral deposits ing interest in the relationship between fluid within a genetic context. This is prescribed by openings in the rocks other than reflected by the number of major books pub- those of ordinary pore space These openings lished in the last decade spanning subject areas of super-capillary size.. Notable exam- By the late s and early s papers were ples include: Fluids in Subduction Zones Tarney no longer limited to mineralization studies but et al. This growth, culminating in a publication agement and nuclear waste disposal sectors. Fractures, fluid flow and mineralization: Geological Society, London, Special Publications, ,  Data have been normalized for total number of publications in the database for each year. It seemed that current ideas on the interrelationships between now, some 15 years on, was a timely moment to fracturing and fluid flow, particularly in relation reassess the subject of fluid flow and fracturing to the genesis of hydrothermal mineral deposits. It was also and mineralization felt that this was an appropriate way to celebrate the life and work of Dave Johnston whose An issue that has long been recognized as interests were very much in this field. With these fundamental in fluid flow research is how rock aims in mind three communities of geoscien- permeability is defined and how to quantify it tists were invited to a meeting in Dublin in adequately for fractured rock systems. The papers collected in this volume sized that rock permeability is the key parameter evolved from those presented at the meeting and in any model of fluid flow and transport in Downloaded from http: This is particularly true for hydrothermal nesses, have fractal properties for example, the mineral deposits that form as a result of focused paper by Stowell et aL on veins hosted in flow of a large volume of fluid. As many of the Precambrian rocks of Anglesey, Wales. Roberts papers in this volume illustrate indicated in et aL deduce that the measured fractal dimen- bold , such mineralization is usually structurally sion or D-value is a useful descriptive para- controlled, and hence the need to understand the meter and can potentially be used to predict the role of faulting and fracturing in enhancing rock connectivity of vein systems. From field data permeability becomes paramount. When the isolated vein systems lighted by the landmark paper of Sibson et al. Deformation is localized and could be active in transporting fluid through fluid transport over increased length scales can rock during deformation. Research in neotec- occur, leading to mineral precipitation given tonic areas e. Thus, confirmed, with observational data, that active thickness distributions of mineralized vein sys- faults do move large volumes of fluid through tems would be predicted to have low D-values. Now much research effort is focused From a study of the vein system of the Guana- on how faulting alters the hydrogeological prop- juato epithermal Ag-Au deposit in Mexico, erties of the rock itself, by modifying the frac- Loriga also provides data which show that vein ture pore volume as well as the permeability of thickness populations can be described by a the fault and adjacent areas e. Like Roberts et aL and and rock permeability through linked fracture Gillespie et aL, she concludes that veins with systems is one of the main themes that recurs in power-law distributions will be more prone to various sections in this volume. This approach has proved mental differences between stratabound vein effective in quantifying the geometry and scaling arrays arrays in layered rocks, where the veins characteristics of fracture systems, and has led are restricted to individual mechanical units to an increased understanding of how fault and non-stratabound vein arrays based on systems evolve and grow. Localization of studies of vein arrays at ten localities in the deformation in fractures and shear zones leads British Isles, France and Mexico. The strata- to fluid flow localization. When active faults and bound vein arrays have regular spacings con- shear zones link to form percolation networks, trolled by the layer thickness and do not show a the large scale flow systems essential for miner- power-law thickness distribution. In compari- alization can be established e. Fluid flow and fracture systems In the second section of the book the specifics of Vein populations fluid flow in fracture systems is addressed from a number of different perspectives. Veins are a key natural data set in fractured rock using numerical models, in preserving a visible and permanent record of which mechanical and hydraulic behaviour are fluid flow and mineral transport in the rock coupled. They show that, at a critical stress mass. Evidence from field studies shows that state, initially diffuse flow though fracture net- various aspects of veins, especially their thick- works changes to a highly localized flow. The Downloaded from http: At the critical South Africa. Critical evidence is presented state, the variation in vertical flow rates through which shows that deformation was coincident different parts of the network shows a fractal with, and controlled the distribution of, hydro- distribution. This sophisticated 3D model of a fractured ground- is key information in relation to the ongoing water reservoir in Carboniferous limestones in controversy surrounding the genesis of Witwa- southwest Ireland, which explicitly represents tersrand gold and strongly supports a hydro- fractures using data from boreholes to con- thermal origin for these deposits, long regarded strain the distribution of the fracture popula- by many workers to be alluvial placers. This contribution illustrates the sort of thoughts on an old theme are presented by Brown complex modelling and simulation that are more et al. Structural sectors, but which have great potential for data are used to infer that the komatiitic flows mineralization or hydrocarbon studies. This interpretation has considerable sig- crustal regimes. They use photoelastic experi- nificance with regard to exploitation of these ments and theory of brittle failure to obtain pre- deposits. Vein data ways associated with dynamic faulting events. Mineralization, hosted within a Neogene volcanic centre, is controlled Structural controls on mineralization by fractures associated with a regional fault system. Variations in fluid properties with depth The third section of the volume is devoted to are observed, indicating that gold precipitation mineral deposits. A collection of seven papers occurred in response to competing processes covers a variety of topics with the general theme of boiling and dilution in the vein system. A provocative paper by Cox re-examines during thrusting to be the major control of existing ideas on the genesis of mesothermal gold mineralization in the unusual emerald deposits deposits, applying new concepts in percolation in the Eastern Cordillera of the same country. Arguments are pre- The final paper in this section, by Cloke et al. It is shown how a craton have a fractal distribution with a D-value regional understanding of basin evolution and of c. If it is assumed that this D-value can be fluid pathways is important for mineral and extended to other areas, then the authors predict hydrocarbon exploration. This contribution that companies can improve their exploration illustrates how economic geologists, whether strategies by comparing observed deposit dis- their quest be for ore or hydrocarbons, can tributions with fractal dusts. An important new benefit from modern concepts of basin analysis data set is presented by Jolley et ai. The geochemistry ent approaches documented in previous sections of fluids trapped within veins e. One of the main flow and mineralization. This Such interdisciplinary collaboration is essential represents a development of some of the ideas if further advances are to be made in this presented by Dave Johnston Johnston et al. Mineral and Hydrocarbon of the Irish Midlands Basin. Behind the scenes, the north-northeast and northwest trending struc- tireless logistical support given by Patrick Wyse tures appear to play an important control on Jackson, Neil Kearney, Frank Hendron, Declan Burke, Stephen Donnolly, Jeff Lord, Mags Duncan, localizing fluid flow and mineralization. Garth Earls, Mike Boland and the staff at of the Irish Midlands by constructing 2D Tara Mines Navan , Minorco Services Ireland Lish- coupled fluid and heat flow simulations of the een and Arcon Mines Galmoy are acknowledged for two competing models topo-graphically driven their assistance in running the field trip. We thank all regional flow and deposit specific density driven contributors to the meeting for presenting the science convection. Their paper also shows the power that is contained in this volume and for creating an of sequential 3D basin reconstructions in aiding occasion that Dave himself would have truly enjoyed. The following referees donated their time and the understanding of the tectonic evolution of expertise for reviewing the manuscripts, often under the Irish Midlands during the Carboniferous. Geology of Mineral Deposits. Hydrological signatures of earthquake strain. Journal of Geo- References physical Research, 98, 22 Rock Fractures and Fluid Flow: American Geolo- Contemporary Understanding and Applications. Origin, Migration Transport in

Rocks. Basement structural controls on Journal of the Geological Society, boniferous Geology. Geological Society, London, London, , Special Publications, , The influence of fault zone pro- J. The Behaviour and Influence of Fluids in cesses on fluid flow and diagenesis.

## Chapter 2 : rock fractures and fluid flow | Download eBook PDF/EPUB

*In the intervening years, Dave carried out postgraduate research recount of his various exploits. at Monash University, Melbourne and gained a This volume on 'Fractures, Fluid Flow and Mineralization' is a fitting tribute to his memory.*

Consequently, the magnitude of the stress at one of the tips of a long and thin discontinuity Figure 2. Rock Fractures and Fluid Flow: Contemporary Understanding and Applications. The National Academies Press. Note that the stresses at points A and B are equal and will be negative if P is greater than twice the hydrostatic stress. Page 39 Share Cite Suggested Citation: Two regions are defined: For this case the expression for stress in a region immediately surrounding the tip based on the assumption of linear elasticity is given by Lawn and Wilshaw, The symbols r and l are defined in Figure 2. For the case of a uniformly loaded fracture of half-length l, the stress intensity factor is The term m is the stress driving the relative displacement of the fracture walls for a particular mode of fracture Lawn and Wilshaw, This equation, together with the previous one, shows that stresses increase near a fracture tip as the fracture lengthens. The remaining terms depend on the geometric factors about the fracture tip; r is the radial and is the angular component Figure 2. For larger r this relationship breaks down. In reality, stress concentrations at the crack tip cause inelastic behavior e. However, if the inelastic zone is small, the above-mentioned expressions from linear elastic fracture mechanics can be used to analyze the fracturing process Rice, Regional stress fields are generally insufficient to initiate fractures. As a result, heterogeneous stress concentrations are generally necessary for fracture propagation. The heterogeneity and textures in rocks can cause pervasive heterogeneities in the stress field. In detrital sedimentary rocks, for example, grains are stress concentrators Figure 2. In porous sandstone, fracturing on the grain scale is controlled primarily by stress concentration at the contact points between adjacent grains, as shown by Figure 2. In crystalline rocks, structural defects and mismatches between adjacent grains may be the source of stress heterogeneities. Perhaps the most important source of heterogeneities in the stress field is due to geological structures induced by previous deformation at all scales. Once initiated, fractures themselves significantly alter the stress field in adjacent rock. To illustrate this process, consider the two-dimensional theoretical mean stress fields about a joint Figure 2. The mean stress is the average of the in-plane principal stresses i. Both fractures are of arbitrary length 2l and are subject to a unit driving stress. Uniaxial tension is applied to the joint, and simple shear is applied to the fault. Although the stress fields are different in each case, they are highly heterogeneous and show large stress concentrations near the fracture ends. For the case of the fault, regions of enhanced tension and enhanced compression are arranged antisymmetrically about the fault. The locations and orientations of dilational structures e. From Gallagher et al. Right, thin section of Entrada sandstone showing fracturing controlled by contacts between the grains. Page 41 Share Cite Suggested Citation: From Pollard and Segall Such a correspondence encourages the use of mechanical analyses as a predictive tool in geological research. The global-scale inhomogeneity in the stress field is evident from a plate tectonic map of the earth showing the distributions of earthquakes, active volcanoes, and mountain chains. Stresses are high enough to cause active deformation in the interiors of some continents, but the higher intensity of deformation along relatively narrow plate boundaries is evidence for higher stress concentrations in these regions. In many cases the geometry and mechanics of large structures allow the characteristics and spatial distribution of smaller structures to be predicted. For example, if the geometry and dimensions of a lava bed or regional strike-slip fault are known, the geometry of accompanying fractures can be inferred. This approach is an economical way to estimate fracture heterogeneity in an aquifer or reservoir because it does not FIGURE 2. The correspondence between the locations of the increasing and decreasing mean stress values near the fracture tips in Figure 2. Page 42 Share Cite Suggested Citation: It can also be used in conjunction with the tools described in other parts of this report. It should be noted, however, that the task of predicting subsurface fractures is more difficult in complexly deformed areas and, obviously, when information about the regional structures is limited. According to linear elastic fracture mechanics, a fracture will propagate when the stress intensity factor exceeds a critical stress intensity factor or fracture toughness KIC, KIIC, and KIIIC , which is assumed to be a material property and expresses the intrinsic resistance to fracture propagation. For mode I loading the circumferential tensile stress at a small distance from the fracture tip is largest in the plane of the fracture. Therefore, joints propagate in their own plane perpendicular to the direction of the greatest tension near the joint front. As noted earlier Figures 2. Remote compressive loads can induce localized tensile stresses, as can the presence of flaws with high fluid pressure Secor, , ; Hubbert, ; Price,  The formation and propagation mechanisms of shearing-mode fractures are enigmatic. Although fracture toughnesses for mode II and mode III KIIC, KIIIC fractures exist conceptually, they have not been measured reliably in the laboratory, and it is not completely clear how they influence faults that link together by opening-mode fractures e. As a fault propagates, slip on it increases, and this fact has important hydrologic effects. Few faults in nature and few shear fractures in laboratories slip without significantly deforming either the material between the sliding surfaces or the adjacent wall rock. Slip commonly results in zones of brecciated rock and zones of gouge along faults. Zones of breccia can have relatively high hydraulic conductivities. Gouge zones, in contrast, tend to be highly impermeable. Breccia zones and gouge zones for large faults can reach hundreds of meters in thickness. As a result, portions of some faults are extremely conductive while others are practically impermeable. In addition, fault slip commonly juxtaposes different types of rocks. This can cause the hydraulic character of opposing sides of a fault to differ sharply. The style of fault formation depends on the stress state during slip and on the lithologic and physical properties of the host rock. For example, faulting in porous sandstone occurs by a combination of collapsing of pores and fragmenta- Page 43 Share Cite Suggested Citation: This deformation is localized into a narrow band Figure 2. The reduction in permeability perpendicular to a narrow zone of deformation bands may be as large as three orders of magnitude Pittman, ; Seeburger et al. In laboratory compression tests on low-porosity rocks such as granite, shear fractures form by a rather intricate process. First, en-echelon dilating microcracks open perpendicular to the direction of least compression; when these coalesce, FIGURE 2. From Peng and Johnson  Page 44 Share Cite Suggested Citation: The localization of microcracks during loading is fairly well understood for a review see Einstein and Dershowitz, thanks to improved stiff loading frames and acoustic emission techniques e. The en-echelon arrangement of microcracks apparently reflects the fact that each microcrack influences the location of the next microcrack Du and Aydin, ; Olson and Pollard, ; Reches and Lockner,  The mechanics of fault propagation, the nature of friction and slip on faults, and permeabilities across faults are still poorly understood Rice, ,  There is a great need to understand the micromechanical processes of faulting in a host of common geological media e. Below are summaries of available information on the geometry of single joints and faults. Geometry of Single Joints The geometry of a joint depends on how it propagates and terminates. As a result, joint geometry is controlled by such factors as the geometry of the fractured rock mass, loading conditions, and interactions with neighboring fractures. For example, joints in layered rocks are commonly formed perpendicular to the layers. A joint is initiated at a flaw and propagates away from the flaw if sufficient energy is provided by the loading system. The joint in Figure 2. Once the propagation front reaches the top boundary of the layer, the front propagates laterally and becomes nearly perpendicular to bedding. This manner of propagation is common in sedimentary rocks Bahat and Engelder, ; Engelder,  Using joint surface features, Engelder and Lacazette described the growth of joints in siltstone-sandstone beds, which they interpreted in terms of a natural hydraulic fracturing mechanism. A long joint in a single thin layer can be depicted as rectangular, with a lateral dimension much larger than the vertical dimension. The lateral dimension of an individual joint is typically a few tens of meters to a few hundreds of meters. Laubach , for example, presents data from the Frontier Formation in Wyoming that shows maximum joint lengths of about 40 m. Page 45 Share Cite Suggested Citation: The existence of thin shale laminae between the layers may cause offsets and discontinuities in the composite joints, as illustrated in the figure. Thick shale units usually impede jointing, thereby causing the strata-bound joints, that is, joints contained in certain stratigraphic units. In volcanic rocks, thermally driven joints form perpendicular to cooling surfaces. Individual joints are also composites of joint segments Figure 2. Their longest dimension vertical in the figure is also perpendicular to the cooling surface. From Helgeson and Aydin  Page 46 Share Cite Suggested Citation: From DeGraff and Aydin  The geometries of single joints in massive rocks or very thick sedimentary layers have not been studied in a comprehensive manner but clearly can be complex. The patterns of surface markings on many joints in massive rocks resemble the pattern of Figure 2. As they grow, however, portions of the joints may twist out of plane, giving them an appearance vaguely similar to a multibladed screw propeller. This twisting tends to develop most spectacularly in massive rocks, but it also occurs on a small scale in thinly layered rocks, with a fringe of fractures twisting out of plane along joint margins near bedding interfaces. Interpreting the trace geometries of joints i. Nonetheless, data on joint trace lengths commonly are collected to describe joint geometries because these data are accessible.

## Chapter 3 : 3 Hydrology: Fluid Flow â€“ Characterization and Remediation of Fractured Rock

*Hydrothermal mineralization is usually structurally controlled so it is important to understand the role of faulting and fracturing in enhancing rock permeability and facilitating fluid flow and mass transfer.*

Finally, since clustering is an intrinsic prop- erty of fractals, it is suggested that power-law veins could be inherently more prone to miner- alization as they tend to form large clusters i. In other words, clusters would act as pathways for the circulation of ore-mineralized fluids. Conclusions The mineralized vein system forming the Gua- najuato mining district represents an excellent data set to test the systematics of vein size. Vein thickness population distributions of individual data sets are best described by power-law dis- tributions whose exponents ranging from â€”0. The combined data for the whole district still maintain the same relation- ship with the exponent equal to the mean of those calculated for individual data sets  This relationship holds true over at least four orders of magnitude. The good agreement in scaling relationship between data recorded at different scales of resolution, and in geometri- cally different vein systems, suggests that they may be related to the same growth process. Power-law vein thickness distributions provide a basis to estimate the population of vein thick- nesses of a vein system and a tool for inferring the growth process. By predicting the numbers and the sizes of veins within the target volume, realistic interpolation and extrapolation from available data are then possible. The method can also place upper and lower limits to the sizes over which prediction is feasible. This work was carried out under EC Contract No. Ireland, as part of an integrated regional structural study for mineral exploration centred on the Las Torres Mine, Guanajuato. I thank Industriales Peoles for permission to carry out the study at Guanajuato and, in particular, at Las Torres mine. I also thank D. Millar of ERAMaptec for their help during the data collection and the data analysis. The work has benefited from stimulating discussions with J. Watterson of the Fault Analy- sis Group at Liverpool. Finally, many thanks to K. Consideraciones acerca de la evolution tectonica durante el Cenozoico de la Sierra de Guanajuato y la parte meridional de la Mesa Central. A method for estimation of the density of fault displacements below the limit of seismic resolu- tion in reservoir formations. Eco- nomic Geology, 70,  The fractal geometry of vein systems - potential for ore reserve calculation. Irish Association for Economic Geology,  Mineral Industry Research Organisation. Fractal geometry of vein system. An example from the Viking graben. Tectonophy- sics, ,  Estimation of discontinuity spacings and trace length using scanline surveys. Ore deposits of the Guanajuato District, Mexico. Society of Eco- nomic Geology Guidebook, 6,  The Techniques of Modern Structural Geology. Society of Economic Geology Guidebook, 6,  A fractal relationship between vein thickness and gold grade in drill core from La Codosera, Spain. Economic Geology, 89,  The Mechanics of Earthquakes and Faulting. Fractals in the Physical Sciences. Implications of chaos, scale- invariance, and fractal statistics in geology. Palaeo- geography, Palaeoclimatology, Palaeoecology, 89,  Fractals and Chaos in Geology and Geophy- sics. Analysis of the relationship between displacements and dimen- sions of faults. Journal of Structural Geologv, 10,  Populations of faults and fault displacements and their effects on estimates of fault-related regional extension. Journal of Struc- tural Geology, 14,  The importance of small scale faulting in regional extension. Determination and interpreta- tion of fault size populations: Fault dimensions, displacements and growth. Pure and Applied Geophysics, ,  Quantitative analysis of popula- tion of small faults. Journal of Structural Geology, 16,  Changes in fault displacement populations correlated to linkage between faults. Journal of Structural Geology, 18,  The prediction of small-scale faulting in reservoirs. Critical stress localization of flow associated with deformation of well-fractured rock masses, with implications for mineral deposits DAVID J.

## Chapter 4 : Fractures, Fluid Flow and Mineralization | Ken McCaffrey and Lidia Lonergan - calendrierdelas

*Fractures, Fluid Flow and Mineralization. With fracture-controlled flow dominating in magmatic and hydrothermal environments, permeability is a critical parameter. Understanding the causes of.*

Fractures, Fluid Flow and Mineralization. Geological Society, London, Special Publications,  Structural controls on hydrocarbon and mineral deposits within the Kutai Basin, East Kalimantan. Geological Society, London, Special Publications, ,  It has countrywide coverage and approximately members reside overseas. The Society is responsible for ail aspects of the geological sciences including professional matters. The Society is a Registered Charity, No. Published by The Geological Society from: Japan Kanda Book Trading Co. Fractures, fluid flow and mineralization: Scaling systematics of vein size: Critical stress localization of flow associated with 69 deformation of well-fractured rock masses, with implications for mineral deposits JONES, M. Prediction of static and dynamic fluid pathways within and around dilational jogs Structural controls on mineralization Cox, S. Are gold deposits in the crust fractals? Thrust-fracture network and hydrothermal gold mineralization: Adularia-sericite gold deposits of Marmato Caldas, Colombia: Fluidized hydrothermal breccia in dilatant faults during thrusting: Nickel ore troughs in Archaean volcanic rocks, Kambalda, Western Australia: Fracture-controlled fluid flow in the Lower Palaeozoic basement rocks of Ireland: Indeed, many former students now work in a diverse range of geology- related industries. He firmly believed that aca- demia could interact and collaborate more closely with industry to their mutual benefit. Thus, he was elected as a council member for dthe Irish Association for Economic Geology. In his other role as President of the Irish Geological Association he was keen to bring geology to a wider public audience. Dave talked freely to students and colleagues and liked nothing better than discussing geology over a pint after a day in the field. He was a deeply caring individual who made time to help anyone who needed it. Throughout, he remained closely attached to his home and family in North Dublin and considered himself to be very for- dtunate to be able to do what he loved best, geological research based in the magnificent surroundings of Trinity College. Dave will be remembered as a lively and colourful character who enjoyed life to the full, whether it be playing rugby, scuba diving, doing fieldwork or travelling. He always had a bad joke or a strange story to tell, often it was the many slightly bizarre On 2 October , Dave Johnston disappeared while working in the field at Annagh Head, incidents that always seemed to happen to him. These usually involved the series of clapped-out Belmullet, County Mayo, Ireland. He is believed vehicles that he always seemed to own. There was to have been washed from the shoreline by a the time his car rolled down a cliff in Donegal, freak wave. Anyone having been appointed as a lecturer in the who knew or met Dave has a similar story to Department of Geology. In the intervening years, Dave carried out postgraduate research recount of his various exploits. PhD for his work on the structural controls of Uranium deposits in the Rum Jungle area, As George Sevastopulo so appropriately said at Northern territories. He is greatly missed by and base-metal deposits and the underlying his former students, many colleagues and friends tectonics and structure of Ireland. In recent around the world. McCaffrey forefront in the application of fractal and chaos School of Geological Sciences, theory to geological phenomena and the quanti- Kingston University, Kingston-upon-Thames, fication of mineral deposits in particular. Irish Journal of Earth Sciences, 12, ore deposits- structural and chemical controls. Evidence for a Caledonian liferous Mineralization. Geological Society of orogeny in Poland. Transactions of the Royal Australia Short Course,  Earth Sciences, 85,  The Variscan thermal history of west Clare, fluidised peperite? 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